2006

Massachusetts Highway Department

Project Development & Design Guide

EOT

MASS HIGHWAY

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Chapter 1
Introduction

Introduction

Transportation and quality of life in our Commonwealth communities are inextricably linked. This connection is largely influenced by the role that highways, streets, and sidewalks play in our lives. Excellent transportation is critical to a healthy and vibrant Commonwealth. One of the priorities of the Executive Office of Transportation (EOT) is the development and maintenance of a comprehensive and effective multimodal transportation network.

MassHighway, in its role as steward for our roadways, must consider a broad range of factors in maintaining and improving this system, including:

- Safety for all users
- Functionality – the need for access and mobility
- Accessibility for people with disabilities – as a prerequisite to access to employment, recreation, and healthcare
- Mutual support and compatibility between transportation facilities and services and the adjacent land uses and associated activities they serve
- Consistency with transportation plans and policies, and environmental regulations, that guide the community, the region, the state, and the Federal government
- Transportation facility design and operational requirements established by others
- Input and participation from local constituents, and the appropriate local, regional and state reviewing agencies
- Cost effectiveness – the value returned to the Commonwealth for the investments made in transportation

The Commonwealth of Massachusetts is committed to caring for the built and natural environments by promoting sustainable development practices that minimize negative impacts on natural resources, historic, scenic and other community values, while also recognizing that transportation improvements have significant potential to contribute to local, regional, and statewide quality of life and economic development objectives.

1.1 Purpose of the Guidebook

Well-designed transportation infrastructure that is responsive to its context is the product of thoughtful planning. By bringing together transportation professionals, local residents, and interest groups, transportation planning can produce public facilities and programs that support community goals, provide safe and efficient transportation for individuals and goods, enhance the economy, and protect the natural environment.

The purpose of this Project Development & Design Guide (Guidebook) is to provide designers and decision-makers with a framework for incorporating context sensitive design and multi-modal elements into transportation improvement projects. The emphasis is to ensure that investments in transportation infrastructure encourage projects that are sensitive to the local context while meeting the important needs of the people they serve.

1.2 Guiding Principles of the Guidebook

The following are the Guiding Principles for development of this Guidebook.

- **Multimodal Consideration** — to ensure that the safety and mobility of all users of the transportation system (pedestrians, bicyclists and drivers) are considered equally through all phases of a project so that even the most vulnerable (e.g., children and the elderly) can feel and be safe within the public right of way. This includes a commitment to full compliance with sate and federal accessibility standards for people with disabilities.
- **Context Sensitive Design** — to incorporate, throughout project planning, design, and construction, the overarching principles of Context Sensitive Design (a collaborative, interdisciplinary approach that involves all constituents to develop a transportation facility that fits its physical setting and preserves scenic, aesthetic, historic and

environmental resources, while maintaining safety and mobility for all users).

- **A Clear Project Development Process** — to establish a clear and transparent project development and design process that can be administered consistently throughout the state. The ideal is a process that results in project consensus among constituents which can be expeditiously accomplished within reasonable project cost.

1.2.1 Multi-Modal Consideration

A guiding principle of the Guidebook is that the roadway system of the Commonwealth should safely accommodate all users of the public right-of-way including:

- Pedestrians, including people requiring mobility aids (canes, service animals, wheelchairs, walkers, and scooters)
- Bicyclists
- Drivers and Passengers
  - Transit vehicles
  - Trucks
  - Automobiles and Motorcycles

Chapter 87 of the Acts of 1996 requires MassHighway to "make all reasonable provisions for the accommodation of bicycle and pedestrian traffic…"

Historically, highway design manuals have been focused on guidelines to ensure safe operation of motor vehicles. This Guidebook does not diminish the importance of providing a safe operating environment for motor vehicles -- rather the Guidebook provides balanced guidance on public right-of-way design objectives to serve both non-motorized (i.e. bicycles and pedestrians) and motorized travel.

This Guidebook takes the approach that non-motorized transportation modes are fundamental considerations in the design process. As such, pedestrian and bicycle design requirements within a shared right-of-way are integrated throughout the design chapters. In addition, guidance and references for off-road pedestrian and bicycle facilities is presented as a separate chapter within this Guidebook. Design requirements associated with public transit operations are also integrated into the chapters throughout the Guidebook.

It is the policy of EOT and the Commonwealth to encourage designers and decision-makers to fully consider these modes of transportation throughout the planning, design, and construction phases of a transportation improvement project. Ultimately, thoughtful consideration and evaluation of all modes should result in a robust, multimodal transportation system for the Commonwealth that accommodates all users safely and efficiently within the public right-of-way.

1.2.2 Context Sensitive Design

A second guiding principle of the Guidebook is that roadway projects should be planned and designed in a context-sensitive manner. This Guidebook has been developed to ensure that projects intended to improve the roadway network in the Commonwealth are implemented in such a way that the character of the project area, the values of the community, and the needs of all roadway users are fully considered.

An important concept in planning and design is that every project is unique. Whether the project is a modest safety improvement, or a ten-mile upgrade of an arterial street, there are no generic solutions. Each project requires designers to address the needed roadway improvements while safely integrating the design into the surrounding natural and built environment. Several characteristics of context-sensitive projects have been identified through Federal Highway Administration (FHWA) research and workshops. Among these concepts, the following are adopted by this Guidebook:

- The project satisfies its purpose and needs as agreed to by a wide range of constituents. This agreement is forged in the earliest phase of the project and amended as warranted as the project develops.
- The project is a safe facility for users of all ages and abilities as well as for the surrounding community.
- The project meets minimum design standards for accessibility for people with disabilities and gives attention to universal design principles.
- The project is in harmony with the community and preserves environmental, scenic, aesthetic, historic, and built and natural resources of the area.
- The project is well managed and involves efficient and effective use of the resources (time, budget, community) of all involved.

- The project is designed and built with the least possible disruption to the community.
- The project is seen as having added lasting value to the community.

The Guidebook draws from the state-of-the-art in roadway design. Design guidelines are consistent with those described in the 2004 Edition of *A Policy on the Geometric Design of Highways and Streets by the American Association of State Highway and Transportation Officials* (AASHTO), also known as the “Green Book.” The Guidebook also incorporates the additional guidance contained in AASHTO’s A *Guide for Achieving Flexibility in Highway Design* (2004), *Guide for the Planning and Design of Pedestrian Facilities* (2004), and *Guide for the Planning and Design of Bicycle Facilities* (1999), as well as the Federal Access Board’s *Draft Guidelines for Accessible Right-of-Way* (2002), the Massachusetts Architectural Access Board’s *Rules and Regulations* (2005), and the USDA Forest Service’s *Outdoor Recreation Accessibility Guidelines* (2005).

In addition, research conducted under the auspices of the *Transportation Research Board* (TRB) and other organizations was considered and incorporated into the Guidebook, as appropriate. Finally, best-practices found in the manuals of other states and communities, as well as design guidance formulated specifically for this Guidebook, are included throughout.

1.2.3 A Clear Project Development Process

A third guiding principle of the Guidebook is to present a clear project development process that can be easily understood by project proponents and constituents and simply and consistently administered throughout the Commonwealth.

Often, the process through which a project is developed is as important as the design standards employed. The project development process outlined in this Guidebook defines the need for early identification of issues and alternatives, open and continuous involvement with project constituents, and a clear decision-making process. This process should ensure that community values, natural, historic, and cultural resources, and transportation needs are fully considered throughout the planning, design, and construction phases of a project.

A clear and consistent project development process is important for a number of reasons. The most significant are:

- To encourage early planning and evaluation so that project needs, goals and objectives, issues, and impacts can be identified before significant resources are expended.
- To ensure context sensitivity through an open, consensus-building dialog with project constituents.
- To achieve consistent expectations and understanding between project proponents and those entities who evaluate and prioritize projects (including MassHighway's Project Review Committee and Metropolitan Planning Organizations as described in Chapter 2).
- To facilitate efficient allocation of resources based on pre-established project selection criteria and consistency with local, regional, and statewide priorities.

An effective process, helps achieve projects that respect the values of the community and the natural and built environment, while meeting the transportation needs. The FHWA and AASHTO clearly establish the importance of a sound project development process for achieving context-sensitive highway solutions in their *Flexibility in Highway Design* and *A Guide to Achieving Flexibility in Highway Design* publications.

1.2.3.1 Objective, Coordinated, Transparent, and Inclusive Transportation Decision-making

The transportation decisions we make today will affect our Commonwealth for many years to come. While transportation improvements can generate increased mobility and allow economic growth, they also profoundly affect the nature of our communities and our environment. For these reasons, it is vital that the Commonwealth have an objective and inclusive transportation planning and project-development process, in which all of the effects of transportation proposals can be understood and considered.

Communication about, administration of, and understanding of the process through which potential projects are evaluated can improve the efficiency of the allocation of transportation resources. If project proponents and reviewers share a continuing dialog about project issues, review procedures, and evaluation criteria, then proponents are likely to focus their energy on projects that have strong support and avoid spending scarce resources to advance projects that will ultimately be rejected.

Decisions should be made in a coordinated manner, with decision-makers considering the needs of all affected citizens and ensuring that services are delivered in the most efficient and orderly way. Decisions should also be made in as transparent a way as possible, with public knowledge not only of the final decisions but of the process used to reach those decisions. And lastly, all decisions should be made in an inclusive manner, with the active participation of individuals, businesses, interest groups, and affected constituencies.

Early in 2003, the Executive Office of Transportation initiated an effort to develop a set of objective transportation *Project Evaluation Criteria*. These evaluation criteria make it possible for all decision-makers to assess transportation projects across modes in a consistent and systematic manner.

Transportation agencies and Metropolitan Planning Organizations (MPOs) are using objective evaluation criteria at several steps of the project development process:

- To evaluate projects early in the planning process;
- To evaluate projects at various milestones to ensure that resources are allocated to sound projects, thereby increasing effectiveness and reducing costs; and
- To evaluate projects for inclusion in MPO Transportation Improvement Programs, Regional Transportation Plans, and transportation agency capital plans.

Chapter 2 of this Guidebook provides a description of the *project evaluation criteria* and provides guidance on how they should be integrated into the MassHighway project development process.

1.3 Use of this Guidebook

The Guidebook describes the project development procedures and design guidelines applicable to projects with MassHighway involvement. It is expected that this guidance will also be valuable to municipalities, authorities, and other entities involved in the design and development of highways and streets, and other transportation facilities.

This Guidebook should be followed if one or more of the following situations exist:

- When MassHighway is the proponent; or
- When MassHighway is responsible for project funding (state or federal-aid projects); or
- When MassHighway controls the infrastructure (projects on state highway).

This may include projects that are privately funded or projects that are funded by other state or federal sources. If a municipality is pursuing a project on local roads with local funds, Chapter 90 allocations, block grants, or other programs, the procedures described in this Guidebook remain useful but do not need to be strictly followed. Municipalities should consult with the District Highway Office for guidance to ensure compliance with the requirements of the specific funding program.

In addition to MassHighway, many other entities may be involved in a project, either as a proponent or as a constituent. The Guidebook is a useful resource to a broad range of constituents, including:

- MassHighway and other State Authorities
- Metropolitan Planning Organizations
- Regional Planning Agencies
- Local elected officials, boards, and authorities
- The general public and interest groups
- State and Federal regulatory agencies
- Consultants and design professionals

Before any project design work is undertaken, users of this Guidebook are urged to read Chapter 2 - Project Development. Chapter 2 details the progression of steps to be taken, ranging from project conceptualization through completion. The Chapter also discusses the importance of coordinating project elements with appropriate groups or organizations to ensure a successful process.

1.4 Structure of the Guidebook

All projects from this point forward will be developed using English Units and incorporate applicable elements from this point forward of *A Policy on Geometric Design of Highways and Streets* (2004) by the American Association of State Highway and Transportation Officials (AASHTO), as reflected in this Guidebook. An outline of the various chapters of the Project Development & Design Guide follows:

Project Development (Chapter 2)
The Project Development chapter is designed to broaden the users' understanding of project development, from idea through construction. The chapter describes how projects progress through planning, design, environmental review, and right-of-way steps; how projects move from the design phase into the construction phase; and a suggested process for assessing projects after completion.

Basic Design Chapters (Chapters 3 to 14)
The Basic Design chapters describe guidelines which are the basis for how pedestrians, bicyclists, and drivers of motor vehicles will share roads safely. These include:

- Chapter 3, Basic Design Controls – provides important guidance on roadway and area type (context), the design values for facility user groups, level-of-service criteria, and target design speed.
- Chapter 4, Horizontal and Vertical Alignment – establishes parameters for designing the horizontal and vertical alignments of streets and highways.
- Chapter 5, Cross-Section and Roadside Elements – discusses the spatial requirements and options for allocating roadway right-of-way among the various facility users (pedestrians, bicycles, and vehicles).
- Chapter 6, Intersections – addresses the proper treatment of intersections of streets, highways, and pedestrian facilities.

- Chapter 7, Interchanges – gives guidance on how to access and egress controlled-access transportation facilities through interchange design.
- Chapter 8, Drainage and Erosion Control – provides design approaches and methods for drainage control and storm water management for transportation improvement projects.
- Chapter 9, Pavement Design – details the pavement design requirements for transportation projects.
- Chapter 10, Bridges – addresses how structural design elements should be approached in the overall context of the transportation project.
- Chapter 11, Shared Use Paths and Greenways – provides guidance on the planning and design of off-road shared use path and trail facilities.
- Chapter 12, Intermodal Facilities and Rest Areas – overviews the design considerations for intermodal facilities and rest areas.
- Chapter 13, Landscape and Aesthetics – integrates landscape planning and design considerations in the overall project development process.
- Chapter 14, Wildlife Accommodation – provides a framework for when and how to provide for wildlife accommodation as part of transportation improvement projects.

Toolbox (Chapters 15 to 17)
The Toolbox chapters deal with special design elements and traffic management strategies to address special and unique circumstances. These include:

- Chapter 15, Access Management – overviews the Commonwealth and local responsibilities and strategies for managing access along highways.
- Chapter 16, Traffic Calming and Traffic Management – provides a primer on traffic calming and traffic management strategies and their applicability.
- Chapter 17, Work Zone Management – discusses the safe and efficient management of travel through construction zones.

Plans, Specifications, and, Cost Estimates (Chapter 18)
The Plans, Specifications, and Cost Estimates chapter outlines standard technical plan and specification requirements for designers and MassHighway officials that are engaged in the design of projects.

1.5 Addenda and Updates

Transportation planning processes and design guidance are constantly changing. This section is provided in order to present any new or refined planning and design guidance or procedures as they are issued.

There are no addenda or updates to this Guidebook currently available.

Chapter 2

Project Development

Project Development

Project Development is the process that takes a transportation improvement from ***concept*** through ***construction***. There are several goals for this process:

- To ensure context sensitivity though an open, consensus-building dialog among project proponents, reviewers, the public, and other parties.
- To foster thinking beyond the roadway pavement to achieve the optimum accommodation for all modes.
- To encourage early planning, public outreach, and evaluation so that project needs, goals and objectives, issues, and impacts can be identified before significant resources are expended.
- To achieve consistent expectations and understanding between project proponents and those entities who evaluate, prioritize, and fund projects.
- To ensure allocation of resources to projects that address local, regional, and statewide priorities and needs.

Project delays and escalating costs are discouraging to everyone involved. Projects that are ultimately built but do not meet expectations in addressing needs are also frustrating. This project development framework, and the principles that it embraces, will:

- Help carry out projects effectively;
- Ensure good project planning, design, and implementation; and,
- Set the stage for long-term success.

Effective partnerships on projects are important throughout project development and require strong commitment and action from all Individuals involved, whether they be MassHighway or Federal Highway Administration (FHWA) staff, elected officials, local planning and public works professionals, citizens, or consultants. Real partnerships require ongoing relationships of trust and collaboration.

The project development process is one of a set of tools needed to achieve context-sensitive design. The process is structured to encourage public outreach throughout planning, design, environmental review, and construction so that those affected by transportation projects are in general agreement regarding the project's need, the selected approach to meet this need, and the refinements to the project that result as the process evolves. Section 2.9 of this chapter overviews public outreach approaches and tools to assist in establishing an effective project development process.

This project development process is complemented by the inclusion of the project's context as a basic design control. Flexibility for determining specific design elements that satisfy the project need, and are responsive to the context of the project, is inherent in the subsequent chapters of this Guidebook.

Applicable Projects

Project proponents are required to follow the process described in this chapter whenever MassHighway is involved in the decision-making process. The project development procedures are, therefore, applicable to any of the following situations:

- When MassHighway is the proponent; or
- When MassHighway is responsible for project funding (state or federal-aid projects); or
- When MassHighway controls the infrastructure (projects on state highways).

In addition to MassHighway, many other agencies and organizations may be involved in a project. These procedures are written to be a useful resource for projects that are locally sponsored, funded, and reviewed, as well as for those which fall under the jurisdiction of other Massachusetts authorities. Projects with local jurisdiction and local funding sources are not required to go though this review process unless the project is located on the National Highway or Federal-Aid Systems. Proponents designing projects on local roads, however, may benefit from the project development steps outlined in this chapter and the design guidance found in subsequent chapters.

Project Development Process Overview

The project development process is initiated in response to an identified need in the transportation system. It covers a range of activities extending from identification of a project need to a finished set of contract plans, and to construction.

The identified transportation need might include one or more of the following: a congestion problem, a safety concern, facility condition deterioration, a need for better multi-modal accommodation, an environmental enhancement, or an economic improvement opportunity. The development of solutions to address these needs often involves input from transportation planners, community leaders, citizens, environmental specialists, landscape architects, natural resource agencies, local public works officials, permitting agencies, design engineers, financial managers, and agency executives. Solutions might target a single mode of transportation, or address the range of road users including pedestrians, bicyclists, transit operators, automobile drivers, and truckers moving freight and goods. It is important to engage the right team of people on the project from the beginning.

The sequence of decisions made through the project development process progressively narrows the project focus and, ultimately, leads to a project that addresses the identified needs. There should be ample opportunities for public participation throughout the process.

Transportation decision-making is complex and can be influenced by legislative mandates, environmental regulations, financial limitations, agency programmatic commitments, and partnering opportunities. Decision-makers and reviewing agencies, when consulted early and often throughout the project development process, can ensure that all participants understand the potential impact these factors can have on project implementation. An eight-step project development process is defined to move a project from problem identification to completion, as illustrated in Exhibit 2-1.

Exhibit 2-1
Overview of Project Development

PROCESS	OUTCOMES
STEP I Problem/Need/Opportunity Identification	1. Project Need Form (PNF)
STEP II Planning	2. Project Planning Report (If necessary)
STEP III Project Initiation	3. Project Initiation Form (PIF) 3. Identification of Appropriate Funding 3. Definition of Appropriate Next Steps 3. Project Review Committee Action
STEP IV Environmental/Design/ROW Process	4. Plans, Specs and Estimates (PS&E) 4. Environmental Studies and Permits 4. Right-of-Way Plans 4. Permits
STEP V Programming	5. Regional and State TIP 5. Programming of Funds
STEP VI Procurement	6. Construction Bids and Contractor Selection
STEP VII Construction	7. Built Project
STEP VIII Project Assessment	

Source: MassHighway

These eight steps are described in detail in the subsequent sections of this chapter.

2.1 Step I: Problem/Need/Opportunity Identification

Projects begin with the identification of a problem, need, or opportunity. This can result from a regularly maintained asset or performance management system, such as MassHighway's bridge management system, the top 1,000 intersections safety list, or a recent corridor or area planning process. Problem, need or opportunity identification can also occur through the regional planning initiatives of a Metropolitan Planning Organization or arise from community, legislative, or citizen input. Communities and state transportation agencies are responsible for providing a wide range of transportation services. A number of on-going system management and planning processes are often where projects begin. These include:

- Long-Range Transportation Plans
- Statewide, Regional, and Metropolitan Area Plans
- Corridor Studies and Plans
- Asset Management Systems
  - Bridge
  - Pavement
- Performance Management Systems
  - Congestion Management
  - Safety Management
- Operational Plans and Initiatives
- Road Safety Audits
- Local/Community Plans
- Americans with Disabilities Act (ADA) Program Access. (These improvements must be incorporated in all transportation improvement projects or may be proposed as separate barrier removal projects.)

Road safety audits, noted above, are a relatively new activity in the United States with more emphasis on crash prevention—designing safer new roads and modifying existing roads before crash statistics reveal a problem. Road safety audits foster safer road projects by promoting elimination or mitigation of safety hazards (such as dangerous intersection layouts) and encouraging incorporation of crash-reducing features (such as traffic control devices, delineation, etc.) during the planning and design stages of project development.

2.1.1 Problem/Need/Opportunity Definition

As problems, needs, or opportunities for improvements arise they can be simple and straightforward, or complex in nature without an obvious solution at the start.

Most issues are addressed through the development of a discrete project, specifically tailored to solve the identified need or problem. These projects could include, as examples: geometric improvements at an intersection, or increased parking and improved bicycle and pedestrian access at a transit station where parking demand clearly exceeds supply, or traffic control enhancements. These types of projects often proceed relatively quickly from issue identification into actual design.

Other more significant needs require a robust multi-modal planning effort to identify possible solutions and analyze various alternatives. For example, with a corridor whose roadway network is overly congested, or whose transit service is overcrowded, there may be a need for a corridor- or location-specific planning study. These studies may require an extensive public participation process to identify the problems and examine a wide range of possible solutions through an alternatives analysis.

As a first step in the project development process, the proponent would lead an effort to:

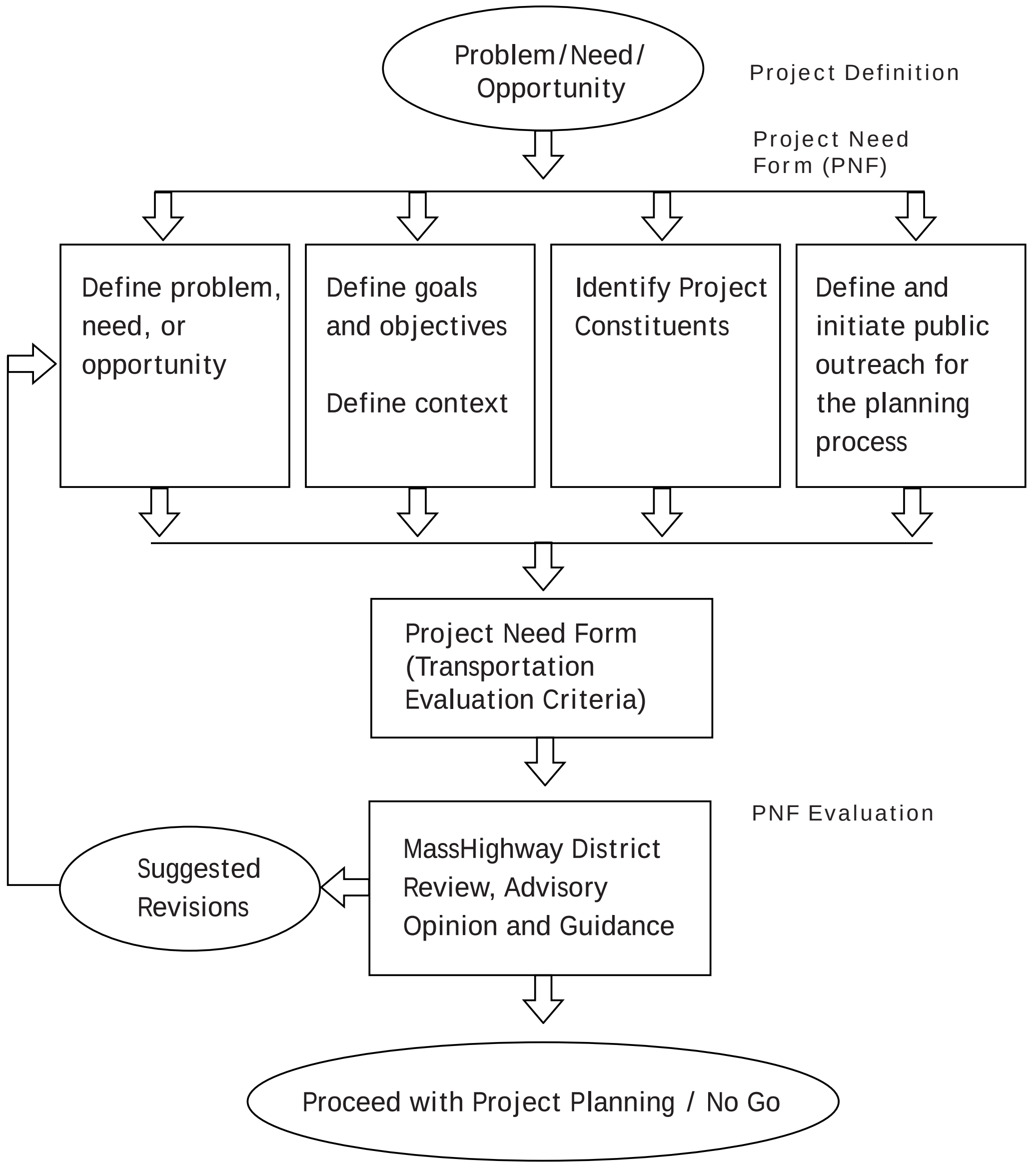
- Define the problem, need, or opportunity based on objective criteria;
- Establish preliminary project goals and objectives; and,
- Define the scope of planning and public outreach needed.

2.1.2 Project Need Form

This step in the project development process leads to completion of a **Project Need Form** (PNF). The problem/need/opportunity identification and PNF process is illustrated in Exhibit 2-2. The PNF provides sufficient material to understand the transportation need(s), and results in one of the following three outcomes:

- Verification of the problem, need, or opportunity to enable it to move forward into design;
- Determination of the level of further project planning warranted; or,
- Dismissal of a project from further consideration.

Exhibit 2-2
Step I: Problem/Need/Opportunity Identification



Source: MassHighway

A copy of the Project Need Form is provided in Appendix 2-A-1 of this chapter. Electronic versions of this form and instructions for completion can be found on MassHighway's website (www.mass.gov/mhd).

At the beginning of this process, the proponent should meet with potential participants, such as MassHighway District staff, the MPO, regional planning agencies, environmental agencies, local boards and officials, and community members. This proactive, informal review and consultation can help ensure the project will develop with fewer problems in future phases.

The Project Need Form is important to define the condition, deficiency, or situation that indicates the need for action — the ***project need***. The statement should be supported by facts, statistics, or even by plans or photographs to the extent that information is available.

The project need is not a project description (such as “replace a bridge” or “reconstruct a road”). That approach “decides” the project outcome too early in the process. A goal of the PNF is to state, in general terms, the deficiencies or needs related to the transportation facility (such as “the bridge is structurally deficient” or “the pavement is in poor condition”). The Project Need Form should document the problems and explain why corrective action is needed. An example of a need could be:

> *The intersection is hazardous. The high-crash rate at the intersection illustrates this problem.*

Other examples might be:

> *There is significant congestion at the intersection. During peak periods, traffic from the side street has difficulty exiting onto the main street and long queues develop.*

Or:

> *There is no formal accommodation for bicycles or pedestrians between the elementary school and the large residential neighborhood to the north where a significant portion of the student body live.*

The purpose of a project is driven by these needs. As examples, the purpose might be to improve safety, to enhance mobility, to enhance commercial development, to improve structural capacity, to enhance pedestrian and bicycle movement, etc., or some combination of these.

2.1.3 Transportation Evaluation Criteria

The MPOs and MassHighway use transportation evaluation criteria (TEC) to assess whether proposed transportation projects should be supported with state or federal funding. The criteria are organized by two basic project purposes: preserving the current transportation system; and improving or expanding the transportation system. A discussion of these criteria are provided as Appendix 2-A-2 to this chapter. These are useful in the preparation of a Project Need Form and should be submitted as an attachment, if available.

2.1.4 Identify Project Constituents and Public Outreach Plan

When defining the project need, the proponent should also think about public support of the project. To achieve this, the Project Need Form should:

- Identify interested parties;
- Document public outreach and feedback to date (if any); and
- Outline a public participation process for moving forward.

More information on the types of project constituents and elements of an outreach plan are found in Section 2.9.

2.1.5 Project Planning Scope

With the preliminary elements of a project defined (need, goals and objectives, project constituents, etc.) in the Project Need Form, the planning scope necessary to move the project forward requires definition.

The proponent may need to conduct planning activities appropriate to the extent and complexity of the type of project under consideration to ensure that all project benefits, impacts, and costs are objectively estimated:

- For a straightforward project (examples might include a sidewalk project, roadway resurfacing, or a traffic signal equipment upgrade), the proponent can seek approval to advance the project to design from the ***Project Need Form***. In this case, the proponent defines the actions proposed to address the project need(s), describes the alternatives considered (if necessary), and documents any anticipated impacts as part of the Project Need Form. (This may also be the best approach where detailed planning for the project has already occurred and is documented).
- For more complex projects (as examples, if there are several alternatives to consider, if there are contextual constraints which add complexity to the solution, or if there is keen public interest), the project proponent should define the range of actions to be

considered and suggest a planning scope for a ***Project Planning Report***. Guidance on the scope of this effort is provided in the next section of this chapter.

2.1.6 Project Need Form Review

Once the Project Need Form is prepared, it is submitted to the MassHighway District Office and Metropolitan Planning Organization staff for initial review. MassHighway typically develops a multi-disciplinary team to review project requests.

The intent of the Project Need Form review process is to allow the proponent to propose a project at its most basic level to the MassHighway District Office and MPO staff. Through this process, MassHighway and MPO staff can provide guidance for project scoping and planning considerations, in addition to suggestions for likely steps needed for project approvals. This guidance can be very valuable, especially if given before the proponent invests significant time and resources in the project design. The MassHighway and MPO staff suggestions at this stage can go a long way in ensuring the project's success.

Through this review, the proponent may be asked to answer questions that arise from the PNF review, to provide further documentation on the alternatives considered, and/or to complete (additional) public outreach.

After the Project Need Form has been reviewed and evaluated by the MassHighway District Office, a project requiring further planning would move into Planning (Step II). Some projects that are straightforward, or are supported by prior planning studies, are expected to move directly to Project Initiation (Step III).

Step I Outcomes:

The following are potential outcomes from Step I of the development process:

- Agreement by the project proponent and the District on the problem and project definition (extent and magnitude) to enable it to move forward into design (no further planning required); or
- Determination that there is a problem, need, or opportunity to address but further project planning is warranted to better define the project; or
- Advice on alternatives to consider and the planning process; or
- A recommendation that the project be dismissed from further consideration. (For example, the proponent's analysis may reveal that the projected negative impacts outweigh the expected benefits, thus reducing the project's likelihood for approval in the subsequent review and programming phase).

2.2 Step II: Planning

In this phase, the proponent identifies issues, impacts, and potential approvals required so that subsequent design and permitting processes are understood. Project planning also helps to define project responsibilities and benefits through a simultaneous public outreach process to obtain input and feedback on planning and design considerations. Providing public outreach opportunities throughout the entire project development process makes project success more likely.

The Project Need Form and its review will outline the scope of issues to be considered in the planning phase. The level of planning needed will vary widely based on the complexity of the project (from streamlined to more involved and complex). A more involved alternatives analysis is integrated as part of the planning process for all new facilities. It is also required for improvement or expansion projects where the feasibility of achieving the desired enhancements with acceptable impacts and reasonable investment is unclear at the outset. During the review of the Project Need Form, the necessary level of effort and responsibilities for planning will be determined. Typical planning requirements for different project types are illustrated in Exhibit 2-3.

2.2.1 Project Planning Report

Projects that require further planning will result in the preparation of a Project Planning Report. Many traditional planning studies such as corridor studies, functional design reports, and location studies can serve as a project planning report if done in a fashion that is consistent with the principles of this Guidebook and completed with public participation.

A generalized outline for the basic project planning process is provided in Exhibit 2-4. It is expected that this outline will be tailored for each project. The process described is not intended to be overly prescriptive or burdensome. Rather, the project proponent is encouraged to tailor planning activities appropriate to the extent, complexity, and type of project to ensure that all project benefits, impacts, and costs are objectively estimated. As part of this process, the proponent must also conduct a public participation program, provide information regarding the project's consistency with state and regional policies, and decide, based on all the information gathered in the planning process as well as public input, whether to continue the project development process and submit a Project Initiation Form (PIF) under Step III. Regular check-in meetings with the MassHighway District Office are helpful though this process.

Exhibit 2-3
Likely Planning Approaches for Different Types of Projects

	Likely Planning Approach		
	Project Need Form	Project Planning Focused on a Clear and Feasible Solution and Minor Variants	Full Alternatives Analysis
System Preservation			
Roadways, Sidewalks, and Multiuse Paths			
Maintenance	▲		
Resurfacing	▲		
Reconstruction/Reconfiguration within Existing Pavement	▲	•	
Bridges			
Maintenance	▲		
Rehabilitation	▲		
Replacement	▲	•	
System Improvement or Expansion			
New Roadway or Multiuse Path	▲	▲	•
Widened Roadway, Sidewalk or Addition or Multiuse Path Widening	▲	•	•
Intersection, Roundabout, or Traffic Signal Modification	▲	•	
New Interchange or Interchange Reconfiguration	▲		▲
Median, Roadside Safety, or Signage Improvements	▲	•	
Traffic Calming, Streetscape, Lighting, or Transit Enhancements	▲	▲	•
New or Widened Bridge	▲	▲	•
New or Expanded TDM/Park-and-Ride Lot	▲	•	
New or Expanded Traffic Management System	▲	•	

▲ Required
• Suggested for projects categories indicated and required for more complex projects with each category

Source: MassHighway

The detailed steps in the planning process, as outlined in Exhibit 2-4, are further described in the following pages.

2.2.1.1 Part A: Define Existing Context, Confirm Project Need(s), Establish Goals and Objectives

The first step is to confirm project need through an inventory of existing conditions. Once the project need is confirmed, the proponent should clearly articulate the goals and objectives for the project. The level of alternatives analysis and detail necessary for developing the Project Planning Report is directly related to the complex or straight-forward nature of the project.

Inventory and Data Collection/Site Walk

A site visit should be the first step in project planning as it provides an opportunity to view the project area with local project constituents and technical specialists familiar with the features or concerns related to the project. Information should be compiled or collected to provide the range of data appropriate for the project.

Exhibit 2-4
Overview of Project Planning Tasks

Part A: Define Existing Context, Confirm Project Need(s)
Establish Goals and Objectives

- Inventory and Data Collection/Site Walk
- Definition of the Community Context
- Definition of Transportation and Land Use Functions
- Project Goals and Objectives

Part B: Initial Public Outreach

- Early Local Issues Meeting
- Environmental Agencies Coordination
- Individual Outreach Meetings

Part C: Project Definition

- Development of Alternatives (if necessary)
- Establishment of Basic Design Controls and Evaluation Criteria
- Define Future Conditions (if necessary)
- Screening of Alternatives
  - Project benefits
  - Project Impacts
  - Consistency with appropriate policies and plans
  - Cost

Part D: Project Review and Refinement

- Project Presentation Meeting
- Resource Agencies Coordination
- Alternative Refinement
- Concept Engineering Plans
- Evaluation Matrices

Part E: Final Recommendations

- Project Definition
  - Description of the proposed project and project alternatives considered
- Project Benefits and Impacts
  - Consistent with appropriate state and regional criteria
- Project Consistency with Policies and Local Plans
  - Consistency with appropriate State and Regional policies and plans
- Public Participation Process
  - Documentation of planning public participation process
- Final Recommendations

Source: MassHighway

Key items to investigate during a site visit are described below:

- Context resources (environmental, cultural, historic, and man-made constraints) are mapped for the project area.
- Travel demands (for all modes) and crash data are necessary to identify any capacity and/or safety problems, or potential safety problems.
- Pavement and structure sufficiency and inventory information is helpful in determining the extent of treatment necessary for these features. A pavement management system evaluation and rating is recommended, along with photo documentation of the site.
- An access audit to survey accessibility elements such as: curb ramp locations, slopes, and obstacles; location of crosswalks; audible signals; transportation signage; sidewalk width, slope, and obstacles; connectivity; and driveway/sidewalk intersections.
- Hydraulic analysis to help to determine hydraulic adequacy of the structure or the effect on the floodplain where bridges or structures are involved.
- Right-of-way information helps to identify property owners and property lines.

Utility information is useful in determining any special needs required for utility relocation(s).

A detailed survey of the project area helps to identify the location of various features and resources potentially affected by the proposed improvement (although it is not necessary at this point in the project development process).

Definition of Community Context

It is important for the project proponent to understand the planning context, land uses, and character of the project location and surrounding community. Local knowledge or a site visit is important in understanding surrounding land uses and community character. A USGS topographic base map, GIS mapping information, and orthographic photos can be used to identify and document various aspects of the area. These guides can show surrounding land uses and land cover (open fields, forest and forest type if known, agricultural land, town, village, city, or commercial corridors); visually distinct areas such as buildings, land forms, valleys, hilltops, notches, water bodies, rivers, streams, and watercourses; prominent views and vistas along the road; public facilities or places; recreational facilities; trees; and the relationship to intersecting roads and activity centers. Some of this information may also be available from the previously completed PNF and Transportation Evaluation Criteria Form. Understanding the project context is further described in Chapter 3 of this Guidebook.

Definition of Transportation and Land Use Functions

It is important for the project proponent to understand the multi-modal aspects of the project location. During the site visit, the project proponent must be cognizant of bicycle and pedestrian movements, or the potential for these movements, and public transportation availability. The proponent should also be aware of the proximity of connection points for other modes of freight and passenger transportation.

Any transportation solution must conform with local and regional plans. Pertinent sections of the local and regional land use and transportation plans should be reviewed as part of project planning. This includes transportation and land use, local and regional policies as they relate to the project location, the roadway involved, the city or town, and the region. Designated growth areas, historic districts, designated scenic roads and areas, unique natural areas, agricultural conservation districts, and areas designated for future access management by official city or town maps should be acknowledged in the vicinity of the project location. It is important that future planned land uses be understood and the city or town's and region's goals for growth, protection of natural and historic resources, and future transportation facilities be acknowledged. The relationship between transportation facility function and land use is further described in Chapter 3.

Project Goals and Objectives

From information obtained during data collection and the input received at the Early Local Issues Meeting (as discussed below), the project proponent will define goals and objectives for the project consistent with the plans and policies of the state and local community. This statement will be the crux of the definition and evaluation of alternatives and the development of the Planning Report.

The project goals and objectives statement is similar in form and function to the purpose and need statement of an environmental document and is suitable for use in these documents if they are required for the project. The problem must be adequately explained, identified, and described. The needs for the project must conclusively show that the project is justified. The language should be clear and understandable to the layperson.

2.2.1.2 Part B: Initial Public Outreach

Public outreach and input in a project should begin early in project planning and before there is a recommended course of action. This process starts with an early informational meeting and continues at strategic milestones during the planning process. Effort should be made to reach a broad spectrum of interested parties at this early project stage. Planning for larger or more complex projects might also be well served by the establishment of an advisory Task Force or Steering Committee at the outset.

Helpful information on public outreach is provided in Section 2.9 of this chapter.

General public outreach guidelines and tools are described in Section 2.9 of this chapter.

Local Issues Meeting

A “Local Issues Meeting” should be held early in the planning process, aimed primarily at gathering local and regional comments. This meeting is not a forum to present proposals or develop solutions. (For larger projects, or for those that cross multiple jurisdictions, more than one Local Issues Meeting may be required.) This meeting should also serve to foster a working relationship with local community members. This is accomplished by listening to issues and ideas and making every attempt to incorporate sound and cost effective suggestions into the analysis of alternatives.

Comments from the Local Issues Meeting need to be documented and made available to all who were present, or to those who request them. The minutes of the Local Issues Meeting should be included in the Planning Report and kept at an accessible central location at the municipal offices. Following the Local Issues Meeting, the project proponent must evaluate the comments received and ensure that appropriate details are integrated into project planning. Once the issues have been identified, one of the project proponent’s biggest challenges is to balance these issues with all of the other project issues and work to incorporate community concerns in project decision-making and design, as appropriate. It is important to give due consideration to all comments expressed through the public process.

The project proponent is encouraged to review the process for Environmental Documentation and Permitting in Section 2.4.2 and details on the Federal and State laws and requirements in Appendix 2-A-6.

Environmental Agencies Coordination

Regulatory agencies that have a role in protecting the state's resources and a responsibility to issue permits for transportation projects that affect these resources, in coordination with local, regional, and state resource staff, may provide available research information for the Local Issues Meeting. Depending on the complexity of the project and resources present in the project area, these agencies should be invited to the meeting and given an opportunity to present issues or concerns, either in writing before the meeting or in person at the meeting. The agency's preliminary comments regarding whether resources are present in the problem area and their extent and potential significance is valuable insight at this stage of project development. The resource agencies should be given as much advance notice of the meeting as possible.

Ideally, environmental issues are identified through this process and public response to the issues is sought, as appropriate, at the meeting. However, the formal inter-agency discussion and resolution of regulatory issues occurs during later steps in the Project Development Process (see Section 2.4.2).

Individual Outreach Meetings

There may be key individuals, local officials, agencies, or advocacy groups that may not be at the Local Issues Meeting but who may be worth seeking out for valuable input. These individuals or groups are often identified at the local meeting by a local official or resident saying "you should really speak to so and so…" The project team should allow time to conduct informal outreach meetings to round out its understanding of project issues, opportunities, and constraints. Any significant issues that develop out of the individual meetings should be recounted to the community as the process evolves.

2.2.1.3 Part C: Project Definition

After initial public outreach, the next steps are to refine project goals and objectives, review alternatives, and define the project. These steps should reflect comments received during the public and agency outreach described above.

Development of Alternatives

Several reasonable build alternatives might need to be investigated and considered. Alternatives should be developed using the design guidance provided in subsequent chapters of this Guidebook. In some cases, only cursory review of alternatives may be required.

Many resources are available to the designer in this Guidebook to support the development of these alternatives. In particular, Chapter 3 presents guidance on the basic design controls that should be considered when establishing alternatives. Chapter 5 of this Guidebook provides insight into the spatial requirements for different user groups and how space might be shared or separated by user group within the right-of-way. Chapters 6 and 7 provide detailed guidance on intersection and interchange treatments. Initial planning concepts should be developed in accordance with the appropriate design guidance provided in this Guidebook to accurately reflect their spatial requirements, impacts, and benefits.

If one or more build alignments are developed, they should include the following information:

- Alternative typical roadway sections addressing the needs of all users.
- Multi-modal accommodation and operational assumptions regarding allocation of right-of-way, traffic controls, and enhancements.
- Accessibility issues, especially slope or cross-slope concerns that may be difficult to resolve.
- Compatibility with adjacent land uses and its associated activity.
- Conceptual roadway or project alignment (existing and proposed), approximate limits of impact, and approximate boundaries of resources. A scale of 100 feet per inch is useful for these concepts. For smaller problem areas such as urban locations, intersections, and bridges, a smaller scale (40 or 50 feet to the inch) should be used. (Profile sheets would only be developed for the areas with proposed grade changes.)
- Critical cross-sections, defined as points where structures and resources are avoided or impacted by the typical section. Structures are defined as buildings, bridges, walls, and culverts (48 inches or larger).
- Cost estimate, in accordance with the MassHighway's conceptual cost estimate guidelines.

Accurate estimates, to the extent that they can be calculated at this early stage of project development, are extremely important.

The project proponent must take care to examine multi-modal needs and possibilities for improvements during the alternative development process. These possibilities are to be addressed in the planning report and the feasibility and potential of each option discussed. Transportation Systems Management, Travel Demand Management, Traffic Calming, and Intelligent Transportation Systems may also be reasonable alternatives to evaluate. If the project has any Intelligent Transportation Systems (ITS) elements, it should also be confirmed at an early stage that the project scope and design is consistent with the regional ITS architecture. (Periodic checks regarding continued conformance with the regional ITS architecture should be incorporated into each stage of the design process.)

Establishment of Basic Design Controls and Evaluation Criteria

Basic design controls serve as the foundation for establishing the physical form, safety and functionality of the facility. Some design controls are inherent characteristics of the facility (for example, its context and the existing transportation demands placed upon it). Other basic design controls are selected or determined by the designer, working with the proponent, to address a project's purpose and need (for example, the level of service provided to pedestrians, bicyclists, and drivers). Selecting appropriate values or characteristics for these basic design controls is essential to achieve a safe, effective, context sensitive design. Chapter 3 illustrates the basic design controls and their influence on the physical characteristics of a roadway:

- Roadway Context, including Area Type, Roadway Type, and Access Control (Section 3.2)
- Roadway Users (Section 3.3)
- Transportation Demand (Section 3.4)
- Measures of Effectiveness (Section 3.5)
- Speed (Section 3.6)
- Sight Distance (Section 3.7)

Each of these basic design controls should be researched and their values established as part of the project planning process. These basic design controls, once established, are carried forward through project design.

Transportation evaluation criteria for assessing each alternative need to be established early in the planning process. The evaluation criteria discussed in Appendix 2-A-2 are useful to compare the effectiveness and impacts of the various alternatives considered. Appropriate criteria for the project type should be carried through the planning process to assess the transportation benefits, costs, and impacts of proposed alternatives at each stage of their development. The transportation effects of projects are not the only consideration in evaluating projects. Other considerations, including the Commonwealth's sustainable development principles, community goals, and local partnerships, should be used to evaluate projects. These criteria, as discussed in Section 2.1.3 and provided in the Appendix to this chapter, should be explicitly incorporated into the alternatives evaluation process.

Define Future Conditions

Projects that are developed should serve a useful function for some time into the future. Projects that involve significant capital investment are generally assumed to have a 20-year life while projects of lesser investment are generally assumed to have a five-year or ten-year life. This assumption requires the planner to anticipate what is going to happen to transportation demands in the future with and without the project to assess the project's effectiveness at meeting needs. Chapter 3, Section 3.4, presents important considerations in forecasting transportation demand for projects.

Screening of Alternatives

The alternatives should be fully described with concise and illustrative graphics or plans. To the extent that project design elements (i.e., sidewalks, bike lanes, travel lanes, bridge types, etc.) are known, they should be described.

Alternatives should be developed to comparable levels and presented in an evaluation matrix. The evaluation matrix visually presents the alternatives in a manner that facilitates comparison and helps ensure that the impacts of each alternative are consistently considered for the purposes of screening the best option among all of the alternatives.

Visual depictions of project alternatives are useful to convey the full extent of the project.

The project's effects should be described to the maximum extent known at this point in the planning process. The analysis that is compiled and summarized should characterize:

- Benefits
- Impacts
- Consistency with local and regional plans and policies
- Costs

The matrix should quantify resource impacts of each alternative, to the extent that they can be identified at this stage of project development. The cost of a project is a significant portion of the transportation-related decision making process and should be justified by improvements in safety, public need and/or asset management, balanced with environmental and other contextual constraints. Therefore, the cost estimate procedure must be unbiased and comprehensive (to include all engineering and permitting, right-of-way, utility relocation costs, mitigation costs, and construction costs). It must place all reasonable alternatives on the same level for fairness in the selection process. An alternative with too high of an estimate might be eliminated, while an alternative with a low estimate could be selected due to misrepresentation.

At this stage of planning, it is also appropriate to start thinking about project funding. This includes an exploration of funding sources, their requirements and restrictions, obligations for local share of project costs, other partnering opportunities, etc. Additional guidance on project estimating and funding issues is provided in Section 2.4.3.1 of this chapter.

Project review team meetings (sometimes called "planning charrettes") may be beneficial during this phase of the planning process to review the alternative plans, cost estimates, and the evaluation matrix. If the project involves a Task Force or Steering Committee, this is an excellent opportunity to get them involved in the details of the project.

A more detailed alternatives analysis, as described in Section 2.4.2 and Appendix 2-A-3, may be necessary for complex projects, or for locations with a wide range of competing demands and numerous constraints. This process is similar to that required for MEPA or NEPA review (see Section 2.4.2 for more information on these review requirements).

2.2.1.4 Part D: Project Review and Refinement

Once alternatives have been considered and the project better defined, the proponent needs to ensure continued public and agency involvement in the project review and refinement process, as outlined below.

Project Presentation Meeting

The project proponent should hold a public meeting and invite the constituents as previously defined to overview the alternatives considered, the proposed project, and to solicit input.

If the project as defined is unacceptable, the project proponent should attempt to resolve any conflicts. Failing this, the project proponent should develop new alternatives and evaluation matrices, and schedule a new Project Presentation Meeting. This process should continue until a preferred alternative is determined.

During these meetings, it is helpful to provide handout materials that present the project and its alternatives so that the participants have a reference to review. A visual depiction of each build alternative is beneficial. The visual representation should be prepared so that a layperson can understand the alternative being presented. An example of how a project might be presented is provided in Exhibit 2-5. The project proponent should facilitate a discussion of how each alternative addresses the needs of the project as well as its drawbacks.

Minutes of the Project Presentation Meeting need to be documented and made available. These minutes are important to document public comments that may be valuable input to the design process and to ensure that there are no misunderstandings concerning overall public consensus on the project as defined. The minutes should be sent to all attendees, local officials, MassHighway, Federal Highway Administration, the regional planning agency, and the regulatory agencies that have project jurisdiction or special expertise, and made available to the public at an accessible municipal location. The recipients of the minutes should have a set time period from the postmarked date to contest them and add clarifications. These minutes will also be included in the planning report.

Resource Agencies Coordination

For projects with anticipated impacts to sensitive natural and manmade resources, this is an appropriate time in the process to assess future requirements for project development with affected state and federal regulatory agencies.

The proponent should solicit comments from resource agencies regarding their views on the various alternatives under consideration, the required environmental permits, and the process moving forward. If there are accessibility issues, this may be the time to request a written "Advisory

Opinion” or variance from the Massachusetts Architectural Access Board, if needed. Guidance on environmental permits, the responsible agency, and the anticipated time required to secure is provided in the Appendix to this chapter.

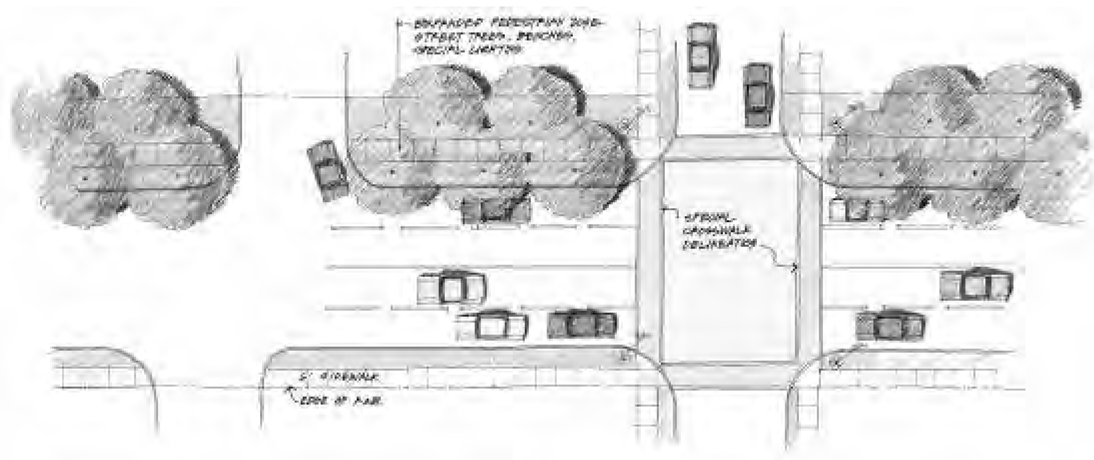
Alternative Refinement

Input received from the public or the affected environmental resource agencies may require refinement to the preferred alternative(s). These refinements may involve minor changes to previously developed concepts or the development of a conceptual engineering plan for the preferred action in greater detail. As part of this process, the evaluation matrices should be updated to reflect the project’s anticipated benefits and costs. (It is imperative that the agencies be informed of any project changes that take place during the “Project Planning” and “Project Design” phases of the development process.)

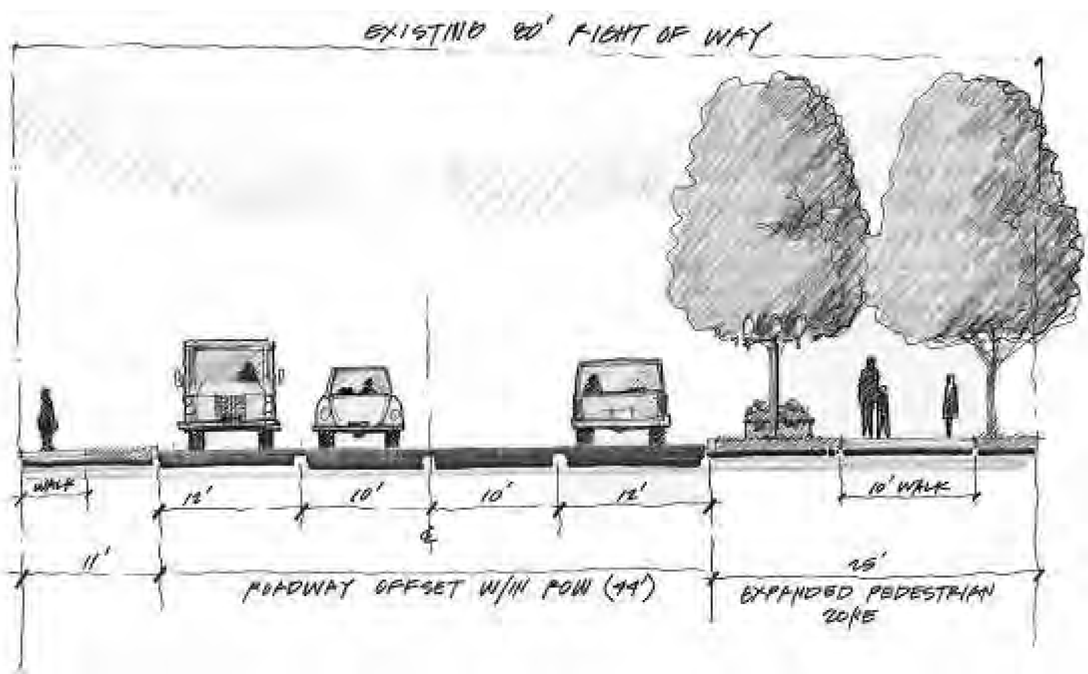
The information developed during this task should be as accurate as possible at this stage of project development as it may be the basis for early environmental documentation (such as an Environmental Notification Form/ENF) or as part of an application for project funding.

Exhibit 2-5
Example of Visual Representation of a Project Alternative

Plan View



Cross-sectional View



Source: King Street Corridor Study, Northampton, MA 2003

2.2.1.5 Part E: Final Recommendations

In this last component of the planning process, the proponent documents the process, public outreach, and decisions made, as described below.

Draft Planning Report

Following public, local, regional, and environmental agency review of the alternatives and proposed project, the planning report can be completed and made ready for review. The planning report documents the need for the project, existing and future conditions, alternatives considered, public outreach outcome, and the solution recommended. It is important that, at a minimum, the Project Planning Report summarize the:

- Project Definition:
  - Description of the proposed project and project alternatives considered
- Project Benefits and Impacts:
  - Consistent with appropriate state and regional criteria
- Project Consistency with Policies and Local Plans
- Public Outreach Process:
  - Documentation of public outreach during planning process
- Final Recommendations

The project proponent may, at their own discretion, distribute the draft planning report to the appropriate local officials, staff, or key project constituents for review.

The project proponent may also elect to have final public review of the planning recommendations by holding an additional public meeting or by notifying past project participants of the availability of the draft planning report at an accessible municipal location for review.

Final Planning Report

Upon receipt of comments and public input (if sought on the draft report), the project proponent will finalize the *Project Planning Report*.

2.2.2 Detailed Alternatives Analysis

A more complex set of needs may warrant a more detailed planning and conceptual engineering review of alternatives, their impacts and benefits, and implementation issues as part of the *Project Planning Report*. This is particularly true when it is unclear what actions are "feasible" to address the identified needs. In this case, the proponent should develop base information, document resources, and complete transportation planning analysis and conceptual engineering of the alternatives in more depth to verify "project feasibility" and the preferred action.

This level of alternatives analysis is appropriate for all new facilities and for improvement or expansion projects where the feasibility of achieving the desired enhancements with acceptable impacts and reasonable investment is unclear at the outset. The key objectives of this effort are to assess alternatives to determine their engineering feasibility, environmental impacts and permitability, economic viability, and public acceptance.

Additional details on the conduct of a Detailed Alternatives Analysis are found in Appendix 2-A-3.

2.2.3 Review of Planning Efforts

Upon completion of the project planning effort, the project proponent has essentially two options based on its outcome: delay or drop the project from consideration, or submit the *Project Planning Report* with a Project Initiation Form and Transportation Evaluation Criteria to the Project Review Committee and the Metropolitan Planning Organization for review, as discussed in the next section. The intent of this process is to allow the proponent to present a project for review and preliminary funding consideration.

Through this review, the PRC and the MPO can provide insight on project design considerations in addition to likely steps needed for project approvals. With this approach, valuable guidance can be provided prior to the proponent investing significant time and resources in project design.

Ideally, at this stage, the project will be well documented, locally reviewed and endorsed, and proceed to *Step III: Project Initiation*, as outlined in the following section.

Step II Outcomes:

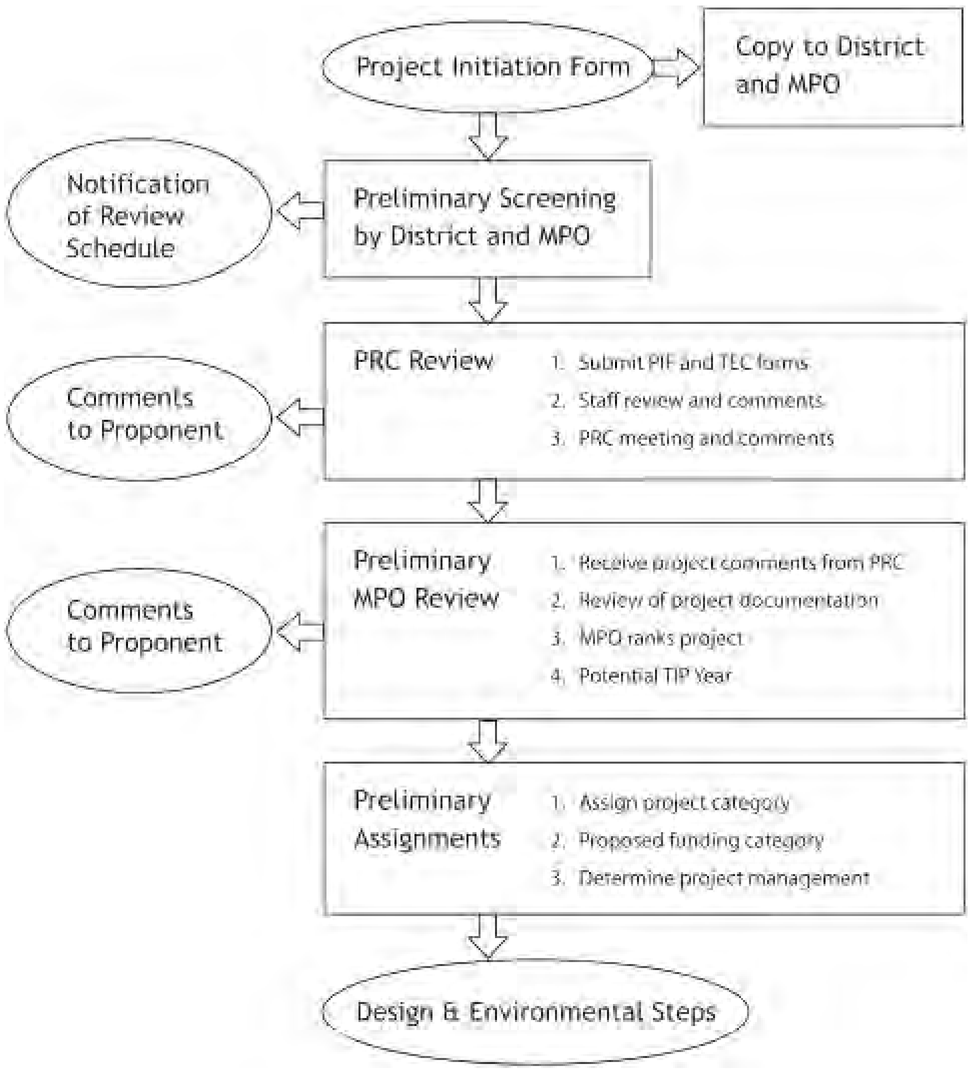
The decisions that are expected at this point in the project development process are:

- Consensus on project definition (or projects, where multiple projects result from the planning process) and decision to submit a Project Initiation Form to enable it to move forward into environmental documentation and/or design; or
- A recommendation that the project be dismissed from further consideration or delayed. (This would reflect a case where the interest in the project may have waned through the *Project Planning Report* review if, in the sponsor's analysis, the issues identified counterbalance the expected benefits, thus reducing the project's likelihood for a favorable outcome in the subsequent review and programming phase.)

2.3 Step III: Project Initiation

If a community or agency is seeking to have their project constructed with state or federal funds, the project needs to be approved by the Project Review Committee, and later programmed by the MPO. The third step in the process formally begins the review and evaluation of the project by the PRC and the MPO (following their own review procedures). This step is illustrated in Exhibit 2-6.

Exhibit 2-6
Step III: Project Initiation



Source: MassHighway

2.3.1 Project Initiation Form (Project Initiation Form)

The Project Need Form or Project Planning Report detail the final recommendations for the project resulting from early project planning. The next step in the project development process involves summarizing the findings and direction defined in a Project Initiation Form used by the PRC and the MPO for project review and evaluation. The PIF will include the following information to be documented by the proponent:

- Project Type and Description, including locus map
- Summary of Project Planning Process
- Preliminary identification of the Project Category for review and programming purposes
- Definition of the proposed project management responsibility
- Definition of an interagency (including local boards) coordination plan
- Definition of a public outreach plan for the design process
- Project Need Form or Project Planning Report as an attachment
- Transportation Evaluation Criteria as an attachment

At this stage, the proposed project is well enough defined to be subjected to a formal review. This review will give the project proponent full consideration of the project's viability as compared to other projects competing for limited funds. It is anticipated that advice and guidance for the next steps in the project development process will also be offered through this review. The Project Initiation Form for use in this process is provided in the Appendix 2-A-4 to this chapter.

The Project Initiation Form and the project planning documentation is reviewed and evaluated to verify needs, the effectiveness of the proposed project approach, and to provide direction on next steps. A two-step process is generally envisioned:

- The Project Review Committee reviews the project in terms of the Executive Office of Transportation's statewide priorities and criteria, and documents its findings; and,
- The MPO reviews the Project Review Committee findings and makes a preliminary assessment of the project for funding and programming within its regional priorities (the MPO programming process is formalized under Step V: Programming). An assessment of the time frame for the project needs to be made at this point to

give the proponent a sense of when funding might become available.

The *Project Review Committee*, comprised of staff from MassHighway and chaired by the Chief Engineer, meets regularly to review proposed transportation projects that involve MassHighway. The PRC assesses the merits of each project using the Transportation Evaluation Criteria and within the context of statewide needs. Ultimately, the PRC must approve all projects to be implemented using state or federal funding.

2.3.2 MassHighway Project Review and Evaluation

2.3.2.1 MassHighway District Review

Copies of the PIF and project planning documents are provided for MassHighway District review. The district will identify issues for consideration by the Project Review Committee during their formal consideration of the project.

Preliminary Project Review Committee Screening

The Project Review Committee staff will conduct an initial screening of the Project Initiation Form, TEC, and the PNF or Project Planning Report for the following considerations:

- Determination of Consistency with Policy and Planning Initiatives
  - State Growth Management and Transportation Policies
  - Regional Transportation Plan
  - State and Regional modal plans and Regional ITS Architecture
  - Local Plans, as summarized by the project proponent
- Assessment of Transportation Evaluation Criteria (“Objective Criteria”)
  - Condition
  - Usage
  - Mobility
  - Safety
  - Cost Effectiveness
  - Community Effects and Support
  - Land Use and Economic Development
  - Environmental Effects

2.3.2.2 Project Review Committee Review and Comment

After review and recommendation by the Project Review Committee staff, project recommendations are made for formal consideration by the Project Review Committee with respect to project funding and scheduling. The Project Review Committee will meet approximately quarterly to review Project Initiation Forms and recommendations prepared by its staff.

MassHighway's PRC includes the Chief Engineer, each District Highway Director (5), and representatives from:
- *Project Management*
- *Environmental*
- *Planning*
- *Right-of-Way*
- *Traffic*
- *Bridge, and*
- *Capital Expenditure Program Office (CEPO)*

At this point, the Project Review Committee will provide comments to the proponent identifying additional planning needs or provide guidance for the development of the environmental and design documents. Alternatively at this point in the process, the project may be determined to be unlikely with current available funds or undesirable due to its lack of effectiveness in addressing identified needs. The Project Review Committee may also elect to forward the project to the MPO, with its comments and findings, for prioritization and potential programming, or for inclusion in its Long Range Plan. A PRC positive recommendation denotes that a project is eligible for a specific funding category. It does not guarantee that the project has dedicated funding. The most common avenue to secure funding is through the MPO process. Appendix 2-A-5 summarizes the MPO and its role in transportation decision-making and programming.

Step III Outcomes:

The outcomes that are possible at this point in Step III of the project development process are:

- Guidance and support to move the project forward into design and programming review by the MPO; and
- Definition of a Project Management Plan to define roles and responsibilities for the subsequent design, environmental, right-of-way and construction steps in the process; or
- A recommendation that the project be dismissed from further consideration.

2.3.3 MPO Review and Comment

After approval by the Project Review Committee, projects to be programmed by the MPO are forwarded for review and assessment for future regional transportation resource allocations. It is expected that the MPO (and its Regional Planning Agency) will review project planning documentation and the Project Review Committee comments to start their effort. The MPO will review and assess the project in comparison to other projects under consideration in its region and determine the potential year for funding in the TIP.
The MPO will also be able to review projects that are not approved by the Project Review Committee and can provide additional comments to the proponent so that future submissions can be streamlined.

At this stage in the process it is possible but unlikely that the project would get fully programmed by the MPO. For projects given favorable review, this most often happens later during or after the design phase (see Step V).

Step III Outcomes:
Likely outcomes from the MPO review of the Project Initiation Form and TEC in Step III of the project development process are:

- Project Transportation Evaluation Criteria Score
- Possible TIP Year
- Tentative Project Category
- Tentative Funding Category

2.4 Step IV: Environmental, Design and ROW Process

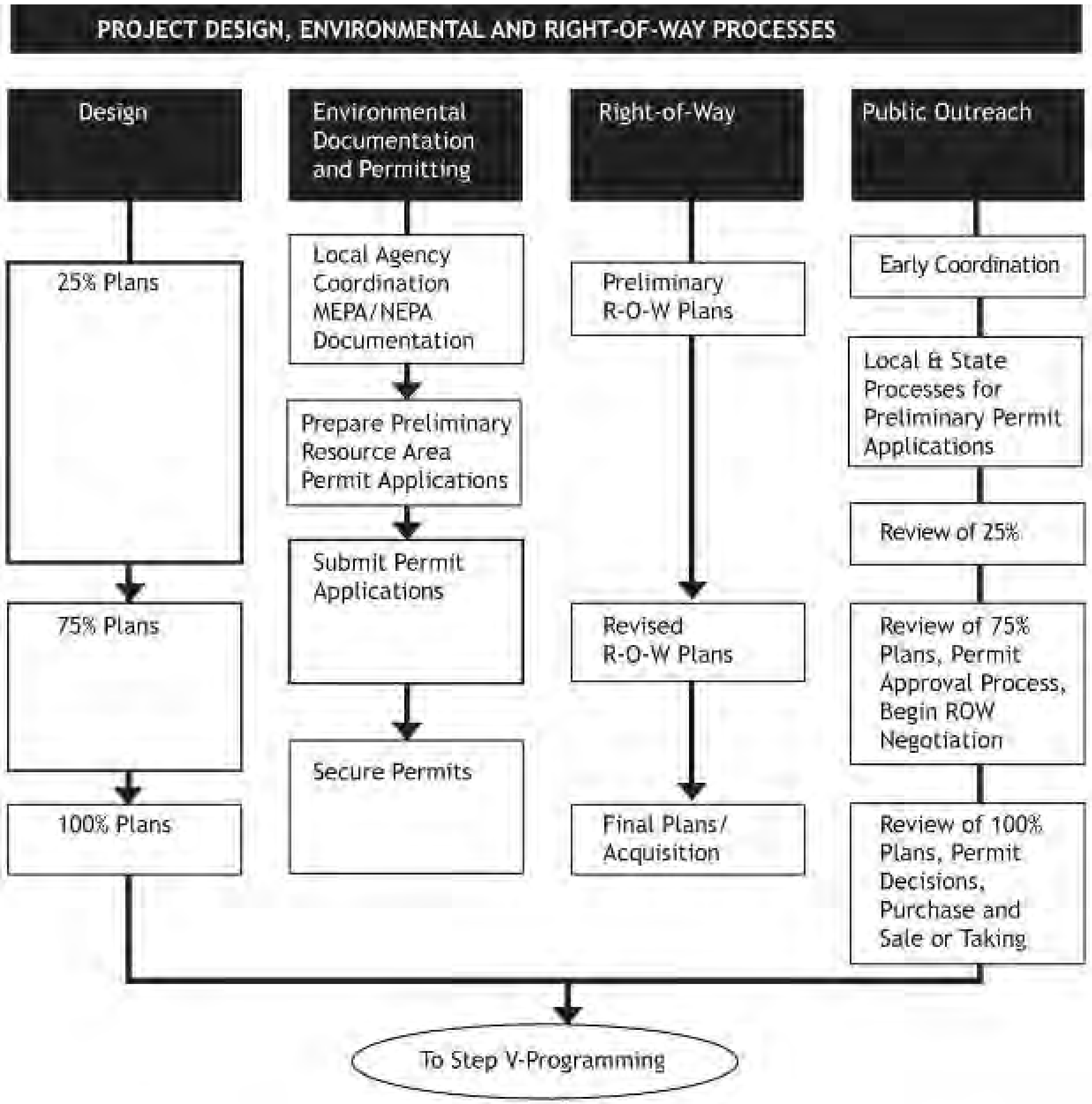
Step IV begins the process of environmental review, project design, and right-of-way (ROW) acquisition (if necessary) so that the project can be constructed. As illustrated in Exhibit 2-7, the process involves four distinct, but tightly integrated, elements:

- Public Outreach (Section 2.4.1)
- Environmental Documentation and Permitting (Section 2.4.2)
- Project Design (Section 2.4.3)
- Right-of-way confirmation/acquisition (Section 2.4.4)

Public outreach activities and requirements are integrated within each of the technical tasks. This continual involvement will help to ensure the project's ultimate success.

Although the technical requirements for environmental, design, and ROW efforts are presented sequentially in this Guidebook, these activities are conducted concurrently and in a coordinated process to ensure that the ultimate project is acceptable, constructible, permittable, and addresses the customer's needs. All these activities are keyed to the design process schedule. The fundamental design steps are outlined in Exhibit 2-8 and may vary somewhat depending upon project characteristics. Ideally, this work should immediately follow the planning effort to take advantage of both existing conditions research and public support/consensus about the need for action.

Exhibit 2-7
Environmental, Design and ROW Processes



Source: MassHighway

2.4.1 Public Outreach Plan and Requirements for the Environmental, Design, and Right-of-Way Process

Continued public outreach in the design and environmental process is essential to maintain public support for the project and to seek meaningful input on the design elements. This public outreach is often in the form of required public hearings, but can also include less formal dialogues with those interested in and affected by a proposed project.

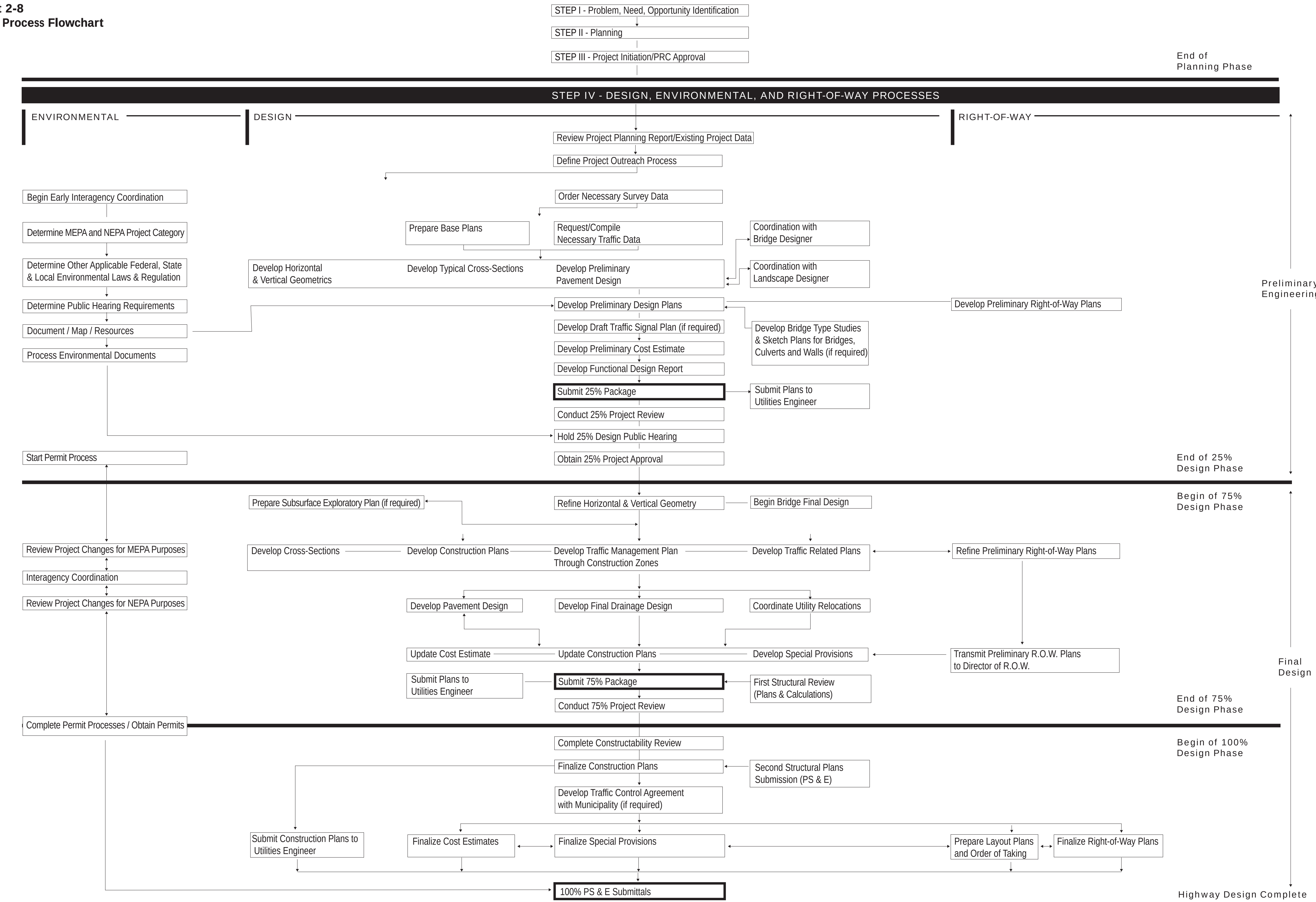
A public hearing, or opportunity for a public hearing, is required by state law for all highway projects as part of a process that also encourages a variety of citizen involvement techniques such as informal public meetings, briefings, workshops, or charrettes. Public hearings are legally recognized formal meetings held at particular times during the project development and design phases. A Public Hearing is required for any project that:

- Requires additional right-of-way;
- Substantially changes the layout or functions of connecting roadways or of the facility being improved;
- Has a substantial adverse impact on abutting property; or
- Has a significant environmental, social or economic, or other effect.

An additional public hearing will be provided when there has been:

- A significant change in the proposed project (or design details);
- Identification of significant environmental, social, or economic effects not considered at earlier Public Hearings;
- Substantial unanticipated development in the project area; and,
- An unusually long time lapse (for example, more than two years) since the last public hearing.

Exhibit 2-8
Design Process Flowchart



In addition to the mandated published and posted legal notices of the hearing, the project proponent should consider using other outreach methods to attract all interested parties. If a federal Environmental Assessment or Impact Statement or state Environmental Impact Report is required, a public hearing should be held during the period of the public review. The public would then have the opportunity to comment on the impacts of the project as well as the project design.

Early coordination and public information is particularly important for projects requiring the filing of a Coast Guard Permit. The requirement for securing a Coast Guard Bridge Permit should be identified early in the design process prior to the 25 Percent stage. The appropriate level of information should be provided to the Coast Guard to allow them to advertise the Public Notice to Mariners. The 25 Percent Design Public Hearing can then be held as a joint hearing with the United States Coast Guard. The Design Public Hearing Notice should also include a statement that the project will require a Coast Guard Permit and that the Design Public Hearing will serve as a public forum to comment on the Coast Guard Permit process.

There are many opportunities for public meetings or hearings on the project throughout the project development process as described in Section 2.9 of this chapter. All meetings should be held in accessible locations with materials relevant to the meeting made available in alternative formats upon request. Key public meetings during the environmental/design/ROW process are discussed below:

- **Location/Design Public Hearing** — A Location/Design Public Hearing signals a decision point for major projects and is held after an environmental document is circulated, but before MassHighway is committed to a specific alternative from among the reasonable and feasible alternatives under consideration, including the No-Build alternative. The hearing(s) is usually held during the planning process but can also be held during preliminary engineering.

  This Public Hearing provides the public the opportunity to provide input into the determination of the need for, and the location and design of, a proposed project. It also serves as a means of summarizing any previous comments and concerns relative to the alternatives under consideration, and provides a formal review of the major points being addressed in the environmental document.

- **Design Public Hearing** — A Design Public Hearing is held for all projects subsequent to the review and acceptance of the 25 Percent Design Plans by MassHighway.
- **Permit or Clearance Hearings** — Many of the specific environmental review requirements for projects have their own public outreach requirements. These requirements must also be satisfied to obtain the necessary environmental permits and clearances.

Public meetings, open houses, briefings or workshops or other informal gatherings of MassHighway officials, public officials, and local citizens to share and discuss proposed actions are encouraged. These alternative outreach approaches are discussed in Section 2.2 of this chapter.

2.4.2 Environmental Documentation and Permitting

Early involvement by the project proponent to understand and develop a plan of action to address the anticipated environmental consequences of the project is essential. This effort can also shape a more environmentally responsive and sustainable design. This section describes some standard procedures which help to identify initial project design parameters, initiate early coordination with the community to identify issues specific to the project, and define essential information to incorporate into the 25 Percent Design to initiate early environmental reviews.

2.4.2.1 Early Coordination

Early coordination requirements by the project proponent are described on the following pages (some of this may already have been completed as part of project planning):

- The designer must initiate early coordination with the local environmental boards and commissions to review the project area and identify any specific issues or concerns.
- The designer should initiate early coordination with the appropriate local historical commission(s) by requesting their review and comment on the proposed scope of work and/or a locus plan showing project limits and should copy the State Historic Preservation Officer (a standardized letter is included in Appendix 2-A-6 of this chapter).

- The designer should consult with the MassHighway Cultural Resources Unit for early coordination with the Tribal Historical Preservation Officer (THPO), if necessary.
- The designer will send copies of the proposed scope of work and a locus plan showing project limits to other environmental agencies to initiate early coordination.

For projects affecting rivers and streams, the proponent should consult with the Massachusetts Department of Fish and Game (Riverways Program), Division of Marine Fisheries (marine resources, especially diadromous fish), National Heritage and Endangered Species Program (Biomap and Living Waters Analyses), and the National Park Service (Wild and Scenic Rivers System).

All correspondence from the early coordination tasks should be documented, copied to key project participants, including MassHighway's Project Manager, the District Office, and the MassHighway Environmental Section, and made part of the project's permanent record.

2.4.2.2 Determine MEPA and NEPA Project Category

MEPA Determination

The designer, in coordination with the MassHighway Environmental Section, will be responsible for determining the MEPA and NEPA project category. The designer should obtain or develop the necessary information to enable this determination to be made. The type of information needed is discussed with the MassHighway Environmental Section. All environmental review and permit submissions and coordination with the agencies will be made through the MassHighway Environmental Section. Copies of all applications, submissions, and permits will also be sent to the District Environmental Engineer.

A determination should be made, in compliance with the MEPA regulations, whether the project: (1) does not trigger MEPA jurisdiction, (2) exceeds the ENF review thresholds, or (3) is a categorical inclusion and requires an EIR. MEPA Review Thresholds are provided as an attachment to this chapter.

Some of the ENF review thresholds are based on the amount of wetland impact proposed. Therefore it is critical for the designer to know the square footage or number of acres of wetland alteration at the time of the determination of MEPA project category. This information will help the designer to determine whether (a) a variance from the Wetland Protection Act is needed or (b) a Superseding Order of Conditions is needed. If a variance or Superseding Order of Conditions is needed, then MEPA review is required.

If it is determined that the project exceeds the MEPA review thresholds, the designer should prepare an Environmental Notification Form (ENF) and submit it to the MassHighway Environmental Section for processing at the Executive Office of Environmental Affairs (MEPA Unit). After the consultation and scoping period, EOEA will determine whether an Environmental Impact Report (EIR) is required. If, prior to filing, it is determined that the project is a categorical inclusion, an ENF and an EIR are required. A mutual decision will be made at that time if the designer or the Environmental Section will be responsible for the preparation of the ENF and EIR. Classification of a project in accordance with the MEPA review thresholds should be discussed with the MassHighway Environmental Section.

NEPA Determination

If the project involves federal funds or other federal action, a determination should also be made regarding compliance with the National Environmental Policy Act. A determination should be made in accordance with the regulators of the lead federal agency regulations (in most cases, FHWA) whether the project:

(1) is a categorical exclusion (CE) (Class II action) and does not require federal agency approval,

(2) is a CE (Class II action) but requires additional documentation and FHWA approval,

(3) requires preparation of an Environmental Assessment (EA) (Class III action), or

(4) requires preparation of an EIS.

As indicated in the "Begin Interagency Coordination Section," an agreement should be reached with the appropriate federal agencies on the NEPA project category. The MassHighway Environmental Section will facilitate such an agreement.

The designer is responsible for the preparation of the necessary CE documentation. The scope and details about CE documentation, EAs, EISs, and the NEPA process must be coordinated with the MassHighway Environmental Section.

2.4.2.3 Determine Other Applicable Federal, State and Local Environmental Laws and Requirements

The proponent, or their designated designer, in coordination with the MassHighway Environmental Section, will be responsible for identifying and complying with all other applicable federal, state and local environmental laws and requirements. A list of potential environmental permits/clearances based on project funding is provided in the Appendix to this chapter.

The project proponent should develop a checklist of the anticipated environmental documentation and permits and schedule a coordination meeting to review these assumptions and their requirements with the MassHighway Environmental Section. A brief description of the Federal and State Laws and Requirements, their common regulatory thresholds, and environmental clearance timelines are provided in Appendix 2-A-6.

2.4.2.4 Process Environmental Documents

The project proponent is responsible for the environmental documentation needed for the MEPA and NEPA processes and other required permits and clearances. Preparing and processing this environmental documentation should occur concurrent with the development of the 25 Percent Design plans.

For the MEPA process, the environmental documentation may include (1) an Environmental Notification Form and (2) A Draft Environmental Impact Report and a Final Environmental Impact Report. For the NEPA Process, the environmental documentation may be (1) documentation for a categorical exclusion, (2) an Environmental Assessment, or (3) a Draft Environmental Impact Statement and a Final Environmental Impact Statement. A determination of the environmental documentation required is described above. Additional details about the MEPA and NEPA processes can be found on the internet (for MEPA, see www.mass.gov.envir/mepa; for NEPA, see http://environment.fhwa-dot.gov/projdev).

Interagency Coordination

Project delays can be minimized by early and on-going coordination with Federal, state, and local agencies with jurisdiction by law or special expertise. Proponents should consult the MassHighway Environmental Section, or its website, regarding this effort. If, for some reason, coordination with resource agencies did not take place in the planning process, the early steps of the design phase offer another key opportunity to perform necessary interagency coordination with resource agencies to:

- Use their technical expertise
- Reach agreement on the determination of NEPA project category
- Perform field investigations
- Discuss existing environmental deficiencies
- Determine which issues and concerns are most important
- Discuss avoidance alternatives and minimization measures
- Discuss need for wild life accommodation (see Chapter 14 and Exhibit 14-1)
- Determine which appropriate mitigation measures should be evaluated
- Determine the likelihood of obtaining any necessary permits

For projects involving Environmental Impact Statements, the appropriate time to initiate interagency coordination is during scoping. Scoping is the required process of determining the range of alternatives and impacts that will be considered in that document.

For other projects, a consultation meeting scheduled with the MEPA Office of EOEA is a good time to begin interagency coordination. All interagency coordination should be documented. In all cases, coordination with environmental resource agencies and boards should take place before completion of the preliminary (25 Percent) design.

2.4.2.5 Environmental Requirements for the Preliminary (25 Percent) Design Submission

Appendix 2-A-7 provides detailed information concerning environmental elements of the project to be included with the 25 Percent Design Submission to assist in the identification of project impacts and to expedite environmental clearances. Also included in Appendix 2-A-7 is a 25 Percent Design Submission Checklist.

The designer should also consult MassHighway's website for additional useful information (www.mass.gov/mhd/. Copies of all correspondence during information gathering should be made part of the project's permanent record.

2.4.2.6 25 Percent Submission Environmental Review

MassHighway's Environmental Section will evaluate the data collected during the 25 Percent Design process and the plans submitted. They will determine whether the project can be designed to desired design criteria, or if design changes or mitigation plans will be required to resolve environmental issues and community concerns.

If the 25 Percent Design package is a resubmission for a project that has already been reviewed, the designer will also distribute to the MassHighway Environmental Section a summary of any proposed design changes to any previous submissions for the project.

Review Project Changes for MEPA Purposes

After the initial MEPA project category determination and MEPA processing, the designer, in coordination with the MassHighway Environmental Section, will have responsibility to periodically review changes to the highway project during the design phase to determine whether future MEPA review is needed. If there have been changes to the original project and the project was statutorily exempt or categorically excluded from the MEPA regulations then the designer must determine whether the changed project is still statutorily exempt or categorically excluded. If so, then no further MEPA review is necessary at that time. If the changes are such that the project now exceeds the review thresholds, or is now a categorical inclusion, then further MEPA review is necessary. The designer should refer to the *Determine MEPA and NEPA Project Category* (described above), discuss with the MassHighway Environmental Section, and take the appropriate action.

If the original project exceeded the MEPA review thresholds or was a categorical inclusion and the project has changed, then the designer may need to prepare a Notice of Project Change (NPC) and submit it to the MassHighway Environmental Section for processing. Additional details about the Notice of Project Change are to be discussed with the MassHighway Environmental Section. Based on information in the Notice of Project Change, EOEA will determine whether the change in the project or change in the ambient environment significantly increases the environmental consequences of the project and warrants resubmission of an ENF, re-scoping, supplementary documentation, or a further EIR.

There are cases where a project involving wetlands originally did not exceed the MEPA review thresholds for highway projects and wetland permits (i.e., it was a categorical exclusion) but now requires further MEPA review because the wetland permit threshold is exceeded. This can happen when (1) the information about wetlands at the time of the determination of MEPA project category was unknown or incorrect (see “Determine MEPA” and “NEPA Determine Project Category” sections) or (2) when the project changes and the wetland impacts change.

Also, even if no changes are made to a project that requires an EIR, further MEPA review may be necessary. If more than three years have elapsed between the filing of a Final ENF and the filing of a Final EIR, or if more than five years have elapsed between the filing of a Final EIR and a substantial commencement of the project, the designer, through the Environmental Section, must notify EOEA. EOEA will consult with MassHighway, agencies, and persons who previously participated in project review and will determine whether the lapse in time or change in the ambient environment significantly increases the environmental consequences of the project and warrants resubmission of an ENF, re-scoping, supplementary documentation or further EIR.

The MEPA process can be time-consuming and result in design changes to the project. It is, therefore, critical that the designer perform this periodic review often, whenever a project change is contemplated. At a minimum, the designer should perform this review at the 25 Percent, 75 Percent, and 100 Percent Design phases.

Review Project Changes for NEPA Purposes

After approval of the categorical exclusion determination, FONSI, or Final EIS, the designer, in consultation with the MassHighway Environmental Section and FHWA, will be responsible for periodically reviewing the highway project during the design phase to determine whether or not the approved environmental document or categorical exclusion determination remains valid. The periodic review should be documented when determined necessary by FHWA. This review should occur at the same time as the review of project changes for MEPA purposes and also prior to requesting any major project approvals from

FHWA (i.e., authority to undertake final design, authority to acquire a significant portion of the right-of-way, or approval of plans, specifications, and estimates).

Interagency Coordination

Continual interagency coordination is imperative throughout the design phase to address issues that may affect the processing of permit applications. These issues can be discussed and resolved before they cause a critical disagreement or time delays on a specific project. Follow-up contact with resource agencies will determine whether additional information on the project is needed.

This coordination may also alleviate the need to reopen an environmental issue at the time the permit is applied for, which may be well after this issue was presumed to have been resolved in an environmental document. If interagency coordination is performed properly, there should be no surprises during the permitting process.

2.4.2.7 Define and Initiate Permit Process

Environmental clearances and permits should be secured as early on in the design process as is practicable. When used in this Guidebook, the term "Permit Process" refers to any process or regulatory program that involves obtaining a permit or some other type of sign-off from a federal, state, or local agency. The following are examples:

- Section 4(f) Approval
- Section 404 Permit
- Coast Guard Bridge Permit
- Section 10 Permit
- Section 106 Clearance
- Water Quality Certification
- Coastal Zone Management Concurrence Determination
- Wetlands Order of Conditions/Resource Area Delineation
- Chapter 91 License or Permit
- NPDES Permit

Identification of applicable permits is completed prior to the 25 Percent Design Submission. Initial coordination, data gathering continues throughout the design process. Formal submission of applications to regulatory agencies should be done as soon as the required information is available, but no later than the 75 Percent Design Submission. The project proponent is responsible for obtaining all required permits.

Before initiating design, the designer should take time to review all prior planning documents and public input received on the project.

Each permit process is unique and involves interagency coordination, information submission, possibly special public hearings, and specific forms or applications. Additional details of the permit process are provided as an attachment to this chapter or may be obtained from the MassHighway Environmental Section or on their website. It is critical that the Coast Guard Bridge Permit process start during the development of the 25 Percent Design. When a Bridge Permit is required, the Coast Guard has to publish the Public Notice to mariners and requires the critical elements, as indicated in the Coast Guard Public Notice checklist included in Appendix 2-A-7, be provided. (It is most useful if the Coast Guard Permit hearing be held concurrent with the 25 Percent Design Hearing, as discussed previously).

A good first step in this process is to develop an environmental permit checklist that indicates all environmental permits or clearances required and not required for the project (see also Appendix 2-A-7).

2.4.2.8 Complete Permit Processes

During the period from 25 Percent but no later than 75 Percent Design, the designer will complete and submit all necessary forms or applications to the appropriate agencies for the required permits. Permit applications (including subsequent copies of all completed correspondence, etc.) and permits will be copied to the appropriate District Environmental Engineer.

2.4.3 Project Design

The Project Design Process is fully described in Exhibit 2-8, presented earlier in this section. There are generally three major phases of design, including:

- Preliminary Design (25 Percent Submission)
- Final Design
  - 75 Percent Submission
  - 100 Percent Submission
- Plans, Specifications, and Estimate (PS&E)

If the project is being designed by a municipality, they should consider retaining a MassHighway qualified designer. As the project moves into design, the project defined in the Project Planning phase is developed in more detail and design documents for the project are produced. It is imperative that the designer is knowledgeable about the context of the project, about the issues raised during planning, and about the desires of the community, MassHighway, and the regulatory agencies concerning project implementation prior to initiating the design.

Title sheets to all plans (with the exception of the final stamped mylars) should be stamped with the design stage (25, 75, 100, PS&E) and date.

2.4.3.1 Preliminary Design Process (25 Percent)

The first step in the design process is referred to as preliminary design and results in the submission of 25 Percent Design plans. The following activities are necessary to develop the preliminary (25 percent) project design.

Order Necessary Survey Data

If existing survey data is not adequate to design the project, the project proponent must obtain additional survey data. This data may be in the form of either a sufficiently detailed aerial or ground survey. If the project proponent is MassHighway, the request is made to the Survey Section, providing as much specific project location data as possible. All survey work, whether completed by the designer or MassHighway, must be in accordance with the *MassHighway Survey Manual*.

Prepare Base Plans

This activity includes checking field notes, establishing coordinates, determining the scale used in plotting, and plotting the survey on base plans, base profiles, and base (original ground) cross-sections. Work involved in plotting includes computing and adjusting the baseline, traverses and levels. Details on base plan preparation are included in Chapter 18 of this Guidebook.

Request/Compile Necessary Traffic Data

The designer must obtain data on the transportation operational characteristics for the project area. These data are likely available from the Project Planning phase. For more information, please refer to Section 2.2 or Chapter 3, Section 3.4 of this Guidebook and the Traffic Section of MassHighway's 25 Percent Design phase submission requirements provided in the Appendix to this chapter. Both existing and projected transportation data is requested for all modes of travel using the facility.

Develop Horizontal and Vertical Geometrics

The designer must develop the basic roadway horizontal and vertical geometry. All geometric data must be calculated at this stage (stations, bearings, distances, horizontal and vertical curve data, etc.). The design criteria are discussed in Chapter 4.

Develop Typical Cross-Sections

Typical cross-sections are developed based on design requirements. Typical cross-sections show design elements that will predominate throughout the project. For additional detail, the designer should refer to Chapter 5. Particular attention should be paid to multimodal accommodations in the definition of these cross-sections and work completed during the planning phase to address user needs.

The designer should also seek to minimize impacts to utilities, to the extent feasible and without compromising user accommodation, as utility impacts can significantly contribute to project costs and delays.

Coordination with Bridge Design

The structural designer (if applicable) should be engaged early on in the development of typical cross-sections and horizontal and vertical alignments to integrate roadway and structural elements of the project.

Coordination with Landscape Design

If landscape designers have not been previously involved in the project, they should be consulted at this point to assist integration in the roadside, structures, urban design and scenic consideration into geometric design (horizontal, vertical, and cross-sectional elements). Additional guidance on landscape design is provided in Chapter 13 of this Guidebook.

Develop Draft Traffic Signal Plan (if required)

A Draft Traffic Signal Plan is developed based on guidelines provided in the most current version of the *Manual on Uniform Traffic Control Devices*. This plan shows the proposed placement of traffic control devices and is based on traffic counts, turning movements, warrants, and capacity analyses. This is in accordance with the "25 Percent Submission Guidelines" prepared by the MassHighway Traffic Section.

Develop Bridge Type Studies and Sketch Plans for Bridges, Culverts, and Walls (if required)
Based on guidelines provided in the *MassHighway Bridge Manual*, bridge type studies must be developed for bridges, culverts and/or walls which are not included in the *MassHighway Construction Standards*. The Type Studies are a preliminary presentation of the overall concept of the proposed structure which shows all pertinent details for the preparation of sketch plans and contract plans. The MassHighway Bridge Section has recently streamlined this process for routine bridge replacement projects. (See the *MassHighway Bridge Manual* for more information.)

The project proponent should also be familiar with the guidelines for Wildlife Accommodation (Chapter 14), if applicable, and the regulatory requirements of the Army Corps of Engineers and U.S. Coast Guard for locations over wetlands and waterways.

Develop Preliminary Pavement Design
The pavement design anticipated for the project needs to be developed including determination of rigid or bituminous pavement and a design section. Chapter 9 details the appropriate pavement design to be completed at this stage of design.

Develop Preliminary Right of Way Plans
Right-of-way requirements for the project should be estimated at this stage in design. Preliminary 25 Percent plans should include:

- Parcel Numbers
- Dimensions for all proposed acquisitions
- Areas of anticipated takings and easements

Develop Preliminary Cost Estimate
The proponent should prepare a preliminary cost estimate based on the latest project information. It is important that this estimate be as complete as possible based on quantity estimates and current unit prices and with contingencies. Refinements are to be expected as the design develops, but this estimate should reflect project costs as accurately as they can be defined at the 25 Percent Design stage.

This cost estimate should itemize the **participating** (costs to be covered by the anticipated funding source) and **non-participating** (costs to be covered by the proponent) items. The determination of what work elements are eligible for funding should relate back to the project need definition. As an example, a project to install a new traffic signal to address a high crash location would likely not cover costs to install new street trees, unless they replace trees that are impacted by the signal installation. Conversely, if the project's intent is to restore a blighted downtown area, streetscape, ornamental lighting, and pedestrian amenities would likely be appropriately included in the participating items.

For transportation improvement projects that impact existing landscape or utilities, work to restore these items is generally eligible for state or federal funding. Typical landscape restoration activities are discussed in Chapter 13. Utility costs generally include replacement-in-kind. Improvements (betterments) to municipal sewer and water systems are considered non-participating items. Relocation of overhead utilities to underground is also a non-participating item. Except for certain types of projects, streetscape amenities are generally non-participating items.

Occasionally, project proponents may seek to use materials or treatments on projects that are outside standard practices such as block pavers vs. cement concrete sidewalks, granite vs. bituminous curbing, or traffic signal posts and mast arms. Incremental costs are often calculated and considered as non-participating costs in these situations. Consideration should always be given to how, and by whom, non-standardized items are to be maintained. Early consultation with MassHighway for project-specific guidance on what elements are likely to be participating or non-participating is beneficial. The project proponent should also be aware of unique requirements or restrictions dictated by the anticipated funding category. Information on alternative funding sources which may be available to offset the costs of the non-participating items can be obtained from the Executive Office of Transportation.

Functional Design Report

A Functional Design Report (FDR) is a necessary component for all transportation and safety improvement projects submitted to MassHighway for 25 Percent review, including mitigation projects developed through the Massachusetts Environmental Protection Agency (MEPA) process. Roadway resurfacing, and maintenance projects are generally exempt from this requirement. Guidelines for the submission of a FDR are included on MassHighway's website.

Design Exceptions Report

The design guidance contained in this Guidebook is intended to provide project proponents with sufficient flexibility to address the unique and diverse conditions encountered on the Commonwealth's streets and highways; however, there may still be occasions when design exceptions are necessary. For these circumstances, the project proponent must complete a Design Exception Report as part of the FDR, as discussed in Section 2.11 of this chapter, and transmit it to MassHighway with the 25 Percent Design. Guidelines for submitting a Design Exceptions Report are included on MassHighway's website and in Appendix 2-A-11 of this Chapter.

25 Percent Project Submission

Available layout and geometric data and reports developed in previous tasks are assembled for submission and review by MassHighway. A checklist of the 25 Percent Design submission requirements is provided in Appendix 2-A-8 to this chapter.

Submit Plans to Utilities Engineer

Concurrent with the 25 Percent submission, the construction plans should be submitted to the MassHighway Utilities Engineer as indicated in the Submission Guidelines.

25 Percent Project Review

The 25 Percent package is reviewed by FHWA, municipalities, and MassHighway design personnel, as necessary. The review is conducted to identify problems and to ensure that the project is advancing properly. Comments resulting from the review must be addressed prior to proceeding with the Design Public Hearing.

Conduct 25 Percent Design Hearing

A Design Public Hearing is held for projects subsequent to the review and acceptance of the 25 Percent Design plans by MassHighway.

Obtain 25 Percent Project Approval

The 25 Percent Design approval is the first written approval in the highway design process by MassHighway and/or FHWA. The designer must receive the 25 Percent project approval before proceeding with the project into Final Design.

2.4.3.2 Initiate Final Design (75 Percent)

Once the preliminary design has been reviewed and approved by MassHighway, the designer proceeds into the final design process, as outlined below.

Refine Horizontal and Vertical Geometry

The designer will refine the horizontal and vertical alignment, if required.

Prepare Subsurface Exploratory Plan (if required)

After the alignment, profile, location, and structure types have been defined and approved (25 Percent approval), a subsurface exploratory program is developed for the required design. Before developing the program, the designer should contact the Soils Unit of the Research and Materials Section of MassHighway to discuss the proposed program of investigations. Plans for the program are then developed and submitted to the Research and Materials Section for review and/or implementation. Information required to implement a subsurface exploratory program includes:

- Boring locations plotted on plans, including a schedule showing station, offset, highest bottom elevation, and a column for remarks and boring notes. Borings for proposed structures should also be plotted, including the footing outlines.
- The District Offices will be furnished with a list of all property owners with their mailing addresses so they can be notified.
- A list of all the utilities within the project limits (as well as the name, address, and telephone number of the appropriate utility or public official to contact) will be made available to the MassHighway Research and Materials Section to include in the special provisions of the boring contract.

For additional details, the designer is referred to the *MassHighway Materials Manual* and the *MassHighway Bridge Manual*.

Develop Construction Cross-sections

The proposed roadway cross-sections, based on the horizontal and vertical geometry, and the typical sections, are drawn on the base (original ground) cross-sections. These cross-sections are included as part of the contract documents.

Develop Construction Plans

The horizontal and vertical geometry, including the location lines, developed in the preceding activities are refined. The plans should include all drawings and data necessary for construction of the proposed project. Chapter 17 of this Guidebook provides details on construction plan requirements.

Develop Traffic Management Plan (TMP) Through Construction Zones

A Traffic Management Plan is required for any project which disrupts existing travel patterns during construction (this includes pedestrians, people with disabilities, bicyclists, and motor vehicles). If a project is on a local road or uses a local road for a detour, the municipality must review and approve the TMP. The MassHighway Traffic Engineer or District Highway Director reviews and approves TMPs as appropriate. Chapter 10 discusses traffic control through construction zones.

Develop Traffic-related PS&E Data

For projects involving lighting, traffic signals, signs, pavement markings, and traffic controls for construction operations, plans, special provisions and estimates are submitted to the Traffic Engineer for review and approval.

Develop Pavement Design

The designer will conduct the pavement design analysis. All pavement designs will be reviewed and approved by the MassHighway Pavement Design Engineer. The design must conform to approved MassHighway methods and must include the documentation of all background data as detailed in Chapter 9 of this Guidebook.

Develop Drainage Design

The designer is responsible for developing a comprehensive drainage plan that will adequately drain the roadway. In addition, the drainage plan must also protect the adjacent landowners, wetlands, and public water supplies from drainage related problems. The designer determines the sizes, types, locations, and construction details for each drainage appurtenance based on hydraulic calculations and environmental considerations. When a bridge or major culvert is involved, the MassHighway Hydraulics Section, Bridge Section and Environmental Section should be consulted. Chapter 8 of this Guidebook and the *MassHighway Storm Water Handbook* should be consulted prior to initiating drainage design.

Coordinate Utility Relocations

Although the Utilities Engineer provides direct MassHighway contact with the utilities, the designer may be involved in the process to ensure that the relocations are appropriate. The designer's level of effort for this activity varies with the project, the utility involved, and the type of relocation. In addition, the designer may also be involved in coordinating Force Account and Betterment Agreements.

Update Construction Plans

In addition to all of the known existing details, the plans should include the following proposed details.

- road surface
- roadway width
- centerline
- drives and walks
- traffic control devices
- edging, curbing, and berms
- drainage appurtenances
- ditches
- bicycle accommodations
- landscaping
- sub-drains
- water supply
- roadside barriers
- demolitions
- bridges
- slopes
- fences
- curb cut ramps
- pedestrian access/accessible route for people with disabilities
- wetland resource areas
- vernal pools

Chapter 18 discusses the content of the construction plans.

Develop Special Provisions

The designer develops special provisions for the project. Special provisions are used to explain conditions or special construction practices not covered in the current edition of the *Massachusetts Standard Specifications for Highways and Bridges* or *Supplemental Specifications to the Standard Specifications for Highways and Bridges*. In the preparation of special provisions, refer to Standard Nomenclature and Designation of Items. A draft copy of the special provisions must be provided at the 75 Percent submission.

Special provisions will include but not be limited to:

- Scope of Work (including locus map, project limits, and project length)
- Provisions for Travel and Prosecution of Work

- Work schedule
- List of Utility owners (with name and address, of contact person)
- List of Items which have material options
- Individual contract items not covered in Standard Specifications, or if deviations to the Standard Specifications are made. The MassHighway Standard Nomenclature booklet identifies those items specifically requiring a Special Provision
- Special Precautions (other facilities such as structural foundations, ponds, streams, etc.)
- Special permission or construction methods stipulated in the environmental permits
- Copies of Permits, Licenses, Certificates, or Orders of Conditions (when available)
- Scheduling requirements (milestones, completion dates)

The Specification Section will provide standard inserts ("boiler-plate") into the special provisions booklet.

Update Cost Estimate
Definitive costs for some items previously uncertain (because they depend on design features impossible to specify earlier) can now be calculated. All costs should be consolidated so that the 75 Percent estimate reflects total costs as accurately as the latest project data will allow. An update of all non-participating and participating items must be included as part of this submission.

75 Percent Project Submission
All materials developed for the project are compiled and submitted at this time. This includes a written response to comments received on the 25 Percent submission. A checklist of the 75 Percent submission requirements is provided in Appendix 2-A-9 to this chapter. It is also helpful in the review process if all significant changes in the design that have occurred since the 25 percent approval are summarized and explained in the transmittal letter.

Submit 75 Percent Plans to Utilities Engineer
The 75 Percent plans are transmitted to MassHighway's Utilities Engineer for distribution to the affected utilities for their review. All betterments and special utility considerations are noted.

75 Percent Project Review

The 75 Percent Design Package is reviewed by the FHWA, various MassHighway sections, and municipalities, as appropriate. A coordinated on-site review with representatives of affected groups should be considered at this time, including MassHighway District construction personnel.

75 Percent Project Approval

The 75 Percent approval is granted when the plans are approximately 90 Percent complete, and all the steps between the 25 Percent and 75 Percent stages in the Submission Guidelines have been properly addressed. After 75 Percent approval, the designer can proceed with the preparation of the 100 Percent/PS&E for the project.

2.4.3.3 100 Percent and PS&E Design Package

After review of the 75 Percent Design, the designer needs to complete the following steps to complete the design process.

Develop Traffic Control Agreement with Municipality (if required)

A Traffic Control Agreement is prepared for city or town roads, if necessary. It is not required for state highway projects or non-Federal-aid projects. The agreement will define the permanent traffic control, regulations, and devices needed to ensure the system will be operated and maintained as designed. The agreement will be signed by the highest elected local authority, by the Town or City Council, by the municipal legal counsel, and by MassHighway. Copies are distributed to the FHWA, City/Town, MassHighway Commissioner, Traffic Section, and the District Highway Director.

Finalize Construction Plans

Construction plans are finalized and assembled during this activity. Final construction plan requirements are further discussed in Chapter 18.

Finalize Cost Estimates

Project quantity estimates are prepared based on a list of items compiled for the project. The designer must use a computer spreadsheet to enter the quantities and unit prices for each item. The designer must prepare a cost summary sheet. Chapter 18 describes MassHighway estimating procedures.

Submit Construction Plans to Utilities Engineer

The completed construction plans are transmitted to the Utilities Engineer for distribution to the affected utilities. All betterments and special utility considerations are noted. For additional information, refer to the MassHighway *Utility Accommodations Policy* and the 100 Percent Submission Guidelines.

100 Percent Plans, Specifications, and Estimate (100 Percent PS&E) Submittal
The designer completes the project, checking to ensure that all information necessary to construct the project is complete and is in the proper format. All items in the 100 Percent Submission Guidelines must be submitted at this time. A checklist of the 100 Percent/PS&E requirements is provided in Appendix 2-A-10 to this chapter. Necessary copies are made and the plan is sent to the appropriate section manager for final processing.

MassHighway's Project Manager is responsible for forwarding the specifications and estimate to the Capitol Expenditure Program Office (CEPO) for processing and then to the Specifications Section for construction advertising.

2.4.4 Right-of-Way

Layout plans, descriptions, and orders of taking are required to establish highway right of way for all projects which involve land acquisitions. The proposed layouts may result in changes to existing state highway layouts or to existing county, city, or town layouts, or may revise existing limited access provisions. All proposed layouts must be accurately computed. Where a project involves more than one municipality, separate layouts are required for each. Railroad baselines should be tied to the state highway layout.

The process for acquiring right of way or easements needs to be progressed as the design progresses.

2.4.4.1 Preliminary Right-of-Way Plans (25 Percent Design)

When land acquisition or easements are involved, the designer must identify existing and proposed layout (locations) lines, easements, property lines, corner markings, names of property owners, access points, and the dimensions and areas of estimated takings and easements as part of the 25 Percent Design.

When land acquisitions are made by MassHighway, ROW plans are required. Specific requirements for developing Preliminary Right-of-Way Plans are provided in Chapter 18 of this Guidebook.

Preliminary ROW and/or layout plans will be prepared at 25 Percent Design to produce legible reproductions. Each sheet will be labeled "Preliminary Right of Way."

As required by state law, when land acquisitions are made by the state or a municipality, the process should be followed in accordance with The Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1978 as amended. Certification of this layout procedure by the MassHighway Right of Way Bureau is required (MGL Chapter 81). It is advisable that the municipality work closely with the Right-of-Way Bureau during the entire acquisition process to facilitate the necessary acquisition and ensure that Federal and State requirements are met. At the initiation of the process, the municipality must designate a coordinator/liaison to work with the Community Compliance section of MassHighway.

Guidance documents for municipalities involved in property acquisition for Federal-Aid and Non-Federal-Aid projects are available on MassHighway's website.

Preliminary Right-of-Way Plans (75 Percent Design)
The designer will confirm the acquisitions in the 25 Percent ROW submittal are adequate for the 75 Percent Design, or provide revised ROW Plans. ROW acquisition information will be posted on the preliminary ROW plan by the designer when the designer obtains the information.

2.4.4.2 Final Right-of-Way Plans (100 Percent/PS&E Design)

After the Layout or Taking documents are recorded, the preliminary ROW plan will become the final ROW plan. Each sheet of the plan will be labeled "Final Right-of-Way Plan," and the plan will be subject to any additions and revisions that may be required later. Any additions and revisions with dates will be noted. Specific requirements for the Final Right-of-Way Plans are presented in Chapter 18 of this Guidebook.

Finalize Layout Plans and Order of Taking
As soon as feasible after the 75 Percent project approval, Layout Plans and the Order of Taking are finalized by the designer. This involves checking the plans for completeness and preparing the Order of Taking. Layout Plans are discussed in Chapter 18.

2.4.5 Completion of Environmental Permitting/Design/ Right-of-Way Process

The conditions under which the project design and environmental permitting are complete and approved is when all documents necessary to publish the bid documents are complete, unless otherwise directed by the Deputy Chief Engineer of the MassHighway

Projects Section, the Chief Engineer of MassHighway, or the MassHighway Commissioner.

The recommended format for submitting the final Federal Aid and Non-Federal Aid Plans, Special Provisions & Estimate are described in Chapter 18 of the Highway Guidebook and the *Standard Specifications for Highways & Bridges*.

2.4.5.1 PS&E Completeness Review

Upon receipt of a PS&E submittal, MassHighway will review the submittal for completeness as follows:

- Three completed copies of the PS&E.
- Bridge Section approval of the Bridge Plans, Special Provisions & Estimate.
- No proprietary items in the Special Provisions & Estimate unless they are justified as an overriding public interest. (Federal oversight projects require FHWA approval.)
- The PS&E satisfies all the latest Engineering Directives/Policies/Codes/Manuals.
- Hazardous Materials Special Provisions & Estimate are included.
- Environmental Permits, Licenses and their conditions (if any) are included.
- Project ITS elements conform to the regional architecture.
- The Right-of-Way Certificate and its conditions (if any) are included.
- Commitment letter from the Municipality for Non-Participating funding is included.
- If Federal Aid, the project is in the current year STIP and the estimated cost is within the approved STIP amount. (For projects under $5 million, the total cost must be within $500,000 of the STIP amount; for projects costing more than $5 million, the total cost must be within 10 percent of the amount programmed on the STIP.)
- Special provisions are provided for the asterisked items in the Preliminary Estimate Proof Sheet. Care should be taken not to duplicate the standard specifications.
- Items mentioned in the Special Provisions are also in the Estimate.

- The names, addresses, and phone numbers of the utilities owners, municipalities' officials and other contact persons are in the contract.

2.4.5.2 Submission of Plans, Specifications, and Estimate for Procurement

MassHighway is responsible for submitting the final PS&E package to the Capital Expenditure Program Office (CEPO) and the Construction Contracts Section. The final PS&E is distributed when the project design is complete and all documents necessary to publish the project advertisement are in order, unless otherwise directed by the Deputy Chief Engineer of the Projects Section, the Chief Engineer of MassHighway, or the MassHighway Commissioner.

2.4.5.3 Environmental Permit Checklist Review

In addition to ensuring completeness of the design and right-of-way process, the proponent needs to ensure that all necessary environmental permits and clearances are complete.

Step IV Outcomes:
A designed and permitted project ready for construction.

Depending upon whether or not a project has been programmed, the next step in the project development process is either Step V, Programming, or Step VI, Procurement.

2.5 Step V: Programming

The programming of transportation improvements can be a complex and sometimes lengthy process involving local, state, and federal agency approvals, depending on the scope of the project. Programming, which typically begins during design, can occur at any time during the process from planning to design. Public support for the project is critical and can significantly alter the implementation process and schedule.

Once the proposed project is approved by the Project Review Committee, in Step III described previously, the PRC should notify the District and the MPO. The Metropolitan Planning Organization will consider the project's programming schedule during its annual Transportation Improvement Program (TIP) development process. Funding for the project can be allocated once the project is placed on the TIP and the project is ready to move forward.

When a new TIP is being developed, all of the communities in the Metropolitan Planning Organization region are notified and asked to submit those projects they would like included on the TIP. This annual solicitation for projects takes place during the first three months of the calendar year. The list of projects submitted by the communities is compiled with those submitted by the MPO member agencies (the Planning Agency, MassHighway, EOT and the Regional Transit Authority), and projects that remain from the previous TIP. Regional TIPs are also amended from time to time, depending upon local needs and the status of individual projects.

The following process should be followed by the community for those projects proposed on federal-aid eligible, locally maintained roadways:

- The MassHighway District Office notifies the community and the MPO in writing if the project is approved by the Project Review Committee. (The District Office will notify the community if the project is not considered viable as a MassHighway-sponsored project and that it is more suitable as a Chapter 90 project.)
- Following MassHighway project approval, the community should contact their MPO to request that the project be placed on the TIP.
- The MPO considers the project in terms of regional needs, evaluation criteria and compliance with the Regional Transportation Plan.

- The MPO votes on approving the project for inclusion in the Draft Regional TIP, which is presented to the public for review.
- The MPO votes on approving the project for inclusion in the Final Regional TIP, which includes revisions based on public input.

There are several sources of funding for transportation projects. It should be noted that many other projects compete for the same money; therefore, the priority of the project will determine if it is assigned to a funding category and programmed in the TIP. Typical funding categories include:

- **National Highway System (NHS)** – Funds for projects on all National Highway System roadways. NHS roadways include Interstate routes and a large percentage of urban and rural arterials. The funding split for this program is 80 percent federal funds, 20 percent state funds. All projects on NHS roadways are to be designed in conformance with the latest edition of the AASHTO's *A Policy on Geometric Design of Highways and Streets*.
- **Non–Federal Aid (NFA)** – Funds for construction, reconstruction, and improvement projects on roads and bridges in urban and rural areas at the discretion of the state. The state share is 100 percent of the project costs (Not typically included in TIP, except in the Boston Region).
- **Surface Transportation Program (STP)** – Funds for projects chosen by states and localities on any roads that are not functionally classified as local or as rural minor collectors. These roads are referred to as Federal-aid roads. The funding split for this program is 80 percent federal funds, 20 percent state funds.
- **Congestion Mitigation / Air Quality (CMAQ)** – Funds for projects in the Clean Air Act non-attainment areas for ozone and carbon monoxide. The funding split for this program is 80 percent federal funds, 20 percent state funds.
- **Highway Bridge Replacement / Rehabilitation** – Funds the replacement or repair of bridges based on structural adequacy, safety and serviceability. The funding split for this program is 80 percent federal funds, 20 percent state funds.
- **Interstate Maintenance (IM)** – Funds rehabilitation, restoration, and resurfacing on the interstate highway system. Also funds the reconstruction of bridges, interchanges, and overpasses along existing interstate routes and the acquisition of right-of-way. The

funding split for this program is 90 percent federal funds, 10 percent state funds.

- **Federal Aid (FA)** – Funding for projects that have specialized or proprietary funding or projects for which the specific federal category has not yet been identified.

There may be other applicable funding categories depending on the type of project under consideration. The project proponent should consult the regional planning agency for current information.

2.6 Step VI: Procurement

Once a design is complete, the project is organized within a construction contract, and an open invitation to bidders is published. Construction contractors may review currently available bids through Comm-PASS, the statewide procurement program maintained by the Operational Services Section.

Bids received by MassHighway are opened and reviewed, and will be awarded to the lowest qualified bidder. A current list of contracts available is maintained on MassHighway's website (www.mass.gov/mhd.)

2.7 Step VII: Construction

After a construction contract is awarded, the proponent and the contractor will need to develop a construction management plan. The permitting agencies, local authorities, and affected members of the general public need to be informed of the plan. These entities should also be notified as changes in construction areas and activities occur throughout the project.

2.7.1 Public Participation During Construction

Before construction activities begin, the proponent and construction manager must determine the appropriate type of public notification and participation needed. Different projects result in different types of disruption to transportation and other nearby activities. For simple projects, including resurfacing, a minimal degree of public participation may be needed. For these types of projects, the proponent should, at a minimum, notify abutters of the impending construction activity.

For complex projects, the proponent may need to schedule a construction management plan meeting with abutters and other project participants (local boards, interest groups, business associations, etc.). At this meeting, the proponent can describe the types of construction activity needed, construction phasing, and durations. Issues and concerns associated with the construction period can be identified and adjustments made to the construction management program to minimize community impacts as a result.

2.7.2 Construction Management and Monitoring

Careful management and monitoring of construction activities is necessary for most projects to ensure that quality standards are maintained, environmental commitments honored, and community expectations are met.

2.8 Step VIII: Project Assessment

Project Assessment can be used as a tool to further improve the project development and delivery processes. Although completion of this process will depend upon the proponent, three important pieces of information can be gathered through this brief, informal process. These include:

- Constituent input into project development process:
  - Were the proponent's expectations for guidance, review, and feedback met?
  - Was the project timeline reasonable?
  - Was the public outreach program for the project appropriate and effective?
  - Were community concerns about the project addressed and community comments incorporated into the planning and design processes?
  - Were appropriate design controls selected for determining the design outcome?
  - Was the project construction effectively managed so that community impacts were minimized?
- Constituent review of the project design elements
  - Was the project need addressed?
  - Is the resulting project consistent with its context?
  - What specific design elements are judged to be successful and recommended for future projects?
  - What specific design elements are judged to be unsuccessful and should be reconsidered, and why?
- Follow-up of Punch List items
  - Are there project elements that still need to be completed?
  - Has the project resulted in any situations requiring follow-up or adjustment to meet the original or newly-created project needs?

2.9 Public Outreach

Public outreach is anticipated throughout the project development process to ensure that the project continues to meet its intended purpose, benefits from input and feedback from interested citizens, local and regional groups, and elected officials, and maintains strong support. Public outreach is integrated into every step of the project development process defined in this chapter. This active participation will ensure a role for the public to help shape the project that emerges from the process. It is particularly important to provide opportunities for public outreach early in project planning.

2.9.1 Identify Project Constituents

Early in the project development process, the proponent should consider the public support for the project and the constituency that it serves. ***Project constituents*** are groups and individuals that are involved in, have an interest in, or are affected by a proposed project. They can either be formal participants in the process, or can be represented by other participants in the process. Different types of projects involve different constituents, and different levels of planning and review. Project constituents include some or all of the following entities:

- Federal Highway Administration (FHWA)
- MassHighway
- Metropolitan Planning Organizations
- Regional Planning Agencies
- Regional Transit Authorities
- Transportation Providers
- State and Federal Regulatory Agencies
- National Park Service
- U.S. Coast Guard
- Other State Authorities
- Elected Officials, Public Works Departments, Local Boards, and Commissions, including Conservation Commission
- Facility users (commuters, residents, visitors by all modes)
- Neighbors and citizen groups
- Municipal commission(s) on accessibility
- Regional Independent Living Center(s)

- Advocacy and interest groups (such as local pedestrian or bicycling committees, trucking associations, preservation groups, etc.)
- Private area businesses
- Local emergency responders
- Utilities (including railroads)
- Regional watershed or river management councils

At a minimum, the proponent should contact the appropriate local planning and public works staff, planning commission chair, conservation commission chair, select board chair, and major local property owners in the vicinity of the project area to help determine initial concerns and issues. The proponent should confer with municipal officials to determine which property owners may have legitimate issues that should be addressed by the project. This effort will help identify important local groups such as neighborhood associations, business associations, historical societies, recreation and open space committees, transportation providers, and others who should be informed of the project. It is better to be as inclusive as possible early in the Project Development Process to allow the public to participate and be afforded an opportunity to contribute to the decision-making process for the project. (It should also be made clear to all those attending how comments will be treated and how any expected follow-up will be handled).

Identifying the likely parties that may have interest in the project at the beginning of the project development process helps the project proponent tailor the public outreach program appropriately. The project proponent should define a public participation plan at the outset of each step of the project development process. Tools available for this outreach are described in Section 2.9.3.

2.9.2 Public Outreach Approach

The level of interest and role of the public varies widely by project type and complexity. Exhibit 2-9 provides a public outreach matrix by project type to aid the project proponent in determining the scope of this effort at the outset. Different types of projects are likely to elicit different levels of community, resource agency, and local board interest. These project types are grouped into system preservation projects, and system improvement or expansion projects with guidance provided on the appropriate level of public outreach, as explained further in the following paragraphs.

Exhibit 2-9
Typical Public Outreach Approach for Different Types of Projects

	Necessary and Recommended Public Outreach Approaches						
	Notify abutters and utilities of construction impacts*	Community notification and involve abutters	Early involvement of Local Boards/ Commissions	Early Local Issues Meeting	Public forums at several stages of Planning and Design	Active communication about project progress	Form an Advisory Task Force
System Preservation**							
Roadways, Sidewalks, and Shared Use Paths							
Maintenance	□		□				
Resurfacing	●	□	□				
Reconstruction/Reconfiguration within Existing Layout	▲	▲	▲	●	□	□	□
Bridges							
Maintenance	□		□				
Rehabilitation	●	□	□				
System Improvement or Expansion							
New Roadway or Shared Use Path	▲	▲	▲	▲	▲	●	●
Widened Roadway or Shared Use Path Widening	▲	▲	▲	▲	●	●	□
Intersection or Roundabout Improvements	▲	▲	▲	▲	●	●	□
New Interchange or Interchange Reconfiguration	▲	▲	▲	▲	▲	●	●
Roadside Safety, Sidewalk or Signage Improvements	▲	●	●	●	●	●	
Traffic Calming, Streetscape, Lighting, or Transit Enhancements	▲	▲	▲	▲	▲	●	□
New or Widened Bridge	▲	▲	▲	●	●	●	
New or Expanded TDM/Park & Ride Lot	▲	▲	▲	□	□	□	
New or Expanded Traffic Management System	▲	▲	●	□			

▲ Usually necessary/recommended.

● Suggested for project types indicated and usually necessary for more complex projects within each type.

□ May be helpful for more complex projects for the types indicated.

* The Public Works Department and other utilities should also be consulted to determine if there are any planned improvements to subsurface utilities and infrastructure

** Public outreach may not be needed for system preservation activities such as routine maintenance and resurfacing; however, these projects may offer opportunities to enhance the accommodation of bicyclists or pedestrians and it may be useful to reach out to specific constituencies as projects are being planned. Examples of these types of projects include restriping, new crosswalks, ADA enhancements, or drainage improvements.

Source: MassHighway

The project proponent should carefully consider the best-suited approach to public outreach, depending upon the complexity of the project. Some general approaches to increase awareness of a project and solicit input are described below:

- **Notification of Abutters** — Project proponents for all projects, other than routine maintenance, should, at a minimum, notify abutters of the construction program anticipated and its potential impacts to property and/or operations. This can be informally done through neighborhood flyers or posters, through newspaper notices, or more formally done by certified mail.
- **Notification of Utilities** — Project proponents should notify utilities of the construction program anticipated and its potential impacts to their services or operations. It is important to notify utilities even for routine resurfacing and rehabilitation projects to coordinate any planned utility work. This is especially true for an overlay, since pavement life is shortened considerably following a utility cut.
- **Community Notification** — As projects become more complex, disruptive, and of longer duration, notification should be made to the community as a whole using the public outreach tools discussed in the next section. This community notification helps to increase knowledge of the project and its potential construction-related impacts. Beyond simple notification, the proponent should actively involve abutters, specific local interest groups, and utilities to get a good cross-section of people to participate.
- **Early Involvement of Local Boards and Commissions** — The proponent should consider involving local boards and commissions at the outset of the project. This involvement can help the proponent identify issues the project is likely to face and can help the proponent gauge the type of additional outreach activities that may be most appropriate if the project proceeds. Outreach to local boards and commissions can also be helpful for complex maintenance and resurfacing projects. It is safer to notify all municipal departments/ boards of a project's scope before much design work is started to minimize later concerns or needs for project changes.
- **Early Local Issues Meeting** — An early local issues meeting is important for projects where transportation facilities are being substantially modified, expanded, or replaced. It is recommended that this meeting be widely advertised, as discussed below. This

meeting provides a forum for project constituents to make their concerns known before a course of action is determined. For straightforward projects, this early local meeting, coupled with later opportunities for public hearings during design and permitting, may be sufficient. For more complex projects, or for projects that cover multiple jurisdictions, several early local issues meetings may be necessary.

- **Public Forums or Hearings at Several Stages of Planning and Design** — As project complexity continues to increase, the public participation should include several opportunities for public involvement during the planning and design phases in addition to the early local issues meeting described above. Targeted mailings can be used to generate interest and ensure that concerned parties are contacted. Key milestones where public involvement is especially important include alternatives analysis during the planning process, at key design milestones, or if the project elements change substantially due to increasing refinement of the design. Detailed meeting minutes are recommended for each session. These are discussed in more detail in the Section 2.2.1.2.
- **Active Communication about Project Progress** — In addition to interactive public forums, active communication about project progress is helpful for maintaining consensus and keeping project constituents informed about the project status. One good tool is the *ProjectInfo* menu on MassHighway's website (www.mass.gov/mhd). Several additional tools for communicating project progress are highlighted in the following section.
- **Formation of an Advisory Task Force** — An advisory task force of project constituents can be particularly helpful for maintaining involvement from a consistent group of individuals, representing a cross-section of interests in the project. This formalized type of public outreach is generally reserved for more complex projects with a wide range of alternatives, benefits and potential impacts. In almost all cases, formation of an advisory task force does not replace the need for the other public outreach approaches described above. Citizen Advisory Committees may also be established by the Secretary of the Executive Office of Environmental Affairs (EOEA) as part of the Massachusetts Environmental Policy Act (MEPA) process. The charge of an advisory group should be defined at the outset with an unambiguous definition of the limits of their decision-making

authority. Typically, task forces are advisory bodies that offer input to the process and suggest recommendations.

2.9.3 Public Outreach Tools

There are many aspects of public outreach associated with transportation projects including:

- Informing constituents of a potential project;
- Active participation of project constituents in planning and design;
- Formalized public meetings and hearings; and
- Communication about the progress of a project

Within each of these aspects, there are various outreach tools available which serve different purposes and target different audiences. These tools are applicable throughout the project development process.

The first stage in public outreach is to make people aware of a potential project. Legal notices alone are ineffective at informing the community about upcoming project meetings. The project proponent should consider additional ways to communicate the opportunity to participate in the transportation project development process, such as:

- Local newspaper articles or editorial letters
- Notices to local boards , committees, and local or statewide advocacy groups
- Posters at civic buildings or churches, or in neighborhoods
- Local cable television community event calendars
- A community website posting or community-wide mailing
- Press releases to media outlets
- A community-wide meeting notice or newsletter mailing (or email)
- Flyers to project abutters

Public hearings, or opportunities for public hearings, are required by FHWA for Federal-Aid highway projects as part of a process that also encourages a variety of citizen involvement techniques such as informal public meetings, briefings, and workshops. Public hearings are legally recognized formal meetings held at particular stages of the project development process. If a federal or state environmental document is required, the public hearing should not be held until the document is available for public review. Some environmental or resource agency permits or clearance processes also require public hearings.

All public meetings and hearings should be held in facilities that are fully accessible for people with disabilities, and notices about these meetings should use the International Symbol of Accessibility to indicate that the location is accessible. Handout materials available in alternative formats—Braille, large print, and/or audio cassette—as well as other accommodations (sign language interpreters, CART reporters, etc.) should be indicated in the meeting notices along with specifically how to request these accommodations.

The types of public hearings or meetings that can occur during the project development process are highlighted in Exhibit 2-10. The schedule of these meetings is dependent on project complexity and its permitting requirements.

Formal environmental and design hearings are sometimes ineffective in eliciting community concerns and addressing individual issues. Other ways to communicate with those interested in or affected by projects include:

- **Public Meetings** — informal gatherings of designers, officials, and local citizens to share and discuss proposed actions. These meetings provide an opportunity for informal, less structured conversations about a project, the design elements, and its potential benefits and impacts.
- **Open Houses** —mechanisms for interested parties to gather more detailed information on a project. Open houses facilitate the discussion of particular details of interest to individuals more effectively than traditional hearings or public meetings.
- **Workshops or Charrettes** —smaller groups that facilitate problem solving around design issues for which several options are available and the best solution is unclear.

Exhibit 2-10
Typical Public Meetings during Project Development

Project Development Stage	Public Meetings/Hearings
I. Problem/Need/Opportunity Identification	Local Meetings (Board of Selectmen, Local Transportation Committee, Neighborhood, etc.)
II. Planning	Early Local Issues Meeting(s) Alternatives Presentation (if needed) Project Presentation (if needed)
III. Project Initiation	
IV. Environmental, Design and ROW Process	
Environmental	
<u>Conceptual to 25 Percent Design Phase</u>	
Massachusetts Environmental Policy Act (MEPA) Clearance	
■ ENF	Consultation Session
■ EIR	Public Informational Meeting (if requested)
■ Special Review Procedure	Citizen Advisory Committee Meetings (if established)
National Environmental Policy Act (NEPA) Clearance	
■ CE	None
■ EA	Public Informational Meeting (if requested)
■ EIS	Scoping Hearing Draft EIS Hearing
Other Federal Regulations / Permits	
Section 4 (f) of 1966 US DOT Act	Relies on NEPA Process
Section 106 Historic Properties and Districts	Relies on NEPA Process
Section 131A Endangered Species	Relies on NEPA Process
Section 404 of 1972 Clean Water Act	
Category 1 and 2 ACOE PGP	None
Category 3 (Individual) ACOE PGP	Public Meeting (if requested)
U.S. Coast Guard Section 10 Bridge Permit	Public Hearing
Other State Regulations / Permits	
<u>Conceptual to 25 Percent Design Phase</u>	
■ Chapter 91 Waterways Licensing	Public Hearing for Non-Water Dependent Uses
■ Chapter 254 Historic Properties and Districts	Relies on MEPA Process
<u>75 to 100 Percent Design Phase</u> ■ Massachusetts Wetlands Protection Act (WPA)	Public Hearing(s) with Local Conservation Commission
<u>Construction Phase</u>	
National Pollutant Discharge Elimination System (NPDES)	None
Design	Location Public Hearing[1] Special Hearing[2] Design Public Meeting (25 Percent)
Right of Way Acquisition	Public Hearing and/or Town Meeting
V. Programming	TIP Meetings (varies by MPO)
VI. Procurement	None
VII. Construction	Community Informational Meeting(s)
VIII. Project Assessment	None

1 To seek public input on a major project decision or location.
2 Generally held in response to a community request or to seek additional input for decision-making.
Source: MassHighway

- Other Communication Tools that are effective in providing information to the public and soliciting their input include:
  - **Newsletters** — provide a forum for meeting notification and periodic updates on project status and decisions. Newsletters can either be traditionally mailed or electronically transmitted.
  - **Websites** — allow frequent updates of project status, enabling interested parties to review materials on their own schedule, and facilitate correspondence of questions and responses. Project websites should be designed to meet access standards for electronic media as defined in the Massachusetts Web Accessibility Standards Revision 2.0 available at (www.mass.gov/itd/massgov/publications/workgrouprpt/accessibilitity_report.htm).
  - **MassHighway's Project Information System** — provides internet-based project status information for active design and construction projects through links to the ProjectInfo system.
  - **Project Information Boards** —illustrate project details and provide contact information at the project site facilitating involvement in other forms of outreach.

Successful public meetings require good advance communications and coordination with community leaders, elected officials, the Regional Planning Agencies, and MassHighway beforehand in order to set the agenda and establish the framework for appropriate follow-up and continued communication. The proponent should work closely with local and regional officials on meeting logistics, including location, time, and format.

2.10 Project Development Schedule

The project development process involves a range of tasks within these defined steps (from few to many) and extends over varying lengths of time (from less than a year to more than ten) depending on the complexities of the project, funding sources, and permitting requirements. A schematic schedule of the project development process is provided as guidance in Exhibit 2-11. Additional detail on the timelines that may be involved in the environmental permitting aspects of project development are included as an Appendix to this chapter.

Exhibit 2-11
Project Development Schematic Timetable

Steps/Description	Schedule Influences	Typical Duration
Step I: Problem/Need/Opportunity Identification The proponent completes a Project Need Form (PNF). This form is then reviewed by the MassHighway District office which provides guidance to the proponent on the subsequent steps of the process.	The Project Need Form has been developed so that it can be prepared quickly by the proponent, including any supporting data that is readily available. The District office shall return comments to the proponent within one month of PNF submission.	1 to 3 months
Step II: Planning Project planning can range from agreement that the problem should be addressed through a clear solution to a detailed analysis of alternatives and their impacts.	For some projects, no planning beyond preparation of the Project Need Form is required. Some projects require a planning study centered on specific project issues associated with the proposed solution or a narrow family of alternatives. More complex projects will likely require a detailed alternatives analysis.	Project Planning Report: 3 to 24+ months
Step III: Project Initiation The proponent prepares and submits a Project Initiation Form (PIF) and a Transportation Evaluation Criteria (TEC) form in this step. The PIF and TEC are informally reviewed by the Metropolitan Planning Organization (MPO) and MassHighway District office, and formally reviewed by the PRC.	The PIF includes refinement of the preliminary information contained in the PNF. Additional information summarizing the results of the planning process, such as the Project Planning Report, are included with the PIF and TEC. The schedule is determined by PRC staff review (dependent on project complexity) and meeting schedule.	1 to 4 months
Step IV: Design, Environmental, and Right of Way The proponent completes the project design. Concurrently, the proponent completes necessary environmental permitting analyses and files applications for permits. Any right of way needed for the project is identified and the acquisition process begins.	The schedule for this step is dependent upon the size of the project and the complexity of the design, permitting, and right-of-way issues. Design review by the MassHighway district and appropriate sections is completed in this step.	3 to 48+ months
Step V: Programming The MPO considers the project in terms of its regional priorities and determines whether or not to include the project in the draft Regional Transportation Improvement Program (TIP) which is then made available for public comment. The TIP includes a project description and funding source.	The schedule for this step is subject to each MPO's programming cycle and meeting schedule. It is also possible that the MPO will not include a project in its Draft TIP based on its review and approval procedures.	3 to 12+ months
Step VI: Procurement The project is advertised for construction and a contract awarded.	Administration of competing projects can influence the advertising schedule.	1 to 12 months
Step VII: Construction The construction process is initiated including public notification and any anticipated public involvement. Construction continues to project completion.	The duration for this step is entirely dependent upon project complexity and phasing.	3 to 60+ months
Step VIII: Project Assessment The construction period is complete and project elements and processes are evaluated on a voluntary basis.	The duration for this step is dependent upon the proponent's approach to this step and any follow-up required.	1 month

Source: MassHighway

2.11 Design Exceptions

Some projects being pursued as Footprint Roads projects may require design exceptions. The design exception application will be reviewed by MassHighway in this context.

The design guidance contained in this Guidebook is intended to provide project proponents with sufficient flexibility to address the unique and diverse conditions encountered on the Commonwealth's streets and highways; however, there may still be occasions when design exceptions are necessary. For these circumstances, the project proponent must complete a Design Exception Report and transmit it to MassHighway as part of the Functional Design Report with the 25 Percent Design package.

This Design Guidebook has incorporated AASHTO criteria for Massachusetts' roadway and bridge design. AASHTO criteria are the recognized standard for design based on years of research and empirical data for safe and efficient movement of traffic. Departure from these guidelines requires documentation to support the decision-making process.

The FHWA and MassHighway recognize 13 controlling criteria from AASHTO policy which, if not met, require formal approval of design exceptions. These criteria are:

Roadway and Bridge Criteria

- design speed
- lane width
- shoulder width
- horizontal alignment
- vertical alignment
- grades
- stopping sight distance
- cross slope
- superelevation
- horizontal clearance (other than "clear zone")

Bridge (Only) Criteria

- width
- structural capacity
- vertical clearance

Desirable and minimum standards for most of these controlling criteria are found in various parts of this Guidebook. Structural capacity criteria is found in the *MassHighway Bridge Manual*. Accessible design standards are found in 521 CMR and in the MassHighway *April 2003 M/E Construction Drawing Supplement* and online directives for curb cut ramps and sidewalks. Every reasonable effort should be made to design projects within these ranges. When the minimum standards cannot be achieved, documentation and approval of these as design exceptions are required and must be provided in a Functional Design Report. Use of less than minimum standards must be based on sound engineering judgment, weighing relevant contextual constraints, and other relevant factors. The safety and traffic operational goals of the project sill must be met by the facility with the lower standards.

2.11.1 Design Exception Triggers

If minimum controlling criteria cannot be met, documentation of design exceptions is required for all projects, regardless of functional classification or funding, at the 25 Percent Design stage, to demonstrate that sound engineering judgment was used to design the improvements. Documentation for all MassHighway design exceptions should follow the guidelines included in this manual, FHWA procedures from the *Federal-Aid Program Guide (FAPG) Transmittal 9* and *23 CFR, Part 625* as revised, and relevant FHWA Policy and Engineering Directives. The FHWA guidance should be followed regardless of project funding because of its relevance to all roadway and bridge projects, and the need for consistency in processing design exceptions.

Any exceptions to full compliance with 521 CMR, *The Rules and Regulations of the Massachusetts Architectural Access Board,* should be identified at this point so the MassHighway can either modify the design approach, or seek the appropriate variance from the Access Board.

2.11.2 Design Exception Documentation

Documentation of the design exception should include, but not be limited to:

- Executive Summary:
    - A brief description of the proposed project
    - A listing of the controlling criteria for which a design exception is requested

- Proposed Improvement:
  - Description of proposed project
  - Purpose of improvements; safety, capacity, etc.
    — Type of project; reconstruction, rehabilitation, etc.
  - State if the improvement is a Footprint Roads project
  - Other existing deficiencies to be improved by the project
- Description of the Existing Conditions include:
  - Functional Classification of the roadway(s)
  - Roadway Character and Transportation Demands by All Modes
  - Description of Surrounding Area:
    — Developed or undeveloped
    — Scenic
  - Speeds:
    — Posted
    — 85 percentile
    — Observed
    — Design speed
  - Existing Lane and Shoulder Width (usable shoulder?)
  - Right-of-way Layout
  - Accident Data
  - Environmental Factors:
    — Wetlands
    — Trees
    — Parklands
  - Cultural Resources
    — Historic and archaeological areas
  - Accessibility:
    — Impracticability or equivalent facilitation
- Discussion of Design Exceptions include:
  - A separate discussion of each controlling criteria
  - MassHighway Desirable and Minimum Standards
  - Project proposed values and degree of reduction
  - Typical section(s) or other graphical description of the existing and proposed improvement along with other roadway elements

- An analysis of the accident data as it relates to the controlling criteria
- Discussion of compatibility with adjacent roadway sections and future expectations for corridor improvements
- If a design speed exception is requested, a discussion of effects on other controlling criteria
- Discussion of right-of-way constraints
- Discussion of environmental, cultural resource, or other constraints
- Any features that might be used to mitigate the substandard feature such as signing and striping
- Where compliance with 521 CMR is technically infeasible, or would result in excessive costs and no substantial benefit to a person with disabilities.
- A rough cost estimate of the incremental cost to comply with MassHighway/AASHTO minimum standards. A benefit/cost analysis and/or a Value Engineering assessment may also be included when appropriate data is available.

- Recommendation/Summary
  - The designer must document that reasonable engineering judgment was used to justify the proposed design by drawing from the above information.

Additional guidance for completing a Design Exception Request is provided in Appendix 2-A-11.

2.11.3 Approval Process

The design exception documentation is normally prepared by the design engineer and forwarded to the District Project Development Engineer. The District Project Development Engineer then coordinates review by the Design Exceptions Committee. All design exceptions must be approved by the Chief Engineer. Design exceptions on all projects which require FHWA review are then forwarded to FHWA for approval.

Upon receipt of all approvals, the documentation and the approval letters must be kept in a permanent

MassHighway convenes a committee to review design exceptions. This committee typically includes the District Project Development Engineer and representatives from:

- *The Chief Engineer's Office*
- *Project Management*
- *Environmental*
- *Traffic*
- *Planning*
- *Right-of-way, and the*
- *Pedestrian and Bicycle Accommodation Engineer*

Other representatives may be included as the circumstances dictate.

project file for future reference. The project submittal to the Capital Expenditures Program Office (CEPO) for construction advertising should include a statement such as “design exceptions have been approved for this project and are on file.”

2.12 For Further Information

- A Policy on Geometric Design of Highways and Streets, AASHTO, 2004.
- Guide for the Development of Bicycle Facilities, AASHTO, 1999.
- Guide for the Planning and Design of Pedestrian Facilities, AASHTO, 2004
- A Guide to Achieving Flexibility in Highway Design, AASHTO, 2004.
- *Highway Capacity Manual*, Transportation Research Board, 2000.
- Manual on Uniform Traffic Control Devices, Federal Highway Administration, 2003.
- Development of the Bicycle Compatibility Index: A Level of Service Concept, Implementation Manual, FHWA-RD-98-095,1998.
- *Transit Capacity and Quality of Service Manual,* Transportation Research Board, Transit Cooperative Research Program. Report 100, 2nd Edition, 2003.
- *42 U.S.C. 4332(2)(C)* – National Environmental Policy Act.
- M.G.L. c.30, Section 61 to 62H and 301 CMR 11.00 – Massachusetts Environment al Policy Act.
- *A Guide to Best Practices in Context Sensitive Solutions,* Transportation Research Board, National Cooperative Highway Research Program. Report 480. Washington, DC, 2002.

2-A

Project Development Appendix

2-A-1

Project Need Form (PNF)

All new MassDOT Highway projects are now identified and initiated using the MassDOT Project Intake Tool (MaPIT). The Project Need Form (PNF) is part of this tool. You need a GeoDOT account to log into MaPIT.

Log into MaPIT
https://massdothpi.esriemcs.com/mapit/

Request a GeoDOT account
https://www.mass.gov/forms/request-a-geodot-account

2-A-2

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Transportation Evaluation Criteria

Transportation Evaluation Criteria

Beginning in 2004, MPOs began using formal, written evaluation criteria ("Transportation Evaluation Criteria") to assess projects for inclusion in the TIP. These criteria are first applied to projects during their earliest stages to provide a broadly based overview and rating of many, often competing, elements to assist in eventual project assessment and prioritization by the regional MPO. These criteria are useful in the preparation of a Project Need Form (submitted as an attachment, if available) and required as part of the Project Initiation Form submission.

Criteria for Highway System Preservation Projects

Highway System Preservation Projects include roadway maintenance, resurfacing, and reconstruction (should be within the existing road footprint); bridge maintenance, rehabilitation, and replacement; and other infrastructure preservation. For these types of projects, both condition and usage criteria apply as described below:

Condition

- Pavement condition (in consideration of pavement management principles)
- Pavement structural adequacy (as available)
- Bridge condition
- Condition of other bridge infrastructure elements
- Degree and severity of deterioration of other infrastructure
- Compliance with minimum access standards

Usage

- Traffic volumes and truck usage
- Pedestrian and bicycle usage and/or connectivity (as it is sometimes difficult to provide good pedestrian and bicycle data, connectivity to other trails, downtown areas, neighborhoods, schools, etc., should also be considered)
- Effect on connectivity for the closure or restriction of bridges
- Effect on safety and congestion

Cost Effectiveness (as applicable)

- Cost per daily traffic (average daily traffic or ADT) and/or pedestrian/bicycle user, as available
- Cost per lane mile
- Cost per ADT/lane mile

Criteria for System Improvement/Expansion Projects

Highway System Improvement/Expansion Projects include new or improved roadways and intersections, bridges, bicycle, and pedestrian facilities, and park & ride/transportation demand management facilities. For these types of projects four criteria categories are applied, including: condition and service quality, mobility, safety and security, and other effects, described below.

Condition and Service Quality

- Condition of improvement for facility (roadways and intersections, bridges, bicycle/pedestrian facilities and park & ride/transportation demand management facilities)

Mobility

- Magnitude and duration of congestion
- Travel time and connectivity/access
- Number of new pedestrians, bicycles, or transit riders that will use the facility (if available) or other measure of project's potential to encourage non-automobile oriented travel (influenced by the project's proximity to activity centers and destinations--downtowns, neighborhoods, schools, parks, etc., as well as by its connectivity to other existing or planned bicycle and pedestrian routes).

Safety and Security

- Crash rate compared to state average (if crash rate is not available, a general assessment of anticipated safety impacts can be substituted)
- Transportation security and evacuation routes
- Bicycle and pedestrian safety
- Bicycle comfort index (as described in Chapter 3)

Community Effects and Environmental Justice

- Residential
- Environmental justice for low income and minority neighborhoods
- Public support

Land Use and Economic Development

- Business
- Sustainable development
- Consistency with local and regional plans

Environmental and Air Quality/Climate Effects

- Air and water quality
- Historical and cultural resources
- Wildlife habitat and endangered species

Cost Effectiveness

- Cost per ADT and/or pedestrian/bicycle user, as available
- Cost per lane mile
- Cost per ADT/lane mile

Appropriate criteria for the project type are used to gauge the transportation needs and, through the planning process, to assess the transportation benefits, costs, and impacts of proposed projects. There may be several criteria that apply and many that do not, depending upon the type of project under consideration. The proponent is encouraged to tailor the criteria to the project.

The purpose of the criteria is to support the objective, transparent review of projects across the Commonwealth for eventual prioritization, programming, and construction. The evaluation criteria also provide useful guidance to assist in the problem definition.

The criteria developed for *Highway System Preservation Projects* and *Highway System Improvement or Expansion Projects* are used to support the preparation of the Project Need Form and (if required) the Project Planning Report, as discussed in Sections 2.1 and 2.2 of this chapter. It is helpful to attach the Transportation Evaluation Criteria form to the PNF for review, to the extent that it is available. Every region has adopted their own version of the Transportation Evaluation Criteria. The project proponent should consult with his/her regional planning agency to ascertain the TEC criteria and form in use for that region.

Project Compatibility With Other Policies and Programs

The transportation effects of projects are not the only consideration in evaluating projects. The project should also be integrated with local land use policies and goals so that, in total, the desired community objectives are achieved. Other important considerations, including the Commonwealth's sustainable development principles, and local partnerships, should also be used to evaluate projects. If the project has any Intelligent Transportation Systems (ITS) elements, it should also be confirmed at an early stage that the project scope and design is consistent with the regional ITS architecture. (Periodic checks regarding continued conformance with the regional ITS architecture should be incorporated into each stage of the design process.)

Section 23 CFR Parts 655 and 940, FHWA Final Rule (and FTA Policy) – Intelligent Transportation System Architecture and Standards — implements section 5206(e) of TEA-21 and requires that projects funded with highway transit trust fund moneys (highway and transit) conform to the national ITS architecture and applicable standards. The rulemaking directs local implementation through the development of regional ITS architecture tailored to meet local needs. Four regional ITS architectures have been developed and adopted for Massachusetts. If the Project Needs Form notes an ITS component in the proposed project, then the designer/proponent, in consultation with the MassHighway District Projects Section staff and regional planning agency staff, is responsible for monitoring and periodic review during the design process to ensure consistency between project ITS elements and the regional ITS architecture. More information is available at http://www.eot.state.mas.us/regionalitsarchitecture/.

Sustainable Development promotes development that integrates the energy, environmental, housing, and transportation agencies' policies, programs and regulations to care for the built and natural environment. Toward this mission, the U.S. Department of Transportation and the Office of Commonwealth Development encourage the coordination and cooperation of all agencies, the investment of public funds wisely in smart growth and equitable development, and give priority to investments that will deliver living wage jobs, transit access, housing, open space, and community-serving enterprises. Several of the sustainable development principles are summarized in Exhibit 2A-2-1 and provide useful guidance for proponents of transportation projects.

Exhibit 2-A-2-1
Commonwealth's Transportation-related Sustainability Principles

- **Redevelop First.** Support the revitalization of community centers and neighborhoods. Encourage reuse and rehabilitation of existing infrastructure rather than the construction of new infrastructure in undeveloped areas.
- **Concentrate Development.** Support low impact development that is compact, conserves land, integrates uses, and fosters a sense of place. Create walkable districts by mixing commercial, civic, cultural, educational and recreational activities with open space and housing for diverse communities.
- **Conserve Natural Resources.** Construct and promote buildings and infrastructure that use land, energy, water and materials efficiently.
- **Restore and Enhance the Environment.** Protect and restore environmentally sensitive lands, natural resources, wildlife habitats, and cultural and historic landscapes. Preserve critical habitat and biodiversity.
- **Provide Transportation Choice.** Increase access to transportation options, in all communities, including land- and water-based public transit, bicycling, and walking. Invest strategically in transportation infrastructure to encourage smart growth.
- **Increase Job Opportunities.** Attract businesses with good jobs to locations near housing, infrastructure, water, and transportation options. Expand access to educational and entrepreneurial opportunities. Support the growth of new and existing local businesses.
- **Plan Regionally**. Support the development and implementation of local and regional plans that have broad public support and are consistent with these principles. Foster development projects, land and water conservation, transportation and housing that have a regional or multi-community benefit.

2-A-3
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Detailed Alternatives Analysis

Detailed Alternatives Analysis

A more complex set of project needs may warrant a more detailed planning and conceptual engineering review of alternatives, their impacts and benefits, and implementation issues as part of the Project Planning Report. This is particularly true when it is unclear what actions are “feasible” to address the identified needs. In this case, the proponent should develop base information, document resources, and complete transportation planning analysis and conceptual engineering of the alternatives in more depth to verify “project feasibility” and the preferred action.

This level of alternatives analysis is appropriate for all new facilities and for improvement or expansion projects where the feasibility of achieving the desired enhancements with acceptable impacts and reasonable investment is unclear at the outset. The key objectives of this effort are to assess alternatives to determine their engineering feasibility, environmental impacts and permitability, economic viability, and public acceptance.

MassHighway District staff and the load required planning staff can advise project proponents when a detailed Alternatives Study is likely to be warranted.

Project Mapping

Expectations for determining the feasibility of a project alternative (especially one that has physical impacts) requires the development and use of reliable base mapping.

Important factors in determining whether adequate mapping is available for this phase of project development are:

- The age of the mapping and whether project area features have changed dramatically;
- The availability of vertical elevations and details;
- The scale and coverage of mapping as it relates to the scale of the alternatives being considered; and,
- How constrained the project area is (the more constrained, the more accurate the mapping needs to be).

At this stage of project development, the proponent needs to determine whether existing project area mapping will suffice for the alternatives analysis or whether new mapping is needed. If new mapping is required, it should be obtained at a scale and in a format that can be made compatible with the requirements for carrying the alternative into design (see Chapter 18, for information on base mapping requirements for MassHighway design projects). GIS and/or ortho photography, depending on the level of detail available, may be appropriate for this effort.

Environmental Resource Considerations and Documentation

This detailed alternatives analysis should, if possible, determine the degree to which an alternative is considered preferable from an environmental or social perspective. Typically, these studies are done relatively early in the process of implementing a project or strategy. Therefore, when estimating the areas of wetland disturbed or number of residences impacted by a facility it would be appropriate to provide a range or otherwise indicate the extent of the uncertainty in such estimates. However, with respect to some environmental considerations, there are specific federal and state laws which can have a great deal of influence in planning for potential facilities. Early coordination with MassHighway's Environmental Division is encouraged to gain an understanding of the actual project issues.

Generally, it would serve the project proponent well to ensure that the alternatives analysis identifies, maps, analyzes, and documents the environmental and social resources in the project area to an acceptable degree of detail so that all potential "red flags" are identified with regard to the alternative's environmental impacts, the public's acceptance of these impacts, and ultimately, the permitability of the project. The project proponent should consider incorporating some or all of the early environmental coordination tasks defined by MassHighway, and described in Section 2.4.2 of this Guidebook, into the scope of this analysis.

Ideally, work completed under the planning study to identify and assess project alternatives is done in a manner that is consistent with requirements for environmental documentation under the National Environmental Policy Act (NEPA) and the Massachusetts Environmental Policy Act (MEPA) as described in Section 2.4.2 of this chapter. An important product of the planning process directly usable in an environmental document is a clear statement of the need for a new/improved facility. Analysis of alternatives described in this section should also be developed in a manner that is directly usable in the environmental review process.

Development of Alternatives/Conceptual Engineering

Alternatives analysis should, at least initially, consider a wide range of alternatives. Such alternatives, which would be selected from those advocated by interested groups or recommended by local or State government could include various transportation facility types for all modes of transportation (pedestrian, bicyclist, driver, or transit operator) and range of management strategies that may potentially serve an important purpose and address a need for transportation of people and goods.

The alternatives under consideration should be documented and screened as previously discussed. As the options are screened and refined through the analysis process, the level of detail for the remaining alternatives is enhanced to sharpen the project proponent and the public's understanding of the alternative's implementation issues and feasibility.

For physical options, it is assumed that the concept plans will be superimposed on base mapping (as described above) at a sufficiently detailed scale (100 scale for unconstrained areas, 40 or 50 scale for constrained locations). A general checklist, provided as guidance, on what may be beneficial to show on the base mapping includes:

- The location, widths, and names of all existing or platted streets or other public ways within or adjacent to the project location area;
- The location of all sidewalks, crosswalks, bus stops and amenities within or adjacent to the project location area;
- Existing accessible route(s), including curb-cut ramps, associated crosswalks, and audible crossing signals;
- The location of all bicycle facilities and amenities within or adjacent to the project location area;
- All buildings;
- All property lines and property use/ownership;
- Existing utilities;

- Trees and stonewalls;
- All natural watercourses, wetlands, ponds, lakes, etc.
- Private driveways or curb cuts;
- All standard and accessible parking spaces and loading spaces; and
- All pavement markings, signs, and traffic control.

Through this alternatives development process, public outreach should, to the extent practicable, be collaborative and be designed to avoid focusing attention on new facilities or strategies that are not likely to be implemented. Rather, it should focus on those screened alternatives that appear to be reasonably implementable projects and educate project participants about why prior alternatives were determined to be infeasible within the context of the study.

2-A-4

Project Initiation Form (PIF)

All new MassDOT Highway projects are now identified and initiated using the MassDOT Project Intake Tool (MaPIT). The Project Initiation Form (PIF) is part of this tool. You need a GeoDOT account to log into MaPIT.

Log into MaPIT
https://massdothpi.esriemcs.com/mapit/

Request a GeoDOT account
https://www.mass.gov/forms/request-a-geodot-account

2-A-5

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Role of the MPO

Role of the MPO

The regional Metropolitan Planning Organizations (MPOs) are important transportation decision-making entities in Massachusetts that have the responsibility for allocating federal funding to transportation projects. Massachusetts has thirteen planning regions, ten of which qualify as MPOs according to federal rules:

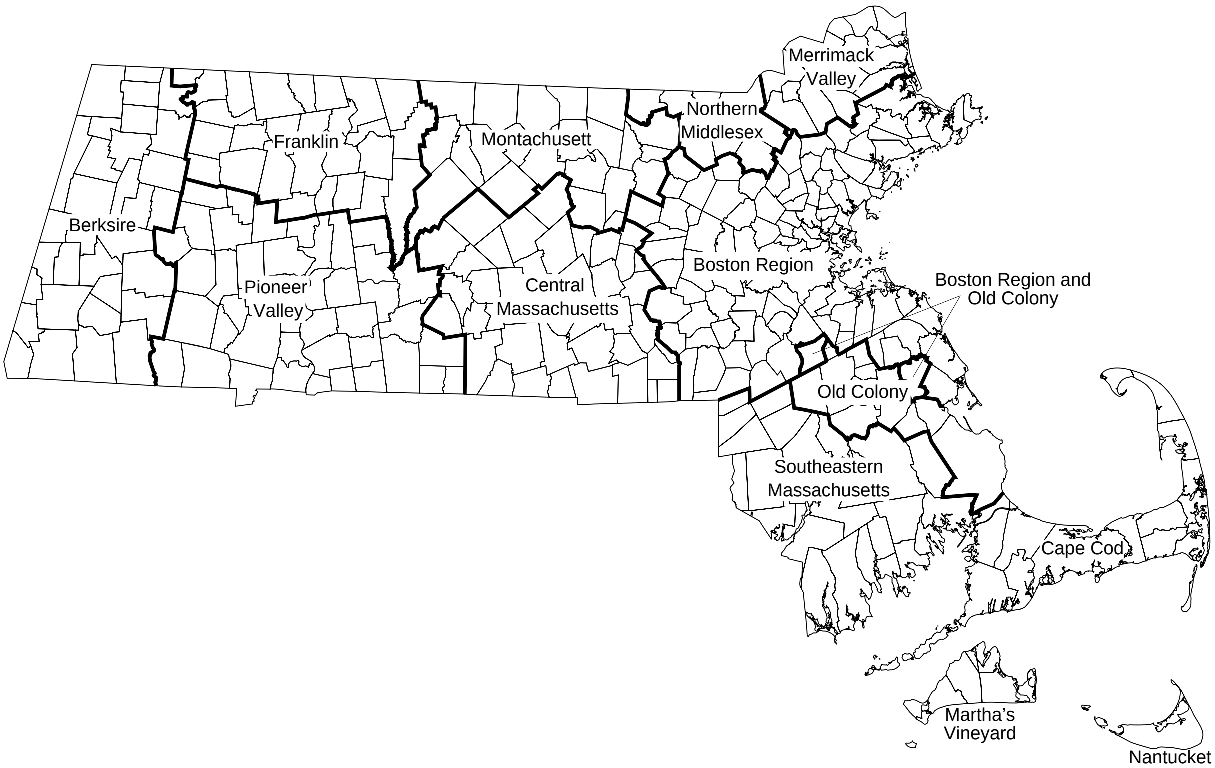
- Berkshire Region MPO
- Boston Region MPO
- Cape Cod MPO
- Central Massachusetts MPO
- Merrimack Valley MPO
- Montachusett Region MPO
- Northern Middlesex MPO
- Old Colony MPO
- Pioneer Valley MPO
- Southeastern Massachusetts MPO
- Franklin Region
- Martha’s Vineyard
- Nantucket

The other three planning regions – Franklin Region, Martha’s Vineyard, and Nantucket – do not meet federal population requirements for establishment of MPOs. However, in these regions, the Regional Planning Agency, along with the Regional Transit Authority, EOT, and MassHighway, cooperatively perform all the functions of an MPO. A map of the Massachusetts planning regions is shown in Exhibit 2-A-5-1.

The MPOs include local elected officials, major transportation operators, and appropriate state officials in transportation decision-making. The Secretary of Transportation chairs each MPO with membership varying from four to fourteen members, typically including MassHighway, the Regional Planning Agency, and the Regional Transit Authority.

Local elected officials are generally selected bi-annually using an agreed upon election process. From a transportation perspective, perhaps the most important function of the MPOs is the development of Regional Transportation Plans and Regional Transportation Improvement Programs (TIPs).

Exhibit 2-A-5-1
Massachusetts Metropolitan Planning Regions



Federal planning regulations require MPOs to prepare long-range regional transportation plans every four years. These plans summarize regional transportation goals and objectives, describe the regional transportation system and existing conditions, evaluate alternative courses of action, and recommend short- and long-term strategies and actions.

Regional plans are required to be fiscally constrained, meaning that the value of projects contained in the plan cannot exceed reasonable estimates of available funding, and must be in conformance with the State Implementation Plan for air quality.

Every year, each MPO prepares a five-year Transportation Improvement Program that allocates state and federal transportation funds, both highway and transit, for the region. The TIP must be consistent with the long-range regional transportation plan, be fiscally constrained by year, and include an annual element of projects to be completed in the first year of the TIP. For example, if a region is expected to have $10 million in state and federal funding available, the MPO will prepare a TIP that contains $10 million in transportation projects.

Beginning in 2004, MPOs began using formal, written evaluation criteria to assess projects for inclusion in the TIP. These criteria are first applied to projects during their earliest stages to provide a broadly based overview and rating of many, often competing, elements to assist in eventual project assessment and prioritization by the regional MPO. More detail on the Transportation Evaluation Criteria are presented in Appendix 2-A-2.

Transportation agencies such as MassHighway, the MBTA, or the Regional Transit Authorities cannot use federal funds for a project unless it is included in the TIP of the respective MPO. The State Transportation Improvement Program (STIP) is, by definition, an amalgamation of the thirteen regional TIPs.

Understanding the MPO's role in project planning and programming is extremely valuable to proponents seeking funding assistance for their projects. Coordination with the MPO or the regional planning agency is worthwhile early in the project development process.

2-A-6

2-A-6

Common Environmental Laws and Regulations, Thresholds, and Timelines

Common Environmental Laws and Regulations, Thresholds, and Timelines

A brief description of the common Federal and State Laws and Requirements, their regulatory thresholds, and environmental clearance timelines are provided in this Appendix. Please also refer to the 259, Designs Submission Checklist for Early Environmental Coordination items in Appendix 2-A-7.

Federal Laws and Requirements

- **Section 4(f) of 1966 U.S. D.O.T. Act** — FHWA (or other Department of Transportation agency, as applicable) approval is needed for any Federal-aid highway project using land from a publicly-owned park, recreation area, historic property or wildlife and waterfowl refuge. A historic property may be a bridge, building, structure, site, district, or object. Either an individual or programmatic Section 4(f) evaluation document must be prepared. There must also be coordination with the public official having jurisdiction over the Section 4(f) property.

- **Section 404 of 1972 Clean Water Act (33USC1344)** — A permit is required from the U.S. Army Corps of Engineers (USACE) for highway projects involving discharge of dredged or fill material into waters of the United States. Jurisdiction under this law extends to all wetlands and waters of the United States. There are three classes of permits issued: Programmatic General Permit (PGP) Category I and Category II, and Individual Permit/Class III.

  A PGP II and an individual permit involves consultation by the U.S. Army Corps of Engineers with the other Federal Resource agencies including U.S. Environmental Protection Agency and the U.S. Fish and Wildlife Service. Other federal approvals such as a water quality certification and a coastal zone consistency statement (if applicable) is needed before the USACE will issue the Section 404 permit.

  Any design for a NEW river or stream crossing must conform with the General Standards contained in the *Massachusetts River and Stream Crossing Standards: Technical Guidelines* (as stipulated in the Massachusetts Programmatic General Permit, dated January 20, 2005) in order to qualify for a Category 1 (Non-Reporting) authorization. Otherwise, MassHighway or the project management will consult with the U.S. Army Corps of Engineers

(ACOE) under the Category 2 or Individual Permit review process if an open bottom arch or bridge span is impractical.

- **Section 401 of 1972 Clean Water Act** — A water quality certification is required from the Massachusetts Department of Environmental Protection (DEP) for any federal permit (e.g., Section 404 permit, Coast Guard Bridge Permit) to conduct an activity which may result in a discharge into waters of the United States. Additional details about the water quality certification process should be discussed with the MassHighway Environmental Section.

- **1972 Coastal Zone Management Act** — A coastal zone consistency review and concurrence determination is required from the Massachusetts Coastal Zone Management (CZM) Office for Federal-aid highway projects or projects requiring other federal actions located within the designated coastal zone. This review is to ensure consistency with the state coastal zone policies.
- **Section 9 of River and Harbor Act of 1899** — A permit is required from the U.S. Coast Guard for certain highway projects involving bridges or causeways over tidal or otherwise navigable waters. Other federal approvals such as water quality certification and a coastal zone consistency statement (if applicable) are needed before the U.S. Coast Guard will issue the Bridge Permit. Projects that are funded by FHWA and are "replacement in kind" may be eligible for an exemption from a Coast Guard Permit. The Consultant should obtain data on boat length and size from the local harbormaster, and other knowledgeable agencies, and consult with the MassHighway Environmental Section.
- **Section 10 of River and Harbor Act 1899** — A permit is required from the U.S. Army Corps of Engineers for highway projects requiring construction in or over navigable waters, the excavation from, or dredging or disposal of materials in such waters, or any obstruction or alteration in a navigable water (e.g. stream channelization).
- **Section 106 of the 1966 National Historic Preservation Act** — Section 106 is a process involving FHWA, MassHighway, the Massachusetts State Historic Preservation Officer, the appropriate Tribal Historic Preservation Officer, and the Advisory Council on Historic Preservation which must be followed for any Federal-aid highway project affecting bridges, districts, structures, sites (including archaeological sites) or properties of religious and cultural significance identified by Federally recognized Indian tribes that are listed in, or eligible for listing in the National Register of Historic Places. Additional details about the Section 106 process should be discussed with the MassHighway Environmental Section.

- **National Pollutant Discharge Elimination System (NPDES) Construction General Permit** — As authorized by the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States. Point sources are discrete conveyances such as pipes or man-made ditches. The NPDES Construction General Permit is administered by the United States Environmental Protection Agency and requires preparation of a Storm water Pollution Prevention Plan (SWPPP) for construction activities. Additional details about the NPDES process should be discussed with the MassHighway Environmental Section.

State Laws and Requirements

Bridge projects funded by a State Transportation Bond, which are functionally equivalent and in a similar location, are exempt from the Wetlands Protection Act (WPA), Chapter 91, and MEPA. The project proponent should consult with the Environmental Section for a determination.

- **Wild and Scenic Rivers Act (16USC1271) –** The Act establishes the policy that certain rivers of the Nation which, with their immediate environments, possess outstandingly remarkable scenic, recreational, geological, fish and wildlife, historic, cultural, or other similar values, shall be preserved in free-flowing condition, and that they and their immediate environments shall be protected for the benefit and enjoyment of present and future generations. The Act both identifies specific river reaches for designation as wild or scenic, and provides criteria to be used for classifying additional river reaches. The National Wild and Scenic River System was established to protect the environmental values of free-flowing streams from degradation by impacting activities, including water resources projects. The National Park Service and designated local Wild and Scenic River Management Council have review project permits to ensure that the action will not adversely affect the river system. This review function is most often through the ACOE on Section 404 permits (including section 10 of Rivers and Harbors Act) and through the Coast Guard (Section 9 of the Rivers and Harbors Act) for navigatable waterways.

- **Massachusetts Wetland Protection Act MGL Chapter 131, Section 40 as administered by 310 CMR 10.00** -- This act applies to projects which remove, fill, dredge, or alter a resource area defined in the Wetland Regulations. Resource areas are defined as:
  - Bordering Vegetated Wetlands (BVW) or salt marsh

- Any bank, or any water body or waterway or a Coastal Bank
- Land under any water body (LUW), waterway, the ocean, or a salt pond
- Riverfront Area - Extends 200 feet (25 feet in municipalities with large populations and in densely developed areas) on each side of perennial rivers or streams
- Land subject to coastal storm flowage
- Isolated or bordering land subject to flooding
- Coastal Beaches and tidal flats
- Coastal Dunes
- Designated Port
- Banks or land under a Fish Pier
- Barrier Beaches
- Land containing shellfish

A buffer zone is defined as land within 100 feet horizontally of any resource area listed above. Request for a Determination of Applicability must be filed to determine if an Order of Conditions must be obtained from the local conservation commission. If work is proposed within a resource area, then a Notice of Intent must be submitted to the local conservation commission. If work is proposed in a buffer zone, then either a Notice of Intent or an Abbreviated Notice of Resource Area Delineation needs to be filed with the local Conservation Commission.

Appeals of Conservation Commission decisions are made to the Department of Environmental Protection (DEP). DEP is also the authority to whom variance requests are made. Variances are required if the general performance standards of the WPA cannot be met, such as if 5000 square feet or more of Bordering Vegetated Wetland is proposed for filling. Details regarding appeals or variances should be discussed with the MassHighway Environmental Section.

- **Rivers Protection Act –** The Rivers Protection Act, Chapter 258 of the Acts of 1996, protects nearly 9,000 miles of Massachusetts riverbanks – helping keep water clean, preserving wildlife habitat, and controlling flooding. The law creates a 200-foot riverfront area that extends on both sides of rivers and streams. In certain urban areas, the riverfront area is 25 feet. The riverfront area provides the eight interests of the Wetlands Protection Act: protection of public and private water supply, protection of groundwater supply, protection of land containing shellfish, protection of wildlife habitat, flood control, storm damage prevention, prevention of pollution, and protection of fisheries. The law also establishes the policy of the state to protect the natural integrity of rivers and to encourage and establish open space along rivers. This law is administered through the WPA.

- **Chapter 91** — A Chapter 91 Waterways license is required from DEP for highway projects that do not qualify for the bridge exemption and which involve construction, dredging and filling performed in private and Commonwealth tidelands, as well as great ponds and certain rivers and streams. Additional details about the Chapter 91 process are to be discussed with the MassHighway Environmental Section.
- **Chapter 254** — A process involving the Massachusetts Historical Commission which must be followed for highway projects affecting bridges, districts, structures, or sites (including archaeological sites) listed in the State Register of Historic Places. All properties listed in, or formally determined by the Keeper to be eligible for listing in, the National Register of Historic Places are automatically listed in the State Register. In most cases, completion of the Section 106 process for a Federal-aid highway project will satisfy the requirements of the Chapter 254 process. Additional details about the Chapter 254 process should be discussed with the MassHighway Environmental Section.

LIST OF ABBREVIATIONS

ACEC	*Area of Critical Environmental Concern*
ACOE	*U.S. Army Corps of Engineers*
ANRAD	*Abbreviated Notice of Resource Area Determination*
BLSF	*Bordering Land Subject to Flooding*
BVW	*Bordering Vegetated Wetland*
CE	*Categorical Exclusion*
CH 91	*Chapter 91 Waterways License or Permit*
DEP	*Massachusetts Department of Environmental Protection*
DOA	*Determination of Applicability*
EA	*Environmental Assessment*
EIR	*Environmental Impact Report Prepared Under MEPA*
EIS	*Environmental Impact Statement Prepared Under NEPA*
ENF	*Environmental Notification Form*
EOEA	*Executive Office of Environmental Affairs*
EPA	*U.S. Environmental Protection Agency*
FA	*Federal Aid*
FHWA	*Federal Highway Administration*
FONSI	*Finding of No Significant Impact*
ILSF	*Isolated Land Subject to Flooding*
JP	*Joint Processing Meeting (ACOE, EPA, National Marine Fisheries, MCZM, U.S. Fish & Wildlife)*
LUW	*Land Under Water*
MA SHPO	*Massachusetts Historic Preservation Officer*
MCZM	*Massachusetts Coastal Zone Management*
MEPA	*Massachusetts Environmental Policy Act*
MGL	*Massachusetts General Law*
MHC	*Massachusetts Historic Commission*
MOA	*Memorandum of Agreement*
NEPA	*National Environmental Policy Act*
NFA	*Non Federal Aid*
NOI	*Notice of Intent*
NR	*National Register*
OOC	*Order of Conditions*
ORAD	*Order of Resource Area Determination*
PGP	*Programmatic General Permit*
RDA	*Request for Determination of Applicability*
RFA	*Riverfront Area*
ROD	*Record of Decision*
SOOC	*Superceding Order of Conditions*
STURAA	*Surface Transportation & Uniform Relocation Assistance Act of 1987*
SWPPP	*Storm Water Pollution Prevention Plan*
USCG	*United States Coast Guard*
WPA	*Wetlands Protection Act*
WQC	*Water Quality Certificate*
WQC SF	*Water Quality Certificate Standard Form*

ENVIRONMENTAL CLEARANCE TIMELINES

FILING/PERMIT APPLICATION	COMMON REGULATORY THRESHOLDS
ANRAD	Required when seeking approval of BVW boundary lines prior to proposing work or designing a project.
CG Permit	Required for work in commercially navigable (includes historic usage) or tidal waterways where there is a change in the hydraulic opening of the bridge.
	STURAA Approval may be granted to coastal bridge projects with federal funds allocated towards construction where the navigational opening remains unchanged and where vessels 21 feet or greater do not pass under the bridge.
CH 91 License	Bridge projects subject to the Footprint Bridge Exemption are exempt from CH 91.
	Maintenance projects are exempt from CH 91.
	CH 91 applies to all waterways including Great Ponds (10 or more acres in size), the Connecticut River, sections of the Westfield River, non-tidal portions of the Merrimack River and any non-tidal river or stream on which public funds have been expended for stream clearance, channel improvement, or any form of flood control or prevention work, either upstream or downstream within the river basin, except for any portion of any such river or stream which is not normally navigable during any season by any vessel including a canoe etc. and work in all filled tidelands except landlocked tidelands and all filled lands lying below the natural high water mark of Great Ponds.
	Activities requiring a license include any construction, placement, excavation, addition, improvement, replacement, reconstruction, demolition or removal of any fill or structures, not previously authorized.
CH 91 Permit	Activities requiring a permit include beach nourishment and dredging within jurisdictional areas.
	Lowering the water level of a Great Pond.
ENF	Widening 4 feet or more for a half mile or more.
	Cutting 5 or more mature living public shade trees (not trees within State Highway Layout) 14" or more in diameter @ breast height.
	Altering bank or terrain 10 ft or more from the edge of pavement for 1/2 mile or more except for the installation of structures such as sidewalks, drainage systems, etc.
	Work in an ACEC.
	Altering 5,000 sf or more of BVW.
	Eliminating 300 linear feet of stone wall.
	Provided that a permit is required in accordance w/MGL c 21D, new capacity or expansion in capacity for the storage, recycling, treatment or disposal of hazardous waste.
	Creation of 5 or more acres of impervious area.
	Direct alteration of 25 or more acres of land.
	Conversion of land in active agricultural use to nonagricultural use.
	Conversion of land held for natural resources purposes in accordance with Article 97.
	Construction of 300 or more new parking spaces at a single location.
EIR	Constructing a new road 2 or more miles in length.
	Widening an existing road by 1 or more travel lanes for 2 or more miles.
	New interchange on a completed limited access highway.
	Requiring a variance from the WPA.
	Altering 1 or more acres of Salt Marsh or BVW.
	Altering 10 or more acres of other wetlands.
	Altering 50 or more acres of land.
	Creating 10 or more acres of impervious area.
MCZM Concurrence	Work in water within the coastal zone when at least a PGP II or a Coast Guard Permit is required. Also will require concurrence when MEPA thresholds are triggered.

ENVIRONMENTAL CLEARANCE TIMELINES

NOI	Under the WPA, required when proposing direct activity in or impact to resource areas subject to protection, including BVW, LUW, Bank, RFA, BLSF, ILSF, etc.
	The NOI is a 1 page form which the contractor must complete and file with EPA at least 48 hours prior to the start of construction.

NPDES	The National Pollution Discharge and Elimination Systems Program is adminstered by EPA and requires the filing of an NOI and the preparation of a SWPPP for projects involving construction projects with 1 or more acres of earth distrubance.

PGP I	Under 5,000 s.f. of cumulative impacts to Waters of the U.S.
	Instream work limited to July 1 to October 1.
	Maintenance dredging less than 1,000 c.y. not in a Special Aquatic Site.
	No impacts to Special Aquatic Sites or Essential Fish Habitat.

PGP II	Over 5,000 s.f. but under 1 acre of cumulative impacts to Waters of the U.S.
	Maintenance dredging greater than 1,000 c.y. but less than 25,000 c.y. not in a Special Aquatic Site.
	Work within the confines of a Wild and Scenic River.
	Temporary fill and excavation up to 1 acre in Special Aquatic Sites including salt marsh.
	Work in Essential Fish Habitat.

Individual ACOE Permit	Over 1 acre of impacts to Waters of the U.S.
	Maintenance dredge over 25,000 c.y. or any amount in a Special Aquatic Site.
	Permanent fill or excavation (any amount) in Special Aquatic Sites such as salt marsh, mudflats, pools and riffles, and vegetated shallows.

Programmatic 4(f)	Programmatic 4(f) Evaluations & Approvals for FHWA Projects that Necessitate the Use of an Historic Bridge. *Note: NFA NR Eligible historic bridge projects requiring a CG Permit will need an Individual 4(f) Evaluation and Approval.*

RDA	Required when work/activity will occur within 100 feet from the edge of BVW, LUW, Bank etc. or sometimes within Riverfront Area especially 100-200 feet from a perennial stream or river.

SWPPP	As of March 1, 2003, any construction project resulting in earth distrubance of 1 or more acres must file a NOI and a SWPPP concurrently with EPA in accordance with the NPDES requirements. The SWPPP is generally a list of best management practices to be used during construction in order to contorl erosion and sediment transport.

WQC	If under 5,000 s.f. of cumulative impacts, WQC is considered automatic with the issuance of an OOC.
	Over 5,000 s.f. of cumulative impacts.
	Over 100 c.y. of dredging.
	Any impacts associated with Bridge Projects that are exempt from the WPA.
	Work within an ORW.
	Any work requiring an Individual ACOE permit.

WQC SF	Expedited 42 day DEP review and permit issuance on Footprint Bridge projects may be sought provided certain criteria are met and provided DEP agrees to the expedited review.

Variance from the WPA	Non Limited projects with over 5,000 s.f. of impacts to BVW.
	Direct impacts to salt marsh or work within 100 feet of a salt marsh that will directly impact the salt marsh.

ENVIRONMENTAL CLEARANCE TIMELINES

LAW/REGULATION	ADMINISTRATIVE AGENCY	FILING	PERMIT/ACTION	AGENCY REVIEW TIME BEFORE ACTION/ISSUING PERMIT UNLESS OTHERWISE NOTED
State				
Wetlands Protection Act (WPA)	Local Conservation Commissions	RDA	DOA	30 to 60 days (average)*
Wetlands Protection Act (MGL Ch 131 § 40)		ANRAD	ORAD	30 to 60 days (average)*
Wetlands Protection Regulations (310 CMR 10.00)		NOI	OOC	30 to 60 days (average)*
	DEP	Appeal	SOOC	6 to 12 months (average)
		Appeal for Variance	SOOC	12 months (average)**
Massachusetts Environmental Policy Act (MEPA)	EOEA/MEPA Unit	ENF	Secretary's Certificate or Scope	30 days from date published in the Monitor
Massachusetts Environmental Policy Act (MGL Ch 30 § 61-62h)				
MEPA Regulations (301 CMR 11.00)		Draft & Final EIR	Secretary's Certificate	2 to 3 years (minimum)^
Public Waterfront Act (Chapter 91)	DEP	Waterways License Application	Waterways License	4 to 9 months (average)
Public Waterfront Act (MGL Ch 91)				
Waterways Regulations (310 CMR 9.00)		Waterways Permit Application	Waterways Permit	3 to 4 months (average)
Federal				
National Environmental Policy Act (NEPA)	FHWA	CE	Concurrence	2-4 weeks (average)
NEPA of 1969, as amended (Pub. L. 91-190, 42 U.S.C. 4321-4347, January 1, 1970, as amended by Pub. L. 94-52, July 3, 1975, Pub. L. 94-83, August 9, 1975, and Pub. L. 97-258, § 4(b), Sept. 13, 1982)		EA	FONSI	3-6 years (average)
NEPA Regulations (40 CFR 1500-1508), TA 6640.8		EIS	ROD	3-6 years (average)
Army Corps of Engineers Permitting (404 Permit)	ACOE/JP Meeting	Project Impact Documentation	PGP I (non-reporting)	1 day to 1 month (average)
Section 404 of the Federal Clean Water Act (33 U.S.C. 1251 *et seq*.)		Letter to ACOE & Project Documentation	PGP II (Screened at JP Meeting)	2 months (average)
Section 10 of the Rivers & Harbors Act of 1899 (33 U.S.C. 401, 403) Applies to Non Bridge Structures in Navigable Waters.		Individual Permit Application	Individual Permit	9 to 12 months (average)
US Coast Guard	USCG	Project Impact Documentation	Letter of Permission	30 days (average)
Coast Guard Bridge Permit (1. 33 U.S.C. 401, 491 et seq. 511 et seq., 525 et seq., and 535, and Acts of Congress authorizing the construction of bridges, including international bridges)	USCG	Bridge Permit Application	Bridge Permit	9 to 12 months (average)
Various Memoranda of Understanding & Guidance Documentation	FHWA	STURAA Approval Request	STURAA Approval	30 days (average)

NOTE 1: Add 2 to 3 months to all the above timeframes to account for internal review and preparation.

NOTE 2: All above timeframes can be extended by the permitting/review agencies if additional information is requested.

* Add 30 to 60 days if work will occur within an Estimated Habitat of Rare Wildlife.

** The determination resulting frm appeal would be a "final decision of the Commissioner."

^ This time period is from the time of filing the Draft, to the issuance of the Secretary Certificate on the Final, depending on the extent of comments received on the Draft and Final documents and the amount of time necessary to address the comments.

ENVIRONMENTAL CLEARANCE TIMELINES

LAW/REGULATION	ADMINISTRATIVE AGENCY	FILING	PERMIT/ACTION	AGENCY REVIEW TIME BEFORE ACTION/ISSUING PERMIT UNLESS OTHERWISE NOTED
Section 4(f) Approval Section 4(f) (49 USC 303) Section 4(f) 23 CFR ch 1 § 771.135 Various Memoranda of Understanding	FHWA	Programmatic 4(f) Documentation	Programmatic 4(f) Approval	30 days (average)
	Lead Federal Agency	Individual 4(f) Documentation	Individual 4(f) Approval	4 to 6 months (average)
National Pollutant Discharge Elimination System Water Pollution Control Act Amendments of 1972 (The Clean Water Act) Title 40 of the CFR at Part 122, 64 CFR 68722	EPA	NOI & SWPPP%	Construction Permit	Contractor to File 48 Hours Prior to Construction
Federal & State				
Water Quality Certification (WQC) Federal Clean Water Act (33 U.S.C 1251 *et seq*.) Massachusetts Clean Waters Act (MGL ch 21 §§ 26-53) 401 Water Quality Certification (314 CMR 9.00) Massachusetts Surface Water Quality Standards (314 CMR 4.00)	DEP	Individual WQC Application for Major or Minor Projects	WQC	120 or 150 days (minimum)
		WQC SF for Expedited Review	WQC	42 days
		NOI & Under 5,000 s.f. of impact (No work in ORW, etc.)	Automatic w/OOC	See WPA
Coastal Zone Consistency Review ~ Federal Coastal Zone Management Act 16 (U.S.C. 1452, Sec. 303 (1) and (2)) Massachusetts Office of Coastal Zone Management (MGL ch 21A, § 4A) Coastal Zone Management Program Federal Consistency Review Procedures (301 CMR 21.00)	MCZM	Through ENF or EIR Processes	Concurrence Determination	See MEPA Review Times
		Through ACOE PGP I	Automatic Concurrence with MCZM Policies	Same as PGP I Timeline
		Through ACOE PGP II	May Need Individual Concurrence/Depends on Project Impacts and JP Meeting	Same as PGP II Timeline
		Individual Concurrence Letter	Concurrence Determination	Up to 180 Days

NOTE 1: Add 2 to 3 months to all the above timeframes to account for internal review and preparation.

NOTE 2: All above timeframes can be extended by the permitting/review agencies if additional information is requested.

~ MCZM thresholds are the same as MEPA, ACOE and CG thresholds. MCZM reviews projects during the MEPA, ACOE, and CG permitting processes and determines if the project is consistent with the Massachusetts State Coastal Policies. Review times are dependent on the issuance of state permits. MCZM can only issue concurrence after all state permits have been issued.

% Construction Contractor is Responsible for Preparing & Filing Documents and Obtaining this Permit for Projects

ENVIRONMENTAL CLEARANCE TIMELINES

LAW/REGULATION	PROPONENT	RESOURCE AGENCY	PERMIT/ACTION	AGENCY REVIEW TIME BEFORE ACTION/ISSUING PERMIT UNLESS OTHERWISE NOTED
Cultural Resources Review				
Federal Section 106 Review: National Historic Preservation Act of 1966, as amended (16 USC 470) (36 CFR Part 800)	FHWA	MA SHPO	No Historic Properties Affected	N/A#
			No Historic Properties Adversely Affected	21 days ##
			Historic Properties Adversely Affected	90 days ###
Federal Appendix C Review: 33 CFR 325 Appendix C	ACOE	MA SHPO	No Historic Properties Affected	30 days
			No Historic Properties Adversely Affected	45 days ##
			Historic Properties Adversely Affected	90 days ###
State Chapter 254 Review: M.G.L. ch 9, §§, 26-27c, as amended by St. 1988, ch 254 (950 CMR 71)	MassHighway	MHC	No Historic Properties Affected	30 days
			No Historic Properties Adversely Affected	30 days
			Historic Properties Adversely Affected	30 days

NOTE 1: Add 2 to 3 months to all the above timeframes to account for internal review and preparation.

NOTE 2: All above timeframes can be extended by the permitting/review agencies if additional information is requested.

FHWA's 2004 Section 106 Programmatic Agreement authorizes MassHighway to review and clear proejcts not affecting historic properties in-house, with no resource agency review.

Assumes documentation of consultation with local historical commission has been included in effect finding package and 30 day MA SHPO review period.

Assumes documentation of consultation with local historical commission has been included in effect finding package. Assumes 30 day MA SHPO review period; additional time to consult with interested parties; FHWA/ACOE review and processing of documentation; and ratification of MOA amongst relevant parties.

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Environmental Requirements for 25 Percent Design

Environmental Requirements for 25 Percent Design

This Appendix contains information concerning environmental elements of the project to be included with the 25 Percent Design Submission. Inclusion of these data early in the process is intended to assist in the identification of project impacts and expedite environmental clearances. Also included is a 25% Design Submission Checklist. The designer should also consult MassHighway's website for additional useful information *(www.mass.gov/mhd/environ/publications.)*

Cultural Resources

- Show all bridges and culverts within or adjacent to the project limits and label all those having MassHighway BDEPT numbers.
- Provide photographs of all known historically significant buildings/structures within or adjacent to the project limits, show their location and label all those having numbered street addresses.
- Show the location of historic district boundaries.
- Label all historical/locally significant monuments and markers and, if possible, show their future location if they are proposed to be moved.
- Show a detail of the proposed type of street lighting.
- Label and show preliminary tops and bottoms of slopes and limits of all proposed takings and easements.
- Label all preliminary wall locations.
- Identify potential landscaping enhancement opportunities.
- Show all proposed trees to be removed that have a 14" or greater diameter at breast height (DBH).
- Provide copies of all correspondence with the local historic commission.

Hazardous Materials

- Identify locations of known sources of hazardous waste and hazardous material releases within the project limits (with appropriate tracking numbers).

Wetland and Water Resources

- Show the location of all existing drainage structures and existing and proposed drainage discharge locations.
- Show the location of all wetland resource areas within 100 feet of the project limits (e.g., bordering and isolated vegetated wetland areas and land under water) including the ordinary high water (i.e., one-year flood) of waterways and water bodies.
- Show the location of potential wetland replacement areas.
- Show on a separate locus any storm water “critical areas” as defined in the DEP Stormware Standards (cold water fisheries, Zone IIs, public swimming beaches, shellfish growing areas, and drinking water reservoir watershed).
- Show on a separate locus any Federal Emergency Management Administration (FEMA) floodplain.
- Show on a separate locus any Estimated Habitat for Wildlife or Area of Critical Environmental Concern (ACEC).
- Provide photographs in digital format of all bridge replacement/rehabilitation projects that include work in water or wetlands. Photographs should clearly show riverbanks of all four quadrants of the bridge and include any proposed wetland replication or flood compensation storage areas. All submissions for roadway reconstruction projects should include photos of all cross culverts where work is proposed.
- If a water body can be used for boating/canoeing, consider maintaining or increasing the clearance under bridges. Any related information should be clearly identified on the plans.

Section 4(f) Properties

- Show and label the location of all publicly owned parks, recreational areas, wildlife and waterfowl refuges and historic properties/sites.

Information Sources

The following references, databases, and information sources may be helpful to the designer during the preparation of 25 Percent plans:

Project History

- Local Planning/Public Works/Economic Development Departments (Location/Feasibility Studies)
- Regional Planning Agency (Corridor Planning Studies)
- Major Environmental Documents (EA, EIR/EIS, 4(f) Documentation)
- Design Reports
- Bridge Type Studies

Hazardous Materials Site Screening (40 CFR, 310 CMR, sec. 30)

- Massachusetts Geographic Information System (available from MA GIS - htpp//www.mass.gov/mgis/massgis.htm) for mapping and a data base of certain hazardous material sites
- Federal: Comprehensive Environmental Recovery Compensation Liability Act (CERCLA) List (Federal Superfund Site List)
- State: Department of Environmental Protection (DEP) Bureau of Waste Site Clean-up (21E) — also known as the Massachusetts Oil and Hazardous Materials Release Prevention and Response Act (MA Superfund)
- Local: Fire Department/Fire Prevention Office, Board of Health, for known underground tanks and/or spills

Cultural Resources (Section 106) of the National Historic Preservation Act of 1966 as amended (36 CFR, Part 800) and M.G.L. Ch. 9 ss. 26-27C as amended by Ch. 254 of the Acts of 1988 (950 CMR 71)

- Local Historical Commissions
- State/National Register of Historic Places (available on MA GIS)
- The Inventory of Historical and Archaeological Assets of the Commonwealth (available at Massachusetts Historical Commission (MHC))
- Corridor Planning Studies

- MA GIS contains mapping and a data base of certain cultural resources
- Tribal Historic Preservation Officer (consult with MassHighway Cultural Resource Unit)

Wetlands and Water Resources

- FEMA Maps
- MA Surface Water Quality Standards (Outstanding Water Resources (ORW))

Rare and Endangered Species and Habitat

- MA Division of Fisheries & Wildlife (MA National Heritage Program)
- MA Natural Heritage Atlas
- MA GIS contains mapping and a data base of priority habitats of rare species and estimated habitats of rare wildlife

National Environmental Policy Act and Massachusetts Environmental Policy Act (NEPA/MEPA)

- Area of Critical Environmental Concern (ACEC): MA GIS, Executive Office of Environmental Affairs (EOEA) (MEPA Unit)

Section 4(f) Properties (49 USC Section 303) Publicly Owned Parks, Recreational Areas, Waterfowl Refuges, Historic Sites

- Department of Conservation and Recreation (DCR)
- Local planning department, parks department, public works department, historical commission
- MA Division of Fisheries & Wildlife
- Division of Conservation Services at EOEA
- MA GIS contains mapping and a data base of certain publicly owned properties.

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USCG PERMIT APPLICATION REVIEW CHECKLIST

TO:
FROM:
RE:
FILE #:

Permit Application Type:
Application Received:
Deficiency Review Date:

The following is needed prior to the review and filing of the permit application for the above-mentioned project. Also, attached are sample USCG application plan sheets for your use.

Application & Narrative

- ☐ Applicant
- ☐ Consultant
- ☐ Project Information
- ☐ Authority Information
- ☐ International Bridges
- ☐ Proposed Clearances and Elevations
- ☐ Existing Bridge Structure, clearances and Elevations at the Bridge Site
- ☐ Removal of a Bridge
- ☐ Construction Activity
- ☐ Alternatives to the Proposed Project
- ☐ Identify any Public Parks, Recreation Areas, Natural Habitats, Historic or Cultural Sites Located Within One-Half Mile of Project Site
- ☐ Section 4(f)
- ☐ Coastal Zone Consistency Certification
- ☐ Wetlands
- ☐ Floodplain
- ☐ Water Quality Certificate (WQC)

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USCG PERMIT APPLICATION REVIEW CHECKLIST

- ☐ Endangered Species
- ☐ Wild and Scenic River
- ☐ Prime or Unique Farmlands
- ☐ Statewide Implementation Plan (SIP)
- ☐ Noise Levels
- ☐ Displacement of Residences or Businesses
- ☐ State and Local Authorizations
- ☐ Other Federal Agency Approvals
- ☐ Essential Fish Habitat Assessment
- ☐ Fill Above and Below Mean High Water
- ☐ Names and Addresses of Adjacent Property Owners
- ☐ Underlying Studies, Reports, and Other Information
- ☐ Construction Sequence – Anticipated - In the sequence, include when the sedimentation controls, cofferdams, method of dewatering, and etc. will be implemented.
- ☐ Forward the Response letter from Mass Natural Heritage and endangered Species Program.
- ☐ Forward an electronic copy of the WQC application and project narrative with revisions. Email – peter.martellucci@state.ma.us

Construction Plans for CG application

GENERAL

- ☐ Submit one original set of plans on mylar or linen size 8 ½ X 11 inches. Submit fewest number of sheets possible, showing significant structural details. Plans must be of good reproducible quality.
- ☐ Each drawing must have simple title, date and number (e.g., sheet 1 of 2, sheet 2 of 2) in lower right hand corner.
- ☐ Show graphic scale and north arrow on each individual plan sheet.
- ☐ All dimensions and distances must be shown in both English and metric measurement systems.

MASS HIGHWAY

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USCG PERMIT APPLICATION REVIEW CHECKLIST

- ☐ State government datum used in plan and elevation views and location of datum. Datum utilized should be the same for all drawings submitted. Provide survey notes or report showing calculations used to derive elevations and identify referenced tidal bench mark.

VICINITY MAP

- ☐ Clearly identify entire work site.
- ☐ Show course of river.
- ☐ Identify structures crossing waterways within ½ mile of proposed structure.
- ☐ Show location of any public park, recreation area, wildlife or waterfowl refuge or any historic site in the vicinity.

PLAN VIEW

- ☐ Show existing shorelines.
- ☐ Show ebb and flood in tidal waters and direction of flow in non-tidal rivers. Show unusual current patterns if applicable.
- ☐ Show mean high and low waterlines if the proposed activity is in tidal areas. Show ordinary high water line and ordinary low water line if proposed activity is in a lake, river or stream.
- ☐ Show an existing bridge, if any is to be replaced, and whether or not it is to be removed.
- ☐ If the bridge will have a draw, show the draw in the open and closed positions.
- ☐ Show principal dimensions of structure from grade to grade. Show length, width, etc. Show location and dimensions of sidewalks, railings, pipelines, etc.
- ☐ Show location of dredging, excavation, fill or rap-rip. Give approximate number of cubic yards and type of material.
- ☐ Identify and show location of any fenders, dolphins, piles, cables, etc. existing or to be constructed in the waterway. Identify type of material to be utilized.
- ☐ Show limits of maintained navigational channel, if applicable.
- ☐ Show axis of channel.
- ☐ Show horizontal clearances, normal to the axis of the channel.
- ☐ Show water depth at mean low or ordinary low water at various locations in the channel, under, upstream and downstream of the bridge.

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ELEVATION VIEW

- ☐ Show mean high and mean low water elevations in tidal areas. Show ordinary high and low water in non-tidal areas.
- ☐ Show horizontal clearances normal to the axis of the channel(s).
- ☐ Show vertical clearances above mean high or ordinary high water. Vertical clearances should be shown at waterward face of each pier and at center of navigational channel.
- ☐ Show proposed and existing contour of waterway bottom.
- ☐ Show 100 year flood height and flood of record.

SECTION VIEW

- ☐ Include location of sidewalks, fishing platforms, railings pipelines, fenders, rip-rap, etc.

FENDERS (if applicable)

- ☐ Show fenders in plan and elevation views including detail of attachment to pier, countersunk bolts, and relationship to mean high and low waterlines (on elevation view).

Title Blocks -Show the following items in the title blocks located in the lower your drawings:

- ☐ Applicant/Agent and Owner
- ☐ North Arrow
- ☐ Waterway name
- ☐ Mile point of bridge location, **in miles and metric equivalent**
- ☐ City, County and State
- ☐ Date of plans
- ☐ Sheet number of total number of sheets in set

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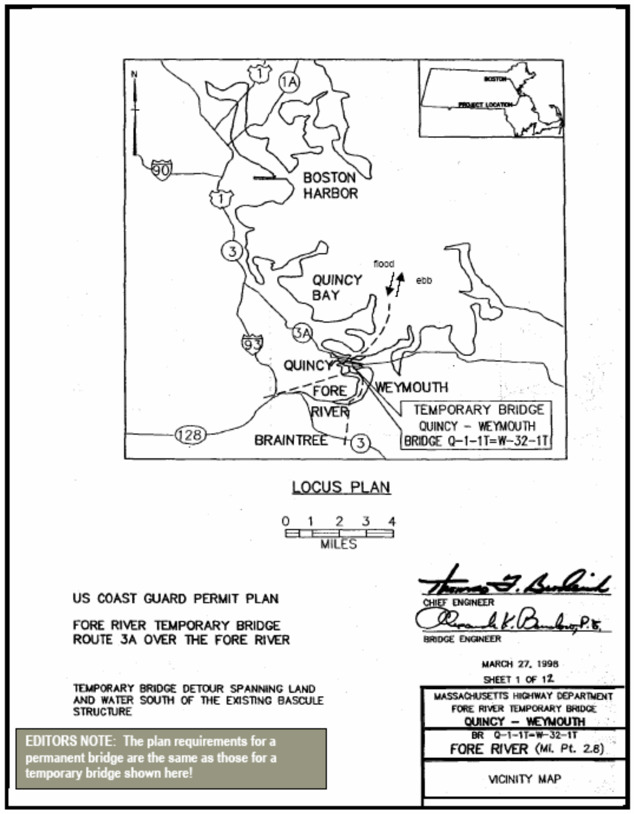

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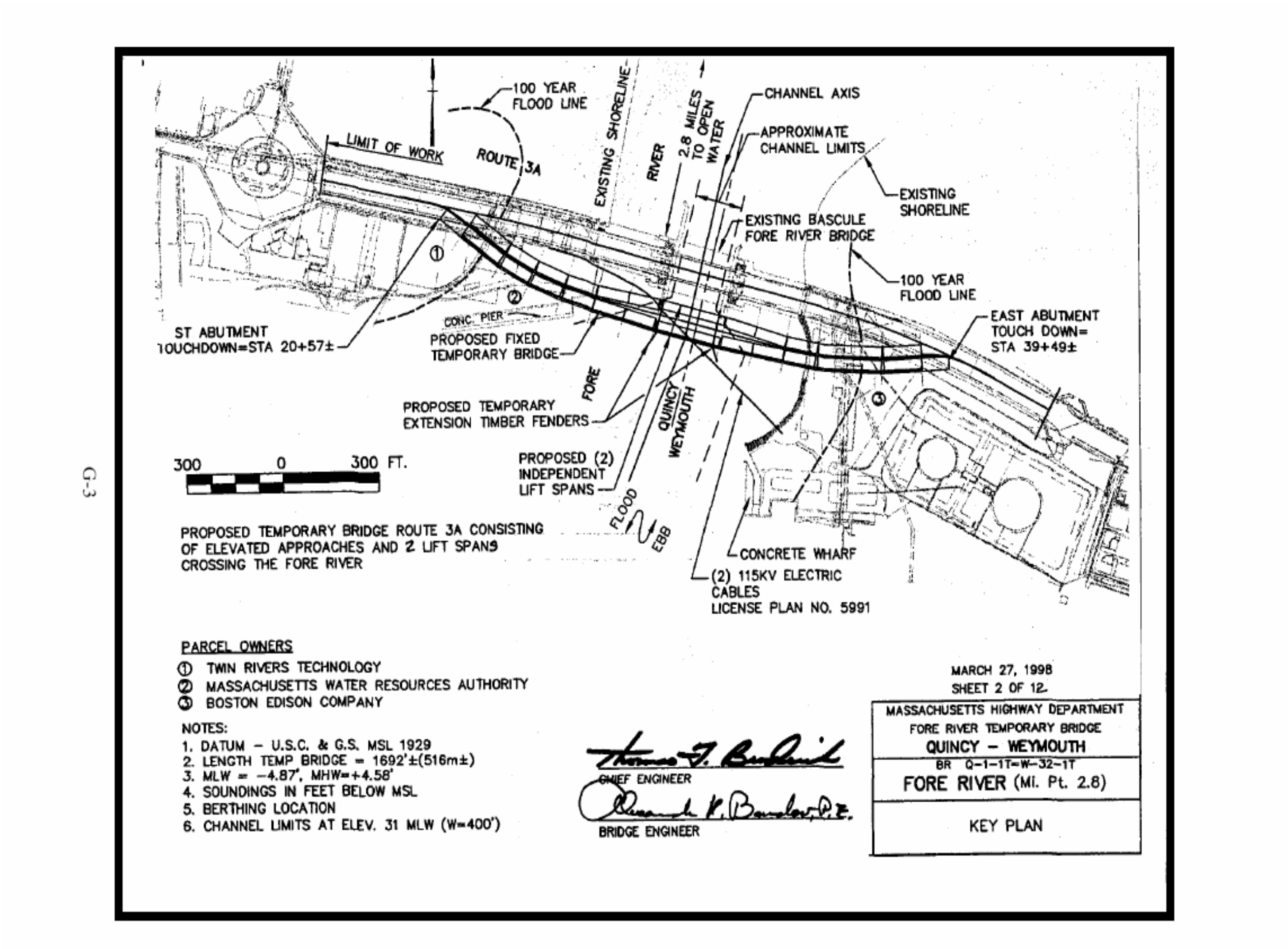

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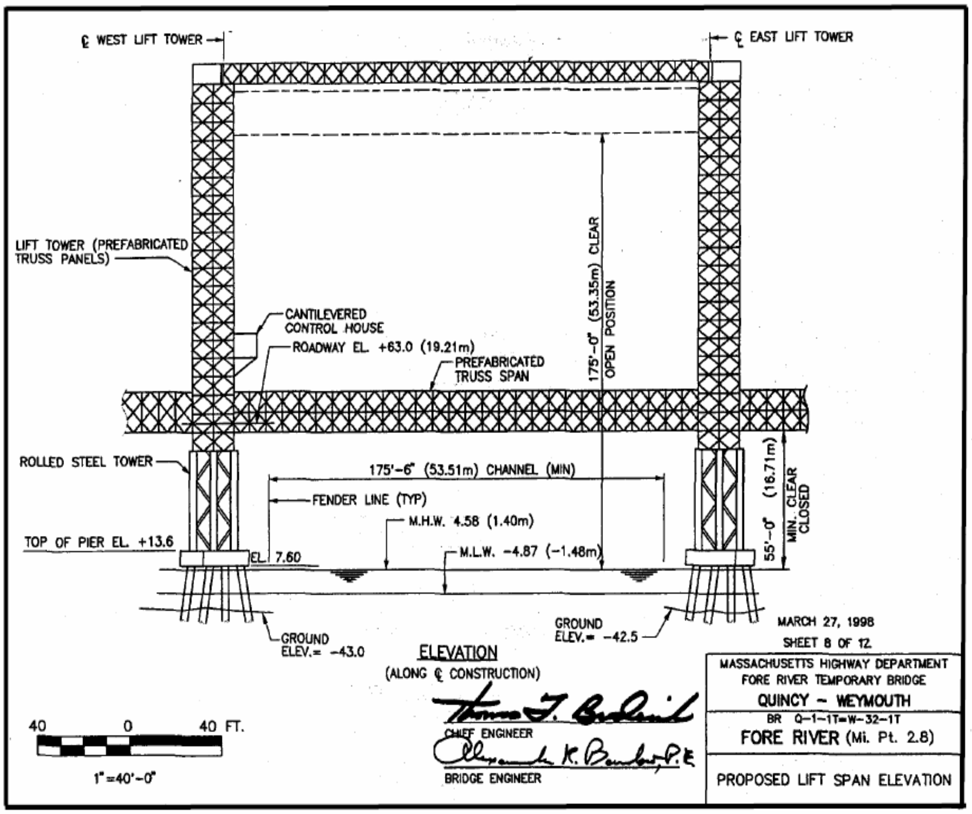
G-4



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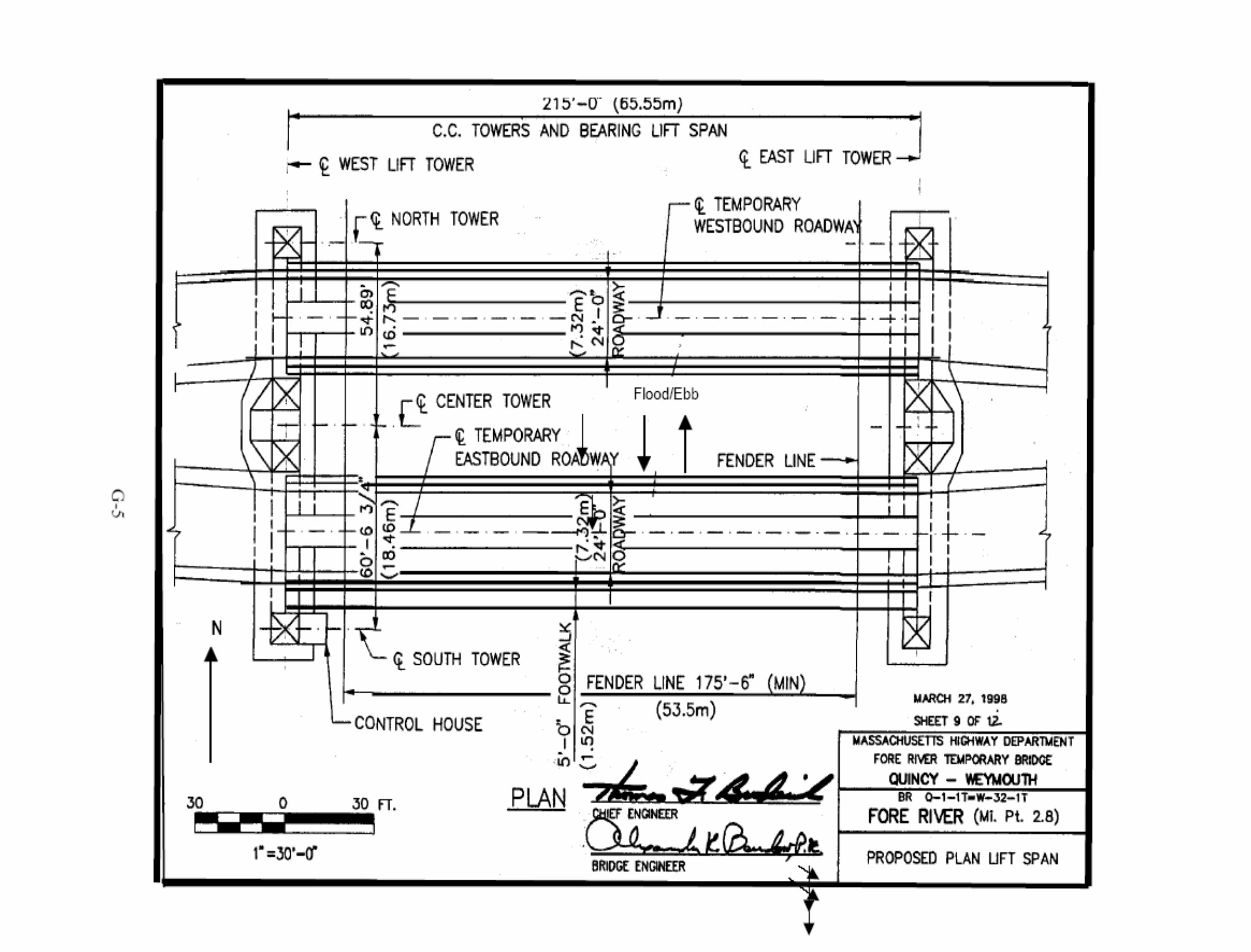

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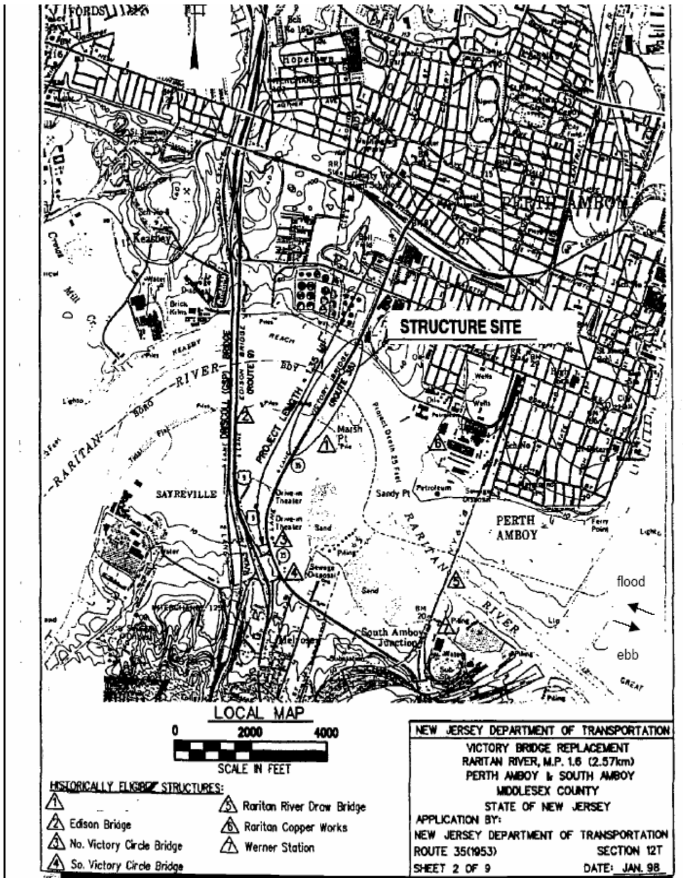

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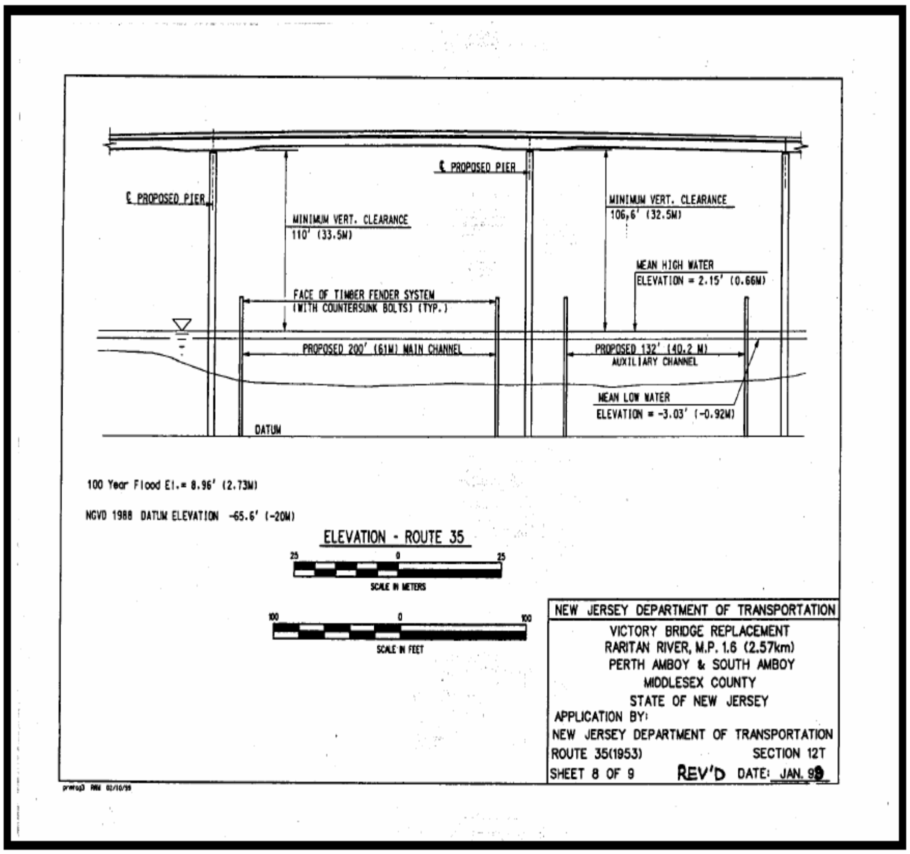
G-7



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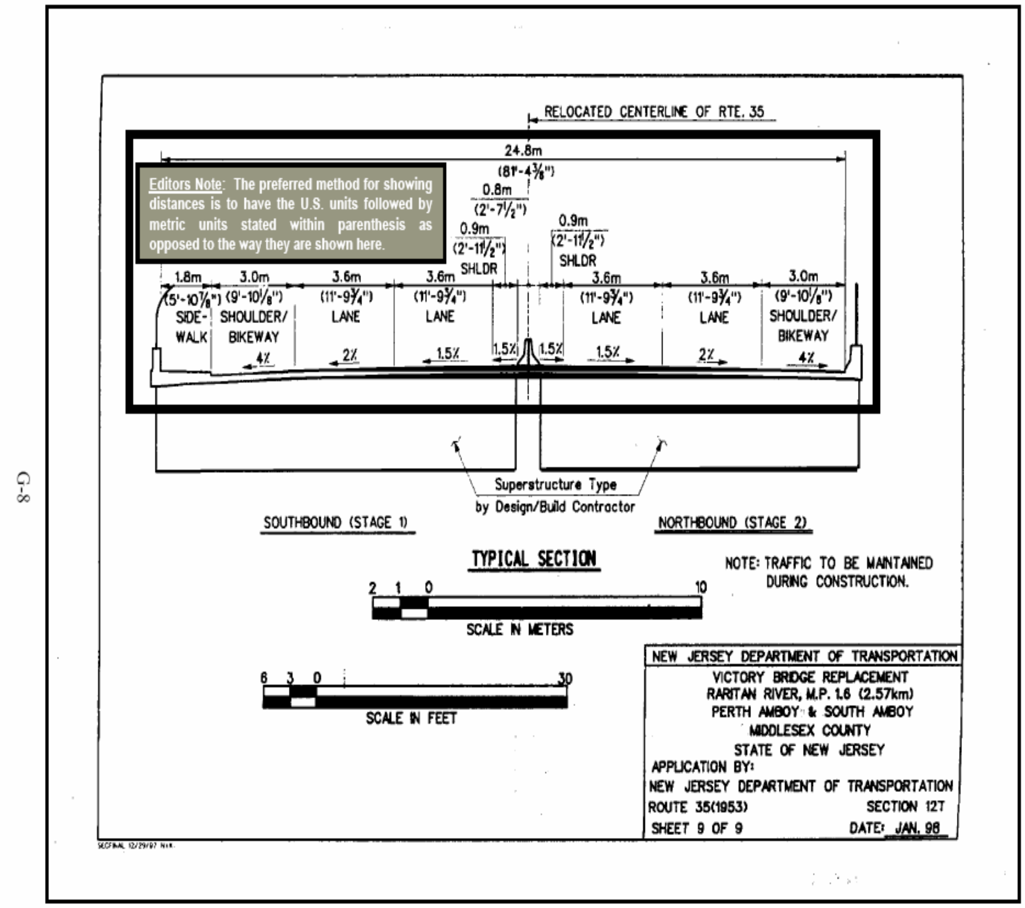

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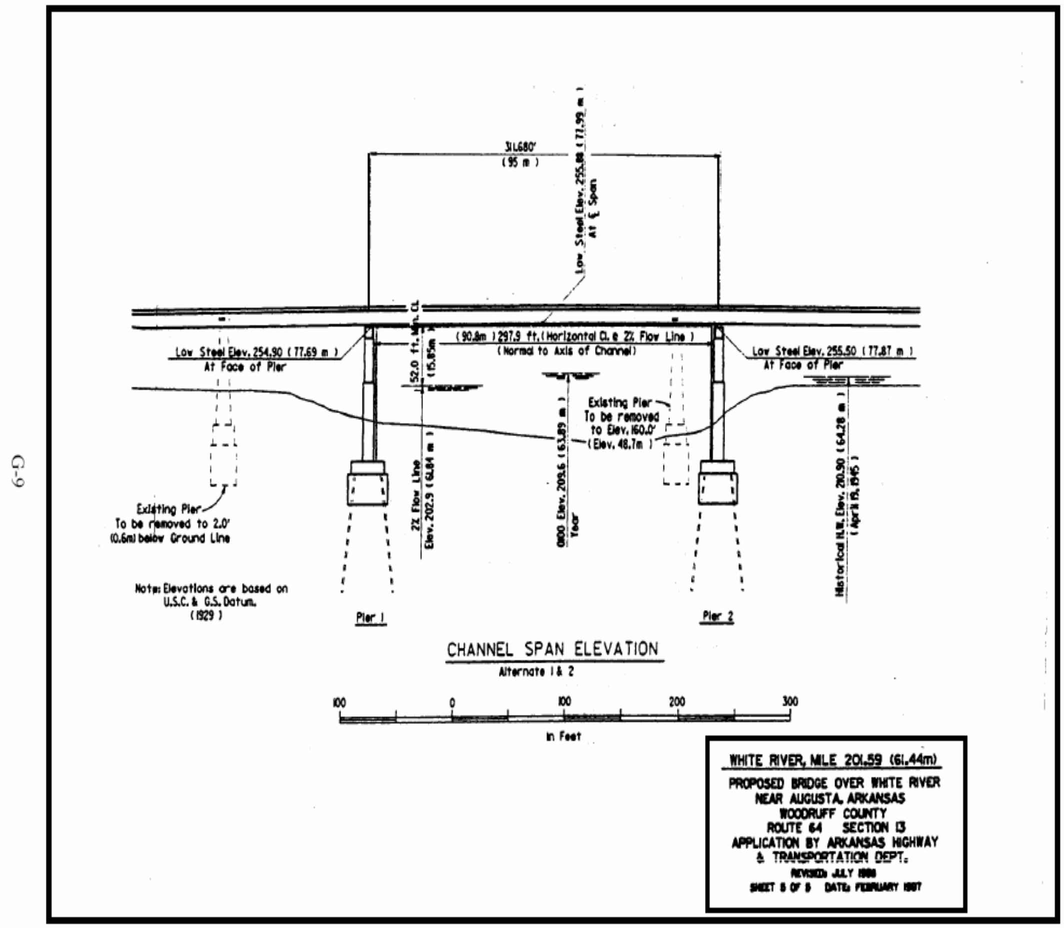

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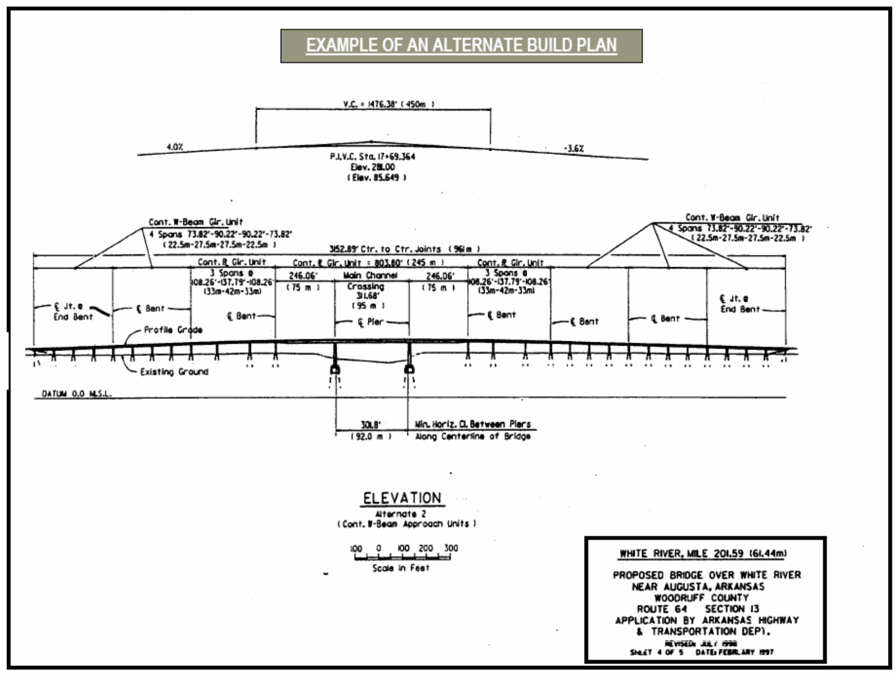


If you have any questions regarding this Checklist, please feel free to contact me.

Pete Martellucci, Wetlands Reviewer
MassHighway, Environmental Section
10 Park Plaza, Rm 4260
Boston, MA 02116
phone: (617) 973-8250
fax: (617) 973-8879

January 2, 2006

RE: **Eastfield/Rehabilitation of Bridge E-15-001, Main St. (Route 250) over Long River**
(MHD Project Number **123456**)
Section 106 Review

Sarah Storey, Chairperson
Eastfield Historical Commission
100 Main Street
Eastfield, MA 05555

Dear **Ms. Storey**:

The Massachusetts Highway Department (MassHighway) and the **Town of Eastfield** propose to **rehabilitate Bridge E-15-001, which carries Main Street (Route 250) over the Long River in Eastfield.** It is anticipated that this project will be supported in part with federal funds and will require review, therefore, under Section 106 of the National Historic Preservation Act of 1966 as amended (36 CFR 800). The enclosed project information is provided for the **Eastfield** Historical Commission's review in compliance with the regulations governing Section 106.

The existing bridge is a five-span concrete T-beam structure with an overall length of 120 feet and an overall width of 48 feet. Erected in 1937, the existing superstructure is carried on two 1937 concrete abutments and four earlier masonry piers. The proposed project will rehabilitate the existing substructure and replace the existing concrete T-beams with a new, five-span steel stringer superstructure carrying a 58-foot-wide deck. It is estimated that 180 feet of roadway approach work will be required at each end of the bridge.

MassHighway and the **Town of Eastfield** request that the **Eastfield** Historical Commission review the enclosed materials at its earliest convenience, and solicit any comments that the Commission wishes to make regarding this project. Written comments should be submitted to: John Blundo, P.E., Chief Engineer, Massachusetts Highway Department, 10 Park Plaza, Boston, MA 02116, Attn: Geoffrey Fulgione.

If you have any questions concerning the enclosed project information, please feel free to contact **John Smith** (617 973-**0000**) of MassHighway's Project Management Section. If you have any questions concerning the Section 106 process, please feel free to contact Geoffrey Fulgione (617 973-8253) of MassHighway's Cultural Resources Unit.

Sincerely,

William Johnson
ABC Consultants

atts: scope of work
locus plan

xcs: B. Simon, DSHPO, with atts.
G. Fulgione, MassHighway, with atts.

2-A-8

25 Percent Checklist

The latest 25 Percent Checklist is available online at:

https://www.mass.gov/files/documents/2018/02/16/PDDG_Workbook.xlsx

2-A-9

2-A-9

75 Percent Checklist

The latest 75 Percent Checklist is available online at:

https://www.mass.gov/files/documents/2018/02/16/PDDG_Workbook.xlsx

2-A-10

100/PSE Percent Checklist

The latest 100/PSE Percent Checklist is available online at:

https://www.mass.gov/files/documents/2018/02/16/PDDG_Workbook.xlsx

2-A-11

2-A-11

Design Exception Process

The latest Design Exception Process is available online at:

https://www.mass.gov/info-details/massdot-design-exception-reports

Chapter 3

Basic Design Controls

Basic Design Controls

3.1 Introduction

Basic design controls serve as the foundation for establishing the physical form, safety, and functionality of the transportation facility. Some design controls are inherent characteristics of the facility (e.g., its physical context and the existing transportation demands placed upon it). Other basic design controls are selected or determined by the designer, working with communities and users to address a project's purpose and need. Selecting appropriate values or characteristics for these basic design controls is essential to achieve a safe, effective, and context sensitive design.

This chapter illustrates these basic design controls and their influence on the physical characteristics of a roadway or other transportation facility:

- Roadway Context (Section 3.2)
- Roadway Users (Section 3.3)
- Transportation Demand (Section 3.4)
- Measures of Effectiveness (Section 3.5)
- Speed (Section 3.6)
- Sight Distance (Section 3.7)

3.2 Roadway Context

The context of a roadway is a critical factor to consider in developing a project's purpose and need, making fundamental design decisions such as cross-section determination, and selecting detailed design elements such as street light fixtures or other construction materials. Development of a roadway design that is sensitive to, and respectful of, the surrounding context is important for project success.

As described in Chapter 2, context-sensitive design refers to both the process and its results. An open community process that begins early in project development is needed to ensure that there is consensus about a project's purpose and need. This process needs to continue through the design phase so that the features of the project are assembled to produce an overall solution that satisfies the project's purpose and need, respects surrounding resources, and is consistent with community values.

Projects within the footprint of an existing, safely operating roadway are sometimes proposed when sensitive environmental and community resources are encountered.

Historically, the highway design process has focused on a project's transportation elements, particularly those associated with motor vehicle travel. A context-sensitive design should begin with analysis of the contextual elements, such as environmental and community resources, of the area through which a roadway passes. As described later in this chapter, the concept of area types has been developed to help the designer understand the users, constraints, and opportunities that may be encountered in different settings.

Once the designer has an understanding of the area surrounding the road and the road's users, the designer should consider the transportation elements of the roadway, its function within the regional transportation system, and the appropriate level of access control. Thus, three main elements of context are considered in design:

- **Area Type** – the surrounding built and natural environment
- **Roadway Type** – the role the roadway plays in terms of providing regional connectivity and local access
- **Access Control** – the degree of connection or separation between the roadway and the surrounding land use

3.2.1 Area Types

The context of a roadway begins with its environmental context, which includes nearby natural resources, terrain, and the manmade environment (development patterns, historic, cultural, and recreational assets). The environmental context can be a determinant of the desired type of accommodation for different users. This context often establishes the physical constraints of the roadway alignment and cross-section, and influences the selection of motor vehicle design speed. Throughout this Guidebook, this environmental context is generalized as ***area type***.

A roadway frequently traverses a variety of changing environs. Additionally, the volume and character of pedestrian, bicycle, public transit, and motor vehicle activity can change considerably along its route. Land use is the fundamental determinant in the function of a road; as land use changes along a road, the road's functions also change. Roadways must be designed in a manner that serves the existing land use while supporting the community's future land use goals. Chapter 15 also discusses land use strategies that a community can use to preserve the functionality of its roads or further support community values.

Traditionally, roadways have been classified either as "rural" or "urban." It is important to recognize that a roadway's formal classification as urban or rural (which is determined from census data using periodically-adjusted criteria adopted by the United States Office of Management and Budget) may differ from actual site circumstances or prevailing conditions. An example includes a rural arterial route passing through a small town. The route may not necessarily be classified as urban, but there may be a significant length over which the surrounding land use, prevailing speeds, and transportation functions are more urban or suburban than rural. For this reason, it is important for the designer, working with the community and project reviewers, to determine an appropriate area type or types for a project early in the planning process.

Area types are illustrative of the broad range of environments that the designer may encounter throughout the Commonwealth. The designer should also identify unique or project-specific contextual elements that will influence the design beyond those generalized for the following area types. These might include, as examples, schools, churches, historic features, environmental resources, area bike facilities, sidewalks, and bus stops.

3.2.1.1 Rural Area Types

Rural areas are generally undeveloped or sparsely settled with development at low densities along a small number of roadways or clustered in small villages, as illustrated in Exhibit 3-1. Rural areas are often distant from large metropolitan centers.

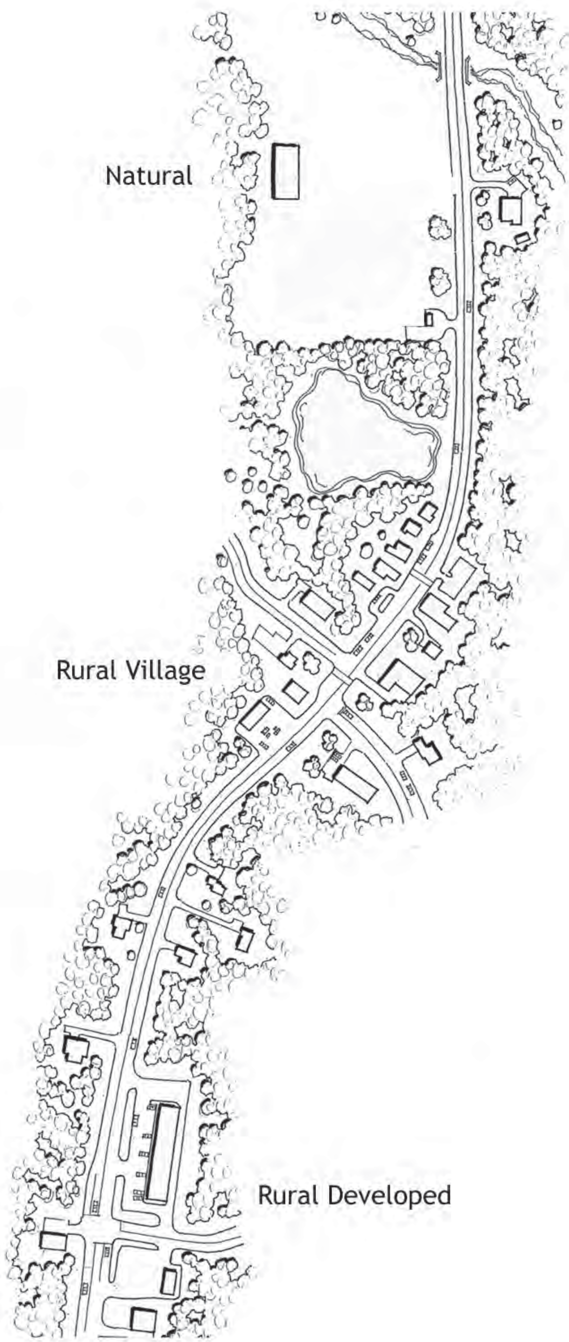
3.2.1.2 Suburban Area Types

Suburban areas vary widely in character and are usually found outside the core of a metropolitan area. Some components of suburban zones may appear rural in character, while others are densely populated and more closely resemble urban areas, as illustrated in Exhibit 3-2. Three different area types characterize the suburban context zone.

3.2.1.3 Urban Area Types

Urban areas are typically found at the core of a large metropolitan area. In many cases, the urban area includes a central business district (CBD) with high density commercial and residential development surrounding the CBD. Open space is generally found in formal parks or urban preserves, as illustrated in Exhibit 3-3. Although individual area types are described below to illustrate the land use variations found in the urban area, the roadway elements described in the subsequent chapters recognize that a consistent design approach is typically applied to urban areas given the similarities in parcel access, pedestrian activity, bicycle activity, and transit availability across these land use variations.

Exhibit 3-1
Rural Area Types



Natural

This is the traditional concept of rural space, where the roadway travels through forest land, farm land, and other open space. There are few access points along the roadway and little or no development. Design constraints tend to involve topographic, environmental, scenic or historic resources. Pedestrian, bicycle and transit activity is usually infrequent and of low volume. However, bicyclists and pedestrians may be attracted to low-volume roadways traversing scenic rural areas.

Village

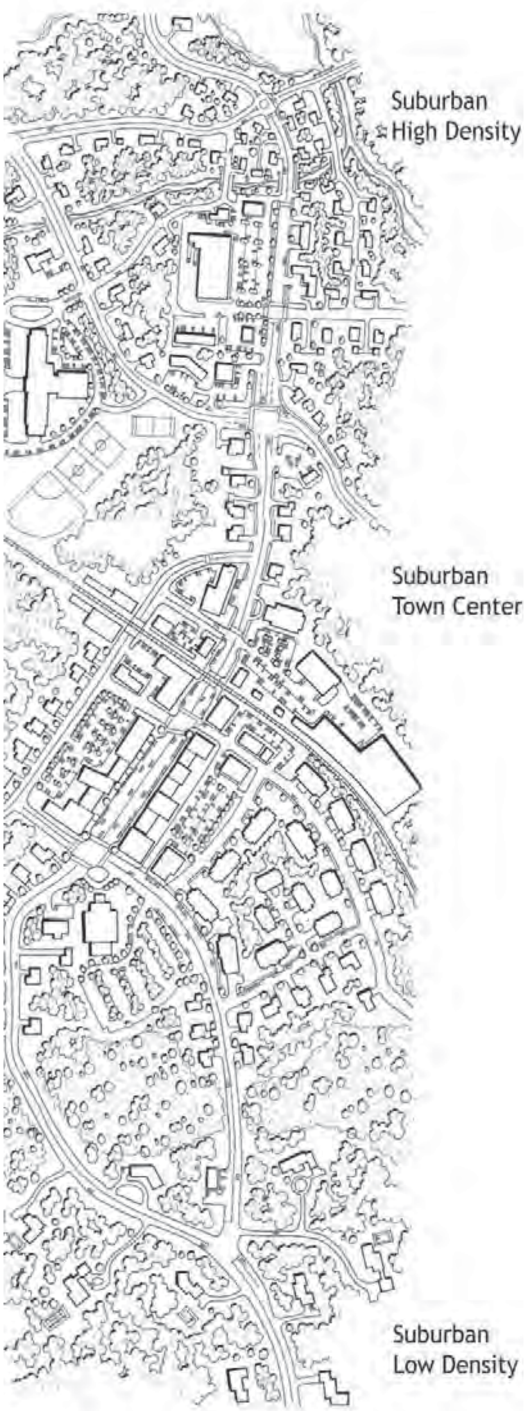
This is an isolated built-up area with storefronts, civic uses, and interspersed housing. Varied building setbacks, and frequent driveways and intersections are common. Individual property frontage is generally less than 200 feet. Right-of-way is usually constrained by the built environment. Pedestrian activity can be moderate to high and bicycle activity is often generated to, from, and within villages. Transit activity may be present, but is uncommon. An important safety consideration for design is the often rapid transition between rural natural or rural developed areas to a rural village.

Developed

This is an area of low-density residential development or occasional commercial uses. Buildings generally have large setbacks from the roadway and are frequently invisible due to tree cover. Occasional driveways require a driver to be more alert for entering and exiting vehicles than in rural natural areas. The consideration of future development and/or desires to retain the rural character of the area are important considerations in project development. Pedestrian and bicycle activity are more frequent than in natural areas, but generally of modest scale. Transit activity is uncommon.

Source: MassHighway

Exhibit 3-2
Suburban Area Types



High Density

This category covers a wide range of suburban development where the majority of the roadside is intensively developed with a mix of property-types and building setbacks. Residential property frontage is often less than 200 feet and intensive commercial development, including strip development, is frequently encountered. Right-of-way is usually restricted to a moderate extent by the built environment. Frequent driveways are usually encountered and influence the operating characteristics of roadway users including the prevailing travel speeds. If facilities are available, pedestrian and bicycle activity can be high, although most properties are often designed primarily for motor vehicle access. Transit service is sometimes present.

Village/Town Center

This is a built-up area of commercial and residential uses. The commercial uses are usually concentrated together and are notable for a uniform building setback. Residential areas consisting of properties with frontage of less than 200 feet often define the edges of a suburban town center. Pedestrian and bicycle activity are the highest in town centers compared to the other suburban settings and sidewalks are usually present. Right-of-way is usually restricted by the built environment. On-street parking is often found in these areas. Travel speeds are usually lower than in other suburban areas.

Low Density

These are transitional areas where roadways have a mix of natural and developed characteristics. Residential development is low to moderate in density, and there are isolated commercial properties. There are generally large setbacks to buildings and individual property frontage usually exceeds 200 feet. Frequent low volume driveways and intersections have an impact on the travel speed and operating characteristics of roadway users. Pedestrian and bicycle activity is higher than in rural developed areas and transit service through these areas is occasionally encountered.

Source: MassHighway

Exhibit 3-3
Urban Area Types

Urban Park

Open space in the urban area is usually found in parks or preserves. Pedestrian and bicycle facilities along roadways usually interconnect with the network of paths and trails through the open space. Roadways are often bounded by sidewalks and often include on-street parking to support use of the open space. Driveways are usually infrequent in open spaces, although path and trail crossings of the roadway may be common.

Urban Residential

Urban residential districts usually consist of multifamily developments at a common scale and setback along roadway corridors. Sidewalks are usually present and on-street parking is common, although not universally found in these areas. Off-street parking is usually located in parking structures or parking lots. Driveways are usually consolidated for entire buildings or blocks. High levels of pedestrian, bicycle, and transit activity are usually found in these areas.

Central Business District (CBD)

The majority of development is usually commercial or mixed-use. Access to property is the primary function of the roadway network. On-street parking is often found along road and structured parking facilities are common. Pedestrian, bicycle and transit activity is nearly always present and of substantial volume. A definitive network of sidewalks and pedestrian routes linking densely developed parcels is usually present. Transit centers where multiple bus routes converge are often found. Rail transit stations and intermodal facilities may also be encountered.

Source: MassHighway

3.2.2 Roadway Types

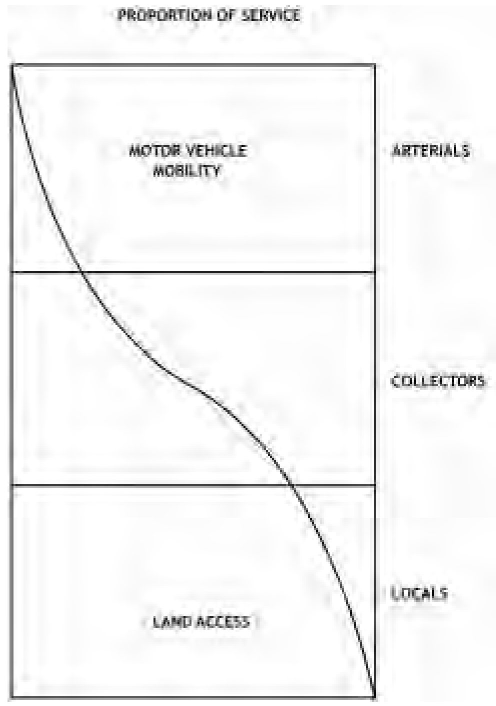
The transportation network is composed of several different types of roadways that provide different functions, traditionally referred to as a it's functional class. The primary purpose of some roads is to facilitate movement of vehicles (bicycles, cars, trucks, buses and light rail) between major cities and towns. The primary purpose of other roads is to provide access to the adjoining land. Most roads provide a combination of these purposes, as illustrated in Exhibit 3-4. ***Roadway type,*** defined by the facility's role in the state and regional transportation system, together with its area type, is an important contextual consideration for design. The roadway type should be selected to reflect the actual role that the roadway plays in the transportation system, as defined through the project development process.

A typical trip will often entail traveling along a variety of roadway types, each of which provides a different degree of local access and a different degree of regional connectivity. The roadway type reflects its degree of local access and regional connectivity as illustrated schematically in Exhibit 3-5 and described below:

- **Freeways** are primarily for interstate and regional travel (high regional connectivity at high speeds with limited access to adjacent land and limited access for pedestrians and bicyclists).
- **Major arterials** service statewide travel as well as major traffic movements within urbanized areas or between suburban centers (high regional connectivity at a wide range of speeds, and a lower level of local access than the following roadway types).
- **Minor arterials** link cities and towns in rural areas and interconnect major arterials within urban areas (high to moderate regional connectivity at a wide range of speeds, and moderate degrees of local access).
- **Major collectors** link arterial roadways and provide connections between cities and towns (moderate to low regional connectivity at a wide range of speeds, and higher degree of local access than arterials and freeways).
- **Minor collectors** connect local roads to major collectors and arterials (lower regional connectivity at lower speeds and higher degrees of local access than the previous roadway types).
- **Local roads and streets** - Not intended for regional connectivity (low speeds with a high degree of local circulation and access).

Exhibit 3-4

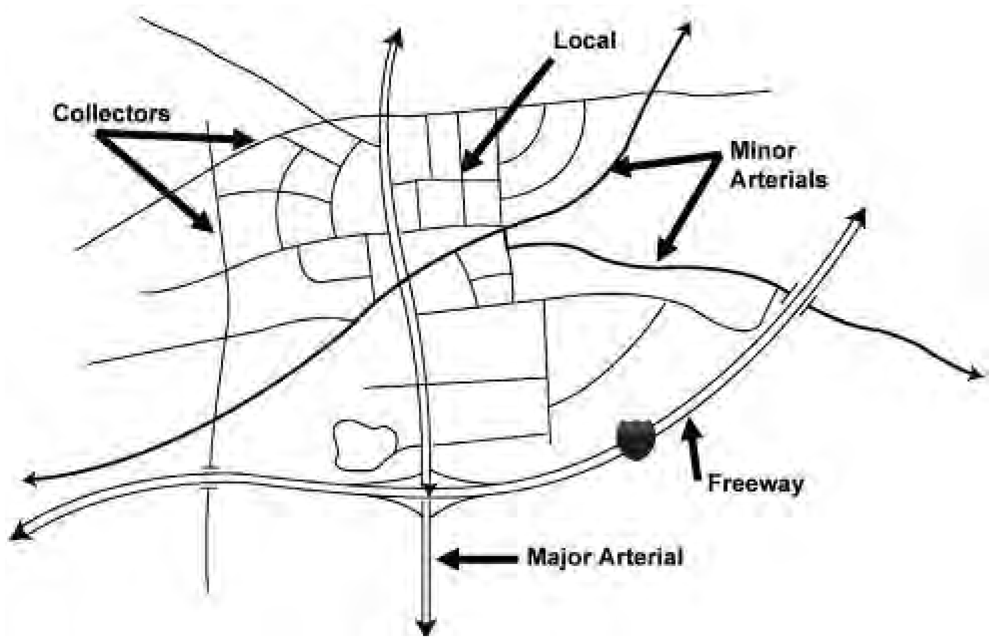
Conceptual Framework of Roadway Type



Source: Adapted from Safety Effectiveness of Highway Design Features, Volume 1, Access Control, FHWA, 1992

Exhibit 3-5

Schematic Representation of Roadway Type



Source: MassHighway

3.2.2.1 Relationship to the Formal Functional Classification System

The functional classification system developed by the Federal Highway Administration and applied to all roadways in the United States remains a key element of system planning so that a safe and efficient transportation network, providing the desired level of regional connectivity and land access, is developed and maintained. This classification system is also used as a determinate of federal funding eligibility. Formal functional classifications include: Interstate, Principal Arterial, Rural Minor Arterial or Urban Principal Arterial, Rural Major Collector or Urban Minor Arterial, and Rural Minor Collector or Urban Collector.

This formal classification often serves as a useful starting point, but the designer should not simply rely on this formal designation as a design control. The roadway type should be selected to reflect the actual role that the roadway plays in the transportation system, as defined through the project development process. For example, a roadway may serve a high number of regional trips, but may pass through a town center with frequent driveways, close intersection spacing, and high levels of pedestrian activity. In this case, the roadway serves as both an arterial and a local road. The designer should work closely with the community, users, and project reviewers to determine the roadway characteristics and appropriate design considerations to serve both the regional purpose of the roadway and its role in the local setting.

3.2.3 Access Control

Access control is a term used to define how access to adjacent properties is regulated and designed along a roadway. Access control is among the most useful tools available to maintain safe and efficient roadway operations for all users. Judicious use of median treatments, driveway permits, and safe driveway geometry can improve roadway safety and enhance the operation of the road without undue burden on accessing bordering property.

The degree of access control is influenced by the roadway type and area type. For example, access controls are usually more stringent on arterials than on collectors and local roads, reflecting the mobility and land access functions of these roadways. Likewise, access controls are often given more consideration in developing areas where there is flexibility for future land use to conform to an access management plan than in developed areas where the pattern of land use has been established. However, the designer should consider existing access points along a roadway and the possibility for changes that are consistent with the project's purpose and need. For example, it may be possible to relocate, redesign, or consolidate driveways along an existing roadway. A thorough understanding of access control will help the designer select an appropriate design speed, planning parameters, and desired level-of-service for the facility's users.

Access control is exercised by statute, zoning, right-of-way purchases, driveway controls, turning and parking regulations, geometric design (e.g., raised medians, grade separations, and frontage roads), and local right-of-way permitting, frequently administered by local Public Works Departments.

Roadways can be designed with the following approaches to access control:

- **Full Control** – Full control gives priority to through traffic by providing access only at grade-separated interchanges with selected public roads. No at-grade crossings or private driveway connections are allowed. "Freeway" is the common term used for this type of highway. Full access control maximizes the capacity, safety, and speeds on the freeway.
- **Partial Control** – Partial control of access is an intermediate level between full control and regulatory restriction. Under partial control of access, priority is given to through traffic, but a few at-grade intersections and private driveway connections may be allowed. Partial control of access may be provided for certain arterial and collector roadways. The proper selection and spacing of at-grade intersections and service connections will provide a safe balance between the regional connectivity and local access functions of the facility.
- **Statute, Zoning and Regulation** – If access points are properly spaced and designed, the adverse effects on roadway capacity and safety will be minimized. The design should enable vehicles to enter and exit safely with a minimum of interference to through traffic. Statutory control may be used, for example, on a rural or urban arterial highway to limit access only to public road crossings. Driveway regulations and permits are often used to control the geometric design of an entrance, driveway spacing, and driveway proximity to public road intersections. Zoning may also be used to effectively control the adjacent property development so that

major generators of traffic will not develop; however, zoning regulations are at the discretion of the local government.

While the designer may have substantial flexibility in defining the access control during the project development process for new roadways, the options may be substantially more complex or limited on projects that are modifying existing roadways. The *Access Management Manual* published by the Transportation Research Board in May of 2003 provides guidance on the application of access management techniques for both existing and new roadways. Access management techniques are also discussed further in Chapter 15.

3.2.4 Parkways

Parkways are a unique category of roadway that have special relationships to the surrounding area, perform unique transportation functions, and illustrate one of the earliest approaches to access control. Parkways, in Massachusetts practice, differ from ordinary state highways because they are understood to be within parklands and are distinguished by their scenic and landscape qualities, or access to such qualities, and for their recreational uses. They fall into three general categories.

Narrow, linear parkways, intended to link larger park or reservations to one another, and originally designed with internal carriage roads and bridle paths for recreational use, make up the first category. Examples of this type in the Boston area are the Riverway, Jamaicaway and West Roxbury Parkway. The parkway layout is sufficiently wide to include scenic and interesting natural features and provide a natural separation from surrounding developed areas; their narrow linear or curvilinear layout accommodated recreational drives through their length from one significant park or reservation to another. In many instances the carriage roads became increasingly integrated with the surrounding roadway network.

The second category of parkways is the group of landscaped boulevards established under the provisions of the Boulevard Act of 1894 and other subsequent, specific enabling legislation. Like earlier parkways, these boulevards were intended as links to outlying Reservations. Examples in the Boston area include the Fellsway, Revere Beach Parkway and Blue Hills Parkway. Boulevards were often laid out with reservations for electric trams and with a deliberate separation between general local access traffic and recreational traffic.

As regional roadways crossing multiple communities, many became important arteries for automobile traffic.

Park access roads characterize the third category of parkways. These parkways were intended initially to provide internal access to a park or reservation's features. Unquity Road in the Blue Hills Reservation and the summit roads at Mount Greylock Reservation are examples of park access roads. Many of these roads serve their original purposes; others have been substantially altered by the construction of extensions or links to other roads.

Special design considerations are often encountered when designing projects on parkways due to their scenic, historic, and recreational value. Many of the context-sensitive design approaches and considerations described in this Guidebook are appropriate for identifying these considerations and suitable design approaches. However, the proponent and designer must also work closely with the parkway's owner to determine appropriate design considerations for the particular parkway.

Many parkways are owned and controlled by the Department of Conservation and Recreation (DCR). The DCR is currently developing guidelines for the preservation of its parkways. When available, these guidelines should be followed for parkway projects. In some cases, MassHighway is involved in parkway projects due to project funding or other circumstances. In these instances, MassHighway will work cooperatively with the proponent and parkway owner to review or develop a design that is suitable for the parkway.

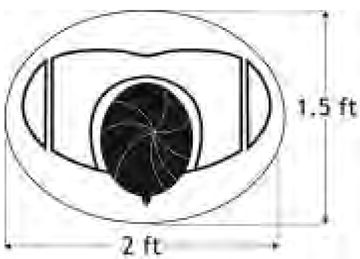
3.3 Roadway Users

A fundamental expectation in roadway design is that all users will be accommodated safely. Virtually all roadways serve a variety of users including pedestrians, bicyclists, motor vehicle drivers and passengers. In a few cases, such as freeways, roadways serve almost exclusively motor vehicle traffic. Early in the process, the designer needs to determine the composition of users anticipated for the facility. Appropriately accounting for all user characteristics is essential for obtaining a safe and efficient roadway. Experience demonstrates that when human and vehicular factors are properly accommodated, the safety and effectiveness of the highway or road system is greatly enhanced.

Consideration of roadway users' characteristics and selection of appropriate accommodation can also influence on the roadway's effectiveness for businesses and residential users, the economic health of the region, the physical health of the population, and the quality of the built and natural environment.

The characteristics of these varied roadway users are important controls that influence the physical design of a roadway, as described in the following sections.

3.3.1 The Pedestrian



Pedestrian Body Ellipse

All travelers are pedestrians at some point during their trip, and pedestrians are a part of every roadway environment. In some cases pedestrians are regular users of the roadway while in others, pedestrians may be using the roadway in emergency circumstances, such as accessing a disabled automobile. Pedestrian facilities include sidewalks, paths, crosswalks, stairways, curb cuts and ramps, and transit stops. Depending on the speed and volume of motor vehicle traffic, pedestrians may also share the road or use shoulders to complete a trip.

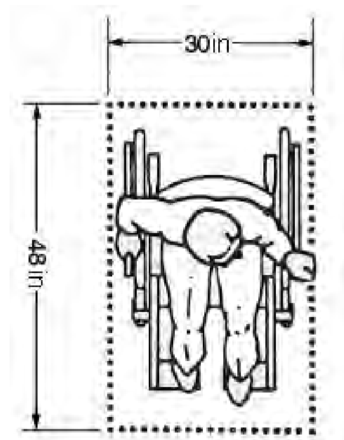
Designers should understand that there is no single "design pedestrian" and that the transportation network should accommodate a variety of pedestrians, including people with disabilities. For example, children perceive their environment differently from adults and are not able to judge how drivers will behave. Children usually walk more slowly, have a shorter gait, and have a lower eye height than adults. On the opposite end of the spectrum, older adults may require more time to cross streets, desire more predictable surfaces, benefit from handrails in steep areas, and may require places to rest along their route. People who are blind or who have limited sight require audible and tactile cues to safely navigate sidewalks and crosswalks. People with limited cognitive abilities may rely on symbols and take longer to cross the street. People using wheelchairs or scooters may travel across an intersection faster than someone walking, but it is more difficult to see them from the seat of a truck, SUV, or car. It is important to recognize that pedestrians exhibit a wide range of physical, cognitive, and sensory abilities, but they all comprise the pedestrians that a designer needs to accommodate. In fact, 20 percent of the pedestrian population has some disability, and that number is growing as a result of the aging of our population.

MassHighway intends to accommodate all pedestrians in the design and construction of pedestrian facilities.

When thinking about likely pedestrian travel between activity centers (i.e., residence to school, parking to store, etc.), distance is the primary factor in the initial decision to walk. Most people are willing to walk 5 to 10 minutes at a comfortable pace to reach a destination, which equates to a distance of about 0.2 to 0.4 mile. Although longer walking trips are possible, a trip of 1.0 mile is generally the longest distance that most people are willing to walk on a regular basis. The designer should ensure that pedestrian network connectivity and safe crossings are provided between activity centers. In addition to the characteristics described above, the spatial dimensions of pedestrians and their operating characteristics are key critical aspects that influence the detailed design elements of pedestrian facilities.

3.3.1.1 Spatial Needs of Pedestrians

Pedestrians require a certain amount of physical space in order to maneuver comfortably. The space requirements of pedestrians influence the ability for individuals to freely select their speed and the carrying capacity of a pedestrian facility. The *Highway Capacity Manual* provides methodologies for evaluating how a pathway serves the demand placed upon it, or how wide a sidewalk should be for a given demand. Space requirements are also influenced by the characteristics of those who use wheelchairs or other assistive devices.



Spatial Needs for Wheelchairs

A simplified body ellipse of 2 by 1.5 feet with a total area of 3 square feet is used as the basic space for a single pedestrian. This represents the practical minimum space required for standing pedestrians. The clear space for a person sitting stationary in a wheelchair is generally understood to be 2.5 feet by 4 feet, although people using scooters and power chairs may require even more space. A person using crutches, a service animal, or a walker typically requires 36 inches clear width. In evaluating a pedestrian facility, an area of 8.0 square feet is typically considered to allow a buffer zone for each pedestrian and approximately twice that is needed for a person using a wheelchair or a white cane. These dimensions indicate that a 3 foot pathway is adequate for single file pedestrian flow in one direction, in the absence of vertical obstructions along the route. To allow free passing of pedestrians, a walkway that is at least five-feet wide and clear of obstructions is required. Walking is often a social activity, and frequently pedestrians walk in pairs or groups. To account for this common behavior, it may be desirable to design facilities that enable two people to walk or ride their chair abreast, requiring approximately 6 feet of width. In areas with high pedestrian traffic, greater widths are desirable as described in Chapter 5.

3.3.1.2 Pedestrian Level-of-Service Measures

The *Highway Capacity Manual (HCM)* provides definitions of level of service based on spatial and delay measurements. The HCM provides level-of-service analysis for a variety of pedestrian facilities, including sidewalks, paths and crosswalks. Pedestrian levels of service are defined similar to traffic operations using a LOS A to LOS F rating system. For conditions such as sidewalks and street corner queuing areas, the level of service is based on the pedestrian demand (flow rates) and density. For shared pedestrian-bicycle facilities, the level of service is based on the number of times bicyclists pass pedestrians. Several new pedestrian level-of-service measures that account for a greater number of environmental factors are being developed through research. In addition to the level of service indicated by the HCM procedures, the designer should also consider geometric, traffic, urban design, and streetscape elements that influence pedestrian comfort.

At signalized intersections, the pedestrian level of service is based on the average delay a person experiences waiting to cross the street. This delay is independent of pedestrian volume and is calculated solely on the signal cycle length and the amount of green time provided to pedestrians.

At unsignalized crosswalks, the pedestrian level of service is related to vehicular volumes, speeds, and the resulting gaps in the traffic stream suitable for pedestrian crossings. Although adherence is not universal, at unsignalized crosswalks, vehicles often yield to pedestrians, as required by law, increasing the level-of-service from that derived using *Highway Capacity Manual* procedures. Careful design review of the crossing locations must be performed during the project development process to ensure adequate visibility exists for compliance with this law.

Chapter 6 of this Guidebook presents specific design advice about how to accommodate pedestrians within the right-of-way at intersection locations.

3.3.2 The Bicyclist

Safe, convenient and well-designed facilities are essential to encourage bicycle use. Roads designed to accommodate bicyclists with moderate skills will meet the needs of most riders. Young children are primarily the bicyclists who may require special consideration, particularly on neighborhood streets, in recreational areas, and close to schools. Moderately skilled bicyclists are best served by:

- Extra operating space when riding on the roadway such as bicycle lanes, usable shoulders, or wide curb lanes;
- Low speed streets (where cars share travel lanes); and
- A network of designated bicycle facilities (bicycle lanes, side-street bicycle routes and shared use paths).

Paths for bicyclists (which generally also serve other non-motorized users) supplement the roadway network and are discussed in detail in Chapter 11. The design of roads for bicycling should consider these factors:

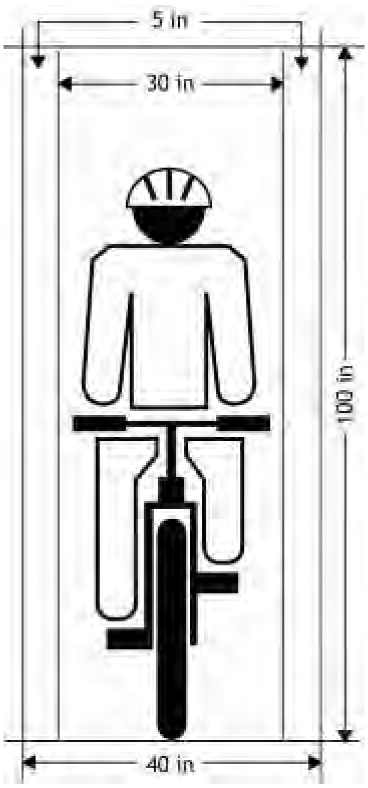
Shared-Use Path Users

- Providing width sufficient for motorists to pass bicyclists without changing lanes on high speed or high volume roadways;
- Removing roadway obstacles that could cause bicyclists to fall;
- Directing bicyclists to scenic and low traffic routes by guide signs and/or pavement markings;
- Providing signalized crossings of major roads when warranted for those who are not comfortable making left-turns in heavy traffic.

When bicycles are used on public streets and roads, bicyclists are subject to the same traffic rules as motor vehicle operators with some exceptions as noted in the Massachusetts General Laws (see Chapter 85 11B). The following sections describe the spatial needs and level-of-service measures for bicyclists.

3.3.2.1 Spatial Needs of Bicyclists

The bicyclist's operating characteristics include required width, angle of lean when negotiating curves, sight distances, and clear zones. Clear width requirements may differ somewhat depending on bicycle type. Typically, bicyclists require a clear width of at least 40 inches. A clear width of at least 48 inches is necessary to accommodate bicycles with trailers or adult tri-cycles. The required height of operating space is 100 inches.



Bicycle Operating Space

An operating space of 4 feet is assumed as the minimum width for one-way bicycle travel. Where motor vehicle traffic volumes, truck and bus volumes, or speeds are high, a more comfortable operating space of 5 to 6 feet is desirable. Also, adjacent to on-street parking, 5 to 6 feet is desirable to provide space for the opening of car doors into the travel lane.

A critical design consideration is the minimal tire surface contact with the ground and the susceptibility of bicycle tires to damage. The minimal tire contact means that longitudinal seams and cracks, sand, mud, wet leaves, metal utility covers and decking, and skewed railroad tracks can precipitate a crash. Longitudinal cracks as narrow as 1/4 inch and surface edges higher than 1/2 inch can cause loss of control. Avoidance of road debris or obstacles forces bicyclists to swerve and these maneuvers are often unexpected by a driver sharing the same lane. Placement of obstacles in the travel path of bicyclists should be avoided.

3.3.2.2 Bicycle Level-of-Service Measures

The level of service for bicyclists on shared use paths (where bicyclists share the path with pedestrians, in-line skaters, etc.) is also evaluated on a LOS A to F scale for different settings. For such paths, the level of service is determined by the nature and number of interactions between bicyclists, pedestrians, in-line skaters, and other obstacles such as dogs and baby strollers.

Bicycle LOS at intersections is similar to that experienced by motor vehicles since bicycles are subject to the same traffic control. These LOS considerations are explored in more detail in Chapter 6.

The level of service for on-road bicycle travel is based on the adjacent traffic volumes, speed and the width of the shoulder or bicycle lane. Other factors, such as vehicle mix and on-street parking, can also influence bicycle level of service for on-road facilities. Procedures for determining bicycle level of service on uninterrupted bicycle facilities are provided in the Highway Capacity Manual. Other tools have been developed to assess level of service for on-road facilities. The two primary sources are the Landis' *Toward a Bicycle Level of Service* (BLOS) methodology and the Federal Highway Administration's Development of the *Bicycle Compatibility Index* (BCI). Although the BCI methodology is the most widely-accepted methodology for determining bicycle LOS, current research is developing new level-of-service models for bicyclists.

3.3.3 The Driver

Roadway design is based on the assumption that motor vehicle drivers are competent and capable; however, the design of a roadway also needs to account for a large variation in driver skill and ability. The *AASHTO Policy on Geometric Design of Highways and Streets* discusses human factors in detail.

3.3.3.1 Spatial Needs of Motorists

When a roadway or intersection is under design, the largest design vehicle likely to use that facility on a regular basis should be used to determine the selected design values. Typically, trucks and buses require larger design values than passenger cars, which makes determining the type of specific design vehicle an important design consideration. Exhibit 3-6 summarizes the range of vehicle dimensions. Actual vehicle widths may vary from the dimensions listed in the table due to manufacturer and aftermarket vehicle variations such as side view mirror extensions.

On local streets the design might fully accommodate smaller trucks with the knowledge that, at intersections, the occasional larger truck can back up while turning and can encroach upon opposing lanes. These types of decisions are situation-specific and depend on the frequency of larger vehicles, the amount of other traffic, the character of the area, and other factors.

Exhibit 3-6
Design Vehicle Dimensions

Vehicle	Vehicle Length	Vehicle Width	Operating Width[1]
Passenger Cars and Light Trucks	19.0 feet	7.0 feet	9.0 ft
School Bus	36.0 feet	8.0 feet	10.0 ft
Transit Bus	40.0 feet	8.5 feet	10.5 ft
Single Unit Truck[2]	30.0 feet	8.0 feet	10.0 ft
Tractor-Trailer	55.0 feet	8.5 feet	10.5 ft

Source: *A Policy on the Geometric Design of Streets and Highways*, AASHTO, 2004. Chapter 2 Design Controls and Criteria
1 Assuming one-foot clearance on both sides of vehicle
2 The SU-30 design vehicle is commonly used to model emergency response vehicle operations

Spatial dimensions and motor vehicle speeds are closely related. The following is a brief discussion of the motor vehicle characteristics used in arriving at design values.

- Stopping sight distances depend on the speed of operation and vehicle braking characteristics.
- Horizontal curvature depends on the side friction between tire and roadway, among other factors.
- Truck acceleration and deceleration rates are factors in the design of highway vertical alignment.
- Vehicles are restricted in how sharply they can negotiate a turn by their physical dimensions and tire friction, which influences curb radii at intersections.
- Another turning characteristic of vehicles is the transitional nature of their turning path. Vehicles cannot immediately turn to their desired turning radius but have an entering and exiting transition into that radius. This has led to the use of compound curves on highways.
- Lane and shoulder widths are derived from the design width of vehicles and horizontal clearances to allow safe operation.

Further discussion of design vehicles is provided in AASHTO's *A Policy on the Geometric Design of Highways and Streets*.

3.3.3.2 Driver Level-of-Service Measures

The level of service for drivers on a facility reflects the speed and capacity provided for motor vehicle travel. Additionally, the vehicular level of service often influences the quality of public transit service provided along a roadway corridor. Different level-of-service measures apply to different components of the roadway. In general, there are two categories of vehicular level-of-service measures:

- Uninterrupted flow (two-lane highways, multi-lane highways, freeway segments, and freeway ramps) for which level of service is based on the concepts of average travel speed, percent time following, and density measures.
- Interrupted flow (signalized intersections, unsignalized intersections, and roundabouts) for which level of service is based on the amount of delay experienced by vehicles using the facility.

Levels of service for motor vehicles range from LOS A to LOS F, with LOS E representative of operation approaching or at capacity. The *Highway Capacity Manual* (HCM) provides procedures for determining levels of service for a variety of facility types.

3.3.4 Public Transit

Public transit within a roadway is usually provided with transit buses. A representative bus used by the local transit agency should be included as a design vehicle on roadways where transit service is provided, or is anticipated during the expected life of the project. The designer should also consider the design characteristics and potential location of bus stops, stations, and other intermodal facilities. Most buses are lift-equipped, generating the need for five-foot (measured at the curb and parallel to the vehicle) by eight-foot (measured from the curb or vehicle edge) level pad adjacent to the accessible sidewalk. This allows for the deployment of the lift and space to maneuver on and off of it. The designer should also ensure that pedestrian connectivity—including curb cut ramps and accessible drop off areas to these facilities are provided.

Articulated Transit Bus

In less frequent circumstances, rail transit is provided along a roadway or within a center median. The detailed clearance, station, and operational needs of rail transit should be integrated into the roadway design in these conditions. Other features such as exclusive lanes and traffic signal pre-emption can improve transit operations within a roadway. Transit design considerations are discussed further in Chapters 5, 6, and 16.

In terms of level of service, there are many measures of transit quality of service as outlined in the *Transit Capacity and Quality of Service Manual.* Most of these, such as vehicle type, operating hours and frequency of service, are independent of roadway design. For the purpose of roadway design, the key considerations are the location and design of bus stops, the travel time through a corridor, the pedestrian and bicycle routes connecting to the facility, and waiting areas to access transit.

For specific projects, there may be transit design elements that influence the roadway design. Where transit operations are present or expected, the designer should coordinate with the transit agency during the project development process to ensure that transit operational requirements are included in the design.

3.4 Transportation Demand

Transportation demands – volume, composition, and patterns – are important design controls. The greater the demand for a facility, the more important are its operational and safety characteristics. The designer must have a good understanding of existing and anticipated demands by pedestrians, bicyclists, and drivers. Community planning goals, the selected design year, and performance measures for a project are key determinants of how the design achieves the project’s purpose and need.

3.4.1 Design Year

Projects are designed to accommodate travel demands likely to occur within the life of the facility under reasonable maintenance. This involves projecting future conditions for a selected planning horizon year. Projections of future demand for major transportation investments are usually made for the 15 to 25 year range. For large projects, the designer should usually select 20 years from the expected facility completion date as the design year. This is a reasonable compromise between a facility's useful life, the uncertainties of long-range projections, and the consequences of inaccurate projections. For smaller, less capital intensive projects, a 5- to 10-year planning horizon is generally used.

Forecasts of future activity levels should reflect community and regional plans, community setting, and the project's purpose and need. Based on these considerations, a future conditions forecast represents a technical analysis and policy consensus on the type and developed intensity of land use, future regional economic activity, presence of transit service, the needs of pedestrian and bicyclists, and many other factors.

Forecasts of future activity levels should include estimates of pedestrian and bicycle activity. Particular care must be used when forecasting pedestrian and bicycle volumes. Many times there is latent demand above observed pedestrian and bicycle volumes because pedestrian and bicycle facilities do not yet exist in the project area, are substandard, or do not provide complete connectivity to attractions. It is important to evaluate future land development, including any potential attractors such as transit stops, schools, parks and retail uses that may be located near moderate and high-density residential development.

Planners and designers need to determine the appropriate estimates of activity levels for design. For the typical project undertaken within a community, such as an intersection improvement or a corridor access management project, the forecast is based on existing conditions. First, traffic counts (including pedestrian and bicycle trips) are conducted to determine when the peak hour(s) of traffic occurs. Second, seasonal adjustments are made, if necessary, to ensure the count data are representative of at least average annual conditions. Lastly, future conditions are estimated by adding to or subtracting from the existing traffic volumes to account for known development and transportation projects, and an annualized factor is generally applied to account for potential areawide growth or decline. Regional travel demand models are often used in planning larger transportation projects.

To evaluate the future conditions, planners and designers first collect and evaluate existing conditions' data to establish a baseline.

Although the typical process for forecasting traffic volumes assumes that traffic will increase over time, there are situations where traffic volumes may decline or remain relatively constant over time. It is important that traffic forecasts for a roadway design project reflect likely conditions over the project's life and are not selected arbitrarily. Municipal planning departments, regional planning agencies, EOT planning, as well as MassHighway, can provide assistance in seasonal adjustments and in validating the assumptions regarding future traffic estimates.

3.4.2 Volume and Composition of Demand

The composition of transportation demand is an important element in the design of roadways. The designer should develop a realistic design scenario including the volume and mix of activity for all modes as described below.

3.4.2.1 Pedestrian Demands

Pedestrian counts should be completed to determine pedestrian flows and patterns. The pedestrian counts should include sidewalk demands, crossing demands, and storage demands at corners, traffic islands, and medians (total number of pedestrians waiting to cross the street).

In addition to relying on counts of pedestrians, the designer should also evaluate the project area to determine if there is latent demand for pedestrian accommodation due to an uncomfortable existing walking environment, missing links in the pedestrian network, or expected changes in development patterns. The likelihood of latent demand can be assessed by looking at surrounding land uses and their propensity to generate pedestrian activity. One can also look for conditions like pathways worn along the roadside to determine if pedestrian connectivity is underserved.

It may be important to complete pedestrian counts for other times of the day (beyond the typical morning and evening peak hours) and/or on weekends, depending on the project area. For example, if a project area is heavily influenced by a school, it is be important to observe pedestrian flows during morning and mid-afternoon periods. Public assembly facilities and transit stops or stations also merit special consideration because they can produce high volumes of pedestrians over short durations.

To determine the appropriate locations for pedestrian counts (including project area intersections), it is important to review current pedestrian routes between activity centers. Informal paths or crossing locations may warrant supplemental pedestrian observations during project planning.

3.4.2.2 Bicycle Demands

Bicycle demands should be counted during peak hours concurrent with vehicle turning movement counts. As with pedestrian activity, the designer should also evaluate the project area to determine if there is potential latent demand for bicycle accommodation. Additional consideration of bicycle demands during other periods of the day and/or on weekends may warrant supplemental counts, as discussed in the prior section. Methods for forecasting bicycle demand are still evolving through national transportation research. Common practices to gage future demands currently include sampling demand at similar settings or facilities and evaluating surrounding land uses for their propensity to generate bicycle activity.

3.4.2.3 Motor Vehicle Traffic Volumes

Daily, peak hour, and patterns of motor vehicle traffic are needed as input to the planning and design of roadway facilities. Some key definitions of traffic volume measures are listed below:

- **Average Annual Daily Traffic (AADT)** — The total yearly volume of automobiles and trucks divided by the number of days in the year.
- **Average Daily Traffic (ADT)** — The calculation of average traffic volumes in a time period greater than one day and less than one year. (ADT is often incorrectly used interchangeably with AADT.)
- **Peak-Hour Traffic (PH)** — The highest number of vehicles passing over a section of highway during 60 consecutive minutes. **T(PH)** is the PH for truck traffic only.
- **Peak-Hour Factor (PHF)** — A ratio of the total volume occurring during the peak hour to the maximum rate of flow during a given time period within the peak hour (typically is 15 minutes).
- **Design Hourly Volume (DHV)** — The one-hour volume in the design year selected for determining the highway design. (In many cases, designers look at the typical worst case weekday morning or evening peak hour or the 30th highest hour of the year to assess the geometric requirements of their design.)
- **K-factor (K)** — The K-factor is the percent of daily traffic that occurs during the peak hour.

Manual turning movement counts (TMCs), including heavy vehicle movements, at intersections, and automatic traffic recorder/vehicle classification counts (ATRs) counts along roadways are generally needed for planning and design of transportation projects and can be used to provide estimates of the values listed above. These counts should also include pedestrian and bicycle activity, where present. Pedestrian and bicycle counts should be performed in fair weather.

3.4.2.4 Design Volumes and Traffic Composition

The design hourly volume (DHV), or daily peak hours, will affect many design elements including the desired number of travel lanes, lane and shoulder width, and intersection layout. The design volume may also influence the level of service provided and the accommodation appropriate for pedestrians and bicyclists.

Daily traffic estimates are also useful in making design decisions related to the total user benefit of a proposed improvement. For example, the benefit of highway safety roadside improvements is directly related to the crash exposure (expressed in ADT) on the road.

Sometimes selection of the design hour entails judgment regarding the conversion of daily traffic to peak hour traffic volumes. Other times, when data from continuous traffic count stations are used, the design hourly volume is based on the peaking characteristics of the facility over an entire year. For rural areas, the DHV is typically based on the 30th or 50th highest hour. In urban areas, the DHV typically represents the 100th highest hour. In some circumstances, a lesser design hour is appropriate. These design hour volumes are usually selected since they capture operating conditions expected to occur on a regular basis and have been shown to have dependable statistical relationships to measured ADT on a roadway.

The choice of the design hour volume has a significant impact on the characteristics of a project. Designers should ensure that the design hour volume is selected such that the facility is well-matched to the traffic volumes it will carry on a regular basis and is not “over-designed.” For example, accommodating a high volume expected to occur infrequently will result in a project that is costly and has significant adverse impacts. Likewise, accommodating a lower design volume that is frequently exceeded may result in significant congestion and not meet the level-of-service expectations for various users.

Large or heavy vehicles, such as trucks and buses, have different operating characteristics from passenger cars and bicycles and can affect traffic operations. Therefore, the number of trucks and buses expected to use a facility needs to be estimated for both the daily and peak hour conditions, in planning and design.

For highway capacity purposes, “heavy vehicles” are typically defined as all buses, single-unit trucks, and truck combinations other than light delivery trucks. (Light delivery trucks have two axles with four tires). In addition, the impact of transit operations (such as buses making stops along a roadway) must be considered in operational analysis of the roadway.

3.5 Measures of Effectiveness

Through the project development process and with public input, the designer should evaluate the project (and its alternatives, if applicable) using several measures of effectiveness. Suggested measures of effectiveness and analysis techniques for consideration during project planning and design are described below. Many of these measures of effectiveness are included in the transportation evaluation criteria (see Appendix 2-A-2) used by transportation agencies or MPOs for project evaluation and prioritization. The following sections discuss transportation or contextual measures of effectiveness.

3.5.1 Transportation Measures of Effectiveness

The following measures of effectiveness are related specifically to the transportation function of a facility and how the facility accommodates its users.

3.5.1.1 Condition of Facilities

State transportation policy places an emphasis on improving the condition of existing facilities. Projects on existing facilities should return a facility to a state of good repair by addressing existing structural, pavement surface, or other deficiencies. Techniques such as pavement testing and bridge inspections can be used to identify existing deficiencies.

3.5.1.2 Safety

The safety of transportation facilities is a primary concern in planning and design. Some projects are specifically proposed to address known safety problems; however, all projects should result in a facility that safely accommodates its users. Corridor safety audits and analysis of crash records can be useful for identifying existing safety hazards. Project design elements should be selected based on their historic safety performance and expected operating characteristics.

3.5.1.3 Mode Choice

Many projects result in improved accommodation for particular modes. The effectiveness of these projects can be measured by the degree to which they allow users to choose the mode best-suited to their trip purpose and personal values within the broader framework of the community, the region, and the environment. The traditional level-of-service measures described below can also be useful tools for evaluating the improvement in accommodation for each user group.

3.5.1.4 Network Connectivity

In many instances, projects are proposed to fill in missing links within a network so that connections by a particular mode are possible. The effectiveness of these projects can be evaluated based on the demand for the connection and how well the facility satisfies that demand using the traditional level-of-service measures described below.

3.5.1.5 Level of Service

The overall objective of the design process is to provide the desired level of service for each roadway user, therefore achieving a safe and efficient facility for all users.

To characterize the quality of movement through a transportation network, level-of-service (LOS) objectives are broadly used. Levels of service traditionally relate to the project's context and the demand characteristics of the facility. A single level of service for a transportation facility that reflects the quality of service provided to all users would be ideal; however, a multimodal LOS framework is still at the preliminary stage of development. Therefore, the designer should evaluate the LOS provided to each user group separately and should test design alternatives as necessary to meet the LOS goals for all users of the project. Several analytical methodologies and computer software packages are available to estimate LOS for facility users.

The designer should also carefully consider the level-of-service interactions between different user groups when designing a roadway. A good design will provide a reasonable level of service to all users, within the context of the project. As the design is refined, the resulting levels of service may differ from the goals selected at the beginning of the project development process.

Particular care must be taken when determining desired levels of service and how that level of service meets the needs of roadway users and helps meet the purpose and need of a project. In general, the desired level of service is determined through consensus of the affected community and the facility owner. Like many elements, the designer should ensure that project participants have a thorough understanding of the resulting level of service from the design so that expectations are met, or the project's purpose and need is refined.

3.5.2 Contextual Measures of Effectiveness

The following measures of effectiveness are associated with how the transportation facility relates to its context including its physical surroundings and community function.

- **Environmental and Community Resource Preservation** – Projects can impact environmental and community resources to different degrees. In many cases, highly-effective projects minimize their impacts to these resources. GIS and landscape analysis are helpful for considering the environmental and cultural resource implications of a project. Traditional planning and design tools such as plan, and cross-section analyses can also be helpful.
- **Aesthetics and Community Enhancement** – Aside from impacts to nearby resources, transportation projects are an important aesthetic element within their context. Well-designed facilities can complement their surroundings while poorly-designed projects can be a detriment to the visual experience of users and facility neighbors. Some community enhancement projects are proposed specifically to improve the aesthetics of a facility within a community. Visualization techniques including three-dimensional modeling and landscape analysis are helpful for considering the aesthetic implications of a project. Traditional planning and design tools such as plan, and cross-section analyses can also be helpful.
- **Economic Development** – Economic development is often an important consideration in project planning and design. Some projects are proposed specifically to spur economic development. In other cases, there is concern around the development implications of a project, such as sprawl. Economic impact and land use analyses can help in the evaluation of the economic development potential and land use implications of projects.
- **Environmental Justice** – Projects can serve or impact individual communities and demographic groups disproportionately. Demographic analyses based on race, income, and other factors can be helpful to understand and address these differential impacts. A project should provide a choice of modes based on the economic conditions and typical incomes of specific communities.
- **Impact Mitigation** – Some projects are proposed specifically to address environmental or community impacts of existing transportation facilities. For example, noise walls are often proposed to shield sensitive land uses from highway noise. Many of

the planning and visualization techniques described above are available to assess the effectiveness of these project elements. Additionally, environmental monitoring and modeling techniques for noise, vibration, and air quality can be helpful.

- **Accessibility** – The federal Americans with Disabilities Act requires that public entities such as the Commonwealth and municipalities provide accessible sidewalks and curb cut ramps. Access features are an important part of any MassHighway project that includes pedestrian facilities.

3.6 Speed

Speed is an important factor considered by travelers in selecting a transportation mode or route. Speed can also influence the physical characteristics of the transportation infrastructure. Many design elements such as horizontal and vertical curvature and superelevation are directly related to speed. Other features, such as lane and shoulder width, and the width of the roadside recovery clear zones for errant vehicles, can vary with, but are not a direct function of the design speed.

The objective in the planning and design of a roadway is to determine a speed that is appropriate for the context (as described in Section 3.2), results in a safe facility for all users, is consistent with the community's goals and objectives for the facility, and meets user's expectations. Once an appropriate speed is selected, the designer needs to tailor design elements to that speed.

Speed is defined as the distance traveled by an object in a certain period of time. Speed is commonly expressed in miles-per-hour or feet-per-second in the context of transportation planning and design. Several measures and characteristics of speed are important to understand when designing a roadway, as described in the following sections. These measures are most often used to describe motor vehicle operations, although they are also applicable to pedestrian and bicycle movement.

3.6.1 Speed Limits

Speed limits in Massachusetts are determined in accordance with Section 17 and Section 18 of Chapter 90 of the Massachusetts General Laws. Speed limits are established in one of two ways:

- Section 18 addresses how ***posted speed limits*** are established. The posted speed limit is generally determined based on an evaluation of the observed operating speeds according to the criteria in the *Manual on Uniform Traffic Control Devices*. (The current accepted practice is to establish the posted speed based on existing speed information. The posted speed should be the speed at which the majority of existing motorists are traveling at or below.)

- Section 17 defines ***"reasonable and proper" speed limits*** for roadways not otherwise posted. For these roadways, the speed limit is as follows:

    - 50 mph on a divided highway outside of a thickly settled district or a business district;
    - 40 mph on any other roadway outside of a thickly settled district or a business district; and
    - 30 mph within a thickly settled district or a business district.

According to Chapter 90 of the Massachusetts General Laws, a "thickly settled district" is an area in which houses or buildings are, on average, less than 200 feet apart for a distance of one-quarter mile or more.

3.6.2 Motor Vehicle Running Speed

Running speed characterizes the time necessary to travel a predetermined distance along a roadway (incorporating both time while moving and stopped delays). Measures of running speed can vary substantially by day of week and time of day based on traffic conditions. Average running speed is usually used to characterize conditions on a roadway for analytical (planning, route selection, air quality analyses, etc.) purposes rather than for the design of roadway geometrics.

3.6.3 Motor Vehicle Operating Speed

Operating speed is the measured speed at which drivers are observed operating their vehicles in fair weather during off-peak hours. Operating speed is measured at discrete points along a roadway. Operating speeds are usually reported using percentile speeds with the 50^{th} percentile (average) and 85th percentile (the speed at which 85 percent of vehicles are traveling at or below) speeds are often used to characterize the operating speed on a roadway.

The roadway's features such as curves and topography, width, access to adjacent properties, presence of pedestrians and bicyclists, parking, traffic control devices, lighting, etc., affect the operating speed. During peak periods, when traffic congestion or intersection operations are controlling movement along a corridor, observed operating speeds may be substantially lower than the operating speed measured during off-peak conditions when the roadway's design and context are controlling speed. Numerous studies have indicated that drivers will not significantly alter what they consider to be a safe operating speed, regardless of the posted speed limit unless there is constant heavy enforcement.

3.6.4 Target Speed for Motor Vehicles

The ***target speed*** is the desired operating speed along a roadway. The appropriate target speed is determined early in the project development process, and should consider:

- The context of the roadway including area type, roadway type, and access control;
- The volume, mix, and safety of facility users; and
- The anticipated driver characteristics and familiarity with the route.

The designer should balance the benefits of high speeds for long-distance, regional motor vehicle travel with environmental, community, right of way, and cost constraints. When high speeds are selected, the designer should also include design elements to maintain the safety of pedestrians and bicyclists, as described in Section 3.6.7.

3.6.5 Selecting Motor Vehicles Design Speed

Design speed is the selected speed used to determine various geometric features of the roadway. The design speed should be a logical one with respect to the target speed and existing operating speed. When selecting a design speed, understanding the existing operating speed and target speed addresses: (1) the need to meet the expectations of drivers based on the roadway environment, and (2) the ways in which the setting influences the desired speed.

It is important to understand the inter-relationship between speed and roadway geometry. Selection of a design speed influences the physical geometrics of the roadway. Similarly, the physical geometrics of the roadway are important determinants of the operating speeds that will result on the facility.

Typically, the higher the functional classification, the higher the design speed. Exhibit 3-7 provides recommended ranges of values; however, where significant constraints are encountered, other appropriate values may be employed. The relatively wide range of design speeds recognizes the range of roadway types, context, and topography. The provision of a range in design speeds, combined with general guidance on selection of a design speed as noted above, represents perhaps the greatest flexibility afforded the designer. Designers should exercise judgment in the selection of an appropriate design speed for the particular circumstances and conditions. In general, an appropriate design speed should be within approximately 5 mph of travel speeds.

When determining the appropriate design speed the designer should also consider the volumes and composition of the expected non-vehicular and vehicular traffic, the anticipated driver characteristics, and driver familiarity with the route. The designer should consider expected operations throughout the day, including both peak and non-peak hours. Indeed, non-peak traffic flow will generally control the selection of a reasonable design speed. The design speed may vary for any given route as it traverses rural, suburban, and urban areas.

Once these factors have been evaluated and an appropriate design speed determined, the geometric elements should be designed consistently to that level. The designer should document the factors leading to the selection of an appropriate design speed. This documentation is particularly important for selected design speeds below the existing posted speed limit, below the "reasonable and proper" speed for the type of roadway and area as discussed in Section 3.6.1, or below the measured operating speed. Where it is not possible to meet the selected design speed for one location or design element along a corridor, a design exception and appropriate warning signage may be justified, as discussed later in this section.

Exhibit 3-7
Design Speed Ranges (Miles per Hour)

	Roadway Type					
		Arterials		Collectors		Local
Area Type	Freeway	Major*	Minor	Major	Minor	Roads
Rural Natural	50 to 75	40 to 60*	35 to 60	30 to 60	30 to 55	20 to 45
Rural Developed	50 to 75	40 to 60*	35 to 60	30 to 60	30 to 55	20 to 45
Rural Village	N/A	30 to 45	30 to 40	25 to 40	25 to 35	20 to 35
Suburban Low Intensity Development	50 to 75	30 to 60*	30 to 55	30 to 55	30 to 55	20 to 45
Suburban High Intensity Development	50 to 75	30 to 50*	30 to 50	25 to 50	25 to 40	20 to 40
Suburban Town Center	N/A	25 to 40	25 to 40	25 to 40	25 to 35	20 to 35
Urban	50 to 75	25 to 50	25 to 40	25 to 40	25 to 35	20 to 35

N/A Not Applicable
* A higher design speed may be appropriate for arterials with full access control
Source: Adapted from A Policy on Geometric Design of Highways and Streets, AASHTO, 2004 – Chapter 3 Elements of Design

Higher design speeds impose greater challenges and constraints on designers. Designers faced with difficult or constrained conditions may consider selecting a lower design speed for an element or portion of the highway. This practice can cause problems in that a large number of drivers may not “behave” as the designer desires or intends them to. Designs based on artificially low speeds can result in inappropriate geometric features that violate driver expectations and degrade the safety of the highway. The emphasis should be on the consistency of design so as not to surprise the motorist with unexpected features. Therefore, the design speed should only be based on the speed limit if the speed limit is consistent with existing operating speeds or physical constraints of the built environment.

Designers should not propose an alternative design speed for a highway or segment of a project as a design exception. A serious fundamental problem with accepting or allowing a design exception for design speed is based on its importance relative to all features of the highway. A reduction in the design speed may be unlikely to affect overall operating speeds. It will potentially result in the unnecessary reduction of all of the speed-related design criteria rather than just the one or two features that led to the need for the exception. The acceptable alternative approach to a design speed exception is to evaluate each geometric feature individually, addressing exceptions for each feature within the context of the appropriate design speed.

Occasionally, projects retain geometric elements, such as tight curves, superelevation, or restricted sight distances that are designed for a speed lower than the design speed for the corridor. This may be due to adjacent land use, or to environmental or historic constraints. In these cases, the designer should recommend a posted speed consistent with the geometric features. Where it is desirable to maintain a higher consistent speed throughout a corridor, the designer should install appropriate cautionary signing at locations with design elements that do not meet the criteria for the posted speed.

3.6.6 Design Speed and Traffic Calming

The term traffic-calming refers to a variety of physical measures to reduce vehicular speeds primarily in residential neighborhoods. The lowering of operating speeds is often the appropriate solution to addressing safety problems. Such problems typically involve vehicle conflicts with pedestrians, bicyclists, and school children.

Research has shown that measurable reductions in operating speeds are possible through traffic-calming. A local road or street, and in some instances other roadways that function as a local road or street, may have an existing operating speed far in excess of the speed limit or the target speed. In these cases it may be acceptable, and consistent with good engineering practice, to develop a design that will lower the operating speed.

Generally, the design speed selected for traffic calming elements should be consistent with the target speed for the corridor as a whole. The traffic calming elements should not result in operating speeds substantially lower than the target speed at certain points along the corridor and higher speeds elsewhere. Selection of a reasonable design speed for traffic calming elements, selection of type of elements, and the spacing of traffic calming elements can help achieve the desired uniform reduction in operating speed along a roadway.

Great care must be exercised to ensure that the proposed design will actually reduce the operating speeds to levels consistent with the design. The burden is on the individual designer of a traffic-calming feature to document a reasonable expectation that the proposed measures will reduce the operating speed. Once traffic calming has been implemented, monitoring of the performance of the project should be undertaken to assure that speeds have indeed been reduced, and to provide valuable lessons for future traffic-calming projects. Chapter 16 provides more detail on tools and techniques for traffic calming.

3.6.7 High Speeds and Safety for Pedestrian and Bicyclists

In every case, the designer should seek to maintain or improve safety for all user groups. Safety is often measured both in terms of the likelihood of a crash and the expected severity of a crash. As motor vehicle speeds increase, the severity of crashes between motor vehicles and bicycles or pedestrians increases. In the high speed environment, safety for pedestrians and bicyclists can be enhanced by reducing the exposure of bicyclists and pedestrians to motor vehicle traffic, thereby reducing the likelihood of crashes.

Along roadway segments, greater separation of motor vehicle and non-motorized users can be provided by including shoulders, bicycle lanes, or buffered sidewalks. These design elements are explored in more detail in Chapter 5. At crossings, the exposure of bicyclists and pedestrians to high speed motor vehicle traffic can be mitigated through signal-controlled crossings, grade separation, and installation of crossing islands or medians. These measures are explored in Chapters 6 and 16.

3.6.8 Selecting Bicycle Design Speed

Bicycle design speed is also an important consideration. In most cases, the design speed for bicycles is no more than 20 mph; thus, for on-road travel, the design speed chosen for motor vehicles appropriately accommodates bicycles. Shared use paths should be designed for a selected speed that is at least as high as the preferred speed of the faster bicyclists. Current practice suggests a design speed of 20 mph for bicyclists. (Although bicyclists can travel faster than this, to do so would be inappropriate for this type of shared use setting.) Design and traffic controls can be used to deter excessive speed and encourage faster bicyclists to use the roadway system; however, lower design speeds should not be selected to artificially lower user speeds. When a downgrade exceeds four percent, or where strong prevailing tailwinds exist, a design speed of 30 mph is advisable. Downgrades in excess of six percent should be avoided on shared use paths.

On unpaved paths, where bicyclists tend to ride more slowly, lower design speeds of 15 mph for most conditions, and 20 mph where there are grades, are appropriate.

3.6.9 Selecting Pedestrian Design Speed

Much like other roadway users, the speed at which people walk varies considerably; however, walking speed usually does not have a substantial influence on the geometric design of roadways. A critical exception to this is the pedestrian's influence on the design of intersections and crosswalks, and the timing of traffic signals. The choice of walking speed for intersections and traffic signal design is discussed in the *Manual on Uniform Traffic Control Devices (MUTCD)* and is further discussed in Chapter 6.

3.7 Sight Distance

Sight distance is the length of roadway ahead that is visible to the roadway user. In most cases, specific sight distance measures apply to motor vehicles and bicyclists. The four following aspects are commonly discussed for motor vehicle sight distance:

- Stopping sight distance,
- Passing sight distance,
- Decision sight distance, and
- Intersection sight distance.

All of these sight distances are related to the design speed of the roadway. The designer should refer to AASHTO's *A Policy on Geometric Design of Highways and Streets* for detailed information for the use and calculation of sight distances.

3.7.1 Stopping Sight Distance

The provision of adequate *stopping sight distance* (SSD) is a critical sight distance consideration for design and is described in more detail below.

3.7.1.1 Motor Vehicle Stopping Sight Distance

Stopping sight distance is the distance necessary for a vehicle traveling at the design speed to stop before reaching a stationary object in its path. The sight distance at every point along a roadway should be at least the stopping sight distance. Exhibit 3-8 provides stopping sight distances for a range of design speeds and grades.

Exhibit 3-8
Motor Vehicle Stopping Sight Distances

	Stopping Sight Distance (ft) by Percent Grade (%)						
		Downgrade			Upgrade		
Design Speed	0	3	6	9	3	6	9
20	115	116	120	126	109	107	104
25	155	158	165	173	147	143	140
30	200	205	215	227	200	184	179
35	250	257	271	287	237	229	222
40	305	315	333	354	289	278	269
45	360	378	400	427	344	331	320
50	425	446	474	507	405	388	375
55	495	520	553	593	469	450	433
60	570	598	638	686	538	515	495
65	645	682	728	785	612	584	561
70	730	771	825	891	690	658	631
75	820	866	927	1003	772	736	704

Source: A Policy on Geometric Design of Streets and Highways, AASHTO, Washington DC, 2004. Chapter 3 Elements of Design

3.7.1.2 Bicycle Stopping Sight Distance

For on-road travel, the stopping sight distance for motor vehicles appropriately accommodates bicycles. However, bicycle stopping sight distance is an important consideration in the design of off-road facilities such as shared use paths. Detailed information on the design of these facilities, including stopping sight distance, is provided in Chapter 11.

3.7.1.3 Sight Distance for Pedestrians

There is not a parallel “stopping sight distance” consideration for pedestrians since they usually travel at lower speeds and can stop within a few feet. However, the designer must consider the importance of pedestrians’ ability to view and react to potential conflicts. The designer should provide adequate sight lines at street crossings, around corners, and at other locations where pedestrians interface with other users. For example, at street crossing locations, pedestrians should be able to see a sufficient portion of the traffic stream to judge the suitability of gaps for crossing the street. More detailed information regarding the design of street crossings is presented in Chapter 6.

3.7.2 Passing Sight Distance

For two-lane highways, passing maneuvers in which faster vehicles move ahead of slower vehicles must be accomplished on lanes regularly used by opposing traffic. If passing is to be accomplished safely, **passing sight distance** is necessary to allow the passing driver to see a sufficient distance ahead, clear of traffic, to complete the passing maneuver without cutting off the passed vehicle and before meeting an opposing vehicle that appears during the maneuver. The AASHTO's *A Policy on Geometric Design of Highways and Streets* includes detailed information for the use and calculation of passing sight distances.

3.7.3 Decision Sight Distance

Decision sight distance adds a dimension of time to stopping sight distance to allow a driver to detect and react to an unexpected condition along a roadway. Decision sight distance is suggested when there is evidence that it would be prudent to provide longer sight distance, such as when complex decisions are needed or when information is difficult to perceive. It is the distance needed for a driver to detect an unexpected or otherwise difficult-to-perceive information source or condition in a roadway environment that may be visually cluttered, recognize the condition or its potential threat, select an appropriate speed and path, and initiate and complete the maneuver safely and efficiently. Exhibit 3-9 provides decision sight distances for a range of design speeds.

Exhibit 3-9
Decision Sight Distances

	Decision Sight Distance (ft)				
	Avoidance Maneuver				
Design Speed	A	B	C	D	E
30	220	490	450	535	620
35	275	590	525	625	720
40	330	690	600	715	825
45	395	800	675	800	930
50	465	910	750	890	1030
55	535	1030	865	980	1135
60	610	1150	990	1125	1280
65	695	1275	1050	1220	1365
70	780	1410	1105	1275	1445
75	875	1545	1180	1365	1545

Avoidance Maneuver A: Stop on rural road: time (t) = 3.0 sec
Avoidance Maneuver B: Stop on urban road: time (t) = 9.1 sec
Avoidance Maneuver C: Speed/path/direction change on rural road: time (t) varies between 10.2 and 11.2 sec
Avoidance Maneuver D: Speed/path/direction change on suburban road: time (t) varies between 12.1 and 12.9 sec
Avoidance Maneuver E: Speed/path/direction change on urban road: t varies between 14.0 and 14.5 sec
Source: *A Policy on Geometric Design of Streets and Highways*, AASHTO, Washington DC, 2004. Chapter 3 Elements of Design

3.7.4 Intersection Sight Distance

Sight distance is provided at intersections to allow drivers to perceive the presence of potentially conflicting vehicles. This should occur in sufficient time for a motorist to stop or adjust their speed, as appropriate, to avoid colliding in the intersection. Sight distance also allows drivers of stopped vehicles with a sufficient view of the intersecting roadway to decide when to enter or cross the intersecting roadway. If the available sight distance for an entering or crossing vehicles is at least equal to the appropriate stopping sight distance for the major road, then drivers have sufficient sight distance to anticipate or avoid collisions. However, in some cases, this may require a major-road vehicle to slow or stop to accommodate the maneuver by a minor-road vehicle.

To enhance traffic operations, intersection sight distances that exceed stopping sight distances are desirable. The *Highway Capacity Manual* provides guidance on gap acceptance for vehicles departing from minor approaches which can be used to calculate one measure of intersection sight distance. Additionally, AASHTO's *A Policy on the Geometric Design of Highways and Streets* provides procedures to determine desirable sight distances at intersections for various cases are described below and include:

- Case A – Intersections with no control on any approach
- Case B – Intersections with stop control on the minor street
- Case C – Intersections with yield control on the minor street
- Case D – Intersections with traffic signal control
- Case E – Intersections with all-way stop sign control
- Case F – Left turns from the major road

3.7.4.1 Intersection Sight Triangle

Clear sight triangles are those areas along the intersection approach legs that should be clear of obstructions that can block road user's view of oncoming traffic. The dimensions of the triangle are based on the design speed of the intersecting roadways and the type of traffic control used at the intersection, grades on the roadways, and the roadway width. Two types of clear sight triangles are used at each intersection: approach sight triangles and departure sight triangles. Approach sight triangles are applicable for when the minor road driver is in motion while departure sight triangles apply when the minor road vehicle is accelerating from a stop position.

3.7.4.2 Identification of Sight Obstructions within Sight Triangles

Within a sight triangle there are many obstructions that can obscure the driver's view of oncoming vehicles. These may include buildings, vegetation, longitudinal barriers or retaining walls, side slopes, etc. The horizontal and vertical alignment of the intersecting roadways and any visual obstructions should be considered. For design purposes, the driver's eye is assumed to be 3.5 feet above the roadway. The object that is used for design approximates the height of an automobile and is assumed to be 3.5 feet above the roadway.

Where the sight distance value used in design is based on a single-unit or combination truck as the design vehicle, it is also appropriate to use the eye height of a truck driver in checking sight obstructions. The recommended value of a truck driver's eye height is 7.6 feet above the roadway surface.

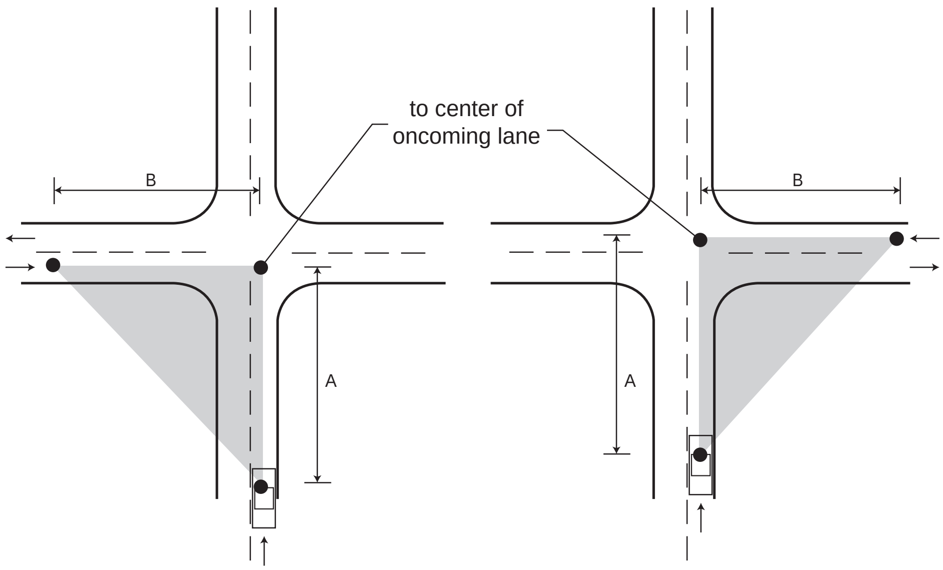
3.7.4.3 Case A - Intersections with No Control on Any Approach

Where intersection movements are not controlled by a traffic control device (i.e., signal, STOP or YIELD sign), drivers approaching the intersection from any direction must be able to see potentially conflicting vehicles in sufficient time to stop before reaching the intersection.

The intersection sight triangle, as illustrated in Exhibit 3-10 is formed by the sight distance along the minor street (indicated as Distance A) and the intersection sight distance along the major street (indicated as Distance B). The corresponding distances, arrayed by design speed are based on the distance traveled as the approaching driver perceives and reacts to the presence of a possibly conflicting vehicle, and brings their own vehicle to a stop. For example, based on the values Exhibit 3-10, an intersection of a major street with a design speed of 40 miles per hour with a minor street with a design speed of 25 miles per hour would require a sight distance defined by an intersection sight distance of 195 feet (major street) and 115 feet (minor street). If the minor street was on a 6 percent grade then the intersection sight distance would be 127 feet (115 feet multiplied by the 1.1 grade adjustment factor) for the downgrade and 104 feet for the upgrade.

Exhibit 3-10
Sight Triangle Case A

Approach Sight Triangles



Sight Triangle Legs: Case A – No Traffic Control

Design Speed (mph)	Length of Legs, both major and minor streets, A and B (feet)
15	70
20	90
25	115
30	140
35	165
40	195
45	220
50	245
55	285
60	325
65	365
70	405
75	445

For approach grades greater than 3 percent, apply factors below.

Approach Grade Adjustments to Sight Distance

Design Speed (mph)	Approach Grade						
	-6	-5	-4	-3 to +3	+4	+5	+6
15-20	1.1	1.0	1.0	1.0	1.0	1.0	1.0
25-30	1.1	1.1	1.0	1.0	1.0	1.0	0.9
30-40	1.1	1.1	1.1	1.0	1.0	0.9	0.9
40-45	1.1	1.1	1.1	1.0	0.9	0.9	0.9
50+	1.2	1.1	1.1	1.0	0.9	0.9	0.9

Source: A Policy on Geometric Design of Streets and Highways, AASHTO, Washington DC, 2004. Chapter 3 Elements of Design

3.7.4.4 Case B – Stop Control on Minor Street

At an intersection with stop control on the minor street, as illustrated in Exhibit 3-11, the stopped minor-street driver must be able to see motor vehicles and bicycles approaching on the major street from either direction, at sufficient distance to allow crossing or turning maneuvers from the minor street. The leg of the intersection sight triangle on the minor street (Dimension A) is the distance between the driver's eye and front of vehicle (8 feet) plus distance from front of vehicle to edge of pavement (6.5 feet, prefer 10 feet) plus the distance from edge of pavement to middle of lane of interest (e.g., 6 feet for a right turn, 18 feet for a left turn on an undivided 2-lane highway, etc.) The major street leg of the triangle is the intersection sight distance along the major road (Dimension B).

Left Turns from Stop Controlled Minor Street

For motor vehicles making a left turn, the intersection sight distance along the major street (Dimension B) is given for an intersection of 2-lane streets in Exhibit 3-11. For example, at a design speed of 35 miles per hour on the major street, and with the minor street driver's eye at 14.5 feet from the edge of the major street travel lane, the intersection sight distance (Dimension B) is 390 feet. It is recommended that this intersection sight distance (Dimension B) be applied along the major street in both directions from the intersection.

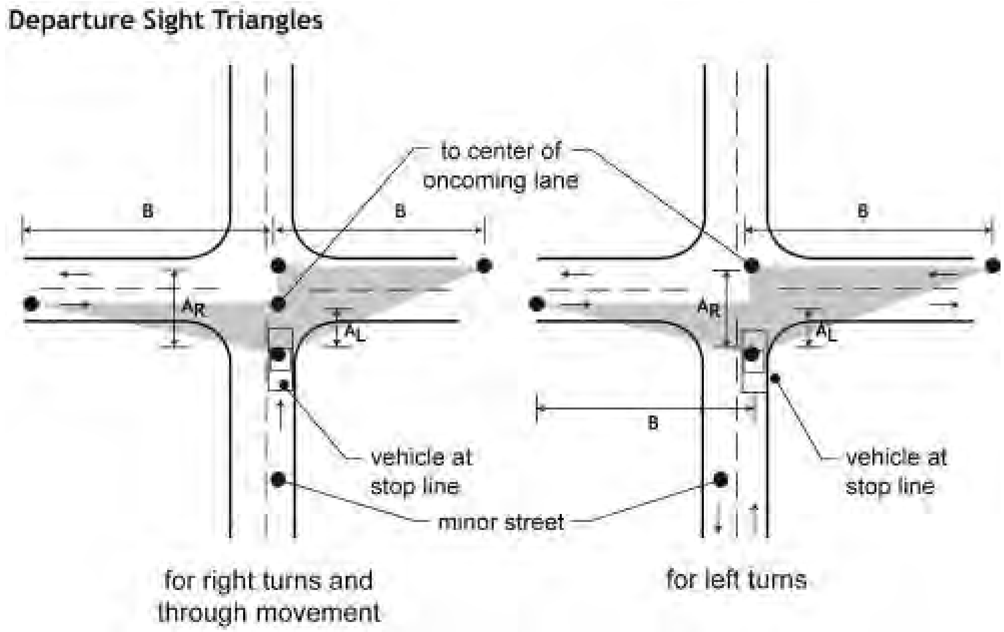
Right Turns from Stop Controlled Minor Street

For motor vehicles making a right turn from the minor street, the intersection sight distances are given in Exhibit 3-11.

Through Movement from Stop Controlled Minor Street

For motor vehicles crossing the major street from a stop-controlled minor street, the intersection sight distances are given in Exhibit 3-11.

Exhibit 3-11
Sight Triangle Case B



Sight Triangle Legs: Case B – Stop Control on Cross Street

Major Street Design Speed (mph)	Length of Sight Triangle Legs (feet)			
	Minor Street for Vehicles Approaching From Right (A_R, feet)	Minor Street for Vehicles Approaching From Left (A_L, feet)	Major Street For Left Turns (B, feet)	Major Street for Right Turns or Through (B, feet)
15	32.5	20.5	170	145
20	32.5	20.5	225	195
25	32.5	20.5	280	240
30	32.5	20.5	335	290
35	32.5	20.5	390	335
40	32.5	20.5	445	385
45	32.5	20.5	500	430
50	32.5	20.5	555	480
55	32.5	20.5	610	530
60	32.5	20.5	665	575
65	32.5	20.5	720	625
70	32.5	20.5	775	670
75	32.5	20.5	830	720

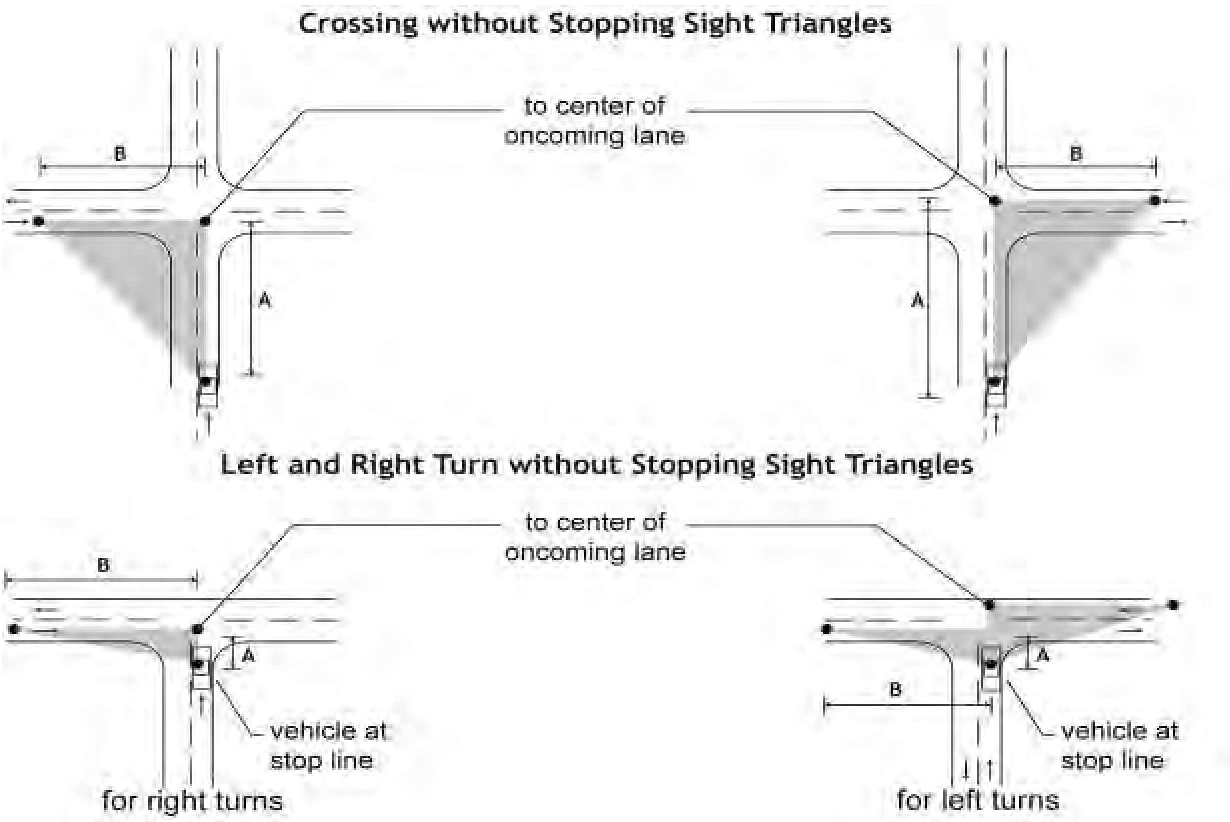
Sight triangle legs shown are for passenger car crossing or turning into a two-lane street, with grades (all approaches) 3 percent or less. For other grades and for other major street widths, recalculate using AASHTO *Green Book* formulas.

Source: *A Policy on Geometric Design of Streets and Highways*, AASHTO, Washington DC, 2004. Chapter 3 Elements of Design

3.7.4.5 Case C - Yield Control

At intersections with yield control on the minor street, the minor street driver are permitted to enter or cross the major road without stopping, if there are no potentially conflicting vehicles. Yield-controlled approaches generally need greater sight distance than stop-controlled approaches. For four-leg intersections with yield control on the minor road, two separate pairs of approach sight triangles should be provided – one set to accommodate crossing the major road and the other to accommodate left and right turns. Both sets of sight triangles should be checked for potential sight obstructions. For three-leg intersections with yield control on the minor road, only the sight triangles to accommodate left and right turns need to be checked. The major and minor street legs of the sight triangle are shown in Exhibit 3-12.

Exhibit 3-12
Sight Triangle Case C



Sight Triangle, Case C: Yield Control on Cross Street

	Crossing Without Stopping Sight Triangle Legs[a] (feet)		Left and Right Turn Without Stopping Sight Triangle Legs[a] (feet)	
Design Speed (Major Street, mph)	Minor Street (A, feet)	Major Street[b] (B, feet)	Minor Street (A, feet)	Major Street (B, feet)
15	75	145	82	180
20	100	195	82	240
25	130	240	82	295
30	160	290	82	355
35	195	335	82	415
40	235	385	82	475
45	275	430	82	530
50	320	480	82	590
55	370	530	82	650
60	420	575	82	710
65	470	625	82	765
70	530	670	82	825
75	590	720	82	885

a Sight triangle legs shown are for passenger car crossing or turning into a two-lane street, with grades (all approaches) 3 percent or less. For other grades and major street widths, recalculate length of legs from AASHTO *Green Book* formulas.

b Lengths are for design speeds of 20 to 50 mph on minor road. For other minor road design speeds, recalculate length of legs from AASHTO *Green Book* formulas.

Source: A Policy on Geometric Design of Streets and Highways, AASHTO, Washington DC, 2004. Chapter 3 Elements of Design

Case C – Yield Control at Roundabouts

At roundabouts, the location needing evaluation of intersection sight distance is at the entries. The entry sight distance evaluation uses two conflicting approaches: entering stream (i.e., those vehicles entering from the immediate upstream entry) and circulating stream (i.e., those vehicles on the circular roadway). The length of the conflicting leg is shown in Exhibit 3-13 for a range of conflicting approach speeds. The sight distance legs for roundabouts follow the curvature of the roadway, therefore distances should be measured not as straight lines but as distances along the vehicular path. The FHWA *Roundabout Guide* recommends limiting the length of the approach leg of the sight triangle to 49 feet.

Exhibit 3-13
Roundabout Intersection Sight Distance: Computed Length of Conflicting Leg

Conflicting Approach Speed (mph)	Computed Distance (ft)
10	95.4
15	143.0
20	190.1
25	238.6
30	286.3

Source: Roundabouts: An Informational Guide, FHWA, Washington DC, 2000.

3.7.4.6 Case D - Intersections with Traffic Signal Control

At signalized intersections, the first vehicle stopped on one approach should be visible to the driver of the first vehicle stopped on each of the other approaches. Where right turns on red are permitted, the sight distance triangle for a right turn from stop applies (Case B). Left-turning motor vehicles and bicycles should have sufficient sight distance, into the opposing roadway, to be able to select gaps sufficient to make their left-turn movement (Case B). Where this distance is insufficient, most likely due to vertical or horizontal curvature, the remedies can include confining the left turn to a protected signal phase, or prohibiting the left turn.

3.7.4.7 Case E - Intersections with All-Way Stop Control

At intersections with all-way stop control, the first stopped vehicle on one approach should be visible to the drivers of the first stopped vehicles on each of the other approaches. For this reason, all-way stop control may be a preferable option at intersections where, due to topographic or man-made constraints, sight distances for other types of control cannot be obtained.

3.7.4.8 Case F - Left Turns from the Major Road

Drivers turning left across oncoming traffic of a major roadway require sufficient sight distance to determine when there is time to complete the maneuver. If stopping sight distance has been provided continuously along the major road and if sight distance for Case B (stop control) or Case C (yield control) has been provided for each minor-road approach, sight distance will generally be adequate for left turns from the major roads. Therefore, no separate check of sight distance for Case F may be needed. However, at three-leg intersections or driveways located on or near a horizontal curve or crest vertical curve on the major road, the availability of adequate sight distance for left turns from the major road should be checked. In addition, the availability of sight distance from divided highways should be checked because of the possibility of sight obstructions in the median. Intersection sight distances for Case F is listed in Exhibit 3-14.

Exhibit 3-14
Case F Intersection Sight Distance

Design Speed (mph)	Sight Triangle Leg (feet)
15	125
20	165
25	205
30	245
35	285
40	325
45	365
50	405
55	445
60	490
65	530
70	570
75	610
80	650

Intersection sight distances shown are for passenger car making a left turn from an undivided highway. For other conditions and design vehicles, recalculate length of legs using AASHTO *Green Book* formulas.

Source: *A Policy on Geometric Design of Streets and Hi*ghways, AASHTO, Washington DC, 2004. Chapter 3 Elements of Design

3.8 For Further Information:

- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004.
- *Guide for the Development of Bicycle Facilities*, AASHTO, 1999.
- *Guide for the Planning and Design of Pedestrian Facilities,* AASHTO, 2004
- *A Guide to Achieving Flexibility in Highway Design*, AASHTO, 2004.
- *Highway Capacity Manual*, Transportation Research Board, 2000.
- *Manual on Uniform Traffic Control Devices*, Federal Highway Administration, 2003.
- *Real-Time Human Perceptions: Toward a Bicycle Level of Service,* Landis, Bruce, Transportation Research Record 1578, Washington DC, Transportation Research Board, 1997.
- *Development of the Bicycle Compatibility Index: A Level of Service Concept, Final Report,* FHWA-RD-98-072, 1998.
- *Development of the Bicycle Compatibility Index: A Level of Service Concept, Implementation Manual,* FHWA-RD-98-095, 1998.
- *Transit Capacity and Quality of Service Manual*, Transportation Research Board, Transit Cooperative Research Program. Report 100, 2nd Edition, 2003.
- *TRB Special Report 254 Managing Speed: Review of Current Practices for Setting and Enforcing Speed Limits*, Transportation Research Board, Washington DC, 1998.
- *Flexibility in Highway Design*, Federal Highway Administration, Washington, DC.
- *A Guide to Best Practices in Context Sensitive Solutions*, Transportation Research Board, National Cooperative Highway Research Program. Report 480. Washington DC, 2002.
- *ADAAG Manual: A Guide to the Americans with Disabilities Act Accessibility Guidelines,* The U.S. Architectural and Transportation Barriers Compliance Board (The Access Board). Washington, DC, 1998.
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Chapter 4
Horizontal and Vertical Alignment

Horizontal and Vertical Alignment

4.1 Introduction

This chapter discusses design considerations and criteria for incorporating horizontal and vertical curves in a roadway's alignment. All types of roadways are discussed in this chapter - ranging from local low-speed facilities to median divided highways. A horizontal curve in a roadway refers to the alignment, or how "straight" the roadway section is. A vertical curve refers to a roadway's change in elevation, or the "flatness" of the roadway.

As described in Chapter 3, the operating characteristics of drivers and motor vehicles place the greatest constraints on curvature. In most cases, application of the design controls for motor vehicles satisfies the design controls for bicycles and pedestrians, including those with disabilities . This means that the criteria for vehicles are more restrictive than the criteria for pedestrians and bicyclists – thus incorporating a bend or a grade in a roadway segment that satisfies the design criteria for a motor vehicle will also likely satisfy to design criteria for pedestrians and bicyclists. The goal of the designer in the layout of a roadway is to convey users between their point of origin and their point of destination along a path in a safe and efficient manner that is compatible with the environment and the users' operational characteristics.

Roadways must respect the existing and developed environment through which they pass while balancing the needs for safety and cost-effectiveness. As a result, roadways are not always flat and straight – they possess vertical and horizontal curves in their alignments to circumvent or be compatible with existing constraints. Alignment constraints typically include topographical variation, natural resource areas, property ownership, land use, cost, and environment. Introduction of curvilinear alignments is necessary when the designer encounters these constraints.

Good alignment design is critical in the effort to balance the needs and safety of the road user with the value of preserving the integrity of the environment.

When an improvement is being pursued as a footprint road project, and the roadway operates safely, the designer may elect to retain existing alignment features.

The designer must use engineering judgment applied to a variety of factors to develop effective and efficient geometry in three dimensions. These factors include:

Horizontal Curves

- compatibility between existing and proposed conditions (controls)
- topographical/terrain variations
- vehicle characteristics
- driver limitations
- design speed
- lines of sight
- roadway cross section
- radius of curve
- superelevation (or banking)
- length of curve
- tangent-to-curve transition
- profile
- drainage considerations
- cost

Vertical Curves

- compatibility with existing grades and elevations on adjacent land and approaching roads and driveways/entrances adjacent to the new alignment
- design speed
- sight distance
- vertical clearances
- lengths of grade

- entrance considerations associated with acceleration and deceleration
- horizontal alignment
- drainage considerations
- costs

When using a combination of horizontal and vertical curves, it is important to consider the effects of the combination of both. It may be necessary to use more gradual change in each to meet sight distance, acceleration, and other needs safely, as described in Section 4.4

The process of incorporating horizontal and vertical elements into a roadway's design begins with the identification of the proposed corridor and location of critical constraints that must be considered for preservation throughout the design process. The critical constraints that drive the design process include, but are not limited to:

- project limits
- private property
- pedestrian functions
- accessibility for people with disabilities
- significant cultural (historical/archaeological) areas and features
- regulated wetlands
- natural drainage courses
- endangered species habitat
- intersecting roads and driveways
- underground and overhead utilities
- rail facilities

A balanced design will identify these constraints early in the process and align the vertical and horizontal position of the road to protect, preserve, or meet the requirements of each to the extent practicable.

4.2 Horizontal Alignment

Horizontal alignment, combined with vertical alignment, serves as the primary controlling element associated with the design of all types of public streets and highways. Engineering judgment and experience plays a major role in selecting horizontal geometry that meets desired design criteria. There are a variety of factors that are important in the selection of a horizontal curve or series of curves. In general, the designer should take into account the following considerations:

- Existing environmental and other constraints should be identified on the base mapping to assist the designer in minimizing impacts to wetlands, historical and archaeological features, private and protected property, and permanent structures. To the extent possible, these constraints should serve as boundaries through which the designer must fit the geometry.
- The relationship of the roadway to wetlands and waterways and the interaction of different types of roadway drainage with these resources should be considered.
- For improvements to existing roadways, geometry should be concentric with and/or parallel to the existing roadway layout so that new impacts to the surrounding area are minimized.
- Horizontal alignment should be as smooth and as direct as possible while responsive to the topography. Flatter curvature with shorter tangents is generally preferable to sharp curves connected by long tangents. Angle points should be avoided.
- Curves with small deflection angles (5 degrees or less) should be long enough to avoid the appearance of a kink. Curves should be 500 feet long for a central angle of 5 degrees and increased 100 feet for each degree decrease in central angle.

  The minimum length of horizontal curves (Lc) should be:

  - Lc desirable = 30V (high speed controlled-access facilities)
  - Lc minimum = 15V (other arterials)

  (Where V = design speed in miles per hour)

- Broken back curvature (a short tangent between two curves in same direction) should be avoided because drivers do not expect to encounter this arrangement on typical highway geometry.

- Abrupt reversals in alignment and sharp curvature on long, high fills should be avoided.

- If compound circular curves are required in an effort to fit the highway to the terrain or to other constraints, large differences in radius should be avoided. The radius of the largest curve should not be more that 1.5 times the radius of the smaller curve (except for highway ramps). On ramps, the ratio of the larger curve to the smaller curve should not exceed 2:1.

- The horizontal alignment should be in balance with the vertical profile and cross section rotation associated with superelevation. This is accomplished through the use of a cross sectional analysis. Under this analysis procedure, the alignment is plotted onto the cross section to the lines and grades dictated by the geometry. Should the impacts on the existing topography, private property, environmental areas, etc. be significant for successive cross sections, then modification to the vertical and horizontal geometry should be considered to minimize the impacts, thereby optimizing a balanced geometric design. See Section 4.4 for more information regarding the combination of the design of horizontal and vertical alignments.

- Horizontal curves should be avoided on bridges whenever possible. These cause design, construction, and operational problems. Where a curve is necessary on a bridge, a simple curve should be used on the bridge and any curvature or superelevation transitions placed on the approaching roadway.

4.2.1 Types of Horizontal Curvature

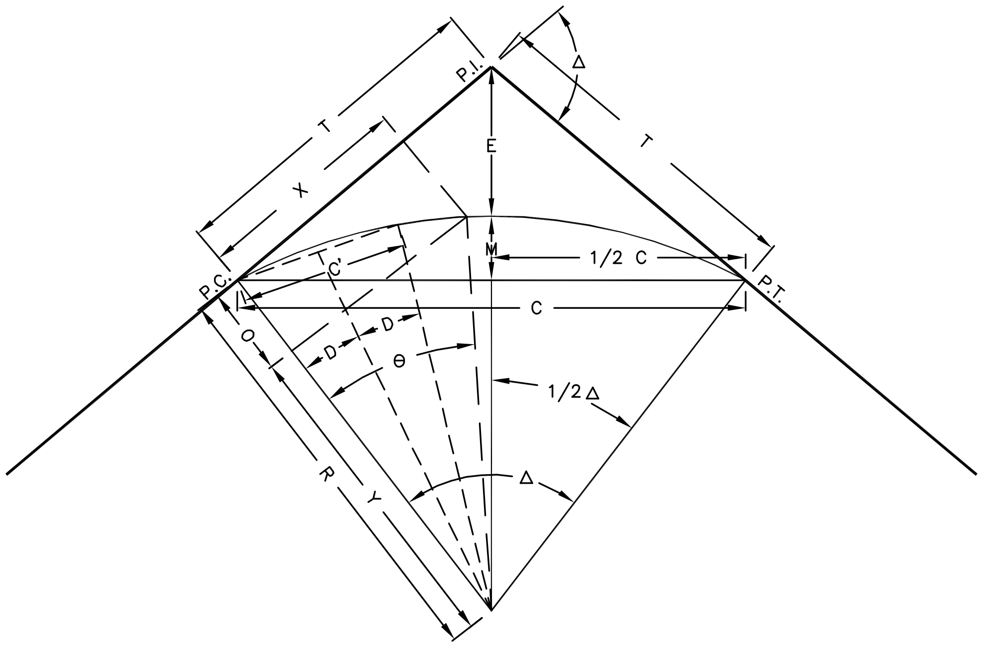
Normally, in the Commonwealth of Massachusetts, simple circular curves are used in design; however, compound or spiral curves may be considered throughout the length of a curve to fit the roadway into a constrained corridor. For circular curves the radius definition is used, with design curves expressed to the nearest 20 feet.

4.2.1.1 Simple Curves

A simple curve has a constant circular radius which achieves the desired deflection without using an entering or exiting transition. This is the most frequently used curve because of their simplicity for design, layout, and construction as shown in Exhibit 4-1.

Exhibit 4-1

Simple Circular Curve



R =	Radius	D =	Deflection Angle for Chord C'
C =	Long Chord	T =	Length of Tangent
C' =	Any Chord Length	O =	Tangent Offset
M =	Middle Ordinate	P.C. =	Point of Curvature
L =	Length of Arc	P.I. =	Point of Intersection
E =	External Distance	P.T. =	Point of Tangency
△ =	Intersection Angle = Central Angle	X =	Distance Along Tangent

FORMULAS

$T = R\tan(\triangle/2)$ $\quad C = 2R\sin(\triangle/2)$ $\quad E = R(\sec(\triangle/2) - 1)$

$M = R(1 - \cos\triangle/2)$ $\quad L = \frac{\triangle}{360}(2\pi R)$ $\quad \sin D = 1/2 \div C'R$

TANGENT OFFSET METHODS

$0 = R - (R^2 - x^2)^{0.5}$

$\sin \Theta = X/R$

$Y = R\cos\Theta$

$0 = R - Y$

Source: MassHighway

Elements of a horizontal curve:

- Δ DELTA (Central Angle). The value of the central angle is equal to the *I* angle. Some authorities call both the intersecting angle and central angle either *I* or A.
- R RADIUS. The radius of the circle of which the curve is an arc, or segment. The radius is always perpendicular to back and forward tangents.
- PI POINT OF INTERSECTION. The point of intersection is the theoretical location where the two tangents meet.
- PT POINT OF TANGENCY. The point of tangency is the point on the forward tangent where the curve ends. It is sometimes designated as EC (end of curve) or CT (curve to tangent).
- PC POINT OF CURVATURE. The point of curvature is the point on the back tangent where the circular curve begins. It is sometimes designated as BC (beginning of curve) or TC (tangent to curve).
- POC POINT ON CURVE. The point on curve is any point along the curve.
- L LENGTH OF CURVE. The length of curve is the distance from the PC to the PT, measured along the curve.
- T TANGENT. The length of tangent is the distance along the tangents from the PI to the PC or the PT. These distances are equal on a simple curve.
- C LONG CHORD. The long chord is the straight-line distance from the PC to the PT. Other types of chords are designated as follows:
- c The subchord distance between the PC and the first station on the curve.
- C’ Any chord distance between two points along a curve.
- E EXTERNAL DISTANCE. The external distance (also called the external secant) is the distance from the PI to the midpoint of the curve. The external distance bisects the interior angle at the PI.

- M MIDDLE ORDINATE. The middle ordinate is the distance from the midpoint of the curve to the midpoint of the long chord. The extension of the middle ordinate bisects the central angle.
- D DEFLECTION ANGLE. The deflection angle for chord C'.

At a minimum, curve data shown on the drawings should include the radius, length of curve, central angle, and tangent length. Plan information should also include the stations at the PC and PT.

4.2.1.2 Reverse Curves

A reverse curve consists of two simple curves joined together, but curving in opposite directions. For safety reasons, the use of this curve should be avoided when possible. As with broken back curves, drivers do not expect to encounter this arrangement on typical highway geometry.

4.2.1.3 Compound Curves

Compound curves are a series of two or more simple curves with deflections in the same direction immediately adjacent to each other. Compound curves are used to transition into and from a simple curve and to avoid some control or obstacle which cannot be relocated. The following guidelines should be followed when using compound curves:

- Compound curves are appropriate for intersection curb radii, interchange ramps, and transitions into sharper curves.
- As the curvature becomes successively sharper, the radius of the flatter circular arc should not be more than 50 percent greater than that of the sharper arc.
- Superelevating compound curves requires careful consideration. This is discussed in Section 4.2.4.
- Exhibits 4-2 and 4-3 illustrate a typical compound curve layout and design for compound curvature transition.

4.2.1.4 Minimum Radius of Horizontal Curvature

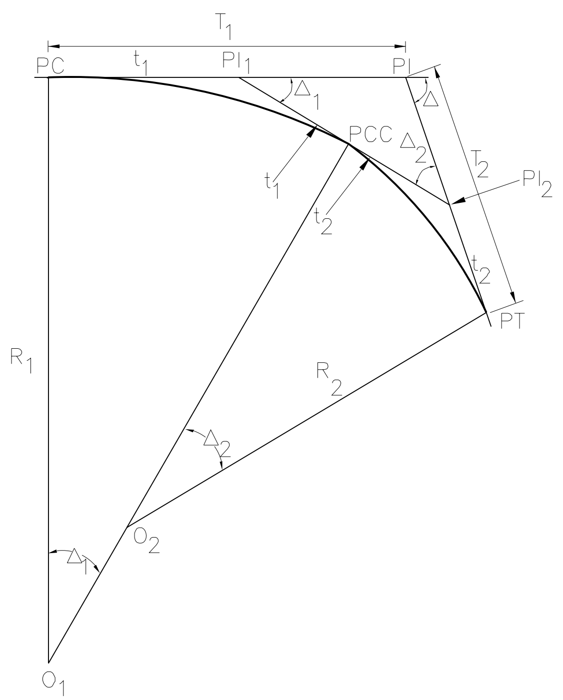
The values for horizontal curvature are derived from the design speed, superelevation rate, and side friction factors. The basic equation is:

$$R_{MIN} = \frac{V^2}{15(0.01e_{MAX}+f_{MAX})}$$

Where: R_{MIN} = minimum radius of curve, feet
e = superelevation rate*
f = side friction factor (see AASHTO Green Book for values)
V = vehicle speed, mph
(Note: e = 6.0% is the maximum rate used in the Commonwealth of Massachusetts)

The design values derived from the equation above are dependent upon selection of superelevation rates as described in Section 4.2.4.

Exhibit 4-2
Compound Curve Layout

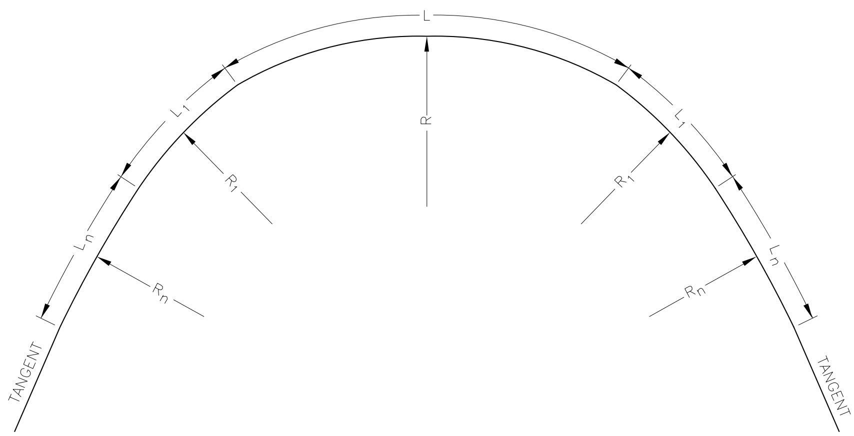


Formulas

$PI - PI_1 = \dfrac{\sin \Delta_2 (t_1 + t_2)}{\sin \Delta}$	$\Delta = \Delta_1 + \Delta_2$
$PI - PI_2 = \dfrac{\sin \Delta_2 (t_1 + t_2)}{\sin \Delta}$	$\Delta_2 = \Delta - \Delta_1$
$T_1 = t_1 + PI - PI_1$	$t_1 = R_1 \tan(\Delta_1/2)$
$T_2 = t_2 + PI - PI_2$	$t_2 = R_2 \tan(\Delta_2/2)$
$L_1 = (\Delta_1 / 360)(2 \pi R_1)$	$C_1 = 2R_1 \sin(\Delta_1/2)$
$L_2 = (\Delta_2 / 360)(2 \pi R_2)$	$C_2 = 2R_2 \sin(\Delta_2/2)$
$M_1 = R_1 (1 - \cos\Delta_1/2)$	$E_1 = R_1 (\sec(\Delta_1/2) - 1)$
$M_2 = R_2 (1 - \cos\Delta_2/2)$	$E_2 = R_2 (\sec(\Delta_2/2) - 1)$

Source: MassHighway

Exhibit 4-3
Compound Curvature Transition



L_n = The greater of:

a) Three seconds running time at the design speed.
b) The length of runoff plus the length of tangent runout, or
c) The length of runoff plus the length required to superelevate to curve R_1.

L_1 = The greater of:

a) Three seconds running time at the design speed.
b) The length to superelevate curve R1 and R.

L = The greater of:

a) Three seconds running time at the design speed.
b) Two times the length required to superelevate to curve R, or
c) A minimum length of 350 ft.

Minimum Allowable Radii without Transition

Design Speed (mph)	50	55	60	70	75
Radius (ft)	3940	4600	6560	6560	8200

Where the horizontal curves are of radii less than “R” shown in table above:

1. Curves R1…R_n are introduced for the purpose of making the transition from the tangent to curve “R”.
2. Curves R1…R_n are compounded with “R”.
3. The radius of curves R1 …R_n is to be no more than 1.5 times the radius of the preceding curve, i.e. , R1 = 1.5R, etc., starting from each end of curve “R”.
4. The curves are increased in radius until “R_n” is at least equal to the values indicated for the respective speeds shown on the table above.
5. Superelevation should be developed as discussed in Section 4.2.3.

Source: MassHighway

4.2.2 Horizontal Stopping Sight Distance

Horizontal sight distance on the inside of a curve is limited by obstructions such as buildings, hedges, wooded areas, walls, abutments, cut slopes, headlights, vertical curvature, or other topographic features. A comprehensive field survey should identify these obstructions on the critical cross sections and on the base plans.

Safe sight distance must be provided on the inside of horizontal curves to allow the driver sufficient brake reaction time to bring the vehicle to a stop. Obstructions which interfere with the needed sight distance should be moved or removed, if possible. If the obstruction can not be removed, consideration should be given to realigning the road (horizontal and/or vertical) or providing appropriate warning signage.

On horizontal curves, a designer must provide a "middle ordinate" between the center of the inside lane and the sight obstruction. The basic equation is:

$$M = R\left[\left(1 - \cos\frac{28.65S}{R}\right)\right]$$

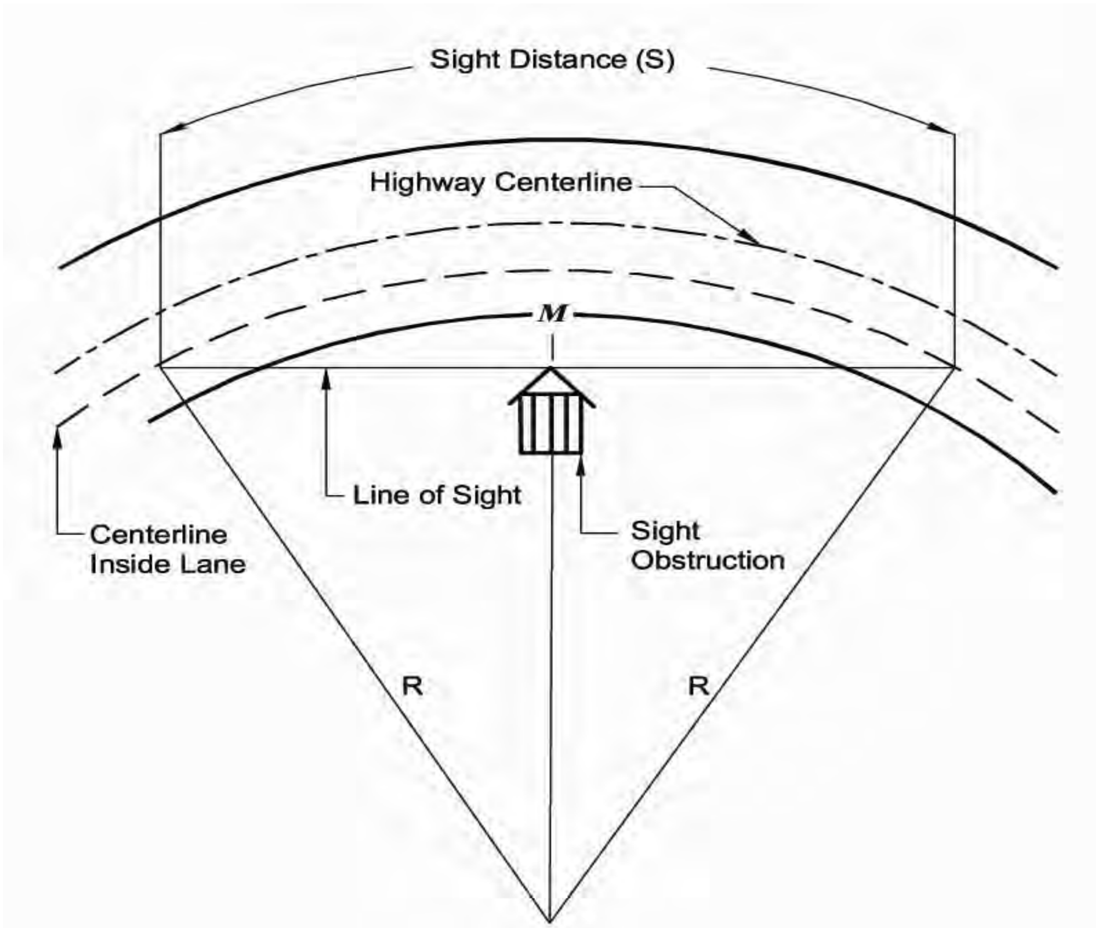
Where: M = middle ordinate, or distance from the center of the inside lane to the obstruction, feet.
R = radius of curve, feet.
S = sight distance, feet.

The designer should use the following:

- Exhibit 4-4 illustrates the concept of a middle ordinate and its impact on sight distance around a curve. Exhibit 4-5 is a design chart showing the horizontal sight line offsets (middle ordinate) needed for clear sight areas that satisfy stopping sight distance criteria presented in Exhibit 3-8 for horizontal curves of various radii. The designer should make every practical effort to achieve the stopping sight distance criterion.

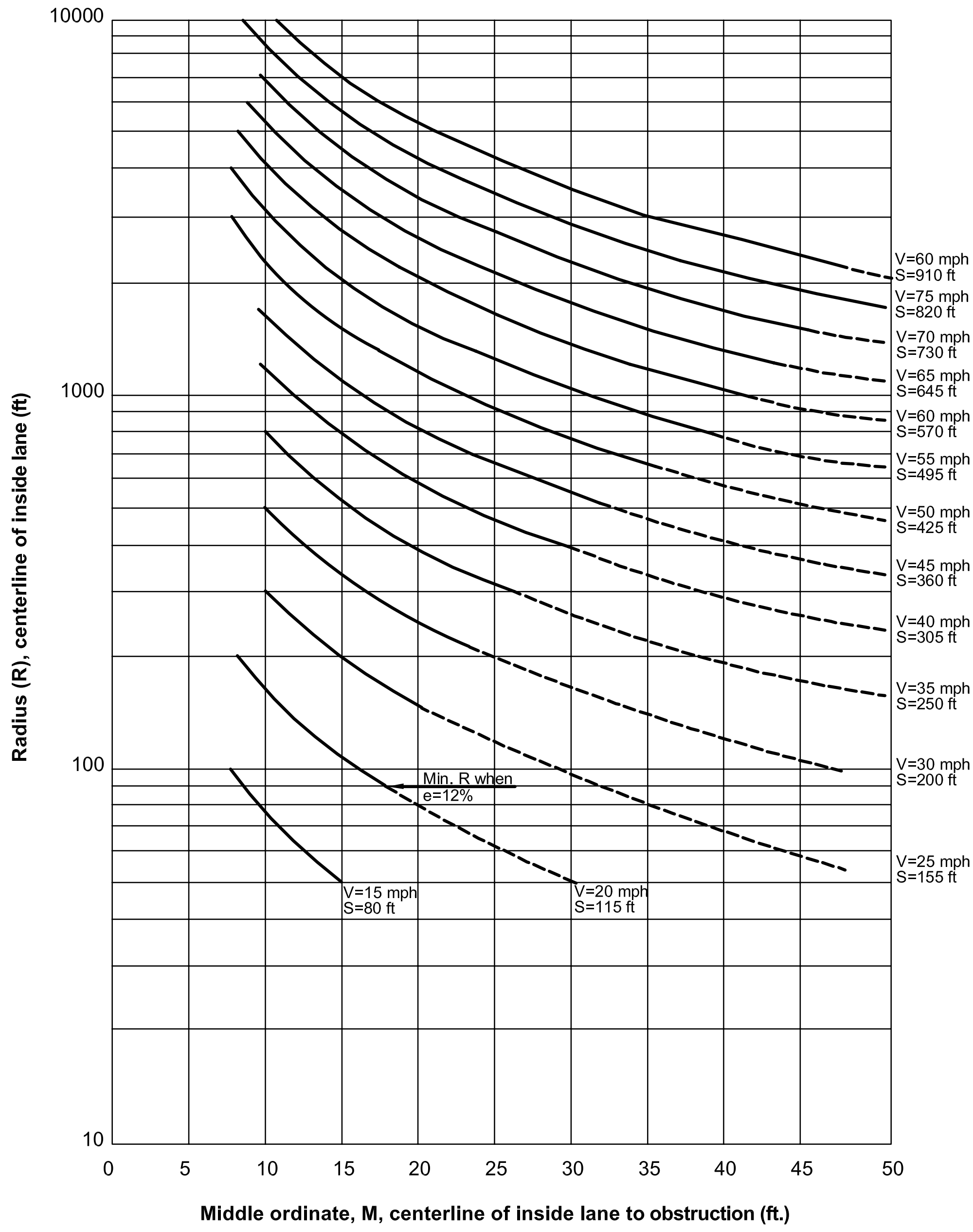
  The stopping sight distance is based on eye height of 3.5 feet and object height of 2 feet. The line-of-sight intercept with the view obstruction is at the midpoint of the sight line and 2.75 feet above the center of the inside lane.

Exhibit 4-4
Sight Distance on a Curve



Source: *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004. Chapter 3 Elements of Design

Exhibit 4-5
Horizontal Stopping Sight Distance Criteria



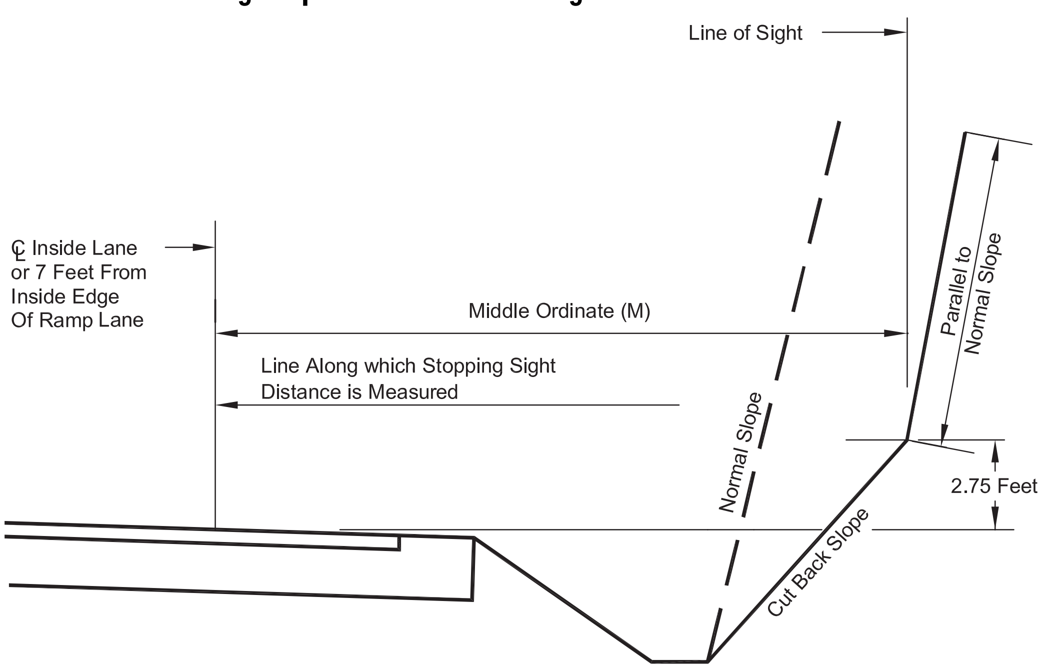
Source: *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004. Chapter 3 Elements of Design

- If a designer concludes that decision sight distance is needed, greater distance will have to be provided. Chapter 3 discusses those highway conditions where decision sight distance is appropriate and provides procedures for determining the distance. The calculated value would then be used in the basic equation for determining the middle ordinate on the horizontal curve. Also, refer to Chapter 3 in AASHTO's *A Policy on Geometric Design of Highways and Streets*, for further information.

- Normally, it is not practical to provide passing sight distance on horizontal curves. These values yield very large numbers for the middle ordinate. In addition, many drivers will not pass on horizontal curves regardless of the available sight distance. Passing should not be allowed where passing sight distance can not be achieved.

Exhibit 4-6 illustrates the method of ensuring adequate sight distance in cut sections.

Exhibit 4-6
Method of Cutting Slope for Horizontal Sight Distance

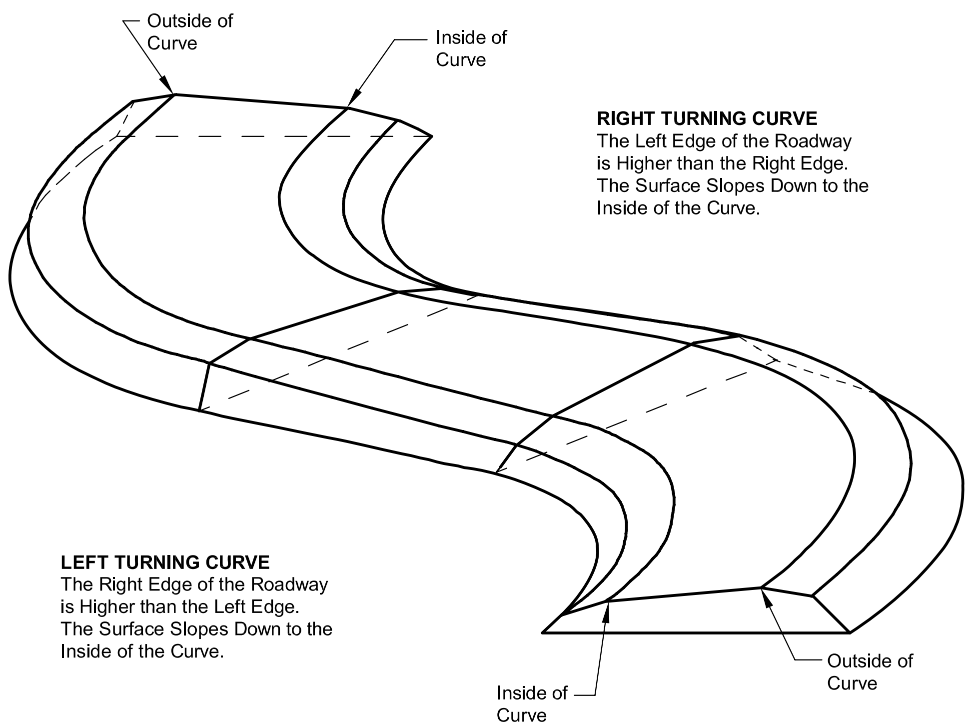


Source: MassHighway

4.2.3 Superelevation

Superelevation is the banking of a roadway around a curve as illustrated in Exhibit 4-7. The purpose of employing superelevation of the roadway cross section is to counterbalance the centrifugal force, or outward pull, of a vehicle traversing a horizontal curve. Side friction developed between the tires and the road surface also counterbalances the outward pull of the vehicle. A combination of these two concepts allows a vehicle to negotiate curves safely at higher speeds than would otherwise be possible.

Exhibit 4-7
Superelevation for Left and Right Turning Curves



Source: MassHighway

Incorporating superelevation into a roadway's design may help avoid roadside obstacles that might otherwise be impacted by the alignment. In contrast, superelevation may not be desirable for low-speed roadways to help limit excessive speeds or in urban settings to limit impacts to abutting uses or drainage systems and utilities. Moreover, superelevation may not be desirable when considering pedestrian or bicycle accommodations along the roadway segment. Like other roadway design elements, designers must consider the trade-offs of introducing superelevation in a roadway's design.

The maximum useable rate for superelevation (e_{max}) is controlled by several factors: climate conditions, terrain conditions, type of area, and the frequency of slow moving vehicles. Because of winter snow and icing conditions, the rate of superelevation should not exceed the rate on which a vehicle standing or traveling slowly would slide toward the center of the curve when the pavement is icy; therefore, the maximum rate of superelevation (e_{max}) used in Massachusetts is 6.0 percent. On roadways with lower design speeds (less than 45mph), designing without superelevation is often acceptable because the outward pull of a vehicle negotiating a curve is lower.

4.2.4 Maximum Superelevation Rates and Minimum Curve Radii

Exhibit 4-8 provides minimum curve radii for common superelevation rates of 4 percent and 6 percent across a range of design speeds. The values in the exhibit are minimum radii possible with rates of superelevation commonly used in undeveloped or lightly-developed areas (Rural Natural, Rural Developed, Rural Village, and Suburban Low Intensity). The designer should provide flatter curves wherever possible. It may be necessary to provide flatter curvature when the minimum radius will not provide the necessary stopping sight distance due to sight line obstructions along the edges of the roadway (See Section 4.2.3).

Although superelevation is advantageous for traffic operation, various factors often combine to make its use impractical in many built-up areas (such as Suburban High Intensity, Suburban Town Centers and Urban Areas). Such factors include wide pavement areas, the need to meet the grade of adjacent property, surface drainage considerations, and frequency of cross streets, alleys, and driveways. Therefore, horizontal curves on low-speed roadways in urban areas may be designed without superelevation, counteracting the centrifugal force solely with side friction. Designing without superelevation is often a suitable design practice for low-speed roadways (less than 45mph). If site specific conditions allow, designers should avoid using a superelevation to the extent possible for design speeds of 35 mph or less and use a normal crown in the roadway cross-section.

Exhibit 4-8
Minimum Design Radii for Common Superelevation Rates
(e = 4 Percent or e = 6 Percent)

Design Speed (mph)	Minimum Design Radius (ft) with e = 4 %	Minimum Design Radius (ft) with e = 6 %
15	45	40
20	90	85
25	155	145
30	250	235
35	375	340
40	535	485
45	715	645
50	930	835
55	1190	1060
60	1500	1330
65	Not Permitted	1660
70	Not Permitted	2040
75	Not Permitted	2500

Note: For design speeds less than 35 mph, designers should avoid using superelevation to the extent possible.
In recognition of safety considerations, use of e_{max} = 4.0% should be limited to developed areas (such as suburban high intensity, suburban town centers, and urban areas).
Radii are rounded to the nearest 5 feet

Source: *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004 Chapter 3 Elements of Design

The minimum radius or sharpest curve without superelevation is reached when the side friction factor developed to counteract centrifugal force and adverse cross slope reaches the maximum allowable value based on safety and comfort considerations. For travel on sharper curves or at higher speeds, superelevation is needed. A maximum superelevation rate of 4.0 percent is commonly used. A maximum superelevation rate of 6.0 percent may be justified on sharper curves where adequate transition lengths are available.

For roadways in areas with design speeds of 45 mph and below, Exhibit 4-9 provides the minimum radii for 2.0 percent, 0 percent, and -2.0 percent (no superelevation) rates of superelevation. The 2.0 percent column represents the situation where the normal pavement crown is replaced with a consistent 2.0 percent cross slope.

Exhibit 4-9
Minimum Radius (ft) with Low or No Superelevation
(e of -2.0 Percent, 0 Percent, and 2.0 Percent)

Design Speed (mph)[1]	Percent Superelevation (e) - 2.0 %	0 %	2.0 %
15[1]	50	50	45
20[1]	110	100	95
25[1]	200	185	170
30[1]	335	300	275
35	510	455	410
40	765	670	595
45	1040	900	795

Note: Radii are rounded up to the nearest 5 feet
1 For design speeds less than 35 mph, designers should avoid using superelevation to the extent possible.
Source: *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004 Chapter 3 Elements of Design

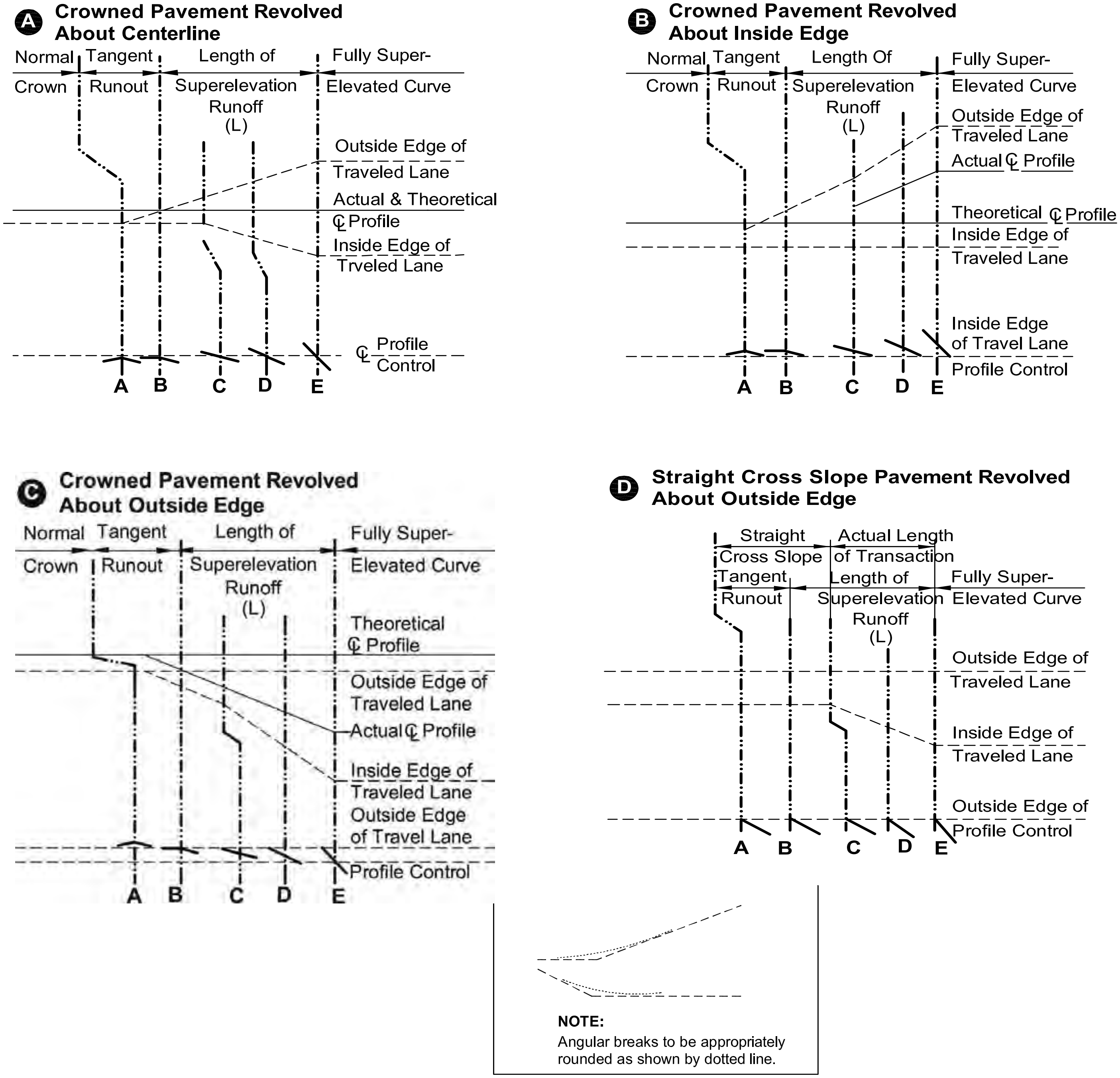
4.2.5 Superelevation Transitioning

The development of superelevation on a horizontal curve requires a transition from a normal crown section, which is accomplished by rotating the pavement. The pavement may be rotated about the centerline or either edge of the travel lanes.

There are five basic cross section controls — (-a-) through (-e-) — involved in transitioning the pavement to obtain full superelevation illustrated in Exhibit 4-10.

- **Cross section (-a-)** is the normal crown section where the transitioning begins.
- **Cross section (-b-)** is reached by rotating half the pavement until it is level.
- **Cross section (-c-)** is attained by continuing to rotate the same half of pavement until a plane section is attained across the entire pavement section, at a cross slope equal to the normal crown slope.
- **Cross section (-d-)** is the rate of the cross slope at any intermediate cross section between (-c-) and (-e-) is proportional to the distance from Cross section (-e-).
- **Cross section (-e-)** is achieved by further rotation of the planar section, the entire pavement section, to attain the full superelevation at a cross slope equal to (e).

Exhibit 4-10
Methods of Attaining Superelevation



Source: A Policy on Geometric Design of Highways and Streets, AASHTO, 2004. Chapter 3 Elements of Design

Superelevation runoff is the general term denoting the length of highway needed to accomplish the change in cross slope from a section with adverse crown removed (-b-) to a fully superelevated section (-e-), or vice versa.

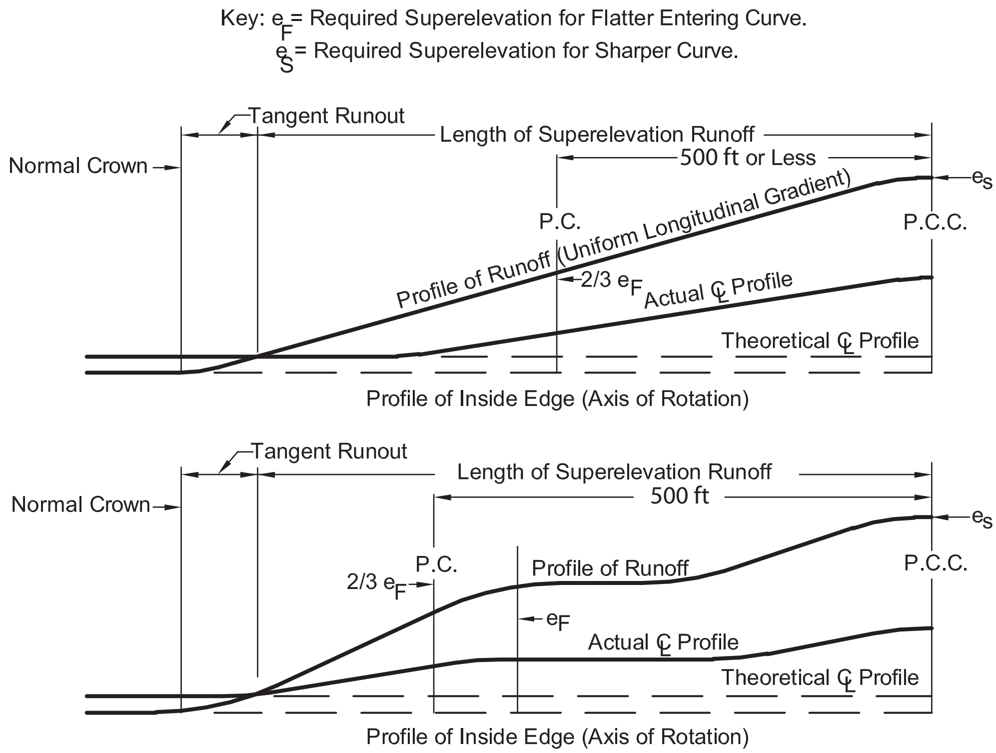
Tangent runout is the general term denoting the length of highway needed to accomplish the change in cross slope from a normal section (-a-) to a section with the adverse crown removed (-b-), or vice versa.

4.2.5.1 Design Considerations

- Superelevation is introduced or removed uniformly over the lengths required for comfort and safety.
- Place approximately two-thirds of the runoff on the tangent section and one-third on the horizontal curve.
- Angular breaks occur in the vertical profile in the superelevation transition areas. To smooth these breaks, when the vertical angle points are greater than 1%, short vertical curves are required. The minimum vertical curve length in feet can be used as numerically equal to the 5.3 times the design speed in mph. Greater lengths should be used where possible.
- On compound curves the following criteria should be met:
  - Full superelevation for the sharpest curve should be attained at the PCC.
  - If the flatter entering curve is less than or equal to 500 feet, a uniform longitudinal gradient should be used throughout the transition.
  - If the flatter entering curve is longer than 500 feet, it may be preferable to consider the two curves separately. Superelevation for the entering curve would be developed by the 2/3-1/3 distribution method. This rate would be maintained until it is necessary to develop the remaining superelevation for the sharper curve.

Exhibit 4-11 illustrates the two transition methods for compound curves.

Exhibit 4-11
Superelevation on Compound Curves



Source: *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004. Chapter 3 Elements of Design

- The minimum superelevation runoff lengths for roadways wider than two lanes should be as follows:
  - Three-lane traveled ways; 1.25 times the corresponding length for two-lane traveled ways.
  - Four-lane undivided traveled ways; 1.5 times the corresponding length for two-lane highways.
  - Six-lane undivided traveled ways; 2.0 times the corresponding length for two-lane traveled ways.

4.2.5.2 Axis of Rotation

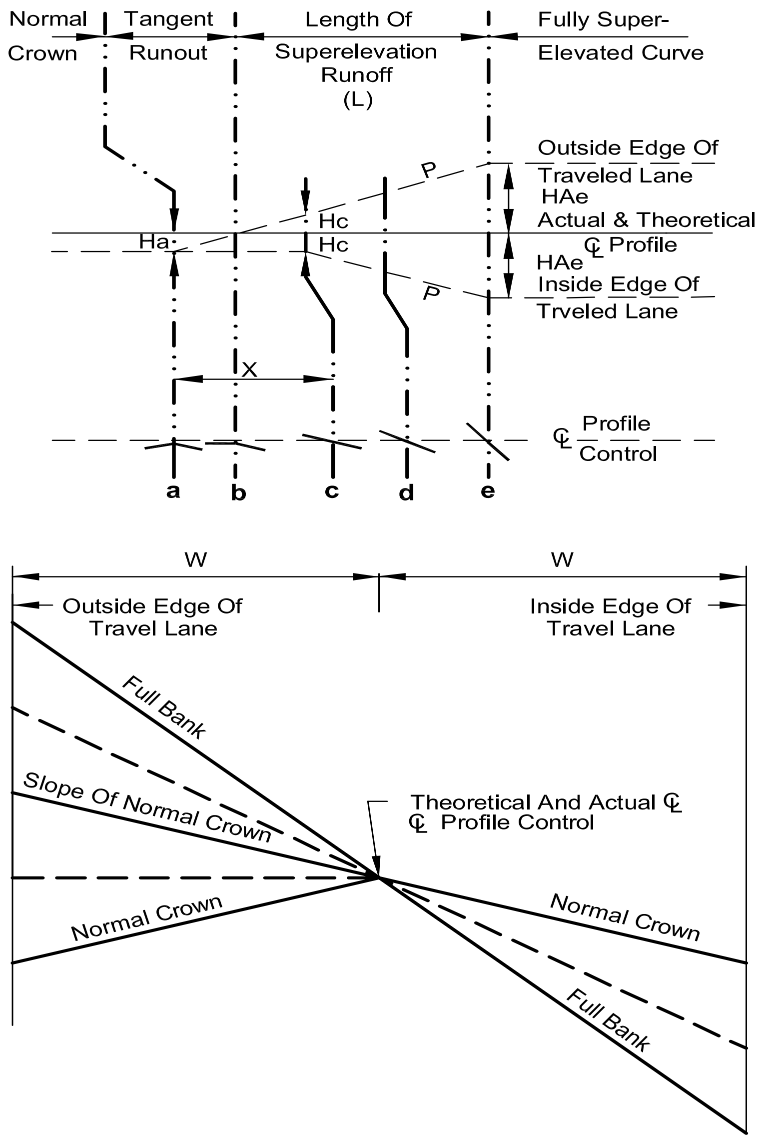
To attain superelevation an axis must be selected about which the pavement is rotated. In general there are four methods that may be selected:

- **Rotation about the centerline profile of traveled way.** This is generally the preferred method for two lane and undivided multilane roadways and when the elevations of the outside of roadway must be held within critical limits, such as in an urban area to minimize the impact on adjacent properties. This is also the method that distorts the edge line profiles the least. Exhibit 4-12 graphically demonstrates how the roadway superelevation is developed for this method.

- **Rotation about the inside-edge profile of traveled way.** This is generally the preferred method when the lower edge profile is of concern, such as when the profile is flat and the inside edge of the roadway needs to be controlled for drainage purposes. Exhibit 4-13 graphically demonstrates how the roadway superelevation is developed for this method. This method is suitable for ramps.
- **Rotation about the outside-edge profile of traveled way.** This method is similar to inside edge rotation except that the change is effected below the outside-edge profile instead of above the inside edge profile. This method is used when the higher edge profile is critical, such as on divided highways where the median edge profiles are held. Exhibit 4-14 graphically demonstrates how the roadway superelevation is developed for this method.
- **Rotation about the outside-edge profile of traveled way when the roadway has a straight cross-slope at the beginning of transition (-a-).** The outside-edge rotation is shown because this point is most often used for rotation of two-lane one-way roadways, with profile along the median edge of traveled way or for the traveled way having a typical straight cross-slope. Exhibit 4-15 graphically demonstrates how the roadway superelevation is developed for this method.

Exhibit 4-12
Banking Undivided Highways – Rotation Around Centerline

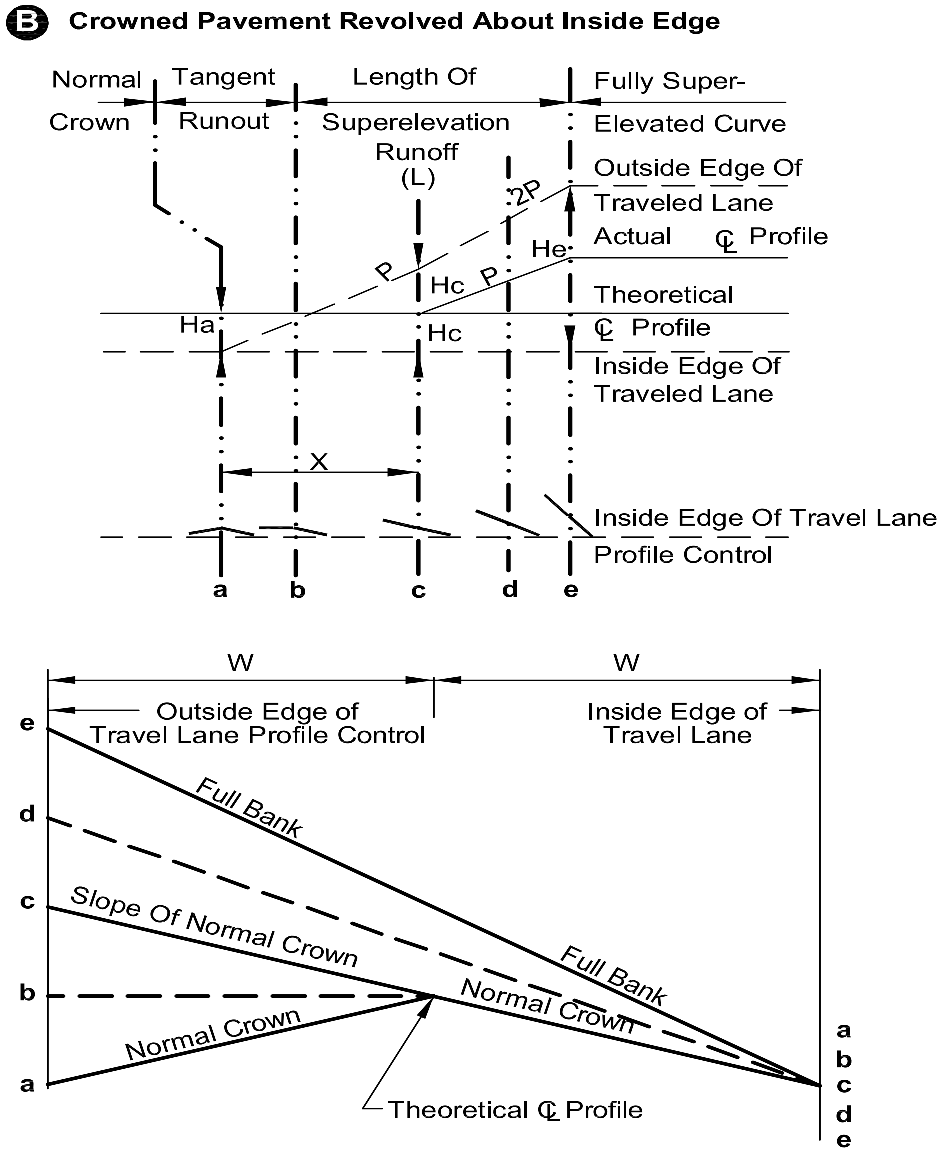
A Crowned Pavement Revolved About Centerline



Equations:	Where:
Hc = 8 x W	W = Width of travel lane(s) from C_L
Ha = 8 x W	S = Normal cross slope
HAe = e x W	e = Superelevation rate at full bank
P = (e x W) / L	L = Length of runoff
Tangent Runout = Ha / P	P = Rate of transition
X = 2 x Tangent runout	

Source: A Policy on Geometric Design of Highways and Streets, AASHTO, 2004. Chapter 3 Elements of Design

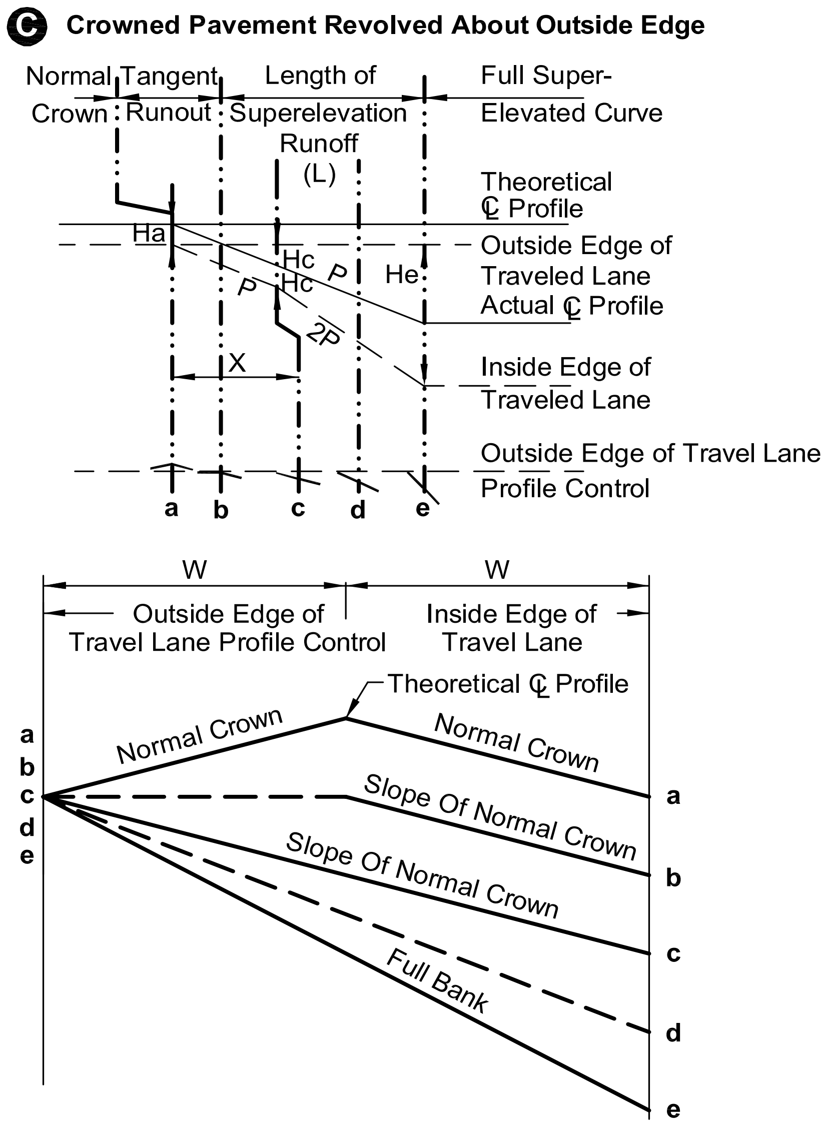
Exhibit 4-13
Banking Undivided Highways – Rotation About Inside Edge



Equations:	Where:
Ha = 8 x W	W = Width of travel lane(s) from C_L
Ho = 8 x W	S = Normal cross slope
He = 2 x e x W	e = Superelevation rate at full bank
P = (e x W) / L	L = Length of runoff
Tangent Runout = Ha / P	P = Rate of transition
2P = 2 x P	
X = 2 x tangent runout	

Source: A Policy on Geometric Design of Highways and Streets, AASHTO, 2004. Chapter 3 Elements of Design

Exhibit 4-14
Banking Undivided Highways – Rotation about Outside Edge



Equations:

Ha = 8 x W

Ho = 8 x W

He = 2 x e x W

P = (e x W) / L

Tangent Runout = Ha / P

2P = 2 x P

X = 2 x tangent runout

Where:

W = Width of travel lane(s) from C_L

S = Normal cross slope

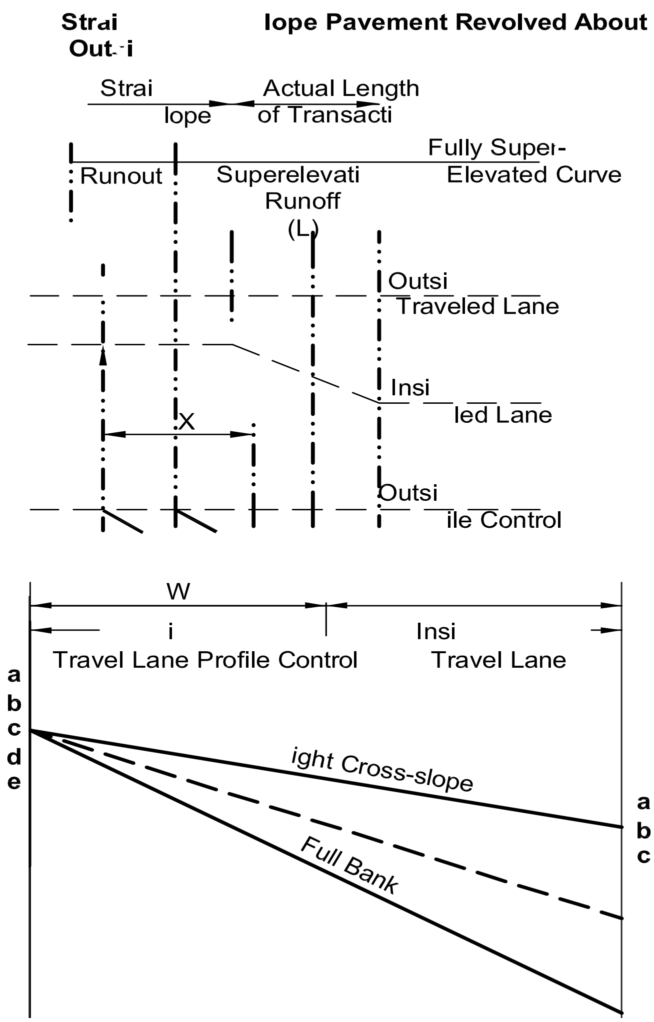
e = Superelevation rate at full bank

L = Length of runoff

P = Rate of transition

Source: A Policy on Geometric Design of Highways and Streets, AASHTO, 2004. Chapter 3 Elements of Design

Exhibit 4-15
Undivided Highways – Straight Cross Slope, Rotation About Outside Edge



Equations:
Ha = 8 x W
Ho = 8 x W
He = 2 x e x W
P = (e x W) / L
Tangent Runout = Ha / P
2P = 2 x P
X = 2 x tangent runout

Where:
W = Width of travel lane(s) from C_L
S = Normal cross slope
e = Superelevation rate at full bank
L = Length of runoff
P = Rate of transition

Source: A Policy on Geometric Design of Highways and Streets, AASHTO, 2004. Chapter 3 Elements of Design

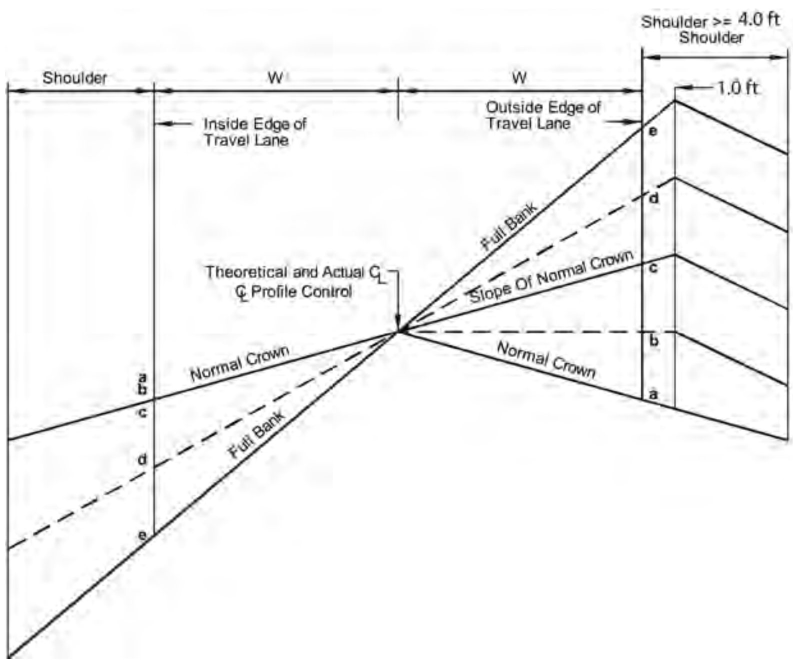
On a divided highway with a wide median, rotate each road separately and provide a compensating slope in the median. When using the centerline profile or the outside-edge as axis of rotation, the designer should evaluate the resulting edge profile of the low edge of sag and crest curves to ensure that positive drainage is preserved.

4.2.5.3 Shoulder Superelevation

All shoulders of 4.0 feet or greater should slope away from the travel lanes on superelevated curves. The maximum algebraic difference between the travel lane slope and shoulder slope ("rollover") is 0.09 ft/ft. Shoulders less than 4.0 feet wide should slope in the same direction as the travel lane as illustrated in Exhibit 4-16.

In the Commonwealth of Massachusetts, the grade break for shoulders occurs 1.0 feet outside the lane line; therefore an additional 1.0 foot must be added to the outside travel lane dimension to calculate shoulder edge profiles.

Exhibit 4-16
Highway with Paved Shoulders



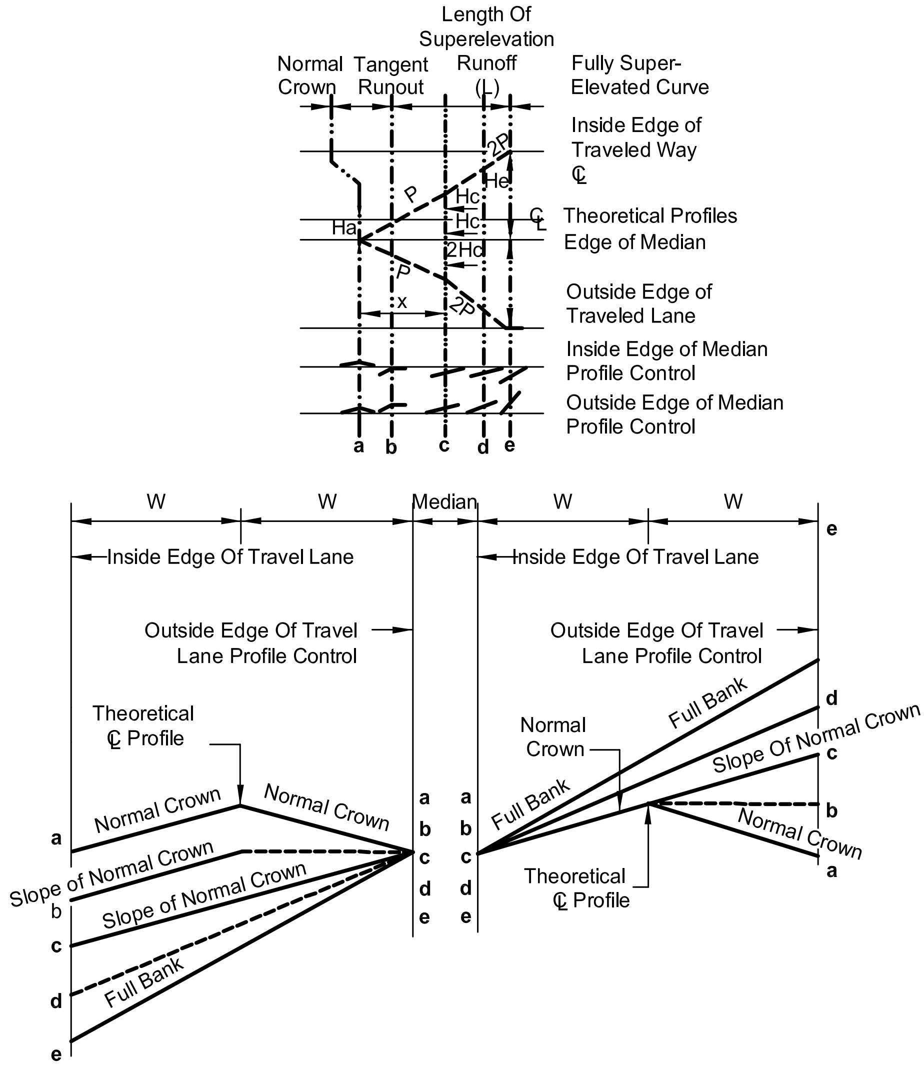
Source: MassHighway
Note: Shoulder treatments are typical for all methods of superelevation.
Shoulder less than 4.0 ft. should slope in the same direction as the travel lane.
"Roll-over" between travel lane and shoulder cannot exceed 0.09.

4.2.5.4 Divided Highways with Medians

Divided highways with medians require special consideration.

- **Medians of less than 10 feet** – To minimize the distortion between the two outside edges of the median, the center of the cross section may be used as the axis, with the whole roadway rotated about the center line of the median as a plane section. This method is limited to moderate superelevation rates.
- **Medians wider than 10 feet** – Where both roadways are crowned separately, the axis of rotation should be at the median edges for each side of the roadway, or the gutter lines where applicable. In this case the median is held in a horizontal plane. This method is illustrated in Exhibit 4-17.
- **Medians wider than 40 feet** – It may be preferable to develop the superelevation on each roadway independently with medians greater than 40 feet. The rotation may be made for each side of the roadway using any of the methods illustrated in Exhibits 4-12 to 4-16 as considered appropriate by the designer.

Exhibit 4-17
Banking Divided Highways – Rotation About Median Edge



Equations:

Ha = 8 x W

Ho = 8 x W

He = 2 x e x W

P = (e x W) / L

Tangent Runout = Ha / P

X = 2 x tangent runout

2P = 2 x P

Where:

W = Width of travel lane(s) from C_L

S = Normal cross slope

e = Superelevation rate at full bank

L = Length of runoff

P = Rate of transition

Source: A Policy on Geometric Design of Highways and Streets, AASHTO, 2004. Chapter 3 Elements of Design

Superelevation Design and Runoff Lengths

As it is desirable to select a curve radius larger than the minimum, the design superelevation rate needs to be selected for the actual radius used and the selected design speed. Exhibit 4-18 provides the design superelevation rates (for an undivided highway banked around the centerline) for a range of curve radii and design speeds with maximum superelevation of 6.0 percent. The formula related to this exhibit can be found in Exhibit 4-12

Exhibit 4-19 provides superelevation runoff lengths for a variety of design superelevations and design speeds, both for two lane and four-lane cross-sections.

Exhibit 4-18 may also be used to calculate the minimum desirable length of tangent between two reversing curves of minimum radii. The superelevation rate of zero may be used to determine the intervening length of tangent between reversing curves even if neither is superelevated. Because two-thirds of the maximum superelevation should be provided at the PC and PT of the curves, the minimum tangent length is two-thirds of the sum of the superelevation runoff lengths.

Superelevation runoff lengths should be long enough so that the rate of change (slopes) of the edges of pavement relative to the centerline does not exceed empirically developed controls. These maximum relative gradients, (which provide a minimum length of runoff) are given in Exhibit 4-20.

Exhibit 4-18
Minimum Radii for Design Superelevation Rates, Design Radius and Design Speeds (e_{max} = 6%)

	Design Speed (V_d)												
e (%)	15 mph R (ft)	20 mph R (ft)	25 mph R (ft)	30 mph R (ft)	35 mph R (ft)	40 mph R (ft)	45 mph R (ft)	50 mph R (ft)	55 mph R (ft)	60 mph R (ft)	65 mph R (ft)	70 mph R (ft)	75 mph R (ft)
1.5	868	1580	2290	3130	4100	5230	6480	7870	9410	11100	12600	14100	15700
2.0	614	1120	1630	2240	2950	3770	4680	5700	6820	8060	9130	10300	11500
2.2	543	991	1450	2000	2630	3370	4190	5100	6110	7230	8200	9240	10400
2.4	482	884	1300	1790	2360	3030	3770	4600	5520	6540	7430	8380	9420
2.6	430	791	1170	1610	2130	2740	3420	4170	5020	5950	6770	7660	8620
2.8	384	709	1050	1460	1930	2490	3110	3800	4580	5440	6200	7030	7930
3.0	341	635	944	1320	1760	2270	2840	3480	4200	4990	5710	6490	7330
3.2	300	566	850	1200	1600	2080	2600	3200	3860	4600	5280	6010	6810
3.4	256	498	761	1080	1460	1900	2390	2940	3560	4250	4890	5580	6340
3.6	209	422	673	972	1320	1740	2190	2710	3290	3940	4540	5210	5930
3.8	176	358	583	864	1190	1590	2010	2490	3040	3650	4230	4860	5560
4.0	151	309	511	766	1070	1440	1840	2300	2810	3390	3950	4550	5220
4.2	131	270	452	684	960	1310	1680	2110	2590	3140	3680	4270	4910
4.4	116	238	402	615	868	1190	1540	1940	2400	2920	3440	4010	4630
4.6	102	212	360	555	788	1090	1410	1780	2210	2710	3220	3770	4380
4.8	91	189	324	502	718	995	1300	1640	2050	2510	3000	3550	4140
5.0	82	169	292	456	654	911	1190	1510	1890	2330	2800	3330	3910
5.2	73	152	264	413	595	833	1090	1390	1750	2160	2610	3120	3690
5.4	65	136	237	373	540	759	995	1280	1610	1990	2420	2910	3460
5.6	58	121	212	335	487	687	903	1160	1470	1830	2230	2700	3230
5.8	51	106	186	296	431	611	806	1040	1320	1650	2020	2460	2970
6.0	39	81	144	231	340	485	643	833	1060	1330	1660	2040	2500

Source: *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004 Chapter 3 – Elements of Design
Note: Based on banking an undivided highway (2 or 4 lanes) around the centerline. See Exhibit 4-12.

Exhibit 4-19
Superelevation Runoff Length for Design Superelevation and Design Speed

	Design Speed V_d																									
	15 mph		20 mph		25 mph		30 mph		35 mph		40 mph		45 mph		50 mph		55 mph		60 mph		65 mph		70 mph		75 mph	
	Number of Lanes Rotated. Note that 1 lane rotated is typical for a 2-lane highway, 2 lanes rotated is typical for a 4-lane highway, etc.																									
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
e (%)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)	L_r (ft)
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.0	31	46	32	49	34	51	36	55	39	58	41	62	44	67	48	72	51	77	53	80	56	84	60	90	63	95
2.2	34	51	36	54	38	57	40	60	43	64	46	68	49	73	53	79	56	84	59	88	61	92	66	99	69	104
2.4	37	55	39	58	41	62	44	65	46	70	50	74	53	80	58	86	61	92	64	96	67	100	72	108	76	114
2.6	40	60	42	63	45	67	47	71	50	75	54	81	58	87	62	94	66	100	69	104	73	109	78	117	82	123
2.8	43	65	45	68	48	72	51	76	54	81	58	87	62	93	67	101	71	107	75	112	78	117	84	126	88	133
3.0	46	69	49	73	51	77	55	82	58	87	62	93	67	100	72	108	77	115	80	120	84	126	90	135	95	142
3.2	49	74	52	78	55	82	58	87	62	93	66	99	71	107	77	115	82	123	85	128	89	134	96	144	101	152
3.4	52	78	55	83	58	87	62	93	66	99	70	106	76	113	82	122	87	130	91	136	95	142	102	153	107	161
3.6	55	83	58	88	62	93	65	98	70	105	74	112	80	120	86	130	92	138	96	144	100	151	108	162	114	171
3.8	58	88	62	92	65	98	69	104	74	110	79	118	84	127	91	137	97	146	101	152	106	159	114	171	120	180
4.0	62	92	65	97	69	103	73	109	77	116	83	124	89	133	96	144	102	153	107	160	112	167	120	180	126	189
4.2	65	97	68	102	72	108	76	115	81	122	87	130	93	140	101	151	107	161	112	168	117	176	126	189	133	199
4.4	68	102	71	107	75	113	80	120	85	128	91	137	98	147	106	158	112	169	117	176	123	184	132	198	139	208
4.6	71	106	75	112	79	118	84	125	89	134	95	143	102	153	110	166	117	176	123	184	128	193	138	207	145	218
4.8	74	111	78	117	82	123	87	131	93	139	99	149	107	160	115	173	123	184	128	192	134	201	144	216	152	227
5.0	77	115	81	122	86	129	91	136	97	145	103	155	111	167	120	180	128	191	133	200	140	209	150	225	158	237
5.2	80	120	84	126	89	134	95	142	101	151	108	161	116	173	125	187	133	199	139	208	145	218	156	234	164	246
5.4	83	125	88	131	93	139	98	147	105	157	112	168	120	180	130	194	138	207	144	216	151	226	162	243	171	256
5.6	86	129	91	136	96	144	102	153	108	163	116	174	124	187	134	202	143	214	149	224	156	234	168	252	177	265
5.8	89	134	94	141	99	149	105	158	112	168	120	180	129	193	139	209	148	222	155	232	162	243	174	261	183	275
6.0	92	138	97	146	103	154	109	164	116	174	124	186	133	200	144	216	153	230	160	240	167	251	180	270	189	284

Source: *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004 Chapter 3 Elements of Design

Exhibit 4-20
Maximum Relative Gradients

Design Speed (mph)	Maximum Relative Gradient (%)	Equivalent Maximum Slope
15	0.78	1:128
20	0.74	1:135
25	0.70	1:143
30	0.66	1:152
35	0.62	1:161
40	0.58	1:172
45	0.54	1:185
50	0.50	1:200
55	0.47	1:213
60	0.45	1:222
65	0.43	1:233
70	0.40	1:250
75	0.38	1:263

Source: *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004 Chapter 3 Elements of Design

4.3 Vertical Alignment

Roadway vertical alignment is controlled by design speed, topography, traffic volumes and composition, highway functional classification, safety, sight distance, typical sections, horizontal alignment, climate, vertical clearances, drainage, economics, and aesthetics. In general, the designer should consider the following:

- In level terrain, the designer's ability to efficiently satisfy the design controls can be accomplished without construction difficulty or extraordinary expense; however, as the terrain becomes more challenging, as in rolling or mountainous terrain and developed areas, significantly more complicated construction techniques must be employed to achieve compatibility between the road alignment and the surrounding ground. Introducing vertical curves to minimize the disruption to the existing environment may result in sight distance or clearance issues and may require truck climbing lanes for higher-speed facilities. The designer must balance these factors when introducing vertical curves into a roadway alignment.
- Where a highway crosses a waterway the profile of the highway must be consistent with the design flood frequency and elevation. (See Chapter 8 Drainage and Erosion Control).

- The roadway elevation must provide sufficient clearance and cover for construction of culverts and other components of the drainage system.
- When a highway is located where environmental resources exist the vertical alignment should be designed to minimize impacts.
- Vertical alignment should be properly coordinated with the natural topography, available right-of-way, utilities, roadside development, and natural and man-made drainage patterns.

4.3.1 Grades

Roadway grades have a direct correlation to the uniform operation of vehicles. Vehicle weight and the steepness of the roadway grade have a direct relationship on the ability of the driver to maintain uniform speed. Exhibit 4-21 presents the recommended maximum highway grades in an effort to achieve uniform vehicular operation for various design speeds. Flatter grades should be used where possible.

On a long ascending grade it is preferable to place the steepest grade at the bottom and flatten the grade near the top. In order to facilitate positive highway drainage, the highway must have a minimum longitudinal tangent gradient of 0.4% and preferably 0.5%.

Maximum grade recommendations are presented for the area types described in Chapter 3 and vary depending upon the terrain in which the facility is located. For most locations in Massachusetts, the level or rolling terrain category is applicable.

Grades on shared facilities should be carefully considered to accommodate all modes of intended transportation.

Where pedestrian or bicycle facilities follow a roadway alignment, these facilities should follow the prevailing grade of the adjacent roadway. See Chapter 11 for design guidance on facilities in separate rights-of-way. If bicycles share the roadway with motor vehicles, consideration should be given to providing extra width or a bicycle climbing lane on the uphill side. A designated bicycle lane may not be necessary on a downgrade where bicyclists travel as fast (or nearly as fast) as motor vehicles.

In addition to the maximum grade, the designer must consider the length of the grade. The gradient in combination with its length will determine the truck speed reduction on upgrades. Exhibit 4-22 shows how a typical heavy truck, approaching a grade at a given speed, loses speed as it travels along the length of the grade. For general design purposes, a 10 mph speed reduction should be used.

Exhibit 4-21
Recommended Maximum Grades

Freeways

(All Areas)

Terrain	Percent Grade for Selected Design Speed (mph) 50	55	60	65	70	75
Level	4	4	3	3	3	3
Rolling	5	5	4	4	4	4
Mountainous	6	6	6	5	--	--

a Grades 1% steeper than the value shown may be provided in mountainous terrain or in urban areas with crucial right-of-way controls.

Arterials and Highways

(Rural Villages, Suburban High-Intensity, Suburban Town Center, and Urban Areas)

Terrain	Percent Grade for Selected Design Speed (mph) 30	35	40	45	50	55	60
Level	8	7	7	6	6	5	5
Rolling	9	8	8	7	7	6	6
Mountainous	11	10	10	9	9	8	8

(Rural Natural, Rural Developed, and Suburban Low Intensity Areas)

Terrain	Percent Grade for Selected Design Speed (mph) 40	45	50	55	60
Level	5	5	4	4	3
Rolling	6	6	5	5	4
Mountainous	8	7	7	6	6

Collectors and Local Roads

(Rural Villages, Suburban High Intensity, Suburban Town Center, and Urban Areas)

Terrain	Percent Grade for Selected Design Speed (mph) 20	25	30	35	40	45	50	55	60
Level	9	9	9	9	9	8	7	7	6
Rolling	12	12	11	10	10	9	8	8	7
Mountainous	14	13	12	12	12	11	10	10	9

Note: Short lengths of grade in urban areas, such as grades less than 500 ft in length, one-way downgrades, and grades on low-volume urban collectors may be up to 2 percent steeper than the grades shown above.

Collectors

(Rural Natural, Rural Developed, and Suburban Low Intensity Areas)

Terrain	Percent Grade for Selected Design Speed (mph) 20	25	30	35	40	45	50	55	60
Level	7	7	7	7	7	7	6	6	5
Rolling	10	10	9	9	8	8	7	7	6
Mountainous	12	11	10	10	10	10	9	9	8

Note: Short lengths of grade in urban areas, such as grades less than 500 ft in length, one-way downgrades, and grades on low-volume urban collectors may be up to 2 percent steeper than the grades shown above.

Local Roads

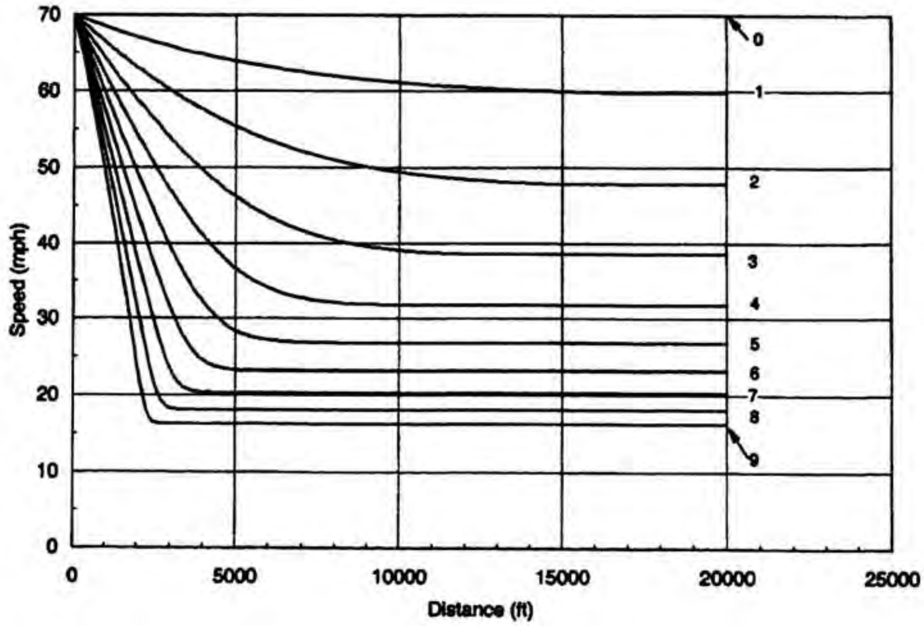
(Rural Natural, Rural Developed, and Suburban Low Intensity Areas)

Terrain	Percent Grade for Selected Design Speed (mph) 15	20	25	30	35	40	45
Level	9	8	7	7	7	7	7
Rolling	12	11	11	10	10	10	9
Mountainous	17	16	15	14	13	13	12

Note: Short lengths of grade in urban areas, such as grades less than 500 ft in length, one-way downgrades, and grades on low-volume urban collectors may be up to 2 percent steeper than the grades shown above.

Source: *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004 .Chapter 4 Rural and Urban Arterials; Chapter 5 Freeways

Exhibit 4-22
Speed-Distance Curves for a Typical Heavy Truck for Deceleration on Upgrades



Note: Curves are for grades between 0 and 9%.
For starting speeds other than 70mph, distance is interpolated along the grade curve for the desired speed reduction.
Source: *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004. Chapter 3 Elements of Design

Where an upgrade is preceded by a downgrade, trucks will often increase speed to make the climb. A speed increase of 5 mph on moderate downgrades (3-5%) and 10 mph on steeper grades (6-8%) of sufficient length are reasonable adjustments. These can be used in design to allow the use of a higher speed reduction curve. However, these speed increases may not be attainable if traffic volumes are high enough that a truck is likely to be behind a passenger vehicle when descending the grade.

4.3.2 Truck Climbing Lanes

If a critical length of grade in Exhibit 4-21 is exceeded, then a truck climbing lane may be warranted provided the construction costs and environmental impact are reasonable. The *Highway Capacity Manual* and AASHTO's *A Policy on Geometric Design of Highways and Streets* presents the detailed methodology for truck climbing lanes on two-lane highways. On freeways and expressways, the Highway Capacity Manual presents the accepted methodology.

When determining if a truck climbing lane is warranted, the designer must select a level of service. Preferably, the level of service should not be allowed to fall below that desired for the project as determined through the parameters described in Chapter 3 and determined in the project development process. At restricted locations, the ascending roadway facility may be operating below these guidelines before a truck climbing lane is warranted. If a truck climbing lane is warranted and the costs are reasonable, the following criteria should be followed for designing the lane:

- Lane width should be the same as the adjacent lane, but not less than 12 feet. The useable shoulder width should be at least 4 feet.
- The full width of the climbing lane should be achieved at the point where a truck will have reduced its speed by 10 mph.
- The full width of the climbing lane should, when feasible, extend to the point where the truck speed has returned to within 10 mph of the typical auto speed. At a minimum it should extend to a point where full passing sight distance becomes available.
- The entering taper should preferably be 25:1 and at least 150 feet long.
- An exiting or merging taper not sharper than 50:1 is preferred. It should be 200 feet or more in length.

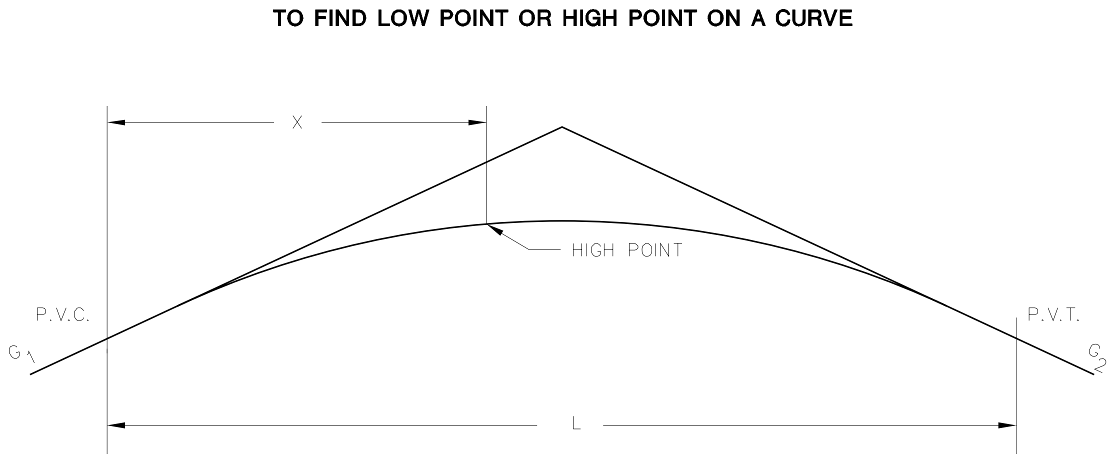
4.3.3 Vertical Curves

Vertical curves are employed to effect gradual change between roadway grades. Vertical curves should be simple in application and should result in a design that is safe and comfortable in operation, pleasing in appearance, and adequate for drainage. The design of vertical curves should comply with the following general considerations:

- All vertical crest and sag curves are in the shape of a parabola. The computations for vertical curves are shown in Exhibits 4-23, 4-24, and 4-25. Design controls for vertical curves are generally based on the formula $K = L/A$ where L is the length of curve in feet and A is the algebraic difference in grades expressed as a percent. The designer's use of K values facilitates geometric design. The tables are calculated to provide the minimum sight distances for the corresponding design speed.
- K is the horizontal distance required to effect a 1% change in grade.

- Vertical alignment should use a smooth grade line with gradual changes, consistent with the type of highway and character of terrain. Grades with break points and short tangent lengths should be avoided.
- On long ascending grades, it is preferable to place the steepest grade at the bottom and flatten the grade near the top. It is also preferable to break a sustained grade with short intervals of flatter grades.
- Maintain moderate grades through intersections to facilitate starting and turning movements. See Chapter 6, (Intersections) for specific information pertaining to vertical alignment at intersections.
- Roller Coaster type profiles, where the roadway profile closely follows a rolling natural ground line along a relatively straight horizontal alignment, should be avoided. This type of profile is aesthetically undesirable and may be more difficult to drive.
- As with horizontal alignment, broken back curvature (short tangent between two curves in same direction) should be avoided because drivers do not expect to encounter this arrangement on typical highway geometry
- Avoid using sag vertical curves in a cut section unless adequate drainage can be provided.

Exhibit 4-23
Parabolic Vertical Curves



G_1, G_2 = Rates of grades expressed in % with proper sign

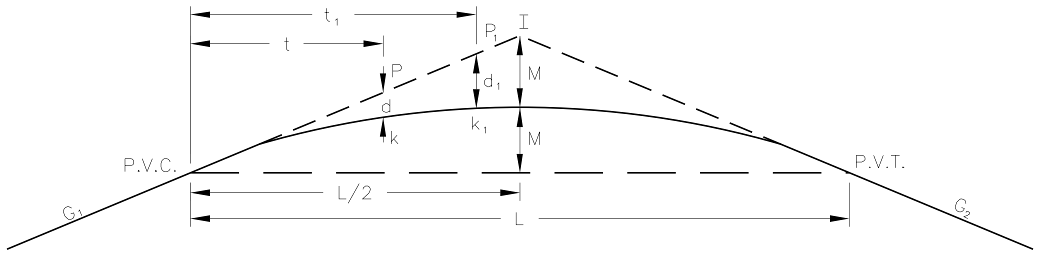
X = { Distance of high point of a crest curve from P.V.C. in feet.
Distance of low point of a sag curve from P.V.C. in feet.

L = Length of curve in feet

$$X = \frac{L\,(G_1)}{G_1 - G_2}$$

Note: In all of the above formulas, $(G_1\text{-}G_2)$ is the algebraic difference in percent grade
Source: MassHighway

Exhibit 4-24
Parabolic Vertical Curves



$G_1, G_2 =$ Rate of grade expressed in percent, with proper sign

A = $(G_1 - G_2)$ algebraic difference of rates of grades expressed in percent

L = Length of curve in stations (The length is measured on a horizontal plane)

M = Middle ordinate in feet

$d, d_1 =$ Corrections (offsets) from grade line to curve in feet

$t, t_1 =$ Distance in stations from P.V.C. or P.V.T. that points k, k_1 on the curve are located

a = Corrector factor, constant for any one curve

$$M = \frac{L(G_1 - G_2)}{8} \text{ or } M = \frac{1}{2}\left(\text{Elev. Point I} - \frac{\text{Elev. at P.V.C.} + \text{Elev. at P.V.T.}}{2}\right)$$

$$a = \frac{M}{\left(\frac{L}{2}\right)^2} = \frac{A}{2L}$$

d = at^2, $d_1 = at_1^2$ etc.

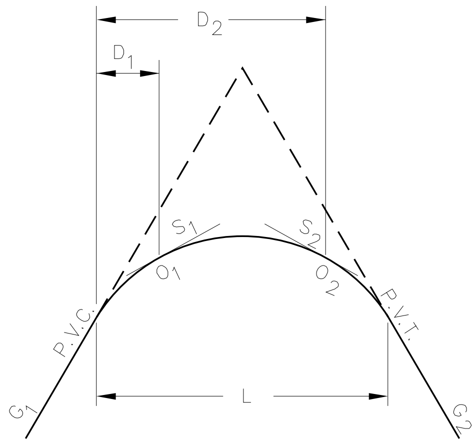
Elev of k = Elev. of P$\pm$ d, Elev. of k_1, = Elev. of $P_1 \pm d_1$, etc., When the algebraic difference of grades is positive, the offsets of d, d_1 … are subtracted from the elevations P, P_1 … on the tangent.

When the algebraic difference of grades is negative, the offsets d, d_1 … are added to the elevations P, P_1 … on the tangent.

Source: MassHighway

Exhibit 4-25
Parabolic Vertical Curves

TO FIND SLOPE OF CURVE AT ANY POINT



G_1, G_2 =	Rate of grade expressed in percent, with proper sign
$(G_1 - G_2)$ =	Algebraic difference in rates of grades
S_1 and S_2 =	Slope in percent of a tangent drawn at points $0_1\ 0_2$ … at distances, $D_1\ D_2$ … from P.V.C. of vertical curve
D_1 , D_2 ... =	Distance in stations
L =	Length of vertical curve in stations

$$S_1 = G^*_1 \pm D_1 \frac{|G_1 - G_2|}{L}, \qquad S_2 = G^*_1 \pm D_2 \frac{|G_1 - G_2|}{L}$$

The sign of $|G_1 - G_2|$ is always positive (absolute value)

* Assign the proper sign to G_1
± Becomes a plus (+) for sag curves
± Becomes a minus (–) for crest curves

Note: The above formula may be used to find the rate of grade of a tangent at any point on a vertical curve and to check slopes of curves for drainage purposes.

Source: MassHighway

4.3.3.1 Crest Vertical Curves

The primary control for crest vertical curves is providing adequate stopping sight distance as described in Chapter 3. Exhibit 4-26 shows computed K values for lengths of vertical curves as required for the value of stopping sight distance for each design speed.

Exhibit 4-26
Design Control for Stopping Sight Distance for Crest Vertical Curves

Design Speed (mph)	Stopping Sight Distance (ft)	Rate of Vertical curvature, K_a	
		Calculated	Design
15	80	3.0	3
20	115	6.1	7
25	155	11.1	12
30	200	18.5	19
35	250	29.0	29
40	305	43.1	44
45	360	60.1	61
50	425	83.7	84
55	495	113.5	114
60	570	150.6	151
65	645	192.8	193
70	730	246.9	247
75	820	311.6	312

Note: Rate of vertical curvature, K, is the length of curve per percent algebraic difference in intersection grades (A). K = L/A
Source: A Policy on Geometric Design of Highways and Streets, AASHTO 2004. Chapter 3 Elements of Design

Crest vertical curves must be balanced with the horizontal alignment. The beginning of the horizontal curve should not be positioned beyond the crest curve in a way that does not allow the advancing driver the ability to see the upcoming change in the horizontal alignment.

For the design of crest vertical curves, the following shall apply:

- **Stopping Sight Distance** —should be available on crest vertical curves. A height of eye of 3.5 feet and a height of object of 2 feet are used. A minimum length curve should be used for driver comfort and vehicular control. The line-of-sight intercept is 2.75 feet or above when the view obstruction is at the midpoint of the sight line.

Where: $L_{min} = 3V$

L_{min} is in feet, V is in mph

Flat vertical curves of less than 0.3% for distances of 50 feet or greater from the crest require careful drainage design. This equates to a K value of 167 or greater.

4.3.3.2 Sag Vertical Curves

Headlight sight distance (see Chapter 7 for additional detail at underpasses) is the primary design control for sag vertical curves on non-illuminated roadways. The height of the headlights is assumed to be 2 feet. The upward divergence of the beam is 1 degree from the longitudinal axis of the vehicle. The curvature of the sag should be such that the headlights will illuminate the pavement sufficiently to provide adequate stopping sight distance.

Exhibit 4-27 shows the range of rounded values of K selected as design controls which provide for minimum headlight sight distance. Minimum lengths of vertical curves for flat gradients are equal to 3 times the design speed in mph.

As for crest curves careful drainage design must be made for K values of greater than or equal to 167.

Designer should check the sight distance under bridges.

4.3.4 Vertical Clearances

Exhibit 4-28 provides the required vertical clearances for all highway types and other clearance criteria. The location of the critical clearance generally occurs where the highest point on the crown line and/or runoff line of the road underpass falls directly under the lowest elevation of the bottom overpass superstructure support member. Refer to the MassHighway Bridge Manual for the method of determining clearances.

Exhibit 4-27
Design Control for Sag Vertical Curves

Design Speed (mph)	Stopping Sight Distance (ft)	Rate of Vertical Curvature, K_a	
		Calculated	Design
15	80	9.4	10
20	115	16.5	17
25	155	25.5	26
30	200	36.4	37
35	250	49.0	49
40	305	63.4	64
45	360	78.1	79
50	425	95.7	96
55	495	114.9	115
60	570	135.7	136
65	645	156.5	157
70	730	180.3	181
75	820	205.6	206

Note: Rate of vertical curvature, K, is the length of curve per percent algebraic difference in intersection grades
Source: A Policy on Geometric Design of Highways and Streets, AASHTO 2004. Chapter 3 Elements of Design

Exhibit 4-28
Vertical Clearances

Minimum[1,4] (ft)	Comments
16.5	Bridges over expressways/freeways
16.5[5]	Bridges over arterial
16.5	Freeway Tunnels
16.5	Tunnels for all other roadway classes
16.5	Bridges over collector
16.5	Bridges over local road
See Note 2	Roadway bridge over railroad
17.0	Sign bridge or pedestrian bridge over roadway
See Note 3	Highway in vicinity of an airport

1. The Chief Engineer shall approve any clearance less than the minimum clearance in writing.
2. The MassHighway Bridge Engineer will coordinate clearance over railroads with the railroads.
3. Clearance in the vicinity of an airport will be coordinated with the FAA through the FHWA.
4. Minimum values allow 4 inches for paving overlays in all cases.
5. New or reconstructed structures should provide 16.5 ft clearance over entire roadway width. In a highly urbanized area a minimum clearance of 14.5 ft may be provided where an alternate route with 16.5 ft clearance is provided. Existing structures that provide 14.5 ft clearance may be retained, if allowed by local statute.
6. Provisions must be made for lighting, overhead signs and pavement overlays.

Source: A Policy on Geometric Design of Highways and Streets, AASHTO 2004. Chapter 3 Elements of Design

4.3.5 Establishing Profiles

When establishing the vertical profile, use the following criteria:

- On freeways, a minimum distance of 1,500 feet should be provided between points of intersection. On other major highways, 1,200 feet is the minimum distance.
- The vertical profile should be in balance with the horizontal alignment (See Section 4.4).
- On divided highways with a median less than 30 feet, including shoulders, the median edges should be at the same elevation. For wider medians, the profiles for the two roadways should be established independently.
- Vertical profiles of urban and local roads are determined considering the existing topography, construction costs, safety, and the abutting properties. The evaluation should establish the critical abutting locations. Buildings, driveways, and steps are especially important when establishing profiles.

4.4 Combination of Horizontal and Vertical Alignment

Horizontal and vertical alignments should be designed concurrently. Their designs complement each other and poorly designed combinations can reduce the quality of both.

Coordinate the horizontal and vertical alignment to obtain safety, uniform speed, pleasing appearance, and efficient traffic operation. Coordination can be achieved by plotting the location of the horizontal curves on the working profile to help visualize the highway in three dimensions.

Horizontal and vertical alignments are among the most important of the permanent design elements. Quality in their design and in their combined design increases usefulness and safety, encourages uniform speed, and improves appearance. The following general controls should be considered in balancing horizontal and vertical alignments:

- Balance curvature and grades. Use of steep grades to achieve long tangent and flat curves, or excessive curvature to achieve flat grades, are both poor designs.

- Vertical curvature superimposed on horizontal curvature generally results in a more pleasing facility. Successive changes in profile not in combination with horizontal curvature may result in a series of dips not visible to the driver.
- A horizontal curve should not begin or end at or near the top of a crest vertical curve. This condition can be unsafe, especially at night, if the driver does not recognize the beginning or ending of the horizontal curve. Safety is improved if the horizontal curve leads the vertical curve, that is, the horizontal curve is made longer than the vertical curve in both directions.
- Curvature in the horizontal plane should be accompanied by comparable length of curvature in the vertical plane.
- Awkward combinations of curves and tangents in both the horizontal and vertical planes should be avoided (i.e., "broken back" curves).
- Horizontal and vertical curvatures should be coordinated to avoid combinations that appear awkward when viewed from a low angle.
- Ideally the vertices of horizontal curves (PI) and vertical curves (PVI) should coincide or be within 1/4 phase of each other.
- Horizontal curvature should lead vertical curvature. i.e., the horizontal curve should be longer than the vertical curve and the PVT and PC should not be at the same point.
- The alignment designs should enhance attractive scenic views of the natural and manmade environment, such as rivers, rock formations, parks, and outstanding man-made structures.
- In residential areas, the alignment design should minimize nuisance factors to the neighborhood. Generally, a depressed facility makes a highway less visible and less noisy to adjacent residents. Minor horizontal adjustments can sometimes be made to increase the buffer zone between the highway and clusters of homes.
- Horizontal curvature and profile should be as flat as feasible at intersections where sight distance along both roads is important and vehicles may have to slow or stop.
- On divided highways, consideration of variation in the width of the median and the use of independent alignments is needed to derive the design and operational advantages of one-way roadways.

- On two-lane roads, the need for safe passing sections (at frequent intervals and for an appreciable percentage of the length of the roadway) often supersedes the general desirability for combination of horizontal and vertical alignment. Passing zones with long tangent sections are needed to secure sufficient passing sight distance.
- Avoidance of a sharp horizontal curve at or near the low point of a pronounced sag vertical curve is important. The road ahead is foreshortened and any horizontal curve that is not flat assumes an undesirably distorted appearance. Further, vehicular speeds, particularly of trucks, often are high at the bottom of grades and erratic operation may result, especially at night.
- To maintain drainage, vertical and horizontal curves should be designed so that the flat profile of a vertical curve will not be located near the flat cross slope of the superelevation transition.

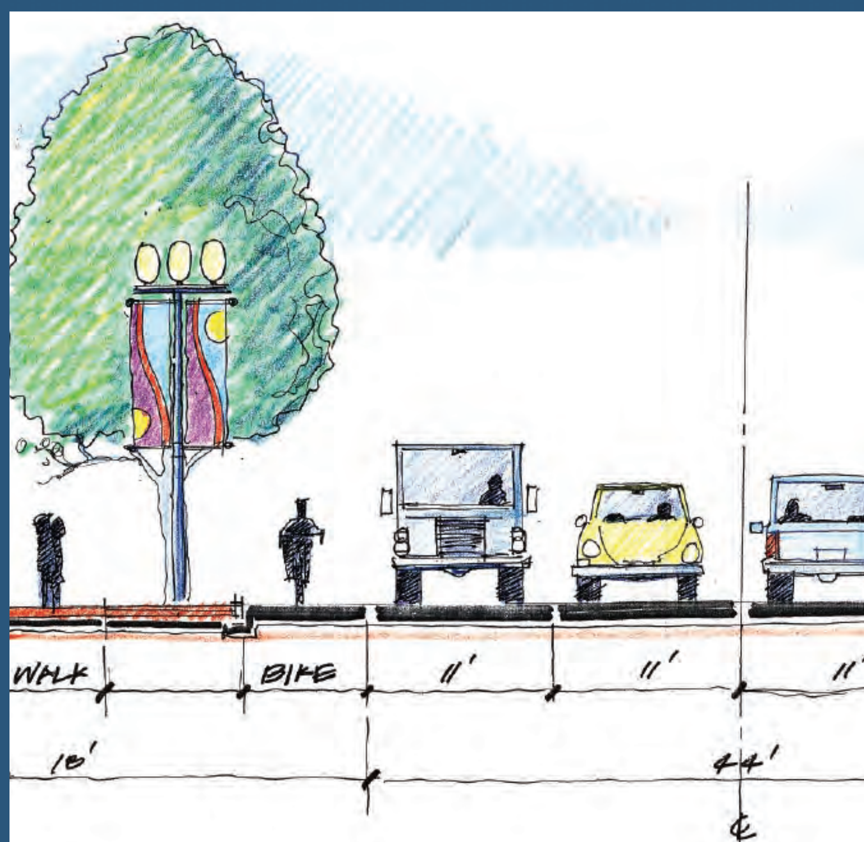
The designer is directed to use the guidelines found in the AASHTO *Policy on Geometric Design of Highways and Streets*, Chapter 3: "Elements of Design, and other applicable publications.

4.5 For Further Information

- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004.
- *Highway Capacity Manual, Special Report No. 209*, Transportation Research Board.
- *Practical Highway Esthetics*, ABCE, 1977.
- *Cross Section and Alignment Design Issues*, TRB No. 1445, 1994.

Chapter 5

Cross-Section and Roadside Elements



Cross-Section and Roadside Elements

5.1 Introduction

The basic design controls described in Chapter 3 influence the width, functional areas of the cross-section, and accommodation for different users. The careful selection of roadway cross-section elements (sidewalks, bicycle accommodation, motor vehicle lanes, etc.) is needed to achieve a context-sensitive design that accommodates all users safely. This chapter describes the various components of roadway cross-section, including ranges of recommended dimensions for different area and roadway types. This chapter also describes basic elements of roadside design.

5.1.1 Multimodal Accommodation and Context Sensitivity

The goals of selecting an appropriate roadway cross-section and the design of roadside elements are:

(1) To develop a transportation infrastructure that provides access for all, a real choice of modes, and safety in equal measure for each mode of travel.

(2) To ensure that transportation facilities fit their physical setting and preserve scenic, historic, aesthetic, community, and environmental resources to the extent possible.

In some cases, these design objectives can be achieved within the available right-of-way. In other cases, additional right-of-way needs to be acquired. Sometimes, tradeoffs in user accommodation need to be made to preserve environmental or community resources located within or adjacent to the right-of-way. In these situations, the challenge is to provide access and safety for each mode of travel. In other situations, it will be necessary to modify environmental characteristics in order to provide safe accommodation.

To assist communities, highway officials, and designers, this Guidebook provides options and recommendations for safe accommodation of pedestrians, bicycles, vehicular traffic, and public transit operations.

General approaches to cross-section formulation are discussed in Section 5.2.

The challenge is to balance the competing interests of different users in a limited amount of right-of-way and to provide access for all, a real choice of modes, and safety in equal measure for each mode of travel.

Approaches to cross-section formulation are presented from right-of-way edge to edge, rather than the more traditional method from center line out. Through this approach, accommodation of pedestrians and bicyclists is positively encouraged, made safer, and included in every transportation project as required under Chapter 87 of state law.

Detailed description of the following cross-section elements associated with different roadway users are described in Section 5.3:

- **Pedestrians including people requiring mobility aids**
  - Sidewalks
  - Shoulder use
  - Shared lanes
  - Shared use paths
- **Bicycles**
  - Bicycle lanes
  - Shoulder use
  - Shared lanes
  - Shared use paths
- **Motor Vehicles including transit**
  - Usable shoulders
  - On-street parking
  - Travel lanes

Once the elements associated with roadway user groups are described, guidance for assembling cross-sections is provided. This guidance describes the elements typically encountered for the roadway and area types defined in Chapter 3.

5.1.2 Additional Topics Covered

In addition to cross-section elements specifically associated with the movement of pedestrians, bicycles, and motor vehicles, there are several other cross-section elements included in this chapter as described below.

5.1.2.1 Public Transit Elements

Public transit often operates as a motor vehicle within the public right-of-way. There are several design features, both within the roadway and on the sidewalk, that should be considered in cross-section design. These are discussed in Section 5.4 and include:

- Rail transit facilities,
- Bus stops, and
- Dedicated lanes.

5.1.2.2 Other Cross-section Design Features

Section 5.5 describes the application of the following features:

- Medians and auxiliary lanes,
- Curbs, berms, and edging, and
- Cross-slopes.

The relationship of these aspects of cross-section design to multimodal accommodation are also described.

5.1.2.3 Roadside Elements

Section 5.6 provides recommendations for treatment of the roadside elements including:

- Clear zones,
- Slopes and cuts,
- Ditch sections, and
- Barrier systems.

5.1.2.4 Utilities and Signage

Utilities are frequently located within the roadway right-of-way. Considerations for the placement of utilities and roadside signage is discussed in Section 5.7.

5.1.2.5 Right-of-Way

Section 5.8 describes how cross-section elements translate into right-of-way requirements. The necessary right-of-way is the summation of all desired cross-section elements (sidewalks, buffer strips, curbs and berms, shoulders and on-street parking, bicycle lanes, travel lanes, and medians) and roadside elements (clear zones, barriers, drainage ditches, utility poles, signage, snow storage area and maintenance areas).

5.2 Multimodal Accommodation

Multimodal Accommodation Performance Goal:

The designer should provide safe, convenient, and comfortable travel for all roadway users.

Once the purpose and need for a project is defined, the designer should determine the most appropriate way to provide safe, convenient, and comfortable accommodation for all users within the context of the project. This process is aided by input from the public and MassHighway during project planning. Descriptive cases for a range of accommodations are provided to assist the designer's understanding of user accommodation approaches that may be applicable in a variety of contexts.

The first three cases describe roadway sections bounded by curb and sidewalk. These cases are most likely to be found in the more densely developed area types introduced in Chapter 3 (Urban, Suburban Village and Town Center, Suburban High Density, and Rural Village). The remaining two cases are for areas without curb and sidewalk and are most likely to be found in the less developed area types (Rural Natural, Rural Developed, and Suburban Low Density).

These descriptive cases are not intended to be "typical sections" applied to roadways without regard for travel speeds, vehicle mix, adjacent land use, traffic volumes, and other factors since application of "typical sections" can lead to inadequate user accommodation (underdesign) or superfluous width (overdesign). Typical sections also leave little room for judgment reflecting the purpose and context of individual projects and can oversimplify the range of values that may be selected for each element of the cross-section.

In the following descriptions, the multimodal accommodation cases are conceptual and reflect a range of potential dimensions for each element. Once the designer determines the multimodal accommodation desired for the project, the designer should select specific dimensions for each cross-section element within the ranges provided later in this chapter. When assembled, the specific elements influence the necessary right-of-way to achieve the accommodation desired for the project. This desired cross-section can then be compared to environmental constraints and available right-of-way. If necessary, additional right-of-way requirements can be identified and/or further refinements to the cross-section can be made. When an improvement is being pursued as a Footprint Roads project, the designer should provide the best accommodation for pedestrians and bicyclists to the extent possible, consistent with Chapter 87 of the Acts of 1996.

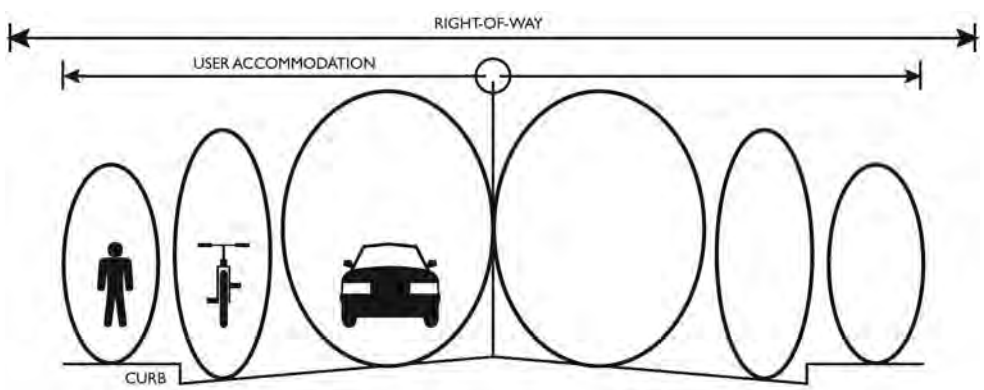
5.2.1 Case 1: Separate Accommodation for All Users

Case 1 provides the maximum separate accommodation for all modes of travel, as illustrated in Exhibit 5-1. This is often the preferred option in terms of providing safe, convenient, and comfortable travel for all users. It is usually found in areas of moderate to high density (urban areas, suburban villages and town centers, suburban high density areas, and rural villages) with curbed roadways.

Case 1 provides for the maximum separation of users, which can provide the highest level of safety and comfort for all users in areas with high levels of activity or where large speed differentials between the motorized and non-motorized modes are present. Case 1 usually requires the most width. In locations where the speed differential between different roadway users is small, or overall activity is low, Case 1 may not be necessary to safely accommodate all users. However, in some instances, this case might be achieved by reallocating space within an existing roadway, thus eliminating potential impacts to the roadside environment.

This case might be considered in a wide variety of conditions including: areas with moderate to high pedestrian and bicycle volumes; areas with moderate to high motor vehicle speeds and traffic volumes; and areas without substantial environmental or right-of-way constraints.

Exhibit 5-1
Case 1: Separate Accommodation For All Users



Source: MassHighway

In Case 1, pedestrians are provided with a sidewalk separated from the roadway by a raised curb and preferably a landscaped buffer. The clear width of the sidewalk should be sufficient to allow pedestrians or wheelchair users to pass without interfering with each others' movement (at least 5 feet excluding the curb and clear from items along the sidewalk such as fire hydrants, signs, trees and utility poles). Sidewalks should be provided on both sides of the street unless there is a condition that suggests that a sidewalk is not needed on one side of the street. This might happen, for example, if there is physical impediment that would preclude development on one side of the street, such as a railroad track or stream.

Provision of a striped bicycle lane or shoulder suitable for bicycle use (4 feet minimum, 5 feet preferred) encourages cyclists to use the roadway. The bicycle lane/shoulder also provides for additional separation between motor vehicle traffic and pedestrians. If on-street parking is present, the bicycle lane should be at least 5 feet wide so that the cyclist is provided with an additional buffer along the parked cars.

Motor vehicles are accommodated within travel lanes wide enough to eliminate encroachment by wider vehicles on either the adjacent bicycle lane or on the opposing motor vehicle travel lane. In addition to providing space for bicycles, shoulders also accommodate emergency stopping, maneuvering, and other functions. Where on-street parking is provided, shoulders or bicycle lanes should be maintained between on-street parking and the travel lane.

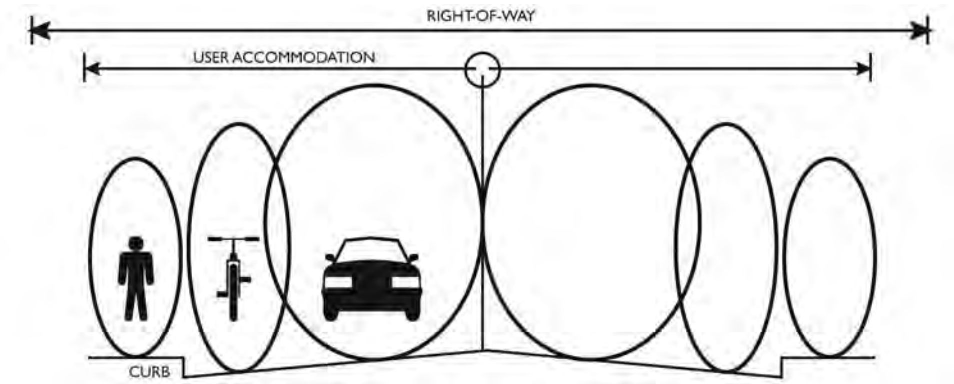
5.2.2 Case 2: Partial Sharing for Bicycles and Motor Vehicles

There are instances in which the width necessary to provide accommodation for case 1 is not available. There are also instances where some sharing and overlap between bicyclists and motor vehicle traffic is acceptable to achieve other environmental or design objectives. Case 2 describes an approach to multimodal accommodation in these situations and is illustrated in Exhibit 5-2.

Case 2 is common in areas of moderate to high density (urban areas, suburban villages and town centers, suburban high density areas, and rural villages), where curbed roadway sections and separate sidewalks are provided.

Pedestrians are provided with a sidewalk separated from the roadway by a raised curb and preferably a landscaped buffer, increasing the safety and comfort of the pedestrian. The clear width of the sidewalk should be sufficient to allow pedestrians or wheelchair users to pass without interfering with each other’s movement (at least 5 feet excluding the curb and clear of other roadside obstructions).

Exhibit 5-2
Case 2: Partial Sharing for Bicycles and Motor Vehicles



Source: MassHighway

In Case 2, there is some overlap between the space provided for bicycle use and that provided for motor vehicle travel. Depending on the lane and shoulder widths provided, Case 2 accommodation may require a Design Exception. Signs or pavement markings indicating that the roadway is shared between cyclists and motor vehicles are appropriate for Case 2 roadways.

This type of accommodation is often used in areas with low motor vehicle speeds, low to moderate motor vehicle traffic volumes, and areas of environmental or right-of-way constraint where a smaller cross-section is necessary.

The designer should carefully consider the allocation of width to travel lanes and bicycle lanes/shoulders to provide the best balance of accommodation between bicycles and motor vehicles. In many instances, on-street parking will also be provided and additional width may be needed to reduce conflicts between bicycles and the adjacent parking. There are different possible configurations of lanes and shoulders possible in Case 2, but all feature some overlap in the space needed by bicyclists and motor vehicles:

- Typical travel lanes combined with narrow shoulders (i.e. 11- to 12-foot lanes with 2- to 3-foot shoulders) provide maneuvering width for truck and bus traffic within the travel lane; however, bicyclists may be forced to ride along and over the pavement markings.

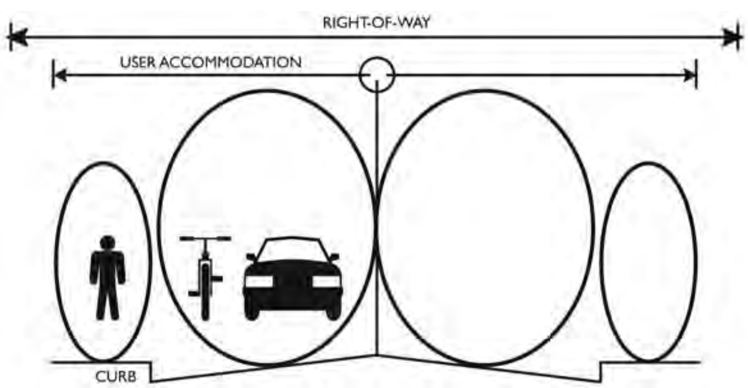
- Narrow travel lanes combined with wide shoulders (i.e. 9 to 11-foot lanes with 4 to 8 foot shoulders) provide greater separation between motor vehicle and bicycle traffic, but may result in motor vehicle traffic operating closer to the center line or occasionally encroaching into the opposing travel lane.

Wide curb lanes have also been used in Case 2; however, studies have shown that motorists and bicycles are less likely to conflict with each other and motorists are less likely to swerve into oncoming traffic as they pass a bicyclist when shoulder striping is provided.

5.2.3 Case 3: Shared Bicycle/Motor Vehicle Accommodation

In Case 3, the accommodation of bicycles and motor vehicles is shared and separate pedestrian accommodation is maintained as illustrated in Exhibit 5-3. Case 3 is most likely to be found in the most densely developed areas (urban areas, suburban villages and town centers and some rural villages) where right-of-way is most constrained. It is also applicable to most residential streets where speeds and traffic volumes are low.

Exhibit 5-3
Case 3: Shared Bicycle/Motor Vehicle Accommodation



Source: MassHighway

Pedestrians are provided with a sidewalk separated from the roadway by a raised curb and preferably a landscaped buffer, increasing the safety and comfort of walking along this roadway. The clear width of the sidewalk should be sufficient to allow pedestrians or wheelchair users to pass without interfering with each other's movement (at least 5 feet excluding the curb and sidewalk clear of other roadside obstructions).

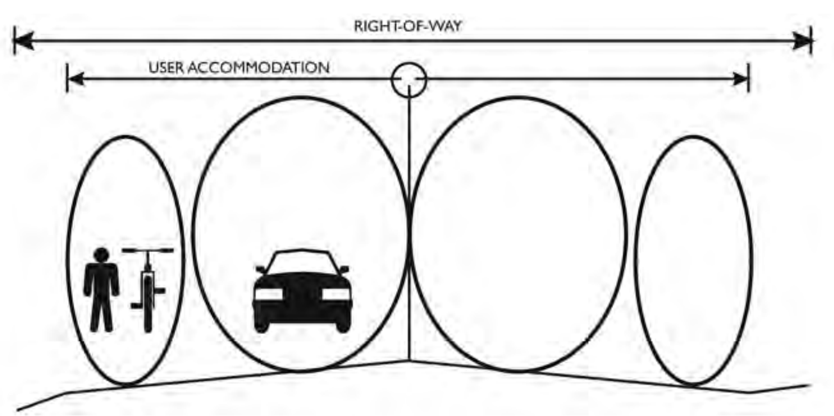
In Case 3, one lane is provided for joint use by motor vehicles and bicycles. For arterial and collector roadways, application of Case 3 will require a Design Exception. This type of accommodation is used in the following conditions: areas with low to moderate motor vehicle traffic volumes; low motor vehicle speeds; and areas of severe right of way constraint where only a minimum pavement section is feasible.

Signs and pavement markings indicating that the roadway is shared between cyclists and motor vehicles should be provided for Case 3 roadways. On-street parking is often found on these roadways and separate shoulders or bicycle lanes are not available.

5.2.4 Case 4: Shared Bicycle/Pedestrian Accommodation

In sparsely developed areas (such as rural natural, rural developed, and suburban low density areas), curbed roadway sections bounded by sidewalk are less common. This case is illustrated in Exhibit 5-4.

Exhibit 5-4
Case 4: Shared Bicycle/Pedestrian Accommodation



Source: MassHighway

In these areas, pedestrians and cyclists are often accommodated on the roadway shoulder. This type of accommodation may be appropriate for areas with infrequent pedestrian activity. In areas with higher pedestrian volumes (either current or anticipated), the pedestrian accommodation described in Cases 1, 2, and 3 is desirable. Pavement striping and a paved shoulder (at least 4-feet wide) for shared pedestrian and bicycle use helps delineate the travel way for motor vehicles, thus increasing safety for all users. Wider shoulders should be provided as motor vehicle speeds and traffic volumes increase.

In Case 4, motor vehicles are accommodated within travel lanes wide enough to eliminate encroachment on the shoulder or the opposing motor vehicle lane. For Case 4, the designer should carefully consider the allocation of right-of-way between travel lanes and shoulders. For example:

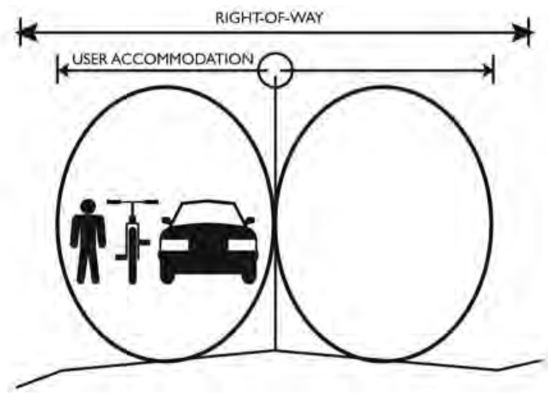
- Typical travel lanes combined with wide shoulders (i.e. 11 or 12-foot lanes with 6-foot or wider shoulders) provide for increased separation between pedestrians, bicyclists motor vehicles. Wider shoulders also provide clearance for emergency stopping and maneuvering.
- Typical travel lanes combined with narrow shoulders (i.e. 11 or 12-foot lanes with 4 foot shoulders) provide maneuvering width for truck and bus traffic within the travel lane, reducing encroachment into opposing lanes and the shoulder. However, conflicts between bicycles and pedestrians are more likely.
- Narrow travel lanes combined with wide shoulders (i.e.,10 to 11-foot lanes with 6 to 8 foot shoulders) provide greater separation between bicyclists and pedestrians, but may result in motor vehicle traffic operating closer to the center line or encroaching on the shoulder.

5.2.5 Case 5: Shared Accommodation for All Users

Vehicles, bicycles, and pedestrians are sometimes accommodated in one shared travel lane, as illustrated in Exhibit 5-5. This condition occurs when there is low user demand and speeds are very low, or when severe constraints limit the feasibility of providing shoulders. With the exception of local roads, Case 5 accommodation will require a Design Exception.

This case provides the smallest pavement width while accommodating all users effectively only in low volume, low speed conditions. Fences, rock walls, tree lines, and other roadside constraints, can further restrict emergency movement by all users. Additional unpaved shoulders or clear zones should be carefully considered to provide additional flexibility and safety. Additionally off-road paths should be considered to improve the accommodation of pedestrians. These paths do not need to follow the road alignment precisely and can sometimes avoid obstacles that preclude sidewalks and shoulders. The designer should note that these paths may be subject to strict interpretation of the walkway design criteria specified in 521 CMR (*Rules and Regulations of the Massachusetts Architectural Access Board).*

Exhibit 5-5
Case 5: Shared Accommodation for All Users



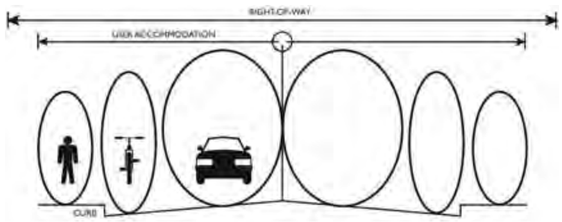
Source: MassHighway

5.2.6 Summary of Accommodation Option

Exhibit 5-6 provides a summary of the multimodal accommodation options available to the designer.

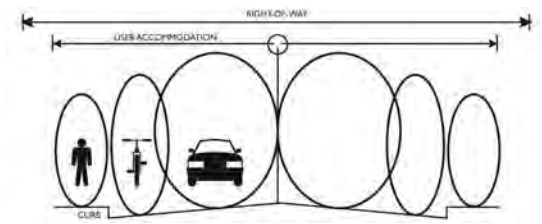
Exhibit 5-6
Summary of Multi-modal Accommodation Options

Case 1: Separate Accommodation for All Users



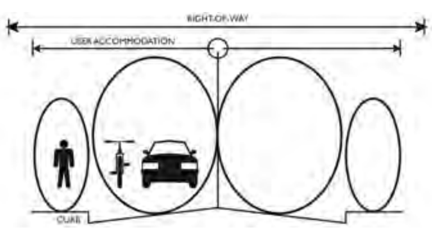
- Often the preferred option to provide safe, convenient, and comfortable travel for all users.
- Appropriate for areas with moderate to high levels of pedestrian and bicycle activity.
- Appropriate for roadways with moderate to high motor vehicle speeds.
- Appropriate in areas without substantial environmental or right-of-way constraints.

Case 2: Partial Sharing for Bicycles and Motor Vehicles



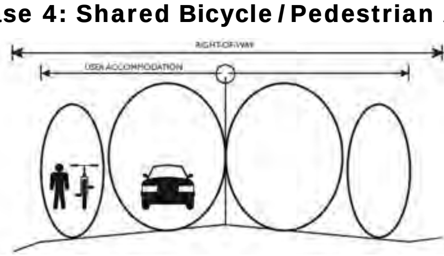
- Used in areas where the width necessary to provide Case 1 accommodation is not available.
- Under Case 2, pedestrians are provided with a sidewalk or separate path while space for bicyclists and drivers overlap somewhat.
- Appropriate in areas with low motor vehicle speeds and low to moderate motor vehicle volumes.

Case 3: Shared Bicycle / Motor Vehicle Accommodation



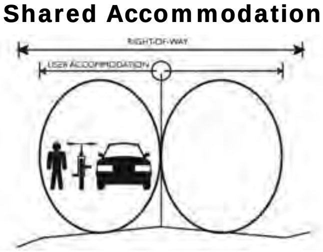
- Under Case 3, pedestrians remain separate but bicycle and motor vehicle space is shared.
- Used in densely developed areas where right-of-way is constrained.
- Also applicable to most residential/local streets where speeds and traffic volumes are low.

Case 4: Shared Bicycle / Pedestrian Accommodation



- Under Case 4, pedestrians and bicyclists share the shoulder.
- Common in rural or sparsely developed areas.
- Appropriate for areas with infrequent pedestrian and bicycle use.

Case 5: Shared Accommodation for All Users



- Under Case 5, all users share the roadway.
- Appropriate where user demands and motor vehicle speeds are very low or when severe constraints limit the feasibility of providing separate accommodation.

Source: MassHighway

5.3 Design Elements

Once the approach to multimodal accommodation is determined, the designer should determine the dimensions of each element to be included in the cross-section. These elements are assembled to develop a desired cross-section. The following sections describe the dimensions of specific cross-section elements that serve different roadway users.

5.3.1 Pedestrians

Pedestrian accommodation should be consistent with the project context, including current or anticipated development density, roadway characteristics, right-of-way dimensions and availability, and community plans. Options for pedestrian accommodation include sidewalks, shoulder use, and shared lanes, as described below, and off-road or shared use paths, as further discussed in Chapter 11.

All roadways along which pedestrians are not prohibited should include an area where occasional pedestrians can safely walk, whether on unpaved walkways, on shoulders in rural or less developed areas, or on sidewalks in more urban areas.

In addition to the type of accommodation, the designer should include other design features that improve the pedestrian environment. For example, the designer can consider selecting a lower motor vehicle design speed that will increase the comfort and safety of the facility for pedestrians. Similarly, the designer should consider geometric features that improve the pedestrian environment, such as crossing islands, curb extensions, and other traffic calming features discussed in more detail in Chapter 16.

The walking path should have a smooth, stable and slip resistant surface that does not induce vibration in wheelchairs and is free of tripping hazards. 521 CMR (*Rules and Regulations of the Massachusetts Architectural Access Board)* apply to "prepared pedestrian ways." Whenever a pedestrian path is created, it must meet the minimum standards for sidewalks ("prepared walks in the public way") or walkways (an exterior path with a prepared surface intended for pedestrian use). These requirements are further discussed in Chapter 6.

5.3.1.1 Sidewalks and Buffers

Sidewalks are paved areas provided along the edges of roadways suitable for pedestrian use. Sidewalks are the most common accommodation provided for pedestrians. Sidewalks are desirable in all areas where pedestrian activity is present, expected, or desired. Sidewalks should be provided in residential areas, near schools, libraries, parks, and commercial areas. Sidewalks should also be provided between transit stops and nearby destinations. Sidewalks should be provided to link residential areas with nearby employment, shopping, and service centers.

In urban areas or village/town centers, raised curb and curb cut ramps are usually provided with sidewalks. A landscaped buffer between vehicular traffic and the sidewalk can provide greater separation from motor vehicles, increasing the comfort and safety of pedestrians. In rural or suburban settings for minor arterials or collector roads with 5 feet or more of buffer space, curbing may not be needed. On-street parking, shoulders, and bicycle lanes can also act as sidewalk buffers.

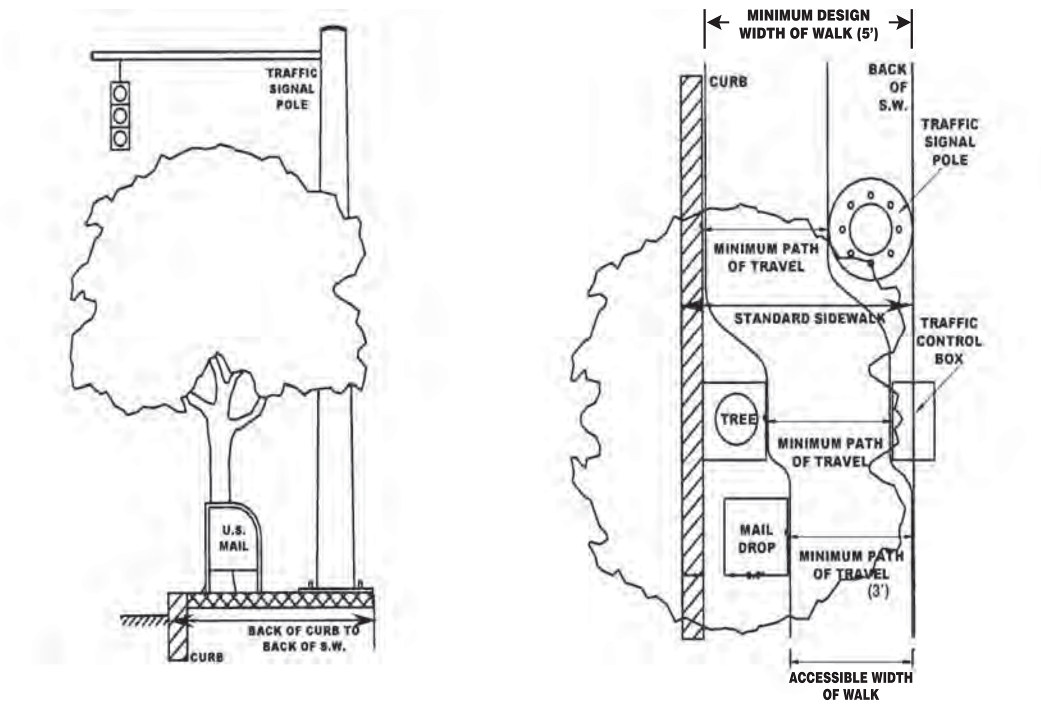
Dimensions and Clear Width

The spatial requirements of pedestrians are described in Chapter 3. The minimum width for a sidewalk is 5 feet excluding the width of the curb, although a 3 foot clear width (plus the width of the curb) is sufficient to bypass occasional obstructions, as illustrated in Exhibit 5-7. When developing plans, the sidewalk is sometimes measured including the width of the curb. If this method of measurement is used, the minimum width of sidewalk is 5 ½ feet.

Wider sidewalks are desirable where there are high pedestrian volumes and where there is no buffer between high speed or high volume roadways. Sidewalk widths of 6 to 12 feet are preferred for most town center and urban locations. Very wide sidewalks (12 to 20+ feet) are also encountered in these settings. Common widths of landscape buffer are between 2 and 6 feet, although larger buffers are possible.

If the sidewalk is not buffered from motor vehicle traffic, then the desirable total width for a curb-attached sidewalk is 6 feet in residential areas and 8 feet in commercial areas.

Exhibit 5-7
Clear Accessible Path

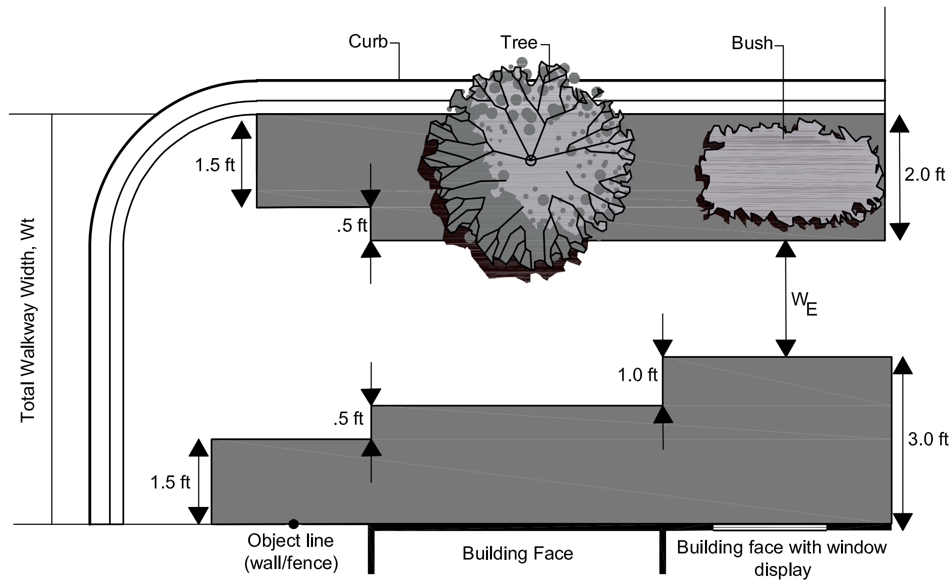


Source: Adapted from the Guide for the Planning, Design, and Operation of Pedestrian Facilities, AASHTO, 2004. Chapter 3 Pedestrian Facility Design

Sidewalks commonly accommodate ***street furniture*** which includes items such as, trees, utilities, streetlights, parking meters, bicycle parking, benches, and refuse barrels. Additionally, sidewalks often abut fences, building edges, or vegetation along their outside edge. These elements influence the required width necessary to accommodate pedestrians, as pedestrians tend to "shy" from these obstructions. The designer should consider the desired location for these sidewalk features and, where they exist, the designer should provide appropriate offsets (or shy distances) to the pedestrian path. Typical ***shy distances*** are illustrated in Exhibit 5-8.

Landscape buffers accommodate a variety of functions, including: safety separation, snow storage, street furniture, landscaping, utilities and traffic control devices. As such, it is preferable that such buffers be at least 5 feet wide.

Exhibit 5-8
Typical Shy Distances Between Sidewalk Elements and Effective Pedestrian Path



Source: Adapted from the Guide for the Planning, Design, and Operation of Pedestrian Facilities, AASHTO, 2004. Chapter 3 Pedestrian Facility Design

All new and reconstructed sidewalks must be accessible to and usable by persons with disabilities. A minimum clear path (W_E) of 3 feet must be continuously provided along a sidewalk. Sidewalk dimensions and clear widths must conform to the accessibility requirements established under 521 CMR (*Rules and Regulations of the Massachusetts Architectural Access Board).*

Sidewalks are also crossed by driveways and intersected by streets. These crossings are described in more detail in Chapter 6. *MassHighway's Standard Construction and Traffic Details* provide illustrations for driveway crossings. As a general approach, the sidewalk should be continuous across driveways and include appropriate transitions for the grade changes associated with these interfaces. For most driveways, it is desirable for the sidewalk elevation to control the driveway design, rather than for the driveway to cut through the sidewalk. However, high volume driveways or driveways exiting high speed roads may be more appropriately designed as intersections, with level connections between the roadway and the driveway. In these cases, pedestrian ramps and crosswalks should be included to provide a continuous path of travel.

Placement

In developed areas, continuous sidewalks should be provided on both sides of a roadway, minimizing the number of pedestrian crossings required. If a sidewalk is provided on only one side of a roadway, the context of the roadway should be the basis for this decision. For example, in undeveloped or low-density areas, or where development is heavily concentrated on one side of the roadway, or there are a significant number of public shade trees, sidewalks on only one side of the road may be sufficient. In these cases, the sidewalk should be provided on the side that minimizes the number of pedestrian crossings. Crosswalks should be provided at reasonable intervals (typically every 200 to 300 feet with maximum separation in developed areas of approximately 500 feet).

5.3.1.2 Shoulder Use

In areas where pedestrian volumes are low, or where both traffic volumes and speed are low, a paved usable shoulder, as described in Section 5.3.3.1, can provide pedestrian accommodation. This occurs primarily in rural natural areas, rural developed, and some suburban low density areas.

On most roadways through sparsely developed areas, a minimum 4-foot shoulder is usually adequate for pedestrian use. A wider shoulder is desirable when there is significant truck traffic or high traffic speeds. The width of shoulders is usually determined through an assessment of pedestrian, bicycle, and motor vehicle needs. When shoulder use is the pedestrian accommodation, it should meet the requirements of “walkways” under 521 CMR, the Massachusetts Architectural Access Board rules and regulations, to the extent feasible.

The decision to use shoulders rather than sidewalks or parallel paths should consider existing and future pedestrian volumes. This is particularly important in developing areas. Even with low pedestrian volumes, it is desirable to provide sidewalks or paths to serve schools, libraries, shops and transit stops.

5.3.1.3 Shared Lanes

Walking within travel lanes may be appropriate for some roadways with very low traffic volumes and vehicle speeds. However, sidewalks or usable shoulders are the preferred accommodation.

Before deciding to provide shared lanes as the only pedestrian accommodation, the designer should be certain that the traffic volumes and vehicle speeds will be low enough, now and in the future, so that all pedestrians can comfortably use the street. When shared lanes are the pedestrian accommodation, they should meet the requirements of “walkways” under 521 CMR, the Massachusetts Architectural Access Board rules and regulations, to the extent feasible.

5.3.1.4 Off Road and Shared Use Paths

A ***shared use path*** is a dedicated facility for pedestrians, bicyclists, roller bladers, etc. Although sidewalks are generally preferred, off-road paths are sometimes suitable in rural and suburban low-density areas. The path should provide the same connectivity as the roadway but can be set back from the roadway and its route can deviate around sensitive environmental areas.

Off-road paths must comply with 521 CMR. Depending on their location to the roadway, these off-road paths may need to meet 521 CMR’s “walkway” regulations as opposed to its “sidewalk” regulations. The slope of sidewalks can follow that of the natural terrain, but the slope of walkways is limited to 5 percent. A walkway that has slopes between 5 percent and 8.3 percent is permitted, but it must meet 521 CMR’s ramp requirements for handrails and rest areas. A walkway that is not along a vehicular way can not have a slope exceeding 5 percent in the build environment. A ramp can not have a slope exceeding 8.3 percent. This is discussed in detail in Chapter 6. The U.S. Access Board guidelines presented in its proposed *Guidelines for Outdoor Developed Areas* provide additional information on the design of paths. The design standards for off-road paths and trails are presented in Chapter 11.

5.3.2 Bicycles

Bicycle accommodation should also be consistent with the project’s context, roadway characteristics, right-of-way, community plans, and the level of service provided for the bicyclist. The designer should ensure that bicycle accommodation is based on anticipated development and community plans.

Bicycles may be present on all highways where they are permitted (bicycles are typically excluded from freeways). In addition to determining the type of accommodation for bicyclists, the designer should include other design features that improve the safety and comfort of the roadway for bicyclists. For example, if motor vehicle speeds are too high, the designer should consider selecting a lower motor vehicle design speed to increase the comfort and safety of the facility for bicycles. Additionally, the designer could consider narrowing motor vehicle lanes to provide wider shoulders. In constrained corridors, even a few feet of striped shoulder can make traveling along a roadway more accommodating for bicycles.

Specific design features that can make roadways more compatible to bicycle travel include uniform widths (where possible), bicycle-safe drainage grates, smooth pavements, adequate sight distances, and traffic signals that detect and respond to bicycles. These design features should be included on all roadways.

Wide cracks, joints, or drop-offs at the edge of the traveled way parallel to the direction of travel can trap a bicycle wheel and cause loss of control, as can holes and bumps in the pavement surface. These conditions should be avoided on all roadways.

Drainage inlet grates and utility covers are potential obstructions to bicyclists. Therefore, bicycle-safe grates must be used, and grates and covers should be located to minimize severe and/or frequent avoidance maneuvering by cyclists. Inlet grates or utility covers in the path of bicycle travel, must be installed flush with the pavement surface. Grates should be hydraulically-efficient versions that do not pose a hazard to cyclists.

The spatial requirements of bicycles are described in Chapter 3. For design purposes a width of 4 or 5 feet is commonly used to accommodate bicycle travel. This portion of the roadway should have adequate drainage to prevent ponding, washouts, debris accumulation and other potentially hazardous situations for bicyclists.

Approaches to bicycle accommodation include bicycle lanes, the use of shoulders, and shared roadways. Off-road shared-use or bicycle paths (see Chapter 11 for more details) are also an option for bicycle accommodation in some limited cases. Also, in some cases, novice bicyclists and children also use sidewalks for cycling.

The FHWA's *Bicycle Compatibility Index* provides a useful tool for reviewing the suitability of various approaches to bicycle accommodation. The types of accommodation typically used are described in the following sections.

5.3.2.1 Bicycle Lanes

Bicycle lanes are portions of the traveled way designed for bicycle use. Bicycle lanes should be incorporated into a roadway when it is desirable to delineate available road space for preferential use by bicyclists and motorists, and to provide for more predictable movements by each. Bicycle lane markings can increase a bicyclist's confidence in motorists not straying into their path of travel. Likewise, passing motorists are less likely to swerve to the left out of their lane to avoid bicyclists on their right. Bicycle lanes are generally considered the preferred treatment for bicycle accommodation. In some cases, they are neither necessary nor desirable due to low-traffic conditions.

Bicycle lanes are most commonly implemented in urban and suburban settings. Frequently, bicycle lanes are found in combination with on-street parking, raised curbs, and sidewalks. In these areas, the bicycle lane also serves the roadway shoulder functions associated with motor vehicles, described in more detail later in this chapter. Contraflow bicycle lanes may be appropriate on one-way streets to increase cyclists connectivity. The treatment of bicycle lanes at intersections and their relationship to turning lanes is provided in Chapter 6.

Dimensions and Clear Width

The minimum width for bicycle lanes is 4 feet when the bicycle lane is adjacent to the edge of pavement; however, 5-foot bicycle lanes are preferred for most conditions, especially when the lane is adjacent to curbside parking, vertical curb, or guardrail. On roadways with higher speeds (50 miles per hour or more) or higher volumes of trucks and buses (30 or more per hour) the minimum bicycle lane width is 5 feet and 6-foot bicycle lanes are desirable. Bicycle lanes wider than 6 feet are generally not used since they may encourage inappropriate use by motor vehicles.

Placement

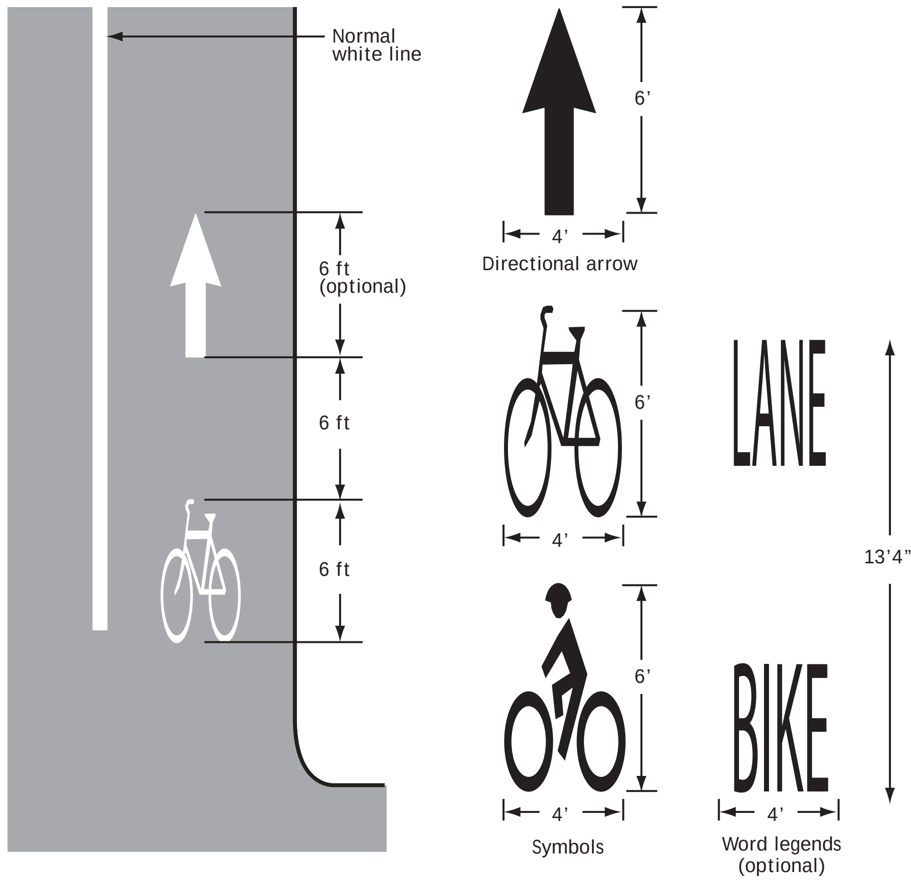
Bicycle lanes are one-way facilities that carry bike traffic in the same direction as the adjacent motor vehicle traffic. Bicycle-specific wrong-way signage may be used to discourage wrong-way travel. On one-way streets, bicycle lanes should be provided along the right side of the road unless unusual conditions suggest otherwise. Bicycle lanes should be designated by a 6-inch solid white line on the right edge of the motor vehicle travel lane. Bicycle lanes within roadways should not be placed between a parking lane and the curb. This situation creates poor visibility at intersections and driveways and it is difficult to prevent drivers from parking in the bicycle lane.

Bicycle lanes should be designated by a 6-inch solid white line on the right edge of the motor vehicle travel lane. This marking should change to a broken white line before any intersections on the right side, providing sufficient distance for motorists to merge to the right side of the roadway before making a right-turn. A 4-inch solid white line or parking space markings on the right edge of the bicycle lane are recommended for added delineation of the bicycle lane when adjacent to parking areas. These markings will encourage parking closer to the curb, providing greater separation between bicycles, parked cars, and moving motor vehicles. These markings can also discourage use of the parking lane and bicycle lane for motor vehicle travel when parking activity is light. Additional bicycle lane pavement markings, as illustrated in Exhibit 5-9, and signage can also be installed to reinforce the intended use of the bicycle lane.

5.3.2.2 Shoulder Use

Much like bicycle lanes, paved shoulders provide space for bicycling outside of the travel lanes. One difference between shoulders and bicycle lanes is that shoulders are usually used for bicycle accommodation in rural and suburban low density areas, where on-street parking, curbs, and sidewalks are rarely encountered. In these locations, shoulders may provide shared accommodation for pedestrians and bicyclists. Another difference between shoulders and bicycle lanes is that the width of shoulders is usually determined through an assessment of combined pedestrian, bicycle, and motor vehicle needs, discussed later in this chapter, in the context of project goals and available space. Additionally, shoulders do not typically include bicycle lane pavement markings.

Exhibit 5-9
Bicycle Lane Pavement Markings



Source: Guide for the Development of Bicycle Facilities, AASHTO, 1999. Chapter 2 Design
Manual on Uniform Traffic Control Devices, FHWA, 2003. Chapter 3 Pavement Markings

To provide bicycle accommodation, shoulders should be at least 4 feet wide. The measurement of the usable shoulder should not include the shy distance from a curb or guardrail where a 5-foot minimum width is recommended. Minimum 5-foot shoulders are also recommended in areas with vehicular speeds over 50 miles per hour, or where truck and bus volumes exceed 30 vehicles per hour, or in areas with on street parking.

Rumble strips, raised pavement markers, or embedded reflectors should not be used where shoulders are to be used by bicyclists, unless there is a minimum clear path of 1-foot from the rumble strip to the traveled way and 4 feet from the rumble strip to the outside edge of paved shoulder. In places adjacent to curb, edging, guardrail or other vertical obstacles, 5 feet between the rumble strip and the outside edge of pavement is desirable. With rumble strips, the total width of the shoulder should be between 7 and 8 feet.

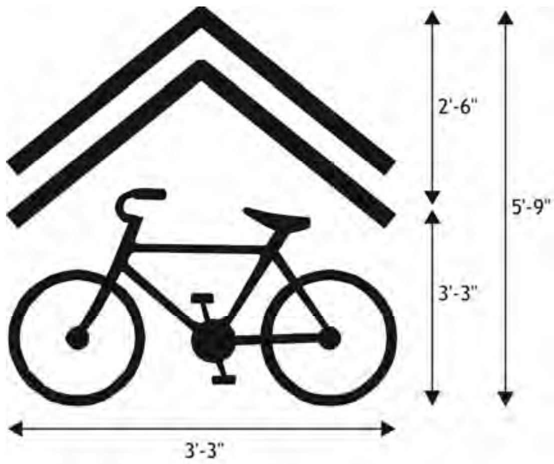
5.3.2.3 Shared Lanes

Shared lanes refer to use of the normal travel lanes by both motor vehicles and bicyclists. By law, bicyclists may use the travel lane. Most roadways in Massachusetts have neither shoulders nor bicycle lanes. Thus lanes shared by motorists and bicyclists are the most common situation. Lanes at least 14 feet wide are generally wide enough to permit motorists to pass bicyclists without changing lanes. On low-volume roadways, motorists will generally be able to pass bicyclists without waiting. If traffic volumes are above a critical threshold, it is desirable to provide enough width for lane sharing.

In cases of low speed, low to moderate traffic volumes, and low occurrence of trucks and buses, the shared lanes may be adequate to support bicycling. Before deciding to provide shared lanes as bicycle accommodation, the designer should be certain that the traffic volumes and motor vehicle speeds will be low enough so that all types of bicyclists can comfortably use the roadway.

In locations where shared lanes are used, the designer should consider using bicycle sharing pavement markings such as those illustrated in Exhibit 5-10 (a demonstration marking currently in use in other states) and “Share the Road” signs as defined in the Manual on Uniform Traffic Control Devices (MUTCD) may also be included in the design. It is important to bear in mind that signs are only a supplement to adequate bicycle accommodation and should never be considered a substitute for them.

Exhibit 5-10
Shared Street Pavement Markings



Source: San Francisco Bicycle Guide

5.3.2.4 Shared Use Paths

Shared use paths are facilities on exclusive right-of-way with minimal cross flow by motor vehicles. Shared use paths should be thought of as a complementary system of off-road transportation routes for bicyclists and others that serves as a necessary extension to the roadway network. The presence of a shared use path near a roadway does not eliminate the need to accommodate bicyclists within a roadway.

Provision of shared-use paths is particularly suited to high-speed, high-volume roadways where the characteristics of traffic flow, roadway geometrics and traffic control are incompatible with bicycle use, except for advanced cyclists. Similarly, shared-use paths can provide a bicycling route parallel to freeways, where bicycling is prohibited. Shared-use paths are also an option in areas of limited right of way or where environmental or cultural resources limit the width of a roadway and a nearby pathway is available. Finally, shared use paths can provide recreational amenities in waterfront areas or near other attractions. Design guidance for shared use paths is provided in Chapter 11.

5.3.3 Motor Vehicles

The major components of the roadway cross-section serving motor vehicle travel are usable shoulders or on-street parking, and travel lanes. In addition to the width of these individual elements, the right lane plus shoulder dimension is important for determining the minimum width for a two-lane two-way roadway, as described later in this chapter.

The width recommendations presented in this section are based on established practices and supplemented by recent guidelines from AASHTO including the recently published *Guide for Achieving Flexibility in Highway Design*. Flexibility is permitted to encourage independent designs tailored to particular situations. For example, MassHighway's Footprint Roads Program is one way designers can seek exemptions from established design criteria under very specific conditions to provide for the preservation of rural, suburban, and village roads.

The width associated with the cross-section elements described in this section is based on the spatial dimensions of design vehicles discussed in Chapter 3. The largest vehicle likely to use the facility on a regular basis is usually selected as the design vehicle and impacts the selection of shoulder and lane width. Usable shoulders, on-street parking, travel lanes, and the right-lane plus shoulder dimension are described in the following sections.

5.3.3.1 Shoulders

The use of shoulders for pedestrian and bicycle accommodation is discussed in the previous sections. ***Shoulders*** are paved and graded areas along the travel lanes to serve a number of purposes as shown in Exhibit 5-11. Shoulders do not include on-street parking since the shoulders can not serve the purposes listed in Exhibit 5-11 if they are occupied by parked cars. On-street parking and its relationship to pedestrian and bicycle accommodation are discussed later in this chapter.

During the planning process, the designer should select an appropriate shoulder width given the roadway's context, purpose and need, bicycle and pedestrian accommodation, speed, and transportation demand characteristics. These considerations should be thoroughly documented in the *Project Planning Report*.

Exhibit 5-11
Minimum Shoulder Width (in feet) to Provide Various Functions

	Roadway Type	
Shoulder Function	Arterials	Collectors
Drainage of Traveled Way	1.0	1.0
Lateral Support of Pavement	1.5	1.0
Encroachment of Wide Vehicles	2.0	2.0
Off-tracking of Wide Vehicles	2.0	2.0
Errant Vehicles	3.0	2.0
Bicycle and Pedestrian Use	4.0	4.0
Emergency Stopping	6.0	6.0
Emergency Travel	6.0	6.0
Mail Delivery and Garbage Pickup	6.0	6.0
Law Enforcement Operations	8.0	6.0
Large Vehicle Emergency Stopping	10.0	10.0
Occasional Travel/Detours	10.0	9.0
Highway Maintenance	8.0	8.0

Source: *Flexibility in Highway Design*, AASHTO 2004. Chapter 6 Cross Section Elements

Exhibit 5-12 provides ranges of shoulder width for different area and roadway types. As shown above, shoulders provide many important safety and operational advantages and the designer should strive to provide 6- to 8-foot shoulders for most arterials. As described in the previous sections, if shoulders are provided for pedestrian or bicycle accommodation their minimum width should be 4 feet.

In areas where horseback riders and agricultural equipment are common, wider shoulders can provide accommodation for these users. In these cases some of the shoulder width can be unpaved.

Exhibit 5-12
Widths of Usable Shoulders (In Feet)

	Roadway Type			
Area Type	Freeways[1]	Arterials[2]	Collectors[2]	Local Roads
Rural Natural	10 to 12	4 to 12	4 to 10	2 to 8
Rural Developed	10 to 12	4 to 12	4 to 10	2 to 8
Rural Village	N/A	4 to 12	4 to 10	2 to 8
Suburban Low Density	10 to 12	4 to 12	4 to 10	2 to 8
Suburban High Density	10 to 12	4 to 12	4 to 10	2 to 8
Suburban Village/Town Center	N/A	4 to 12	4 to 10	2 to 8
Urban	10 to 12	4 to 12	4 to 10	2 to 8

Source: *Flexibility in Highway Design*, AASHTO 2004. Chapter 6 Cross Section Elements

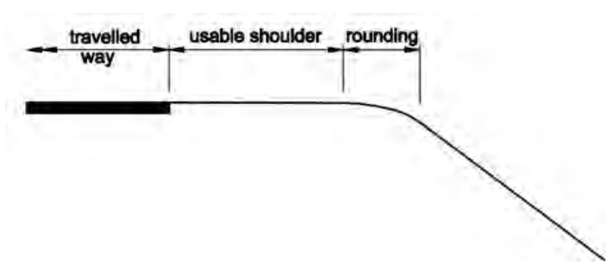
1 Left shoulders are required on Freeways and other divided roadways. See the AASHTO Green Book for left-shoulder guidance.

2 Shoulder widths less than the values shown above may be used if a design exception is obtained. See Chapter 2 for a description of the design exception procedure. Situations where narrower shoulders may be considered are described below.

Note: An additional 2-foot offset from the edge of the shoulder is required to vertical elements over 6-inches in height (such as guardrail).

Minimum 4-foot shoulders are recommended for all arterials and collectors because of the value they provide for bicycle and pedestrian (particularly in rural areas) accommodation, and motor vehicle safety. If a design exception is obtained, shoulders narrower than 4 feet may be used in constrained areas where separate pedestrian accommodation is provided and shared bicycle/motor vehicle accommodation is suitable. Examples of these conditions are where design speeds are less than 45 miles per hour and traffic volumes are relatively low (less than 4,000 vehicles per day), or where the design speed is 30 miles per hour or less. Footprint road projects, as described in Chapter 2, could also consider narrower shoulders.

Exhibit 5-13
Usable Shoulders



Source: Adapted from A Policy on Geometric Design of Highways and Streets, AASHTO 2004, Chapter 4 Cross-Section Elements.

The **usable shoulder** is composed of both a graded shoulder, and, in some cases, rounding of grade transitions at the edge of the roadway, as shown in Exhibit 5-13. Usable shoulders have the following characteristics:

- The area must have a side slope of 1 foot vertical to 6 feet horizontal (1v:6h) or flatter, including rounded areas for grade transitions.
- The area is usually flush with the adjacent roadway and must be free of vertical obstructions higher than 0.5 feet (guardrail, walls, trees, utility poles).
- Shoulders are usually paved. If unpaved, shoulders should be flush with the roadway surface and sufficiently stable to support vehicular use in all kinds of weather without rutting. Additionally, sufficient paved width to accommodate bicycles should be provided.
- An additional 2 feet of clearance should be added to the usable shoulder dimension to allow for an offset to vertical roadway elements over 0.5 feet in height, such as guardrail, bridge rail, concrete barrier, walls, trees, utility poles, etc.
- Usable shoulders must be cleared of snow and ice during the winter months in order to function properly. Therefore, it is often practical for usable shoulders to be paved.
- The edge of the usable shoulder should not be located at the edge of right-of-way. An offset is required for road maintenance, snow removal, and placement of signs.
- In certain instances, usually to control drainage, the use of a mountable berm or edging is permissible within a shoulder area, as discussed later in this chapter.
- At intersections, usable shoulders may be eliminated in order to better provide for turning movements or shorten pedestrian crossing distances. However provisions for bicyclists must be considered when the shoulder is eliminated at intersections.
- Along high speed, high volume roadways, such as freeways, safety considerations may warrant shoulder rumble strips at appropriate locations. (Where bicyclists are permitted, shoulder rumble strips should not be used unless 5 feet of clear shoulder width exists between the rumble strips and the outer edge of the shoulder).

5.3.3.2 On-Street Parking

On-street parking is provided in place of usable shoulders in many different settings to support adjacent land uses. If shoulders are used to accommodate bicycles outside of the on-street parking zone, the designer should maintain the continuity of bicycle routes through the parking zone through the use of bicycle lanes or, at a minimum shared lane markings. Curb extensions are an effective design treatment at intersections and pedestrian crossings that help prohibit illegal parking, reduce the crossing distance for pedestrians, and improve visibility. Curb extensions can be carefully designed so that bicycle travel is not compromised and should only be used in conjunction with active curb-side uses (such as parking or transit stops). Curb extensions should extend no further than 6 feet from the curb (see Chapter 16 for details).

Sidewalks are almost always provided adjacent to on-street parking. Parking provides a buffer between motor vehicle traffic and pedestrians on the sidewalk. On-street parking can also influence the traffic flow along roadways, sometimes resulting in reduced speeds, reduced capacity, and increased conflicts for both bicycle and motor vehicle traffic. Due to its impacts on traffic flow and the safety implications of parking maneuvers at high speeds, on-street parking should not be provided with high design speeds (over 45 miles per hour).

Parking often replaces usable shoulders in village, town center, and urban settings.

Parallel on-street parking requires a minimum of 7 feet of paved cross-section in addition to the required travel lane width and should not be permitted where this width is not available. For areas with high turnover, areas with truck loading, and areas with bus stops, 8 feet of width is recommended. Parking lane widths of 10 feet are desirable in areas with substantial amounts of truck parking or bus stops. Wider parking lanes, up to 12 feet, are established to preserve roadway capacity for possible conversion to travel lanes, or for use as travel lanes during peak periods. However, parking regulations and enforcement are required to preserve the desired operational characteristics of the roadway in these instances.

Requirements for the striping and signage of parallel on-street parking is provided in the *Manual on Uniform Traffic Control Devices* (MUTCD).

Parking can be marked and regulated by time-of-day or other restrictions in high demand/high turnover areas. In other locations, parking may be permitted, but is not formally marked or regulated.

At the time of this Guide's printing, the Federal Access Board's ADA Accessibility Guidelines for public rights of way had not yet been finalized. Notwithstanding this lack of regulation, the Commonwealth and municipalities are required to provide accessible parking if public parking is provided. Accessible parking spaces should be provided in numbers agreed to by localities, and should be located at the end of a block so that they are near a curb cut ramp. Each accessible parking space should be designated with an International Symbol of Access.

On-street angle parking is currently permitted in some rural villages, suburban town centers, and urban areas. Where angle parking is created or retained, the designer should consider back-in angle parking as an alternative to traditional head-in angle parking. Accessible parking should be provided with an adjacent 5-foot to 8-foot access aisle. Eight foot acceptable aisles can accommodate vans with lifts. Additional considerations for angle parking are presented in Chapter 16.

5.3.3.3 Travel Lanes

Travel lanes are the component of the roadway cross section that serves motor vehicle travel, or in some cases, joint use. In most cases, the travel lanes are the widest component of the roadway cross-section. The number of lanes in each direction should be determined based on the design year transportation demand estimates and the selected design level of service determined in the project planning process (see Chapters 2 and 3). In some instances it may be possible to reduce the number of travel lanes to provide sidewalks, landscape buffers, bicycle lanes, and crossing islands.

The width of travel lanes is selected through consideration of the roadway context, approach to multimodal accommodation, the physical dimensions of vehicles, speeds, and other traffic flow characteristics. The normal range of design lane width is between 10 and 12 feet. Travel lanes between 11 and 12 feet in width are usually selected for design cross-sections and are particularly desirable for roadways with higher design speeds (45 miles per hour or more), higher traffic volumes (2,000 or more vehicles per day), or higher truck and bus activity (greater than 30 per hour). Exhibit 5-14 summarizes travel lane widths for various area and roadway types.

Exhibit 5-14
Range of Travel Lane Widths (In Feet)

	Roadway Type			
Area Type	Freeways	Arterials[1]	Collectors[2]	Local Roads
Rural Natural	12	11 to 12	10 to 12	9 to 12
Rural Developed	12	11 to 12	10 to 12	9 to 12
Rural Village	N/A	11 to 12	10 to 12	9 to 12
Suburban Low Density	12	11 to 12	10 to 12	9 to 12
Suburban High Density	12	11 to 12	10 to 12	9 to 12
Suburban Village/Town Center	N/A	11 to 12	10 to 12	9 to 12
Urban	12	11 to 12	10 to 12	9 to 12

1 Lane widths less than the values shown above may be used if a design exception is obtained. See Chapter 2 for a description of the design exception procedure. Situations where narrower lanes may be considered are described below.
2 Minimum 11-foot lanes are required for design speeds of 45 miles per hour or greater.
N/A Not Applicable

Source: Adapted from A Policy on Geometric Design of Highways and Streets, AASHTO 2004, Chapter 4 Cross-Section Elements.

In addition to through lanes, ***auxiliary lanes*** such as additional turning lanes, high-occupancy vehicle (HOV) lanes, climbing lanes, or other lanes may be provided on steep grades, at intersections, or in other special circumstances. Turning lanes at intersections are discussed in detail in Chapter 6. Other auxiliary lanes are discussed later in this chapter. For multilane roadways, the additional lanes (if provided) may be different widths than the curb lanes.

Lanes Wider than 12 Feet

Lanes wider than 12 feet are sometimes used where shoulders are not provided, such as in rural villages, suburban high-density areas, suburban villages and town centers, or urban areas. Another application of wide lanes is in areas with high driveway density. This application provides more maneuvering room for drivers entering or exiting driveways, or in areas of limited sight distance. In these cases wide lanes are typically 12 to 14 feet wide. However, if more than 12 feet is available, it is often preferable to stripe a shoulder.

If necessary, the designer should include additional width on curves to minimize encroachment into opposing traffic, adjacent travel lanes, bicycle lanes, or sidewalks since vehicles off-track, which means that their travel path exceeds the width of the vehicle.

If high volumes of bus and truck traffic are anticipated on a roadway, such as in an industrial park, or on a dedicated busway, the designer may consider whether lanes wider than 12 feet are appropriate.

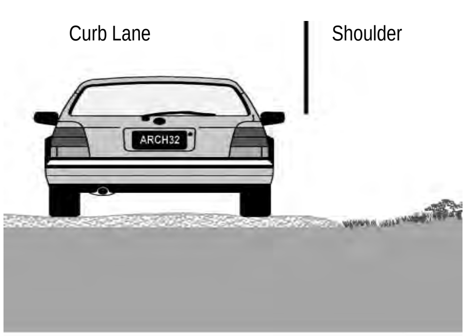
Lanes Narrower than 11-Feet

Narrower lanes reduce the amount of right-of-way dedicated to motor vehicle travel, leaving room for wider sidewalks, bicycle lanes, shoulders and on-street parking. Narrower lanes also reduce the crossing distance for pedestrians and can encourage lower operating speeds. In some settings, narrower lanes help to reduce the impact to roadside environmental or cultural resources. For lower speed, lower volume roads that primarily provide access to adjoining property, (such as minor collectors and local roads) narrower lanes may be appropriate to minimize right-of-way requirements and potential impacts to the built and natural environment.

In areas of limited right-of-way, 10-foot lanes can be provided so that the width of the shoulder can be increased to provide greater separation between pedestrians and bicycles and motor vehicles. The following section discusses the relationship between lane width and shoulder width.

Travel lanes narrower than 10 feet are only appropriate for local roadways and some minor collectors with very low traffic volumes and speeds. Lanes narrower than 9 feet are generally not recommended. However, on some low-volume local roads in residential areas, shared streets that do not allow two cars to pass simultaneously may be provided.

5.3.3.4 Curb Lane Plus Shoulder Width



Curb lane plus shoulder

Independent of the allocation between shoulders and travel lanes, the total width of the curb lane plus shoulder available for bicycle and motor vehicle travel is an important design element. For two-lane roadways, the curb lane plus shoulder width is key for determining the minimum cross-section. For example, a 14-foot curb lane plus shoulder dimension will allow a motor vehicle to pass a bicyclist without needing to change lanes (on a multilane section) or swerve into the oncoming lane (on a two lane section) and is the minimum value for collectors determined using Exhibit 5-11 and 5-14. This example results in a width of 28 feet for a two-lane collector. Using the minimum values in Exhibits 5-11 and 5-

14, the minimum width for a two-lane arterial is 30 feet. Although these minimum examples are provided, the allocation of the pavement width between the curb lane and shoulder should be determined on a project-specific basis, as described in Section 5.2.

5.3.4 Complete Cross-Section Guidance

The previous sections provide guidance and dimensions for accommodation of individual roadway users within the cross-section. The following sections provide more specific guidance for the assembly of cross-sections based on the area and roadway types introduced in Chapter 3 including a discussion of the specific elements and dimensions commonly used in different area types.

5.3.4.1 Freeways

Freeways are the only class of road on which pedestrian and bicycle travel is prohibited, except in unusual or emergency circumstances. Shared use paths are possible within freeway right-of-way to accommodate pedestrian and bicycle travel. The design guidelines for these paths are presented in Chapter 11.

Freeways should have a minimum of two through lanes for each direction of travel. The lanes should be 12 feet wide. Right and left shoulders should also be provided on freeways. Along the right side of freeways, 10-foot shoulders should be provided. The right shoulder should be increased to 12 feet when truck and bus volumes are greater than 250 per hour.

Along the left side of four-lane freeways, 4-foot shoulders should be provided and 8-foot shoulders are desirable. On six (or more) lane freeways, 10-foot left shoulders should be provided. If truck and bus volumes are greater than 250 per hour, then the left shoulder should be increased to 12 feet. An additional 2-foot offset is required from the edge of usable shoulder to any vertical barrier. Additionally, for freeways, rumble strips are recommended along the outside edge of the traveled way to alert errant drivers that they have left the traveled way.

Freeway design standards for Interstate Highways are established by the Federal Highway Administration (FHWA) since they are components of the National Highway System (NHS). Freeways are unlikely to pass through rural villages and suburban town centers since the design characteristics of freeways are incompatible with these area-types.

Some two-lane major arterials are also designed as high-speed roadways with access limited to grade-separated interchanges. Freeway standards may also be appropriate for these roadways.

5.3.4.2 Arterials and Major Collectors

Arterials and major collectors vary widely in character depending upon the areas through which they pass. Arterials and major collectors almost always accommodate pedestrian and bicycle travel. In most instances, arterials and major collectors are designed to accommodate pedestrians and bicycles using the first four cases described in Section 5.2.

Minor arterial in a town center

Sidewalks are usually provided in developed areas (suburban high density areas, suburban villages and town centers and urban areas). Sidewalks may also be desirable in areas with lower development density such as suburban low density areas, rural developed areas and rural villages. In rural natural areas and other sparsely developed areas, pedestrian travel is often accommodated in the shoulder or by side paths.

Usable shoulders are usually provided on arterials and major collectors outside of densely developed areas. In most cases, these shoulders are at least 4 feet wide to accommodate bicycle travel. Shoulders between 6 and 8 feet wide are desirable for emergency stopping and other functions, especially in high volume and high truck and bus areas. When design speeds are high (greater than 45 miles per hour) 10-foot shoulders should be considered. In the case of wide shoulders, it is possible to provide a combination of paved and unpaved surfaces if the circumstances dictate such a treatment.

In rural villages, suburban town centers, and urban areas, usable shoulders are often replaced with on-street parking. In these areas it is desirable to provide bicycle lanes to maintain separate accommodation for bicycles. If there is insufficient right-of-way to support bicycle lanes and parking, then the designer should determine which element to provide within the available right-of-way or should consider traffic calming and shared lane pavement markings to improve the performance of shared bicycle/motor vehicle accommodation.

Travel lanes of 11 and 12 feet are usually provided on arterials and major collectors. In high volume, high truck and bus percentage, and high design speed areas, 12 foot lanes are particularly desirable. 10-foot lanes are sometimes used if speeds and truck and bus volumes are low (less than 250 per day or 30 in one hour), in multilane sections, or to provide wider shoulders in areas of limited right-of-way. Major collectors are sometimes constructed with 10 foot lanes in rural villages, suburban villages and town centers, and urban areas where right of way is particularly limited and competing demands are especially high. Lanes narrower than 10 feet are generally not used on arterials or major collectors.

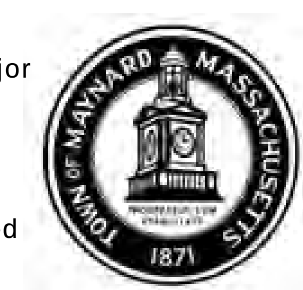
In most cases, the designer should provide a combined shoulder plus curb lane dimension of at least 14 feet so that motor vehicles can pass bicycles without changing lanes or swerving.

5.3.4.3 Minor Collectors

The design of minor collectors is similar to that described above, especially for areas with higher traffic volumes and speeds. However, minor collectors are often designed for low speed, low volume operations. In these cases, minor collectors are sometimes designed to provide shared accommodation for all users, as described in Section 5.2, Case 5, with a curb-lane plus shoulder width of at least 12 feet. The designer may need to consider traffic calming measures to ensure that motor vehicle speeds are appropriate for shared use of the roadway.

5.3.4.4 Local Roads

Local roads are generally constructed to comply with municipal requirements. However, the guidance provided for arterials and major collectors is suitable for local roads with high volumes and high speeds. Much like minor collectors, local roads are sometimes designed to provide shared accommodation for all users. Local requirements should be used to determine the cross-section required for these roadways. On some low-volume local roads in residential areas, shared streets that do not allow motor vehicles to pass simultaneously are acceptable. The designer may need to consider traffic calming measures to ensure that motor vehicle speeds are appropriate for shared use of the roadway.



Local roads should meet municipal standards

5.4 Public Transit Operations

Public transit often operates on roadways. In some cases, rail transit operates within the roadway right-of-way. In other cases, buses operate within mixed traffic and stop along the curbside. Also, a roadway design can incorporate lanes dedicated to, or with priority for, transit operations. The following sections discuss these public transit considerations associated with roadway cross-section. A more detailed discussion of design for transit stops at intersections is provided in Chapter 6.

5.4.1 Rail Transit Facilities

In some areas, rail transit operates within the roadway right-of-way. The designer needs to coordinate with the transit agency to ensure that the physical and operational needs of the rail transit facilities are accommodated within the design. In many cases, the cross-section needs to establish an adequate width to support the track layout, stations and waiting areas. It also needs to accommodate the use of lifts or ramps that might be located within the rail vehicle or on the loading platform. The spatial requirements for these elements varies depending upon the type of rail transit operation and rail vehicle characteristics present or planned for the roadway.

5.4.2 Bus Stops

Project designers must consult with regional transit authorities to determine proper locations for bus stops.

The spacing of bus stops is a critical determinant of transit vehicle and system performance. The consideration of where to locate bus stops is a balance between providing short walking distances to bus stops and the increased travel time when the bus stops frequently. Thus, the decision of bus stop location should be made by the transit agencies and the communities. Bus stop locations also need to carefully consider the availability of sidewalks, crosswalks, and waiting areas. The role of the designer is to evaluate proposed locations to ensure that they are appropriate with regards to safety and operations.

This chapter focuses on mid-block bus stops since bus stops located at intersections are discussed in Chapter 6. Mid-block stops are generally located adjacent to major generators of transit ridership and offer the following advantages:

- Mid-block stops minimize the sight distance impacts of buses on pedestrians crossings (i.e. limited ability to see around the bus).
- Mid-block stops may result in less congested passenger waiting areas.

There are difficulties associated with mid-block stops; for example, mid-block stops create crossing difficulties for pedestrians unless a mid-block crosswalk is also provided. Bus stops and pedestrian routes should be considered together to make sure that the stops are safe and convenient for users (people tend to walk up to ¼ mile to access bus routes). Mid-block stops also require the removal of on-street parking for a substantial distance to accommodate the pull-in, stop, and pull-out maneuvers.

5.4.2.1 Bus Stop Dimensions

The two primary categories of bus stops are (1) curb-side bus stops and (2) bus bays. The most common are curb-side bus stops where the bus simply stops at the curb in the travel lane, shoulder or parking lane. A variation of this is a stop at a curb extension. Bus bays allow the through traffic to flow freely past the stopped bus. Most bus bays occur at mid-block locations, although it is sometimes desirable to create bus bays for far-side stops, with or without a queue jumper lane.

Curbside Bus Stop Zones

The minimum length of bus stops is 80 feet for mid-block bus stops and 60 feet for bus stops at intersections. These dimensions are for a typical 40-foot transit bus. Where articulated buses are used an additional 20 feet is required. Shorter distances may be acceptable to accommodate transit vans or mid-size buses.

An additional 50 feet of length is needed for every additional bus that is typically at the stop at the same time. Unless the stop is used for the layover of buses, a single stop position will be adequate if peak hour bus flow is less than 30 per hour.

Often the curbside stop makes use of a parking lane. Parking lanes are typically 7 to 8 feet wide. Buses require a minimum width of 10 feet. Therefore, if there is significant bus activity along a corridor and it is desirable to allow through traffic to pass unimpeded, a wider parking lane should be provided. In areas without on-street parking, a wide shoulder should be provided if bus stops are frequent and dwell times are long. Some variation to these guidelines may be necessary in constrained areas with sensitive roadside resources.

Bus Bays

The designer must determine when bus bays are more appropriate than curb-side bus stop zones. Among the factors are:

- Traffic in the curb lane exceeds 250 vehicles during the peak hour,
- Traffic speed is greater than 40 mph,
- Bus volumes are 10 or more per peak hour on the roadway,
- Passenger volumes exceed 20 to 40 boardings an hour,
- Average peak-period dwell times exceed 30 seconds per bus, and
- Buses are expected to layover at the location.

60-foot transit bus

It should be noted, however, that when traffic volumes approach 1,000 vehicles per hour per lane, bus drivers tend not to use bus bays due to difficulties encountered in re-entering traffic lanes. Consideration should be given to these operational issues when contemplating the design of a bay on a high-volume road. Acceleration lanes, signal priority, or far-side placements are potential solutions.

Ideally the design of bus turnouts should include tapers and lanes for deceleration and merging, but it is usually not practical to provide deceleration and merging lanes. Some key design elements are:

- A taper of 5 feet in length for every 1 foot of depth (5:1) is the minimum for deceleration. When the bus stop is on the far side of the intersection, the intersection may be used as the entry area to the stop.
- A taper of 3 feet of length for every 1 foot of depth (3:1) is the minimum for reentry. Where the stop is on the near side of the intersection, the width of the cross street is usually sufficient to provide the needed merging space.
- Bus bay widths should be 12 feet, although 10 feet is sufficient when traffic speeds are 30 mph or less.

5.4.2.2 Bus Stop Waiting Areas

The design for the curb-side elements of the bus stop (shelters, boarding platforms, walkways) must conform to ADA requirements. The ADA regulations, as well as the TCRP report *Guidelines for the*

Location and Design of Bus Stops, provide detailed information. Among the key design elements are:

- An accessible pedestrian route to the bus stop.
- To accommodate use of a wheelchair lift, there must be a level (2 percent) landing area at least 60 inches wide. The depth of the landing area must be 8 feet. The bus stop pad must be free of obstructions.
- Bus shelters are typically 5 to 6 feet wide and 10 feet long. Interior clearance of 4 feet is required. Ideally, the shelters area should be sized for the anticipated volume of waiting passengers during peak boarding periods. They must be at-grade or ramped to accommodate a person using a wheelchair.

Bus waiting area

In addition to ADA requirements, the designer should consider urban design issues associated with the location of bus stops including:

- The character and adequacy of access routes for pedestrians, cyclists, and other potential transit users,
- Connectivity to nearby demand centers,
- Streetscape treatments to improve the visual character of the bus stop, and
- Architectural elements of shelter design or selection.

5.4.3 Dedicated Lanes

In some locations, lanes are provided for the exclusive or preferential use by transit vehicles. On most arterials and collectors, the curb lane is most commonly designated as a dedicated or priority transit lane. This choice allows the transit vehicle to stop at curbside bus stops. Often, these lanes are shared with bicycles, right-turning vehicles, taxicabs, bicyclists, or high occupancy vehicles.

Another alternative is to provide dedicated transit lanes within a center median. In this case, passengers must cross the other roadway lanes to reach the transit facility. This alternative operates in a manner similar to rail transit, described earlier in this section.

On freeways and other high-speed, limited access arterials, transit operations, such as express bus routes, can be accommodated in high occupancy vehicle lanes. These lanes are usually located adjacent to a center median.

For all dedicated or priority lanes, the designer should strive to provide adequate lane and shoulder width so that transit vehicles operate with minimal interference from general traffic.

5.5 Other Cross-Section Elements

The following sections describe three important elements of cross section design, medians and auxiliary lanes, cross-slopes required for positive drainage, and curbing.

5.5.1 Medians and Auxiliary Lanes

A ***median*** is the portion of a roadway separating opposing directions of the traveled way. Medians can influence the quality of service and safety provided for all roadway users. For example, medians can break up the width of a roadway and provide refuge for pedestrians crossing the street and vehicles (including bicycles) making turning or crossing movements. Continuous medians can increase the speeds along a roadway, improving its efficiency for motor vehicles; however, this increased speed can have a negative impact on neighborhoods and on the safety of pedestrians and bicyclists. Potential traffic calming applications of medians are discussed further in Chapter 16. Medians can also be used to manage property access, channelize traffic movements, and accommodate aesthetic treatments.

Median width is expressed as the dimension between the edges of traveled way and includes left shoulders if they are provided. A uniform median width is desirable. However, variable width medians may be advantageous where right of way is restricted, at-grade intersections are widely spaced, or an independent alignment is desirable to minimize cut and fill, to minimize environmental impacts, or for aesthetic purposes.

The type of median selected and its dimensions will depend upon many factors, including:

- Area type,
- Roadway type,
- Availability of right of way,
- Transportation demands,

- Pedestrian and bicycle crossings,
- Presence and type of transit operations,
- Design speed,
- Clear zone and recovery area guidelines,
- Landscaping and aesthetic considerations,
- Drainage needs,
- Snow and ice impacts,
- Maintenance considerations, and
- Superelevation impacts.

Medians are most frequently used on multilane roads. Medians may also be included on two-lane roadways; however additional travelway width is often required for emergency vehicle access.

In some cases, medians include auxiliary (turning) lanes that provide access to driveways or increase capacity and safety at intersections. These auxiliary lanes are discussed in more detail in Chapter 6. Several different types of medians are possible as described in the following sections.

5.5.1.1 Raised Medians

Raised medians are central areas at an elevation higher than the surface of the road. A raised curb usually provides this elevation difference. Raised medians are usually found on arterials, collectors and local roads in more densely developed areas with design speeds of 45 miles per hour or less.

Raised medians are often the preferred median type in areas with high pedestrian crossings, where access control is desired, or where decorative landscaping is desired. Raised medians offer some advantages over other median treatments including:

- Mid-block left turns are eliminated,
- Space is available for aesthetic treatments,
- A protected location is available for traffic signs, signals, pedestrian, bicycle, and turning traffic refuge;,
- Left-turns can be more effectively channelized,
- A location is provided for snow storage,
- The median edges are discernible, and

- Drainage may be improved.

Some disadvantages of raised medians when compared to other median treatments include:

- They are more expensive to construct,
- They may require greater widths than other median to serve the same function (e.g., left-turn lanes at intersections),
- Curbs may cause a driver to lose control if struck, and
- Prohibiting mid-block left turns may overload street intersections and may increase the number of U-turns

The minimum total width of the raised median should be 6 feet which allows for a 4-foot raised area with a 1-foot offset between the outside edge of the raised area and the travel lane. In areas with low pedestrian and bicycle activity, raised areas may use sloped edging. This configuration provides the minimal width median and minimum offsets between the travel lane and vertical curb.


Typical raised median on an urban arterial

In most cases, it is desirable to provide an 8- to 10-foot median with a 6-foot raised refuge area and 1- to 2-foot offsets between the vertical curb and the travel lane. Where refuge is required for pedestrians and bicycles vertical curb should be used. Additionally, crossings should be carefully located to serve desired crossing locations and accessibility must be provided for wheelchair users.

Wider medians, between 10 and 18 feet, more effectively support landscaping, provide higher quality refuge, provide increased lateral clearance to signage, streetlights, and landscape features, and support left-turn lanes. When left turns are provided at intersections, an 18-foot width is desirable to support a 12-foot turn lane and maintain a 6 foot median, although narrower configurations are possible. The designer must consider sight distance limitations and potential obstacles when selecting median plantings.

5.5.1.2 Flush Medians

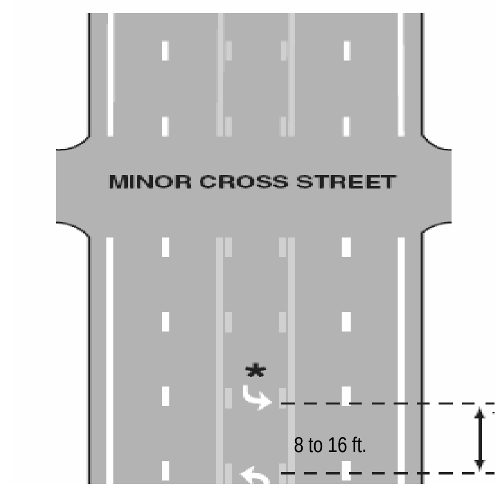
Flush medians contain a central area at approximately the same elevation as the roadway surface. Flush medians are usually found on arterials, collectors and local roads in areas with limited right-of-way. Flush medians may be found on freeways if combined with a median barrier.

A flush median is generally paved and may or may not have a barrier depending on traffic conditions. It is normally crowned to provide positive drainage and discourage parking. The median is often designated using scored concrete or pavement markings. All flush medians should be marked according to the criteria in the *Manual on Uniform Traffic Control Devices* (MUTCD).

When included on arterials, collectors and local roads to provide left-turn lanes, the median is usually between 12 feet and 16 feet wide. The 16-foot median provides for a 4-foot separation from the opposing traffic. In areas with low truck and bus volumes, a left-turn lane as narrow as 10 feet can be provided, reducing the desirable median width to 14 feet. Where left shoulders are provided, the dimension required for usable shoulder should be added to the above median widths.

Two-Way Continuous Left-Turn (TWLT) Lanes

The ***two-way left-turn lane*** is a special application of flush medians which allows turning movements along its entire length. TWLTs may be appropriate in areas with frequent driveway spacing in highly developed, or commercialized areas. Two-way left-turn lanes are appropriate on roadways with no more than two through lanes in each direction and where operating speeds are in the range of 30 miles per hour.



Center two-way left turn lane striping

TWLT lanes may be used where daily traffic through volumes are between 10,000 and 20,000 vehicle per day for 4-lane roadways and between 5,000 and 12,000 vehicles per day for 2-lane roadways. Left-turn movements should consist of at least 70 turns per ¼ mile during the peak hours and/or 20 percent of the total volume. Careful evaluation of individual sites is required for implementation of TWLT lanes.

The signage and striping patterns for TWLT lanes should be designed in accordance with the MUTCD. Lane widths between 12 and 16 feet are suitable for TWLT lanes. On roadways with high volumes, or moderate to high speeds (30 to 45 miles per hour) a 14-foot TWLT lane should be provided. TWLT lanes are not appropriate on roadways with design speeds greater than 45 miles per hour.

In most cases, it is preferable to provide a raised median with periodic turn lanes serving major driveways and intersecting streets instead of a TWLT lane. This preferred treatment provides improved delineation of turning movements and improved pedestrian refuge. However, if driveway spacing is frequent and turning volumes are heavy, then the two-way left-turn lane may be suitable. Access management techniques such as driveway consolidation to facilitate the preferred treatment are discussed in Chapter 15.

5.5.1.3 Depressed Medians

Depressed medians contain a downward sloping central area below the roadway surface, which is usually grassed. Depressed medians are found on freeways and high speed, multilane arterials in rural and suburban settings. Depressed medians are used to separate traffic flows and to provide for roadway drainage. Depressed medians also facilitate the separate alignments for the two directions of the roadway.

A depressed median is usually unpaved and wide enough to provide for a drainage ditch below the roadway gravel subbase. Generally, depressed medians provide better drainage and snow storage than flush or raised medians.

A depressed median is normally a minimum of 60 feet wide, which accommodates most clear zone requirements (see Section 5.6) and allows for two 4-foot left shoulders, 1v:6h or flatter slopes, a 3-foot wide ditch bottom and a 3-foot ditch depth. Greater median widths, within the constraints of right of way, environmental impacts, and construction costs, are desirable. When selecting a width for a depressed median, these additional factors should be considered:

- The appropriate roadside recovery area for the roadway should be considered as outlined in Section 5.6, and
- Provisions for future additions of traffic lanes should be considered.

5.5.1.4 Context Influence on Median Design

Design of medians varies considerably based on the area through which the roadway passes. In rural natural, rural developed, and suburban low density areas, wider medians are often selected. In suburban high density, and urban areas, narrow medians are more frequently encountered. The addition of medians in rural villages, suburban villages and town centers, and some urban areas may conflict with the character of these areas and should be considered carefully from an urban design perspective.

Similarly, the additional right-of-way required for medians may result in increased costs, environmental impacts, and community impacts. The benefits and impacts of providing a median and its width should also be carefully considered. In many cases medians can occupy right-of-way that could be used for other purposes such as bicycle lanes, on-street parking, and wider sidewalks. In cases where medians are proposed for aesthetic purposes, the designer should consider whether it is more advantageous to locate the landscaped space along the sides of the roadway.

In all areas, if a median is desired, a narrow median or barrier, such as double-faced guardrail or concrete “jersey” barriers, may be appropriate to limit the needed right of way and impacts to the natural or built environment. However, for freeways and major arterials, wider medians may provide greater safety and operational benefits and may allow separate alignments for each direction of travel, reducing the impact of the roadway on the surrounding context. While double-faced guardrail or concrete “jersey” barriers may conflict with the character of a particular area, there are times when a constrained width that requires separation calls for these types of barriers to minimize land use impacts.

5.5.1.5 Roadway Type Influence on Median Design

The functions that a median provides vary depending on the type of roadway on which they are found. Medians are provided on all freeways and some arterials, primarily to achieve safety and operational benefits through access management. On collectors and local roads, medians are provided primarily for access management, aesthetic reasons, to provide a location for traffic signals and signage, and to provide refuge for pedestrians or bicyclists crossing the road. Typical median functions for different roadway types are shown in Exhibit 5-15 and discussed in the following sections.

Exhibit 5-15
Typical Median Functions by Roadway Type

Median Function	Freeways	Arterials	Collectors and Local Roads
Separation from opposing traffic	X	X	
Access management	X	X	X
Refuge area for pedestrians and bicyclists		X	X
Refuge for emergency stops	X	X	
Area for control of errant vehicles	X	X	
Reduction in headlight glare	X	X	
Area for deceleration and storage of left-turning and U-turning vehicles		X	X
Enforcement and traffic management areas	X	X	X
Area for storage of vehicles crossing at intersections		X	X
Space for snow storage	X	X	
Landscaping (Medians greater than 10 feet wide)		X	X
Increased drainage collection area	X	X	
Area for placement of luminary supports, traffic signs, traffic signals, guardrail, and bridge piers	X	X	X
Area for future additional lanes (Medians greater than 30 feet wide)	X	X	X

Source: *Flexibility in Highway Design*, AASHTO 2004. Chapter 6 Cross Section Elements

Freeways

All freeways include medians, although the width varies depending upon the surrounding context and the presence of barriers within the median. The median width is often selected to eliminate the need for a center barrier since the warrants for a median barrier are partially dependent upon the median width (see Section 5.6). Many times, the median widths of 60 feet or more are selected. Freeway medians, either with or without a center barrier should provide sufficient width for emergency stopping, maintenance activity, and snow storage.

Designing medians to ensure proper drainage is of the utmost importance since the highest speed on freeways and multilane arterials usually occurs in the left lane along the median edge.

Arterials

Medians are also desirable on arterials carrying four or more lanes. However, the designer should usually provide the most desirable accommodation for roadway users before dedicating space to a median. The median width is often selected based on the need for left-turn storage lanes. Additionally, for unsignalized or rural roadways, a median must be at least 25 feet wide to allow a crossing passenger vehicle to stop safely between the two roadways; however, at signalized intersections, wide medians can lead to inefficient traffic operations. Medians in the range of 12 to 25 feet are commonly selected for these types of roadways.

Collectors and Local Roads

Medians may also be included in the design of collectors and local streets, although these applications are less frequent given the lower speeds and volumes associated with these roadway types. In these cases, medians are often included to enhance the visual appearance of a roadway through decorative landscaping rather than to realize substantial safety or operational benefits. Medians in these circumstances are usually at least 10 feet wide to improve the health of the landscaping and to facilitate its maintenance.

5.5.2 Cross Slopes

Surface cross slopes are necessary on all components of the cross-section to facilitate drainage. This reduces the hazard of wet pavements and standing water. On hot-mix asphalt pavement travel lanes should be designed for a cross slope of 2 percent. Concrete pavements cross slopes should be designed to 1.6 percent for lanes adjacent to the crown, and 2 percent for all other lanes. For lower classes of pavement, higher cross slopes may be desirable to achieve the design drainage. Cross-slopes should also be provided on sidewalks, shoulders, parking lanes, intersections, driveway crossings, and bicycle lanes. 521CMR requires that these cross slopes may never exceed 2 percent in the built condition. MassHighway requires that designers specify them at 1.5 percent to allow for construction tolerances.

5.5.3 Curbs, Berms and Edging

Curbs, berms, and edging are roadside elements, usually constructed of granite or extruded bituminous concrete used to define the pavement edge and to control drainage. Typical types of curbs, berms, and edging and their heights are provided in Exhibit 5-16. The construction details for these elements are illustrated in the *MassHighway Standard Construction and Traffic Details*.

Exhibit 5-16
Typical Curb Heights

Curb Type	Vertical Height (inches)
Bridge curb	8
Barrier curb	6
Sloped edging	4
Type A berm	2

Adapted from A Policy on Geometric Design of Highways and Streets, AASHTO, 2004. Chapter 4 Cross Section Elements

Barrier curbs are vertical and are usually granite. Barrier curbs range in height from 6-to-8 inches with a batter of 15:1 or steeper. Six inch curbs are typically used along roadways. ***Bridge curbs*** are barrier curbs, usually with 8-inch reveal used on bridges to provide additional protection for pedestrians or other bridge elements along the roadside. However, even these curbs are not adequate to prevent a vehicle from leaving the roadway. Where positive protection is required, a suitable traffic barrier should be provided.

Curbs are used extensively on urban and suburban streets and highways. Curbs are not commonly used in rural areas unless they are protecting an adjacent sidewalk. Curbs help restrict vehicles to the pavement area, and define points of access to abutting properties. Vertical curbing is appropriate on lower speed, urban streets where landscaping, signal equipment, streetlights, or other features are located within the median or along the roadside. Vertical curbing should also be used on crossing islands and other locations where protection of pedestrians is needed.

Sloped edging is usually granite and should be used for edge delineation and on traffic islands when design speeds are greater than 45 miles per hour since vertical curbs are not suitable for the high speed environment.

Type A Berm is usually extruded bituminous concrete and can be used when drainage control is needed on roadways that do not have continuous curb. It directs water to closed drainage systems, prevents sloughing of the pavement edge and provides additional lateral support. The Type A berm should be used only:

- where the longitudinal grade exceeds 5% for an extended length, or
- where control and collection of drainage is otherwise required.

Pavement milling mulch, or other suitable material, should be used in lieu of berm under guardrails and in other areas where control of erosion from roadway runoff is a concern.

If the paved shoulders on high speed facilities are not wide enough for a vehicle to move out of the traveled way, sloped edging or berms should be easily mountable to encourage motorists to park clear of the traveled way. Berms or sloped edging used in these situations is 4 inches or less in height and have rounded or plane sloping faces.

5.6 Roadside Elements

Roadside features significantly affect safety, construction and maintenance costs, right of way requirements, drainage, environmental impacts, and aesthetics. The following sections outline the clear zone concept, the treatment of ditch sections and transverse slopes, roadside and median barriers, and impact attenuators. The designer should consult the 2002 AASHTO *Roadside Design Guide* which provides standards and recommendations on the design of roadside elements including clear zones, roadside barriers, median barriers, impact attenuators, side slopes/cuts, and ditch sections.

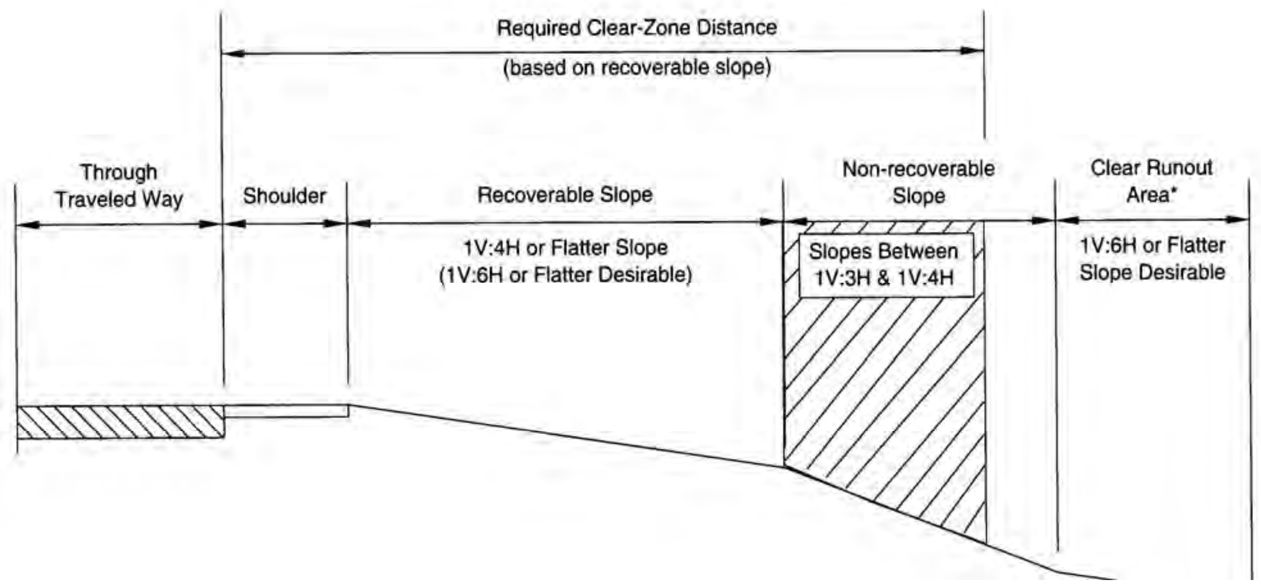
5.6.1 Clear Zones

Clear zones, also referred to as recovery areas, are traversable, unobstructed roadside areas beyond the edge of the traveled way, available for safe use by errant vehicles. This area may consist of a shoulder, a recoverable slope, a non-recoverable slope, and/or a clear run-out area. It should be free and clear of hazards or fixed objects. The width is dependent upon the traffic volumes and speeds, and on roadside geometry. If clear zones cannot be provided, the designer should provide roadside barriers to shield hazards. Clear zones are not normally used in the low speed environment found in densely developed urban and suburban areas.

The designer should consult the 2002 AASHTO *Roadside Design Guide* for further information on clear zones. Obstacles located within the clear zone should be removed, relocated, redesigned or shielded by traffic barriers or crash cushions. If signs, lighting and/or traffic signals are required within the recovery area, breakaway posts should be used or safety treatments must be provided.

The presence of longitudinal slopes, horizontal curves along the roadway, drainage channels, and transverse slopes may influence the recommended clear zone distances. Engineering judgment must be used to determine how much clear zone to provide. These considerations are discussed below and illustrated in Exhibit 5-17.

Exhibit 5-17
Illustration of Clear Zones, Slopes, and Runout Areas



* The Clear Runout Area is additional clear-zone space that is needed because a portion of the Required Clear Zone (shaded areas) falls on the non-recoverable slope. The width of the Clear Runout Area is equal to that portion of the Clear Zone Distance that is located on the non-recoverable slope.

Source: Roadside Design Guide, AASHTO, 2002. Chapter 3 Roadside Topography and Drainage Features

5.6.1.1 Longitudinal Slopes

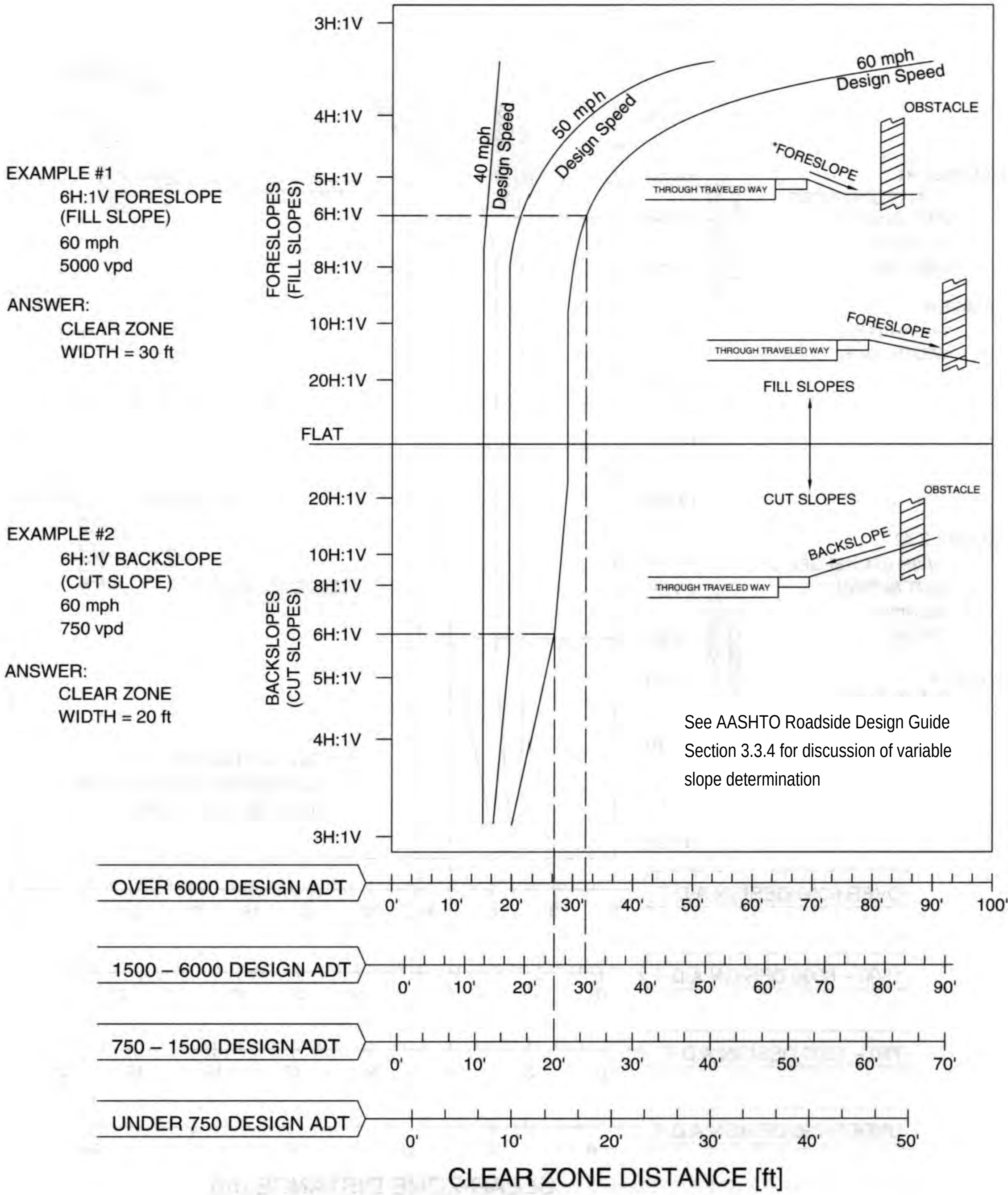
Longitudinal slopes can be either foreslopes or backslopes and run parallel to the roadway. The designer will need to account for these slopes when determining the recommended clear zone. A ***foreslope*** occurs when the roadway is located on a fill and the clear zone slopes down from the roadway. ***Backslopes*** occur when the roadway is located on a cut and the clear zone slopes up from the roadway.

In the case of a backslope within the clear zone, the required distance may be less than the clear zone indicated for a flat roadside. In the case of a foreslope, the required distance may be greater than the clear zone indicated for a flat roadside. Foreslopes can be either recoverable, traversable non-recoverable, or non-traversable, defined as follows:

- **Recoverable Slopes -** A roadway foreslope of 1v:4h or flatter on which a motorist may retain or regain control of a vehicle.
- **Traversable Non-Recoverable Slope** - A roadway foreslope steeper than 1v:4h but flatter than 1v:3h. With slopes of this type in the clear zone, additional run-out area is required at the toe of slope to provide adequate recovery area
- **Non-Traversable Slope** - A roadway foreslope 3h:1v or steeper. On these slopes the errant vehicle is likely to overturn. These slopes are by definition non-traversable and non-recoverable. Barrier protection should be considered when these slopes are located within the clear zone.

The clear zone distance accounting for longitudinal slopes will depend on the degree of the slope, design speed, and roadway design ADT. Exhibit 5-18 illustrates the influence of slopes on the recommended clear zone distances. Exhibit 5-19 provides the recommended clear zones for various slope conditions. When the clear zone contains a traversable non-recoverable foreslope, additional clear zone distance is needed to account for this slope.

Exhibit 5-18
Longitudinal Slope Influences on Clear Zone Distances



Source: Roadside Design Guide, AASHTO, 2002. Chapter 3 Roadside Topography and Drainage Features

Exhibit 5-19
Recommended Clear Zone Distances

		Foreslopes			Backslopes		
Design Speed	Design ADT	6h:1v or flatter	5h:1v to 4h:1v	3h:1v	3h:1v	5h:1v to 4h:1v	6h:1v or flatter
40 mph or less	Under 750	7–10	7–10	**	7–10	7–10	7–10
	750-1500	10–12	12–14	**	10–12	10–12	10–12
	1500-6000	12–14	14–16	**	12–14	12–14	12–14
	Over 6000	14–16	16–18	**	14–16	14–16	14–16
45-50 mph	Under 750	10–12	12–14	**	8–10	8–10	10–12
	750-1500	14–16	16–20	**	10–12	12–14	14–16
	1500-6000	16–18	20–26	**	12–14	14–16	16–18
	Over 6000	20–22	24–28	**	14–16	18–20	20–22
55 mph	Under 750	12–14	14–18	**	8–10	10–12	10–12
	750-1500	16–18	20–24	**	10–12	14–16	16–18
	1500-6000	20–22	24–30	**	14–16	16–18	20–22
	Over 6000	22–24	26–32*	**	16–18	20–22	22–24
60 mph	Under 750	16–18	20–24	**	10–12	12–14	14–16
	750-1500	20–24	26–32*	**	12–14	16–18	20–22
	1500-6000	26–30	32-40*	**	14–18	18–22	24–26
	Over 6000	30-32*	36–44*	**	20–22	24–26	26–28
65-70 mph	Under 750	18–20	20–26	**	10–12	14–16	14–16
	750-1500	24–26	28–36*	**	12–16	18–20	20–22
	1500-6000	28–32*	34–42*	**	16–20	22–24	26–28
	Over 6000	30–34*	38–46*	**	22–24	26–30	28–30

* Where a site-specific investigation indicates a high probability of continuing crashes, or such occurrences are indicated by crash history, the designer may provide clear-zone distances greater than the clear-zone shown in Exhibit 5-18. Clear zones may be limited to 30 feet for practicality and to provide a consistent roadway template if previous experience with similar projects or designs indicates satisfactory performance.

** Since recovery is less likely on the unshielded, traversable 3h:1v slopes, fixed objects should not be present in the vicinity of the toe of these slopes. Recovery of high-speed vehicles that encroach beyond the edge of the shoulder may be expected to occur beyond the tope of slope. Determination of the width of the recovery area at the toe of slope should take into consideration right-of-way availability, environmental concerns, economic factors, safety needs, and crash histories. Also, the distance between the edge of the through traveled lane and the beginning of the 3h:1v slope should influence the recovery area provided at the toe of slope. While the application may be limited by several factors, the foreslope parameters which may enter into determining a maximum desirable recovery area are illustrated in Exhibit 5-17.

Source: Roadside Design Guide, AASHTO, 2002. Chapter 3 Roadside Topography and Drainage Features

5.6.1.2 Horizontal Curves

The presence of a horizontal curve along the roadway may influence the designers recommended clear zone along the outside of the curve. Exhibit 5-20 may be used to adjust the outside clear zone distance based on the degree of the horizontal curve and the design speed of the roadway. These modifications are normally considered only when crash history indicates a need, or a specific site investigation shows a definitive crash potential that could be lessened by increasing the clear zone width, and when such increases are cost-effective. The designer may use superelevation on the horizontal curve which may offset the need to increase the clear zone distance. However, snow and ice conditions may limit the ability to use increased superelevation.

Exhibit 5-20
K_{cz} (Curve Correction Factor)

Radius (ft.)	Design Speed (mph)						
	40	45	50	55	60	65	70
2860	1.1	1.1	1.1	1.2	1.2	1.2	1.3
2290	1.1	1.1	1.2	1.2	1.2	1.3	1.3
1910	1.1	1.2	1.2	1.2	1.3	1.3	1.4
1610	1.1	1.2	1.2	1.3	1.3	1.4	1.5
1430	1.2	1.2	1.3	1.3	1.4	1.4	—
1270	1.2	1.2	1.3	1.3	1.4	1.5	—
1150	1.2	1.2	1.3	1.4	1.5	—	—
950	1.2	1.3	1.4	1.5	1.5	—	—
820	1.3	1.3	1.4	1.5	—	—	—
720	1.3	1.4	1.5	—	—	—	—
640	1.3	1.4	1.5	—	—	—	—
570	1.4	1.5	—	—	—	—	—
380	1.5	—	—	—	—	—	—

$CZ_C = (L_C)(K_{CZ})$

Where: CZ_C = clear zone on outside of curvature, meters (feet)

L_C = clear zone distance, feet, refer to Exhibit 5-18/Exhibit 5-19 (or Figure 3.1/Table 3.1in 2002 Roadside Design Guide)

K_{CZ} = curve correction factor

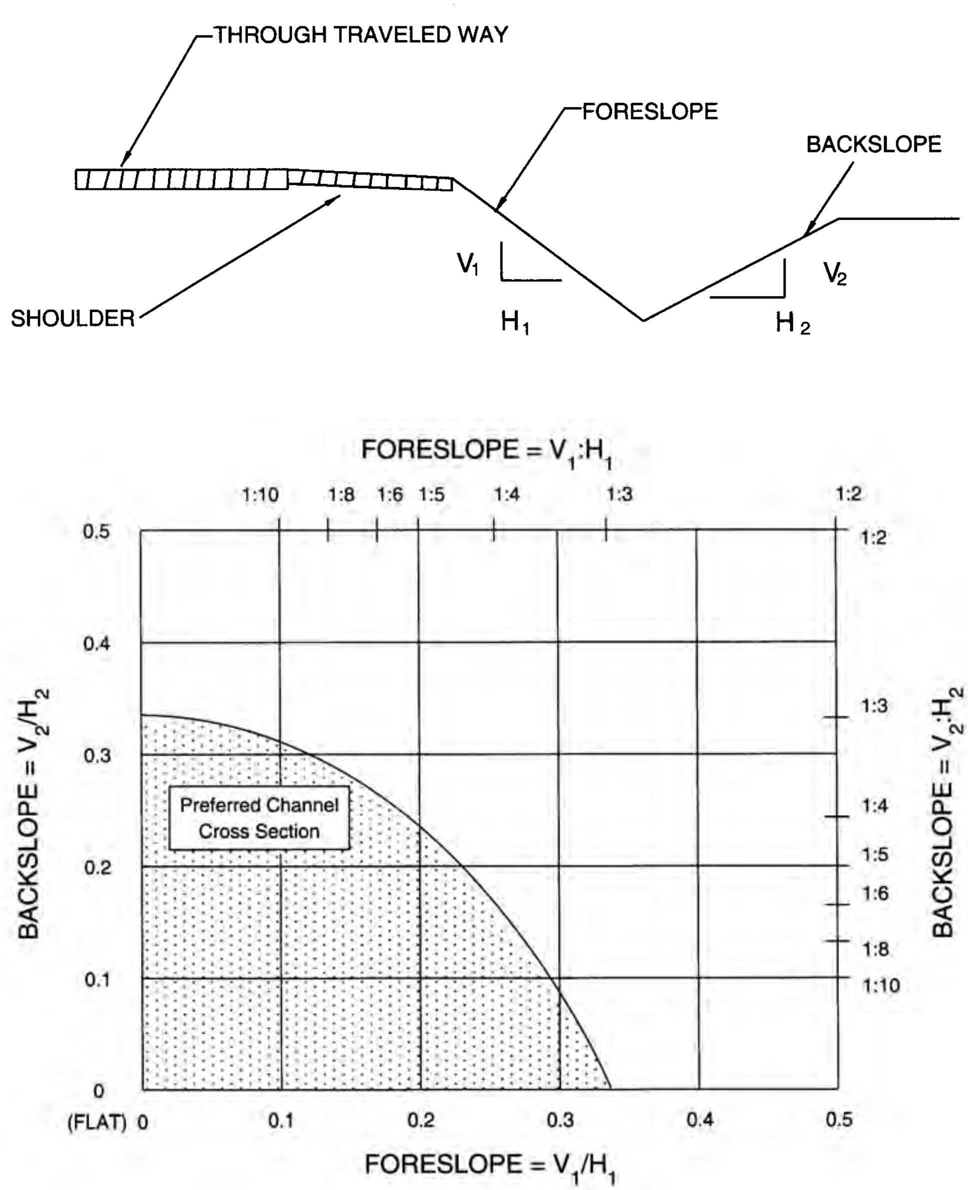
Note: The clear-zone correction factor is applied to the outside of curves only. Curves flatter than 2,860 feet do not require an adjusted clear zone.

Source: Roadside Design Guide, AASHTO, 2002. Chapter 3 Roadside Topography and Drainage Features

5.6.1.3 Drainage Channels

Drainage channels must be designed, built, and maintained with consideration given to their effect on the roadside environment. Drainage channels must also be in compliance with the MassHighway Stormwater Handbook. Drainage channel may be located within the roadway's clear zone provided it meets specific geometric requirements to safely accommodate an errant vehicle. The geometric requirements for these channels are discussed in Chapter 8 of this Guidebook, and Chapter 3 of the AASHTO *Roadside Design Guide,* and illustrated in Exhibits 5-21 and 5-22.

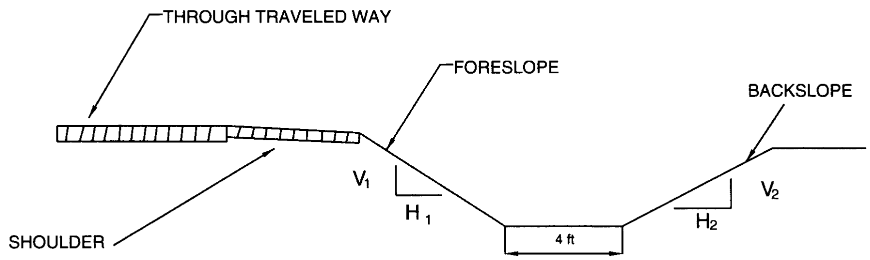
Exhibit 5-21
Preferred Ditch Cross-section

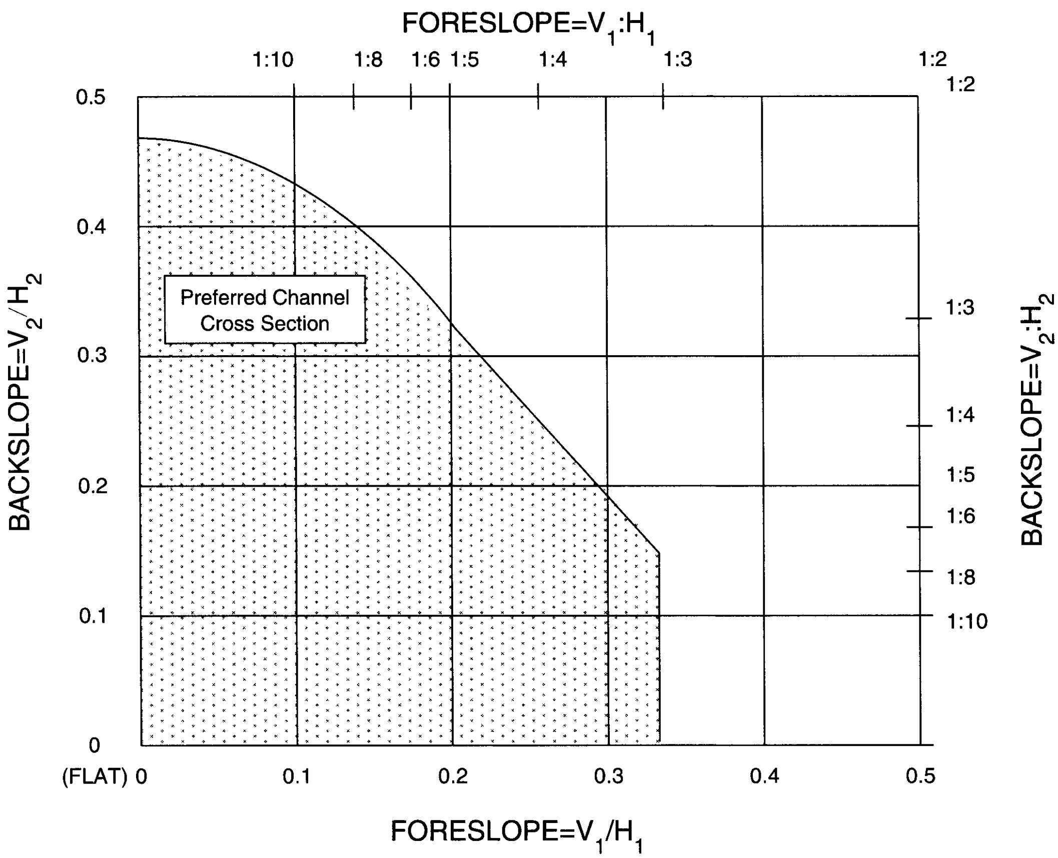


* This chart is applicable to all Vee ditches, rounded channels with a bottom width less than 8 ft. and trapezoidal channels with bottom widths less than 4 ft.

Source: Roadside Design Guide, AASHTO, 2002. Chapter 3 Roadside Topography and Drainage Features

Exhibit 5-22
Preferred Trapezoidal Channel Cross-section





This chart is applicable to rounded channels with bottom widths of 8 feet or more and to trapezoidal channels with bottom widths of 4 feet or more.

Source: Roadside Design Guide, AASHTO, 2002. Chapter 3 Roadside Topography and Drainage Features

5.6.1.4 Transverse Slopes

Common obstacles on roadsides are transverse slopes created by median crossovers, berms, driveways, or intersecting side roads. A ***transverse slope*** is a slope, offset into the clear zone, created by median crossovers, berms, driveways, or intersecting side roads. These are generally more critical to errant motorists than longitudinal slopes because they are stuck head-on by errant vehicles. Transverse slopes of 1v:10h or flatter are desirable. Transverse slopes of 1v:6h or flatter are suggested for high-speed roadways, particularly for that portion of the slope that is located immediately adjacent to traffic. This slope can then be transitioned to a steeper slope as the distance from the through traveled way increases. Transverse slopes steeper than 1v:6h may be considered for densely developed areas or lower speed facilities.

5.6.2 Roadside Barriers

Roadside recovery areas as discussed in Section 5.6.1 should be provided when practical. Where this is not feasible or practical, roadside barriers must be considered when there is a history of run-off-road collisions or when there is a significant potential for such collisions. A ***roadside barrier*** is a longitudinal barrier used to shield motorists from natural or manmade obstacles located along the roadway. Barriers may occasionally be used to protect pedestrians and bicyclists from vehicular traffic. A single-faced longitudinal barrier installed either in the median or on the outside of the roadway is referred to as a roadside barrier. A double-faced longitudinal barrier which is designed to redirect vehicles striking either side of the barrier is referred to as a median barrier, as described in Section 5.6.3.

The primary purpose of barriers is to prevent a vehicle from leaving the roadway and striking a fixed object or terrain feature that is considered more dangerous than the barrier itself. This is accomplished by containing and redirecting the impacting vehicle.

Several design selection criteria are consulted when determining the type of roadside barrier.

Roadside barriers are usually categorized as flexible, semi-rigid, or rigid, depending on their deflection characteristics on impact. Flexible systems are generally more forgiving than the other categories since much of the impact energy is dissipated by the deflection of the barrier. Rigid systems are generally more durable and relatively low in cost when considering their maintenance-free characteristics. Semi-rigid systems provide a combination of these characteristics.

Once it has been decided that a roadside barrier is warranted, the designer must choose the appropriate type of barrier. This choice is based on a number of factors including performance criteria, cost (construction and maintenance), and aesthetics. The *Roadside Design Guide* should be consulted for more information on barrier selection. The following factors should be considered when selecting a barrier system.

- **Performance Capability**: The barriers must be structurally able to contain and redirect the design vehicle.
- **Deflection**: Barriers may require a buffer to account for their flexing during impact. The expected deflection of the barrier must not exceed the available room for this deflection.
- **Site Conditions**: The slope approaching the barrier and the distance from the traveled way may preclude or suggest the use of some barrier types.
- **Compatibility**: The barrier must be compatible with the planned end anchor and capable of transition to other barrier systems such as bridge railings
- **Cost**: Standard barrier systems are relatively consistent in cost, but high-performance railings and aesthetically designed barriers can cost significantly more.
- **Maintenance**: Several factors relating to maintenance are important considerations in barrier selection. These include:
  - ***Routine***: Few systems require a significant amount of routine maintenance.
  - ***Collision***: Generally, flexible and semi-rigid systems require significantly more maintenance after a collision than rigid systems.
  - ***Materials Storage***: Consistency in barrier systems used reduces the needed inventory of spare parts.
  - ***Simplicity***: Simple designs cost less and are more likely to be properly installed and maintained.
  - ***Aesthetics***: Barrier aesthetics are an important consideration to ensure visual consistency with the surrounding context. These considerations are discussed further in Chapter 13.

- ***Field Experience***: Performance and maintenance monitoring data of existing systems should be considered to identify problems that could be reduced or eliminated through selection of a different barrier system.

The following sections describe the types of barriers typically used.

5.6.2.1 Flexible Systems

Flexible systems are designed to provide substantial “give”, or even break away upon impact. They slow an errant vehicle, but sometimes will not completely prevent a vehicle from leaving the roadway area. For this reason, flexible systems require large “clear zones” beyond the edge of the traveled portion of a roadway.

Cable Systems

In the past, a common type of flexible system used routinely in Massachusetts was the three-strand cable system. Three and four-strand cable systems have also been used by other states. Cable systems use posts that are driven into the ground at fixed vertical intervals along the roadside and have other cables attached to them. This system is designed to wrap around the colliding vehicle and redirect it with minimal impact to the vehicle and its occupants. The vehicle's force stretches the cables and the posts bend or break. As this occurs the vehicles’ kinetic energy is dissipated. There are numerous variations on this basic system that have differing hardware, terminal treatments, post intervals, and cable heights. Because this system requires elasticity to deflect the vehicle, adequate clear space from potential hazards beyond the guardrail is essential.

Cable systems are inexpensive and simple to install and they are relatively inexpensive to repair. Because they have little surface area, cable systems do not create much wind resistance or accumulate drifting snow. This facilitates winter maintenance. Roadway snow removal is also simplified because snow can be pushed through the cables. Finally, the cable systems are quite unobtrusive, aiding visibility and forming a visually attractive alternative to many heavier guardrail systems.

However, the cable systems also have several drawbacks. They can sustain considerable damage in vehicular crashes or by snowplows. Also, to be fully effective, the cables must be maintained at the proper tension levels and at the right heights. In a majority of instances, cable tension relaxes over time, creating slackness. Maintenance is required to keep the cables properly tensioned.

Approximately 95 percent of rollover crashes are caused by what is known as “tripping force.” Tripping force occurs when an errant vehicle slides with lateral motion, often with its wheels dug into soft soils or granular materials. If the vehicle reaches critical sliding velocity and hits a low obstacle, such as a slack cable, it is likely to roll over. This is especially true for sport utility vehicles that have a high center of gravity. Alternatively, low weight vehicles can hit a slack cable system and "trampoline" back into traffic causing multi-vehicle crashes.

For these reasons, MassHighway does not routinely use cable systems, However, cable systems are sometimes appropriate in areas that have low to moderate traffic speeds and volumes, and abundant clear space beyond the edge of the roadway, provided that the use of such a system is based on sound engineering judgment. The AASHTO Roadside Design Guide should be consulted for more information on cable systems.

5.6.2.2 Semi-Rigid Systems

The following semi-rigid systems are often used on MassHighway projects:

- **Blocked-Out W-Beam** - This system uses a heavy post with a block out and corrugated steel face (W-beam). Typical post spacing is 6 feet 3 inches on center. Posts may be either steel or wood. The details for this system are shown in the *MassHighway Construction Standards*.

- **Blocked-Out Thrie Beam** - This system is similar to the blocked-out W-beam guardrail, except a deeper corrugated metal face is used. The deeper beam will minimize the possibility of underride or vaulting by impacting vehicles. The details for this system are shown in the *MassHighway Construction Standards*.
- **Steel Backed Timber Rail** - This system consists of heavy wood rail backed with a steel plate and installed on heavy wood posts. Its rustic appearance is sometimes more compatible with the surrounding area. The cost premium may be an important consideration. It may be used only on low volume facilities with design speeds under 55 miles per hour as confirmed by recent crash tests reported in 2002 *AASHTO Roadside Design Guide*.

Because only the full height straight sections have been crash tested, this system must transition to other approved systems at termini and on sharp curves.

5.6.2.3 Rigid Systems

The concrete safety shape barrier is often used in MassHighway projects. The most commonly used concrete safety shape barrier is the F-shape barrier. The F-shape barrier is preferred over other designs because of its better performance with small vehicle impact with respect to vertical roll and redirection. The details for this system are shown in the *MassHighway Construction Standards*.

5.6.2.4 Roadside Barrier Requirements

Once a potential roadside hazard (fixed objects or non-traversable slopes) has been identified, determining barrier warrants involves these steps:

1) Is the hazard within the recovery zone?
2) Can the hazard be removed, relocated, or made breakaway?
3) Can the slope be flattened to provide recovery area?
4) Is the barrier less of an obstacle than the hazard it will shield?
5) Is a barrier installation practical, based on engineering judgment?

Barrier installation guidelines are presented below:

- **Fixed Object and Non-Traversable Hazards** - The barrier warrants for hazards within the roadside recovery zone are to be found in the most recent AASHTO *Roadside Design Guide*, also shown in Exhibit 5-23.
- **Embankments** - Generally, barrier is required to protect slopes steeper than 1:4. Barrier may also be warranted based on the speed, traffic volumes, crash history, and cost-effectiveness. See Exhibit 5-24 to 5-26 for embankment warrant criteria.
- **Bridge Rails or Parapets** (overpass) - These will require an approach section which will securely attach to the rail or parapet. Roadside barrier should also be installed on the trailing end of the bridge, if its end is within the recovery area for opposing traffic. The *MassHighway Construction Standards* provide the details for the transition and attachment to the bridge.
- **Ditches** - See the *AASHTO Roadside Design Guide*.

- **Traffic Signal Support** - Isolated traffic signals within the recovery area on high speed rural facilities may require shielding.

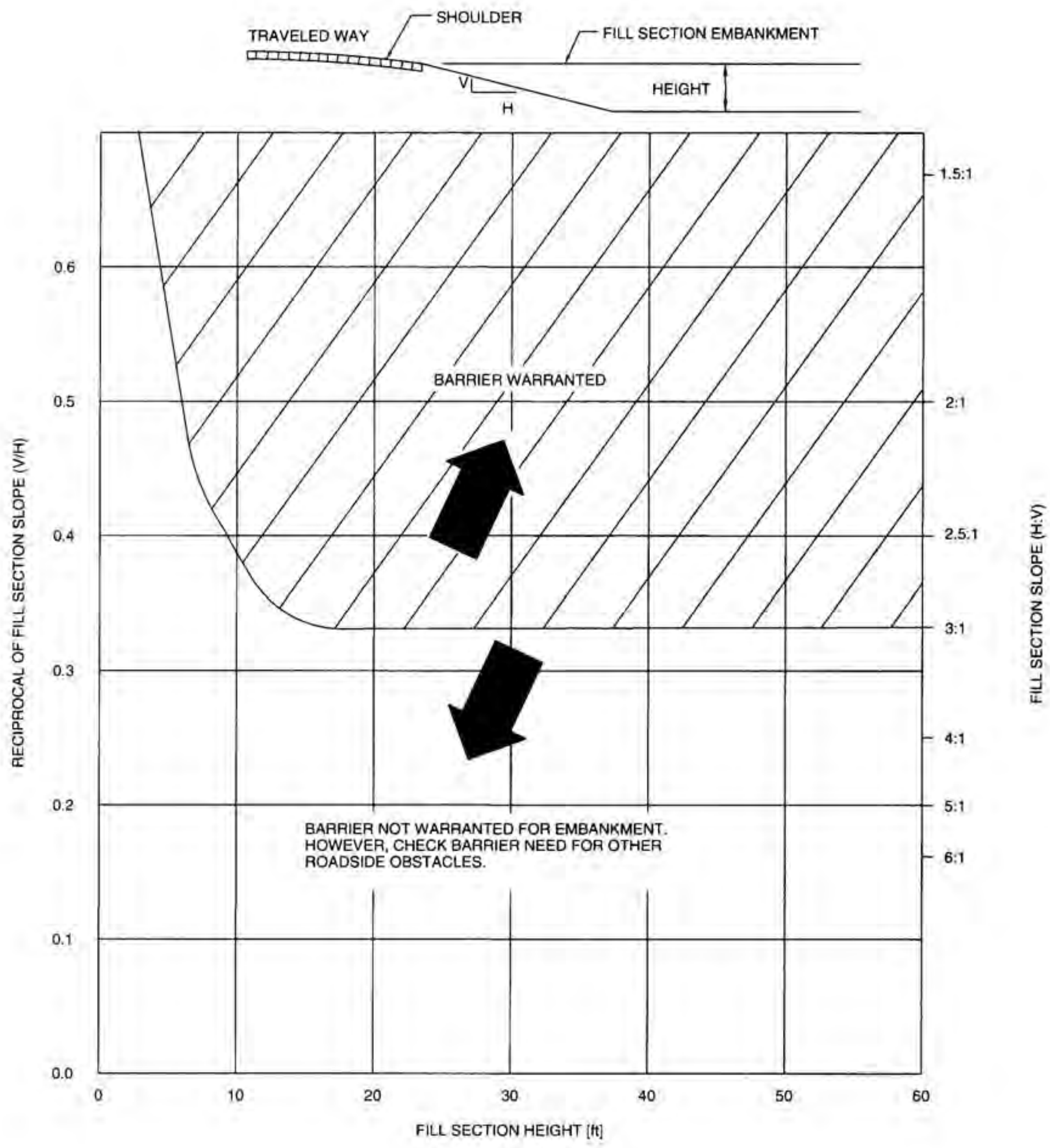
Exhibit 5-23
Barrier Warrants for Non-Traversable Terrain and Roadside Obstacles [1,2]

Obstacle	Warrants
Bridge piers, abutments, and railing ends	Shielding generally required
Boulders	Judgment decision based on nature of fixed object and likelihood of impact
Culverts, pipes, headwalls	Judgment decision based on size, shape, and location of obstacle
Cut & fill slopes (smooth)	Shielding not generally required
Cut & fill slopes (rough)	Judgment decision based on likelihood of impact
Ditches (parallel)	Refer to Exhibit 5-21 and 5-22
Ditches (transverse)	Shielding generally required if likelihood of head-on impact is high
Embankment	Judgment decision based on fill height and slope (see Exhibit 5-24)
Retaining walls	Judgment decision based on relative smoothness of wall and anticipated maximum angle of impact
Sign/luminaire supports[3]	Shielding generally required for non-breakaway supports
Traffic signal supports[4]	Isolated traffic signals within clear zone on high-speed rural facilities may warrant shielding
Trees	Judgment decision based on site-specific circumstances
Utility poles	Utility poles Shielding may be warranted on a case-by-case basis
Permanent bodies of water	Judgment decision based on location and depth of water and likelihood of encroachment

Source: Roadside Design Guide, AASHTO, 2002. Chapter 5 Roadside Barriers

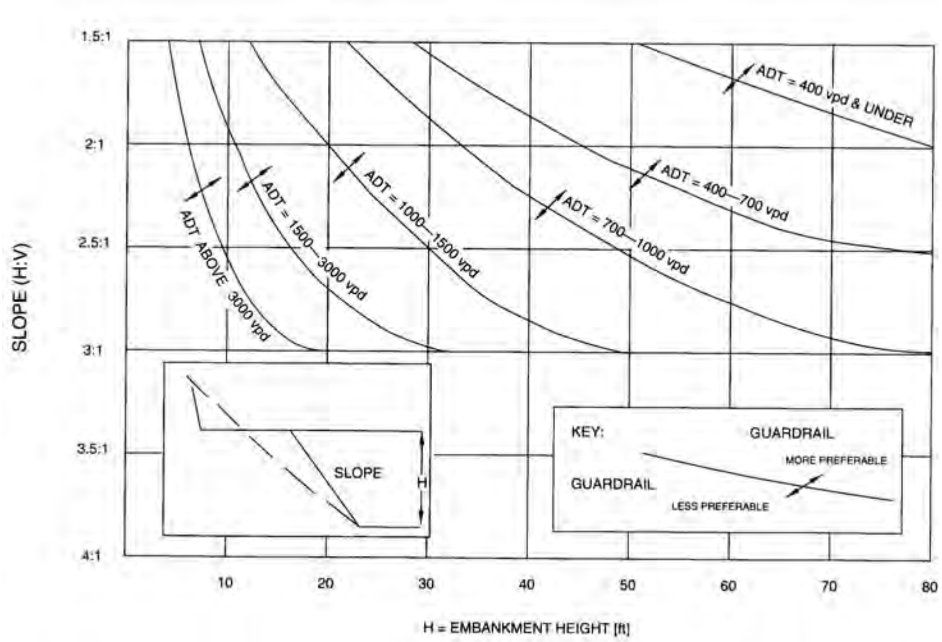
1. Shielding non-traversable terrain or a roadside obstacle is usually warranted only when it is within the clear zone and cannot practically or economically be removed, relocated, or made breakaway, and it is determined that the barrier provides a safety improvement over the unshielded condition.
2. Marginal situations, with respect to placement or omission of a barrier, will usually be decided by crash experience, either at the site or at a comparable site.
3. Where feasible, all sign and luminaire supports should be a breakaway design regardless of their distance from the roadway if there is reasonable likelihood of their being hit by an errant motorist. The placement and locations for breakaway supports should also consider the safety of pedestrians from potential debris resulting from impacted systems.
4. In practice, relatively few traffic signal supports, including flashing light signals and gates used at railroad crossings, are shielded. If shielding is deemed necessary, however, crash cushions are sometimes used in lieu of a longitudinal barrier installation.

Exhibit 5-24
Comparative Risk Warrants For Embankments



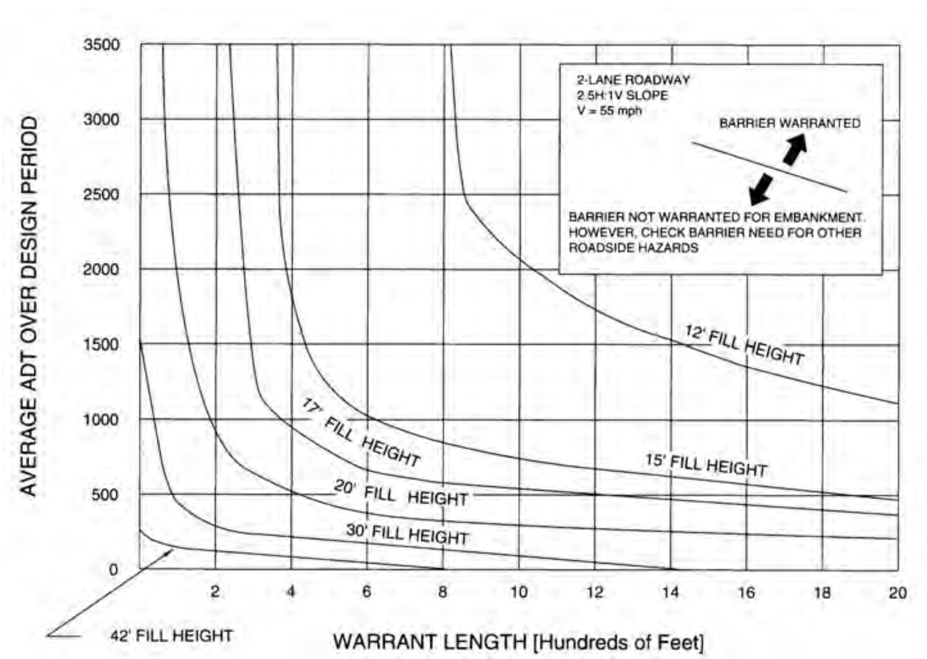
Source: Roadside Design Guide, AASHTO, 2002. Chapter 5 Roadside Barriers

Exhibit 5-25
Example design chart for Embankment Warrants Based on Fill height, slope, and traffic volume



Source: Roadside Design Guide, AASHTO, 2002. Chapter 5 Roadside Barriers

Exhibit 5-26
Example design chart for cost-effectiveness embankment warrants based on traffic speeds and volumes, slope geometry, and length of slope



Source: Roadside Design Guide, AASHTO, 2002. Chapter 5 Roadside Barriers

Once it has been determined that a roadside barrier is warranted, the designer must select a barrier type. The most desirable barrier type is usually one that offers the required degree of shielding at the lowest cost for the specific application. Exhibit 5.27 from the 2002 AASHTO Roadside Design Guide summarizes some key factors for selecting the barrier type.

Exhibit 5-27
Selection Criteria for Roadside Barriers

Criteria	Comments
1. Performance Capability	Barrier must be structurally able to contain and redirect design vehicle.
2. Deflection	Expected deflection of barrier should not exceed available deflection distance.
3. Site Conditions	Slope approaching the barrier and distance from traveled way may preclude use of some barrier types.
4. Compatibility	Barrier must be compatible with planned end anchor and capable of transitioning to other barrier systems (such as bridge railing).
5. Cost	Standard barrier systems are relatively consistent in cost, but high-performance railings can cost significantly more.
6. Maintenance	
A. Routine	Few systems require a significant amount of routine maintenance.
B. Collision	Generally, flexible or semi-rigid systems require significantly more maintenance after a collision than rigid or high-performance railings.
C. Material Storage	The fewer different systems used, the fewer inventory items/storage space required.
D. Simplicity	Simpler designs, besides costing less, are more likely to be reconstructed properly by field personnel.
7. Aesthetics	Occasionally, barrier aesthetics are an important consideration in selection.
8. Field Experience	The performance and maintenance requirements of existing systems should be monitored to identify problems that could be lessened or eliminated by using a different barrier type.

Source: Roadside Design Guide, AASHTO, 2002. Chapter 5 Roadside Barriers

5.6.2.5 Roadside Barrier Design

The following are important considerations in barrier design.

Lateral Offset

The distance from the edge of the traveled way, beyond which a roadside object will not be perceived as an obstacle and result in a motorist's reducing speed or changing vehicle position on the roadway is called the shy line offset. This distance varies for different design speeds as indicated in Exhibit 5-28. If possible, a roadside barrier should be placed beyond the shy line offset, particularly for relatively short, isolated installations. For long continuous lengths of railings, this offset distance is not so critical.

Exhibit 5-28

Suggested Shy Line Offset (Ls) Values

Design Speed [mph]	Shy Line Offset, Ls [ft]
80	12.1
75	10.5
70	9.2
60	7.9
55	7.2
50	6.6
45	5.6
40	4.6
30	3.6

Source: Roadside Design Guide, AASHTO, 2002. Chapter 5 Roadside Barriers

Deflection Distance

The distance between the barrier and the obstacle must not be less than the dynamic deflection of the barrier system. This distance is based on crash tests with a full-size car at 30 miles per hour and a 25-degree angle of impact. The distance is measured from the face of the barrier to the front of the obstacle.

Exhibit 5-29 provides the offset distance for the barrier systems used in Massachusetts based on the crash tests at 30 miles per hour. Concrete barrier is assumed to have no deflection.

Exhibit 5-29
Barrier Offset Distance

Post Spacing	Beam Description	Minimum Offset* (Ft)
Single	Single W - Beam	4.1
Single	Single Thrie - Beam	3.6
Double	Single W - Beam	3.1
Double	Double W - Beam	2.8
Double	Single Thrie - Beam	3.0
Double	Double Thrie - Beam	2.6
Quadruple	Double W - Beam	2.3
Quadruple	Single Thrie - Beam	2.5
Quadruple	Double Thrie - Beam	2.3

*Minimum Offset - Measured from the face of the rail to the front of the obstacle.
Source: MassHighway

Length of Need

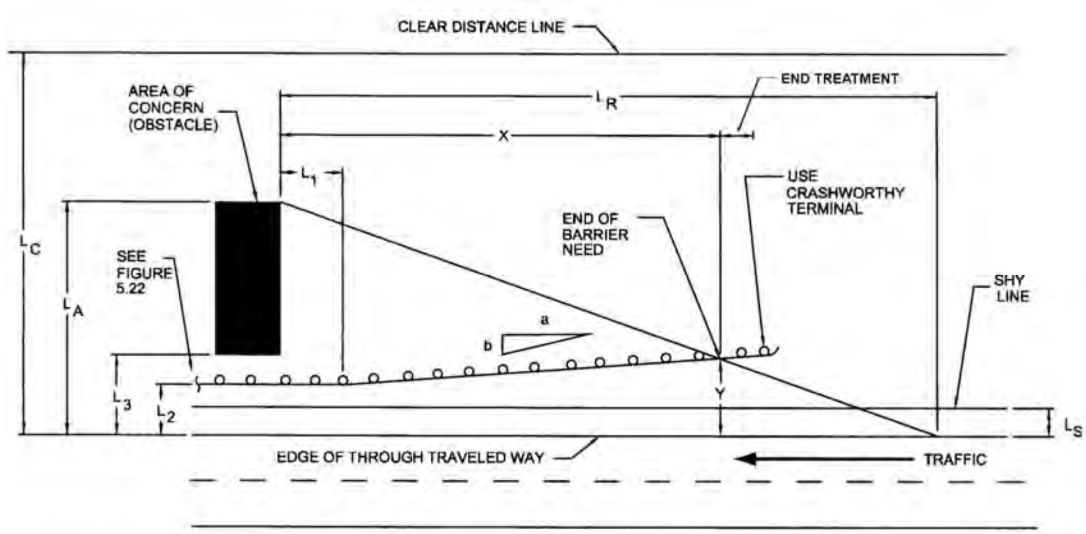
The barrier must be long enough to sufficiently shield the hazard from errant vehicles. The length of the barrier depends on factors depicted on Exhibit 5-30 which include:

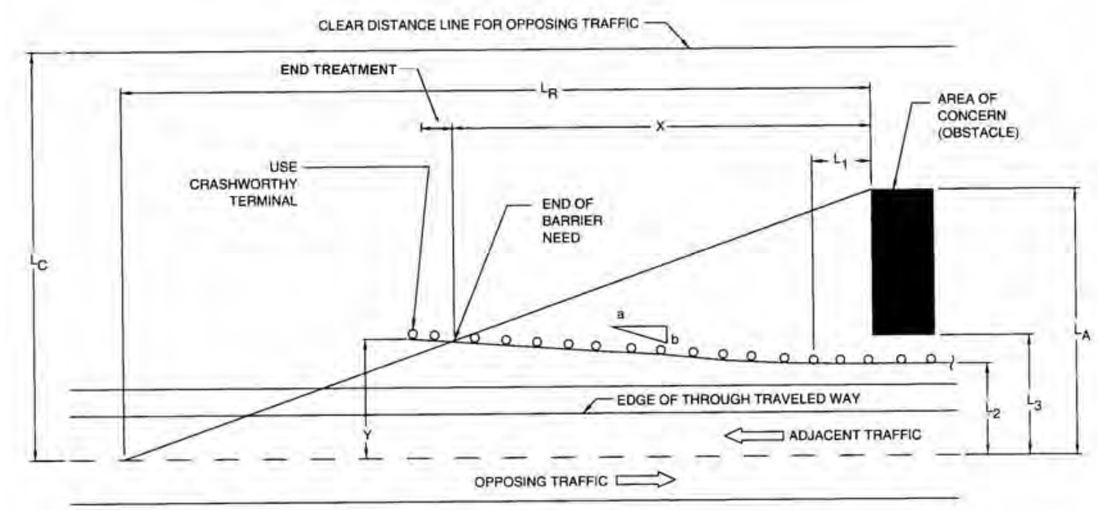
- **(b / a) -** the barrier flare rate (when the barrier is not parallel to the traveled way), see Exhibit 5-31 for suggested flare rates;
- **L_R -** the vehicle runout length (the distance needed for an errant vehicle to come to a stop) which is a function of the traffic volume and design speed, measured from the upstream extent of the obstructions along the roadway to the point at which a vehicle is assumed to leave the roadway, see Exhibit 5-32 for suggested runout lengths;
- **L_A -** the lateral setback from the edge of the traveled way to the back of the obstacle.
- **L_1 -** the tangent length of the barrier upstream from the obstacle; and
- **L_2 -** the lateral distance from the edge of the traveled way to the barrier.

The AASHTO recommended formula used for determining the length of need (X) is:

$$X = \frac{L_A + (\frac{b}{a})(L_1) - L_2}{(\frac{b}{a}) + (\frac{L_A}{L_R})}$$

Exhibit 5-30
Approach Barrier Layout Variables





Source: Roadside Design Guide, AASHTO, 2002. Chapter 5 Roadside Barriers

Exhibit 5-31
Suggested Flare Rates for Barrier Design

Design Speed (mph)	Flare Rate for Barrier Inside Shy Line	Flare Rate for Barrier Beyond Shy Line	
		*	**
70	30:1	20:1	15:1
60	26:1	18:1	14:1
55	24:1	16:1	12:1
50	21:1	14:1	11:1
45	18:1	12:1	10:1
40	16:1	10:1	8:1
30	13:1	8:1	7:1

* Suggested maximum flare rate for rigid barrier system.
** Suggested maximum flare rate for semi-rigid barrier system.
Source: Roadside Design Guide, AASHTO, 2002. Chapter 5 Roadside Barriers

Exhibit 5-32
Suggested Runout Lengths for Barrier Design (L_R)

	Traffic Volume (ADT)			
	Over 6000 vpd	2000 – 6000 vpd	800 – 2000 vpd	Under 800 vpd
Design Speed (mph)	Runout Length (ft) L_R	Runout Length (ft) L_R	Runout Length (ft) L_R	Runout Length (ft) L_R
70	475	445	395	360
60	425	400	345	330
55	360	345	315	280
50	330	300	260	245
45	260	245	215	200
40	230	200	180	165
30	165	165	150	130

Source: Roadside Design Guide, AASHTO, 2002. Chapter 5 Roadside Barriers

End Treatments

The barrier end terminals are used to reduce severity of impacts by gradually slowing and bringing the vehicle to a stop or by redirecting it around the object of concern. Generally, the vehicle must remain upright during and after the collision and not be redirected into adjacent traffic lanes. A terminal can be designed to have full redirection capabilities along its entire length (known as a ***non-gating terminal***), or it can be designed to allow controlled penetration along a portion of its length (known as a ***gating terminal***).

To be crashworthy, the end treatment should not spear a vehicle, cause a vehicle to vault or roll a vehicle for head-on or angled impacts.

Improper roadside barrier end treatment is extremely hazardous to vehicles if hit. Preferably, the roadside barrier should be flared away from the travel lane and, if feasible, should be terminated outside the recovery area. A crashworthy end treatment is considered essential if the barrier terminates within the clear zone or is in an area where it is likely to be hit head-on by an errant motorist. To be crashworthy, the end treatment should not spear a vehicle, cause a vehicle to vault or roll a vehicle for head-on or angled impacts. For impacts within the length of need, the end treatment must have the same redirectional characteristics of a standard roadside barrier until the full length of need is reached. Additionally, the trailing end of the barrier must be protected with a crashworthy end treatment if it is within the clear zone of opposing traffic.

The *MassHighway Construction Standards* illustrate the standard end treatment for roadside barriers. Intersecting streets and driveways may cause special problems for providing the proper roadside barrier end treatment. These must be considered on a case-by-case basis. The following end treatments are most commonly used by MassHighway.

- **Anchored in Back Slope**
  A back slope can be used to eliminate the hazard posed by the ends of traffic barriers. Where conditions permit this is the MassHighway preferred barrier end treatment. Anchorage in back slope should be used wherever a back slope is conveniently near the end of the length of need of the barrier. Full height barrier must be flared a minimum rate of 5:1 to a point in the back slope beyond the recovery area. A 1v:12h or flatter ground slope must be provided in front of the barrier. Consult the *MassHighway Construction Standards* for details on guardrail installation.

- **Special End Treatments**
  Where it is not appropriate for either anchoring in back slope, special end treatments may be used. These must meet *NHCRP 350* testing requirements and be approved by FHWA for general use for the intended application (see Section 9.5 of *NCHRP 350*).

For more details about roadside barrier end treatments, consult the 2002 AASHTO *Roadside Design Guide*.

Minimum Functional Length and Guardrail Gaps

Short runs of guardrail have little value. Likewise, short gaps between runs of guardrail are undesirable. The following general criteria are suggested:

- A minimum length guardrail of 165 feet of full height guardrail plus the end treatment is suggested.
- Gaps of less than 335 feet between guardrail termini should be avoided to the extent possible. The two barrier runs should be connected into a single run. However, this may not be possible at intersecting streets and driveways.

These general criteria for lengths and gaps between successive guardrail termini are not always applicable and are only provided as an initial reference for the designer. In many cases, especially in rural areas along narrow roadways, the designer may have to develop a workable alternative to these suggested criteria.

Placement on Slopes and Behind Curbs

If guardrail is improperly located on slopes or behind curbs, an errant vehicle could impact the barrier too high or too low, with undesirable results. Therefore, these criteria apply:

- Guardrail height is measured from the ground or pavement surface at the guardrail face. For W-beam and for Thrie beam guardrail, this dimension is 1'9"±1". See the *MassHighway Construction Standards* for details.
- Berm and curb must be located to minimize vaulting potential. See the *MassHighway Construction Standards* for details.
- Where guardrail is required to be offset from the edge of pavement, it should not be placed on a slope steeper than 1v:12h.
- Where sidewalks are provided, guardrail should be located along the back edge of the sidewalk.

Transitioning

Transition sections are necessary to provide continuity of protection when two different roadside barriers join, when a roadside barrier joins another system such as a bridge railing, or when a barrier is attached to a rigid object. The transition design should produce a gradual transition in the stiffness and overall protection system so that vehicle pocketing, snagging, or penetration can be reduced or avoided at any position along the transition area. For transition details, consult the *MassHighway Construction Standards* and the *AASHTO Roadside Design Guide*.

Typical Roadside Barrier

Once a type of barrier is selected for a particular longitudinal application, the selected type should be used throughout the run. Transitions from concrete barrier to guardrail or guardrail to concrete barrier should be avoided where possible. Where stiffer sections are required for runs of guardrail, extra posts and rails should be considered. If a transition from steel guardrail to concrete barrier is required, a gradual strengthening and secure attachment to the concrete is required similar to the guardrail to bridge rail transition shown in the construction standards.

If a guardrail run crosses over a retaining wall or culvert, it should be secured to the top of the wall rather than transition to a concrete section. If the section can be installed with only a single post missing, this post can be omitted with nested steel rail. If a concrete run crosses drainage structures, the concrete barrier should be specially designed to accommodate the drainage structure which may be formed in steel in the same shape as the adjacent concrete barrier.

5.6.3 Median Barriers

Median Barriers are double faced longitudinal systems. Median barriers are normally used in narrow medians for separating opposing traffic or for separating traffic flowing in the same direction, i.e. collector-distributor roadways and High-Occupancy Vehicle lanes.

5.6.3.1 Types

MassHighway uses the following types of median barrier systems:

- **Blocked-Out W-Beam**
  This W-Beam system may be used as median barrier on roadways with design speeds of 40 mph or less. The *MassHighway Construction Standards* present the design details.
- **Blocked-Out Thrie-Beam**
  Thrie beam must be used for median barrier system on highway facilities with design speeds over 40 mph.
- **Concrete Median Barrier Double-Faced**
  This barrier is reinforced concrete in which the sloped shape of the

face is designed to minimize occupant injury, redirection into traffic, and the possibility of rollover. Two types, the F-shape and Jersey shape are used for barrier systems. The F-shape is preferred because it better redirects passenger vehicles.

In areas with heavy truck volume, poor roadway geometry, and a history of truck crashes, tall concrete barriers with heights of 3.5 feet or higher may be used. See the *MassHighway Construction Standards* for details. See Chapter 14 of this guidebook for a discussion on how concrete median barriers impact wildlife.

- **Cable Systems**
  As described earlier, cable systems can be used in medians, however, MassHighway typically uses the barrier systems described above due to the maintenance and safety considerations associated with cable systems. The *AASHTO Roadside Design Guide* provides for information on the design of cable barrier systems.

Once it has been decided that a median barrier is warranted, the designer must choose the appropriate type of barrier. This choice is based on a number of factors including performance criteria, cost (construction and maintenance), aesthetics, traffic impacts and personnel hazards of performing maintenance, and aesthetics. The most desirable system is usually one that offers the required degree of shielding at the lowest cost and provides the desired aesthetic for the area. Factors that should be considered when selecting a barrier system are presented in Section 5.6.2. Aesthetic considerations are discussed further in Chapter 13. Additionally, the AASHTO *Roadside Design Guide* should be consulted for more information.

In general, the designer will choose between Thrie Beam Double-Faced Guard Rail and a concrete safety shape. The choice between guardrail or concrete should be based on factors such as the width of median, barrier deflection, cost (construction and maintenance), traffic impacts and personnel hazards of performing maintenance, and aesthetics. Guardrail which deflects upon impact is generally preferred due to the lower impact forces on the vehicle and its occupants. W-beam and cable systems deflect even further than the Thrie beam system. However, the design speed of the roadway usually suggests the use of the Thrie beam system (the majority of roadways in developed areas have a design speed over 40 mph).

On high speed, high volume roadways with significant truck volumes and narrow medians of less than 14 feet, concrete barrier should be strongly considered due to the possibility that if guardrail is used it may deflect into the opposing lanes. Consideration should also be given to the increased likelihood that the barrier may be damaged which could result in higher maintenance costs for guardrail than for concrete. The designer should consider, however, that concrete barrier may not be aesthetically appropriate in undeveloped areas and that the open appearance of guardrail may appear less imposing and may be more acceptable to the public.

Homogeneous barrier type is recommended.

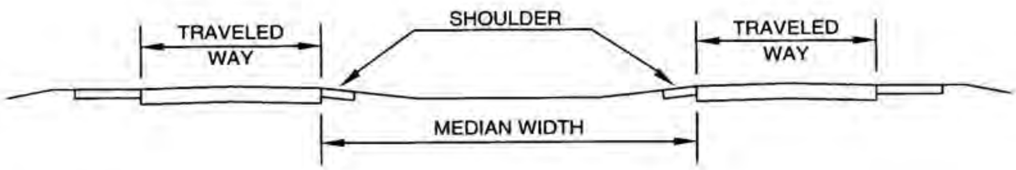
Once a type of median barrier is selected for a particular longitudinal application, it should be used throughout the run. Transitions between dissimilar barrier systems should be avoided. For instance, if a concrete median barrier run crosses drainage structures, the concrete barrier should be specially designed to accommodate the structure. This may be accomplished by forming a section of the barrier from steel in the same shape as the adjacent concrete barrier. Median barrier must be installed with no abrupt horizontal transitions. Flare rates should be designed in accordance with the AASHTO *Roadside Design Guide*.

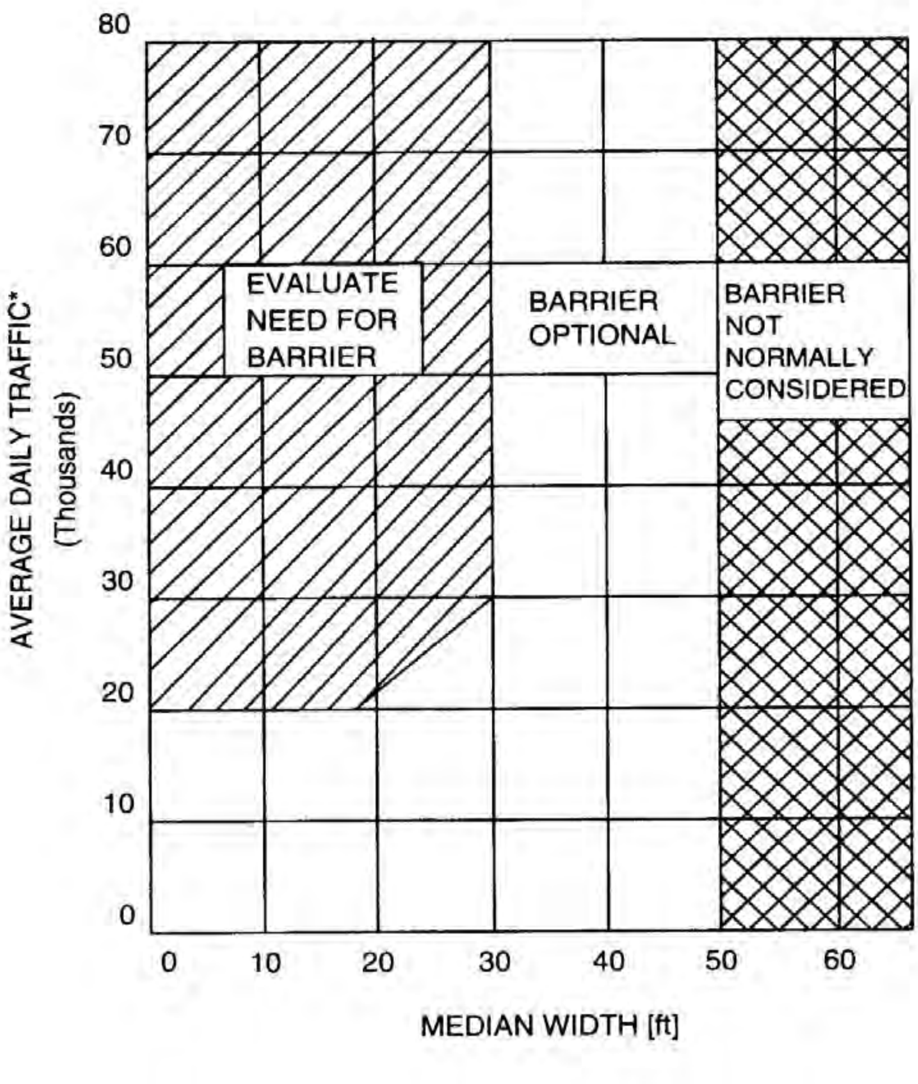
5.6.3.2 Median Barrier Requirements

Exhibit 5-33 presents the requirements for a median barrier based on median width and traffic volumes. In the areas shown as optional, the decision to use a median barrier will be primarily based on costs and crash history. A barrier should not be used where the criteria do not require it, except where a significant number of crossover crashes have occurred. Moreover, wider medians allow more deflection and therefore less rigid and less costly barrier systems.

The exhibit was developed for freeways and expressways. On lower-speed, lower-class highways, judgment must be used and the exhibit may be used for guidance. On non-freeway highways, the designer should evaluate the crash history, traffic volumes and speeds, median width, alignment, sight distance, and construction costs to determine the need for a median barrier. On expressways and highways without access control, the median barrier must terminate at each at-grade intersection. Lower speeds will reduce the likelihood of a crossover crash.

Exhibit 5-33
Median Barrier Warrants





Source: Roadside Design Guide, AASHTO, 2002. Chapter 6 Median Barriers

5.6.3.3 Median Barrier Design

The following should be considered in the design of median barriers:

Lateral Placement

The median barrier will normally be placed in the center of the median. Where roadway conditions dictate different grades between two roadway barrels, median barrier should be placed on the high side of the median. Concrete barrier may split vertically to accommodate the two grade lines. See the AASHTO *Roadside Design Guide and MassHighway Construction Standards* for further guidance and details.

Cross-Slope

A maximum 1v:12h cross-slope must be used between the roadway gutter line and the median barrier. See *MassHighway Construction Standards* for details.

Flare Rate

A median barrier may have to be divided at the approach of superelevated curves or because of obstacles in the median, or flared to terminate in the wide median section. Flare rates in accordance with the AASHTO *Roadside Design Guide* should be used.

Median Barrier Openings

Emergency median crossovers are sometimes needed on access-controlled highways. Where a median barrier is warranted, the opening in the barrier should prevent crossover crashes, provide crashworthy end treatments, and provide sufficient width for emergency vehicles to use. An opening between 80 and 100 feet is a reasonable compromise. At this width, the chances of an errant vehicle passing through the opening are negligible; however, the width is sufficient to allow U-turn maneuvers by emergency or maintenance vehicles. Mechanical gate treatments for emergency openings are available.

Glare Screens

Device which may be used as part of a median barrier to eliminate headlight projection from oncoming vehicles; plantings often considered as an alternative

- Glare screens are rarely warranted in rural areas.
- Narrow medians and high traffic volumes increase the benefits of glare screens. Where the concrete median barrier is warranted

(medians 20 feet or less), a glare screen will often be cost-effective.

- On medians between 20 and 40 feet, a glare screen should be considered where the current traffic volumes exceed 20,000 ADT.
- Glare screens will not normally be used on medians greater than 40 feet wide.
- Tall concrete barrier systems may mitigate the need for glare screens.

Median Barrier End Treatments

An unprotected median barrier end presents a hazard to errant vehicles. A crashworthy end treatment for a median barrier is essential if the barrier is terminated where it is vulnerable to head-on impacts. To be crashworthy, the end treatment must not spear, snag, or roll the vehicle, and vehicle decelerations should not be excessive. The end must be properly anchored and capable of developing the full tensile strength of the barrier.

Because median barriers are normally used in narrow medians, the options for end treatments are limited. Barrier end treatments which have the potential for vaulting or rolling vehicles cannot be used. Therefore, tapered end treatments such as buried ends or ramped concrete barrier ends, are not acceptable treatments for median barrier unless the ends of the barrier can be flared a sufficient distance laterally from the traveled way so as not to be susceptible to head-on impacts.

Where feasible, the median barrier may be anchored in a back slope. This treatment should be designed in accordance with Roadside Barrier End Treatments criteria. This treatment usually requires that the barrier terminate in a wider portion of the median.

The preferred method for treating median barrier terminals in narrow medians is to use Impact Energy Attenuators. These manufactured treatments have been crash-tested to provide energy absorption and/or redirection capabilities in restricted areas.

5.6.4 Impact Energy Attenuators

The following section describes the use and application of impact energy attenuators. For more detailed information, please see the AASHTO *Roadside Design Guide*.

5.6.4.1 Attenuators/Crash Cushions

Median barrier ends located in narrow medians, roadside barrier ends, or other fixed roadside hazards which cannot be relocated must be shielded with appropriate crash cushions. Crash cushions have been crash-tested to conform to the redirection and attenuation requirements of *NCHRP 350*. All attenuators must be successfully retested for *NCHRP 350* and accepted by the FHWA for use on MassHighway projects.

MassHighway recognizes two basic types of crash cushions– a redirective crash cushion and non-directive crash cushion. A crash cushion can be designed to redirect a vehicle impacting the side of the cushion (redirective) or it can be designed to decelerate the vehicle to a stop when impacted on the side (non-directive). MassHighway specifies attenuators in a generic format in order to increase market competition, minimize the use of proprietary product, and ensure that site specific installations are used appropriately.

5.6.4.2 Requirements

Once a hazard is identified, the designer should attempt to remove, relocate, or make the hazard breakaway. If this is not feasible, then the hazard must be shielded with an attenuator. Impact attenuators are most often used to shield fixed point hazards or median barrier ends adjacent to bridge piers, sign supports, and median barrier ends. Barriers which terminate within the recovery area, if not buried in a back slope, are also hazards which must be protected with an attenuator.

The requirements for impact attenuators are under ongoing research. AASHTO prioritizes need on the basis of crash history, traffic volume, and operating speeds. For additional information the designer should consult the *Roadside Design Guide*, and the *Policy on Geometric Design of Highways and Streets*.

5.6.4.3 Design

Once the designer has determined the need for an attenuator in a particular location, the designer determines the type to be used (gating or non-gating), and any limiting width or length for attenuator placement, or other condition to account for reverse-hit, opposite direction traffic in narrow median situations.

NCHRP Report 350 specifies testing guidelines for various roadside elements. Barriers are tested to *NCHRP 350* Condition Type II and VI. Guardrail and highway barrier is generally tested at Type II and III conditions. End treatments and attenuators are generally tested at Type II and III. Bridge rail is tested at Type IV, V, and VI conditions. Information of these testing types is included in the NCHRP Report.

The designer should refer to the current edition of the AASHTO *Roadside Design Guide* and other available literature for further information and a discussion of crash cushions and end treatments.

5.6.4.4 Side Impacts

The attenuator must be designed to sustain side impacts. Nongating attenuators normally will not require repair after side impacts. Gating attenuators, in order to provide some side impact protection, are generally designed at least 2.5 feet wider on each side than the object they protect. Greater widths should be provided where possible.

5.6.4.5 Site Conditions

Several factors at the attenuator site are important to its proper function:

- **Level Terrain** — The attenuator should be placed on a level surface. Most attenuators will not function well on cross slopes exceeding 5 percent. If the attenuator is likely to be struck by a vehicle traveling on a down grade, this additional energy must be compensated for in the design.
- **Curbs** — No curbs, berms or slope edgings are allowed at the attenuator installation. To function properly the vehicle should have a straight, smooth run at the attenuator.
- **Surface** — A paved bituminous or portland cement concrete surface must be installed under permanent attenuator installations where required. Some installations may only require a firmly packed gravel or crushed stone surface end treatment.
- **Orientation** — Gating attenuators must be oriented to maximize the chance of an impact being head-on. Where a gating system is

specified, it should be shown on the plans as set at approximately a 10 degree angle with the travel lane. The angle is measured between the longitudinal axis of the attenuator and the centerline of the highway. However, this is not necessary for those attenuators with nongating capability. Attenuators with nongating capabilities, such as “GREAT” systems, should be aligned parallel to the travel way.

5.6.5 Side Slopes and Cuts

Cut and fill slopes should be designed to ensure the stability of the roadway and be as flat as possible to enhance the safety of the roadside. Much of the necessary information will be provided in a soils report prepared by the Research and Materials Section, although not every project will require a soils report. The designer should consider the following when selecting a cut or fill slope design:

- It is desirable for fill slopes on high speed roadways to be 1v:6h or flatter. All soils (except possibly wetland or muck material) are stable at this rate. Maintenance efforts are greatly reduced, the erosion potential is reduced, and the slopes are safely traversable at 1v:6h. The designer should obtain clear zones where feasible. For fills greater than 15 feet high in wetlands and in other sensitive areas, 1v:2h slopes (with guardrail) are typical. Site conditions may require a slopes up to 1v:1h. Mechanically stabilized slope retaining treatments such as geo-textiles shall be considered for these situations.
- Erosion possibilities must be minimized. To the extent possible, the natural and existing drainage patterns should be preserved. Severely rutted side slopes can cause vehicle rollover even on relatively flat slopes. In good soil, turf can be established on slopes as steep as 1v:1h. However, flatter slopes obviously reduce the erosion potential and should be used where feasible. All slopes shall be planted with sufficient vegetation to stabilize the slope.
- Cut-to-fill transition slopes are particularly susceptible to erosion. The problem is most acute along the bottom of the fill embankment. Special protective measures should be considered here.
- Where the roadway mainline intersects a driveway, side road, or median crossing, the intersecting transverse slopes need to be carefully designed. Transverse slopes of 1v:10h or flatter are

desirable. Transverse slopes of 1v:6h or flatter are acceptable for high-speed roadways. Transverse slopes steeper than 1v:6h may be considered for urban areas or lower speed facilities.

Slopes up to vertical are possible in rock cuts using pre-splitting methods. The typical rock slope is 4v:1h, depending upon the material stability. When feasible, the bottom of the rock-cut slope should be outside of the calculated clear zone. Jagged rock outcroppings exposed to possible vehicle impacts should be avoided. A typical rock cut is shown in the *MassHighway Construction Standards*.

High earth cuts may warrant terracing. Terracing reduces erosion and enhances soil stability. As a general rule, terraces should be provided at approximately 20 foot intervals. The Geotechnical Unit shall be consulted for these designs.

For cut or fill sections, it may be necessary to reduce the clear zone for environmental, cost, right or way or aesthetic considerations. Recent requirements for clear zones frequently increase the cut and fill requirements substantially. Guardrail should be used on fill slope where recovery area is not available. A concrete barrier may be appropriate at cut locations as a retaining wall. A 2-foot offset must be added to the shoulder dimension as is done for guardrail. In cut sections a ditch of sufficient width must be provided behind the barrier to maintain drainage flow from the hillside and to retain rocks and debris which may fall from the hillside.

5.6.6 Ditch Sections

Roadside ditches divert and remove water from the surface and subsurface of the roadway. Chapter 8 discusses the types, hydraulic characteristics, and protective linings for ditches. Roadway ditch foreslopes steeper than 1v:6h are not desirable for safety reasons. In addition, 1v:6h or flatter foreslopes reduce the potential for snow drifts.

Roadside ditches can have several shapes: V, radial, trapezoidal or parabolic. The trapezoidal ditch is the preferred shape when considering safety and ease of design, construction and maintenance. Parabolic and circular ditch sections are used in special circumstances. Examples of these are provided in the *MassHighway Construction Standards*.

5.7 Utilities and Signage

The location of utilities and the placement of signage are often significant issues in the design of roadway improvements as described below.

5.7.1 Utility Placement or Relocation

Since they provide a public service, utilities are allowed to occupy the public right-of-way. Coordination with utility companies is essential during the design and construction process to identify the appropriate location for utilities and the necessary steps for relocation of existing utilities (if required). Ideally, utility placement or relocation will occur is sequence with the construction of the roadway project so that disruption to the public minimized.

In general, overhead utility poles should be located outside the shoulders, sidewalk, and roadside recovery areas (if provided). If utility poles can not be located outside of the sidewalk area, it is important that the minimum clear path of travel for pedestrians described in Chapter 5 is provided. Additionally, utility poles should be offset at least two feet from the face of curb when located within the sidewalk area or buffer strip.

It is usually advisable to assess the condition and need for replacement of below-grade utilities during the planned roadway construction. The proponent should coordinate with municipal departments and other utilities to identify any utility work to be coordinated with the roadway project.

5.7.2 Signage Placement

The types and mountings of signs varies significantly depending on the roadway type and setting. Detailed guidance for the placement of signs is contained in the MUTCD. Similar to utilities, signage cannot protrude into the shoulders or traveled way. In locations where the sidewalk is immediately adjacent to the street, it is often desirable to place signage at the back of sidewalk. If signage is placed along the curb edge, sign posts should be located no closer ½ the width of the sign face plus one additional foot from the face of curb. Additionally, signage can not impede the “accessible route” defined under 521 CMR.

5.8 Right-of-Way

The necessary right-of-way (ROW) width is the summation of all cross-section elements: utility accommodations, clear zones, drainage ditches, sidewalks, buffer strips, curbs or berms, shoulders and bicycle lanes, motor vehicle travel lanes, and medians. Consideration should also be given to the possibility of adding travel lanes in the future. However, land use patterns, availability and cost of right-of-way may dictate the type and width of cross-section elements that are provided.

The ROW width will vary greatly and the designer must always research the current ROW width as an initial step. Typically, an undivided, two-lane rural major collector or arterial has a ROW width of 66 feet. Lower classes of roadway or low volume facilities might have narrower ROWs while major highways require more ROW. In most cases, urban streets and highways have less available ROW than rural highways.

Ideally, ROW width should be uniform along a roadway segment. In urban areas, variable widths may be necessary due to existing development. Varying side slopes and embankment heights may make it desirable to vary ROW width and ROW limits will likely have to be adjusted at intersections and freeway interchanges. Other special ROW controls should also be considered:

- At horizontal curves and intersections additional ROW acquisition may be warranted to ensure that the necessary sight distance is always available in the future.
- In areas where the desired ROW widths cannot be reasonably obtained, the designer will have to consider the advisability of using steeper slopes, revising grades, or using slope retaining treatments.
- Right of way should be acquired and reserved for future improvements such as roadway widening and interchange completion.
- On sections of highway adjacent to railroads, any encroachment on railroad ROW should be avoided, whenever possible.
- Permanent slope easements with maintenance rights should be considered to minimize public ownership of land.

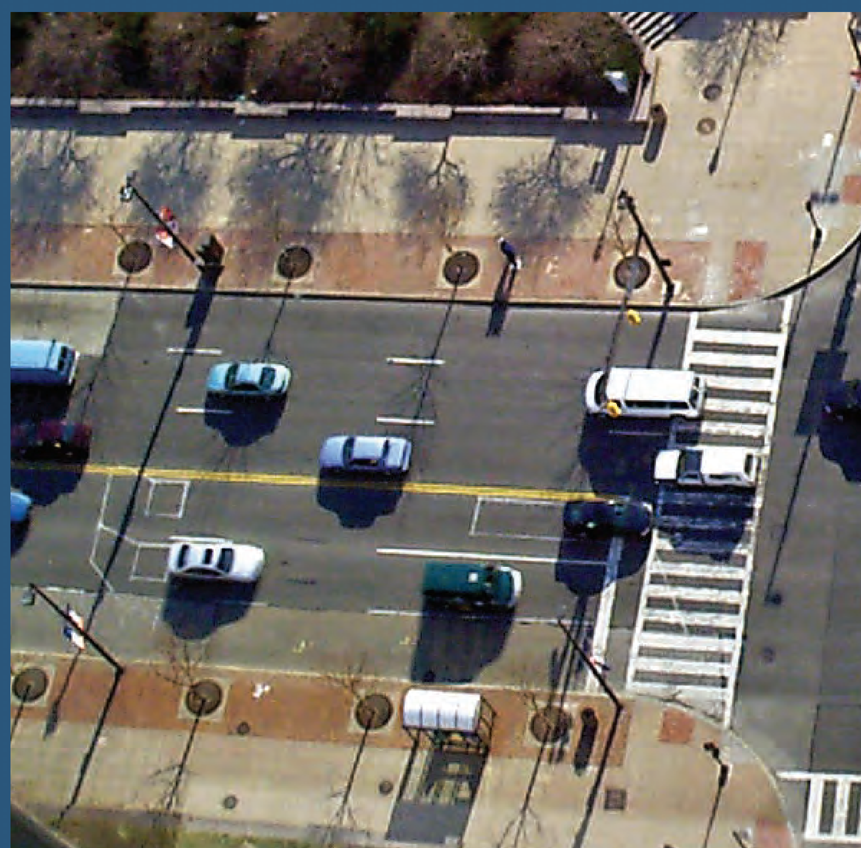
- Because a road is an inherent part of a community, the engineer needs to pay special attention to ROW impact on cultural and commercial features.
- Additional right of way is often required for wetland mitigation.

5.9 For Further Information

- *A Guide to Achieving Flexibility in Highway Design*, AASHTO 2004.
- *Flexibility in Highway Design,* FHWA, 1997.
- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004.
- *Highway Capacity Manual, Special Report No. 209*, Transportation Research Board 1995.
- *Roadside Design Guide*, AASHTO, 2002.
- *A Guide for Transportation Landscape and Environmental Design*, AASHTO, 1991.
- *Guide for High Occupancy Vehicle Facilities*, AASHTO, 2004.
- *Compendium of the Safety Effectiveness of Highway Design Features*, Publication FHWA-RD-91-044 through 049 (6 volumes), 1991.
- *MassHighway Design Policy for Bridge R&R Program for Non-NHS Roadways*, October 1992.
- *Americans with Disabilities Act Handbook*, December 1991.
- *Architectural Access Board, Rules and Regulations*, 521 CMR 1.00 et seq.
- *AASHTO Guide for the Development of Bicycle Facilities, 1999.*
- *FHWA Bicycle Compatibility Index, A Level of Service Concept, Implementation Manual,* Publication FHWA-RD-98-095, 1998*.*
- *AASHTO Guide for the Planning Design and Operation of Pedestrian Facilities, July 2004.*
- *NCHRP Report 350 - Recommended Procedures for the Safety Performance Evaluation of Highway Features,* 1993.
- *TCRP Report 19 – Guidelines for the Location and Design of Bus Stops,* 1996*.*
- *Accessibility Guidelines for Outdoor Developed Areas,* Architectural and Transportation Barriers Compliance Board, 1999.

Chapter 6

Intersections



Intersection Design

6.1 Introduction

An intersection is the area where two or more streets join or cross at-grade. The intersection includes the areas needed for all modes of travel: pedestrian, bicycle, motor vehicle, and transit. Thus, the intersection includes not only the pavement area, but typically the adjacent sidewalks and pedestrian curb cut ramps. The intersection is defined as encompassing all alterations (for example, turning lanes) to the otherwise typical cross-sections of the intersecting streets. Intersections are a key feature of street design in four respects:

- **Focus of activity -** The land near intersections often contains a concentration of travel destinations.
- **Conflicting movements -** Pedestrian crossings and motor vehicle and bicycle turning and crossing movements are typically concentrated at intersections.
- **Traffic control -** At intersections, movement of users is assigned by traffic control devices such as yield signs, stop signs, and traffic signals. Traffic control often results in delay to users traveling along the intersecting roadways, but helps to organize traffic and decrease the potential for conflict.
- **Capacity -** In many cases, traffic control at intersections limits the capacity of the intersecting roadways, defined as the number of users that can be accommodated within a given time period.

This chapter describes the considerations and design parameters for intersections. The chapter begins by outlining definitions and key elements, and then describes the characteristics of intersection users, intersection types and configurations, capacity and quality of service considerations, geometric design elements, and other considerations.

6.1.1 Intersection Users

All roadway users are affected by intersection design as described below:

- **Pedestrians.** Key elements affecting intersection performance for pedestrians are: (1) amount of right-of-way provided for the pedestrian including both sidewalk and crosswalk width, accuracy of slopes and cross slopes on curb cut ramps and walkways, audible and/or tactile cues for people with limited sight, and absence of obstacles in accessible path; (2) crossing distance and resulting duration of exposure to conflicts with motor vehicle and bicycle traffic; (3) volume of conflicting traffic; and (4) speed and visibility of approaching traffic.
- **Bicyclists.** Key elements affecting intersection performance for bicycles are: (1) degree to which pavement is shared or used exclusively by bicycles; (2) relationship between turning and through movements for motor vehicles and bicycles; (3) traffic control for bicycles; (4) differential in speed between motor vehicle and bicycle traffic; and (5) visibility of the bicyclist.
- **Motor vehicles.** Key elements affecting intersection performance for motor vehicles are: (1) type of traffic control; (2) vehicular capacity of the intersection, determined primarily from the number of lanes and traffic control (although there are other factors); (3) ability to make turning movements; (4) visibility of approaching and crossing pedestrians and bicycles; and (5) speed and visibility of approaching and crossing motor vehicles.
- **Transit.** When transit operations involve buses, they share the same key characteristics as vehicles. In addition, transit operations may involve a transit stop at an intersection area, and influence pedestrian, bicycle, and motor vehicle flow and safety. In some cases, the unique characteristics of light-rail transit must be taken into account.

Owners and users of adjacent land often have a direct interest in intersection design, particularly where the intersection is surrounded by retail, commercial, historic or institutional land uses. Primary concerns include maintenance of vehicular access to private property, turn restrictions, consumption of private property for right-of-way, and provision of safe, convenient pedestrian access.

6.1.2 Intersection Design Process

The design of intersections follows the planning process outlined in Chapter 2. The need for intersection improvement is identified and various options for addressing this need are considered and analyzed. The specific design elements of intersections may impact any or all potential users. Sections 6.2 through 6.6 define key terms and discuss intersection users, configurations, traffic control, capacity, and quality of service. Section 6.7 describes the ranges of physical dimensions and the operational characteristics of each intersection design element.

6.2 Definitions and Key Elements

The *major street* is typically the intersecting street with greater traffic volume, larger cross-section, and higher functional class. The *minor street* is the intersecting street likely to have less traffic volume, smaller cross-section and lower functional classification than the major street.

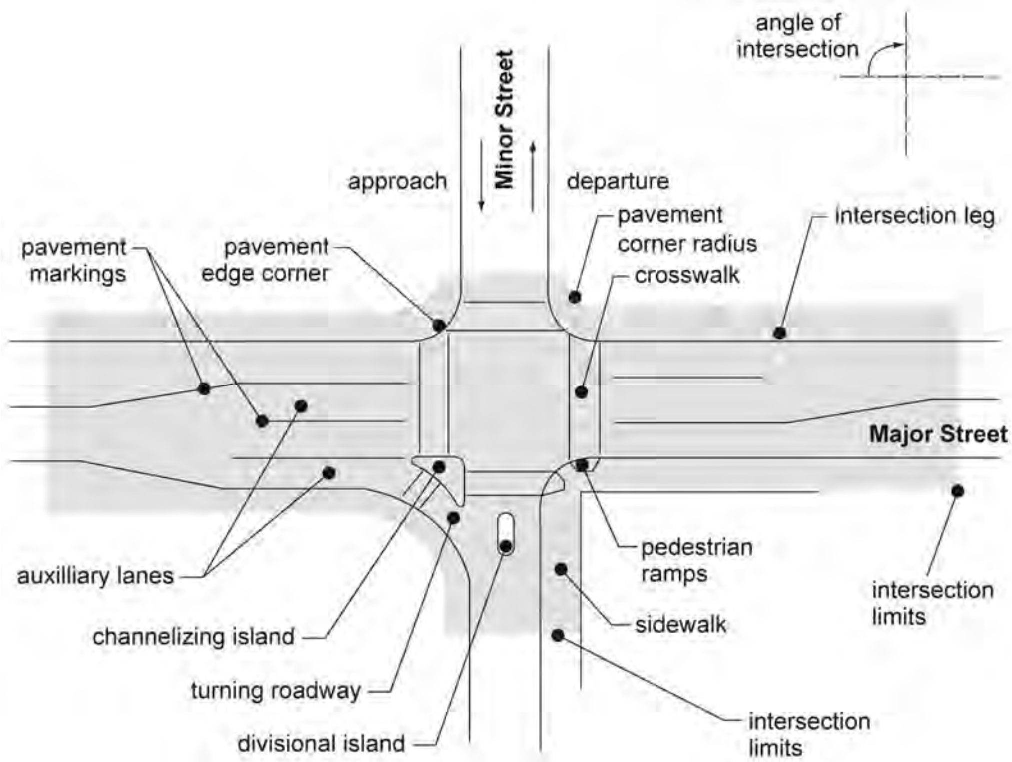
The term *intersection* encompasses not only the area of pavement jointly used by the intersecting streets, but also those segments of the intersecting streets affected by the design. Thus, those segments of streets adjacent to the intersection for which the cross-section or grade has been modified from its typical design are considered part of the intersection. Exhibit 6-1 summarizes the extent and terminology used to define an intersection.

Two geometric features are common to all intersections. The *angle of intersection* is formed by the intersecting streets' centerlines. Where the angle of intersection departs significantly (more than approximately 20 degrees) from right angles, the intersection is referred to as a *skewed intersection*.

Intersection legs are those segments of roadway connecting to the intersection. The leg used by traffic approaching the intersection is the *approach leg*, and that used by traffic leaving is the *departure leg*.

Sidewalks, *crosswalks* and *pedestrian curb cut ramps* are considered to be within the intersection. The *pavement edge corner* is the curve connecting the edges of pavement of the intersecting streets.

Exhibit 6-1
Intersection Terminology



Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004.

In addition to the basic geometric design features, options may be added to improve service for various users. *Auxiliary lanes* are lanes added at the intersection, usually to accommodate turning motor vehicles. They may also be used to add through lanes through an intersection.

Channelizing and divisional islands may be added to an intersection to help delineate the area in which vehicles can operate, and to separate conflicting movements. Islands can also provide for pedestrian refuge.

A *turning roadway* is a short segment of roadway for a right turn, delineated by channelizing islands. Turning roadways are used where right-turn volumes are very high, or where skewed intersections would otherwise create a very large pavement area.

Traffic control devices assign right of way, to both motorized and non-motorized traffic and include traffic signals, pavement markings, STOP signs, YIELD signs, pedestrian signal heads and other devices (such as raised pavement markings, flashing beacons, and electronic blank-out signs).

6.3 User Characteristics

The following sections describe characteristics of intersection users. Pedestrians and bicyclists are presented first, followed by motor vehicle and public transit users. This order of presentation reinforces the need to consider these modes throughout the intersection design process.

6.3.1 Pedestrians

Pedestrian requirements must be fully considered in the design of intersections. There are several important features to consider including:

- **Crossings and Pedestrian Curb Cut Ramp Locations -** Locations should correspond to the placement of sidewalks along approaching streets, and likely crossing locations. Pedestrian curb cut ramps need to ensure accessibility to crossing locations.

- **Walking Speed –** Under normal conditions, pedestrian walking speeds on sidewalks and crosswalks range from 2.5 feet per second to 6 feet per second. Elderly pedestrians and young children will generally be in the slower portion of this range. A walking speed of 3.5 to 4 feet per second for crosswalk signal timing is widely accepted as a guideline for walking speed in crosswalks. The designer should note that the current draft version (2002) of the *ADA Accessibility Guidelines for Public Right-of-way* (not adopted at the time of this Guidebook) requires a maximum walk speed of 3.0 feet per second over the entire length of crosswalk plus the length of one pedestrian curb cut ramp.

- **Pedestrian Flow Capacity –** The number of pedestrians per hour that can be accommodated by the facility under normal conditions.

- **Traffic Control, Yielding and Delay -** In addition to pedestrian flow capacity, pedestrians are significantly affected by the type of traffic control installed at an intersection, the specific parameters of the control, and the resulting motor vehicle operations. At STOP controlled, YIELD controlled, and uncontrolled intersections, pedestrians' ability to cross the street and the delay experienced is influenced by the yielding behavior of motor vehicles. At signalized intersections, the length and frequency of time provided for pedestrian crossings, the clarity of information provided, conflicting turning movements, and motor vehicle yielding are key influences on pedestrians' ability to cross the street, and on delay.

6.3.2 Bicyclists

Bicyclists' needs must be integrated into the design of intersections. When traveling with motor vehicles, bicyclists are subject to motor vehicle traffic laws. Important considerations for bicycle accommodation include:

- **Cross-section -** Bicyclists position themselves for their intended destination regardless of the presence of bike lanes or shoulders. If bicycle lanes are present, the design needs to insure that bicyclists can merge to the proper location based on the bicyclist's intended destination.
- **Operating Speed -** At unsignalized intersections, an average bicycle speed of 15 miles per hour can be assumed on the major street. On the minor street, bicyclists usually stop or slow, and travel through the intersection at speeds well below 15 miles per hour. At signalized intersections, bicyclists receiving the green signal proceed through the intersection at an average speed of 15 miles per hour. Bicyclists who have stopped for a signal proceed through the intersection at speeds well below 15 miles per hour.
- **Bicycle Capacity -** The number of bicycles per hour that can be accommodated by the facility under normal conditions.
- **Traffic Control -** Bicyclists are required by law to obey control devices at intersections. Therefore, traffic control devices need to account for bicycle activity. Traffic signals which operate using detection systems (such as loop detection, video camera, and microwave) must be designed and field tested to be sensitive to bicycles. Many of the aspects of traffic control described for motor vehicles (below) also apply to bicyclists.

6.3.3 Motor Vehicles

The following important characteristics of motor vehicles are considered in intersection design:

- **Design Vehicle -** The largest type of motor vehicle that is normally expected to be accommodated through the intersection.
- **Design Speed -** The motor vehicle speed selected on adjoining segments of roadway.
- **Motor Vehicle Capacity -** The number of motor vehicles that can be moved through an intersection under normal conditions.
- **Traffic Control -** Much like other users, motor vehicles are influenced by the type and timing of traffic control installed at an intersection, and number of other users. At roundabouts, STOP controlled, YIELD controlled, and uncontrolled intersections, motor vehicle capacity and delay are influenced by conflicting traffic streams. At signalized intersections, the time provided for each movement, conflicting turning movements, and the volume and mix of other users are key influences on both motor vehicle capacity and delay.

6.3.3.1 Design Vehicle

The design motor vehicle is the largest type of vehicle typically expected to be accommodated on the street. At intersections, the most important attribute of design vehicles is their turning radius, which in turn influences the pavement corner radius and therefore the size of the intersection. Lane width, another feature related to the design vehicle, has some impact on intersection design, but less than turning radius. The design vehicle may also affect the choice of traffic control device and the need for auxiliary lanes.

The design vehicle for intersections is the larger of the design vehicles selected for the intersecting streets. For example, at the intersection of a minor arterial and a local street, the appropriate design vehicle for the intersection is that required by the minor arterial (i.e., “larger” street). Exhibit 6-2, *Typical Design Vehicles at Intersections*, provides general guidance for selecting design vehicles appropriate for intersection design under conditions of normal traffic composition. At locations where collectors intersect with arterials experiencing high truck volumes, the appropriate truck design vehicle should be selected. Sample turning templates for these motor vehicles are provided in Exhibit 6-3.

Exhibit 6-2
Typical Design Motor Vehicles at Intersections

Functional Class of Major Road	Design Motor Vehicle (AASHTO Category) Typical for Intersection
Freeway	(No Intersections)
Major Arterial	Tractor-trailer Truck (WB-65)
Minor Arterial	Tractor-trailer Truck (WB-50)
Major Collector	Single-unit Truck
Minor Collector	Passenger Car (P)
Local Roads and Street	Passenger Car (P)

Notes: Design vehicles from AASHTO A Policy on Geometric Design of Highways and Streets, 2004
Passenger Car (P) applies to Light Trucks and SUV's
SU category can also be used for school and transit buses

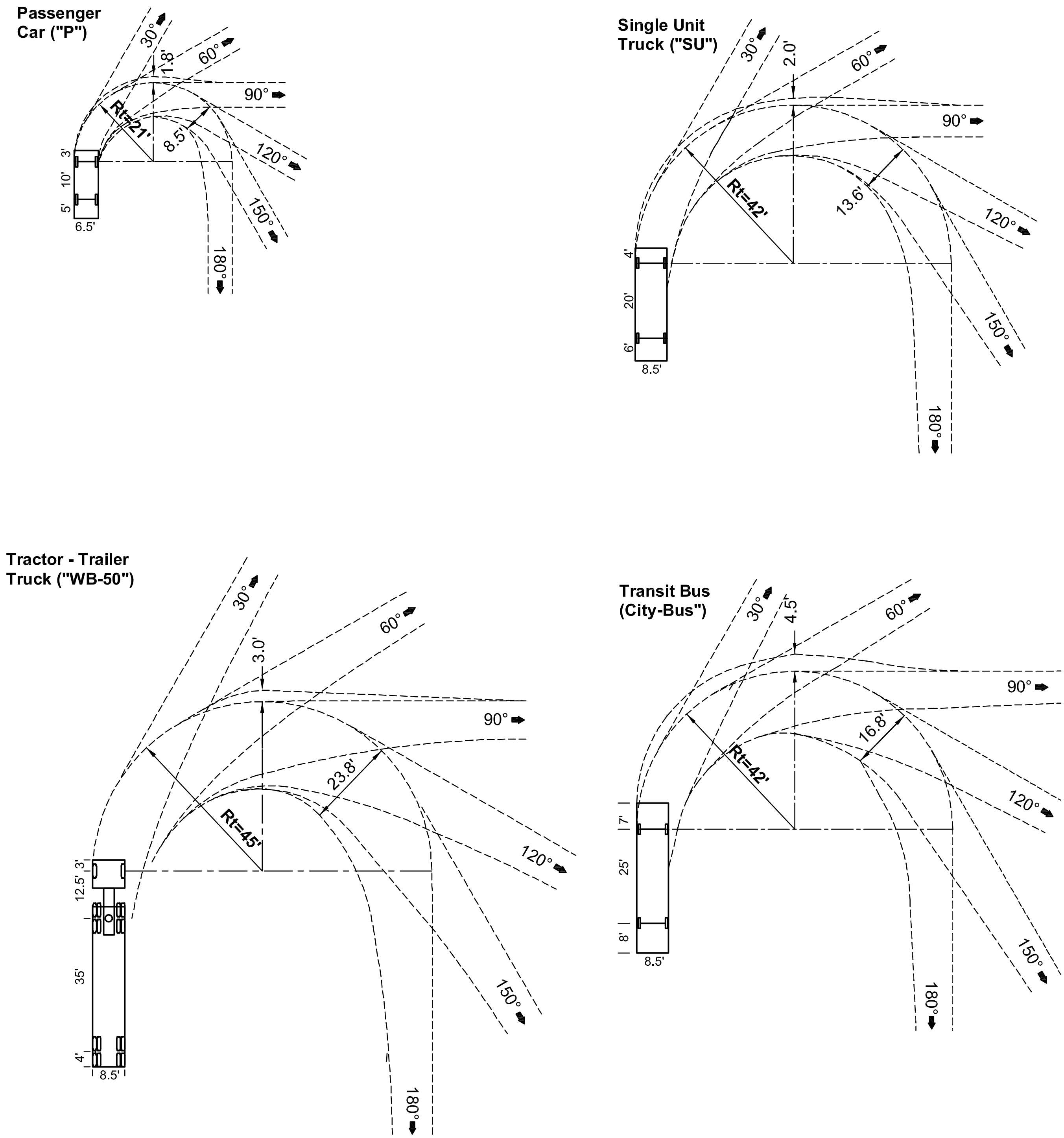
6.3.4 Transit

The design vehicle appropriate for most types of transit service is the "City-Bus" as defined by AASHTO. This vehicle is 40 feet long, 8 feet wide, and has outer and inner turning wheel paths of 42.0 feet and 24.5 feet, respectively. The "mid-size" bus, typically accommodating 22 to 28 passengers, is also used in scheduled transit service. The turning path for the mid-size bus can be accommodated within the single-unit (SU) truck turning path diagram. Tracked transit vehicles, such as trolleys, have turning radii as specified by their manufacturer, and are not accounted for in AASHTO templates. Their interactions with other traffic elements must be taken into account where applicable.

Transit stops are often located at intersections either as a near-side stop on the approach to the intersection or as a far-side stop on the departure leg of the intersection. Location near intersections is particularly advantageous where transit routes cross, minimizing the walking distance needed for passengers transferring between buses.

A bus stop, whether near-side or far-side, requires 50 to 70 feet of curb space unencumbered by parking. On streets without parking lanes or bus bays, buses must stop in a moving traffic lane to service passengers. Passengers typically require 4 to 6 seconds per person to board a bus, and 3 to 5 seconds to disembark. The total amount of time a transit vehicle will block traffic movements can then be estimated using the number of boardings and alightings expected at a stop.

Exhibit 6-3
Sample Vehicle Turning Template



Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004.

Note: Not to scale

6.4 Intersection Types and Configurations

Intersections can be categorized into four major types, as illustrated in Exhibit 6-4, *Intersection Types*.

6.4.1 Simple Intersections

Simple intersections maintain the street's typical cross-section and number of lanes throughout the intersection, on both the major and minor streets. Simple intersections are best-suited to locations where auxiliary (turning) lanes are not needed to achieve the desired level-of-service, or are infeasible due to nearby constraints. Generally, simple intersections provide the minimum crossing distances for pedestrians and are common in low-volume locations.

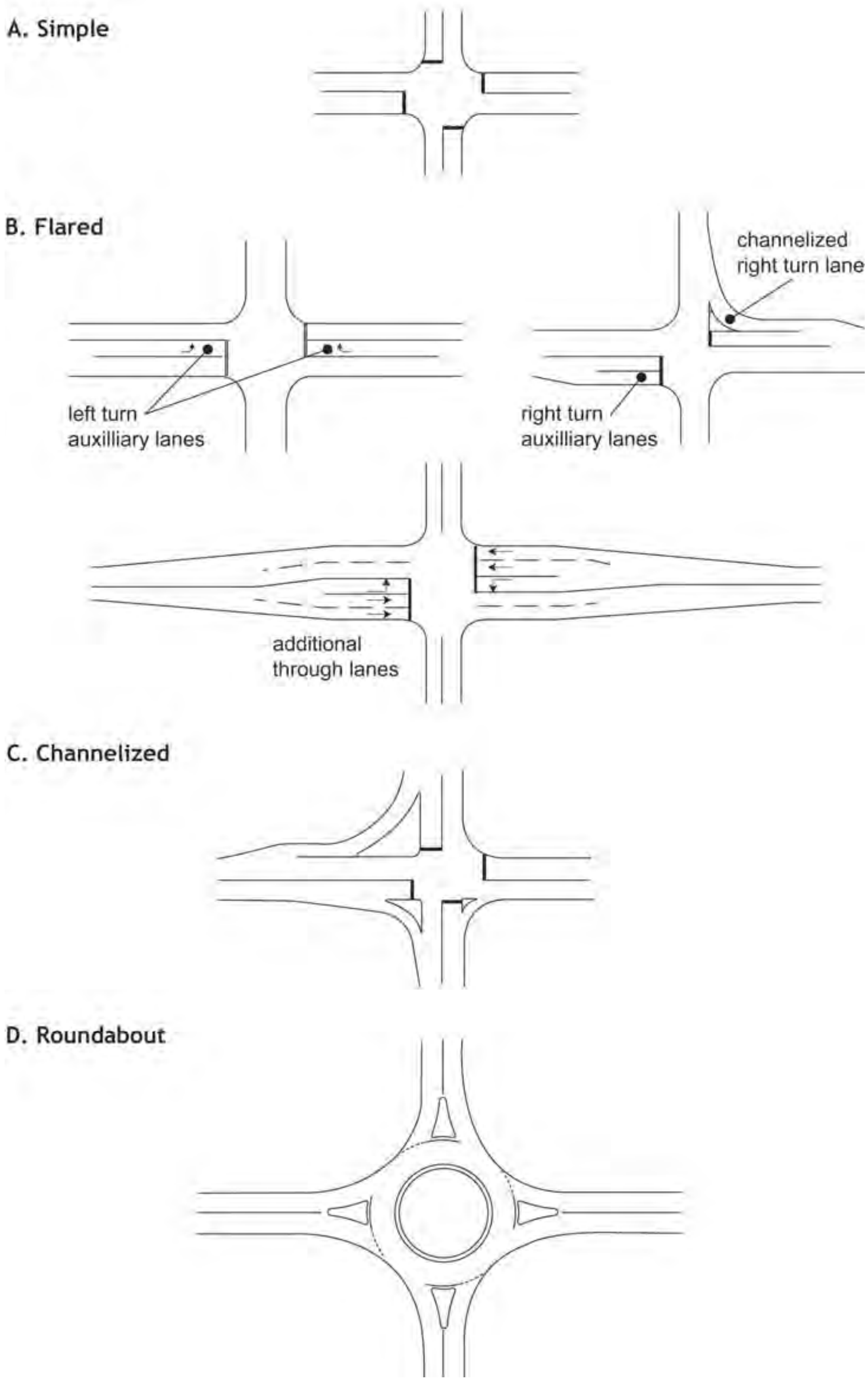
6.4.2 Flared Intersections

Flared intersections expand the cross-section of the street (main, cross or both). The flaring is often done to accommodate a left-turn lane, so that left-turning bicycles and motor vehicles are removed from the through-traffic stream to increase capacity at high-volume locations, and safety on higher speed streets. Right-turn lanes, less frequently used than left-turn lanes, are usually a response to large volumes of right turns.

Intersections may be flared to accommodate an additional through lane as well. This approach is effective in increasing capacity at isolated rural or suburban settings in which lengthy widening beyond the intersection is: not needed to achieve the desired level-of-service; not feasible due to nearby constraints; or, not desirable within the context of the project.

Intersection approaches can be flared slightly, not enough for additional approach lanes but simply to ease the vehicle turning movement approaching or departing the intersection. This type of flaring has benefits to bicycle and motor vehicular flow since higher speed turning movements at the intersection are possible and encroachment by larger turning vehicles into other vehicle paths is reduced. However, adding flare to an intersection increases the pedestrian crossing distance and time.

Exhibit 6-4
Intersection Types



Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004. Chapter 3 Elements of Design

6.4.3 Channelized Intersections

Channelized intersections use pavement markings or raised islands to designate the intended vehicle paths. The most frequent use is for right turns, particularly when accompanied by an auxiliary right-turn lane. At skewed intersections, channelization islands are often used to delineate right turns, even in the absence of auxiliary right turn lanes. At intersections located on a curve, divisional islands can help direct drivers to and through the intersection. At large intersections, short median islands can be used effectively for pedestrian refuge.

Channelization islands are also used in support of left-turn lanes, forming the ends of the taper approaching the turn bay, and often the narrow divisional island extending to the intersection. At "T"-type intersections, a channelization island can guide oncoming traffic to the right of the left-turn lane.

Channelized intersections are usually large and, therefore, require long pedestrian crosswalks. However, the channelization islands can effectively reduce the crosswalk distance in which pedestrians are exposed to moving motor vehicles. The design of channelized intersections needs to ensure that the needs of pedestrians are considered, including pedestrian curb cut ramps or "cut-throughs" that allow wheelchair users the same safe harbor as other pedestrians on channelization islands.

6.4.4 Roundabouts

The roundabout is a channelized intersection with one-way traffic flow circulating around a central island. All traffic—through as well as turning—enters this one-way flow. Although usually circular in shape, the central island of a roundabout can be oval or irregularly shaped.

Roundabouts can be appropriate design alternative to both stop-controlled and signal-controlled intersections, as they have fewer conflict points than traditional intersections (eight versus 32, respectively). At intersections of two-lane streets, roundabouts can usually function with a single circulating lane, making it possible to fit them into most settings.

Roundabouts differ from “rotaries” in the following respects:

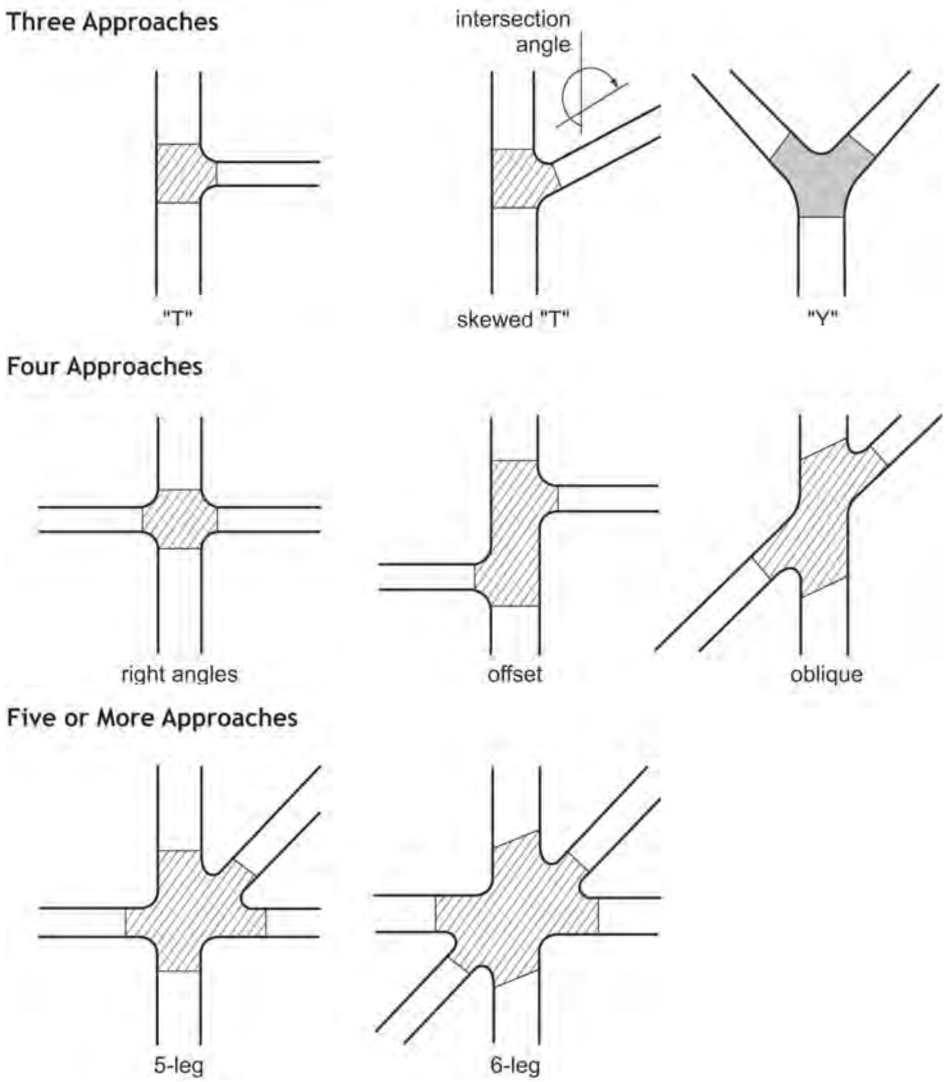
- **Size** – Single lane roundabouts have an outside diameter between 80 and 140 feet, whereas, rotaries are typically much larger with diameters as large as 650 feet.
- **Speed** – The small diameter of roundabouts limits circulating vehicle speeds to 10 to 25 miles per hour, whereas, circulating speeds at rotaries is typically 30 to 40 miles per hour.
- **Capacity** – The slower circulating speeds at roundabouts allow entering vehicles to accept smaller gaps in the circulating traffic flow, meaning more gaps are available, increasing the volume of traffic processed. At rotaries, vehicles need larger gaps in the circulating traffic flow reducing the volume of traffic processed.
- **Safety** – The slower speeds at roundabouts not only reduce the severity of crashes, but minimizes the total number of all crashes, whereas, rotaries typically see high numbers of crashes with a greater severity.

Roundabouts are also considered as traffic-calming devices in some locations since all traffic is slowed to the design speed of the one-way circulating roadway. This is in contrast with application of two-way stop control, where the major street is not slowed by the intersection, or all-way stop control where all traffic is required to stop. Roundabouts can also be considered for retrofit of existing rotaries; however, in cases with very high traffic volumes, traffic signal control may be more suitable.

6.4.5 Typical Intersection Configurations

Most intersections have three or four legs, but multi-leg intersections (five and even six-leg intersections) are not unusual. Examples of intersection configurations frequently encountered by the designer are shown in Exhibit 6-5. Ideally, streets in three-leg and four-leg intersections cross at right angles or nearly so. However, skewed approaches are a regular feature of intersection design. When skew angles are less than 60 degrees, the designer should evaluate intersection modifications to reduce the skew.

Exhibit 6-5
Intersecting Street Configuration and Nomenclature



Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004.

6.5 Traffic Control

Traffic control devices (signals, STOP, or YIELD signs and pavement markings) often control the entry of vehicles into the intersection. Traffic control devices may also be required at intersections of important private driveways with public streets. Examples of important driveways include alleys serving multiple homes, commercial alleys accessing parking, and commercial driveways.

6.5.1 Traffic Control Measures

Potentially conflicting flows (vehicle-to-vehicle or vehicle-to-non-vehicle) are an inherent feature of intersections. At most intersections, therefore, traffic control measures are necessary to assign the right of way. Types of intersection traffic control include:

- Where sufficient visibility is provided in low volume situations, some intersections operate effectively without formalized traffic control. In these cases, normal right of way rules apply.
- Yield control, with traffic controlled by “YIELD” signs (sometimes accompanied by pavement markings) on the minor street approaches. Major street traffic is not controlled.
- All-way yield control on roundabouts.
- Two-way stop control, with traffic controlled by “STOP” sign or beacons on the minor street approaches. Major street traffic is not controlled. The term “two-way stop control” can also be applied to “T” intersections, even though there may be only one approach under stop control. STOP control should not be used for speed reduction.
- All-way stop control, with traffic on all approaches controlled by STOP signs or STOP beacons. All-way stop control can also be a temporary control at intersections for which traffic signals are warranted but not yet installed.
- Traffic signals, controlling traffic on all approaches.
- Flashing warning beacons on some or all approaches.

Generally, the preferred type of traffic control correlates most closely with safety concerns and volume of motor vehicles, bicycles and pedestrians. For intersections with lower volumes, STOP or YIELD control on the cross (minor) street is the most frequently used form of vehicular traffic control.

6.5.1.1 Stop and Yield Control Warrants

Part Two of the *Manual on Uniform Traffic Control Devices* (MUTCD) should be consulted for guidance on appropriate STOP sign usage and placement. In general, STOP signs could be used if one or more of the following exist:

- Intersection of a less important road with a main road where application of the normal right of way rule would not be expected to provide reasonable compliance with the law;
- Street entering a through highway or street;
- Unsignalized intersection in a signalized area; and/or
- High speeds, restricted view, or crash records indicate a need for control by a STOP sign.

STOP signs should be installed in a manner that minimizes the number of vehicles having to stop. At intersections where a full stop is not necessary at all times, consideration should be given to using less restrictive measures, such as YIELD signs. YIELD signs could be used instead of STOP signs if one of the following conditions exists:

- When the ability to see all potentially conflicting traffic is sufficient to allow a road user traveling at the posted speed, the 85^{th} percentile speed, or the statutory speed to pass through the intersection or to stop in a reasonably safe manner;
- If controlling a merge-type movement on the entering roadway where acceleration geometry and/or sight distance is not adequate for merging traffic operation;
- The second crossroad of a divided highway where the median width at the intersection is 30 feet or greater. In this case a STOP sign may be installed at the entrance to the first roadway of a divided highway, and a YIELD sign may be installed at the entrance to the second roadway; and/or
- An intersection where a special problem exists and where engineering judgment indicates the problem to be susceptible to correction by the use of the YIELD sign.

6.5.1.2 Multiway STOP Control

Multiway STOP control can be useful as a safety measure at intersections if certain traffic conditions exist. Safety concerns associated with multiway stops include pedestrians, bicyclists, and all road users expecting other road users to stop. Multiway STOP control is used where the volume of traffic on the intersection roads in approximately equal. The following criteria should be considered for multiway STOP sign installation.

- Where traffic control signals are justified, the multiway STOP is an interim measure that can be installed quickly to control traffic while arrangements are being made for the installation of the traffic control signal;
- A crash problem, as indicated by five or more reported crashes in a 12-month period that are susceptible to correction by a multiway STOP installation. Such crashes include right- and left-turn collisions as well as right-angle collisions;
- Minimum volumes:
  - The vehicular volume entering the intersection from the major street approaches (total of both approaches) averages at least 300 vehicles per hour for any eight hours of an average day, and
  - The combined vehicular, pedestrian, and bicycle volume entering the intersection from the minor street approaches (total of both approaches) averages at least 200 units per hour for the same eight hours, with an average delay to minor street vehicular traffic of at least 30 seconds per vehicle during the highest hour, but
  - If the 85th percentile approach speed of the major street traffic exceeds 40mph, the minimum vehicular volume warrants are 70 percent of the above values.
- Where no single criterion is satisfied, but where the second and third criteria are all satisfied to 80 percent of the minimum values. The 85th percentile speed criterion is excluded from this condition.

At higher combinations of major street and minor street volume, traffic signals become the common traffic control measure. Roundabouts should also be considered in these situations. The decision to use traffic signals should follow the “signal warrants” specified in the MUTCD. These warrants are summarized in the following section.

6.5.1.3 Traffic Signal Warrants

Traffic signals should only be considered where the intersection meets warrants in the *Manual on Uniform Traffic Control Devices* (MUTCD). Where warranted and properly installed, traffic signals can provide for an orderly movement of traffic. Compared to stop control, signals can increase the traffic capacity of the intersection, reduce frequency and severity of crashes, particularly right-angle crashes, and interrupt heavy traffic flow to permit other motor vehicles, pedestrians and bicycles to cross the street.

Unwarranted or poorly timed traffic signals can have negative impacts, including excessive delay to vehicular and pedestrian traffic, disrespect for traffic control devices in general, increased “cut through” traffic on inappropriate routes, and increased frequency of crashes. Key features of the MUTCD warrants are:

The satisfaction of a traffic signal warrant or warrants shall not, in itself, require the installation of a traffic control signal. The traffic signal warrant analysis provides guidance *as to locations where signals would not be appropriate and locations where they could be considered further.*

- ***Warrant 1: 8-hour vehicular volume*****,** met by 500 to 600 vehicles per hour on the major street (both directions, two-four lanes respectively) and 150-200 vehicles on the minor street (major direction, one-two lanes respectively), for any combination of 8 hours daily. A variation (“interruption of continuous traffic”) warrant is met with 750 to 900 vehicles hourly on major street (two-four lanes, both directions), and 75 to 100 vehicles hourly (major direction, one-two lanes), on the minor street. These volumes can be reduced under certain circumstances (see Part 4 of the MUTCD for details).
- ***Warrant 2: four-hour vehicular volume*****,** met on two-lane streets when the volume approaching the intersection on both major street approaches combined plus the higher of the minor street approaches is around 900 vehicles hourly, for four hours daily.
- ***Warrant 3: peak hour*****,** met on two-lane streets when the volume approaching the intersection on both major street approaches combined plus the higher of the minor street approaches is around 1,200 vehicles in a single peak hour.
- ***Warrant 4: pedestrian volume*****,** met with intersection or mid-block pedestrian crossing volumes of at least 100 for each of four hours, or 190 during any one hour, in combination with fewer than 60 hourly gaps of adequate length to allow pedestrian crossing when the volume criteria are satisfied.

- ***Warrant 5: school crossing*****,** met with a minimum of 20 students crossing in the highest crossing hour, and less than one acceptable gap in the traffic stream per minute during the highest crossing hour. Engineering judgment and attention to other remedies (such as crossing guards, improved signage, and crossing islands) are strongly recommended.

- ***Warrant 6: coordinated traffic signal system*****,** where existing traffic signal spacing does not provide the necessary degree of platooning (grouping) of traffic, as needed to provide a progressive operation.

- ***Warrant 7: crash experience*****,** met when crash data indicates a problem remediable by traffic signal installation.

- ***Warrant 8: roadway network*****,** met when the street has importance as a principal roadway network or is designated as a major route on an official plan.

As part of the intersection design process, the detailed warrants, as presented in the *Manual on Uniform Traffic Control Devices*, should be followed. Even if warrants are met, a signal should be installed only if it is determined to be the most appropriate traffic control based on the context of the intersection, as signals do not add capacity to an intersection, they are intended to provide order. In many instances, traffic signal installation will require some widening.

6.5.1.4 Pedestrian Travel at Traffic Signals

Traffic signal design should encompass the following principles for accommodating pedestrians:

- In general, the WALK indication should be concurrent with the traffic moving on the parallel approach.

- Timing of pedestrian intervals should be in accordance with MUTCD and ADA requirements.

- Pedestrians should be given the longest possible walk time, while maintaining balance between motor vehicle flow and pedestrian delay. In most cases, the WALK interval should include all of the time in the vehicle green phase, except for the required clearance interval. Although not preferred, the minimum length for the WALK interval on a pedestrian signal indication is 7 seconds, long enough for a pedestrian to step off the curb and begin crossing. In some limited circumstances, where pedestrian volume is small, walk intervals as short as 4 seconds may be used.

- Signals should be timed to accommodate the average walking speeds of the type of pedestrian that predominantly uses the intersection. (The length of the clearance interval is calculated based on crossing the entire street from curb ramp to curb ramp with an assumed crossing speed of 3.5 feet per second). In areas where a significant portion of expected pedestrians are older or have disabilities, the assumed crossing speed should be reduced to 3.0 feet per second.
- Signal cycles should be as short as possible. Short signal cycles reduce delay, and therefore improve level of service for pedestrians, bicyclists and motor vehicles alike.
- Simple two-phase signals minimize pedestrian waiting time and are therefore preferable for pedestrian service. In some cases, simple two-phase signals also provide the best service for motor vehicle traffic.
- Leading pedestrian intervals (LPI) give pedestrians an advance WALK signal before the motorists get a concurrent green signal, giving the pedestrian several seconds to start in the crosswalk. This makes pedestrians more visible to motor vehicles and allows pedestrians to initiate their crossing without conflict with other traffic.
- Good progression for motor vehicles through a series of signals can be obtained over a wide range of vehicle speeds. In areas with high volumes of pedestrians, a low but well-coordinated vehicle progression speed (20-30 mph) can be used with little or no negative impact on vehicular flow.
- Pedestrian phases incorporated into each signal cycle, rather than on-demand through a call button, may be preferable for some conditions.
- Call button use should be limited to only those locations with traffic-actuated signals (i.e., where the signal does not cycle in the absence of minor street traffic).
- Where call buttons are used, a notification sign should be provided.
- Pedestrian call button actuation should provide a timely response, particularly at isolated signals (i.e., not in a progression sequence),

at mid-block crossings, and during low-traffic periods (night, for example).

- At four-way intersections, curb extensions could be provided to decrease the pedestrian crossing length.

- Pedestrian call buttons and the signals they activate should be maintained in good repair. This requires reliable and predictable button operation, functional signal displays, and the correct orientation of pedestrian signal heads.

Two types of supplemental indications can be used with pedestrian signals. An audible indicator, timed to coincide with the WALK phase, helps vision-impaired pedestrians and may be considered at locations regularly visited by such pedestrians.

The digital “countdown” indication displays the remaining seconds of safe crossing time (i.e., flashing “DON’T WALK” phases or hand/person displays). The countdown is helpful to pedestrians by providing the exact amount of crossing time remaining, thereby allowing them to make their own informed judgment on initiating a crossing, rather than simply following the WALK/DON’T WALK phases. Countdown signals may be considered for crossing approaches with short green time and at locations with high rates of signal-related crashes. Guidelines for the display and timing of countdown indicators are provided in the *Manual on Uniform Traffic Control Devices*. When used, the flashing DON”T WALK counter should end four seconds prior to the onset of the conflicting vehicle movement. However, these four seconds can be included in the clearance interval.

Locating Pedestrian Call Buttons

Pedestrian signal call buttons are used to initiate a pedestrian crossing phase at traffic signals. Where needed, pedestrian call buttons should be located to meet the following criteria:

- The closest call button to a crosswalk should call the pedestrian signal for that crosswalk.
- An arrow indicator should show which crosswalk the button will affect.

- The call button should align with the crosswalk and be visible to a pedestrian facing the crosswalk, unless space constraints dictate another button placement.
- Pedestrian actuated call buttons should be placed in locations that are easy to reach, 30 inches above the sidewalk, facing the sidewalk, clearly in-line with the direction of travel and with at least a 30” by 48” clear, level landing centered on the call button.

Accessible Pedestrian Signal Systems

At signalized intersections, people with vision impairments typically rely on the noise of traffic alongside them as a cue to begin crossing. The effectiveness of this technique is compromised by various factors, including increasingly quiet cars, permitted right turns on red, pedestrian actuated signals and wide streets. Further, low traffic volumes may make it difficult to discern signal phase changes. Technologies are available that enable audible and vibrating signals to be incorporated into pedestrian walk signal systems. The *Manual on Uniform Traffic Control Devices* offers guidelines on the use of accessible pedestrian signals. The Federal Access Board’s draft version (2002) of the *ADA Accessibility Guidelines for Public Right-of-Way* requires the use of audible signals with all pedestrian signals.

6.6 Intersection Capacity and Quality of Service

The “capacity” of an intersection for any of its users (motor vehicles, pedestrians, bicyclists, transit vehicles) is the maximum rate of flow of that user type that can be accommodated through the intersection. Typically, capacity is defined for a particular user group without other user groups present. Thus, for example, motor vehicular capacity is stated in terms of vehicles per hour, under the assumption that no other flows (pedestrians, bicycles) are detracting from such capacity.

Multimodal capacity is the aggregate capacity of the intersection for all users of the intersection. In some cases, the maximum multimodal capacity may be obtained while some individual user flows are at less than their individual optimum capacity.

“Level of service” is defined by the *Highway Capacity Manual*, for each type of intersection user. For each user, level of service is correlated to the amount of control delay encountered by the user at the intersection. Control delay, a result of traffic control devices needed to allocate the potentially conflicting flows at the intersection, reflects the difference between travel time through the intersection at free flow versus travel time under the encountered conditions of traffic control. For drivers, control delay consists of time “lost” (from free-flow time) due to deceleration, waiting at signals, STOP or YIELD signs, waiting and advancing through a queue of traffic, and accelerating back to free-flow speed. For pedestrians and bicyclists, deceleration and acceleration times are insignificant, and control delay is largely the time spent waiting at signals, STOP, or YIELD signs.

Levels of service are somewhat correlated to capacity in that levels of service decline as capacity is approached.

6.6.1 Capacity

“Capacity” (the maximum possible flow) differs importantly from “service volumes” (flows associated with the quality of flow, typically stated as “Level of Service” or “LOS”). These two terms are defined, for pedestrian, bicycle, and motor vehicle flow, in the following sections.

6.6.1.1 Pedestrian Flow Capacity

A pedestrian walkway with uninterrupted flow can carry a maximum volume of approximately 1,380 pedestrians per hour for each foot of walkway width. An 8-foot crosswalk, therefore, would have a capacity of 5,500 pedestrians per hour, assuming they have the use of half (4 feet) of the crosswalk. Under the same assumptions, a 12-foot crosswalk would carry a maximum volume, in half its width, of 8,300 hourly pedestrians.

At signalized intersections, each approach will accommodate pedestrian crossings for 10 to 20 percent of the time, reflecting the intervals that pedestrians can begin to cross with assurance of completing their crossing while traffic is stopped for their approach. An 8-foot crosswalk at a typical signalized intersection, therefore, can carry 550 to 1,100 pedestrians per hour.

At unsignalized locations, the time available for pedestrian flow is dictated by motor vehicle volume and length of the crossing. These two factors, which govern the number of “gaps” in the motor vehicle stream available for safe pedestrian crossing, must be measured on-site to establish the pedestrian flow capacity of an unsignalized intersection. The signal warrants in the MUTCD offer guidance on combinations of motor vehicle and pedestrian volumes that may justify a signal, and therefore reflect the pedestrian capacity of unsignalized intersections.

6.6.1.2 Bicycle Flow Capacity

A bicycle lane (4-6 feet in width) can, with uninterrupted flow, carry a volume of around 2,000 bicycles per hour in one direction. At signalized intersections, bicycle lanes receive the same green signal time as motor vehicles, typically 20-35 percent of the total time. The hourly capacity of a bicycle lane, at a signalized intersection, is therefore 400 to 700 bicycles per hour.

At signalized intersections without bicycle lanes, bicycles are part of the approaching vehicular traffic stream. The combined vehicular capacity (motor vehicles as well as bicycles) is established as defined in Section 6.6.1.3.

At unsignalized intersections with bicycle lanes on the major street, the bicycle flow capacity is the uninterrupted flow volume of 2,000 bicycles per hour. For the STOP-controlled (minor street) approach, the flow capacity for bicycles, whether in bicycle lanes or not, is governed by the speed, motor vehicle volume, and number of lanes of major street traffic. These factors require measurement on-site to establish the bicycle flow capacity of STOP controlled approaches.

6.6.1.3 Motor Vehicle Capacity

At unsignalized intersections, motorized vehicle capacity is governed by the ability of motor vehicles (on the minor street) under STOP control or YIELD control to enter or cross the stream of moving motor vehicles on the major street. This capacity is reached as the number of motor vehicles on both major street approaches, plus the number on the busiest minor street approach totals 1,200 motor vehicles in a single peak hour, or totals 900 motor vehicles hourly over a continuous 4-hour period. At these points, entering or crossing the major street from the STOP controlled or YIELD controlled minor street becomes difficult or impossible. Further increases in intersection capacity at STOP controlled or YIELD controlled intersections can be gained by replacing stop or yield control with signal control or a roundabout. Traffic signal warrants 1, 2, and 3 discussed previously provide detailed guidance on specific combinations of major and minor street volumes associated with the transition from STOP control or YIELD control to traffic signal control.

At signalized intersections, motor vehicle capacity is governed by the number of lanes approaching the intersection, the number of receiving lanes, and the amount of green signal time given to the approach. The total green time available decreases as more signal phases and therefore more red and yellow “lost time” are included in the signal sequences.

A simple but reliable measure of a signalized intersection’s capacity is its “critical lane volume” capacity (CLV capacity), defined as the maximum sum of conflicting movements that can be moved through the intersection at a given level of service as shown in Exhibit 6-6.

Signalized intersection capacity is neared as the CLV reaches 1,500 hourly motor vehicles for intersections with two signal phases (the minimum possible) or 1,375 to 1,425 for intersections with more than two signal phases.

This simple CLV measure can be used for initial assessment of an intersection’s capacity, and also as a reasonableness check on procedures in the *Highway Capacity Manual.* The relationship between CLV capacity and level of service (described in more detail in Section 6.6.2) is summarized in Exhibit 6-7.

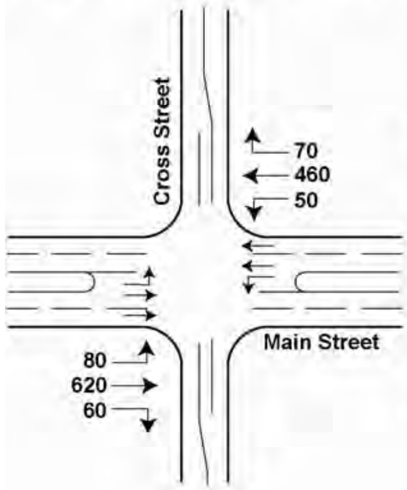
At roundabouts, motor vehicle capacity is governed by the ability of entering traffic to enter the stream of motor vehicles in the circulating roadway. This capacity is neared as the vehicular volume in the circulating roadway (single lane) approaches 1,800 motor vehicles hourly. At this point, entering the stream of circulating motor vehicles within the roundabout becomes difficult or impossible. At this threshold, additional lanes on one or more approaches and a second circulating lane should be considered.

Exhibit 6-6
Computing Critical Lane Volume

Critical lane volume (CLV) is the sum of main street CLV plus the cross street CLV.

The main street CLV is the greater of either: (A) eastbound through and right per lane + westbound left OR (B) westbound through and right per lane + eastbound left.

Similarly, the cross street CLV is the greater of either: (A) northbound through and right per lane + southbound left OR (B) southbound through and right per lane + northbound left.



Example:

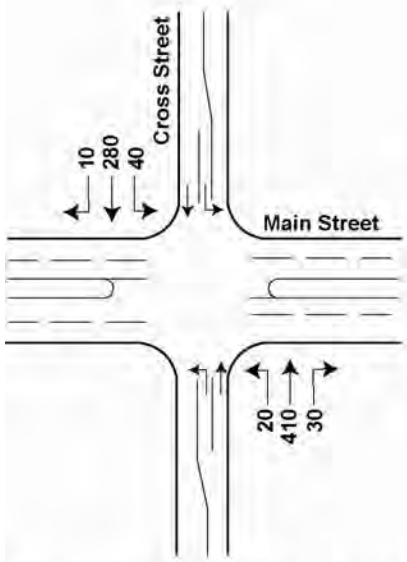
The main street CLV is the larger of either sum:

A. Eastbound through per lane and right turn + opposing left turns: (620 + 60) ÷ 2 + 50 = 390

OR

B. Westbound through per lane + opposing left turns: (460 + 70) ÷ 2 + 80 = 345

Main street CLV is therefore 390.



The cross street CLV is the larger of either sum:

A. Northbound through per lane and right turn + opposing left turn: (410 + 30) + 40 = 480

OR

B. Southbound through per lane + opposing left turn: (280 + 10) + 20 = 310

Cross street CLV is therefore 480.

Total intersection CLV = main street CLV + cross street CLV = 390 + 480 = 870

Notes:

- Critical lane volume (CLV) is the sum of main street CLV plus the cross street CLV.
- The main street CLV is the greater of either: (A) eastbound through and right per lane + westbound left, or (B) westbound through and right per lane + eastbound left.
- Similarly, the cross street CLV is the greater of either: (A) northbound through and right per lane + southbound left, or (B) southbound through and right per lane + northbound left.
- Total intersection CLV = main street CLV + cross street CLV = 390 + 480 = 870.

Source: Transportation Research Board, Circular Number 212, TRB 1980.

Exhibit 6-7
Traffic Flow Related to Critical Lane Volumes[1]

Flow Condition	Corresponding *Highway Capacity Manual* Level of Service	Corresponding Critical Lane Volume (CLV) Vehicles Per Hour – Signal Phases: 2 Phase	3 Phase	4 Phase
Free Flowing (no loaded cycles)	A, B, C	Less than 1200	Less than 1140	Less than 1100
Prevailing Level of Peak-Hour Congestion in Towns and Urban Areas	D	1200 – 1350	1140-1275	1100-1225
Approaching Capacity	E, F	1350 – 1500	1275 - 1425	1225 – 1375

Source: CLV/LOS relationship from Table 6, Transportation Research Circular Number 212, Transportation Research Board, 1980.
1 Based on a peak hour factor of 0.9, limited heavy vehicles, limited turning volumes, and somewhat flat grades.

6.6.1.4 Multimodal Capacity

Under some combinations of users and intersection configuration, achieving a desired flow for one user group diminishes the capacity for another group. Typical situations include:

- Signals with numerous phases (5 to 6 or more) where the “walk” phase is constrained by the green time needed for vehicles on other approaches permitted during the “walk” phase.
- Where buses and other transit vehicles stop for passenger loading/unloading in a lane of traffic approaching or departing an intersection.
- Where exceptionally large volumes of pedestrians crossing an approach require a “walk” phase time greater than the green signal time needed for motor vehicles permitted to move during the same phase.

In situations like these, intersection design should flow from a carefully considered balancing of the needs of the various user groups. However, when determining this balance, the designer also needs to consider that excessive motor vehicle delays can lead to undesirable cut-through traffic patterns on streets not intended for high through volumes. Alternatively, by providing more efficient multimodal opportunities, the motor vehicle demand may be reduced through user modal choice.

6.6.2 Level of Service (LOS)

Level-of-service is one measure of user satisfaction with an intersection. For all users, level-of-service is linked to average delay.

6.6.2.1 Pedestrian Level of Service

Pedestrian level of service is defined by the delay experienced by the pedestrian at the intersection. Exhibit 6-8 summarizes pedestrian level of service for signalized and unsignalized intersections, and roundabouts. The Exhibit also summarizes, for the various levels of service, the propensity for pedestrians to engage in unsafe crossing behavior by accepting dangerously small gaps in traffic for crossing, or ignoring traffic signal indications.

Exhibit 6-8
Pedestrian Level of Service (LOS) Criteria at Intersections

	Average Delay to Pedestrian (seconds)			
Level of Service	Unsignalized Intersections	Signalized Intersections	Roundabout	Likelihood of Risk Taking Behavior
A	Less than 5.0	Less than 10.0	Less than 5.0	Low
B	5.1 – 10.0	10.1 – 20.0	5.1 – 10.0	
C	10.1 – 20.0	20.1 – 30.0	10.0 – 20.0	Moderate
D	20.1 – 30.0	30.1 – 40.0	20.1 – 30.0	
E	30.1 – 45.0	40.1 – 60.0	30.1 – 45.0	High
F	Greater than 45.0	Greater than 60.0	Greater than 45.0	

Source: Highway Capacity Manual, 2000

At unsignalized intersections, the delay in crossing the major street (i.e., approaches not controlled by STOP control) is the time needed for pedestrians to receive a gap in traffic adequate to cross safely. Gaps are, in turn, related to the volume of traffic and the likelihood of driver's yielding the right of way to a pedestrian in the crosswalk. Pedestrians crossing STOP controlled or YIELD controlled approaches do not have to wait for a gap in traffic, but wait for the first vehicle in line to yield right of way. Pedestrian crossings across STOP controlled or YIELD controlled approaches are likely to have a significantly better level of service than crossings at the uncontrolled approaches.

At signalized intersections, the delay to pedestrians is that time spent waiting for the next signal phase permitting safe crossing. Where pedestrian indications are present, this signal phase begins with the WALK display. Where pedestrian indications are not present, the signal phase permitting crossing begins with the red signal indication on the intersection approach to be crossed.

The average delay to pedestrians (i.e., the average time spent waiting for the next signal phase permitting safe crossing) is less than one-half the total signal cycle length. Typically, these cycle lengths are 60 to 90 seconds, resulting in pedestrian delay of 30 to 45 seconds. Longer signal cycles, such as the 120-180 second cycles on major arterials, result in corresponding higher delays (60-90 seconds respectively) for pedestrians. Typically, short signal cycle lengths, therefore, provide better pedestrian level of service than long cycle lengths.

At roundabouts, pedestrians may walk further than at a signalized intersection due to the diameter of the circulating roadway. However, pedestrians cross only a single lane of traffic at a time, taking refuge in the splitter island. Actual delay is likely to be comparable or less than at a normally situated crosswalk.

6.6.2.2 Bicycle Level of Service

Where there is no bicycle lane or shoulder being used by bicyclists, bicycles are considered to be part of the stream of vehicular traffic and they experience the same control delay that would accrue to a motor vehicle in their position in traffic. For streets without bicycle lanes or shoulders, therefore, the bicycle level of service is computed the same as for motor vehicles as described below.

Bicyclists in their lane (or shoulder) “bypass” stopped motor vehicles, and therefore seldom experience delay due to queuing. Delay due to queuing of bicycles is a factor only with extraordinary volumes. Therefore, for bicyclists in bicycle lanes or shoulders at signalized intersections, the average delay can be estimated as one-half of the signal red and yellow time facing that approach. This reflects bicycle arrivals at random, with average delay therefore one-half of the maximum. Level of service for bicycles at signalized intersections is summarized in Exhibit 6-9.

Exhibit 6-9
Bicycle Level of Service (LOS) Criteria at Signalized Intersections

Level of Service	Average Delay to Bicyclist (seconds)
A	Less than 10.0
B	10.1 – 20.0
C	20.1 – 30.0
D	30.1 – 40.0
E	40.1 – 60.0
F	Greater than 60

Source: Highway Capacity Manual, 2000
Delay can be estimated as 0.5 (red and yellow signal time) on bicyclist's approach.

Bicyclists can experience substantial delay at intersections when they are not detected by the traffic signal system. This failure to be detected may result in longer waits for a green signal, inability to obtain a green arrow for a left turn, or a decision to proceed on red.

At unsignalized locations, bicycles on the major street are not likely to be delayed because they have priority over minor street vehicles. Bicyclists crossing or entering the major street from a STOP controlled minor street are delayed by the amount of time required to find an acceptable gap. Field measurement of this time, during peak as well as off-peak periods, is the preferred method of establishing this delay.

At roundabouts, bicycles generally experience the same delays as motor vehicles as they "take the lane" in approaching the circulating roadway.

6.6.2.3 Motor Vehicle Level of Service (LOS)

Motor vehicle level of service (LOS) at an intersection is defined by the *Highway Capacity Manual* in terms of delay experienced by a motor vehicle traveling through the intersection during the busiest (peak) 15 minutes of traffic of the day. Typically, delay is averaged over all approaches with traffic controls (STOP, YIELD, or signal). It can also be computed separately for each approach or each lane group (adjacent lanes with at least one movement in common; for example one lane with through movement adjacent to a lane with through/right-turn movement). Exhibit 6-10 provides motor vehicular level-of-service criteria at intersections.

Exhibit 6-10
Motor Vehicular Level of Service (LOS) Criteria at Intersections

Level of Service (LOS)	Delay, Seconds per Vehicle[1]		
	Unsignalized Intersections	Signalized Intersections	Roundabout
LOS A	Less than 10.0	Less than 10.0	Less than 10.0
LOS B	10.1 to 15.0	10.1 to 20.0	10.1 to 15.0
LOS C	15.1 to 25.0	20.1 to 35.0	15.1 to 25.0
LOS D	25.1 to 35.0	35.1 to 55.0	25.1 to 35.0
LOS E	35.1 to 50.0	55.1 to 80.0	35.1 to 50.0
LOS F	Greater than 50.0	Greater than 80.0	Greater than 50.0

Source: Highway Capacity Manual, (HCM 2000) Transportation Research Board, 2000
1 Delay is “control delay” as defined in HCM 2000, and includes time for slowing, waiting in queues at the intersections, and accelerating back to free-flow speed.

Improving Vehicular Level of Service at Intersections

When attempting to improve the motor vehicular level-of-service at intersections, the designer should work to ensure that the measures to improve motor vehicular level of service do not have a disproportionately negative impact on other intersection users. There are several techniques commonly used to achieve this objective as described in the following paragraphs.

Changing the type of traffic control (for example, transitioning from STOP control to signalization or to a roundabout) may add motor vehicular capacity at intersections. At intersections already signalized, more capacity may be gained from replacing fixed-time signal control with motor vehicle, bicycle and pedestrian-actuated control.

Auxiliary left-turn and right-turn lanes (see Section 6.4.2) increase intersection capacity by removing slowing or stopped vehicles from lanes otherwise usable by through traffic. Auxiliary through lanes (see Section 6.4.2) can be appropriate at isolated signalized intersections and increase intersection capacity. However, the length of the auxiliary lanes for the receiving leg will determine the ability of this extra through traffic to merge. If auxiliary lanes are too short, they may congest the intersection and block the minor street traffic, and fail to reduce delay.

The designer should also note that adding auxiliary lanes increases the crossing distance for pedestrians. The designer should ensure that the level of service increases provided for motor vehicles do not result in large degradations in LOS for other users. Where widening to provide auxiliary lanes is planned, the designer should consider crossing islands and other features to ensure the ability for pedestrians to cross.

At roundabouts, capacity can be increased by an additional approach lane and a corresponding section of additional circulating lane.

Adding parallel links of street network may reduce traffic volumes at an intersection, thereby eliminating or postponing the need to increase its capacity.

6.6.2.4 Multimodal Level of Service

As described throughout this section, the designer should strive to achieve the highest level of service for all intersection users, given the context and demands encountered. The intersection level of service commonly found in various area types is shown in Exhibit 6-11. The designer needs to understand the potential impact that intersection geometrics and traffic control will have on level of service for all modes. Generally, the designer should try to improve or maintain existing levels of service. In most instances, the designer should not propose a design that provides a level-of-service improvement for one user group at the expense of another.

Exhibit 6-11
Common Intersection Level-of-Service Ranges by User Group and Area Type

	Level-of-Service Ranges		
	Pedestrian	Bicycle	Motor Vehicle
Rural Natural	A-B	A-C	A-C
Rural Village	A-C	A-D	A-E(1)
Rural Developed	A-C	A-C	A-C
Suburban High Density	B-E	C-E	C-E
Suburban Village/Town Center	A-D	C-E	C-F(1)
Suburban Low Density	A-C	A-C	A-D
Urban Park	A-C	A-D	B-E
Urban Residential	A-C	B-D	C-E
Urban Central Business District	A-D	B-E	D-F(1)

1 In these instances, queuing at intersections becomes critical in that there should not be impacts that extend to adjacent intersections.
Source: MassHighway

6.7 Geometric Design Elements

The following sections describe many of the detailed design elements associated with intersections including intersection alignment, pavement corner radii, auxiliary lanes, channelization islands, roundabouts, median openings, pedestrian curb cut ramps and crosswalks, bicycle lane treatments, and bus stops.

6.7.1 Intersection Alignment

Intersection alignment guidelines control the centerlines and grades of both the major and minor streets, in turn establishing the location of all other intersection elements (for example, edge of pavement, pavement elevation, and curb elevation).

6.7.1.1 Horizontal Alignment

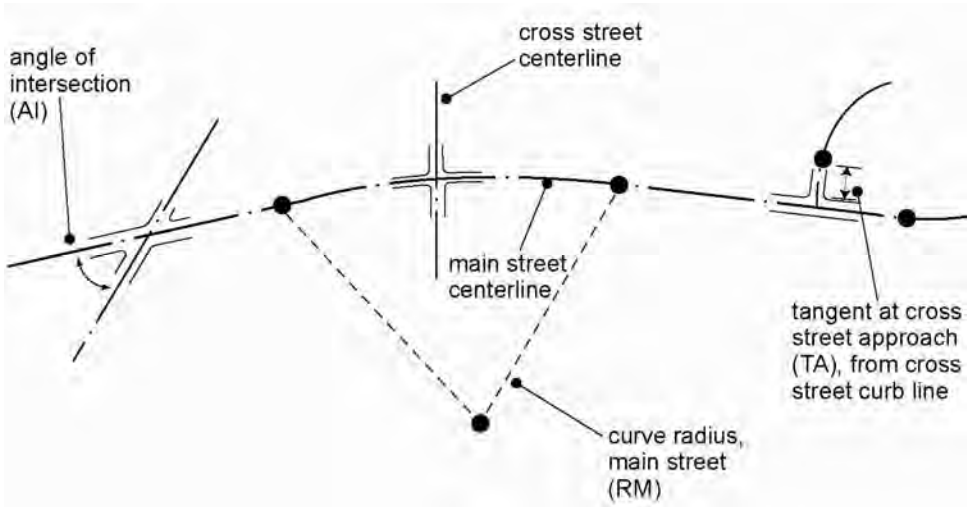
Ideally, streets should intersect as close to right angles as practical. Skewed intersections can reduce visibility of approaching motor vehicles and bicycles, require higher degrees of traffic control, require more pavement to facilitate turning vehicles, and require greater crossing distances for pedestrians.

Guidelines for the maximum curvature at intersections are given in Exhibit 6-12. Curvature through an intersection affects the sight distance for approaching motorists, and may require additional traffic control devices (warning signs, stop signs, signals, pavement markings or roundabouts). On higher-speed roads, superelevation on curves may incline the cross slope of the intersection in a manner uncomfortable to motorists, or in conflict with intersection vertical alignment guidelines described below.

The minimum tangent at cross-street approach (TA) shown in Exhibit 6-12 helps to assure necessary sight distance at the intersection, and to simplify the task of driving for motorists approaching the intersection.

Often, in steep terrain, a permissible grade cannot be achieved with the horizontal alignment guidelines. Typically, this design challenge is resolved by adhering to vertical alignment criteria, while incorporating the necessary flexibility in the horizontal guidelines.

Exhibit 6-12
Horizontal Alignment Guidelines at Intersections



Design Speed (MPH)	Minimum Angle of Intersection (AI, degrees) Arterial Major Street	Collector Major Street	Local Major Street	Minimum Curve Radius, Main Street (RM, feet)	Minimum Tangent Cross Street Approach (TA, feet)
15	60	60	60	45	30
20	60	60	60	85	30
25	60	60	60	155	30
30	60	60	60	250	30
35	60	60	60	365	45
40	60	60	60	500	45
45	65	60	60	660	45
50	65	65	60	835	60
55	65	65	65	1065	60
60	70	65	65	1340	60

Source: MassHighway

6.7.1.2 Vertical Alignment

The major street and minor street profile influence the vertical alignment of an intersection.

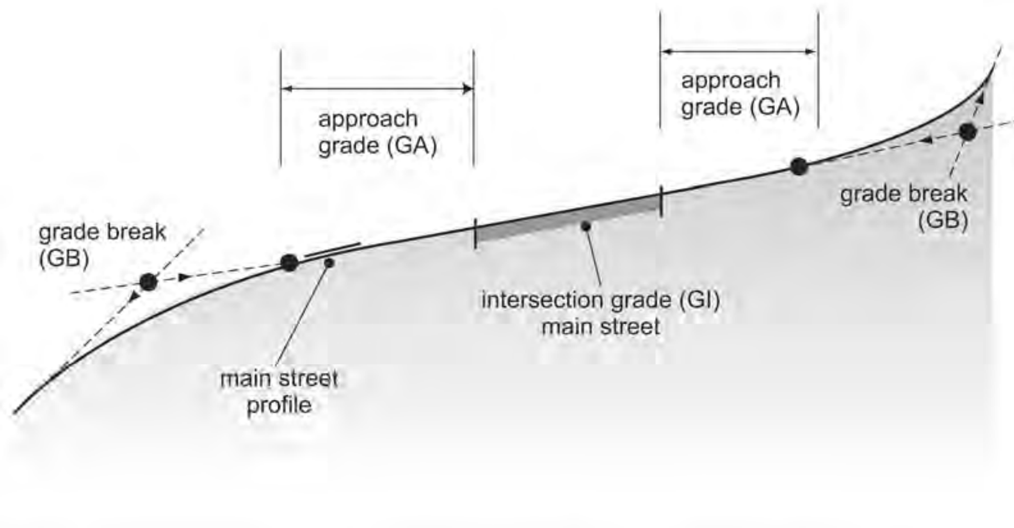
Major Street Profile

The intersection approach grade in the uphill direction, as shown in Exhibit 6-13, affects the acceleration of motor vehicles and bicycles from a stopped condition, and therefore can have an impact on vehicular delay at the intersection. The intersection approach grade in the downhill direction affects the stopping distance of approaching motor vehicles and bicycles.

The length of vertical curves between the non-intersection grade and the intersection approach grades is governed by the guidelines for vertical alignment discussed in Chapter 4.

The intersection grade is the slope of the pavement within the intersection itself. Excessive intersection grade can cause tall vehicles (trucks, buses) to tip while turning. Intersection grade can also have an impact on accessibility for pedestrians with disabilities, by creating a grade on crosswalks.

Exhibit 6-13
Vertical Alignment Guidelines



Design Speed (mph)	Maximum Intersection Grade (GI, %)	Maximum Grade Break (GB, %)	Minimum Length of Approach Grade (GA, feet)
15	5	6	20
20	5	5	40
25	5	4	40
30	5	3	60
35	5	2	60
40	4	2	70
45	4	2	70
50	3	2	70
55	3	1	70
60	3	1	70
65	2	0.5	70
70	2	0.5	70

Source: MassHighway

Minor Street Profile

The profile of the minor street, as shown in Exhibit 6-14, is subject to the same vertical alignment criteria as the major street; however, several inherent features of a minor street, particularly its lower level of usage, will most likely permit a lower design speed for the minor street compared to the major street.

Where the minor street is under STOP or YIELD control (Exhibit 6-14, Part A), the crown of the major street is typically carried through the intersection. Meeting this major street cross-section can result in minor street grades near the intersection that are steeper than that which would occur with the major street crown removed.

At intersections where the major street retains the crown through the intersection, the minor street crown is gradually reduced, typically starting at the beginning of the approach grade, and completed slightly outside the intersection.

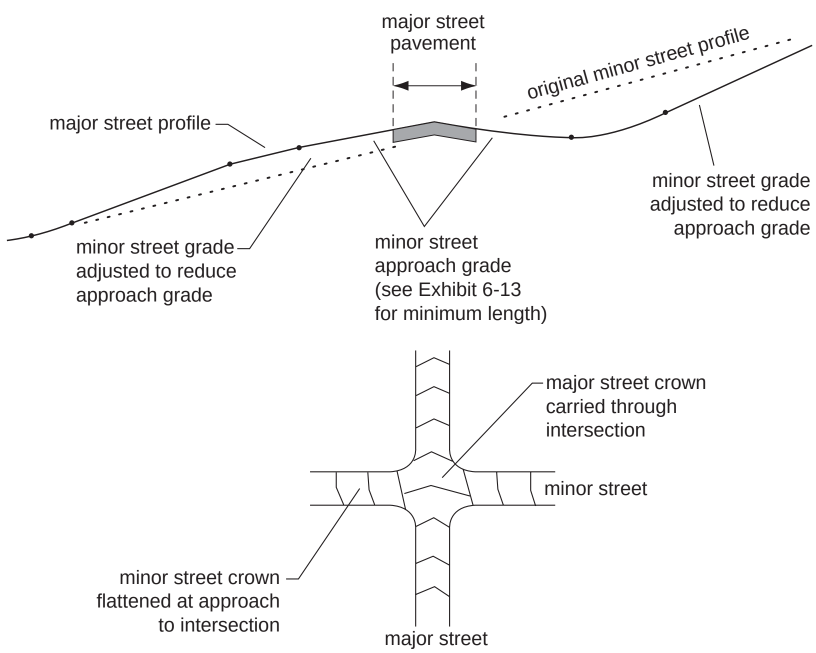
At intersections with signal control, it is customary to remove the crown from both the major street and the minor street. This removal of the crown is advisable for the comfort and safety of motor vehicle drivers and bicyclists proceeding, on either street, at the design speed through a green signal indication. At intersections with all-way STOP control, it may be desirable to remove the crown from both intersecting streets, to emphasize that all approaches are equal in terms of their traffic control.

Eliminating the crown on the major street can, under many circumstances, reduce the amount of modification that must be done to the minor street profile (Exhibit 6-14 Part B). The major street cross slope can be inclined in the same direction at the minor street profile, thereby permitting approach grades on the minor street to be accommodated with minimal alteration to the original minor street profile. Where both major street and minor street crowns are eliminated, their removal is accomplished gradually, typically over the length of the approach grade. Whether crowned or not, pavement grades within the intersection should not exceed the values given in Exhibit 6-13.

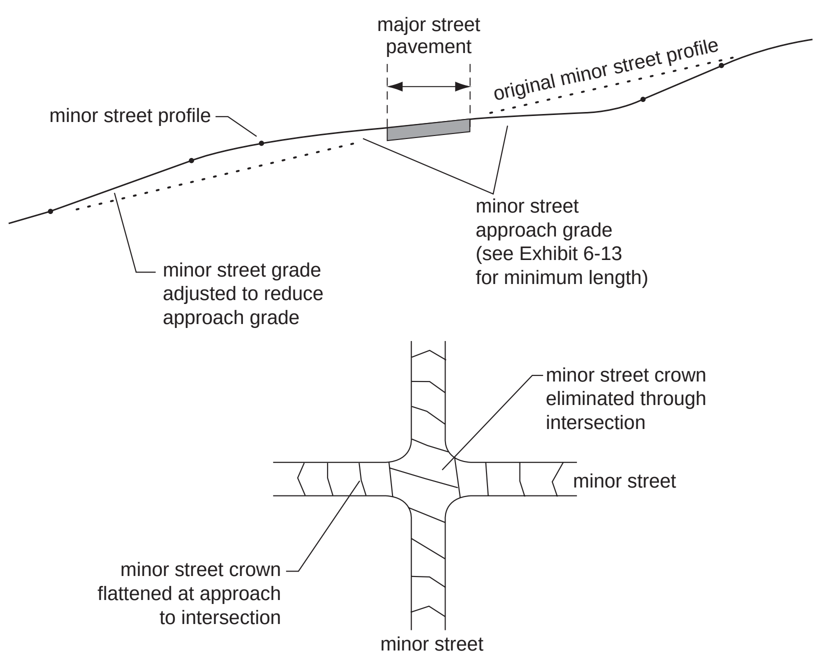
In addition to meeting the vertical profile guidelines as stated above, intersection approaches on both main and minor streets are subject to the intersection sight triangle requirements (see Chapter 3). Under some circumstances, these sight triangle requirements may dictate approach grades or length of approach grades differing from those indicated in the vertical alignment guidelines above.

Exhibit 6-14
Pavement Cross-slope at Intersections

A. Major Street Retains Crown (Stop or Yield control on cross street)



B. Major Street Crown Removed: Signal Control



Source: Transportation Association of Canada

6.7.2 Pavement Corner Radius

The pavement corner radius—the curve connecting the edges of pavement of the intersecting streets—is defined by either the curb or, where there is no curb, by the edge of pavement. The pavement corner radius is a key factor in the multimodal performance of the intersection. The pavement corner radius affects the pedestrian crossing distance, the speed and travel path of turning vehicles, and the appearance of the intersection.

Excessively large pavement corner radii result in significant drawbacks in the operation of the street since pedestrian crossing distance increases with pavement corner radius. Further, the speed of turning motor vehicles making right turns is higher at corners with larger pavement corner radii. The compounded impact of these two measures—longer exposure of pedestrians to higher-speed turning vehicles—yields a significant deterioration in safety and quality of service to both pedestrians and bicyclists.

The underlying design control in establishing pavement corner radii is the need to have the design vehicle turn within the permitted degrees of encroachment into adjacent or opposing lanes. Exhibit 6-15 illustrates degrees of encroachment often considered acceptable based on the intersecting roadway types. These degrees of encroachment vary significantly according to roadway type, and balance the operational impacts to turning vehicles against the safety of all other users of the street. Although the Exhibit provides a starting point for planning and design, the designer must confirm the acceptable degree of encroachment during the project development process. The designer should use also use vehicle turning templates presented earlier in this chapter and in AASHTO's *A Policy on the Geometric Design of Highways and Streets* to confirm appropriate pavement corner designs.

At the great majority of all intersections, whether curbed or otherwise, the pavement corner design is dictated by the right-turn movement. Left turns are seldom a critical factor in corner design, except at intersections of one-way streets, in which case their corner design is similar to that for right turns at intersections of two-way streets. The method for pavement corner design can vary as illustrated in Exhibit 6-16 and described below.

- **Simple curb radius**: At the vast majority of settings, a simple radius (curb or pavement edge) is the preferred design for the pavement corner. The simple radius controls motor vehicle speeds, usually minimizes crosswalk distance, generally matches the existing nearby intersection designs and is easily designed and constructed.
- **Compound curves or taper/curve combinations**: Where encroachment by larger motor vehicles must be avoided, where turning speeds higher than minimum are desirable, or where angle of turn is greater than 90 degrees, compound curves can define a curb/pavement edge closely fitted to the outer (rear-wheel) vehicle track. Combinations of tapers with a single curve are a simple, and generally acceptable, approximation to compound curves.
- **Turning roadways**: A separate right-turn roadway, usually delineated by channelization islands and auxiliary lanes, may be appropriate where right-turn volumes are large, where encroachment by any motor vehicle type is unacceptable, where higher speed turns are desired, or where angle of turn is well above 90 degrees.

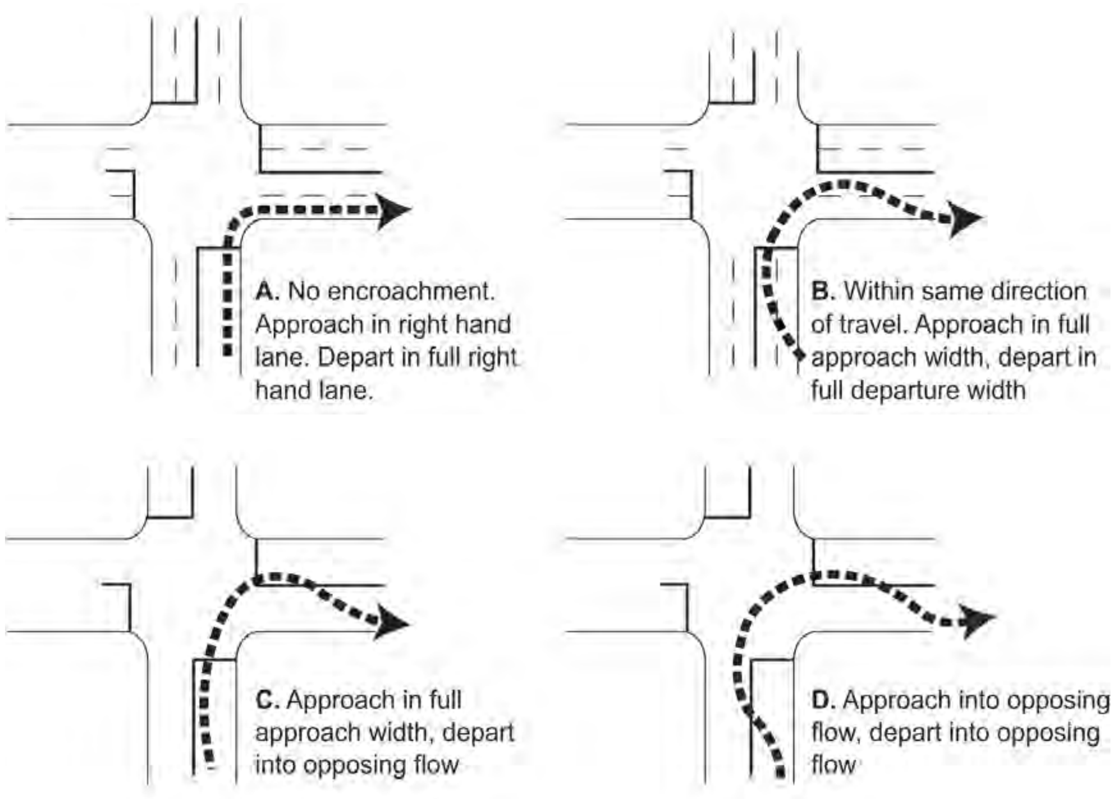
6.7.2.1 Simple Curb Radius

Pavement corner design at simple intersections is controlled by the following factors:

- The turning path of the design motor vehicle. Design motor vehicles appropriate for the various roadway types are summarized in Section 6.3.3 of this chapter.
- The extent (if any) of encroachment, into adjacent or opposing traffic lanes, permitted by the design motor vehicle determined from Exhibit 6-15.
- The "effective" pavement width on approach and departure legs is shown in Exhibit 6-17. This is the pavement width usable, by the design motor vehicle, under the permitted degree of encroachment. At a minimum, effective pavement width is always the right-hand lane and therefore usually at least 11-12 feet, on both the approach and departure legs. Where on-street parking is present, the parking lane (typically 7-8 feet) is added to the effective width on those legs (approach, departure or both) with on-street parking. Typically, legs with on-street parking have an effective pavement width of around 20 feet. The effective width may include encroachment into adjacent or opposite lanes of

traffic, where permitted. A maximum of 10 feet of effective width (i.e., a single lane of traffic) may be assumed for such encroachment.

Exhibit 6-15
Typical Encroachment by Design Vehicle

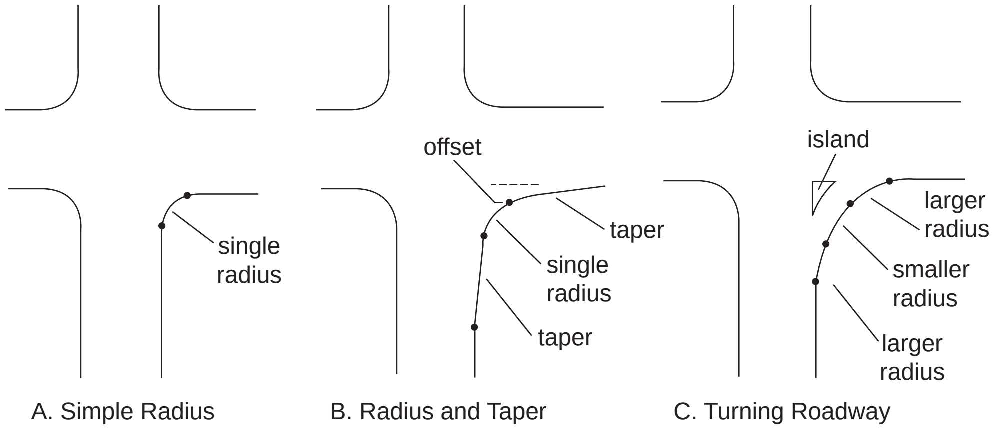


To (Departure Street)

From (Approach Street)	For Tractor/Trailer (WB 50)			For Single-Unit Truck (SU)			For Passenger Car (P)		
	Arterial	Collector	Local	Arterial	Collector	Local	Arterial	Collector	Local
Arterial (Art)	A	B	C	A	B	C	A	A	A
Collector (Col)	B	B	C	B	B	C	A	A	A
Local (Loc)	B	D	D	C	C	D	A	B	B

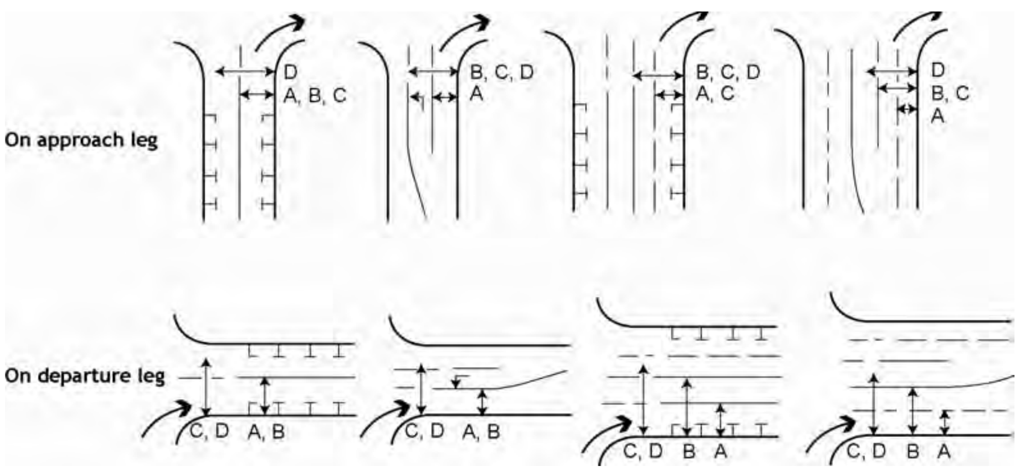
A, B, C, D defined in above diagrams.
Note: Cases C and D are generally not desirable at signal controlled intersections because traffic on stopped street has nowhere to go.
Source: Adapted from ITE Arterial Street Design Guidelines.

Exhibit 6-16
Methods for Pavement Corner Design



Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004. Chapter 9 Intersections

Exhibit 6-17
Effective Pavement Widths



Note: The letters A, B, C, and D refer to the typical encroachment conditions illustrated in Exhibit 6-15.
Source: MassHighway

Exhibit 6-18 summarizes the simple curb radius needed for various design motor vehicles, reflecting the extent of encroachment and effective pavement width. General guidelines can be concluded for right-angle (90 degree) intersections:

- A 15-foot simple curb radius is appropriate for almost all right-angle (90 degree) turns on local streets. This radius permits passenger cars to turn with no encroachment and accommodates the single unit (SU) truck with acceptable degrees of encroachment. The occasional tractor/trailer truck (WB-50) can also negotiate the 15-foot corner radius within its acceptable degree of encroachment.
- Where the major street is a collector street, a 20-30 foot radius is likely to be adequate. Where parking is present, yielding an effective width of 20 feet, the typical design motor vehicle for the intersection (the SU truck) can turn with less than a 20 foot corner radius, without encroachment. On single lane approaches and departures, with no on-street parking, the SU vehicle can be accommodated with a 25-foot radius and an 8-foot encroachment (i.e., a 20 foot effective width) on the departure. At locations where no encroachment can be tolerated, a radius of 40 feet will permit the SU truck to approach and depart within a single lane.
- For arterial streets where the WB-50 truck is the design vehicle, a 35-foot radius is adequate under most circumstances of approach and departure conditions. However, with a single approach and departure lane, and with no encroachment tolerated, a radius as high as 75 feet is required. In this situation, a turning roadway with channelization island may be a preferable solution.

At skewed intersections (turn angle greater than 90 degrees), the simple radius required for the SU and WB-50 vehicle is significantly larger than that needed for 90 degree intersections. Curve/taper combinations or turning roadways may be appropriate in these situations.

Exhibit 6-18
Simple Radius for Corner Design (Feet)

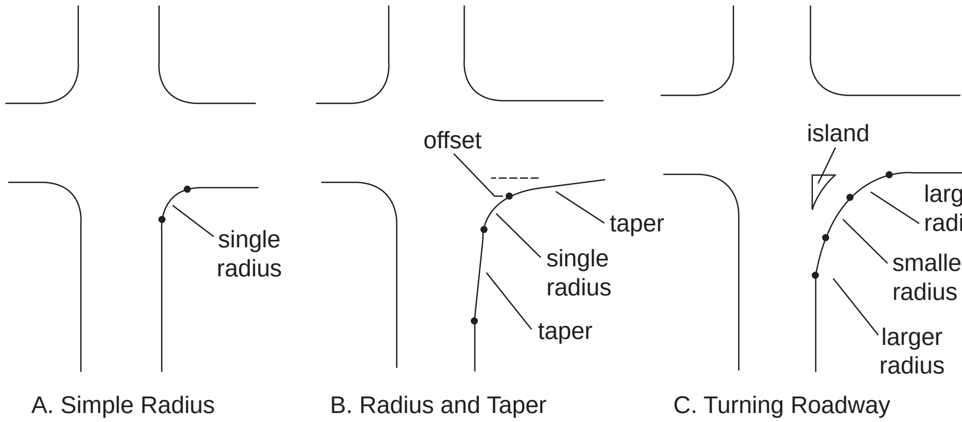
Turn Angle and Effective Width on Approach Leg (feet)	Effective Width on Departure Leg (Feet)							
	Passenger Car (P)		Single-unit Truck (SU)			Tractor-Trailer (WB-50)		
	12	20	12	20	24	12	20	24
90° Turn Angle								
12 Feet	10	5	40	25	10	75	35	30
20 Feet	5	5[(a)]	30	10	5	70	30	20
24 Feet	(b)	(b)	25	5	5[(a)]	70	25	15
120° Turn Angle								
12 Feet	25	10	60	35	25	105	65	50
20 Feet	10	5[(a)]	50	25	20	95	50	40
24 Feet	(b)	(b)	45	20	15	95	50	35
150° Turn Angle								
12 Feet	50	25	130	90	75	170	130	105
20 Feet	30	10	110	75	60	155	115	95
24 Feet	(b)	(b)	100	65	55	155	110	80

Source: P, SU and WB-50 templates from *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004.
(a) Minimum buildable. Vehicle path would clear a zero radius.
(b) Maximum of 20 feet (one lane plus parking) assumed for passenger car operation.

6.7.2.2 Curve/Taper Combinations

The combination of a simple radius flanked by tapers can often fit the pavement edge more closely to the design motor vehicle than a simple radius (with no tapers). This closer fit can be important for large design motor vehicles where effective pavement width is small (due either to narrow pavement or need to avoid any encroachment), or where turning speeds greater than minimum are desired. Exhibit 6-19 summarizes design elements for curve/taper combinations that permit various design motor vehicles to turn, without any encroachment, from a single approach lane into a single departure lane.

Exhibit 6-19
Curve and Taper Corner Design

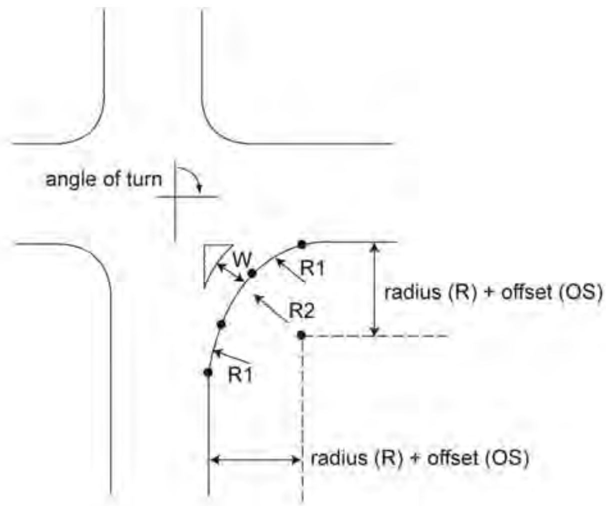


Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004. Chapter 9 Intersections

Curve and Taper Corner Design Elements

Angle of Turn (Degrees)	Design Vehicle	Radius (R, feet)	Offset (OS feet)	Taper Length (T, feet)
75	P	25	2	20
	SU	45	2	20
	WB -50	65	3	45
90	P	20	2.5	25
	SU	40	2.0	20
	WB -50	60	4.0	60
105	P	20	2.5	-
	SU	35	3.0	-
	WB -50	55	4.0	60
120	P	20	2.0	-
	SU	30	3.0	-
	WB -50	45	4.0	60
150	P	18	2.0	20
	SU	30	4.0	32
	WB -50	35	7.0	42

Exhibit 6-20
Turning Roadways and Islands



Turning Roadway, Edge of Pavement			
Angle of Turn (Degrees)	Design Vehicle	Radius (feet) R1-R2-R1	Offset (OS feet)
75	P	100-75-100	2.0
	SU	120-45-120	2.0
	WB -50	150-50-150	6.5
90	P	100-20-100	2.5
	SU	120-40-120	2.0
	WB -50	180-60-180	6.5
105	P	100-20-100	2.5
	SU	100-35-100	3.0
	WB -50	180-45-180	8.0
120	P	100-20-100	2.0
	SU	100-30-100	3.0
	WB -50	180-40-180	8.5
150	P	75-20-75	2.0
	SU	100-30-100	4.0
	WB -50	160-35-160	7.0

Note: W (width) should be determined using the turning path of the design vehicle.

Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004. Chapter 9 Intersections

6.7.3 Auxiliary Lanes

The design elements of three auxiliary lanes types are described in the following sections: left-turn lanes, right-turn lanes, and through lanes. Deceleration and taper distances provided below should be accepted as a desirable goal and should be provided for where practical. However, in urban areas it is sometimes not practical to provide the full length of an auxiliary lane. In such cases, at least part of the deceleration must be accomplished before entering the auxiliary lane. Chapter 9 of AASHTO's *Geometric Design of Highways and Streets* provides more information for the designer.

6.7.3.1 Left-Turn Lane Design Elements

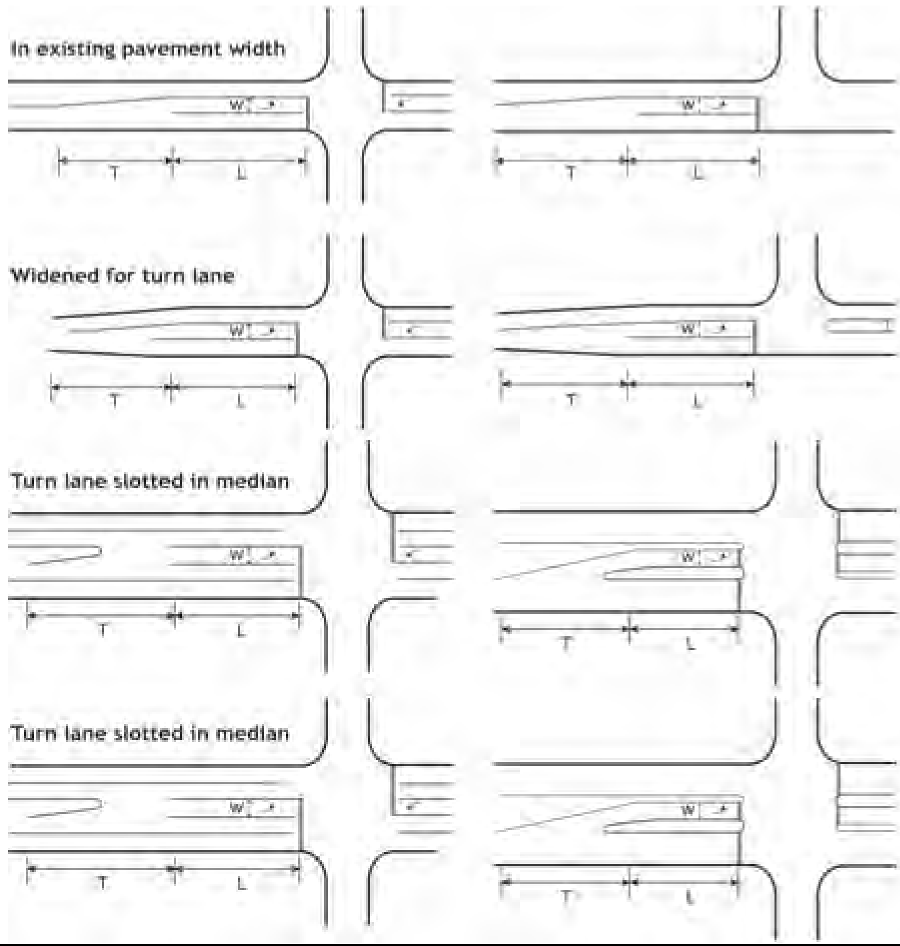
Left-turn lanes remove stopped or slow-moving left-turning motor vehicles from the stream of through traffic, eliminating the primary cause of rear-end crashes at intersections. The safety benefits of left-turn lanes increase with the design speed of the road, as they greatly reduce both the incidence and severity of rear-end collisions. Left-turn lanes also improve capacity by freeing the travel lanes for through traffic only.

The safety and capacity benefits of left-turn lanes apply to all vehicular traffic, motorized as well as non-motorized. However, left-turn lanes add to the pedestrian crossing distance and pedestrian crossing time. The additional street width needed for left-turn lanes may require land taking or removal of on-street parking.

The lengths of left-turn lanes, illustrated in Exhibit 6-21, depend on the volume of left-turning motor vehicles and the design speed. The length of taper required to form the left-turn lane varies with design speed. At signalized intersections, a conservative guideline for determining the storage length of a left-turn lane is 150 percent (1.5 times) of the length of the average number of left-turning vehicles arriving during a single signal cycle in the peak hour.

A more analytical guideline for the length of required storage lane is to obtain the expected length of the left-turn queue and associated probabilities from intersection analysis computations (computerized versions of *Highway Capacity Manual* methodology or derivative programs such as SYNCHRO). Typically, left-turn lanes are sized to accommodate the maximum length of queue for the 95th percentile traffic volumes, a queue length that is exceeded on only 5 percent of the peak-hour traffic signal cycles.

Exhibit 6-21
Left-Turn Lane Design Guidelines



Dimensions for Left-Turn Lane Elements (feet)

Design Speed (mph)	Lane Width (W, feet)	Deceleration Distance (feet)[1]	Storage Distance[2] (feet)	Length of Lane[2] (L, feet)	Taper Length (T, feet)[3]	Widened Taper Length (T, feet)
15-25	10	115	50	165	100	See Note 4
30-35	10	170	50	220	100	See Note 4
40	10-11	275	75	350	110	See Note 4
45	10-11	340	75	415	150	See Note 4
50	11-12	410	75	485	180	See Note 4
55	11-12	485	75	560	180	See Note 4
60	12	530	75	605	180	See Note 4

Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004. Chapter 9 Intersections

1 For deceleration grades of 3 percent or less.

2 Storage distance and therefore total lane length (L) are based on an unsignalized left-turn volume of 100 vehicles hourly. For larger volumes, compute storage need by formula or from intersection analysis queue calculation.

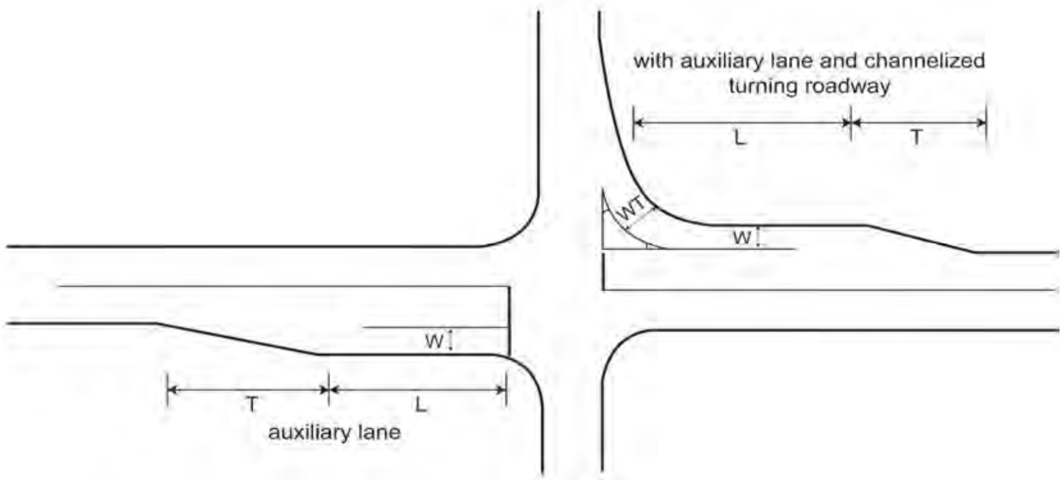
3 This taper length is not applicable for "widened for turn lane" cases, see note 4.

4 For "widened for turn lane" cases, use $T = WS^2/60$ for speeds less than 45 mph and T = WS for speeds 45 mph and greater.

6.7.3.2 Right-Turn Lane Design Elements

Right turn lanes are used to remove decelerating right-turning motor vehicles from the traffic stream, and also to provide an additional lane for the storage of right-turning motor vehicles. Where the right-turn volume is heavy, this removal of the turning motor vehicle from the traffic stream can also remove a primary cause of rear-end crashes at intersections. Design elements for right-turn lanes are summarized in Exhibit 6-22.

Exhibit 6-22
Right-Turn Lane Design Guidelines



Dimensions for Right-Turn Lane Elements (feet)						
Design Speed[1] (mph)	Lane Width (W. feet)	Turning Lane Width (WT, feet)	Deceleration Distance (feet)	Storage Distance[2] (feet)	Length of Lane[2] (L, feet)	Taper Length (T, feet)
15-25	10	14	115	50	165	100
30-35	10	14	170	50	220	100
40	10-11	15	275	60	335	110
45	10-11	15	340	60	400	150
50	11-12	15	410	60	470	180
55	11-12	16	485	60	545	180
60	12	16	530	60	590	180

Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004. Chapter 9 Intersections

1 Based on grades of less than three percent for speeds less than 60 mph. Based on grades of less than two percent for speeds greater than 60mph.

2 Storage distance and therefore total lane length (L) are based on an unsignalized right-turn volume of 100 vehicles hourly. For larger volumes, compute storage need by formula or from intersection analysis queue calculation.

Right-turn lanes provide a safety and capacity benefit for motorized traffic. However, in areas of high pedestrian or bicyclist activity, these benefits may be offset by the additional pavement width in the intersection, higher speeds of motor vehicular turning movements, and vehicle/bicyclist conflict created as motorists enter a right-turn lane across an on-street bicycle lane or across the path of bicycle traffic operating near the curb.

6.7.3.3 General Criteria for Right-Turn and Left-Turn Lanes

Criteria for considering installation of left-turn lanes are summarized in Exhibit 6-23. These criteria are based on a combination of left-turning motor vehicle volumes plus opposing through motor vehicle volumes at unsignalized locations. For example, if 330 vehicles per hour travel eastbound at 40 mph and five percent are turning left, an exclusive left-turn lane is warranted once the westbound volume exceeds 800 vehicles per hour.

Considerable flexibility should be exercised in considering left-turn lanes. Typically, they involve little impact to the setting, while generally yielding large benefits in safety and user convenience. Left-turn lanes may be desirable in many situations with volumes well below those stated. These include to destinations of special interest (shopping, major institutions, etc.), or for locations with marginal sight distance on the main road or a consistent occurrence of rear-end crashes.

Where there is a need for multiple, closely spaced left-turn lanes (due to driveways or small blocks), it may be advisable to designate a continuous center lane as a “two-way left turn lane” (TWLTL) as discussed in Chapters 5 and 15.

Criteria for the installation of right-turn auxiliary lanes are more judgmental than the numerical guidelines for their left-turn lane counterpart. Positive and negative indicators (i.e., conditions favoring or arguing against right-turn lanes) are summarized in Exhibit 6-24.

Exhibit 6-23
Criteria for Left Turn Lanes

A. Unsignalized Intersections, Two-Lane Roads and Streets:

Design Speed	Opposing Volume (motor vehicles per hour)	Advancing Motor Vehicle Volume (vehicles per hour) 5% Left Turns	10% Left Turns	20% Left Turns	30% Left Turns
30 mph or less	800	370	265	195	185
	600	460	345	250	225
	400	570	430	305	275
	200	720	530	390	335
40 mph	800	330	240	180	160
	600	410	305	225	200
	400	510	380	275	245
	200	640	470	350	305
50 mph	800	280	210	165	135
	600	350	260	195	170
	400	430	320	240	210
	200	550	400	300	270
60 mph	800	230	170	125	115
	600	290	210	160	140
	400	365	270	200	175
	200	450	330	250	215

B. Signalized Intersections:

Left-Turn Lane Configuration	Minimum Turn Volume
Single exclusive left-turn lane	100 motor vehicles per hour
Dual exclusive left-turn lane	300 motor vehicles per hour

Source: *Highway Capacity Manual*, 2000

Exhibit 6-24
Criteria for Right-Turn Lane Placement

Positive Criteria (Favoring Right-Turn Placement)	Negative Indicators (Arguing Against Right-Turn Lane Placement)
High speed arterial highways	In residential areas
High right-turn motor vehicle volumes	In urban core areas
High right-turn plus high cross-street left-turn volumes	On walking routes to schools
Long right-turn queues	Where pedestrians are frequent
Intersection capacity nearly exhausted	Low right turn volumes
History of crashes involving right-turning vehicles	
Little to no pedestrian activity	

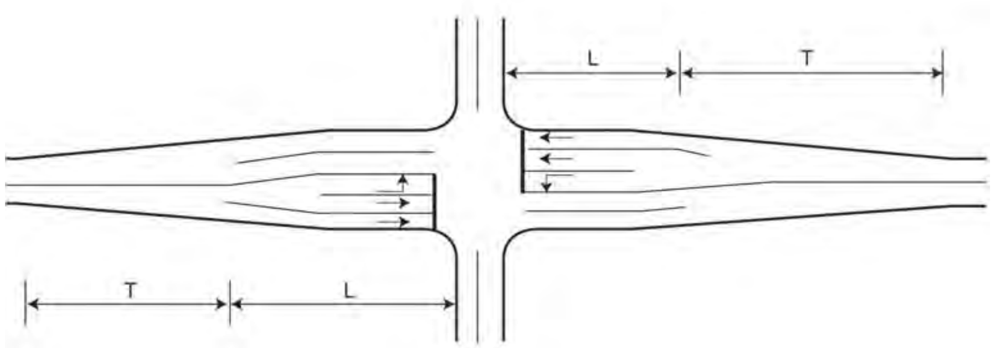
Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004. Chapter 9 Intersections

6.7.3.4 Auxiliary Through Lane Design Elements

Short segments of additional through lane (widening a street through a signalized intersection) can be an effective way of increasing intersection capacity at relatively "isolated" intersections (for example, in rural areas and in settled areas with a minimum of about one-mile spacing between signalized intersections).

Where through lanes are provided, motorists approaching the intersection arrange themselves into two lanes of traffic and merge back to a single lane of traffic on the departure side of the intersection. Merging under acceleration (i.e., on the departure side of the intersection) works well, since gaps (spaces between motor vehicles) are increasing as vehicles accelerate, leaving numerous opportunities to merge as the traffic stream leaves the intersection. Design elements for auxiliary through lanes are given in Exhibit 6-25.

Exhibit 6-25
Auxiliary Through Lane Design Guidelines



Dimensions for Auxiliary Through-Lanes (feet)			
Design Speed (mph)	Lane Width (feet)	Taper Length (T, feet)[1]	Length of Lane (L, feet)
15-25	10	$WS^2/60$	See Note 2
30-35	10	$WS^2/60$	See Note 2
40	10-11	$WS^2/60$	See Note 2
45	10-11	WS	See Note 2
50	11-12	WS	See Note 2
55	11-12	WS	See Note 2
60	12	WS	See Note 2

1 W is the lateral shift required to form the additional through lane.

2 L should be based on anticipated queue derived from intersection operations analysis.

Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004. Chapter 9 Intersections and the Manual on Uniform Traffic Control Devices

6.7.4 Channelization Islands

Channelization islands are used to:

- Delineate the area in which motor vehicles can operate;
- Reduce the area of motor vehicle conflict;
- Bring motor vehicle merging into a safer (smaller) angle of merge; and
- Provide pedestrian refuge.

Ideally, channelization islands are raised above pavement level, typically to curb height (6 inches). Less preferably, they may be flush with the pavement level. Both raised and flush islands may be constructed of a variety of materials, including conventionally finished concrete, scored concrete, or rigid pavers of various types. Some general criteria for the dimensions of channelization islands include:

- Triangular islands should be a minimum of 100 square feet in surface area with one side at least 15 feet in length. Linear islands should be at least 2, and preferably 3 feet or more wide. If they contain signs, they should be at least 4 feet wide. If they intersect pedestrian crosswalks or contain signs, they should be at least 6 feet wide with maximum 1.5 percent slope. The minimum length of linear islands should be 25 feet.
- Channelization islands should contain at-grade passages for bicycle lanes, wheelchair and pedestrian paths, and should generally be placed to avoid impeding bicycle movement, whether or not bicycle lanes are present.
- The edges of channelization islands should be offset from the travel lanes, to guide drivers smoothly into the desired path. Typically, a 2-foot offset is appropriate.

Typical arrangements and applications of channelization are shown in Exhibit 6-26.

6.7.4.1 Right-turn Channelization Islands

A small channelization island can delineate a right-turn lane at a simple intersection (i.e., where neither the approach nor departure lane is flared). This type of channelization is appropriate for large-radius corners. A more common use for the right-turn channelization island is at flared intersections, where a deceleration lane flare is provided on the approach to the intersection, sometimes combined with an acceleration lane flare on the departure side. The largest channelization islands are typically found where an auxiliary right-turn lane is provided on both the approach and departure side of the intersection.

Right-turn channelization islands can benefit pedestrians crossing the affected approaches by providing an interim refuge in the crosswalk. This refuge permits pedestrians to devote full attention to crossing the right-turn lane without needing to assure a safe crossing for the rest of the street. From the channelization island, pedestrians can then proceed across the through lanes of traffic without the complicating factor of crossing the right-turn movement.

6.7.4.2 Divisional Islands

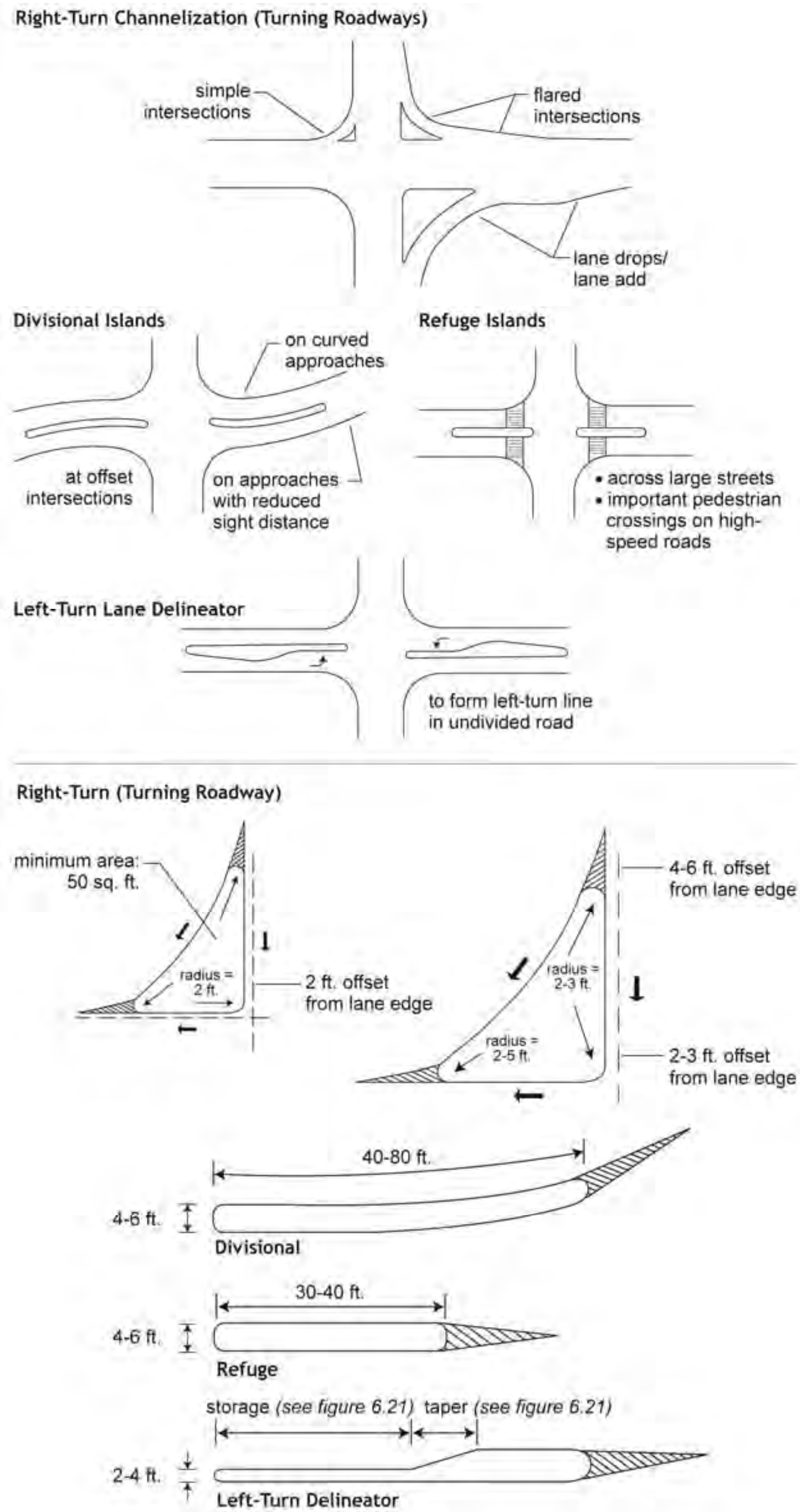
Divisional islands are useful in dividing opposing directions of traffic flow at intersections on curves, or with skewed angles of approach. In such instances, they can improve the safety and convenience for approaching motorists. Although superficially similar to medians, divisional islands differ from them in their short length and relatively narrow width and are discussed further later in this chapter and in Chapter 16.

6.7.4.3 Left-Turn Lane Delineator Islands

The left-turn delineator island resembles a short section of median island, with triangular striping to guide traffic around it. At the intersection end of the island, it is narrowed to provide storage for left-turning motor vehicles and bicycles.

On undivided streets, the left-turn lane delineator island is used to form the left-turn bay. At its upstream nose (i.e., on the approach to the intersection), the island and associated striping shifts the through traffic lane to the right, creating room for the taper and left-turn bay.

Exhibit 6-26
Channelization Islands



Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004. Chapter 9 Intersections

6.7.5 Roundabout Geometric Design Elements

The key elements of geometric design for roundabouts are shown in Exhibit 6-27 and include:

- The circulating roadway, which carries motor vehicles and bicycles around the roundabout in a counterclockwise direction.
- The central island, defining the inner radius of the circulating roadway around it.
- A core area within the central island, from which motor vehicles are excluded.
- A truck apron area on the outer perimeter of the central island, traversable by large motor vehicles.
- The inscribed circle, defined by the outer edge of the circulating roadway.
- Splitter islands, on all approaches, separating the entering from the exiting traffic.
- Crosswalks across approach and departure roadways.

The key design element of the roundabout is its outer diameter, the inscribed circle diameter (ICD). This dimension determines the design of the circulating roadway and central island within it. The alignment of approach and departure roadways and the resulting splitter islands are also established by the inscribed circle. For further information on roundabout design refer to the FHWA publication *Roundabouts: An Informational Guide,* June 2000.

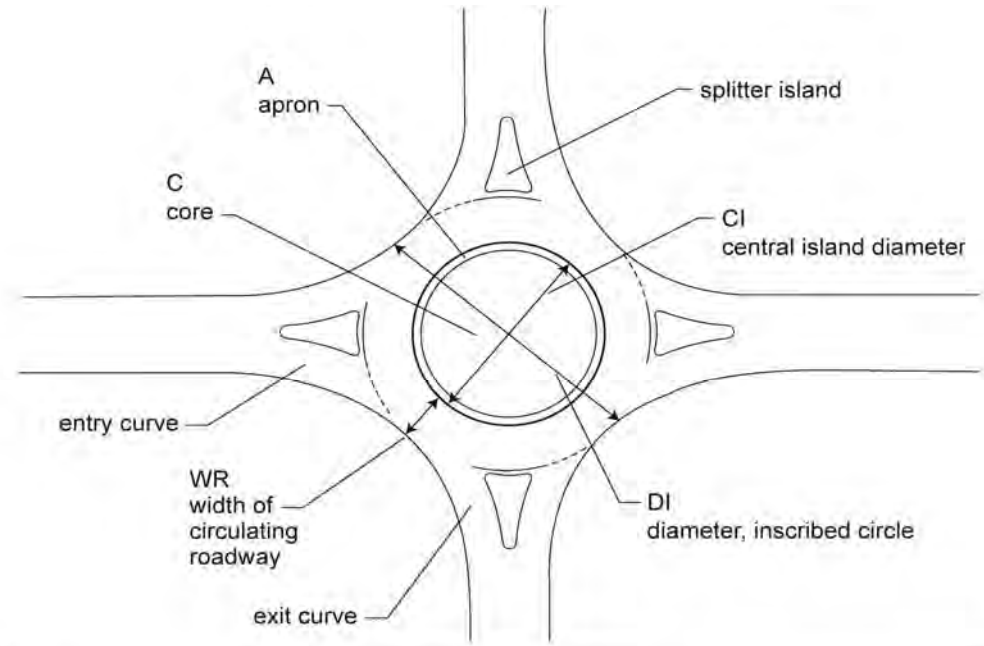
6.7.5.1 Inscribed Circle

The ICD is derived from the motor vehicle. The inscribed circle is established by the outer turning radius of the design vehicle, plus a margin for contingencies encountered in normal operation.

6.7.5.2 Width of Circulating Roadway

The width of the circulating roadway is established from the turning path of the design vehicle plus a margin to allow for normal operating contingencies. The critical turning movement is the left turn, requiring a 270 degree movement around the circle which, in turn, produces the largest swept motor vehicle path and thereby establishes the width of the circulating roadway.

Exhibit 6-27
Circle Dimensions, Single Lane Roundabout



Functional Class Major Street	Design Vehicle	Circle Dimensions (feet) Diameter, Inscribed Circle (DI, feet)	Width, Circulating Roadway (WR, feet)	Central Island Core (C, feet)	Central Island Apron (A, feet)	Central Island Total (CI, feet)
Arterial	Tractor/Trailer (WB -50)	100-130	29-35	55-95	5-10	65-100
Collector	Single Unit Truck (SU)	80-100	17-21	50-80	5-10	60-85
Local	Passenger Car (P)	45-80	16	25-60	3-5	30-65

Note: The design vehicle should be the largest vehicle expected to be accommodated on the street.
Source Roundabouts: An Informational Guide, FHWA June 2000.

6.7.5.3 Central Island

The diameter of the central island is derived from the diameter of the inscribed circle less the width of the circulating roadway. Typically, central islands consist of a core area not intended to be traversed by motor vehicles and bicycles, bordered by a truck apron of a slightly raised pavement not intended to be used by vehicles smaller than a school bus, but available for the inner rear wheel track of larger motor vehicles.

6.7.5.4 Entry and Exit Curves

The entry radius can be varied as desired to achieve the desired entry speed. Curvature is limited only by the need to provide sufficient clearance for the design vehicle.

Entrance roadways are designed so that the continuation of the inside edge of the entry curve joins tangentially to the central island, while the outside edge of the entry curve joins smoothly and tangentially to the outside edge of the circulating roadway. Typically, the entry radii (measured at the outside pavement edge) range from 30 to 100 feet.

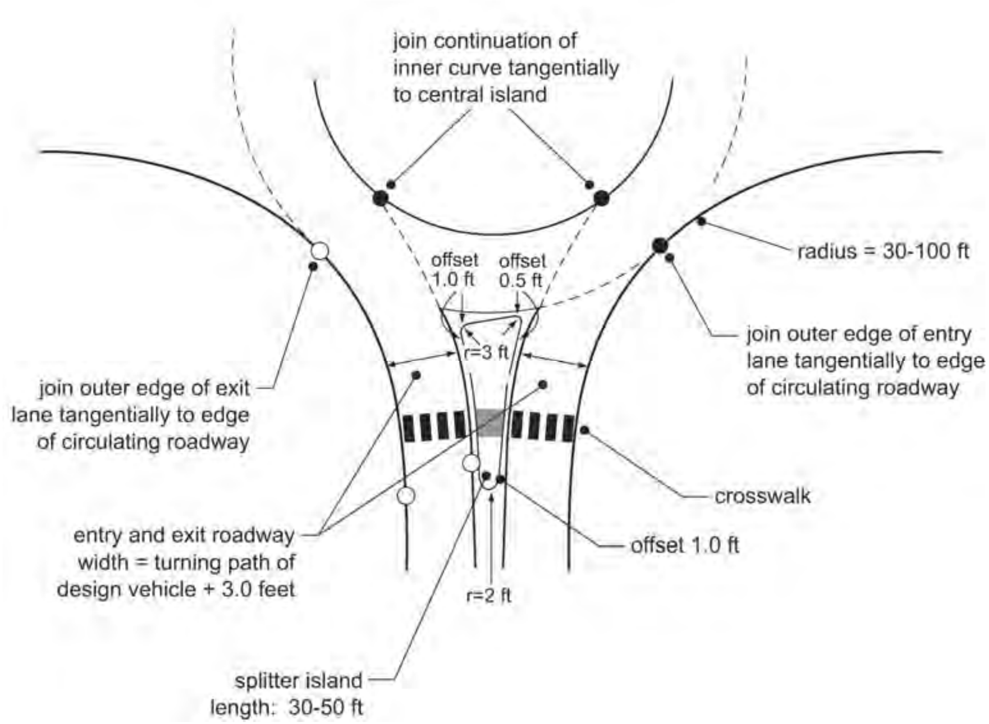
Exit curves join tangentially to the inner and outer diameters of the roundabout in the same manner as the entry curve. The outside exit curve joins smoothly and tangentially to the outside edge of the circulating roadway, while the inside curve, if continued, would join tangentially to the central island. As with the entry curve, the width of the roadway should accommodate the design motor vehicle. The exit path radius (measured at the centerline of the exit curve) should be at least as great as the motor vehicle path around the circulating roadway, so that drivers do not reduce speed upon leaving the circle, or, failing that, overrun the exit curve and collide with the splitter island. Frequently, exit curves have larger radii than entry curves, to reduce the possibility of congestion at the exit points. However, the exit speed should also be influenced by the accommodation of pedestrians and bicyclists.

6.7.5.5 Splitter Islands

Splitter islands are formed by the separation between the entry and exit lanes as illustrated in Exhibit 6-28. Splitter islands guide motor vehicles and bicycles into the roundabout, separate the entering and exiting traffic streams, assure a merge between entering and circulating traffic at an angle of less than 90 degrees, and assist in controlling speeds. Further, splitter islands provide a refuge for pedestrians and bicyclists, and can be used as a place for mounting signs. Larger splitter islands afford the opportunity for attractive landscaping, but signs and landscaping must not obstruct sight distance for approaching motorists.

Splitter islands should be at least 50 feet in total length to properly alert drivers to the roundabout. The splitter island should extend beyond the end of the exit curve to assure that exiting traffic has completed its turn, and to prevent it from crossing into the path of on-coming traffic.

Exhibit 6-28
Entry/Exit Lanes, Single Lane Roundabouts



Source: Roundabouts: An Informational Guide, FHWA, June 2000.

6.7.6 Intersection Median Openings

At intersections where one or both of the streets have divided roadways separated by a median, the design of the median becomes an element in the intersection design. Two factors control the design of the ends of medians at intersections:

1) The turning path of motor vehicles and bicycles making a left turn from the minor street into the major street controls the location and shape of the end of the median in the departure leg of the major street; and,

2) The left turn from the major street into the minor street determines the location and configuration of the median end on the approach leg of this movement.

Right-turn movements are seldom a factor in median opening design. However, the presence of a median may limit the effective pavement width for motor vehicles and bicycles making a right turn. Effective pavement width, as previously discussed, has a large bearing on the corner radius needed for right turns.

6.7.6.1 Design Vehicles for Median Openings

The design vehicle for median openings is the same as the design vehicle selected for the intersection. Roads with medians are likely to be classified as arterial roads, with the appropriate design vehicle therefore being the WB-50 truck. However, for some median openings, the passenger car (P) or single unit truck (SU) design vehicle may be appropriate.

6.7.6.2 Permitted Encroachment at Median Openings

At intersections of streets with medians, turning vehicles may be permitted to encroach into adjacent lanes, according to guidelines discussed earlier. However, on divided highways, encroachment into opposing lanes of traffic is physically impossible, due to the median. Some categories of encroachment, therefore, even though permissible, may not be available for the turn in question.

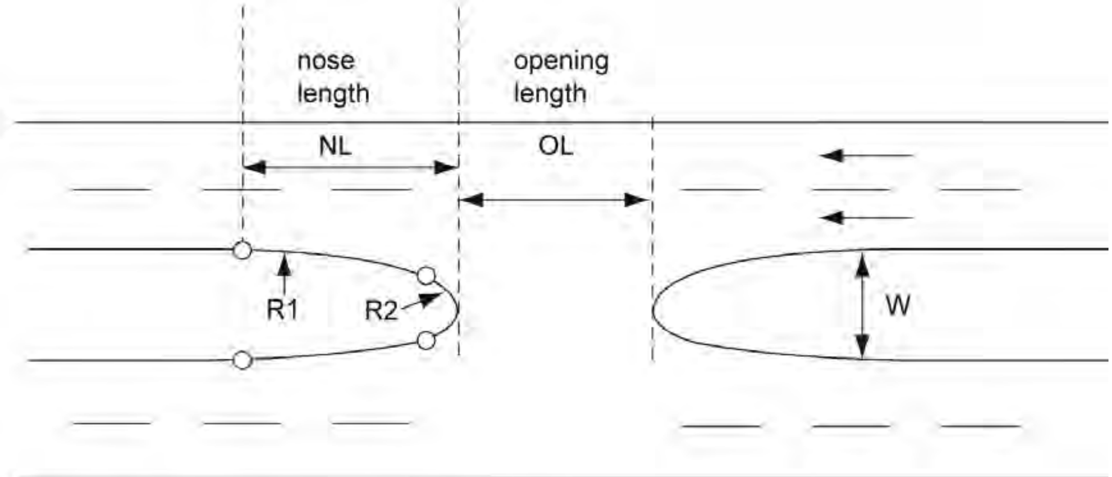
6.7.6.3 Median and Design Controls

The left-turn movement from the minor street into the departure leg of the major street controls the placement and shape of the affected median island. Similarly, the left turn from the divided major street into the minor street controls the placement and shape of the affected median island on that approach leg of the intersection. Where both the major street and the minor street are divided, the four possible left turns control the location and shapes of all four median islands.

6.7.6.4 Median Openings

An important design element is the length of the median opening, as summarized in Exhibit 6-29. Opening dimensions are given for two configurations of median end: semi-circular and bullet-nose. Median openings are given for the three categories of design vehicle addressed throughout this chapter: passenger car (P), single unit truck (SU), and the tractor/50-foot trailer (WB-50).

Exhibit 6-29
Median Openings



Length of Median Opening (OL, feet)

Width of median (W, feet)	Passenger Car (P)		Single Unit Truck (SU)		Tractor/Trailer Truck (WB-50)	
	Semicircular	Bullet nose	Semicircular	Bullet nose	Semicircular	Bullet nose
4	76	76	96	96	146	122
6	74	60	94	76	144	115
8	72	53	92	68	142	110
10	70	47	90	62	140	105
12	68	43	88	58	138	100
14	66	40 min	86	53	136	96
16	64	40 min	84	50	134	92
20	60	40 min	80	44	130	85
24	56	40 min	76	40 min	126	78
28	52	40 min	72	40 min	122	73
32	48	40 min	68	40 min	118	67
36	44	40 min	64	40 min	114	62
40	40 min	40 min	60	40 min	100	57
50	40 min	40 min	50	40 min	95	48
60	40 min	40 min	40 min	40 min	90	40 min
70	40 min	40 min	40 min	40 min	80	40 min
80	40 min	40 min	40 min	40 min	70	40 min
100	40 min	40 min	40 min	40 min	50	40 min
110	40 min	40 min	40 min	40 min	40 min	40 min
120	40 min	40 min	40 min	40 min	40 min	40 min

Note: R1, R2 and NL determined by design vehicle turning paths.
Source: Adapted from A Policy on the Geometric Design of Streets and Highways, AASHTO, 2004. Chapter 9 Intersections

6.7.7 Pedestrian Crosswalks

Crosswalks are a critical element of intersection design. Crosswalks are essential for designating the appropriate path of travel for a pedestrian through the intersection. Crosswalks are defined by pavement markings, textured pavement, and colored pavement as described below. Several techniques are available to shorten pedestrian crossings and for improving crosswalk visibility, as described below.

6.7.7.1 Crosswalk Pavement Markings

Pavement markings indicate to pedestrians the appropriate route across traffic and remind turning motor vehicle drivers and bicyclists of potential conflicts with pedestrians. The crosswalk edge nearest to the intersection should be aligned with the edge of the sidewalk nearest to the road. Accepted crosswalk markings are shown in Exhibit 6-30. When different pavement treatments are used, crosswalks must be bounded by parallel bars. At signalized intersections, all crosswalks should be marked. At unsignalized intersections, crosswalks should be marked when they:

- Help orient pedestrians in finding their way across a complex intersection;
- Help show pedestrians the shortest route across traffic with the least exposure to motor vehicles and bicycles, and to traffic conflicts; or
- Help position pedestrians where they can best be seen by on-coming traffic.

When used without other intersection treatments, crosswalks alone should not be installed within uncontrolled environments when speeds are greater than 40 mph. All crosswalks on the entries and exits of roundabouts should be marked. Crosswalks are typically located one car length back from the yield line or circulating roadway at single-lane roundabouts. For more information, refer to the *Manual on Uniform Traffic Control Devices*.

6.7.7.2 Vehicular Stop Bar Placement

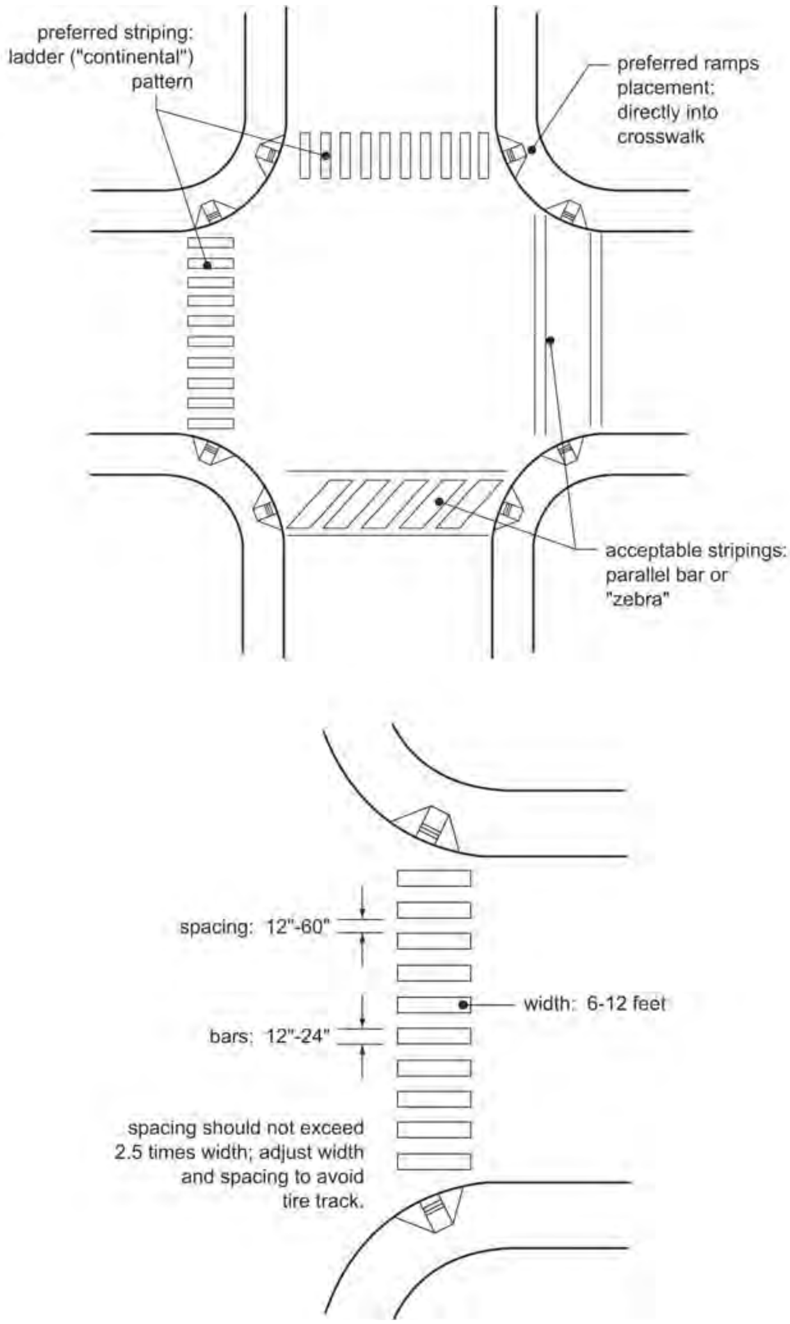
Where crosswalks are provided across a street with a stop line or with traffic signals, there should be a minimum 4-foot spacing between the outer edge of the crosswalk and the nearest edge of the stop bar. Stop bars should be dimensioned in accordance with guidelines in the MUTCD.

6.7.7.3 Methods to Reduce Pedestrian Crossing Distance

Marked or unmarked, crosswalks should be as short as possible. At all intersections, reducing the time pedestrians are in the crosswalk improves pedestrian safety and motor vehicle and bicycle movement.

At signalized intersections, reducing the pedestrian crossing distance can improve capacity for both motor vehicles (longer green time) and for pedestrians (longer WALK interval).

Exhibit 6-30
Crosswalk Elements



Source: Manual on Uniform Traffic Control Devices (MUTCD), FHWA, Washington DC, 2003.

Curb Extensions

Curb extensions shorten the crossing distance, provide additional space at the corner, allow pedestrians to see motor vehicles and be seen by motor vehicle drivers before entering the crosswalk, and keep parking away from crosswalks. Curb extensions are discussed further in Chapter 16.

Crossing Islands and Medians

Raised medians and triangular channelization islands can be used to interrupt extremely long crosswalks. These raised areas:

- Allow pedestrians to cross fewer lanes at a time, reducing exposure time;
- Provide a refuge so that slower pedestrians can wait for a break in the traffic stream;
- Allow pedestrians to focus on traffic from only one direction at a time;
- Reduce the total distance over which pedestrians are exposed to conflicts with motor vehicles; and,
- May provide easily accessible location for pedestrian signal call buttons.

In general, fifty feet is the longest uninterrupted crossing a pedestrian should encounter at a crosswalk, but islands and medians are also appropriate for shorter distances. Islands and medians should not be used to justify signal timing that does not allow pedestrians to complete their crossing in one cycle. Crossing islands are discussed further in Chapter 16.

6.7.7.4 Improving the Visibility of Pedestrian Crossings

Safe pedestrian crossing is dependent on awareness by motorists of the pedestrian. Methods to improve the visibility of pedestrians, in addition to curb extensions, sometimes include textured crosswalks, raised crosswalks, and flashing beacons at mid-block locations as discussed further in Chapter 16.

6.7.7.5 Pedestrian Crossing Prohibitions

Some intersection crossings include conflicts between pedestrians and motor vehicle traffic that are especially dangerous; however, prohibiting pedestrian crossing should be considered only in very limited circumstances, for example:

- Where it would be very dangerous for pedestrians to cross, as where visibility (for pedestrians, motorists or bicyclists) is obstructed and the obstruction cannot be reasonably removed, and where signalization is not an option.

- Where so many legal crosswalks exist that they conflict unreasonably with other modes, as on an arterial street with multiple offset or "T" intersections.

Crosswalks at “T” and offset intersections should not be closed unless there is a safer crosswalk within 100 feet of the closed crosswalk. "Pedestrians Use Marked Crosswalk" signs should be used for crosswalks closed to reduce an excess of crosswalks on a street with “T” or offset intersections. "No Pedestrian Crossing" signs should be used for crosswalks closed for pedestrian safety.

6.7.8 Pedestrian Curb Cut Ramps

There are two preferred configurations of pedestrian curb cut ramps. These configurations include several design elements. Both the configurations and design elements are described in the following sections. Designs for these ramps are provided in MassHighway’s *Standard Construction Details*.

6.7.8.1 Ramp Types

Pedestrian curb cut ramps at marked crossing shall be wholly contained within the markings, excluding any flared sides. Two types of ramp configurations are preferred—perpendicular ramps and parallel ramps. The first has a ramp leading at right angles from the sidewalk into a crosswalk, while the second has a ramp leading into a landing that is flush with the street surface. A third type, a diagonal ramp, is discouraged but permissible for certain specific intersection conditions (see below) under specific conditions.

Perpendicular

Whenever possible, 521 CMR requires that a pedestrian curb cut ramp is oriented so that the fall line of the ramp is in line with the crosswalk and perpendicular to the curb. Where conditions are not constrained, the designer should locate the ramp so that both conditions can be met. A minimum four feet level landing with a cross slope designed at a maximum of 1.5% for each approach at the sidewalk and street level within the designated crosswalk is required.

Parallel

Parallel curb cut ramps are used where the available space between the curb and the property line is too tight to permit the installation of both a ramp and a landing. A minimum four foot landing is necessary between the two ramps.

Diagonal or Apex

Diagonal or “apex” curb cut ramps are single perpendicular pedestrian curb cut ramps located at the apex of the corner. Diagonal ramps are only permitted under the following specific conditions by 521 CMR:

a. *Driver or pedestrian line of sight to or from the front of the level landing on the ramp is impaired, preventing safe observation of crosswalks or approaching traffic at the intersection by a significant immovable or unalterable streetscape feature such as a building structure or historic element, etc.*

b. *Stop line is beyond the allowed limit as stated in the Manual on Uniform Traffic Control Devices.*

c. *Vaults containing electrical, telecommunication, etc. that are under or on the existing sidewalk.*

d. *Large radius corners (30 feet or greater).*

When using diagonal or apex curb cut ramps, there must be a 4 foot level landing at the base (street) level of the ramp that is within the marked crosswalk.

6.7.8.2 Design Elements

Key design elements of pedestrian curb cut ramps include the ramped section, landing areas and side flares as described below.

Ramp Section

The minimum slope possible (given curb heights and sidewalk width) should be used for any pedestrian curb cut ramp. The maximum curb cut ramp slope is 8.33% in the built condition with a cross slope of no more than 2% in the built condition. To ensure that the build conditions do not exceed thee maximums, designers should use standards specifications of 7.5 percent for slopes and 1.5 percent for cross-slopes.

The minimum width of a pedestrian curb cut ramp is at least 3 feet, with 4 feet preferred, exclusive of flared sides. A curb cut ramp shall have a detectable warning that extends the full width and length of the curb ramp. Detectable warnings shall comply with the *ADA Accessibility Guidelines for Buildings and Facilities.*

Curb cut ramps and their approaches shall be designed so that water will not accumulate on walking surfaces. Surfaces of pedestrian curb cut ramps shall be stable, firm, and slip-resistant.

Landings

The basic principle is that every curb cut ramp must have a landing at the top and at the bottom. The landing at the top of a ramp should be a minimum of four feet long (5 feet preferred) and at least the same width as the center curb cut ramp itself. It should be designed to slope no more than 1.5% in any direction, allowing the built condition to slope no more than 2%. A single landing may serve as the top landing for one ramp and the bottom landing for another.

When perpendicular ramps run directly into a crosswalk, the landing at the bottom will be in the roadway. The landing, at least 4 feet long, should be completely contained within the crosswalk pavement markings and should not have a running slope when built no greater than 5 percent. When the parallel ramp landing is within the sidewalk or corner area where a person using a wheelchair may have to change direction, the landing must be a minimum of five feet long and at least as wide as the ramp, although a width of five feet is preferred. The landing may not slope more than 2% when built (1.5% in design) in any direction.

Flares

Flares are graded transitions from the ramp section to the surrounding sidewalk. Flares are typically not part of the route for people using wheelchairs. Flares may be steeper than the ramp where there is a 4-foot deep level landing at the top of the ramp's center landing. The maximum slope of the flare shall be 10% (9% in design). If the landing depth at the top of a pedestrian curb cut ramp is less than four feet, then the slope of the flared side shall not exceed 8.33% in the built condition (7.5% design).

When intersections are located on a hill, it is possible that the side flares ramp can never meet the 8.33% maximum slope requirement. In this situation, the Massachusetts Architectural Access Board may grant a variance to use a steeper side flare slope, typically at least 15 feet long.

Returned Curbs

Flares are not necessary where pedestrians would not normally walk across the ramp, such as where the ramp edge abuts grass, other landscaping, or other non-walking surface. Pedestrian curb cut ramps may have returned curbs or other well-defined edges only when the ramp itself is sloped at 8.33% maximum, and there is no pedestrian approach from either side of the ramp. Such edges shall be parallel to the direction of pedestrian flow, and the adjacent area should clearly prohibit pedestrian use with, for example, plantings, railings, street furniture, etc. The bottom of ramps with returned curbs shall have a four foot minimum clear, level landing that does not extend into a travel lane and is within the crosswalk markings.

6.7.9 Bicycle Lanes at Intersections

On streets without bicycle lanes, a bicyclist's travel through intersections reflects the bicyclist's accommodation at adjacent non-intersection street segments. Where bicyclists share a lane with motorists, they continue through intersections in this shared-lane mode of accommodation. Where a road shoulder is present and used by bicyclists, they approach and depart intersections on the road shoulder or in the travel lane.

On streets with bicycle lanes, the design of bicycle lanes at intersections is complicated by the need to accommodate numerous turning movements by both motorists and bicyclists, often with limited available space. Intersection design is based on the assumption that:

- Motorists making right turns should make their turn from as close to the right-hand curb as practical;
- Bicyclists going straight ahead should be to the left of right turning traffic; and,
- Bicyclists turning left should turn from a left turn lane or the left side of a combination through/left lane.

The bicycle lane marking is a 6-inch wide white solid stripe. Near intersections, the solid stripe should be replaced by a broken line stripe (two-foot–long stripes separated by six-foot-long spaces) where bicycles and vehicles merge. The outer bicycle lane marking is skip striped all the way to the stop bar at controlled intersections, and to the extension of the property line at uncontrolled intersections. The skip stripe alerts bicyclists to the potential for motorists to be crossing their path and encourages safe merging in advance of the intersection. The lanes should resume on the far side of the intersection. When a bicycle lane intersects with a one-way street, or where right turns are prohibited, the bicycle lane markings are solid all the way to the intersection.

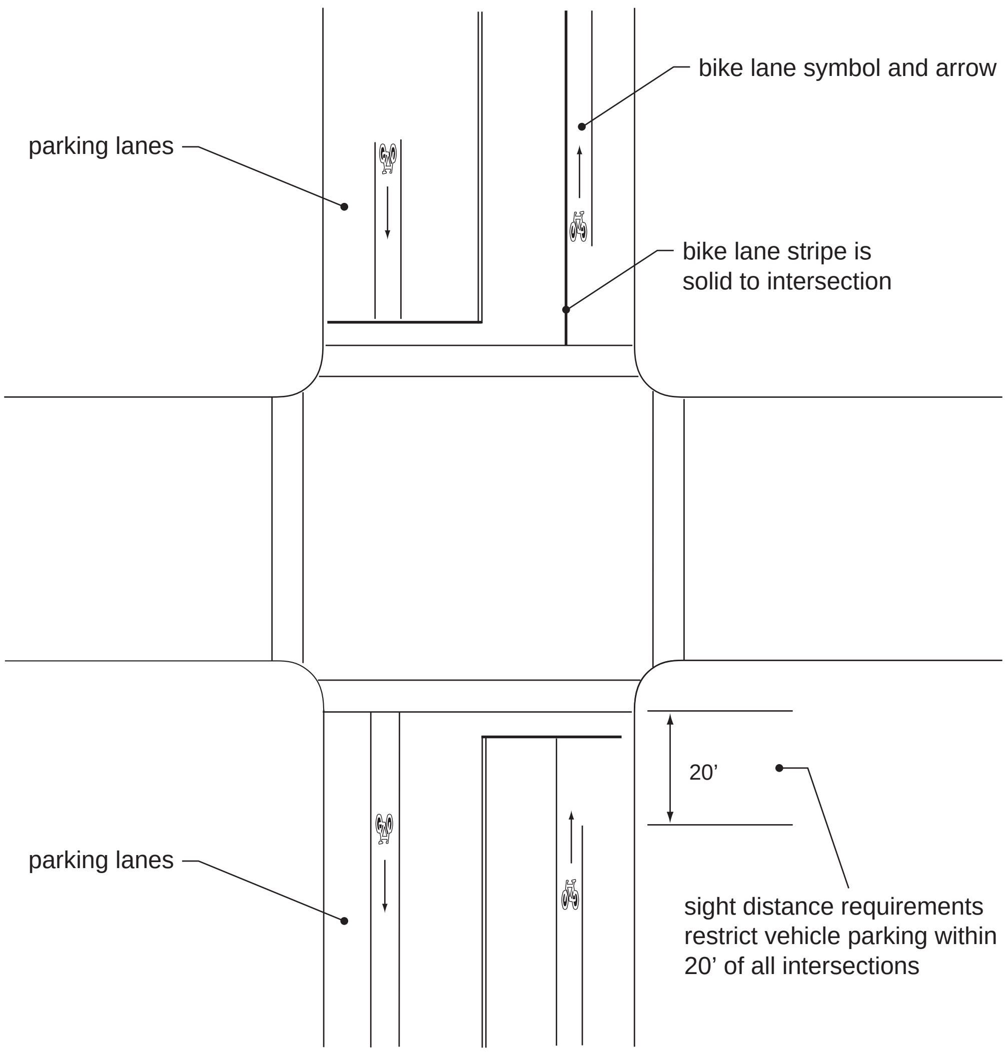
Bicycle lane stripes should not be extended through a pedestrian crosswalk or any street intersection. Exceptions include dashed lines through some complex intersections, and the bicycle lane striping on the side across from the T-intersection should continue through the intersection area with no break.

A typical configuration for bicycle lanes at a simple intersection is illustrated in Exhibit 6-31.

6.7.9.1 Intersections with Bus Stops

Where there is a bus or other transit stop, either near side or far side, the 6-inch solid line should be replaced by two-inch dots separated by six- foot spaces for the length of the bus stop.

Exhibit 6-31
Bicycle Accommodation at a Simple Intersection



Source: Guide for the Development of Bicycle Facilities, AASHTO, 1999.

6.7.9.2 Flared Intersections

Right turn lanes should be used only where justified by a traffic study since they force right-turning vehicles and through bicyclists to cross paths. Where right turn lanes are on streets with bicycle lanes as shown in Exhibit 6-32, the curb lane is designated with markings and signs indicating "Right Turn Only Except for Bicycles." This improves safety for bicyclists by preventing through motorists from passing on the right while still allowing through bicyclists to use the lane. Signs also indicate that motorists should yield the shared lane to the bicyclist. When the width allows, the bicycle lane is dotted to encourage right-turning vehicles to merge right. The bicycle lane then continues for a minimum of 30 feet until the stop bar.

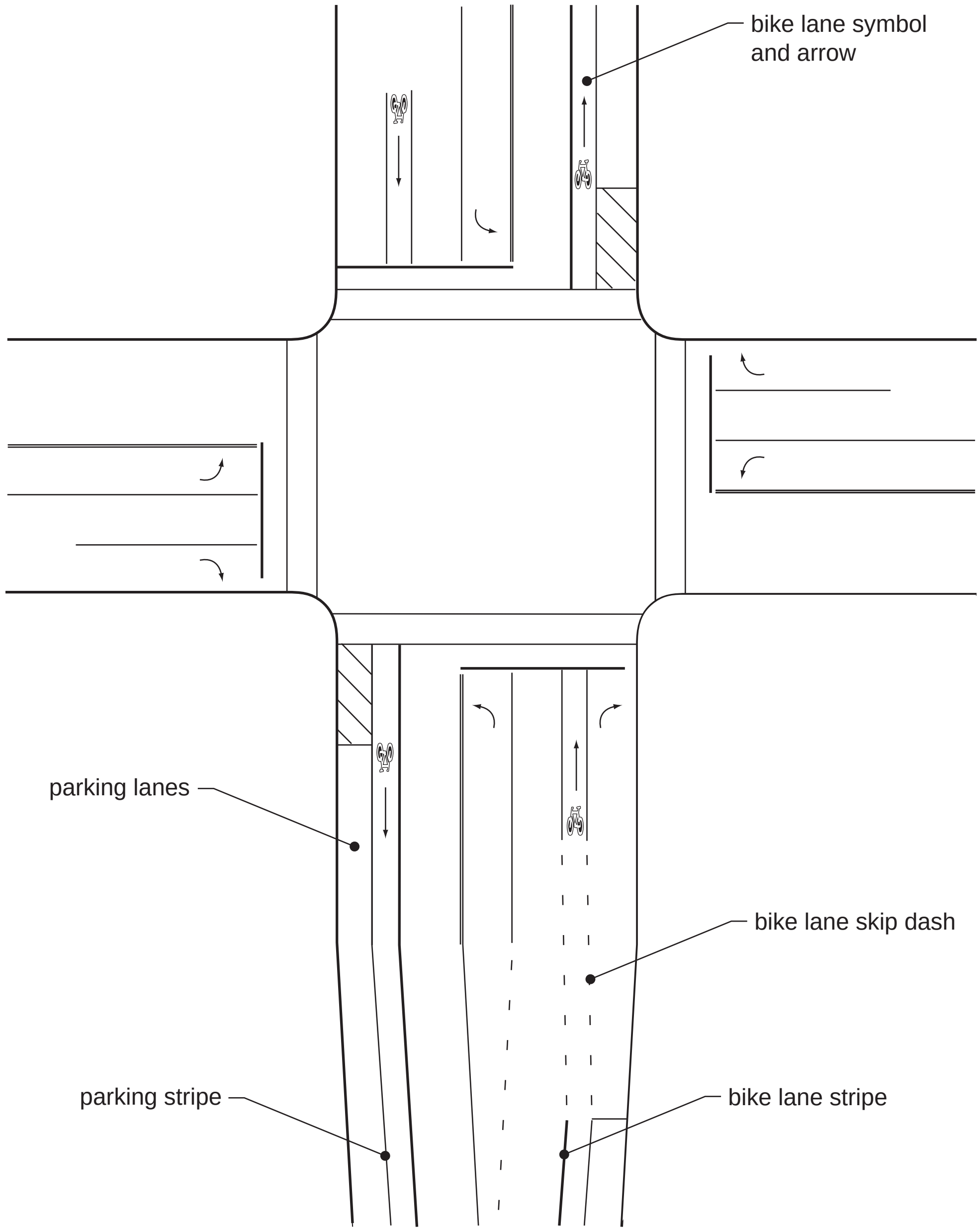
The bicycle lane should not be placed to the left of a right turn lane in three circumstances:

- **Heavy right turn volumes -** At four-legged intersections with heavy right-turn volumes and where it is expected that most bicyclists will make a right-turn (such as where the straight through move leads to a minor side street), the bicycle lane should be placed on the right.

- **T-intersections -** Bicycle lanes should be placed to the right of the right-turn lane. Where left-turn volumes are heavy, a bicycle left-turn lane may be placed between the vehicle left-turn and right-turn lanes.

- **Optional right/straight and right-turn only lanes -** Striped bicycle lanes should end with the beginning of the taper for the right-turn lane, resuming on the far side of the intersection.

Exhibit 6-32
Bicycle Accommodation at a Flared Intersection



For flared intersections with left-turn lanes, the bicycle lane treatment remains.

Source: Guide for the Development of Bicycle Facilities, AASHTO, 1999.

6.7.9.3 Bicycle Lanes at Roundabouts

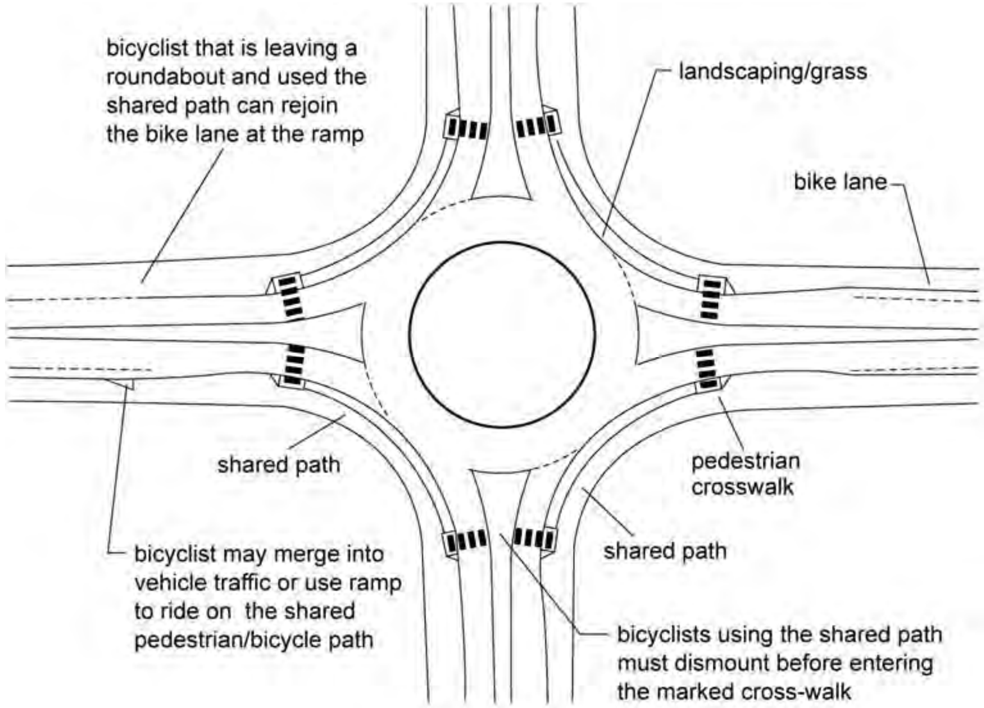
Roundabout design should accommodate bicyclists with a wide range of skills and comfort levels in mixed traffic. Bicyclists have the option of either mixing with traffic or using the roundabout as a pedestrian, as illustrated in Exhibit 6-33.

- Where bike lanes are present, low-speed (approximately 12 to 15 mph) and single-lane roundabouts allow for safe mixing of bicycles and motor vehicles within the roundabout. This option will likely be reasonably comfortable for experienced bicyclists. Bicyclists will often keep to the right on the roundabout; they may also merge left to continue around the roundabout. Motorists should treat bicyclists as other vehicles and not pass them while on the circulatory roadway. The bicycle lane should be discontinued about 100 feet prior to low-speed roundabouts to indicate that bicyclists should either mix with motor vehicle traffic or exit to the shared use path.

- On the perimeter of roundabouts, there should be a sidewalk that can be shared with bicyclists. Less-experienced bicyclists (including children) may have difficulty and discomfort mixing with motor vehicles and may be more safely accommodated as pedestrians in some instances. Bicycle lanes leading toward a roundabout should be discontinued at the beginning of the entry curve of the roundabout, ending in a ramp leading toward a shared use bicycle pedestrian path around the roundabout. Bicycle lanes should resume on the end of the exit curve, beginning with a ramp from a shared use path.

Bicyclists require particular attention within higher speed and double lane roundabouts, especially in areas with moderate to heavy motor vehicle volume. It may sometimes be possible to provide bicyclists with grade separation or an alternative route along another street that avoids the roundabout, which should be considered as part of overall planning. The provision of alternative routes should not be used to justify compromising the safety of bicycle traffic through the roundabout because experienced bicyclists and those with immediately adjacent destinations will use it.

Exhibit 6-33
Bicycle Accommodations at Roundabouts



Source: Guide for the Development of Bicycle Facilities, AASHTO, 1999.

6.8 Other Considerations

Several other considerations important for intersection design are described in the following sections including: sight triangles; intersection spacing; bus stop considerations; other types of roadway crossings; mid-block path crossings; and highway-railroad grade crossings; and driveways.

6.8.1 Intersection Sight Triangles

The intersection sight triangle is a triangular-shaped zone, sufficiently clear of visual obstructions to permit drivers entering the intersection to detect any hazards or conflicts and react accordingly. Intersection sight distance and sight triangles are discussed further in Chapter 3.

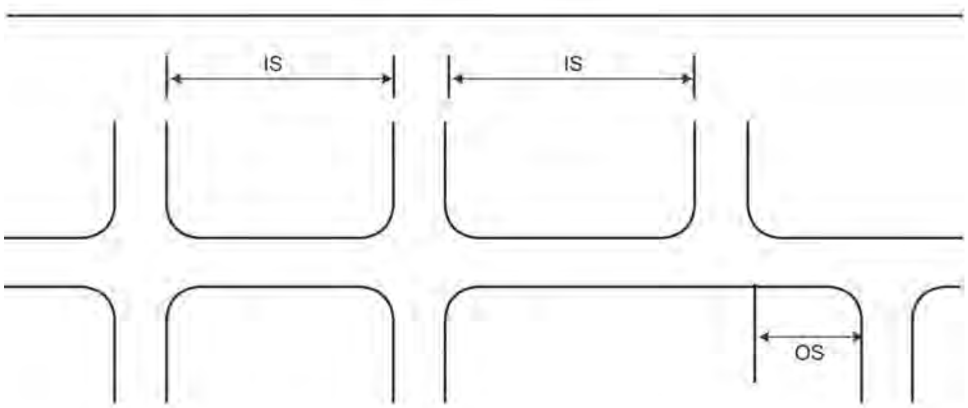
6.8.2 Intersection Spacing

A primary purpose of intersection spacing guidelines is to minimize the possibility of conflicts in traffic operations between adjacent intersections. Examples of such conflicts are queues of traffic extending from one intersection through an adjacent intersection, or intersection spacing that precludes the possibility of traffic signal progression between intersections. On arterials, intersection spacing requirements are intended to minimize the “friction” arising from signal control and turning movements at intersections. Intersection spacing can also influence the pedestrian connectivity along a corridor since crossing opportunities are often located at intersections.

6.8.2.1 Spacing Between Public Street Intersections

Guidelines for spacing between public streets are given in Exhibit 6-34. In most situations, only a minimum spacing is recommended. However, for streets in urban areas, maximum spacings are also recommended to enable a proper density of connecting street network.

Exhibit 6-34
Intersection Space Guidelines



Design Speed (mph)	Spacing (feet) Between: Intersections (IS, feet)	Offset Intersections (OS, feet)
15-30	200	50
35-40	250	75
45-50	350	150
50 +	500	500

Source: Adapted from Congress for the New Urbanism (CNU), AASHTO, 2005

Frequently, intersection spacing is not a controllable element of intersection design, and the spacing is “given” as a fixed condition. In such circumstances, spacing guidelines are not applicable. However, in many situations, particularly involving areas of new development, intersection spacing is an important part of the context, and should be considered in light of the above guidelines.

6.8.2.2 Spacing between Signalized Intersections

Frequently, criteria for the desirable spacing of signalized intersections are confused with that for spacing of all intersections, whether signalized or not. Good signal progression in both directions simultaneously requires signal spacing of approximately 1,200 feet or more, well beyond the ideal spacing for intersections in village, town center, and urban settings. However, signalized intersections, spaced for good signal progression, can be combined with non-signalized intersections, yielding overall intersection spacing with small blocks (ideally around 200 feet) appropriate for urban settings. Mid-block crossings should be spaced no closer than 300 feet from a signalized intersection, unless the proposed control signal will not restrict the progressive movements of traffic.

Good connectivity to the signalized intersections along the major street can be assured with a well connected network of local and collector streets parallel to the major street. With such a network in place, turning movements can be made at all locations, signalized and unsignalized, during non-peak hours. During peak hours, motorists and bicyclists wanting to enter or cross the major street can choose to use the signalized intersections.

6.8.3 Transit Stop Considerations

From the point of view of bus operations, it is desirable to have bus stops located near intersections so that bus riders can approach easily from both the street carrying the bus route and from the minor streets. Further, it is desirable to integrate bus stops with the adjoining pedestrian system (sidewalks, shared use paths and crosswalks) and also with any adjoining bike path/lane system. With respect to intersections, bus and other transit stops may be either:

- Near side, located on the approach leg of the intersection; or,
- Far side, located on the departure leg of the intersection.

Bus and other transit stops at intersections, while advantageous for bus service, create challenges for other vehicle flows, as well as non-motorized travel:

- If the bus stop is in its own lane (typically an extension of parking lanes toward the interior of the block), it must reenter the traffic stream after completing a stop. If, on the other hand, the bus stops in a lane of traffic, it blocks that lane for the duration of the stop.
- At far-side stops, a stopped bus may cause following vehicles to back up through the intersection.
- At near-side stops, where the stopped bus is outside the traffic stream, the reentry of the bus into the traffic stream is likely to occur at a pedestrian crosswalk. At unsignalized locations, this presents a vehicle/pedestrian conflict possibility. Even at signalized intersections, bus drivers may begin their exit from their loading space during the red signal phase, thus conflicting with crossing pedestrians.
- Bus stops and accessible on-street parking will compete for the location nearest the intersection. The locations of both should be resolved with input from the local disability commission, regional independent living center, and transit agency.

The challenges associated with bus stops at intersections are addressed through the following design guidelines:

- Far-side bus stops are generally preferable to near-side stops.
- It is desirable to separate bus loading areas from moving lanes of traffic. Where on-street parking is generally present on the street, such a loading area can be gained by restricting the parking in the vicinity of the intersection. On streets without on-street parking, bus bays may be considered.
- Parking should be restricted for a distance of 60 feet from the beginning of the pavement corner radius. The designated bus loading area should not extend closer than 20 feet to the pavement corner radius. These dimensions apply to both near-side and far-side bus stops.
- Bus pullouts, under some circumstances, may be appropriate at intersection areas. However, the drawback of pullouts—difficulty for the bus in reentering the traffic stream—can be problematic near intersections. Pullouts are more likely to be acceptable at far-side stops, where the exiting bus vehicle is more likely to

encounter acceptable gaps in the traffic stream, compared to a near-side stop on the approach leg of the intersection.

The design of pedestrian and bicycle connections, bus bays, and on-street parking requires additional focus around intermodal facilities such as commuter rail, subway, park & ride and light-rail stations. Design of these facilities is overviewed in Chapter 12.

6.8.4 Mid-Block Path Crossings

At intersections, shared use paths (for pedestrians, bicyclists and other non-motorized users) are accommodated as intersection crosswalks, as described in Section 6.7.8. Where paths cross streets at locations other than at intersections, they should conform to the following guidelines for “mid-block” crossings (the MUTCD provides further guidance on placement and spacing):

- Mid-block path crossings should be used only where needed. Factors likely to produce this need are existing route of paths, availability of right-of-way for path extensions, distance to alternate crossing locations at intersections, and topography.
- Mid-block path crossings should be installed only where stopping sight distance is fully adequate for vehicular traffic on the street being crossed.
- Mid-block path crossings should provide adequate sight distance for pedestrians, bicycles and other users of the path.
- Where mid-block path crossings exceed 60 feet in length, a median island should be considered. Median islands provide the dual benefit of providing a refuge for crossing path users, reducing the size of gap in traffic needed to cross the street safely, and may help alert approaching motorists and bicyclists to the presence of the crossing.
- Median islands should be at least 6 feet wide, to shield bicycles or more than one pedestrian.
- Trees along the roadside at the path crossing, and in larger medians, can call attention of on-coming motorists to the presence of the trail crossing. However, trees and other landscaping should not be allowed to infringe on the sight distance of pedestrians or motorists in the vicinity of the crossing.

- All median or channelizing islands should have pedestrian curb cut ramps or at-grade cut-throughs, in conformance with 521 CMR. At-grade cut-throughs should be sloped gently (maximum of 2 percent in the build condition and 1.5% in design)) to allow drainage.
- On multi-lane arterial streets, pedestrian call button-actuated traffic signals may be appropriate. When installed, such signal installations should have a supplementary call button at the median, as well as at either curb. The Federal Access Board's current draft version (2002) of the *ADA Accessibility Guidelines for Public Right-of-way* (not adopted at the time of this Guidebook) requires audible traffic signals wherever walk signals are installed. Although not yet required, these, along with detectable warnings, will provide strong cues for people with limited sight.
- Pedestrian call buttons should have locator tones for pedestrians with limited sight.
- Paths should be marked by white continental crosswalk markings (longitudinal stripes).
- On-street parking should be removed for a distance (typically 40 to 60 feet) adequate to assure sight distance for path users waiting on the curb.
- An alternative treatment where parking is present is to provide a curb extension, typically 6 feet deep for a 7 to 8 foot parking lane. Curb extensions reduce or eliminate the need for removing parking, and decrease the crossing distance for the path.
- At crossings with marginal sight distance, advance signing or even advance flashing indicators may be appropriate.

6.8.5 Railroad-Highway Grade Crossings

The following guidelines affect the horizontal alignment of streets at a railroad-highway grade crossing:

- Crossings should be avoided on both highway and railroad curves. Railroad curves present a problem of superelevated track crossing the roadway. A curve on the crossing highway prevents any superelevation on the highway, resulting in an awkward or unsafe curve.

- The highway should intersect tracks as near as possible to 90 degrees.
- Ideally, there should not be nearby intersections with streets or driveways. Where it is not possible to provide sufficient distance between the crossing and nearby intersections, traffic signals at the nearby intersection can be interconnected with the grade crossing signal, to enable vehicles to clear the grade crossing as a train approaches.
- The crossing should be wide enough to permit bicyclists to cross the tracks at right angles, while staying in their traffic lane.

The following guidelines apply to the vertical alignment of streets at railroad highway grade crossings:

- The street surface should be at the same plane as the cross-slope of the top of the rails (level for tangent rail and adopting the grade of super-elevated rail) for a distance of 2 feet outside either rail. Beyond this point (i.e., 2 feet from outside edge of rail), the grade should not be more than 1 percent greater than the grade across the tracks.
- Vertical curves should be used to make the transition from the street grade to the rail cross-slope plane described above.

Traffic control devices for railroad-highway grade crossings range from passive (signs, pavement markings) to active (flashing light signals) to restrictive (automatic gates). Consult the MUTCD for detailed criteria for the design and operation of these devices. At crossings protected by active signals or gates, the sight distance requirement is determined by the design speed of the crossing street (see Chapter 3 of this Guidebook).

At crossings without train activated warning devices, the sight distance must allow the driver or bicyclist to observe the approaching train at sufficient distance to permit stopping prior to reaching the crossing. The distance needed for this case depends on the speed of the vehicle and the speed of the train. Detailed sight distances are given for the WB-65 design vehicle in the AASHTO *Green Book.*

Where public sidewalks cross rail systems at-grade, the surface of the continuous passage shall be level and flush with the rail top at the outer edge and between the rails. As required by 521 CMR, the horizontal gap on the inner edge of each rail shall be the minimum necessary to allow passage of wheel flanges and shall not exceed 2½ inches. Where tracks cross a sidewalk, 24-inch wide detectable warnings, complying with 521 CMR, shall be placed on both sides of the tracks across the entire width of the sidewalk, at a sufficient distance from the tracks to allow clearance for the widest vehicle using those tracks. Where multiple tracks are part of the same level crossing, detectable warnings should be placed alongside the outermost track, and not within the sets of tracks.

6.8.6 Driveways

Driveways are points of access from public streets to private property, and are therefore not intersections, as defined in this chapter, although some large volume driveways should be designed as intersections. Guidelines for driveway design and spacing are offered in Chapter 15.

6.9 For Further Information

- *Manual on Uniform Traffic Control Devices for Streets and Highways,* American Traffic Safety Services Association (ATSSA), Institute of Transportation Engineers (ITE), American Association of State Highway and Transportation Officials (AASHTO), U.S. Department of Transportation, Federal Highway Administration (FHA), Washington, D.C., 2003 Edition.
- *Highway Capacity Manual*, Transportation Research Board, Washington, D.C., 2000.
- *A Policy on Geometric Design of Highways and Streets, Fourth Edition*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2001.
- *Roundabouts: An Informational Guide*, Federal Highway Administration
- *Guide for the Planning, Design and Operation of Pedestrian Facilities*, American Association of State Highway and Transportation Officials (AASHTO), 2004.
- *Guide for the Development of Bicycle Facilities,* American Association of State Highway and Transportation Officials (AASHTO), 1999.
- *ADA Accessibility Guidelines for Buildings and Facilities*, The Access Board, amended through September 2002.
- *Guidelines for Driveway Location and Design,* Institute of Transportation Engineers (ITE), 1987.

Chapter 7
Interchanges

Interchanges

7.1 Introduction

As discussed in Chapter 6, it is important that designers consider the needs and activities of the pedestrians, cyclists, and motorists to comprehensively plan for safe and convenient travel through intersections.

In some instances it is not possible, due to safety, spatial constraints or other conditions, to accommodate all users within an at-grade intersection. In these cases, constructing an overpass bridge or underpass structure for the purpose of separating the intersecting facilities should be studied. An interchange can provide the greatest safety and capacity; however, interchanges may not fit well within the existing context and may complicate multimodal accommodation.

This chapter focuses on interchanges to provide connectivity between these facilities. Grade separations without connecting ramps are discussed in Chapter 10.

7.2 Warrants and Planning Considerations

Interchanges and grade separations occur when two or more roadways cross at different levels. A grade separation is a crossing of two roadways, a roadway and railroad, or a roadway and a pedestrian/bicycle facility at different levels. It eliminates crossing conflicts and improves operational efficiency. Grade separations alone do not provide connections or access between the intersecting roadways. Rather, traffic, cyclists and pedestrians on each intersecting roadway remain completely independent from each other. Interchanges provide access between the grade separated roadways by incorporating a network of ramps. Roadways employing interchanges are often freeways and major arterials, commonly referred to as “highways” throughout this chapter. The following sections describe warrants and planning considerations for interchanges.

7.2.1 Warrants

In many instances, the decision to provide a grade-separated interchange should be made based on careful consideration of a number of factors. These factors are referred to as warrants and include:

1. **Design Designation –** Once it is decided to develop a route as a freeway, it should be determined whether each intersecting highway will be terminated, rerouted, or provided with a grade separation or interchange, the chief concern being continuous flow on the freeway.

2. **Safety** – The crash reduction benefits of an interchange may warrant its selection at a particularly dangerous at-grade intersection.

3. **Congestion** – An interchange may be warranted where the level of service of an at-grade intersection is unacceptable and the intersection cannot be modified to provide an acceptable level of service.

4. **Site Topography** – At certain sites, a grade separated interchange may be more feasible than an at-grade intersection due to local topographical conditions.

5. **Traffic Volume** – Interchanges are desirable at cross streets with heavy traffic volumes. The elimination of conflicts due to high crossing volume greatly improves the movement of traffic.

6. **Road-User Benefits** –When interchanges are designed and operated efficiently, they significantly reduce the travel time and costs when compared to at-grade intersections. Therefore, an interchange is warranted if an analysis reveals that road-user benefits will exceed the costs over the service life of the interchange.

Additional reasons for constructing interchanges include the need to provide access to areas not served by other means of access, such as High Occupancy Vehicle (HOV) facilities, highway rest areas, tourist information centers, and highway maintenance facilities.

7.2.2 Contextual Considerations for Interchanges

In all cases, the designer should consider the relationship between the proposed interchange and the surrounding context as described below.

- Does a grade separation currently exist?
- How does the proposed interchange fit within the cultural, historical, aesthetic, and environmental character of the surrounding area?
- Is sufficient right-of-way owned or controlled to construct and maintain the interchange? If not, is land available for acquisition to accommodate the project?
- Does the existence of a high ground water elevation and/or poor soil conditions complicate the design and construction of the required structures?
- If highway illumination is required to maintain adequate lighting levels for safety and/or security, is there a power source available to satisfy this need and is such lighting consistent with the surrounding context?
- Will the introduction of continuous high speed traffic or increased roadway grades create high noise levels requiring the introduction of noise barriers?
- Will the interchange result in substantial air quality improvements? Is mechanical ventilation required due to the physical and operational characteristics of the facility?
- Will existing utility systems be impacted by the construction? Are provisions needed for future utilities required by area municipalities, agencies, and/or public and private utility companies?
- Will elevating one roadway over another infringe upon abutter air rights or impact the operation of a nearby airport?
- Are there unique requirements relative to horizontal and vertical clearances and/or utility crossings associated with the proposed grade separation?
- Has the diversion of some or all of the activity been considered, thereby eliminating the need for grade separation?

- Will detours be required during construction and are existing routes available? Will temporary detour roadways, bridges, or staged construction be required?

7.2.3 Pedestrian and Bicycle Accommodation Through Interchanges

Pedestrian and bicycle accommodation should be maintained through interchanges. In most cases, interchanges are provided between Interstate Highways and other roadways (referred to as the “minor road”). The pedestrian and bicycle accommodation, such as sidewalks, bicycle lanes, and shoulders, on the minor road should be maintained through the interchange area. If pedestrian and bicycle use is permitted on both roadways, then this principle applies to both facilities.

Pedestrian and bicycle accommodation through interchanges is described throughout this chapter. A key factor for maintaining the continuity and safety of pedestrian and bicycle accommodation through interchanges is the configuration of the ramp/minor road intersection described in Section 7.7. As described in this section, diamond-type ramps and signalized ramp terminals are preferable in areas with high pedestrian and bicycle activity.

In some instances it may be preferable to provide crossings of a limited-access roadway separate from an interchange. For example, an overpass or underpass connecting a route parallel to the one crossing at the interchange. This could be a smaller street without an interchange, or a dedicated bicycle and pedestrian crossing.

7.2.4 Interchange Selection Factors

The decision to provide a grade separation without ramps rather than an interchange is often based on the following considerations:

- Lacking a suitable relocation plan for the crossroad, a highway grade separation without ramps may be provided to maintain connectivity of low volume roadways. All users desiring to access one facility from the other are required to use other existing routes. In some instances these users may have to travel a considerable distance, particularly in rural areas.

- Promotion of access to areas not served by frontage roads or other means of access, physically separating railroad grade crossings, providing access to HOV facilities, providing access to concentrations of pedestrian traffic (for instance park developed on both sides of a major arterial), and allowing the passage of bicycles.

- A grade separation without interchange ramps may be provided to avoid having interchanges so close to each other that signing and operation would be difficult. This approach eliminates interference with large major road interchanges and increases safety and mobility by concentrating turning traffic at a few points where it is feasible to provide adequate ramp systems. On the other hand, undue concentration of turning movements at one location should be avoided where it would be better to have additional interchanges.
- In rugged topography the site conditions at an intersection may be more favorable for provision of a grade separation than an at-grade intersection. If ramp connections are difficult or costly, it may be practical to omit them at the structure site and accommodate turning movements elsewhere by way of other intersecting roads.
- Many times partial interchanges are constructed initially because the traffic volumes do not support a full interchange or the required right-of-way is not available when the interchange is first constructed. As time passes however, the need for a complete interchange may develop or the right-of-way may be obtained.

7.2.5 Application to Freeways and Highways with Full Access Control

When full access control is proposed for an existing highway, or a new freeway is proposed, each intersecting public or private way must be handled using one of the following options. The options listed below also apply to pedestrian and bicycle facilities.

- The intersecting facility can be dead-ended effectively terminating through traffic;
- The intersecting facility can be re-routed to maintain connectivity;
- The intersecting facility can be grade separated as either an underpass or an overpass, maintaining through traffic but effectively terminating access to the intersecting highway;
- The intersecting facility can be reconstructed as an interchange, to maintain through traffic access to the freeway.

The importance of the continuity of the crossing road or the feasibility of an alternate route will determine whether a grade separation or interchange is warranted. An interchange should be provided on the basis of the anticipated demand for access to the minor road and the operational effects on the major roadway.

7.2.6 Interchange Spacing

Interchange spacing is an important consideration in the planning and design of new or modified interchanges. Interchange spacing is the distance measured along the main roadway between the centerlines of the intersecting roadways that maintain ramp access to the through highway.

In urban areas, there should be a one-mile minimum spacing between interchanges to allow sufficient space for entrance and exit maneuvers. Closer spacing may require the use of collector-distributor roads to remove the merging/diverging and accelerating/decelerating traffic from the freeway mainline.

In rural, undeveloped areas, interchanges should be spaced no closer than three miles apart. These spacing guidelines are intended to minimize the disruption of entering and exiting traffic to the mainline of the highway and to prevent insufficient sign spacing.

7.2.7 Interchange Justification/Modification Reports

The design and construction of interchanges or grade separations along Interstate highways is controlled by the Federal Highway Administration (FHWA) and requires their approval and conformance to their requirements regarding modifications to and maintenance of the Interstate system. An Interchange Justification Report (IJR) / Interchange Modification Report (IMR) is required for new interchanges or modifications to existing interchanges.

Interchange justification and modification requires approval from the Federal Highway Administration

The designer should consult with FHWA for their latest policy for preparing an IJR/IMR. The policy is applicable to new or revised access points to existing Interstate facilities, and to all NHS freeway facilities. The policy in force at the time of this printing is:

It is in the national interest to maintain the Interstate System to provide the highest level of service in terms of safety and mobility. Adequate control of access is critical to providing such service. Therefore, new or revised access points to the existing Interstate System should meet the following requirements:

1. *The existing interchanges and/or local roads and street in the corridor can neither provide the necessary access nor be improved to satisfactorily accommodate the design-year traffic demands while at the same time providing the access intended by the proposal.*
2. *All reasonable alternatives for design options, location and transportation system management type improvements (such as ramp metering, mass transit, and HOV facilities) have been assessed and provided for if currently justified, or provisions are included for accommodating such facilities if a future need is identified.*
3. *The proposed access point does not have a significant adverse impact on the safety and operation of the Interstate facility based on an analysis of current and future traffic. The operational analysis for existing conditions shall, particularly in urbanized areas, include an analysis of sections of Interstate to and including at least the first adjacent existing or proposed interchange on either side. Crossroads and other roads and streets shall be included in the analysis to the extent necessary to assure their ability to collect and distribute traffic to and from the interchange with new or revised access points.*
4. *The proposed access connects to a public road only and will provide for all traffic movements. Less than "full interchanges" for special purpose access for transit vehicles, for HOVs, or into park and ride lots may be considered on a case-by-case basis. The proposed access will be designed to meet or exceed current standards for Federal-aid projects on the Interstate System.*
5. *The proposal considers and is consistent with local and regional land use and transportation plans. Prior to final approval, all requests for new or revised access must be consistent with the metropolitan and/or statewide transportation plan, as appropriate, the applicable provision of 23 CFR part 450 and the transportation conformity requirements of 40 CFR parts 51 and 93.*
6. *In areas where the potential exists for future multiple interchange additions, all requests for new or revised access are supported by a comprehensive Interstate network study with recommendations that address all proposed and desired access within the context of a long-term plan.*
7. *The request for a new or revised access generated by new or expanded development demonstrates appropriate coordination between the development and related or otherwise required transportation system improvements.*

8. *The request for new or revised access contains information relative to the planning requirements and the status of the environmental processing of the proposal.*

The following is a description of the information typically included in an IJR or IMR submitted to the FHWA:

- A clear description of the location and type of proposed new or modified access. Maps, schematic diagrams, and preliminary design plans should be included as needed to clearly describe the proposal. Drawings and plans should include (as applicable): project limits, adjacent interchanges, proposed interchange configuration, travel lanes and shoulder widths, ramps to be added, ramps to be removed, ramp radii, ramp grades, acceleration lane lengths, deceleration lane lengths, taper lengths, auxiliary lane lengths, "taper" or "parallel" type exit ramps, truck climbing lanes, and collector/distributor roads.
- Purpose and need for the new or revised access points (why it is needed, what are the intended benefits).
- Any background or supporting information that further explains the basis for the proposal (i.e., new highway proposed, planned private developments, known public support, etc.). Maps should show exact locations of all developments. If the purpose of the IMR/IJR is to support one or more proposed developments, the IMR/IJR should say so.
- If the interchange is within a Transportation Management Area.
- If there are any known issues of concern or controversy (environmental, public opposition, etc.).
- A description of the design alternatives considered (diamond interchange, single-point, directional ramps, alternate locations, etc.) and why the proposed alternative was selected.
- Status of environmental studies/permitting process.
- Estimated costs of the project, proposed funding sources (private development, local funds, State or Federal-aid funds), and implementation schedule.
- Relationship and distance of the interchange to adjacent interchanges and the ability to provide adequate signing.

- Any necessary design exceptions from currently adopted AASHTO Interstate design standards.
- Existing and Proposed Limits of Access.
- Schematic drawings showing current and design year traffic volumes for the mainline, ramps, and cross roads.
- Additional proposed traffic signalization, roundabout construction and signing (if applicable).
- Safety issues regarding the existing conditions and proposed alternatives.

7.3 Interchange Types

There are a variety of interchange types available for the conditions encountered. After the decision has been made that an interchange is appropriate for the location, the selection of interchange type is influenced by factors such as operational effects on the mainline and cross street, context sensitivity, multimodal accommodation, topography, potential site impacts, required right-of-way, cost, and anticipated activity levels.

Each interchange must be designed to fit individual site conditions. The final design may be a minor or major modification of one of the basic types, or it may be a combination of the basic types. Freeway interchanges are of two general types: A ***system interchange*** will connect freeway to freeway; a ***service interchange*** will connect a freeway to a lesser facility.

System interchanges are most frequently three-leg, full cloverleaf, or directional interchanges. Service interchanges are most frequently diamond, cloverleaf, or partial cloverleaf interchanges. These basic interchange configurations are described in the following sections.

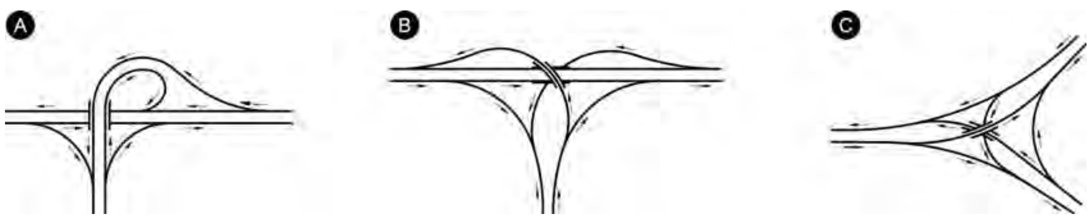
7.3.1 Three-Leg Interchanges

Three-leg interchanges, also known as T- or Y-interchanges, are usually provided where major highways begin or end. Three-leg interchanges should be considered when future expansion to the unused quadrant is unlikely. This is due in part to the fact that three-leg interchanges are very difficult to expand, modify, or otherwise retrofit as a four leg facility.

Exhibit 7-1 illustrates examples of three-leg interchanges with several methods of providing the turning movements. The trumpet type (with a single structure) is shown in Exhibit 7-1(A) where three of the turning movements are accommodated with direct or semi-direct ramps and one movement by a loop ramp. In general, the semi-direct ramp should favor the heavier left-turn movement and the loop the lighter volume. Where both left-turning movements are fairly heavy, the design of a directional T-type interchange shown in Exhibit 7-1(B) is best-suited. A fully directional interchange shown in Exhibit 7-1(C) is appropriate when all turning volumes are heavy or the intersection is between two access controlled highways.

Construction of the configurations in Exhibit 7-1(B) and Exhibit 7-1(C) would be the most costly types because of the multiple structures required in the center of the interchange to accommodate three levels of traffic. For further examples and design considerations of additional T- and Y-interchanges, see AASHTO's *A Policy on Geometric Design of Highways and Streets*.

Exhibit 7-1
Three-leg Interchanges



Source: *A Policy on Geometric Design of Highways and Streets,* AASHTO, 2004. Chapter 10 Grade Separations and Interchanges

7.3.2 Diamond Interchanges

Diamond interchanges use one-way diagonal ramps in each quadrant with two at-grade intersections provided on the minor road. If these two intersections can be properly designed, the diamond is usually the best choice of interchange where the intersecting road is not access controlled. Where topography permits, the preferred design is to elevate the minor road over the major roadway. This aids in deceleration to the lower speed roadway and in acceleration to the higher speed roadway. The advantages of diamond interchanges include:

- Continuity of pedestrian and bicycle accommodation on the minor road is easier to maintain since merging and diverging movements can be avoided;
- Relatively little right-of-way is required;

- The configuration allows modifications to provide greater ramp capacity, if needed in the future;
- Their common usage has resulted in a high degree of driver familiarity;
- All traffic can enter and exit the freeway mainline at relatively high speeds and all exits from the freeway mainline are made before reaching the structure;
- Adequate sight distance can usually be provided and the traffic maneuvers are normally uncomplicated;
- Left-turning maneuvers require little extra travel distance relative to the partial cloverleaf.

The primary disadvantages of a diamond interchange are potential operational problems with the two closely-spaced intersections on the minor road, and the potential for wrong-way entry onto the ramps. For this reason, a median is often provided on the cross road to facilitate proper channelization. Additional signing is also recommended to help prevent improper use of the ramps. Exhibit 7-2 illustrates a schematic of a typical diamond interchange.

7.3.2.1 Compressed Diamond Interchanges

Compressed diamond interchanges are diamond interchanges where the nearest ramp terminal is less than 200 feet from the bridge. These interchanges are often used where right of way is restricted. Adequate sight distance based on unsignalized intersection criteria must be provided even if signals are installed. See Chapter 3 for further discussion of intersection sight distance. For further examples of design considerations, see AASHTO's *A Policy on Geometric Design of Highways and Streets*.

7.3.2.2 Single Point Urban Interchange (SPUI)

The ***SPUI interchange*** (also known as an urban interchange or single-point diamond interchange) consolidates left-turn movements to and from entrance and exit ramps at a single intersection as illustrated in Exhibit 7-3. The primary features of a SPUI are that all four left-turning moves are controlled by a single multi-phase traffic signal system and opposing left turns operate to the left of each other. These features can allow the SPUI to significantly increase the interchange capacity. The advantages of a SPUI include:

- Vehicles making opposing left turns pass to the left of each other rather than to the right, so their paths do not intersect. In addition, the right-turn movements are typically free-flow movements and only the left turns must pass through the signalized intersection. This operation eliminates a major source of traffic conflict, thereby increasing overall intersection efficiency and reducing the traffic signal need to a three-phase operation rather than a four-phase typical of a compressed diamond interchange.

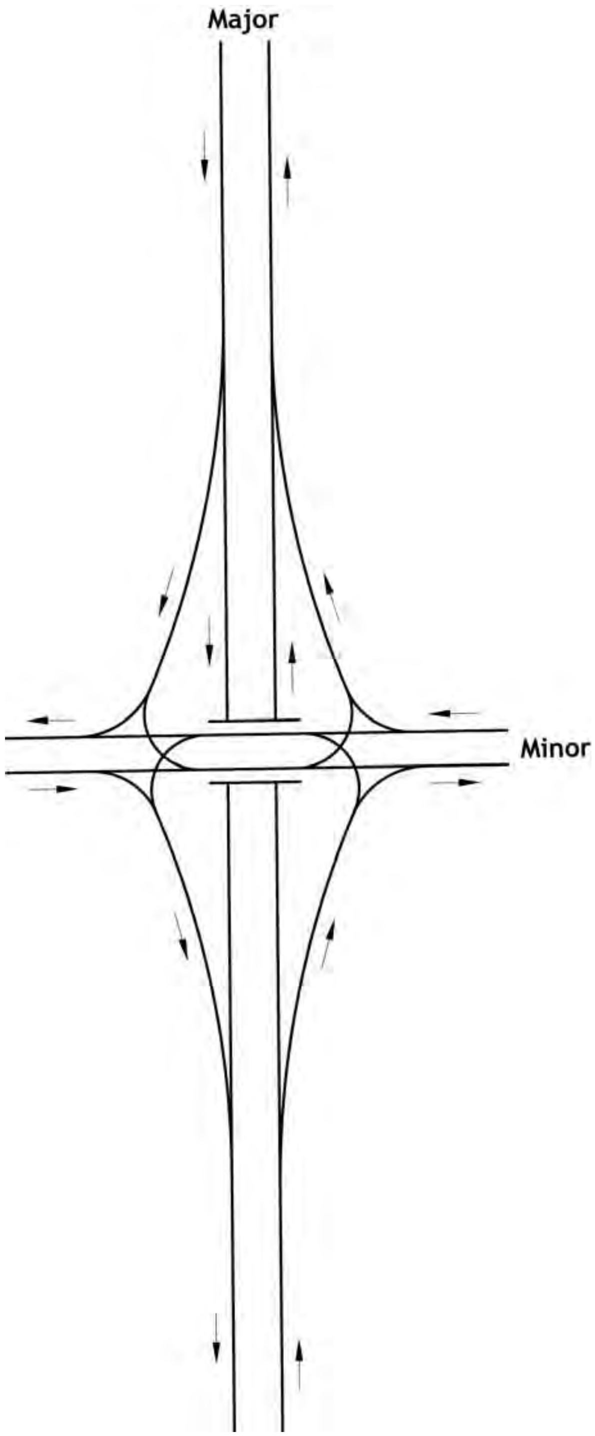
- Since the SPUI has only one intersection, as opposed to two intersections in a conventional diamond interchanges, the operation of a single traffic signal on the crossroad may result in reduced delay through the intersection area.
- Curve radii for left-turn movements through the intersection are significantly flatter than at conventional intersections, and, therefore, the left turns move at a higher speed and discharge more efficiently.
- The configuration can help to reduce left-turning lane storage problems for drivers trying to enter the freeway.
- U-turns can be easily provided for the major roadway within the ramp system.

The primary disadvantages are its higher costs because of the need for a larger structure, the need for a careful design of channelization to minimize driver confusion and the likelihood of wrong-way maneuvers, and the need for careful design of signal timing to accommodate pedestrians and bicyclists. Also, SPUIs built with a skewed angle between two roadways increase clear distances and adversely affect sight distance.

Bicycle accommodation must consider signal timing for slower cyclists. Pedestrian crossing of the cross street at ramp terminals typically adds a signal phase, resulting in reduced operational efficiency for motor vehicles. Special consideration should be given to the location and alignment of cross walks to ensure adequate sight distance, minimize the length of the crossing, maximize vehicular storage lengths, and to coincide with driver expectations.

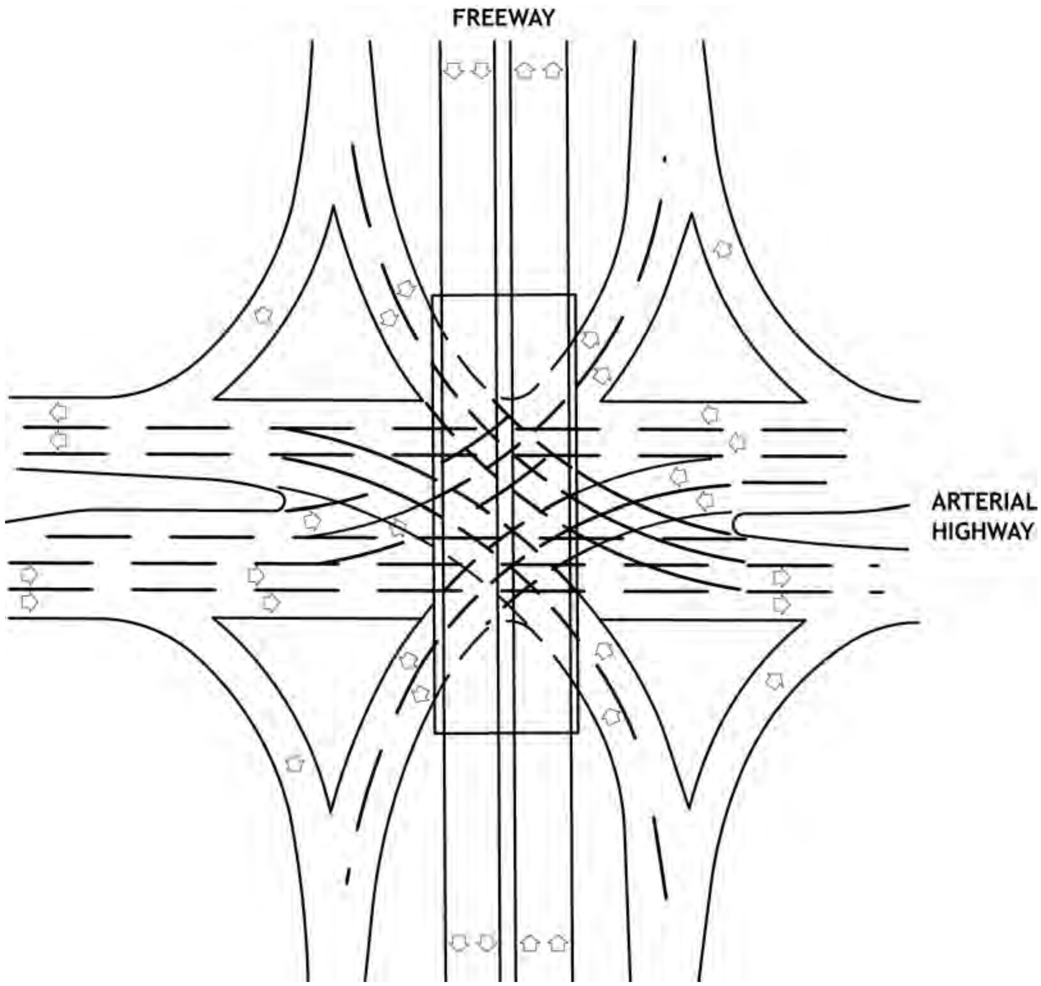
For further discussion, examples and design considerations see *A Policy on Geometric Design of Highways and Streets,* AASHTO.

Exhibit 7-2
Typical Diamond Interchange (Schematic)



Source: *A Policy on Geometric Design of Highways and Streets,* AASHTO, 2004. Chapter 10 Grade Separations and Interchanges

Exhibit 7-3
Single Point Urban Interchange



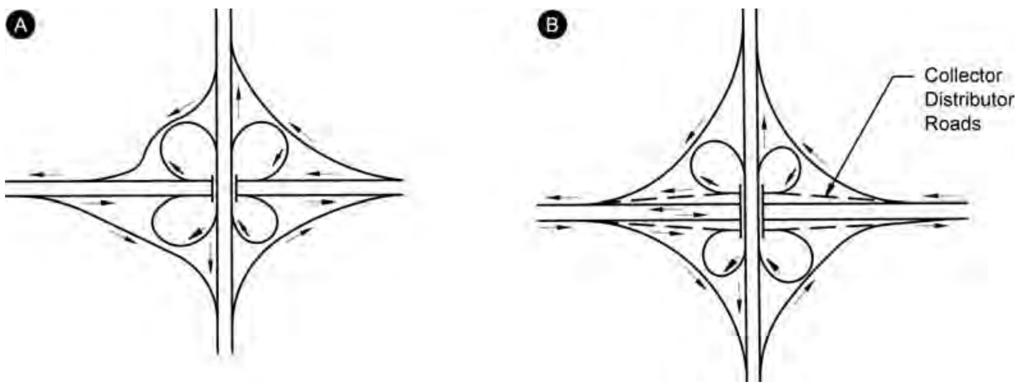
Source: *A Policy on Geometric Design of Highways and Streets,* AASHTO, 2004. Chapter 10 Grade Separations and Interchanges

7.3.3 Cloverleafs

Cloverleaf interchanges are used at four-leg intersections and combine the use of one-way diagonal ramps with loop ramps to accommodate left-turn movements. Interchanges with loops in all four quadrants are referred to as ***full cloverleafs*** and all others are referred to as ***partial cloverleafs***.

Where two access controlled highways intersect, a full cloverleaf is the minimum type design interchange that provides connectivity for all movements between the highways. However, these interchanges introduce several undesirable operational features such as double exits and entrances from the mainline, weaving between entering and exiting vehicles, lengthy travel time and distance for left-turning vehicles, and large amounts of required right-of-way. Therefore, at system interchanges, a collector-distributor (C-D) road is often used to remove the weave from the mainline traffic. Exhibit 7-4 provides typical examples of full cloverleafs with and without C-D roads.

Exhibit 7-4
Full Cloverleafs

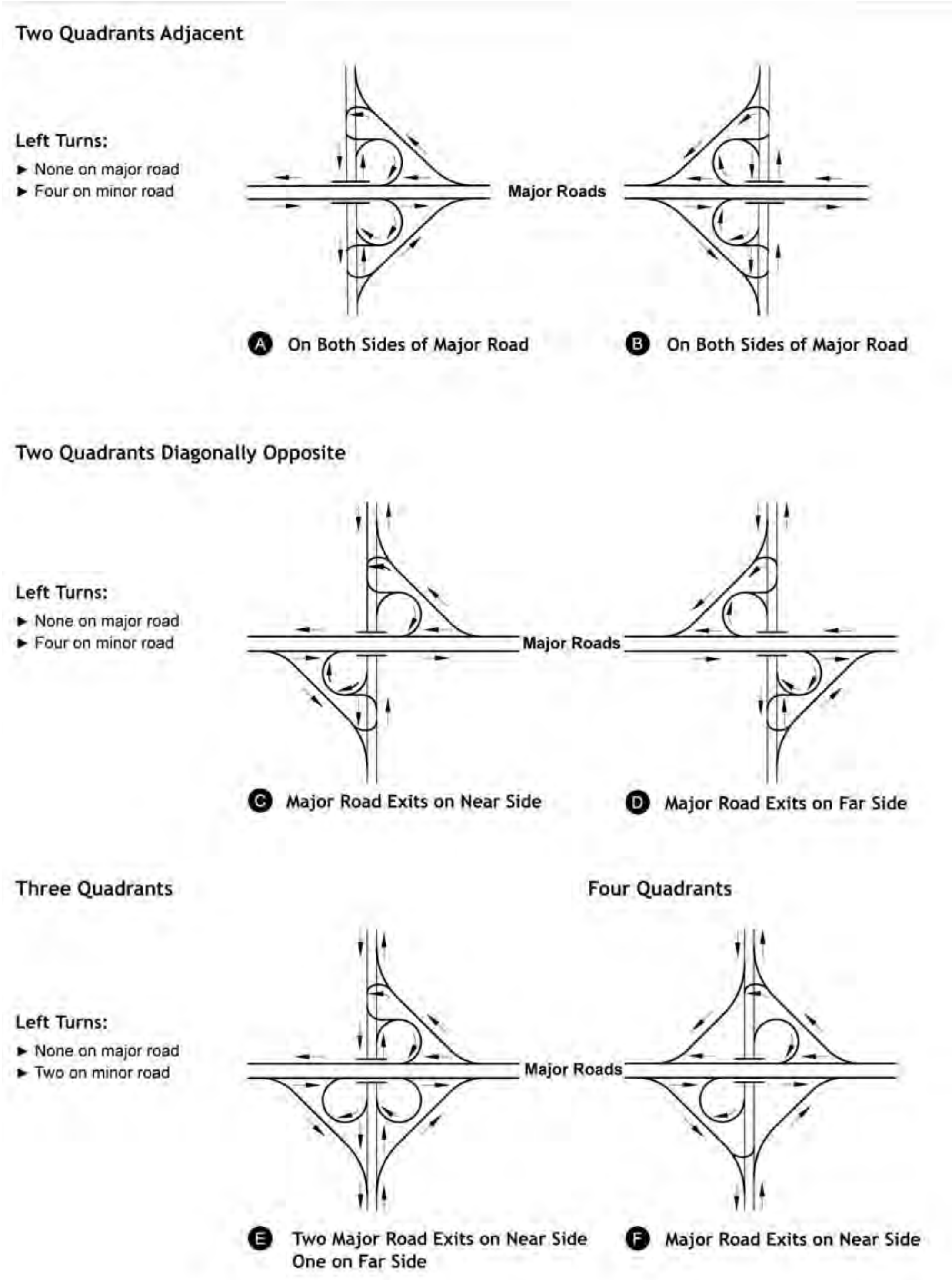


Source: *A Policy on Geometric Design of Highways and Streets,* AASHTO, 2004. Chapter 10 Grade Separations and Interchanges

Partial cloverleafs are often used where right-of-way, multi-modal, and/or environmental restrictions preclude ramps in one or more quadrants. Exhibit 7-5 illustrates six examples of partial cloverleafs. In "A" and "B," both left-turn movements onto the major road are provided by loops, which is desirable. The other examples (C-F) illustrate two loops in opposite quadrants and loops in three quadrants. In these examples, the desirable feature is that no left-turn movements are made onto the major road.

Partial cloverleaf arrangements are generally used when an obstruction prevents construction of ramps in one or more quadrants, or to provide connections for all movements without intersection delays (other than those associated with merging and weaving at a full-cloverleaf interchange). For freeway connections with other arterials, collectors and local roads, diamond interchanges are often preferred as discussed in Section 7.4.1.

Exhibit 7-5
Partial Cloverleaf Arrangements



Source: *A Policy on Geometric Design of Highways and Streets,* AASHTO, 2004. Chapter 10 Grade Separations and Interchanges

7.3.4 Directional and Semi-Directional

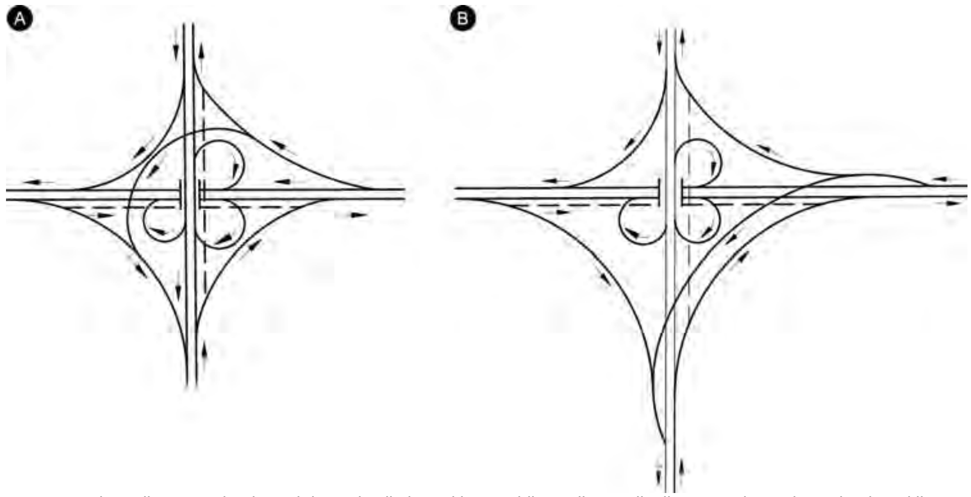
Direct and semi-direct connections are used for important turning movements to reduce travel distance, increase speed and capacity, eliminate weaving, and to avoid the need for out-of-direction travel in driving on a loop. Higher levels of service can be realized on direct connections and, in some instances, on semi-direct ramps because of relatively high speeds and the likelihood of better terminal design. The following definitions apply to directional and semi-directional interchanges:

- ***Direct Ramp Connection*** – A ramp that does not deviate greatly from the intended direction of travel (as does a loop, for example).
- ***Semi-Direct Ramp Connection*** – A ramp that is indirect in alignment yet more direct than loops.
- ***Directional Interchange*** – An interchange where one or more left-turning movements are provided by direct connection, even if the minor left-turn movements are accommodated on loops.
- ***Semi-Directional Interchange*** – An interchange where one or more left-turning movements are provided by semi-direct connections, even if the minor left-turn movements are accommodated on loops.
- ***Fully Directional Interchange*** – An interchange where all left-turning movements are provided by direct connections. Fully directional interchanges are generally preferred where two high-volume freeways intersect. While fully directional interchanges can be costly to construct due to an increased number of bridge crossings, they offer high capacity movements for both through and turning traffic with comparatively little additional area needed for construction.

Direct or semi-direct connections are used for heavy left-turn movements to reduce travel distance, increase speed and capacity, and eliminate weaving. Examples of direct and semi-direct interchanges are shown in Exhibits 7-6, 7-7 and 7-8.

For further variations and examples of interchange types and related design considerations see AASHTO's *A Policy on Geometric Design of Highways and* Streets.

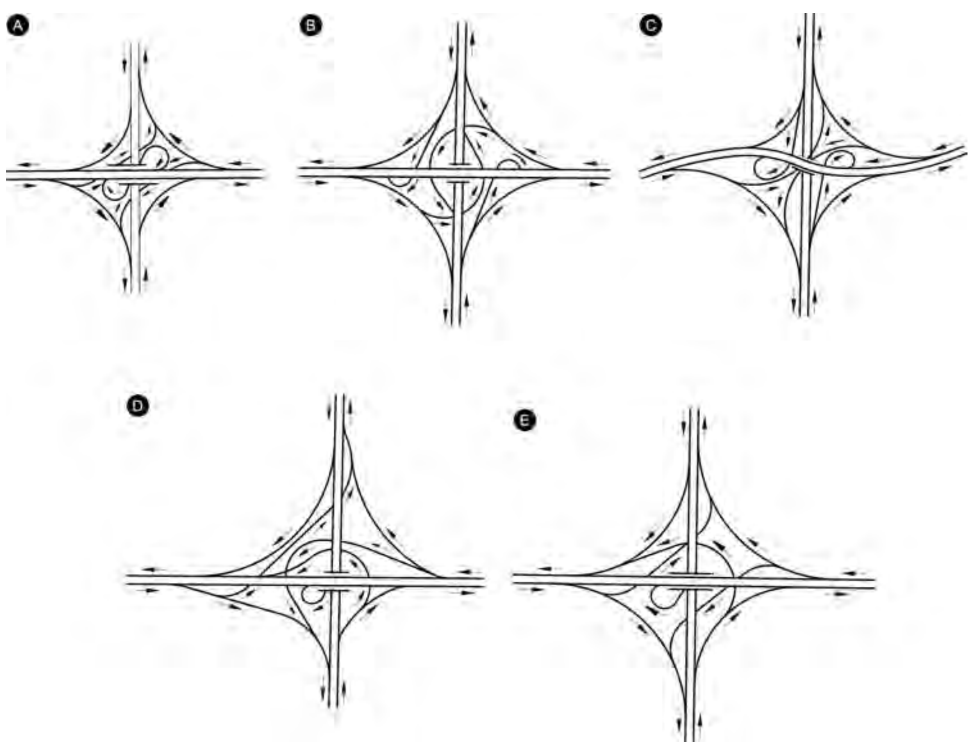
Exhibit 7-6
Semidirect Interchanges with Weaving



Note: Weaving adjacent to the through lanes is eliminated by providing collector-distributor roads as shown by dotted lines.

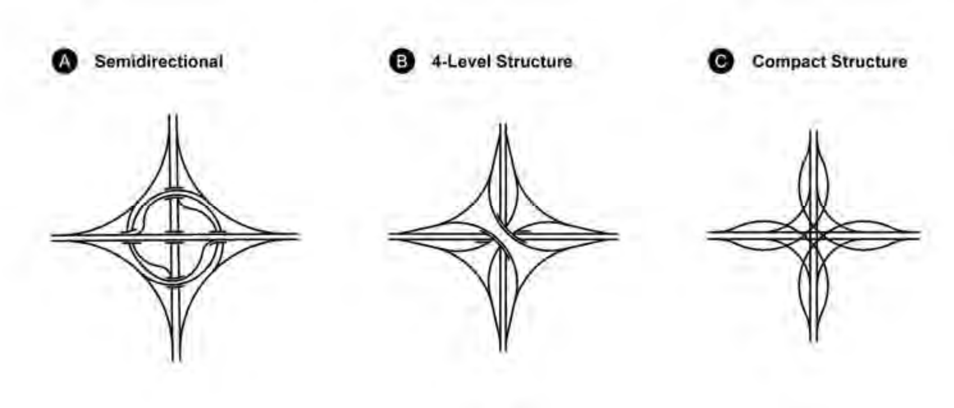
Source: *A Policy on Geometric Design of Highways and Streets,* AASHTO, 2004. Chapter 10 Grade Separations and Interchanges

Exhibit 7-7
Semidirect Interchanges without Weaving



Source: *A Policy on Geometric Design of Highways and Streets,* AASHTO, 2004. Chapter 10 Grade Separations and Interchanges

Exhibit 7-8
Semidirect and Directional Interchanges - Multilevel Structures



Source: *A Policy on Geometric Design of Highways and Streets,* AASHTO, 2004. Chapter 10 Grade Separations and Interchanges

7.4 General Design Considerations

Interchanges are expensive, and it is therefore often necessary to develop and study the feasibility of several alternatives in depth, as described in Chapter 2. Interchanges must also meet the policies set forth by the FHWA and described in Section 7.2.7.

7.4.1 Interchange Type Selection

Once several alternative interchange designs have been developed, they should be evaluated for application to the location under consideration based on the following two key considerations:

- **Context** – In rural areas where interchanges are relatively infrequent, the design is often selected primarily on the basis of consistency (driver expectation) and environmental constraints in the interchange area. In urban areas, where restricted right-of-way and closer spacing of interchanges are common, the design of the interchange may be severely constrained. A collector distributor road may be necessary between closely spaced interchanges. The operational characteristics of the intersecting road and nearby interchanges will also be major influences on the design of an interchange.
- **Accessibility** – Ideally, interchanges should provide for all movements, even when the anticipated turning volume is low. An

omitted maneuver causes confusion to those drivers searching for the exit or entrance. Particular attention to signing must be made to minimize confusion. In addition, unanticipated future developments may increase the demand for a given maneuver. Even when all ramps are not constructed sufficient right-of-way should be acquired for completing the interchange at a later date.

Additionally, interchange design should account for the following transportation system considerations:

- Compatibility with the surrounding highway system;
- Road user impacts (safety, travel distance and time, convenience and comfort for all users including pedestrians and bicyclists);
- Right-of-way impacts and availability;
- Uniformity of exit and entrance patterns;
- Operational characteristics (single versus double exits, weaving, signing); and
- Construction and maintenance costs.

Exhibit 7-9 depicts typical interchange configurations related to classifications of intersecting facilities in rural, suburban, and urban environments.

For system interchanges, directional and semi-directional interchanges are preferred to cloverleaf designs from a user safety and operational efficiency perspective. However, many existing freeways were previously constructed using cloverleaf interchange configurations and projects to modify these existing interchanges are common.

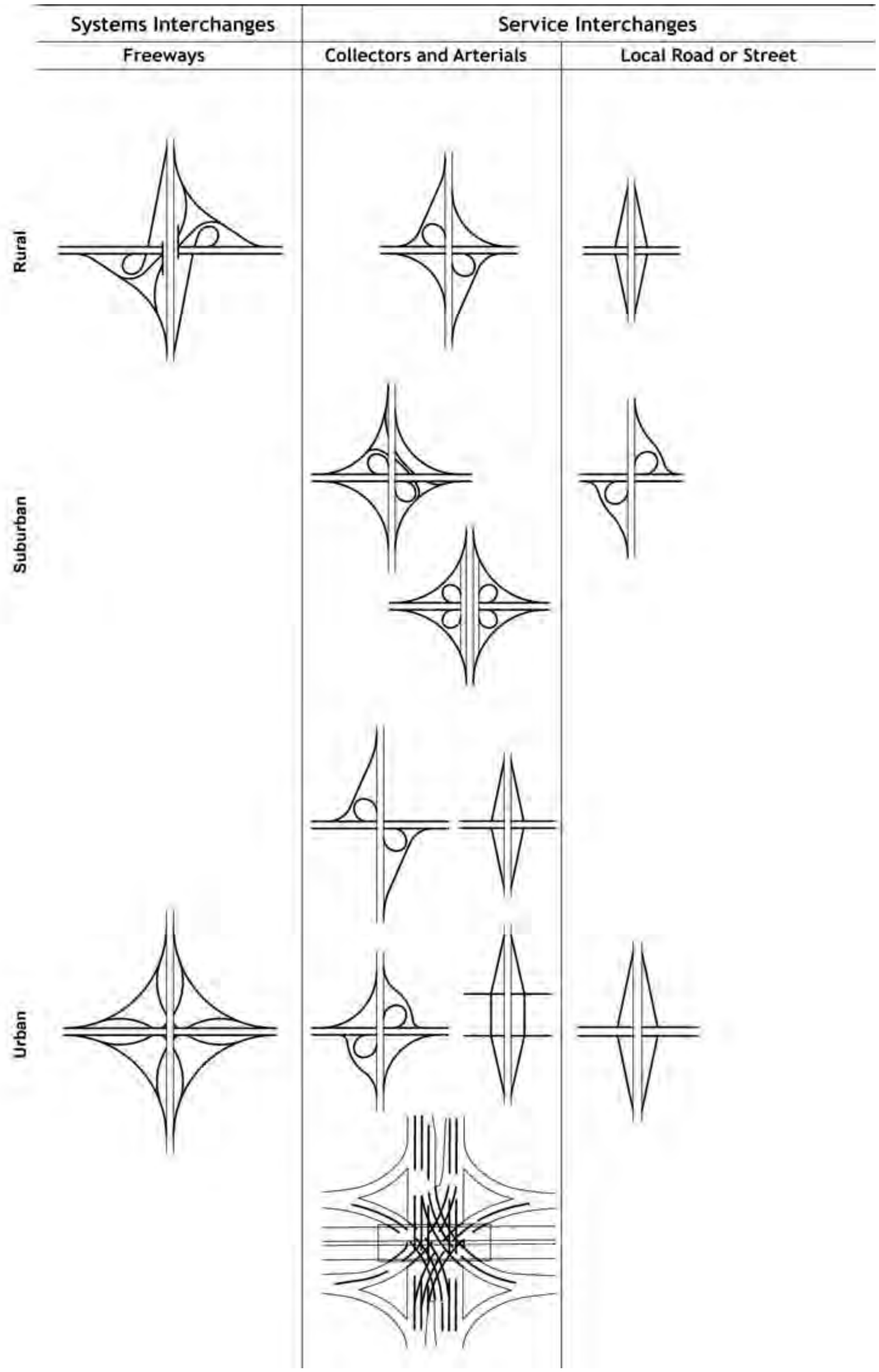
At service interchanges, the choice of interchange is usually between a diamond and cloverleaf configuration. The following should be considered when making the selection:

- Unlike diamond interchanges and partial cloverleafs, full cloverleafs do not employ 90-degree intersections. Pedestrian and bicycle movements along cross streets are more difficult to accommodate safely at full cloverleaf interchanges than at partial cloverleaf or diamond interchanges because vehicular movements are usually free-flow.

- All freeway exit maneuvers at diamond interchanges are executed before reaching the structure, conforming to driver expectations. Diamond interchanges also eliminate weaving on the freeway mainline and cross street. Some partial cloverleaf options can also provide these advantages.
- Partial cloverleafs may be suitable for locations where construction of ramps in one or more quadrants of the interchange is infeasible or undesirable. Partial cloverleafs with loops in opposite quadrants are very desirable because they eliminate the weaving problem associated with full cloverleaf designs.
- The double exit/entrance at cloverleafs can result in signing problems and driver confusion. Collector-distributor roads are often recommended to address signage problems and to reduce weaving on the freeway mainline.
- Ramps at diamond interchanges can be widened to increase storage capacity. Loop ramps, regardless of width, almost always operate as a single lane, thereby limiting storage capacity. Operational capacity needs to consider the control at the ramp terminal and may not always be significantly greater than with free-flow loops.
- The loops in cloverleafs result in a greater travel distance for left-turning vehicles than do diamonds. Loops operate at lower speeds, especially for trucks, which have the potential to turn over if traveling the loop too fast.
- Cloverleafs require more right-of-way and are more expensive to construct than diamonds.
- Full cloverleafs provide higher capacity than most diamond configurations since movements at the ramp terminals are usually free-flow and subject only to weaving and merging delays rather intersection control delay.

Full cloverleaf interchanges are often considered more appropriate than diamonds when traffic volumes are high. However, when compared with the advantages of diamonds in terms of pedestrian and bicycle accommodation, right-of-way requirements, and driver expectations, the designer should investigate measures to increase the capacity of diamond interchanges such as advanced signal phasing, signal coordination on the minor road, roundabout intersections, or SPUI interchanges before selecting a cloverleaf design.

Exhibit 7-9
Interchanges on Freeways as Related to Types of Intersecting Facilities and Surrounding Area



Source: *A Policy on Geometric Design of Highways and Streets,* AASHTO, 2004. Chapter 10 Grade Separations and Interchanges

7.4.2 Capacity and Level of Service

An interchange must be designed to accommodate the anticipated activity levels for the design year (see Chapter 3 for details). The capacity and level of service for an interchange will depend upon the operation of its individual elements along with the interaction and coordination of each of these elements in the overall design. The individual elements are as follows:

- Basic freeway section where interchanges are not present;
- Freeway/ramp junctions or terminals (Section 7.7);
- Weaving areas (Section 7.6.3);
- Ramps (Section 7.7); and
- Ramp/minor road intersections (Section 7.8).

For most situations, the capacity and level of service at interchanges is focused on motor vehicles since interchanges are most often used at freeway connection points.

The basic reference for level of service measures for interchanges is the *Highway Capacity Manual.* It is desirable for the level of service of each interchange element to be at least that provided on the basic freeway section. In addition, the designer should ensure that the operation of the ramp/minor road intersection will not impair the operation of the mainline. This will likely involve a consideration of the operational characteristics on the minor road for some distance in either direction from the interchange.

7.4.3 Safety Considerations

Typical design challenges at interchanges include:

- **Sight Distance at Exit Points** — Sight distance is often determined with respect to the ***gore,*** which is the area where a ramp diverges from the mainline. When feasible, decision sight distance should be provided to enable drivers approaching freeway exits to see the pavement surface from the painted gore nose to the limit of the paved gore. Proper advance signing of exits is also essential and additional signing is required when it is not possible to obtain the decision sight distance.

- **Exit Speed Changes** — The design should provide enough distance to allow safe deceleration from the freeway design speed to the design speed of the first exit curve.
- **Merges** — The most frequent crash-type at interchanges is the rear-end collision at entrances onto the freeway. This problem can be reduced by providing an acceleration lane of sufficient length with adequate sight distance to allow a merging vehicle to attain speed and find a sufficient gap into which to merge.
- **Left-Side Entrances and Exits** — Left-side entrances and exits should be avoided as they are contrary to driver expectations and have been associated with higher crash rates.
- **Fixed-Object Hazards** — A number of fixed objects may be located within interchanges, such as signs at exit gores or bridge piers and rails. These should be removed where possible, placed outside of the recovery area where possible, made breakaway, or shielded with barriers or impact attenuators.
- **Wrong-Way Entrances** — In almost all cases, wrong-way maneuvers originate at interchanges. Some cannot be avoided, but others may result from driver confusion due to poor visibility, deceptive ramp arrangement, or inadequate signing. The interchange design must attempt to minimize wrong-way possibilities. This includes staggering ramp terminals and controlling access in the vicinity of the ramps.
- **Excessive Speed on Minor Roadways** — Ramp and merge designs should slow down drivers leaving the high-speed roadway so that they will not exceed the design speed on the secondary road. The section of the secondary road in the interchange area should have a design speed similar to (not faster than) the design of adjoining sections of that road.

7.5 Traffic Lane Principles

A variety of traffic lane principles are important in the design of an interchange. The application of these principles will help to minimize confusion, operational problems, and the number of crashes.

7.5.1 Basic Number of Lanes and Freeway Lane Drops

The ***basic number of lanes*** is the minimum number of lanes needed over a significant length of a highway based on the overall capacity needs of that section. The number of lanes should remain constant over short distances. For example, a lane should not be dropped at the exit of a diamond interchange and then added at the downstream entrance simply because traffic volumes between the exit and entrance drop significantly. Similarly, a basic lane between closely-spaced interchanges should not be dropped if the estimated traffic volume in that short section of highway does not warrant the higher number of lanes.

Freeway lane drops, where the basic number of lanes is decreased, must be carefully designed. They should occur on the freeway mainline away from any other activity, such as interchange exits and entrances. The following recommendations are important when designing a freeway lane drop:

- **Location** – The lane drop should occur approximately 2,000 to 3,000 feet beyond the previous interchange. This distance allows adequate signing and adjustments from the interchange, but yet is not so far downstream that drivers become accustomed to the number of lanes and are surprised by the lane drop. In addition, a lane should not be dropped on a horizontal curve or where other signing is required, such as for an upcoming exit.
- **Sight Distance** – The lane drop should be located so that the surface of the roadway within the transition remains visible for its entire distance. This favors, for example, placing a lane drop within a sag vertical curve rather than just beyond a crest. Decision sight distance to the roadway surface is desirable. (For information on Decision Sight Distance see Chapter 3).
- **Transition** – The desirable taper rate is 70:1 for the transition at the lane drop. The minimum is 50:1.
- **Right-Side Versus Left-Side Drop** – All freeway lane drops should be on the right side, unless specific site conditions greatly favor a left-side lane reduction.
- **Signing** – Motorists must be warned and guided into the lane reduction. Advance signing and pavement markings must conform to the requirements of the *Manual on Uniform Traffic Control Devices (MUTCD).*

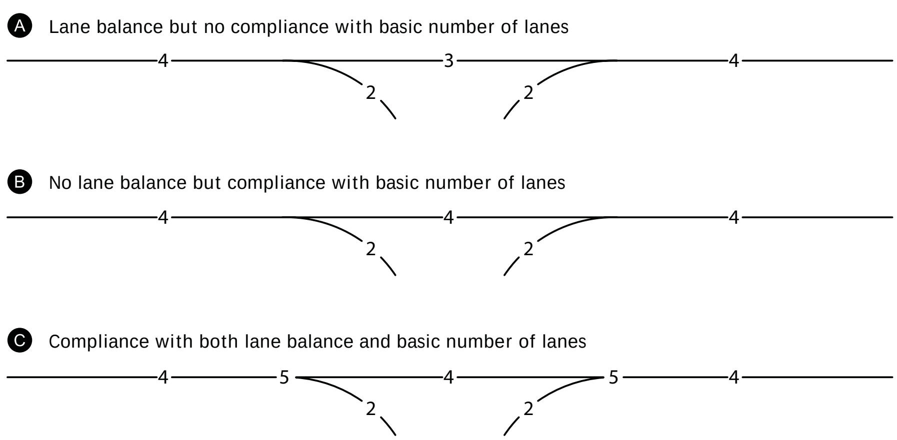
7.5.2 Lane Balance

To realize efficient traffic operation through and beyond an interchange, there should be a balance in the number of traffic lanes on the freeway and ramps. Design traffic volumes and a capacity analysis determine the basic number of lanes to be used on the highway and the minimum number of lanes on the ramps. After the basic number of lanes is determined for each roadway, the balance in the number of lanes should be checked on the basis of the following principles:

- At entrances, the number of lanes beyond the merging of two traffic streams should not be less than the sum of all traffic lanes on the merging roadways, minus one, but may be equal to the sum of all traffic lanes on the merging highway.
- At exits, the number of approach lanes on the highway must be equal to the number of lanes on the highway beyond the exit plus the number of lanes on the exit, minus one. An exception to this principle would be at cloverleaf loop ramp exits which follow the loop ramp entrance or at exits between closely-spaced interchanges; i.e., interchanges where the distance between the end of the taper of the entrance terminal and the beginning of the taper of the exit terminal is less than 1,500 feet and a continuous auxiliary lane between the terminals is being used. In these cases, the auxiliary lane may be dropped in a single-lane exit with the number of lanes on the approach roadway being equal to the number of through lanes beyond the exit plus the lane on the exit.
- The traveled way of the highway should be reduced by not more than one traffic lane at a time.

Exhibit 7-10 illustrates the typical treatment of the four-lane freeway with a two-lane exit followed by a two-lane entrance.

Exhibit 7-10
Coordination of Lane Balance and Basic Number of Lanes



Source: *A Policy on Geometric Design of Highways and Streets,* AASHTO, 2004. Chapter 10 Grade Separations and Interchanges

7.5.3 Auxiliary Lanes

Variations in traffic demand over short distances should be accommodated by means of auxiliary lanes, where needed. An ***auxiliary lane*** is defined as the portion of the roadway adjoining the traveled way for speed change, turning, storage for turning, weaving, truck climbing, and other purposes supplementary to through-traffic movement. The width of an auxiliary lane should equal that of the through lanes. An auxiliary lane may be provided to comply with the concept of lane balance, to comply with capacity requirements in the case of adverse grades, or to accommodate speed changes, weaving, and maneuvering of entering and exiting traffic. Where auxiliary lanes are provided along freeway main lanes, the adjacent shoulder would desirably be 8 to 12 feet in width, with a minimum of 6 feet.

Auxiliary lanes may be added to satisfy capacity and weaving requirements between interchanges, to accommodate traffic pattern variations at interchanges, and for simplification of operations (such as reducing lane changing). The principles of lane balance must always be applied in the use of auxiliary lanes. In this manner the necessary balance between traffic load and capacity is provided, and lane balance and needed operational flexibility are realized.

Operational efficiency may be improved by using a continuous auxiliary lane between the entrance and exit terminals where interchanges are closely spaced, the distance between the end of the taper on the entrance terminal and the beginning of the taper on the exit terminal is short, and/or where local frontage roads do not exist.

Where interchanges are closely spaced in urban areas, the acceleration lane from an entrance ramp should be extended to the deceleration lane of a downstream exit ramp. Exhibit 7-11 shows alternatives in dropping auxiliary lanes.

7.5.4 Distance Between Successive Ramp Terminals

On freeways there are frequently two or more ramp terminals in close succession along the through lanes. To provide sufficient maneuvering length and adequate space for signing, a reasonable distance is required between terminals. Spacing between successive outer ramp terminals is dependent on the classification of the interchanges involved, the function of the ramp pairs (entrance (EN) or exit (EX)), and weaving potential, when applicable. The five possible ramp-pair combinations are:

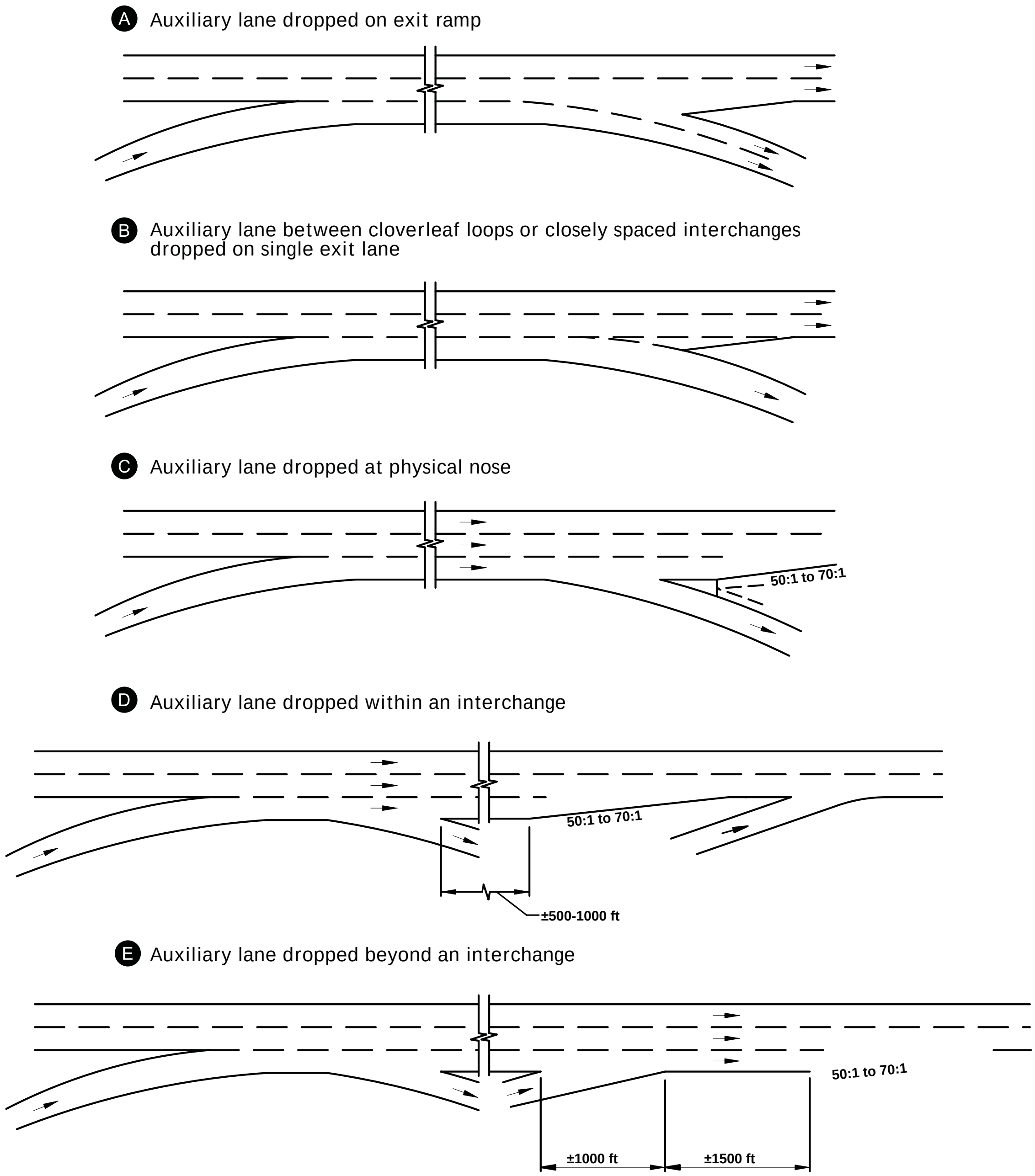
- entrance followed by entrance (EN-EN),
- exit followed by exit (EX-EX),
- exit followed by entrance (EX-EN),
- entrance followed by exit (EN-EX) (weaving), and
- turning roadways.

Distance between successive ramp terminals should be determined by the weaving lengths.

When an entrance ramp is followed by an exit ramp, the absolute minimum distance between the successive noses is governed by weaving consideration. ***Weaving sections*** are highway segments where the pattern of traffic entering and leaving at contiguous points of access results in vehicle paths crossing each other. (See *Highway Capacity Manual* for capacity of weaving sections and Chapter 2 of AASHTO's *A Policy on Geometric Design of Highways and Streets* for weaving lengths and widths.)

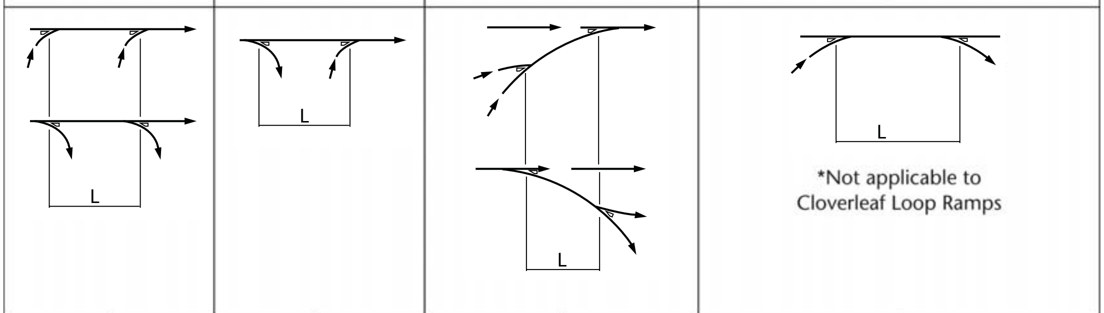
Exhibit 7-12 shows the minimum values for spacing of ramp terminals for the various ramp-pair combinations as they are applicable to the interchange classifications.

Exhibit 7-11
Alternatives in Dropping Auxiliary Lanes



Source: *A Policy on Geometric Design of Highways and Streets,* AASHTO, 2004. Chapter 10 Grade Separations and Interchanges

Exhibit 7-12
Recommended Minimum Ramp Terminal Spacing



EN-EN or EX-EX		EX-EN		Turning Roadways		EN-EX (weaving)			
Full Freeway	CDR or FDR	Full Freeway	CDR or FDR	System Interchange	Service Interchange	System to Service Interchange		Service to Service Interchange	
						Full Freeway	CDR or FDR	Full Freeway	CDR or FDR
Minimum Lengths Measured Between Successive Ramp Terminals									
1000 ft	800 ft	500 ft	400 ft	800 ft	600 ft	2000 ft	1600 ft	1600 ft	1000 ft

Note: **FDR** Freeway Distributor Road **CDR** Collector Distributor Road **EN** Entrance **EX** Exit

Source: *A Policy on Geometric Design of Highways and Streets,* AASHTO, 2004. Chapter 10 Grade Separations and Interchanges

A notable exception to this length policy for EN-EX ramp combinations is the distance between loop ramps of cloverleaf interchanges. For these interchanges the distance between EN-EX ramp noses is primarily dependent on loop ramp radii and roadway and median widths. A recovery lane beyond the nose of the loop ramp exit is desirable.

When the distance between the successive noses is less than 1,500 feet, the speed-change lanes should be connected to provide an auxiliary lane. This auxiliary lane is provided for improved traffic operation over relatively short sections of the freeway route and is not considered as an addition to the basic number of lanes. See AASHTO's *A Policy on Geometric Design of Highways and Streets* for additional information on auxiliary lane design and lane balance criteria at interchanges.

7.5.5 Approaches to Interchanges

Traffic passing through an interchange should be provided with the same level of safety and convenience as that given on the approaching highway. Highway elements, including design speed, alignment, profile, and cross sectional elements, should be consistent with those on the approaching highways. The following considerations are applicable to the design of highway approaches to structures:

- Through interchange areas, changes in alignment and cross sectional elements may be needed to ensure proper operation and to develop the capacity needed at the ramp terminals;
- Pedestrian and bicycle accommodation, consistent with the remaining segments of the roadway, should be continued through interchange area;
- Relatively sharp horizontal or vertical curves should be avoided;
- Four-lane roadways should be divided through interchange areas.

7.6 Freeway/Ramp Junctions

As described in Section 7.5, there are two basic types of freeway/ramp junctions, exits and entrances (often encountered in this order when traveling on the freeway mainline).

7.6.1 Exit Ramps

Exit ramps are one-way roadways which allow traffic to exit from the freeway and provide access to other crossing highways. The following design considerations are applicable to exit ramps.

7.6.1.1 Sight Distance

Decision sight distance (see Chapter 3) should be provided for drivers approaching an exit. Sufficient sight distance is particularly important for exit loops immediately beyond a structure. Vertical curvature or bridge piers can obstruct the exit point if not carefully designed. When measuring for adequate sight distance, the designer should use the pavement surface at the gore nose as height of object.

7.6.1.2 Deceleration Lanes

Sufficient deceleration distance is needed to allow an exiting vehicle to leave the freeway mainline safely and comfortably. All deceleration should occur within the full width of the deceleration lane. The length of the deceleration lane will depend upon the design speed of the mainline and the design speed of the first (or controlling) curve on the exit ramp. In addition, if compound curvature is used, there should be sufficient deceleration in advance of each successively sharper curve.

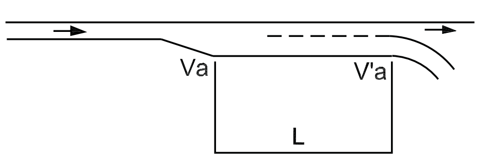
Exhibit 7-13 provides the deceleration distance for various combinations of highway design speeds and exit curve design speeds. Exhibit 7-30 at the end of this chapter illustrates the standard MassHighway designs for freeway exits at interchanges. Deceleration lanes can be the taper-type or the parallel-type, with the parallel-type preferred. It is necessary for a full deceleration lane to be developed and visibly marked well ahead of the gore area.

Exhibit 7-13
Minimum Deceleration Lengths for Exit Terminals with Flat Grades of 2% or Less

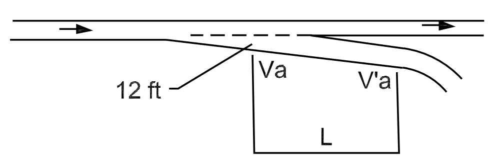
		Deceleration Length L (ft) for Design Speed of Exit Curve V_N (mph)								
		Stop Condition	15	20	25	30	35	40	45	50
Highway Design Speed V (mph)	Highway Speed Reached, V_a (mph)	For Average Running Speed on Exit Curve V'_a (mph)								
		0	14	18	22	26	30	36	40	44
30	28	235	200	170	140	—	—	—	—	—
35	32	280	250	210	185	150	—	—	—	—
40	36	320	295	265	235	185	155	—	—	—
45	40	385	350	325	295	250	220	—	—	—
50	44	435	405	385	355	315	285	225	175	—
55	48	480	455	440	410	380	350	285	235	—
60	52	530	500	480	460	430	405	350	300	240
65	55	570	540	520	500	470	440	390	340	280
70	58	615	590	570	550	520	490	440	390	340
75	61	660	635	620	600	575	535	490	440	390

V = Design Speed of Highway (mph)
V_a = Average Running Speed of Highway (mph)
V_N = Design Speed of Exit Curve (mph)
V'_a = Average Running Speed of Exit Curve (mph)

A Parallel Type



B Taper Type



Source: *A Policy on Geometric Design of Highways and Streets,* AASHTO, 2004. Chapter 10 Grade Separations and Interchanges

Deceleration lanes are measured from the point where the lane reaches 12 feet wide to the painted nose for parallel-type and the first controlling curve for taper-type ramps. Greater distances should be provided if practical. If the deceleration lane is on a grade of 3% or more, the length of the lane should be adjusted according to the criteria in Exhibit 7-15.

7.6.1.3 Superelevation

The superelevation at an exit ramp must be developed to transition the driver properly from the mainline to the curvature at the exit. The principles of superelevation for open highways, as discussed in Chapter 4, should be applied to the exit design with the following criteria applied:

- The maximum superelevation rate in Massachusetts is 6.0 percent.
- Preferably, full superelevation is achieved at the PCC at the gore nose. However, this is subject to the minimum longitudinal slopes described in Chapter 4.
- The paved portion of the gore is normally sloped at 3.0%.

7.6.1.4 Gore Area

The gore area is normally considered to be both the paved triangular area between the through lane and the exit lane and the unpaved graded area which extends downstream beyond the gore nose. The following should be considered when designing the gore:

- Signing in advance of the exit and at the divergence should be in accordance with the *Manual on Uniform Traffic Control Devices (MUTCD)*. This also applies to the pavement markings in the triangular area upstream from the gore nose.
- If possible, the area beyond the gore nose should be free of signs and luminaire supports. If they must be present, they must be yielding or breakaway, or shielded by guardrail or impact attenuators.
- The graded area beyond the gore nose should be as flat as possible. If the difference in elevation between the exit ramp or loop and the mainline increases rapidly, this may not be possible. These areas will likely be non-traversable and the gore design must shield these areas from the driver. Often, the vertical divergence of the ramp and mainline will warrant protection for both roadways beyond the gore.

7.6.2 Entrance Ramps

Entrance ramps are one-way roadways which allow traffic to enter a freeway. Design considerations for entrance ramps are described below.

7.6.2.1 Sight Distance

Decision sight distance should be provided for drivers on the entrance ramp and on the mainline approaching an entrance terminal. Drivers on the mainline need sufficient distance to see the merging traffic so that they can adjust their speed or change lanes to allow the merging traffic to enter the freeway. Likewise, drivers on the entrance ramp need to see a sufficient distance upstream from the entrance to locate the gaps in the traffic stream within which to merge. When measuring decision sight distance for entrance ramps, use 3.5 feet as the height of eye and objects.

7.6.2.2 Acceleration Lanes

A properly-designed acceleration lane will facilitate driver comfort, traffic operations, and safety. Exhibit 7-30 at the end of this chapter illustrates the MassHighway standard designs for entrance ramps. The length of the acceleration lane will primarily depend upon the design speed of the last (or controlling) curve on the entrance ramp and the design speed of the mainline.

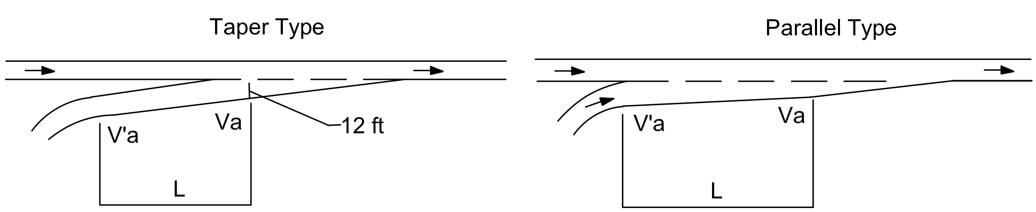
Exhibit 7-14 provides the data for minimum lengths of acceleration lanes. These lengths are for the full width of the acceleration lane, and are measured from the end of the painted nose for parallel-type, and from the end of the last controlling curve on taper-type ramp junctions, to a point where the full 12-foot lane width terminates. Taper lengths, typically 300 feet, are in addition to the acceleration lane lengths. If the acceleration lane is on a grade of 3% or more, the length of the lane should be adjusted according to the criteria in Exhibit 7-15.

The values in Exhibit 7-14 provide sufficient distance for vehicle acceleration; however, they may not safely allow a vehicle to merge into the mainline if traffic volumes are high. Where the mainline and ramp will carry traffic volumes approaching the design capacity of the merging area, the acceleration lane length should be extended by 200 feet or more.

Exhibit 7-14
Minimum Acceleration Lengths for Entrance Terminals with Flat Grades of 2% or Less

		Acceleration Length L (ft) for Entrance Curve Design Speed (mph)								
		Stop Condition	15	20	25	30	35	40	45	50
Highway Design Speed	Highway Speed Reached,	and Initial Speed V'a (mph)								
V (mph)	V*a* (mph)	0	14	18	22	26	30	36	40	44
30	28	180	140	—	—	—	—	—	—	—
35	32	280	220	160	—	—	—	—	—	—
40	36	360	300	270	210	120	—	—	—	—
45	40	560	490	440	380	280	160	—	—	—
50	44	720	660	610	550	450	350	130	—	—
55	48	960	900	810	780	670	550	320	150	—
60	52	1200	1140	1100	1020	910	800	550	420	180
65	55	1410	1350	1310	1220	1120	1000	770	600	370
70	58	1620	1560	1520	1420	1350	1230	1000	820	580
75	61	1790	1730	1630	1580	1510	1420	1160	1040	780

Note: Uniform 50:1 to 70:1 tapers are recommended where lengths of acceleration lanes exceed 1,300 feet.



Source: *A Policy on Geometric Design of Highways and Streets,* AASHTO, 2004. Chapter 10 Grade Separations and Interchanges

Exhibit 7-15
Speed Change Lane Adjustment Factors as a Function of Grade

Design Speed of Highway (mph)	Deceleration Lanes — Ratio of Length on Grade to Length on Level for Design Speed of Turning Curve (mph)	
	All Exit Curve Design Speeds	
All Speeds	3 to 4% Upgrade = 0.9 5 to 6% Upgrade = 0.8	3 to 4% Downgrade = 1.2 5 to 6% Downgrade = 1.35

Design Speed of Highway (mph)	Acceleration Lanes — Ratio of Length on Grade to Length on Level for Design Speed of Turning Curve (mph)				
	20	30	40	50	All Speeds
3 to 4% Upgrade					*3 to 4% Downgrade*
40	1.3	1.3	—	—	0.7
45	1.3	1.35	—	—	0.675
50	1.3	1.4	1.4	—	0.65
55	1.35	1.45	1.45	—	0.625
60	1.4	1.5	1.5	1.6	0.6
65	1.45	1.55	1.6	1.7	0.6
70	1.5	1.6	1.7	1.8	0.6
5 to 6% Upgrade					*5 to 6% Downgrade*
40	1.5	1.5	—	—	0.6
45	1.5	1.6	—	—	0.575
50	1.5	1.7	1.9	—	0.55
55	1.6	1.8	2.05	—	0.525
60	1.7	1.9	2.2	2.5	0.5
65	1.85	2.05	2.4	2.75	0.5
70	2.0	2.2	2.6	3.0	0.5

Note: Ratio from this table multiplied by the length in Exhibit 7-13 or 7-14 gives length of speed change lane on grade.
Source: *A Policy on Geometric Design of Highways and Streets,* AASHTO, 2004. Chapter 10 Grade Separations and Interchanges

7.6.2.3 Superelevation

Ramp superelevation should be gradually transitioned to meet the normal cross slope of the mainline. The principles of superelevation for open highways, as discussed in Chapter 4, should be applied to the entrance design with the following criteria applied:

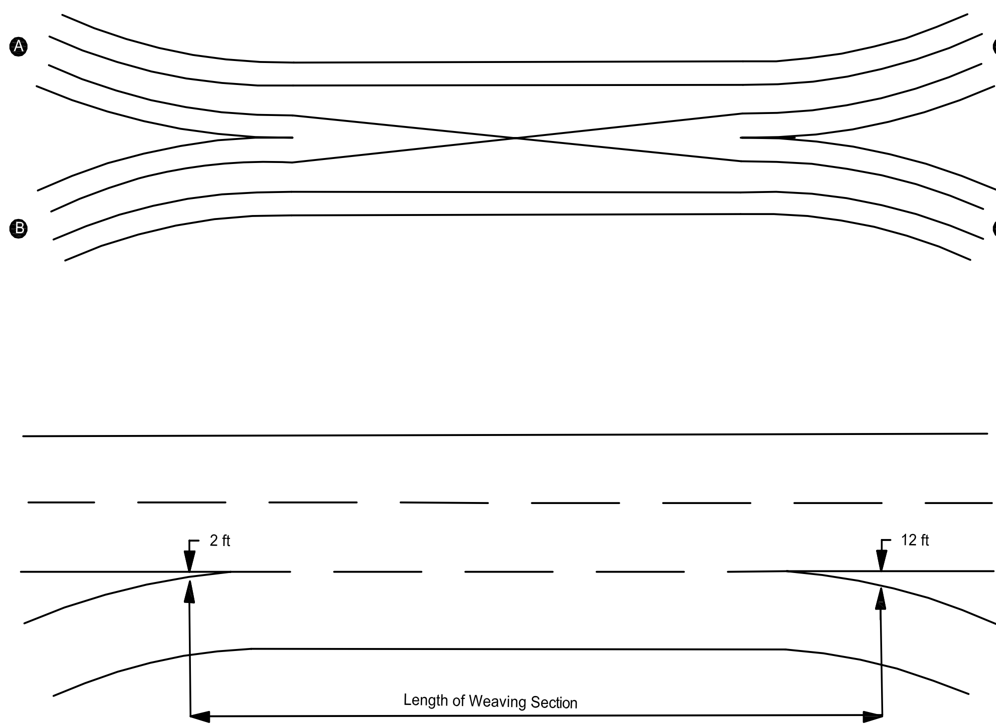
- The maximum superelevation rate in Massachusetts is 6.0 percent.

- Preferably, the cross slope of the acceleration lane will equal the cross slope of the adjacent through lane at the PT of the flat horizontal curve near the entrance gore.
- The superelevation transition should not exceed the minimum longitudinal slopes provided in Chapter 4.

7.6.3 Weaving Areas

Weaving occurs where one-way traffic streams cross by merging and diverging maneuvers. This frequently occurs within an interchange or between two closely spaced interchanges. Exhibit 7-16 illustrates a simple weave diagram and the length over which a weaving distance is measured.

Exhibit 7-16
Weaving Areas



Source: Highway Capacity Manual, TRB, 2000. Chapter 13 Freeway Concepts

The capacity and level of service calculations are made from the methodology presented in the *Highway Capacity Manual*. The methodology determines the needed length on the weaving section to accommodate the predicted traffic conditions, including the weaving and non-weaving volumes and the average running speed of those volumes. Important elements to be considered in this analysis are as follows:

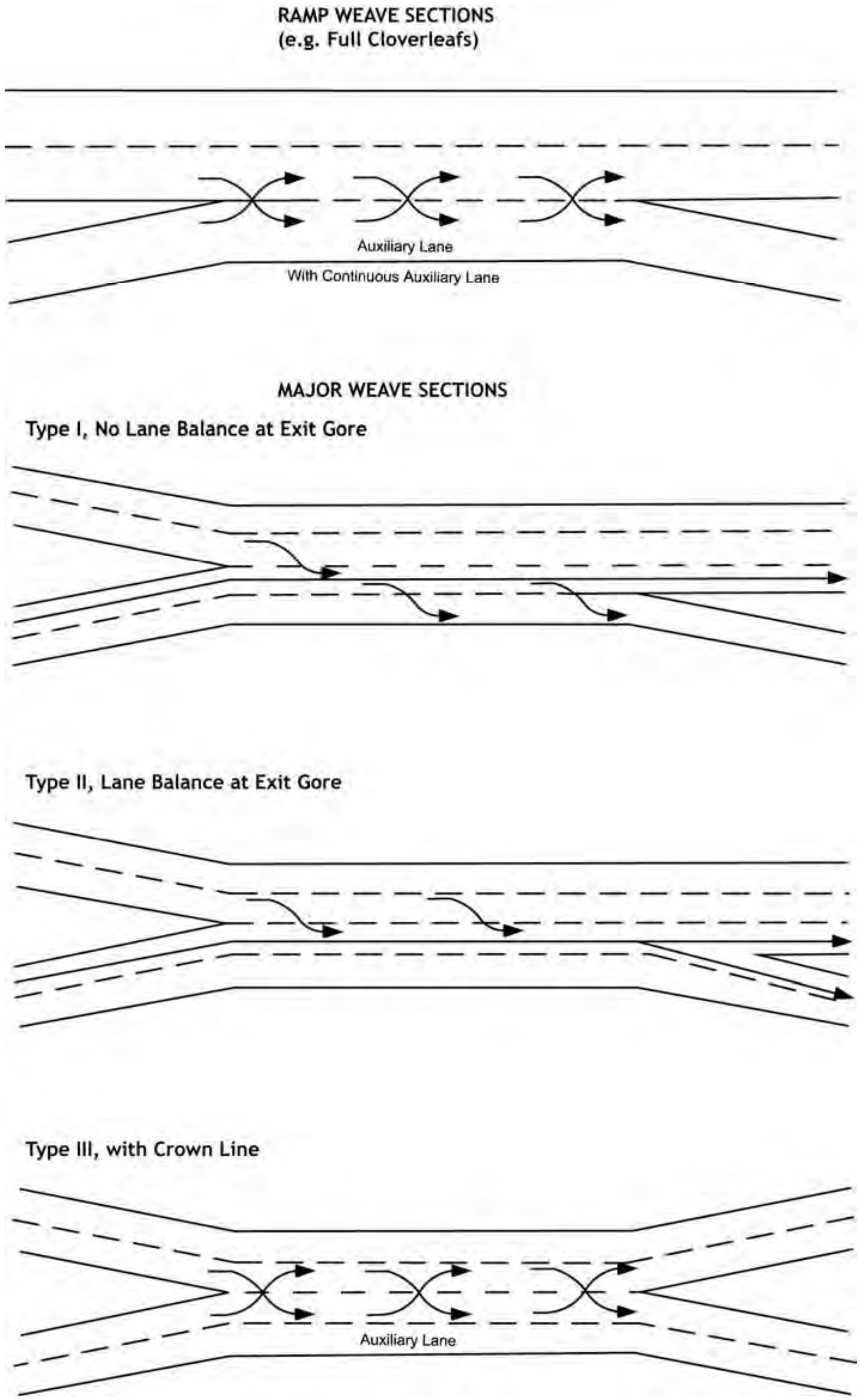
- The number of lanes in the weaving areas;
- The configuration of the section in terms of lane balance (i.e., the adding and dropping of auxiliary lanes);
- The level of service (preferably, it will be the same as the mainline; it should not be more than one level below the mainline); and
- The speed of weaving vehicles should be within 5 mph of non-weaving vehicles to provide acceptable operation.

Exhibit 7-17 illustrates a ramp-weave section and three major-weave sections. The ramp weave section occurs in cloverleaf interchanges where a freeway entrance from an inner loop is immediately followed by an exit onto an inner loop. The entrance and exit are joined by a continuous auxiliary lane. This weaving configuration is complicated because all weaving vehicles are involved in a ramp movement which usually requires reduced speeds due to restrictive geometry. Therefore, three vehicle operations are occurring simultaneously — weaving, acceleration, and deceleration. The methodology in the *Highway Capacity Manual* should be used to determine the needed length for this section.

Exhibit 7-30 at the end of this chapter illustrates the design details for the interior of a clover leaf interchange and provides the minimum distance between the entrance and exit loops within the interchange area. If the weave area is on a freeway, or if the site conditions will not allow the necessary distance, a collector-distributor road should be provided.

Major-weave sections differ from the ramp-weave in that multiple lanes are involved and the geometry allows weaving speeds approximately equal to the speed on the open freeway. The Type 1 weave shown in Exhibit 7-17 is undesirable because of the lack of lane balance. The *Highway Capacity Manual* provides the methodologies for computing the length, capacity and level of service for weaving sections. Regardless of the calculations from the *Highway Capacity Manual*, the minimum desirable length of major-weave section is 1,100 feet.

Exhibit 7-17
Weaving Configuration



Note: The Type I major weave should not be used because of its lack of lane balance at exit gore.
Source: Highway Capacity Manual, TRB, 2000. Chapter 13 Freeway Concepts

7.6.4 Capacity and Level of Service

The capacity and level of service for freeway exits and entrances should be computed using the procedures in the *Highway Capacity Manual*. Those factors which will affect the calculations of traffic operation conditions at freeway/ramp junctions are:

- Acceleration and deceleration distances;
- Number of lanes;
- Type of terrain or grade conditions;
- Merge and diverge volumes; and
- Freeway volumes.

The methodology in the *Highway Capacity Manual* will allow the analysis of isolated ramps or of ramps in association with another ramp upstream or downstream.

Exhibit 7-18 illustrates several of the configurations which can be analyzed using the *Highway Capacity Manual* procedures. Exhibit 7-18 shows volumes which can be accommodated at a ramp junction for a given level of service.

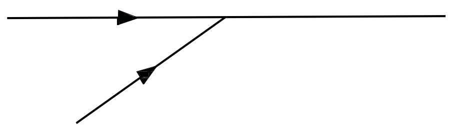
7.6.5 Major Forks and Branch Connections

Major forks are where a freeway separates into two distinct freeways. The design of major forks is subject to the same principles of lane balance as any other diverging area. The total number of lanes in the two roadways beyond the divergence should exceed the number of lanes approaching the diverging area by at least one. Exhibit 7-19 illustrates three schematics for a major fork. It is important that one interior lane has an option to go in either direction. This interior lane should be widened over a distance of about 1,000 to 1,800 feet.

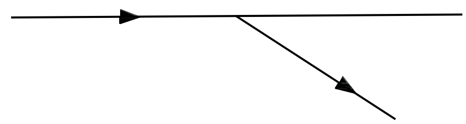
Branch connections are where two freeways converge into one freeway. Exhibit 7-20 illustrates two schematics for a branch connection. When a lane is dropped, as in "B," this should be designed as a freeway lane drop (see Exhibit 7-11) from the outside, not through merging interior lanes.

Exhibit 7-18
Capacity of Ramp Configurations

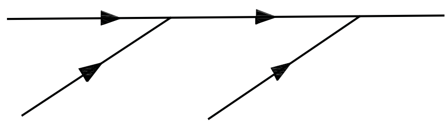
A Isolated On-Ramp



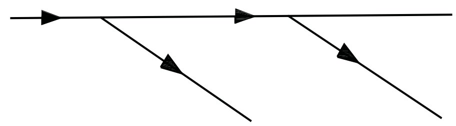
B Isolated Off-Ramp



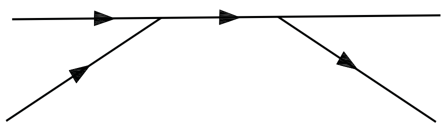
C Adjacent On-Ramps



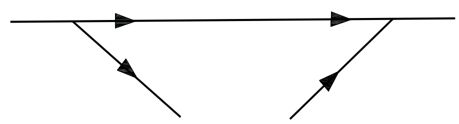
D Adjacent Off-Ramps



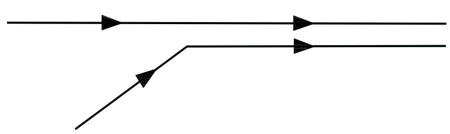
E On-Ramp Followed by Off-Ramp
(No Auxiliary Lane)



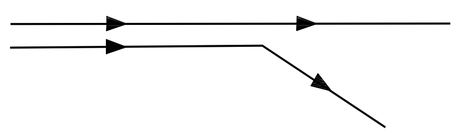
F Off-Ramp Followed by On-Ramp
(No Auxiliary Lane)



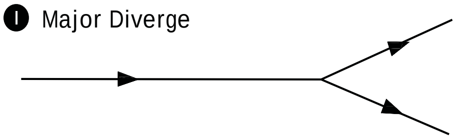
G Lane Addition



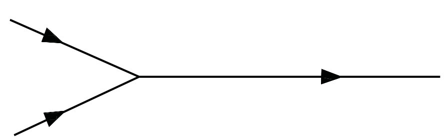
H Lane Drop



I Major Diverge



J Major Merge



Source: Highway Capacity Manual, TRB, 2000. Chapter 13 Freeway Concepts

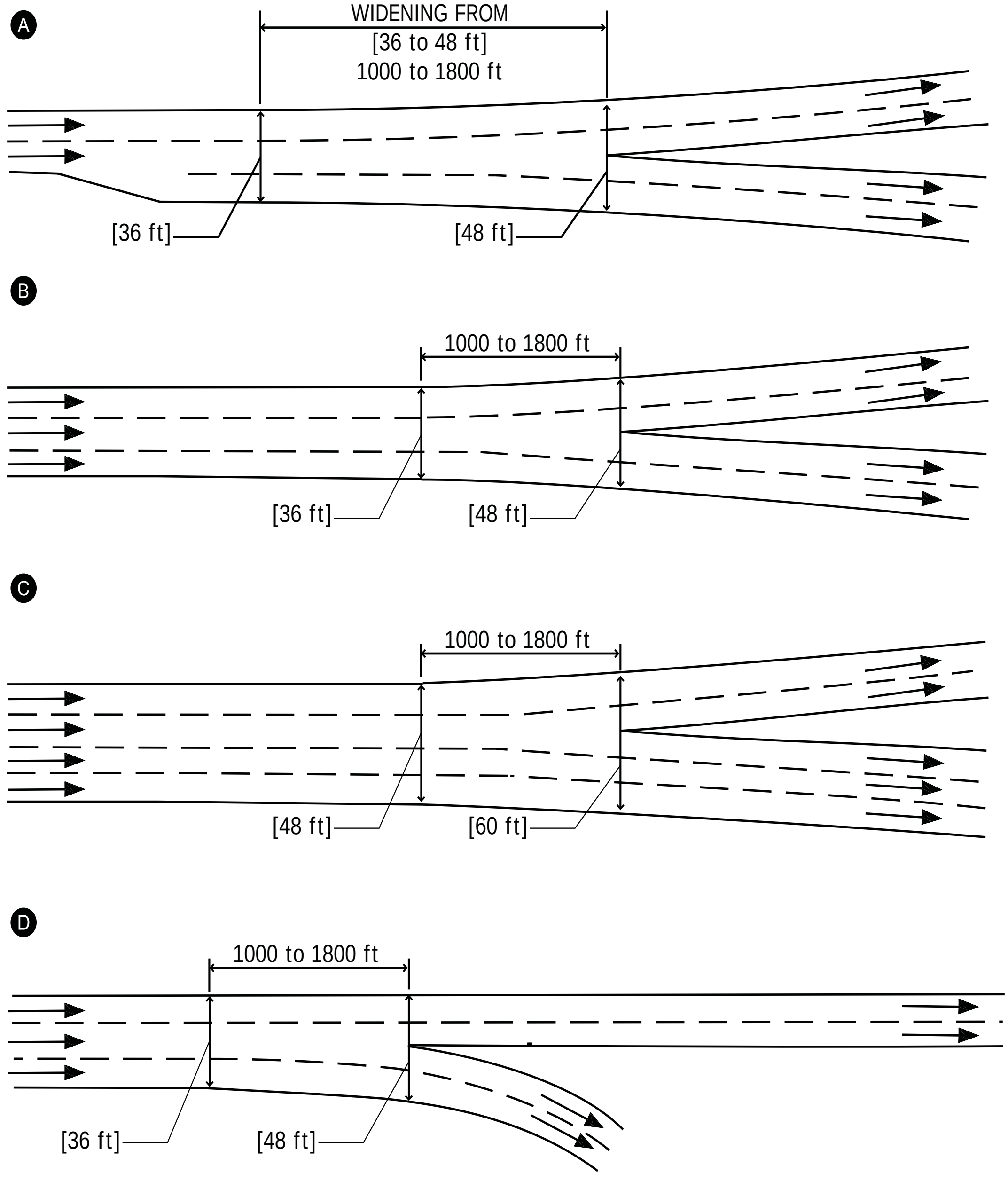
Exhibit 7-18
Capacity of Ramp Configurations (Continued)

Level-of-Service Criteria for Checkpoint Flow Rates at Ramp-Freeway Terminals

Level of Service	Merge Flow Rate (PCPH) Vm[a]	Diverge Flow Rate (PCPH) Vd[b]	Freeway Flow Rates (PCPH) [c]								
			70 mph Design Speed			60 mph Design Speed			50 mph Design Speed		
			4-lane	6-lane	8-lane	4-lane	6-lane	8-lane	4-lane	6-lane	8-lane
A	<600	<650	<1,400	<2,100	<2,800	(d)	(d)	(d)	(d)	(d)	(d)
B	<1,000	<1,050	<2,200	<3,300	<4,400	<2,000	<3,000	<4,000	(d)	(d)	(d)
C	<1,450	<1,500	<3,100	<4,650	<6,200	<2,800	<4,200	<5,600	<2,600	<3,900	<5,200
D	<1,750	<1,800	<3,700	<5,550	<7,400	<3,400	<5,100	<6,800	<3,200	<4,800	<6,400
E	<2,000	<2,000	<4,000	<6,000	<8,000	<4,000	<6,000	<8,000	<3,800	<5,700	<7,600
F	— Widely Variable —										

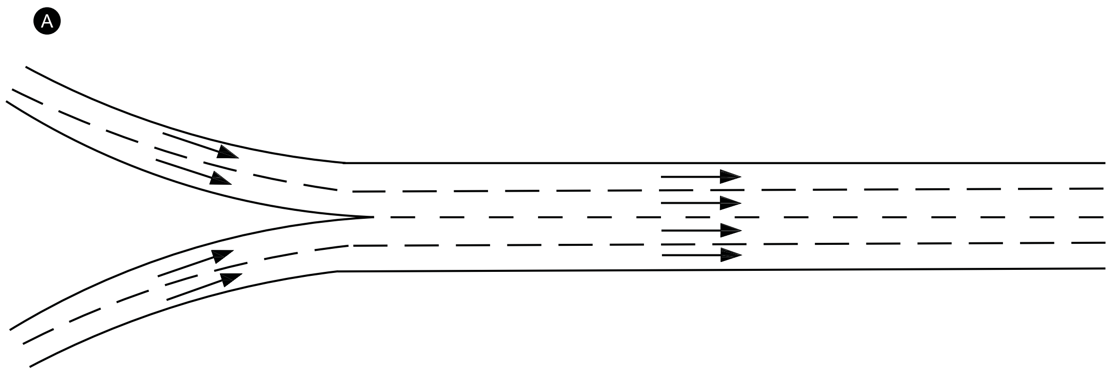
(a) Lane 1 flow rate plus ramp flow rate for one-lane, right-side on ramps.
(b) Lane 1 flow rate immediately upstream of off-ramp for one-lane, right-side ramps.
(c) Total freeway flow rate in one direction upstream of off-ramp and/or downstream of on-ramp.
(d) Level of service not attainable due to design speed restrictions.
Source: Adapted from Highway Capacity Manual, TRB, 2000. Chapter 13 Freeway Concepts

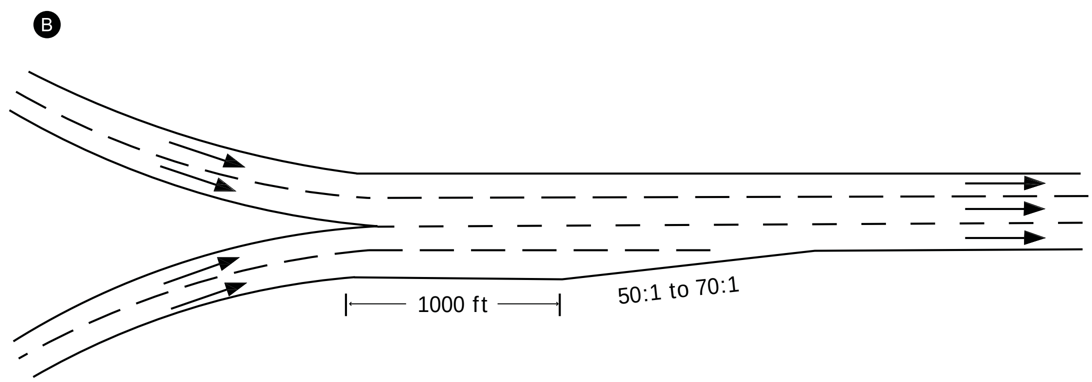
Exhibit 7-19
Major Forks



Source: *A Policy on Geometric Design of Highways and Streets,* AASHTO, 2004. Chapter 10 Grade Separations and Interchanges

Exhibit 7-20
Branch Connections





Source: *A Policy on Geometric Design of Highways and Streets,* AASHTO, 2004. Chapter 10 Grade Separations and Interchanges

7.7 Ramp Design

The term "ramp" includes all types, arrangements, and sizes of turning roadways that connect two or more legs at an interchange. Ramp design should be compatible with safe operations on both the main highway and minor roadway and should accommodate the full transition in driving behavior. Location of ramps and intersections must consider adjacent intersections, existing, and future development.

7.7.1 Geometric Design

Geometric design considerations for ramps include all of the elements for mainline segments. Specific elements to be considered are described below.

7.7.1.1 Design Speed

Ideally, the ramp design speeds should approximate the low-volume operating speed on the intersecting highways. Where this is not practical, the values in Exhibit 7-21 should be used as the minimum design speed. These design speeds apply to the ramp proper and not to the freeway/ramp junction.

If the two intersecting mainlines have different design speeds, the higher of the two should control in selecting the design speed for the ramp as a whole. However the design speed should vary along the ramp, with the portion of the ramp nearer the lower speed highway being designed for the lower speed.

In general, the higher range of design speeds should apply to diagonal ramps for right turns, such as at diamond and cloverleaf interchanges. The low end of the range should apply to loop ramps. Loop ramps with design speeds above 30 miles/hour require extremely large areas and greatly increase the travel distance for vehicles.

If a ramp will be terminating at an at-grade intersection with stop or signal control, the design speeds in Exhibit 7-21 will not apply to the ramp portion near the intersection.

Exhibit 7-21
Guide Values For Design Speed based on Highway Design Speed

	Highway Design Speed (mph)									
	30	35	40	45	50	55	60	65	70	75
Ramp Design Speed (mph)										
Upper Range (85%)	25	30	35	40	45	48	50	55	60	65
Middle Range (70%)	20	25	30	33	35	40	45	45	50	55
Lower Range (50%)	15	18	20	23	25	28	30	30	35	40
Corresponding Minimum Radius (ft)	235	340	485	645	835	1060	1330	1660	2040	2500

Source: *A Policy on Geometric Design of Highways and Streets,* AASHTO, 2004. Chapter 10 Grade Separations and Interchanges

7.7.1.2 Cross Section

Exhibits 7-22 and 7-23 illustrate typical ramp sections as summarized below:

- **Ramp Width** – The typical width is 22 feet for one-lane ramps and 30 feet for two-lane ramps.

- **Cross Slope** – Tangent sections of ramps should be uniformly sloped at 2.0% from the median edge to the opposite edge. MassHighway of has established the maximum superelevation rate at 6.0%.

- **Side Slopes** – Fill and cut slopes should be as flat as possible. If feasible, they should be 1:6 or flatter, thus eliminating the need for guardrail.

- **Bridges and Underpasses** – The full width of the ramp or loop should be carried over a bridge or beneath an underpass.

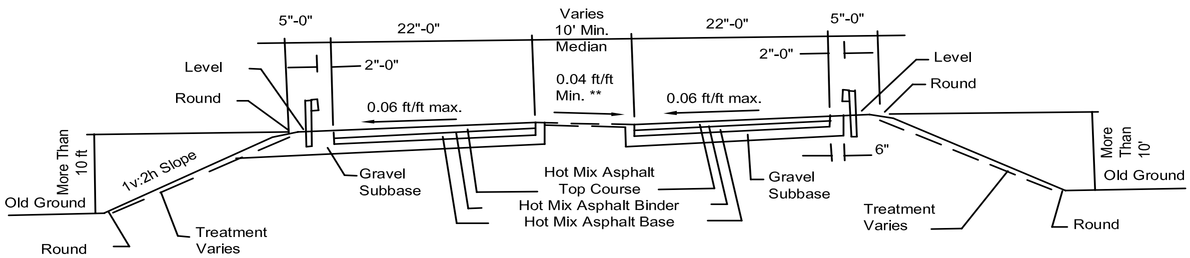
- **Lateral Clearances to Obstructions (Clear Zones)** – Clear zone widths vary from 6-10 feet at 40 mph to 40-50 feet at 70 mph. The slope of the recovery area and traffic volume also plays a role in the selection of the width of the clear zone. (See *AASHTO Roadside Design Guide* as a guide for determining clear zone widths for highway ramps.) Ramps should have a lateral clearance on the right outside of the edge of traveled way of at least 6 feet and preferably 8 to 10 feet, and a lateral clearance on the left of at least 4 feet beyond the edge of the traveled way.

- **Exit Ramp Entrance Width** – Where the through lane and exit ramp diverge, the typical width will be 25 feet. This width will be maintained until the gore nose is reached and transitioned to the standard 22 feet width at approximately a 12:1 rate.

- **Entrance Ramp Terminal Width** – The standard 22 feet width will be transitioned to 14 feet width at the convergence with the through lane as shown in the Exhibits 7-30 at the end of this chapter.

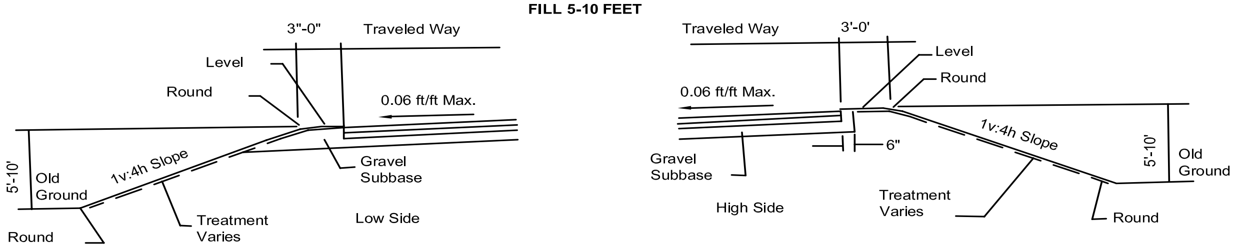
Exhibit 7-22
Typical Sections for Ramps in Fill Areas

FILL MORE THAN 10 FEET

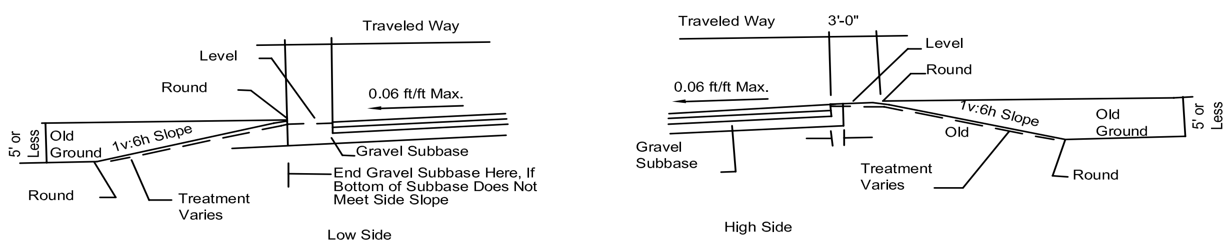


**When the Median is Raised, the Profiles are to be Designed so that the Direction of the Median Cross Slope Pitch Will be Opposite to that of the Traveled Way.

FILL 5-10 FEET



FILL 5 FEET OR LESS



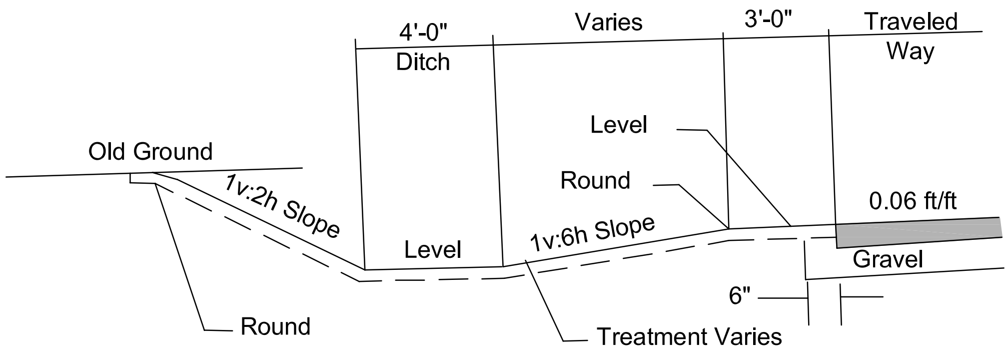
Source: MassHighway

Notes:

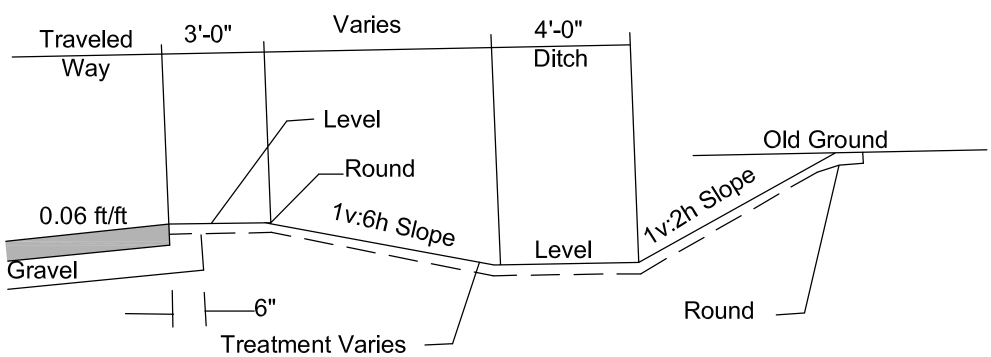
1 The ramp pavement structure will be similar to the mainline unless otherwise noted.
2 See Construction Standards for rounding details.
3 Use hot mix asphalt berm if otherwise required for drainage.

Exhibit 7-23

Ramp Section in Cut Areas



Low Side



High Side

Source: MassHighway

Notes:
1 The ramp pavement structure will be similar to the mainline unless otherwise noted.
2 See Construction Standards for rounding details.
3 Use hot mix asphalt berm if otherwise required for drainage.
4 See Construction Standards for typical rock cut section.
5 Bottom of ditch to be below bottom of subbase, or provide subdrain

7.7.1.3 Horizontal Alignment

Horizontal alignment will largely be determined by the design speed and type of ramp as shown in Exhibit 7-24 and summarized below.

- **Design Speed** – Ramps should be designed for minimum speeds indicated in Exhibit 7-21 unless restricted by site conditions.
- **Outer Connection** – The outer connection at cloverleaf interchanges should be as directional as possible. However, if site conditions are restrictive, it may be allowed to follow a reverse path alignment around the inner loop.
- **Loops** – Loop ramps should be on a continuously curved alignment in a compound curve arrangement, and should follow AASHTO guidelines for length.
- **Superelevation** – MassHighway has established the maximum superelevation rate at 6.0%. It is preferred that the open highway conditions discussed in Chapter 4 should apply for transitioning to and from the needed superelevation. However, because of the restrictive nature of some ramps, this may not be possible. In addition, if the ramp will be terminated at an at-grade intersection with stop or signal control, it is not appropriate to superelevate curves fully near the terminus. The axis of rotation will be the profile edge.
- **Sight Distance** – Sight distance along a ramp should be at least as great as the design stopping sight distance. There should be a clear view of the entire exit terminal, including the exit nose and a section of the roadway beyond the gore. An object height of 0.0 feet should be used to calculate the stopping sight distance at exit areas.
- **Two-Lane Ramps** – The desirable minimum radius is 1,000 feet. See Exhibit 7-25 for typical two-lane exit treatments.

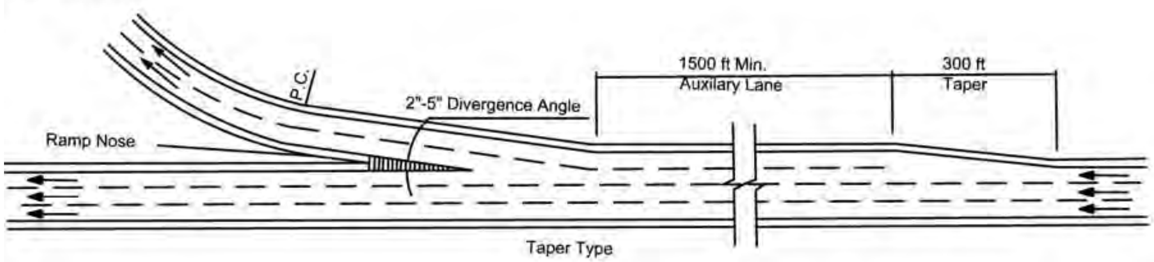
Exhibit 7-24
Minimum Radii for Interchange Ramp Curves

	Design Speed V (mph)							
	10	15	20	25	30	35	40	45
Side Friction Factor, f	0.38	0.32	0.27	0.23	0.20	0.18	0.16	0.15
Assumed Maximum Superelevation, e/100	0.00	0.00	0.02	0.04	0.06	0.06	0.06	0.06
Total e/100 + f	0.38	0.32	0.29	0.27	0.26	0.26	0.25	0.25
Calculated Minimum Radius R, (ft)	18	47	92	154	231	340	485	643
Suggested Design Minimum Radius (ft)	25	50	95	155	235	340	485	645

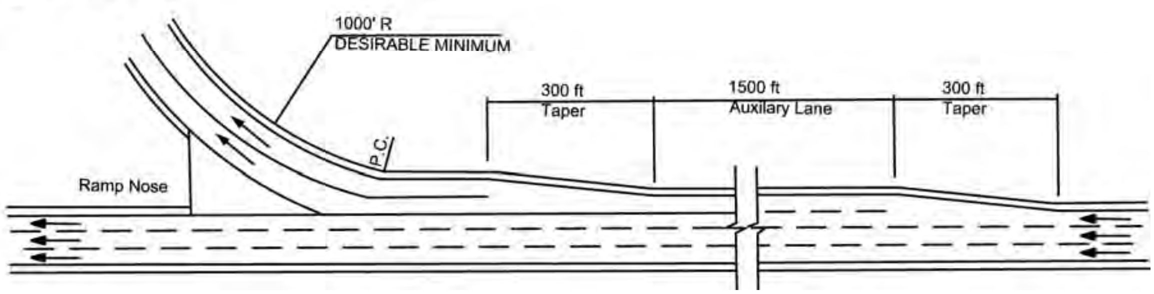
Note: For design speeds greater than 45 mph, use values for open highway conditions
Source: MassHighway

Exhibit 7-25
Two-Lane Exit Terminals

A Taper Type



B Parallel Type



Source: *A Policy on Geometric Design of Highways and Streets,* AASHTO, 2004. Chapter 10 Grade Separations and Interchanges

7.7.1.4 Vertical Alignment

Maximum grades for vertical alignment cannot be as definitively expressed as for highway mainline. The minimum grade is 0.50%. General values of limiting gradient for upgrades are shown in Exhibit 7-26, but for any one ramp the selected gradient is dependent upon a number of factors including:

- The flatter the gradient on the ramp, the longer it will be.
- The steepest gradients should be designed for the center part of the ramp. Landing areas or storage platforms at at-grade intersections with ramps should be as flat as possible.
- Downgrades on ramps should follow the same guidelines as upgrades. They may, however, safely exceed these values by 2 percent, with 8 percent considered the desired maximum grade.
- Ramp gradients and lengths can be significantly impacted by the angle of intersection between the two highways and the direction and amount of gradient on the two mainlines.
- K values and desirable stopping sight distance should meet the minimum design values for vertical curves.

Exhibit 7-26
Ramp Gradient Guidelines

	Ramp Design Speed (mph)			
	20 to 25	25 to 30	30 to 45	45 to 50
Maximum Desirable Grades (%)	6-8	5-7	4-6	3-5

Source: MassHighway

7.7.2 Capacity

Exhibit 7-27 provides the volumes for a given ramp design speed and level of service. Although the exhibit indicates that up to 1,700 passenger car equivalents per hour (pcph) can be accommodated on a single-lane ramp, freeway/ramp junctions are not capable of handling this volume; therefore, 1,500 pcph should be used as a threshold to warrant a two-lane ramp.

Exhibit 7-27
Approximate Service Volumes for Single-lane Ramps

LOS	Ramp Design Speed (mph) ≤ 20	20 - 30	30 - 45	45 - 50	≥50
A	--	--	--	--	700
B	--	--	--	1,000	1050
C	--	--	1,125	1,250	1,300
D	--	1,025	1,200	1,325	1,500
E	1,250	1,450	1,600[1]	1,650[1]	1,700[1]
F	--Widely Variable --				

Source, Highway Capacity Manual, Washington DC 2000
Note: Based on Peak Hour Factor of 1.0, service volumes expressed in passenger cars per hour.
1 For two-Lane Ramps, Multiply Above Values By 1.7 for < 20 mph, 1.8 for 20-30 mph & 45-50 mph, 1.9 for 30-45 mph, and 2.0 for ≥50 mph
-- LOS not achievable due to restricted design speeds

The minimum radius of a two-lane ramp should be 1,000 feet. The capacity of a loop ramp is about 1,250 pcph; however, two-lane loop ramps are very undesirable because of their restrictive geometry. Therefore, if a left-turn movement will exceed 1,250, a directional or semi-directional connection may be needed. Ramps must be designed with sufficient capacity to avoid backups on the main line. The *Highway Capacity Manual* further discusses the capacity of ramps.

7.8 Ramp/Minor Road Intersections

At service interchanges the ramp or loop normally intersects the minor road at-grade at approximately a 90-degree angle. This intersection should be treated as described in Chapter 6. This will involve a consideration of the necessary traffic control devices, capacity, and the physical geometric design elements such as sight distance, angle of intersection, grade, channelization, and turning lanes. However, the following points warrant special attention in the design of the ramp/minor road intersection:

- **Capacity** – In urban areas where traffic volumes may be high, inadequate capacity of the ramp/minor road intersection can adversely affect the operation of the ramp/freeway junction. In a worst case situation the safety and operation of the mainline itself may be impaired by a back-up onto the freeway. Therefore, special attention should be given to providing sufficient capacity and storage for an at-grade intersection with the minor road. This could lead to the addition of lanes at the intersection or on the ramp proper, or it could involve traffic signalization where the ramp traffic will be given priority. The analysis must also consider the operational impacts of the traffic characteristics on the intersecting road and signal timing for pedestrians. The procedures described in Chapter 6 should be used to calculate capacity and level of service for the ramp/minor road intersection.

- **Wrong-Way Movements** – Most wrong-way movements originate at the ramp/minor road intersection. This intersection must be properly signed and designed to minimize the potential for a wrong-way movement.
- **Access Restrictions** – Access to abutting properties or to other local road systems will interfere with the operation and safety of the interchange. Therefore, access must not be permitted from ramps or from the through roadways within the entire limits of the interchange. The no-access layout line should extend a minimum distance of 500 feet from all ramp terminals.
- **Sight Distance** – Chapter 3 discusses the procedure for addressing sight distance at at-grade intersections. This procedure should be used for the ramp/minor road intersection. However, special attention must be given to the location of the bridge pier or abutment because these will present major sight distance obstacles. Methodologies for left-turning and right-turning vehicles presented in Chapter 3 should be used to determine if adequate sight distance is available. The combination of the bridge obstruction and the needed sight distance may result in relocating the ramp/minor road intersection to provide the needed sight distance.
- **Transition** – The transition between high-speed driving on the mainline and safe operating speed on the minor road should take place on the ramps. Ramp and intersection design should require the driver to adopt a safe speed before entering the minor road. Free right-turn and merge is appropriate only when an acceleration taper can be provided, otherwise a full stop is preferred, especially in areas of high pedestrian and bicycle activity. Minor road design should be consistent with adjacent sections.
- **Multimodal Accommodation** – The multimodal accommodation provided on the minor road should be continued through the interchange area. To improve driver response to pedestrian crosswalks and bicycle lanes, 90-degree intersections of ramps

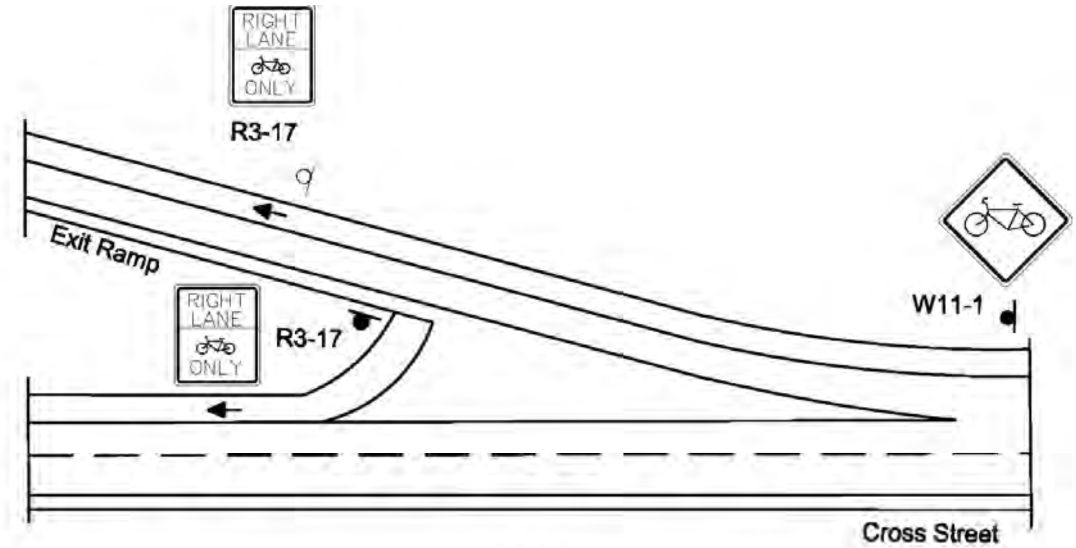
with the minor road are preferable over merge/diverge areas. With 90-degree intersections, the approaches to pedestrian and bicycle accommodation discussed in Chapter 6 are applicable.

In cases where vehicular capacity considerations or existing infrastructure configurations result in merge/diverge areas on the minor road (such as at full cloverleafs), special consideration should be given to the treatment of bicycle lanes as illustrated in Exhibits 7-28 and 7-29. Although full cloverleaf configurations are undesirable in areas with high pedestrian activity, crosswalks should be located so their visibility is maximized for approaching traffic and appropriate warning signs should be provided.

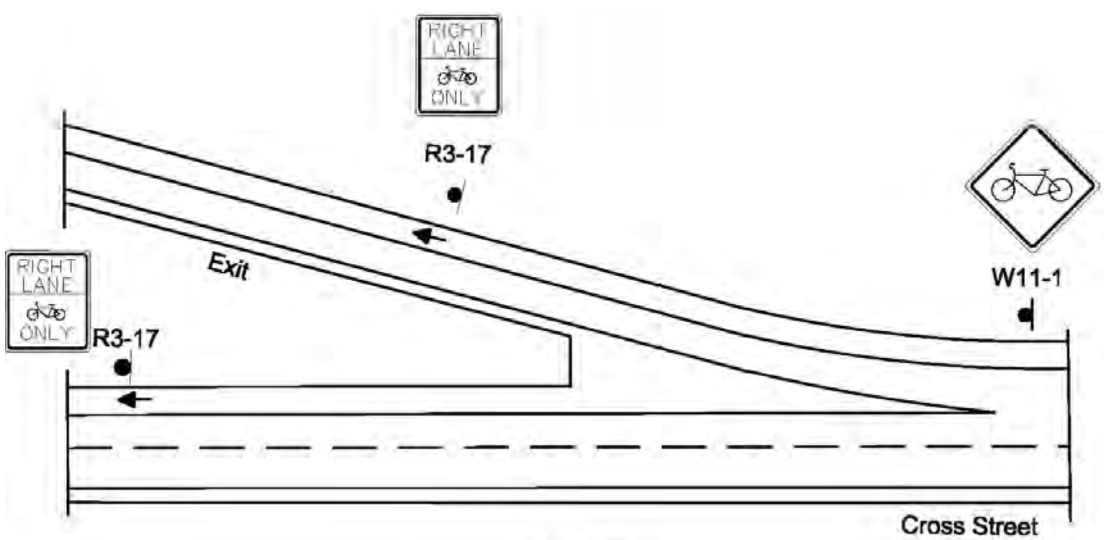
With cloverleaf configurations, the designer needs to accommodate bicycle travel across the merge and diverge areas using the options illustrated in Exhibit 7-28 and 7-29. Considerations for selecting an approach to accommodating bicycle travel through these areas are listed below:

- 90-degree ramp intersections are preferred for bicycle accommodation and should be used in areas with significant bicycle activity when possible.
- Option 1 treatments require a bicyclist to stop before crossing a ramp and are best-suited to high-volume, high speed roadways, where weaving of motor vehicle and bicycle traffic may be hazardous.
- Option 1 may not be feasible where there are substantial grade changes through the interchange gore area.
- Option 2 treatments are suitable in low-speed environments since the cyclist and motor vehicle must weave at the merge and diverge areas.
- Additional advance warning signage and pavement markings can be helpful in accommodating bicycle travel with either of these options.

Exhibit 7-28
Bicycle Lane Crossing of Diverging Ramp



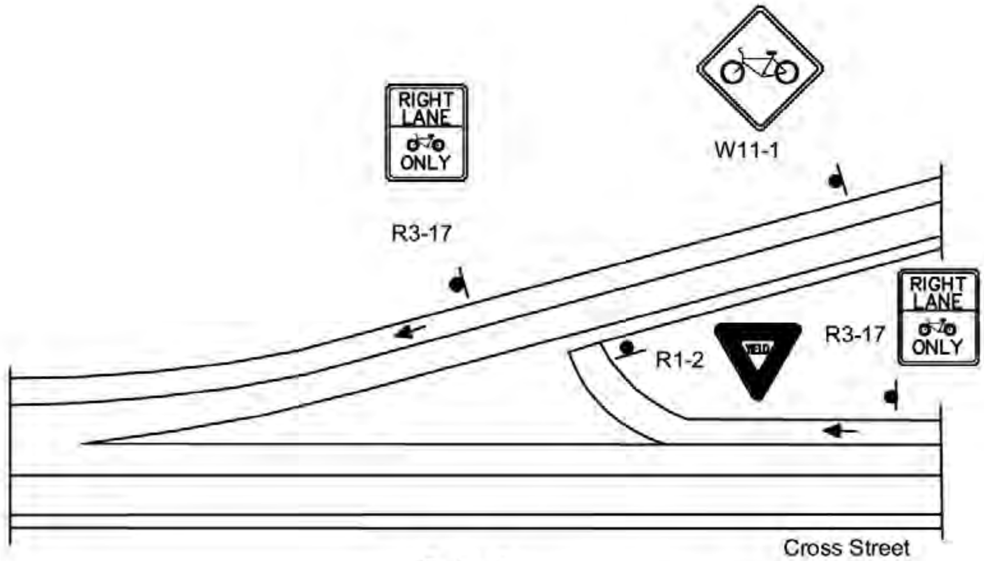
Option 1



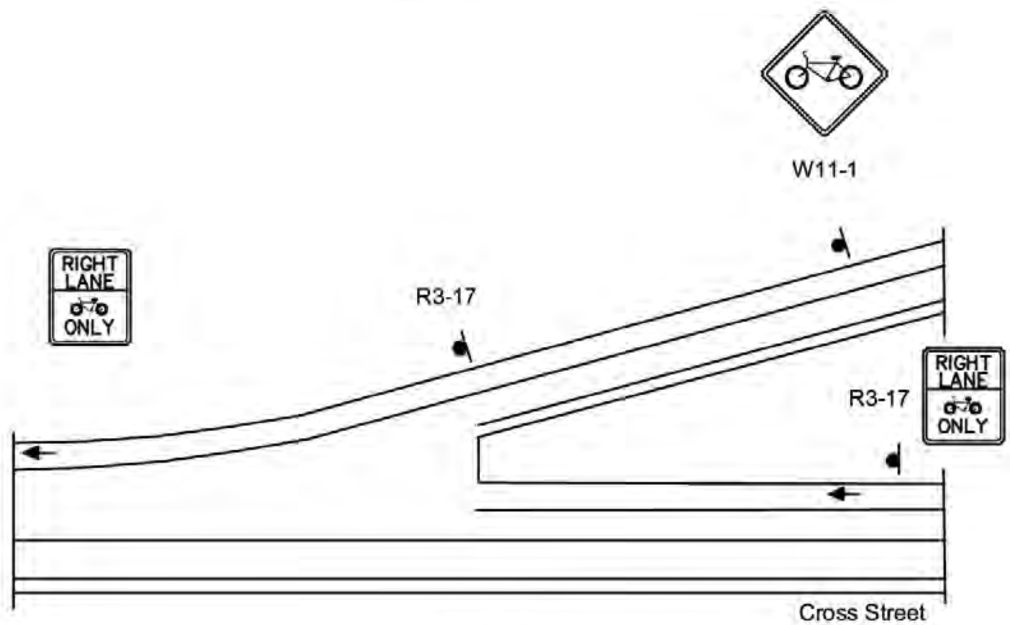
Option 2

Note: All signs and markings, including advance signage and markings, shall conform to the MUTCD. Chapter 3 Pavement Markings
Source: Guide for the Development of Bicycle Facilities, AASHTO, 1999. Chapter 2 Design

Exhibit 7-29
Bicycle Lane Crossing of Merging Ramp



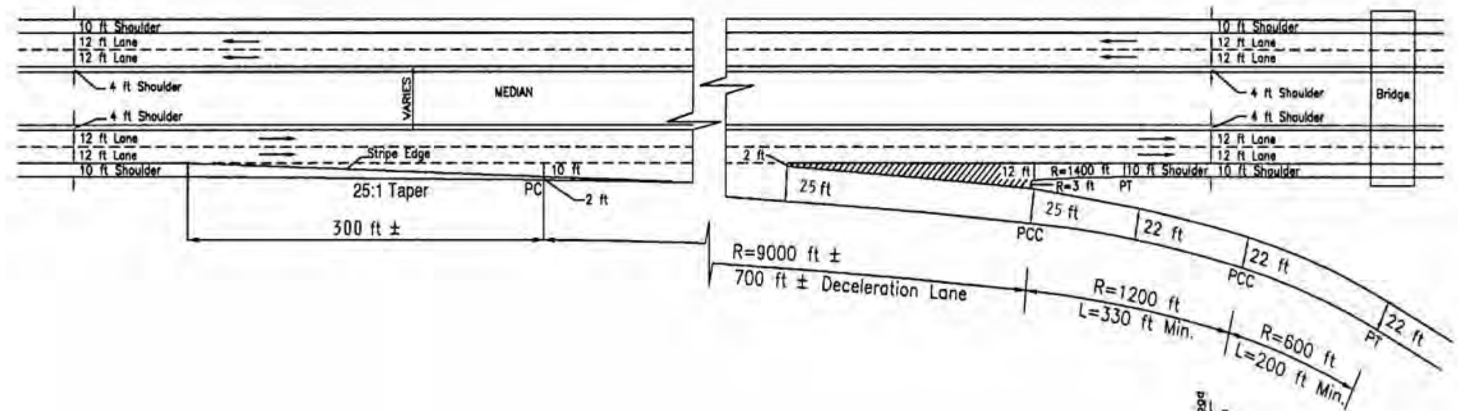
Option 1

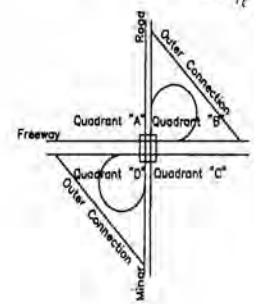


Option 2

Note: All signs and markings, including advance signage and markings, shall conform to the MUTCD.
Source: Guide for the Development of Bicycle Facilities, AASHTO, 1999. Chapter 2 Design

Exhibit 7-30a
Freeway Exit at Interchange (Via Outer Connection of Cloverleaf-Type Ramp)





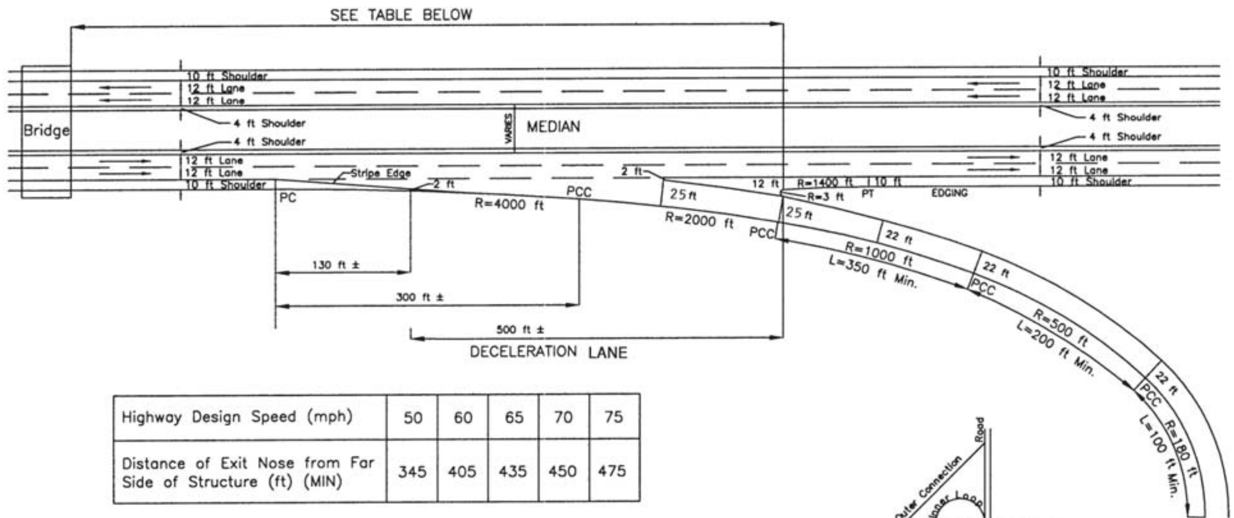
NOTES:

1. When the grade of the freeway is greater than 2%, increase or decrease the deceleration length according to Exhibit 7-15.
2. On the ramp beyond the gore nose, the radius of each successive compound curve should be at least 50% of the radius of the preceding flatter curve.
3. The minimum length of each curve should allow sufficient deceleration distance for the design speed of the following sharper curve
4. The superelevation on the deceleration lane should be developed so that full superelevation (typically 0.06) is attained a the exit gore (PCC of R=1200 ft curve).
5. 4-lane freeway is shown for illustration. This design also applies to freeways with more than 4 lanes.
6. The deceleration distance shown is an example for a specific set of speeds and superelevation. <u>Use Exhibit 7-13 to determine the necessary deceleration distance</u>.

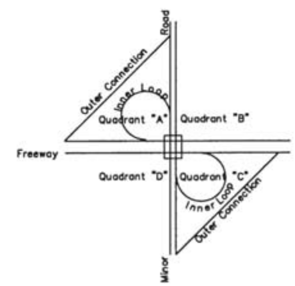
Source: Masshighway

The exit above is applicable to the outer connection in Quadrant “B” and “D”.

Exhibit 7-30b
Freeway Exit at Interchange (Via Inner Loop Connection of Cloverleaf-Type Ramp)



Highway Design Speed (mph)	50	60	65	70	75
Distance of Exit Nose from Far Side of Structure (ft) (MIN)	345	405	435	450	475



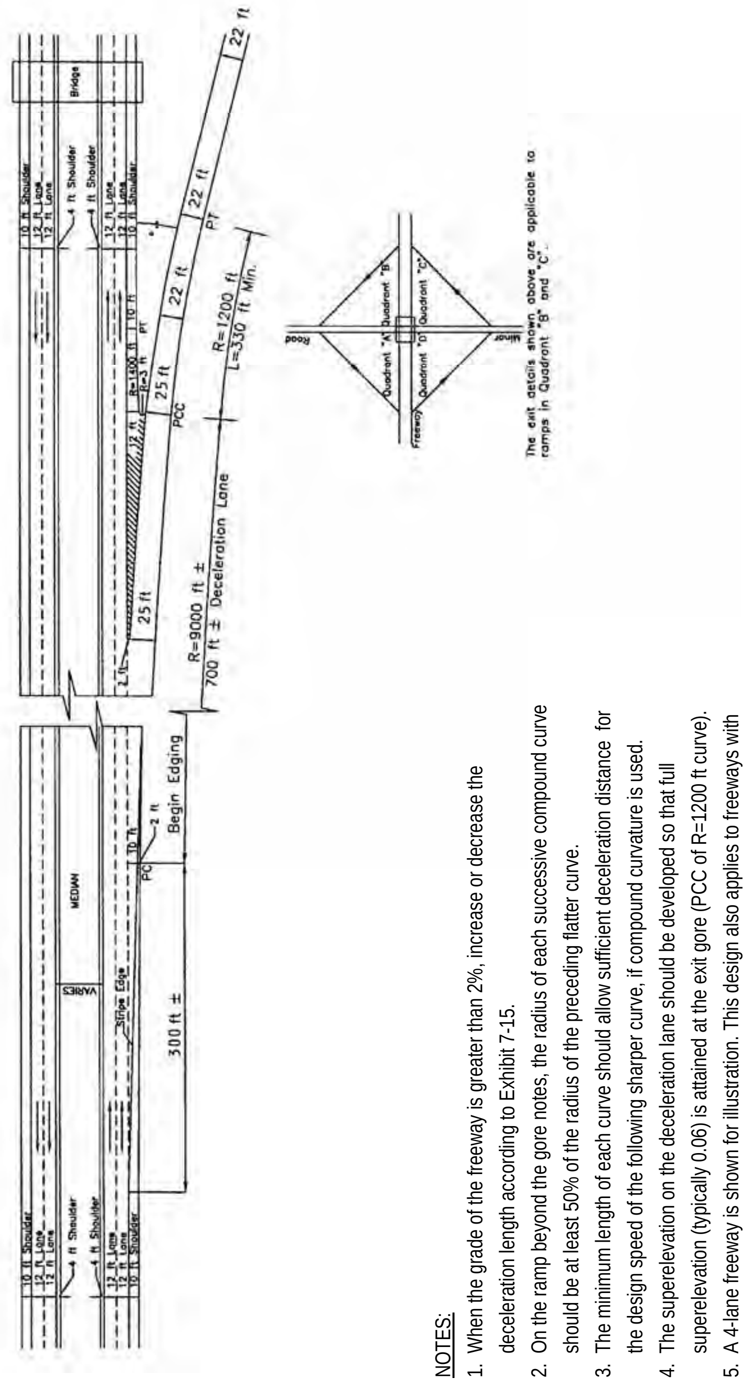
The exit details above are applicable to a ramp in Quadrant “A” when there is no ramp in Quadrant “B” and to a ramp in Quadrant “C” when there is no ramp in Quadrant “D”.

NOTES:

1. When the grade of the freeway is greater than 2%, increase or decrease the acceleration length according to Exhibit 7-15.
2. On the ramp beyond the gore notes, the radius of each successive compound curve should be at least 50% of the radius of the preceding flatter curve.
3. The minimum length of each curve should allow sufficient deceleration distance for the design speed of the following sharper curve, if compound curvature is used.
4. The superelevation on the deceleration lane should be developed so that full superelevation (typically 0.06) is attained a the exit gore (PCC of R=1000 ft curve).
5. 4-lane freeway is shown for illustration. This design also applies to freeways with more than 4 lanes.
6. The deceleration distance shown is an example for a specific set of speeds and superelevation. Use Exhibit 7-13 to determine the necessary deceleration distance.

Source: Masshighway

Exhibit 7-30c
Freeway Exit at Diamond Interchange

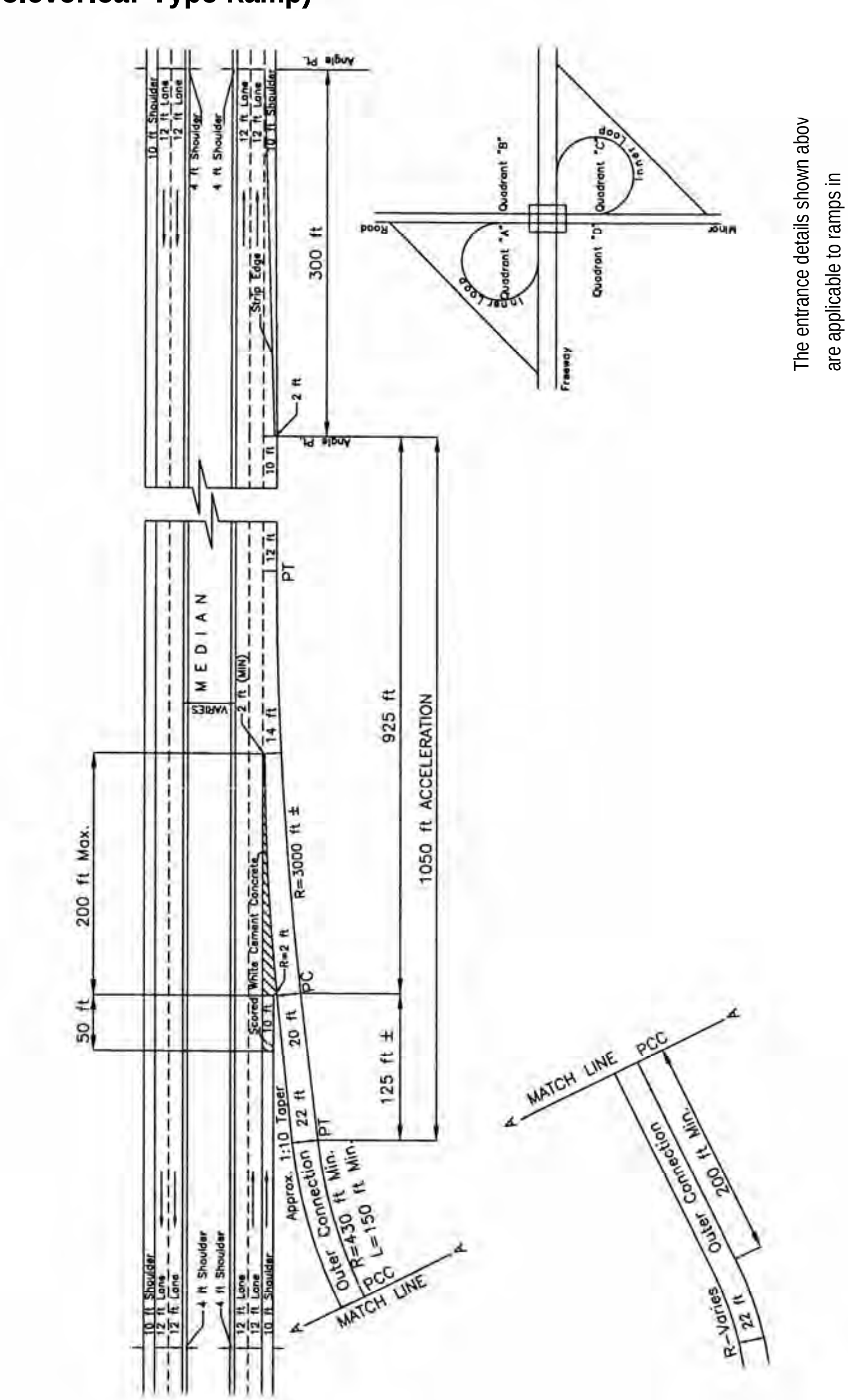


NOTES:

1. When the grade of the freeway is greater than 2%, increase or decrease the deceleration length according to Exhibit 7-15.
2. On the ramp beyond the gore notes, the radius of each successive compound curve should be at least 50% of the radius of the preceding flatter curve.
3. The minimum length of each curve should allow sufficient deceleration distance for the design speed of the following sharper curve, if compound curvature is used.
4. The superelevation on the deceleration lane should be developed so that full superelevation (typically 0.06) is attained at the exit gore (PCC of R=1200 ft curve).
5. A 4-lane freeway is shown for illustration. This design also applies to freeways with more than 4 lanes.
6. The deceleration distance shown is an example for a specific set of speeds and superelevation. Use Exhibit 7-13 to determine the necessary deceleration distance.

Source: MassHighway

Exhibit 7-30d
Freeway Entrance at Interchange (From Outer Connection of Cloverleaf-Type Ramp)



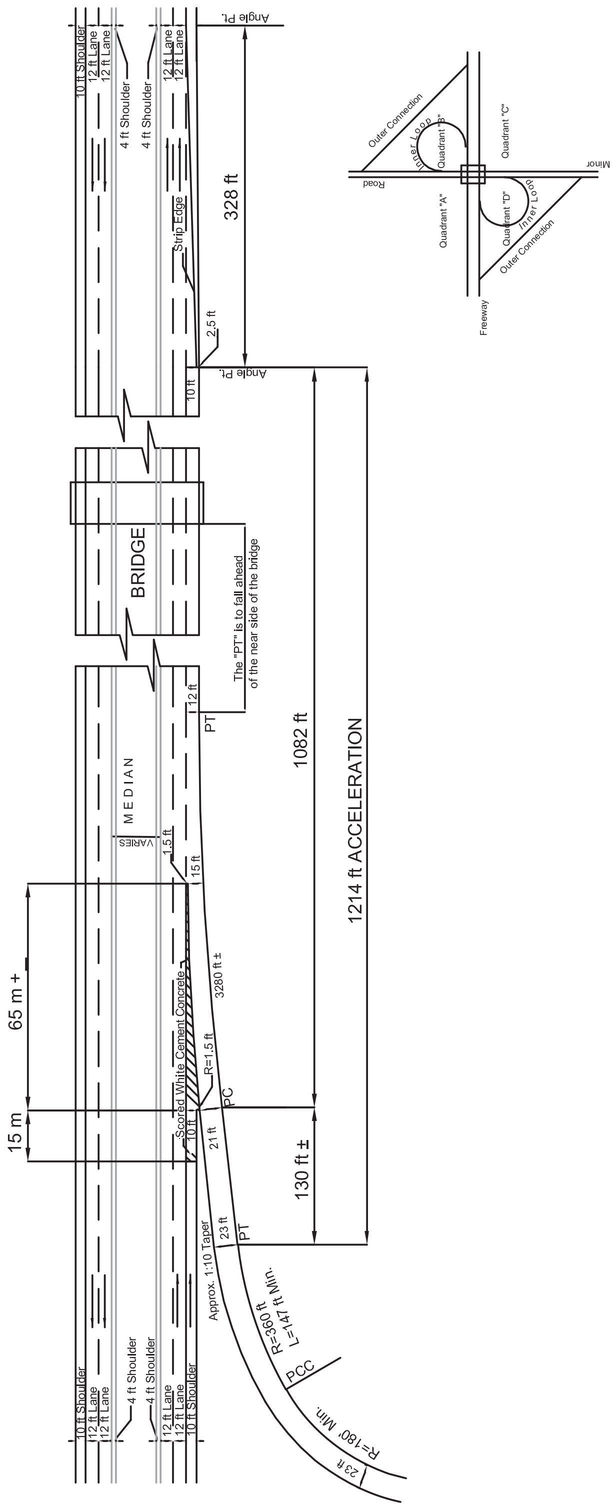
The entrance details shown abov are applicable to ramps in Quadrant "A" and "C".

NOTES:

1. When the grade of the freeway is greater than 2%, increase or decrease the acceleration length according to Exhibit 7-15
2. The method of placing the scored white cement concrete is shown on Construction Standards 105.2.0 and 105.2.1.
3. The acceleration distance shown is an example for a specific set of speeds superelevation. Use Exhibit 7-14 to determine the necessary acceleration length.
4. A 4-lane freeway is shown for illustration. This design also applies to freeways with more than 4 lanes.

Source: Masshighway

Exhibit 7-30e
Freeway Entrance at Interchange (From Inner Connection of Cloverleaf-Type Ramp)



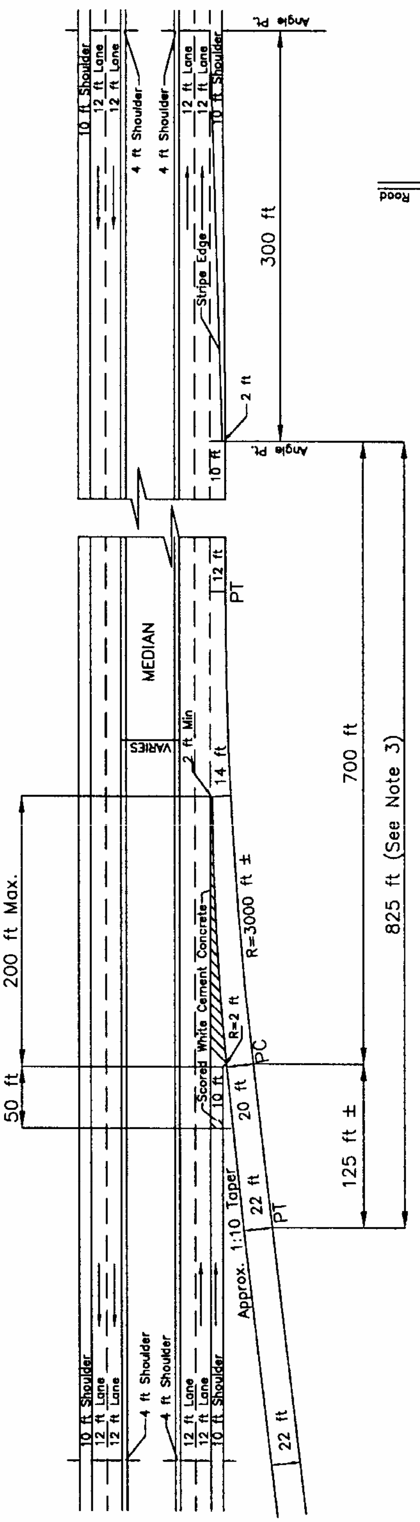
The exit details above are applicable to ramps in Quadrant "B" and "C".

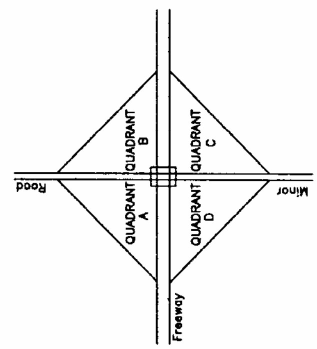
NOTES:

1. When the grade of the freeway is greater than 2%, increase or decrease the acceleration length according to Exhibit 7-15.
2. On the ramp beyond the gore nose, the radius of each successive compound curve should be at least 50% of the radius of the preceding flatter curve.
3. The minimum length of each curve should allow sufficient deceleration distance for the design speed of the following sharper curve, if compound curvature is used.
4. The superelevation on the deceleration lane should be developed so that full superelevation (typically 0.06) is attained a the exit gore (PCC of R=1200 ft curve).
5. A 4-lane freeway is shown for illustration. This design also applies to freeways with more than 4 lanes.

Source: MassHighway

Exhibit 7-30f
Freeway Entrance at Interchange (Diamond-Type Ramp)





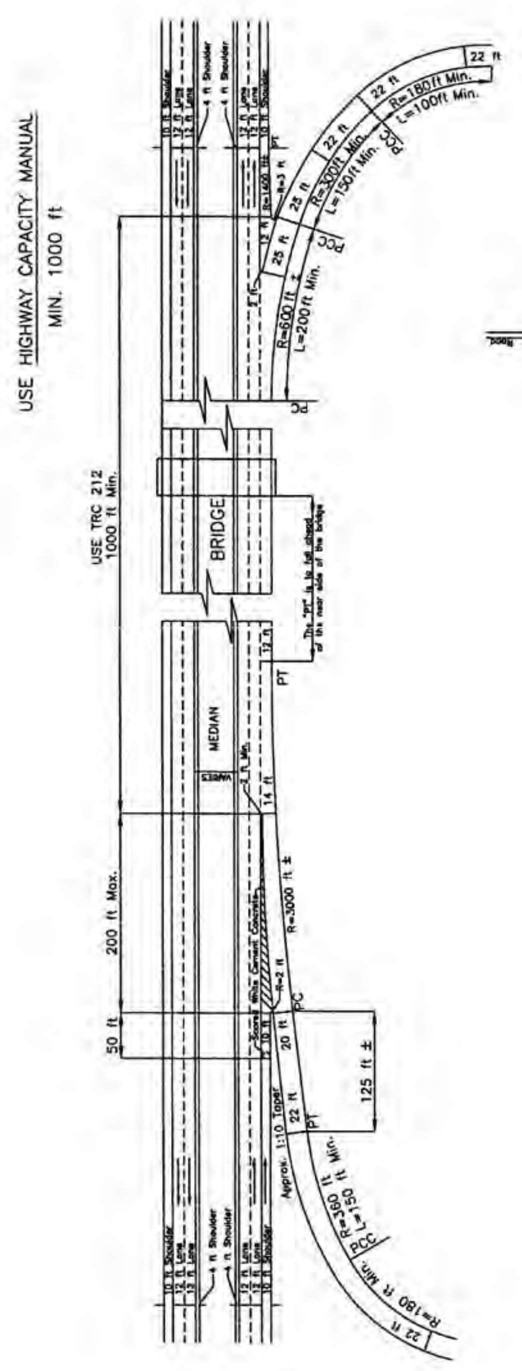
The entrance details shown above are applicable to ramps in Quadrant "A" and "C".

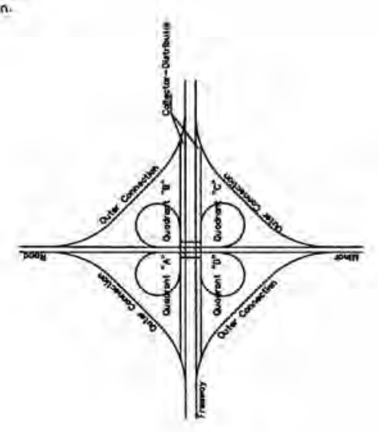
NOTES:

1. When the grade of the freeway is greater than 2%, increase or decrease the acceleration length according to Exhibit 7-15.
2. The method of placing the scored white cement concrete is shown on Construction Standards 105.2.0 and 105.2.1.
3. This should be the minimum distance provided for acceleration regardless of the criteria from Exhibit 7-14.
4. A 4-lane freeway is shown for illustration. This design also applies to freeways with more than 4 lanes.

Source: Masshighway

Exhibit 7-30g
Freeway Entrance – Exit at Interchange (Inner Loop Entrance – Inner Loop Exit of Cloverleaf-Type Ramp)

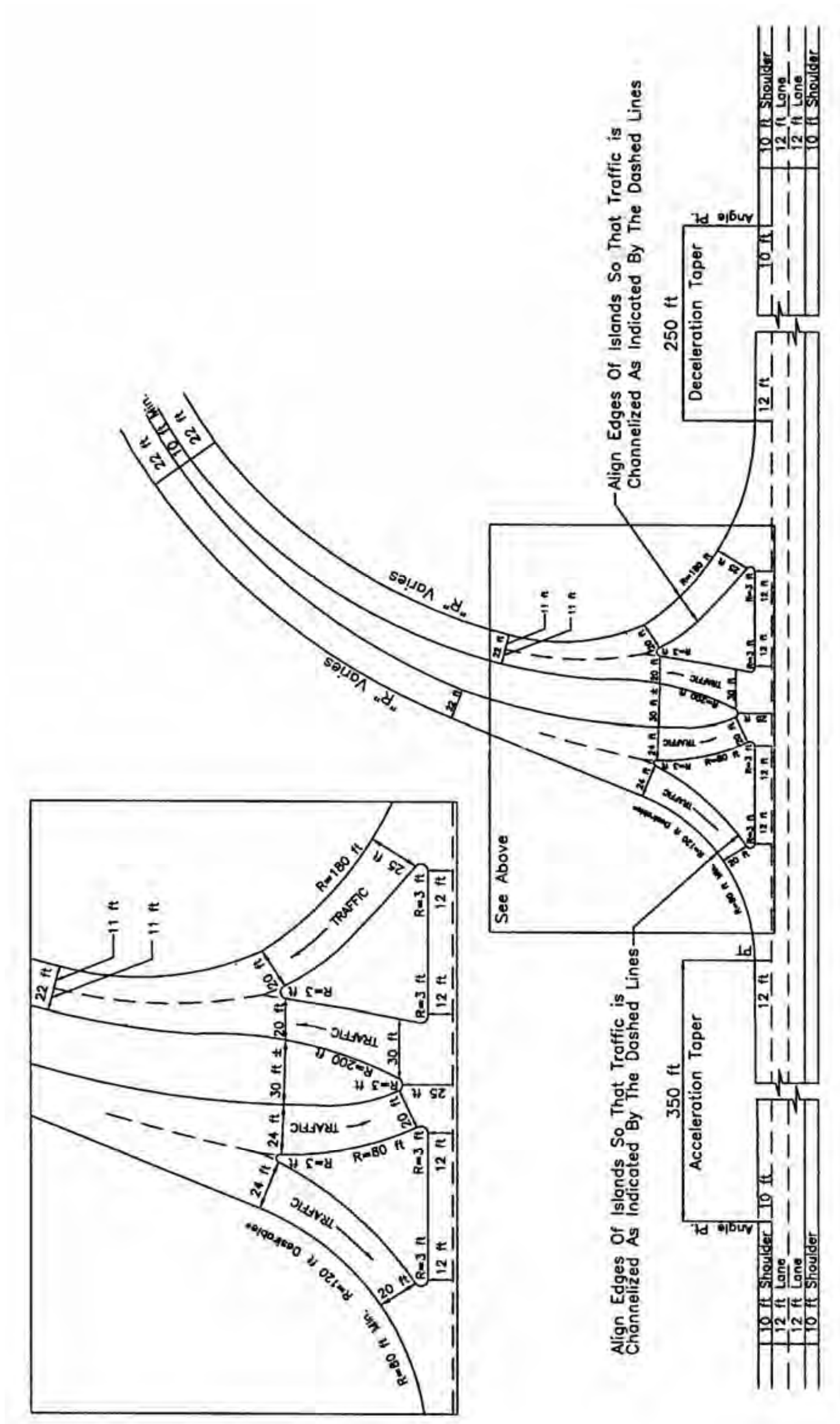




NOTES:
1. A Collector-Distributor road should be provided on the freeway to eliminate weaves on the mainline.
2. When the grade of the freeway is greater than 2%, increase or decrease the acceleration length according to Table 7-15.
3. The minimum length of each curve on the exit loop should allow sufficient deceleration distance for the design speed of the following sharper curve.
4. Desirable, decision sight distance will be available to the exit gore. At a minimum, stopping sight distance will be available. See Section 3.6.
5. The superelevation on the deceleration lane should be developed so that full superelevation (typically 0.06) is attained at the exit gore nose (PCC of R=300 ft curve).
6. A 4-lane freeway is shown for illustration. This design also applies to freeways with more than 4 lanes.

Source: MassHighway

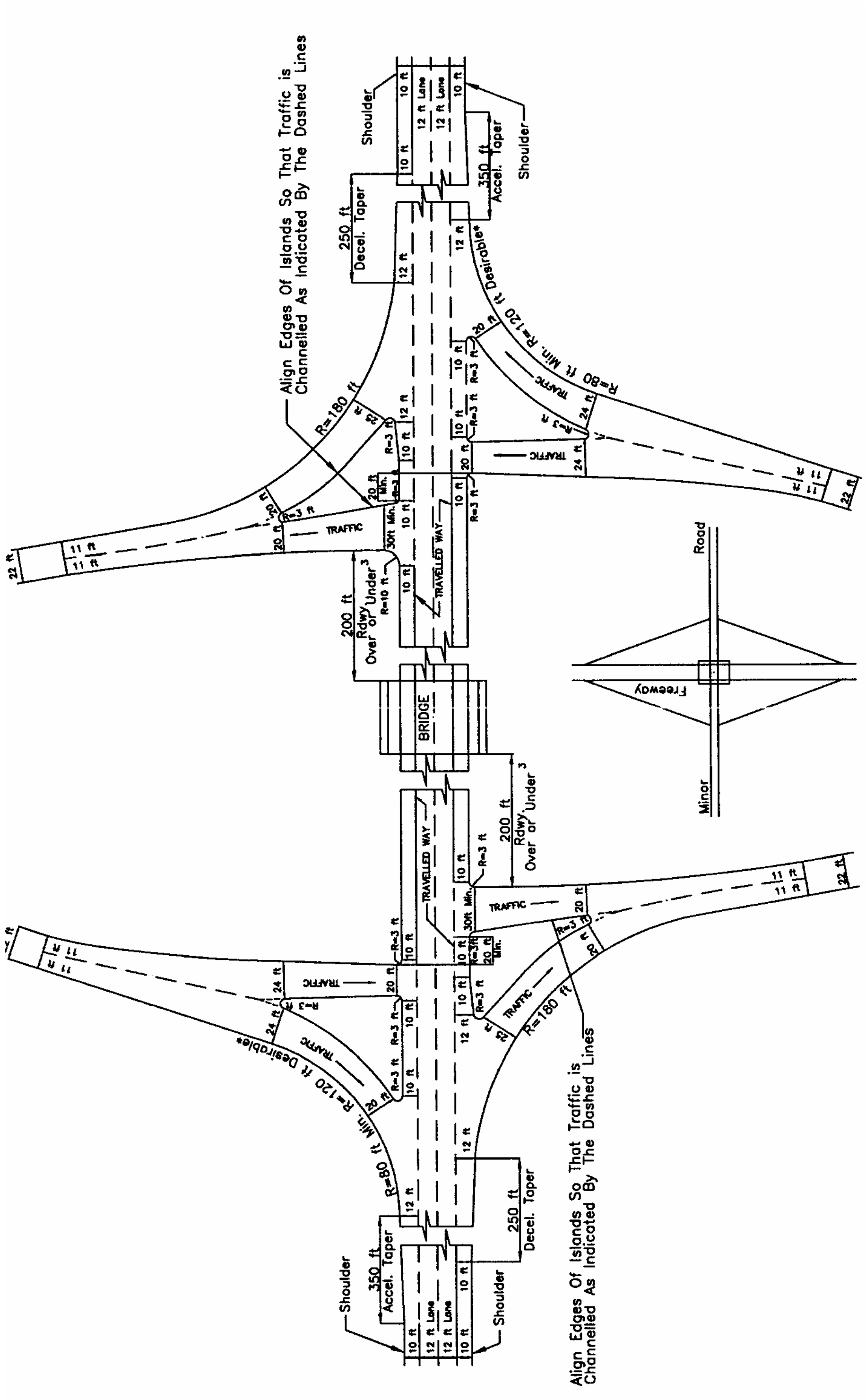
Exhibit 7-30h
Partial Cloverleaf-Type Ramp/Minor Road Intersection



Notes:
1. All islands to be edged.
2. See Chapter 8 for additional details on the design of at-grade intersections.

Source: Masshighway

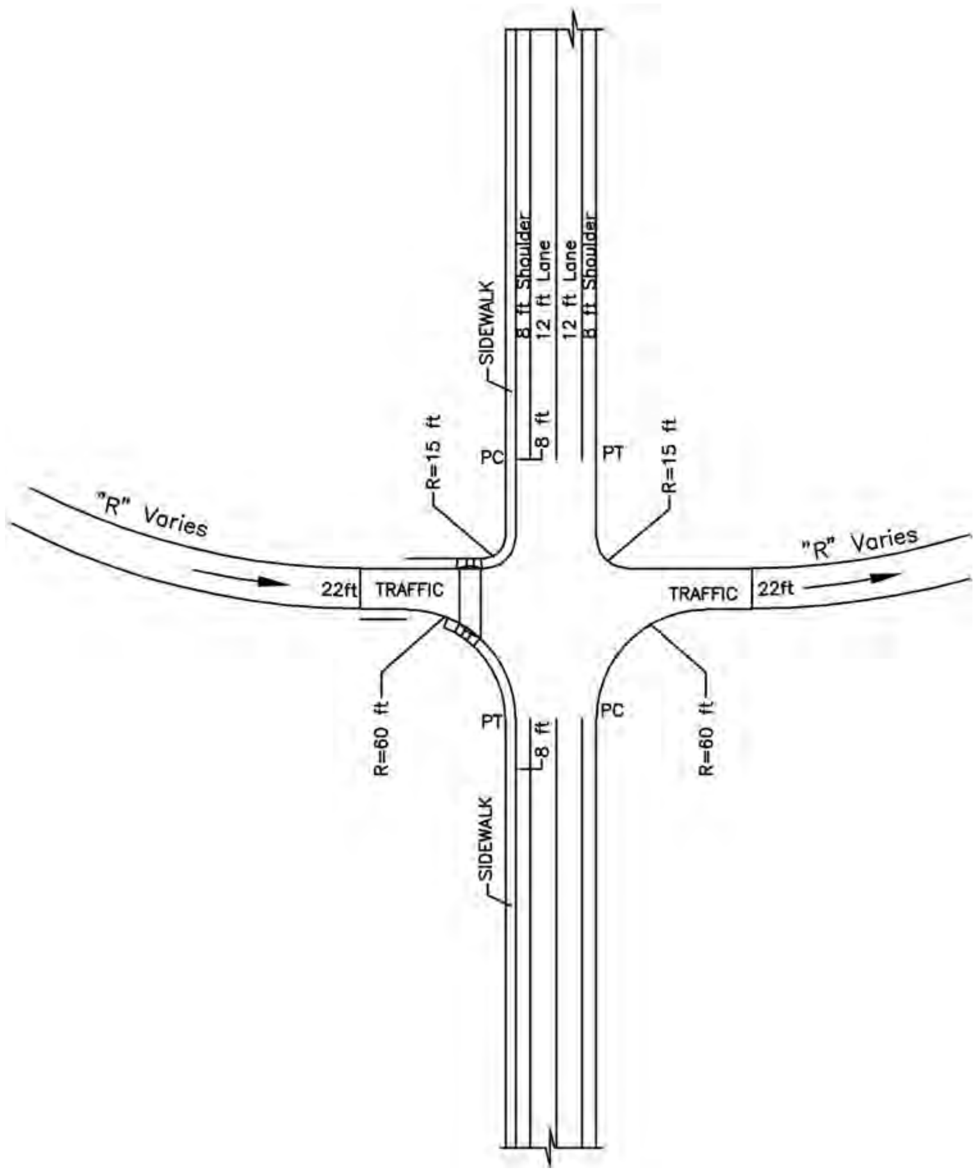
Exhibit 7-30i
Diamond-Type Ramp at Local Roadway



Notes:
1. The directional islands and ramp medians are to be edged.
2. See Chapter 8 for additional details on the design of at-grade intersections.
3. 200 feet is typical. Must meet unsignalized intersection sign distance criteria.

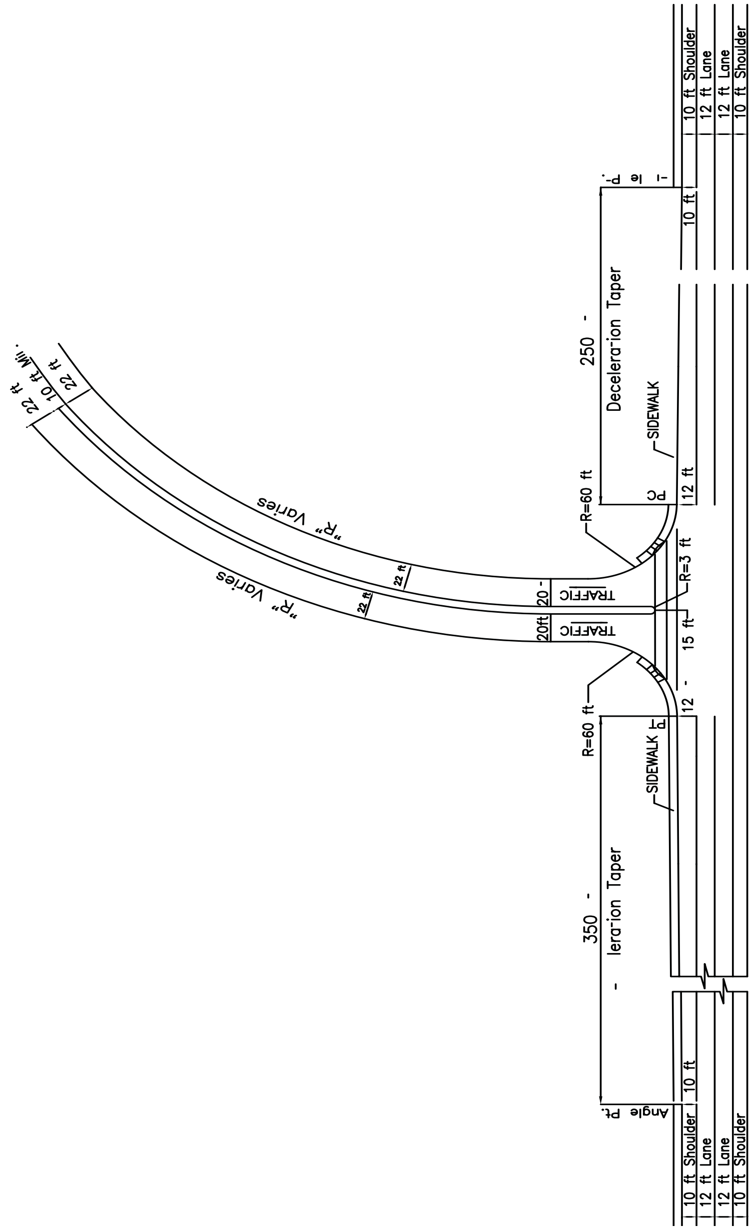
Source: Masshighway

Exhibit 7-30j
Diamond-Type Ramp at a Local Roadway with High Levels of Bicycle and Pedestrian Activity



Notes:
1. All islands to be edged.2. See Chapter 8 for additional details on the design of at-grade intersections.
3. 8-foot usable shoulder assumed on local road.
Source: MassHighway

Exhibit 7-30k
Partial Cloverleaf-Type Ramp at a Local Roadway with High Levels of Bicycle and Pedestrian Activity

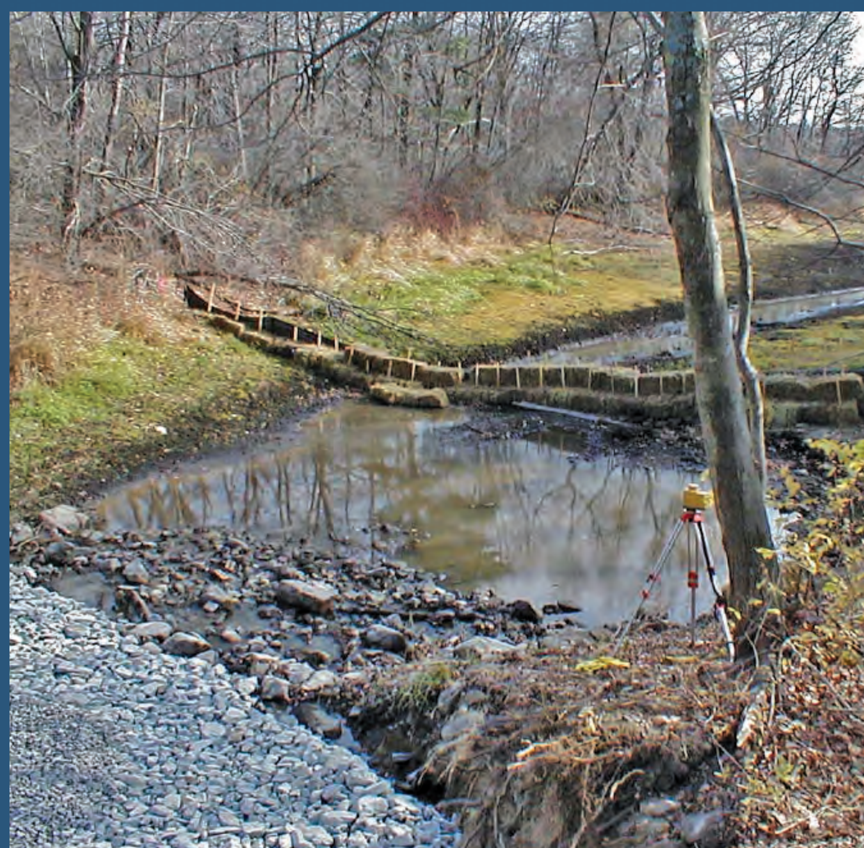


Notes:
1. All islands to be edged.
2. See Chapter 8 for additional details on the design of at-grade intersections.
Source: MassHighway

7.9 For Further Information

- A Policy on Geometric Design of Highways and Streets, AASHTO, 2004.
- Guide for the Development of Bicycle Facilities, AASHTO, 1999.
- Guide for the Planning and Design of Pedestrian Facilities, AASHTO, 2004
- A Guide to Achieving Flexibility in Highway Design, AASHTO, 2004.
- *Highway Capacity Manual*, Transportation Research Board, 2000.
- Manual on Uniform Traffic Control Devices, Federal Highway Administration, 2003.

Chapter 8
Drainage and Erosion Control



Drainage and Erosion Control

8.1 Introduction

One of the most important considerations in roadway design is ensuring proper drainage of surface runoff from the roadway. Additionally, the design of roadways often affects the existing drainage patterns in the surrounding area. The designer also needs to ensure that adequate subsurface drainage is provided to maintain the integrity of the roadway structure.

Improper drainage poses significant safety hazards for all users of a roadway and can have a negative impact on the lifespan of the facility. Drainage design also needs to respect the integrity of natural watercourses, environmental resources, floodplains, and other features of the surrounding context. The evaluation of site hydrology and incorporation of storm water management should be included early in the project development process and to the maximum extent feasible attempt to:

- Avoid and minimize impacts to wetland resource areas
- Reduce and minimize impervious surfaces
- Reproduce pre-development hydrologic conditions
- Fit the improvements to the terrain
- Use vegetated swales and medians
- Improve existing drainage systems

Another important component of drainage design is the preservation of water quality and the minimization of erosion. The flow of water over and adjacent to roadways can result in erosion of soils, which is detrimental both to the roadway's structure and to the surrounding environment. The drainage design should also minimize the potential for the negative impacts of erosion.

Recognizing that roadway runoff is a potential source of water pollution due to the presence of hydrocarbons and particulate matter transported by storm water runoff, the designer should seek to prevent the discharge of untreated storm water runoff to the maximum extent practicable.

This chapter describes MassHighway's procedures for drainage design, principles of hydrology applicable to drainage design, hydraulic design (design of drainage courses and structures), and erosion control during construction.

The *MassHighway Storm Water Handbook* and the *MassHighway Drainage Manual* are companion volumes to this chapter. The designer should use both of these references when developing roadway drainage designs. The designer should also consult the various FHWA Hydraulic Design Series (HDS) and Hydraulic Engineering Circulars (HEC) cited throughout the chapter as well as the 1992 AASHTO *Highway Drainage Guidelines*.

8.2 Procedures

The Hydraulic Section is responsible for the hydraulic design and/or review of major waterway structures. The Bridge Division is responsible for the structural design of all bridges and box culverts with spans over 8 feet. The Highway Design Section is responsible for the design of surface drainage. Where special or unusual conditions are encountered, the designer should consult the Hydraulic Section. The designer should complete the following tasks:

- Develop an understanding of the environmental context and constraints of the project.
- Familiarize him/herself with the environmental documents prepared for the project and incorporate appropriate mitigation measures into the project design.
- Investigate and address environmental concerns associated with adjacent wetlands such as storm water discharge quality and quantity, flood storage capacity, groundwater quality and supplies, pollution prevention in sensitive resources areas, sedimentation, and erosion control.
- Determine whether there are any existing drainage problems that need be addressed as part of the project drainage design.

- Coordinate the drainage design with the roadway design to make sure that all low points are drained and that adequate cover is provided over all new drain lines.
- Refer to Chapter 13 to determine whether proposed medians, off-road graded areas and drainage ditches can be vegetated to reduce the quantity of runoff.
- Design drainage improvements so that they can be easily maintained.

8.2.1 Drainage Law and the Designer's Responsibility

Legal issues related to highway drainage can result from changes to natural drainage patterns caused by highway construction. To avoid these problems, the designer should minimize the adverse effects on adjacent property by using accepted drainage design methods. The designer should be particularly aware of the following legal requirements related to drainage design:

- MGL Chapter 131, Section 40 — Wetlands Protection Act. This act sets forth the requirements, procedures and definitions to determine the effect of altering natural drainage patterns or wetland resource areas. It sets broad guidelines and limitations on the acceptable impacts of road and bridge construction.
- The Department of Environmental Protection issued the Storm water Management Policy and performance Standards on November 18, 1996. DEP issued final guidance related to the Policy and Performance Standards in April 1997. The Storm water Management Policy and Performance Standards are currently implemented through the Wetlands Protection Act and its regulations at the local level. The Policy and Standards may also be applied through various state regulations governing surface and groundwater quality. The Policy and Standards require the designer to consider measures to enhance storm water management including the control of discharge rates, recharge to groundwater, quality of discharge, erosion and sediment controls, and drainage system operation and maintenance activities. The *MassHighway Storm Water Handbook* provides detailed guidance for the designer in preparing cost-effective storm water management designs for roadway and bridge projects that comply with the DEP Storm water Management Policy.

- U.S. Environmental Protection Agency (EPA) National Pollutant Discharge Elimination System (NPDES) — In 1990, the U.S. EPA promulgated rules establishing Phase 1 of the NPDES storm water program. Phase I rules address discharges from large municipal separate storm sewer systems and certain industrial activities, including construction activities disturbing 5 acres or more of land. A Construction General Permit was developed to cover discharges from the construction activities. Coverage under this permit requires filing of a Notice of Intent (NOI) with the EPA Region 1 office and preparation of a Storm Water Pollution Prevention Plan (SWPPP). This General Permit is applicable to highway projects involving disturbance of 5 acres or more. In 1999, the EPA issued the Phase II rule of the NPDES storm water program. The Phase II Rule which became effective on May 1, 2003 reduces the threshold for soil disturbance at construction sites from 5 acres down to 1 acre. Roadway construction projects that exceed the soil disturbance threshold require filing a Notice of Intent with the EPA under the Construction General Permit and preparation of an appropriate SWPPP. In addition to affecting MassHighway construction activities, the NPDES Phase II rule applies to MassHighway as an “operator of MS4s” (as defined under the Phase II Rule). A MS4 Permit was issued to MassHighway by EPA and DEP and a Storm water Plan has been prepared by MassHighway to comply with the permit provisions. Phase II requires implementation of six minimum control measures including the following elements:

  - Public education and outreach;
  - Public participation/involvement;
  - Illicit discharge detection and elimination;
  - Construction site runoff control;
  - Post-construction runoff control; and
  - Pollution prevention/good housekeeping.

  The *MassHighway Storm Water Handbook* provides the controlling guidance relative to compliance with the NPDES Phase II Rule and the DEP Storm water Management Policy. The designer should coordinate with the MassHighway Environmental Section regarding the MassHighway Storm water Plan and any additional requirements under NPDES regarding impacts on endangered and threatened species, historic resources, stressed drainage basins, Total Maximum Daily Load (TMDL) or impaired water bodies.

- MGL Chapter 91, Waterways (DEP) — This act establishes the authority and limitations of the Department of Environmental Protection for any work affecting Boston Harbor, rivers, streams, ponds, and shores along public beaches.
- Section 401 Water Quality Certificate (DEP) — The designer should coordinate with the MassHighway Environmental Section and the Department of Environmental Protection regarding the permitting requirements under this section or any other related permitting requirements such as 303(d) Water Bodies, the MA Surface and Groundwater Quality Standards and Permitting Programs or the MA Watershed Protection requirements.
- MGL Chapter 83, Section 4 Drainage Easements and Liabilities— This act identifies the requirements for obtaining easements for construction or modification of drainage structures. Limits of liability are also established. When utilizing existing drainage outfalls, the designer should determine whether there is an existing drainage easement. If there is no existing drainage easement at the existing drainage outfall that is being utilized, or when designing new drainage outfalls, the designer should coordinate with the Right of Way section to obtain any required drainage easements.
- Section 404 Army Corps of Engineers (ACOE) — Federal law (33 USCA 404) requires that all construction activity involving navigable waters be reviewed and approved. Requirements include the 404 Application Form together with plans, drawings and calculations for the construction activity (See 33 CFR 209). The U.S. ACOE Programmatic General Permit for Massachusetts also requires that all new waterway crossings be designed to facilitate fish passage. The designer should refer to Chapter 14 – Wildlife Accommodation for more information on the general permit.
- Massachusetts Environmental Policy Act (MEPA) — The designer should consult with the MassHighway Environmental Section regarding any permitting requirements under 301CMR Section 11.
- Federal Emergency Management Agency (FEMA) administers the National Flood Insurance Program (NFIP). FEMA has established regulations for modifications to floodways and floodplains. MassHighway coordination with FEMA is required under the following circumstances:

- A Proposed crossing encroachment on a regulatory floodway that would require an amendment to the floodway map;
- A proposed crossing encroachment on a floodplain where a detailed study has been performed but no floodway designated and the maximum allowable (usually 1 foot) increase in the base flood elevation would be exceeded.
- A proposed crossing encroachment where a local community is expected to enter into the regular program within a reasonable period, and detailed floodplain studies are underway.

Details of requirements for meeting the conditions of FEMA and NFIP are contained in a FHWA paper *Procedures for Coordinating Highway Encroachments on Floodplains with FEMA*, and *The Floodway: A Guide for Community Permit Official*s, FEMA.

Exhibit 8-1 provides a schematic for illustrating the FEMA requirements. Note that there can be no surcharge or increase of the 100-year flood profile or impact on the Regulatory Floodway resulting from highway construction. Other documents which provide additional guidance on legal matters are:

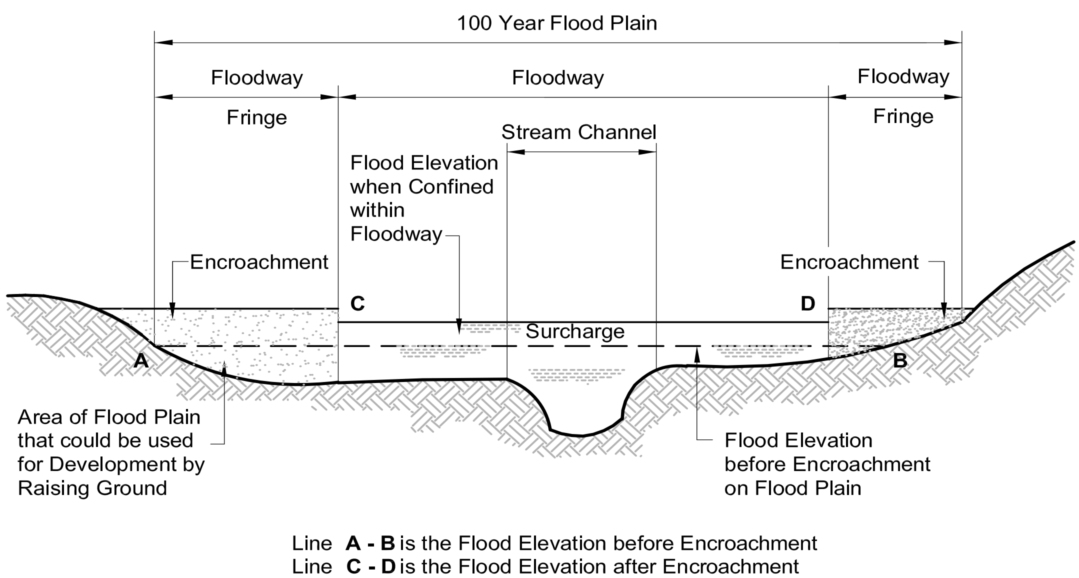
- Federal Floodplain Executive Order No. 11988,
- Federal Wetlands Executive Order No. 11990, and
- *Federal Highway Program Manual*, Volume 6, Chapter 7, Section 3, Subsection 2, "Location and Hydraulic Design of Encroachments on Flood Plains."
- Massachusetts Executive Order No. 149 “Provisions for State Coordination and Participation with the Federal Administration under the National Flood Insurance Act of 1968, as amended.”

The designer should also consult the Massachusetts Wetlands Protection Act regarding any changes to the 100-year flood elevation. The designated 100-year flood plain is regulated by DEP under the Wetlands Protection Act as Bordering Land Subject to Flooding or Land Subject to Coastal Flooding.

8.2.2 Coordination With Other Agencies

Modification of an existing drainage system can affect areas far removed from the area of construction. The designer should be aware of future land use plans and any expected change to watercourses. The designer should investigate any planned future Federal, State and local agency actions affecting drainage in the watershed, including accepted Master Drainage Plans and local Department of Public Works, Conservation Commission and Watershed Council improvement efforts. Early environmental coordination with the environmental permitting agencies including the DEP, ACOE and local Conservation Commission is recommended.

Exhibit 8-1
Floodway Schematic



Source: Federal Emergency Management Agency. (FEMA)

* For highway designs, the surcharge must be zero for the 100-yr base flood. Encroachments by local community actions may result in a surcharge not to exceed 1.0 ft for the 100-yr. base flood.

Definitions:

1. 100-year Flood Plain - the floodplain limits which have a return frequency of once in 100 years. A floodplain is the lowland and relatively flat area adjoining inland and coastal waters. The 100-year floodplain is also the base floodplain.
2. Floodway (Regulatory) - the channel of a river or other watercourse and the adjacent land areas which are regulated by Federal, State, or local governments. The floodway must be reserved in an open manner (i.e., unconfined or unobstructed either horizontally or vertically) to provide for the discharge of the base flood so that the cumulative increase in water surface elevation (surcharge) is no more than a designated amount.
3. Floodway Fringe - that portion of the base floodplain outside of the regulatory floodway.

8.2.3 Documentation Necessary for Drainage Designs

The need for the drainage design should be established before undertaking any detailed investigation (e.g., Is there a flooding problem? Is the present culvert adequate? Is there visual or historic evidence of plugging with debris or sediment? Is the existing storm drain system adequate?).

New or Replacement Culvert — Once the decision to design a new or replacement culvert is made, the following information gathering and coordination is needed:

- Plan, profile and cross-section (at 100-foot intervals) of the channel for distances of at least 300 feet upstream and downstream from the structure, or as directed;
- Flagged wetland resource area boundaries under federal and state jurisdiction within 100 feet of culvert inlet and outlet locations;
- Overbank (flood bank) sections, if required;
- Dimensions of waterway openings and descriptive information of existing hydraulic structures, both upstream and downstream from the proposed structure;
- Highwater elevations (upstream and downstream from existing highways) and date of occurrence;
- Estimated flow velocity and depth during time of survey;
- Roadway profile data to determine possible overtopping;
- As-built or record plan and drainage reports for the existing culvert;
- As-built or record utility plans in the vicinity of the existing culvert;
- Stream geomorphic data;
- Coordination with the MassHighway Environmental Section and natural Heritage regarding documentation of threatened or endangered species; and
- Coordination with the MassHighway Environmental Section and local historic commission to determine whether the existing culvert has any historical significance.

New or Replacement Storm Drain System —Once the decision to design a new or replacement storm drain system is made, the following information is required:

- Roadway plan, profile and cross-section (at 50-foot intervals) of the roadway within the project limits;
- Existing storm drain system layout, and elevations including: drainage structure rim and invert elevations, condition, pipe materials, sizes and directions entering or leaving the drainage structure;
- Location, condition and invert elevations of existing drainage outfalls including headwalls and flared-end sections;
- Flagged wetland resource area boundaries under federal and state jurisdiction within 100 feet of existing drainage outfalls;
- Profile and cross-section (at 50-foot intervals) of the drainage outfall channel for distances of at least 100 feet downstream from the outfall, or as directed;
- Highwater elevations observed at drainage outfalls and date of occurrence;
- Estimated flow velocity and depth at existing drainage outfalls during time of survey;
- As-built or record plan and drainage reports for existing storm drain system;
- As-built or record utility plans in the vicinity of the existing storm drain system;
- Coordination with the MassHighway Environmental Section regarding documentation of threatened or endangered species, watershed TMDL, stressed basins, watersheds contributing to 303(d) listed water bodies or Outstanding Resource Waters as defined under MA Surface Water Quality regulations;
- Compiled information regarding the location of private and public wells (and associated protective zones); and
- Soils data as part of the design of infiltrative drainage systems.

After receiving this information, the designer should conduct a preliminary analysis to determine the drainage requirements. The upstream and downstream limits of the drainage study should be based on the tributary watershed and the limits of any anticipated impacts of the proposed drainage improvements. This includes outlining the drainage areas on a topographic map and calculating the peak discharge. A field trip should verify and supplement the survey data. The designer's field investigation should provide the following information:

- Highwater elevations and evidence of scour;
- Flooding problems and history obtained through personal interviews with local residents, state and municipal highway department personnel, and record information; and
- Estimated flow in channels.

The designer must prepare and retain adequate documentation as part of the drainage design process. At a minimum, this includes:

- A statement of the objective(s) of the proposed drainage facility;
- Conditions before and after construction (particularly any existing damage), including preconstruction photos along any natural watercourses (aerial photographs may be taken to supplement the ground photos);
- Drainage calculations with supporting data and assumptions made for these calculations; and
- A drainage area topographic map for the project site.

All documentation should be consolidated into a package for the permanent project file. It should contain the name of the designer and reviewer and the completion date.

8.3 Hydrology

Hydrology is the study of the properties, phenomena, and distribution of water. The hydrologic analysis will determine the peak discharge for the selected design year. These rates are then used to determine the required sizes of the drainage facilities. The designer may also need to develop flood hydrographs and determine runoff volumes where flood storage capacity is a consideration and there is a need to maintain existing peak discharge rates.

The hydrologic design process includes:

- Selection of the design flood frequency;
- Selection of the appropriate hydrologic method;
- Determination of the peak design discharge; and
- Determination of the flood hydrograph and runoff volume, if required.

8.3.1 Design Storm Frequency

The designer must select a design frequency to calculate the peak rate of runoff. Typical values are 2, 5, 10, 50, and 100-year storm frequencies. As an example, a 50-year storm means there is a 1/50 (0.02) probability that the peak discharge from that storm will be equaled or exceeded once during a given year.

Exhibit 8-2 provides recommended design frequencies. The selected value for a project is based on an assessment of the likely damage from a given peak discharge and the initial construction and maintenance costs of the drainage facility. The designer should consider traffic interruptions, property damage, and possible loss of life. If the discharge from a greater design frequency can be accommodated, at a small additional cost, it should be considered.

Exhibit 8-2
Recommended Design Flood Frequency[1]

		Type of Installation		
Highway Functional Class	Urban/Rural	Cross Culverts	Storm Drain System[2]	Open Channels[3]
Interstate/Freeway/Expressway	Both	50-yr	10-yr[4]	50-yr
Arterial	Urban	50-yr	10-yr[4]	50-yr
	Rural	50-yr	10-yr[4]	50-yr
Collectors/Local	Urban	25-yr[5]	5-yr	25-yr[5]
	Rural	10 or 25-yr	2 or 5-yr	10 or 25-yr

1. The values in the table are typical ranges. The selected value for a project is based on an assessment of the likely damage of a given flow and the costs of the drainage facility.
2. This includes pavement drainage design.
3. This includes any culverts which pass under intersecting roads, driveways, or median crossings.
4. Use a 50-yr frequency at underpasses or depressed sections where ponded water can only be removed through the storm drain system.
5. The selected frequency depends on the anticipated watershed development and potential property damage.

Source: HEC #1, March, 1969. Design of Highway Pavements, pp. 12-5 to 12-6. Note: HEC #12 — Revised, March, 1984.

Note: 100-year requirements must be checked if the proposed highway is in an established regulatory floodway or floodplain, or resource area is defined by the April, 1983 revisions to Ch. 131 MGL, Section 40. See Section 10.1.2.

The DEP Storm Water Management Policy states that the 2-year and 10-year, 24-hour storms must be used in sizing peak discharge controls, if required. It also states that the 100-year, 24 hour storm must also be evaluated to demonstrate that there will not be increased flooding impacts offsite, if peak discharge controls are required. The emergency spillway for detention facilities should be designed for the 100-year storm. The *MassHighway Storm Water Handbook* and the *DEP Storm water Management Policy* should be consulted when determining whether peak discharge controls are required for a project.

8.3.2 Method of Estimating Peak Discharge

Exhibit 8-3 presents a summary of the three hydrologic methods used in Massachusetts: the U.S. Geological Survey (USGS), Wandle Method; the Rational Method; and the Natural Resource Conservation Service (NRCS) method, formerly the Soil Conservation Service (SCS) Method. Each method will provide the estimated discharge (in cfs) expected at a specific location for a given design frequency, drainage area, and set of hydrologic conditions. The highway designer should consider the hydrologic factors incorporated into the methods. Each method has its limitations. The designer should also research existing USGS gauging station data and FEMA Flood Insurance Studies on existing rivers and streams for information regarding existing peak discharges.

Exhibit 8-3
Hydrologic Methods Used in Massachusetts: U.S. Geological Survey (USGS) Wandle Method

Basic Source	"Estimating Peak Discharges of Small Rural Streams in Massachusetts," March 1982
Developed by	S. William Wandle, Jr.
Applicability	
Geographic	Entire State, except streams on Cape Cod, Martha's Vineyard, Nantucket and eastern part of Plymouth County
Size of Drainage Area	0.25 – 260 mi^2 (Eastern Region) 0.49 – 199 mi^2 (Central Region) 0.27 – 162 mi^2 (Western Region)
Type of Structures	Stream culverts
Status	Use when possible
Basic Approach	Calculates peak discharge for design frequency from data at 95 sites in Massachusetts on natural-flow streams for gaged and ungaged sites and sites on gaged streams
Parameters Incorporated	Gaged data Drainage area size Main-channel slope Mean basin elevation Storage index Regional factor
Advantages	Based on gaged data in Massachusetts Most reliable of available methods Applicable to wide range of drainage area sizes
Limitations	Does not apply to sites on streams: ■ where floodplains are significantly affected by regulation, diversion, or urbanization ■ where the usable man-made storage is over 4.5 million cubic feet per square mile ■ just below a reservoir of any size ■ where the basin characteristics significantly differ from those of the gaged sites

Exhibit 8-3
Hydrologic Methods Used in Massachusetts (Continued): Rational Method

Basic Source	FHWA – NHI – 01 - 021 "Urban Drainage Design Manual," Hydraulic Engineering Circular No. 22 (HEC #22) , August 2001
Developed by	Kuichling, 1889
Applicability	
Geographic	Entire State
Size of Drainage Area	Should only be applied to drainage areas smaller than 50 acres
Type of Structures	Pavements, storm drains, open channels, culverts
Status	Use to determine pavement discharge and for other surface runoff calculations
Basic Approach	Calculates peak discharge for design frequency directly from rainfall data, drainage area size, and runoff coefficient
Parameters Incorporated	Rainfall intensity (in/hr) Drainage area (acres) Runoff coefficient

Exhibit 8-3
Hydrologic Methods Used in Massachusetts (Continued): Natural Resource Conservation Service (NRCS) Method

Basic Source	Technical Release No. 55 "Urban Hydrology for Small Watersheds," Revised 2003 "Guidelines for Soil & Water Conservation in Urbanizing Areas of Mass.," App. B, Oct. 1977 Technical Release No. 20 "Computer Program for Project Formulation – Hydrology" 1983
Developed by	NRCS (formerly SCS), U.S. Department of Agriculture
Applicability	
Geographic	Entire State
Size of Drainage Area	Less than 2,000 Acres
Type of Structures	Storm drains, open channels, culverts, detention storage facilities
Status	Use as a check for Rational Method, except for pavement drainage. Use for design of detention storage facilities
Basic Approach	Calculates peak discharge for design frequency from precipitation and drainage area data factoring in water losses from detention, infiltration, evaporation, etc.
Parameters Incorporated	Rainfall data Drainage area (acres) Antecedent moisture condition Hydrologic properties of soils Vegetative cover Topography
Advantages	Straightforward and easy-to-use Reasonably accurate for very small, homogeneous drainage areas Uses many parameters which impact runoff Reasonably accurate for small drainage areas Can be used to develop hydrographs (flow rate with respect to time) Can be used to determine the effect of storage on flow
Limitations	Not based on gaged data Restricted applicability to drainage area size Neglects storage Average slope of drainage area cannot exceed 30% Restricted applicability outside of urban areas because of size of drainage area limitations

At least two methods should be considered for each calculation, except roadway drainage, where only the Rational Method is necessary unless the design of peak discharge controls is required. If a wide range of peak discharges results, the selection will be based on the experience of the design engineer. The Natural Resource Conservation (NRCS) Method should be used when sizing peak discharge controls for roadway drainage.

When using any hydrologic method, the designer should consider future land use based on anticipated changes in the existing land use and any known development plans. The designer should check with the local planning agencies for this information.

8.3.2.1 USGS (Wandle) Method

The USGS Wandle Method is the preferred hydrologic method for sizing stream culverts. It is based on gaged data from 95 sites on small rural streams within Massachusetts and Exhibit 8-4 lists the range of basin characteristics which apply.

Exhibit 8-4
USGS Method: Extremes of Basin Characteristics in Base-Data Network

	Drainage Area (mi^2)	Main-Channel Slope (ft/mi)	Storage (%)	Mean Basin Elevation (ft)
Eastern Massachusetts Region				
Maximum	260	*	*	*
Minimum	.25	*	*	*
Central Massachusetts Region				
Maximum	199	*	22.7	*
Minimum	.49	*	0	*
Western Massachusetts Region				
Maximum	162	449	*	1900
Minimum	.27	4.74	*	400

* Not applicable to estimating method in this region.
Source: *Estimating Peak Discharges of Small Rural Streams in Massachusetts,* USGS.

The USGS method presents three estimating situations, depending on the location of the design site within the watershed — ungaged, gaged, or sites on gaged streams. To use this method, the designer must determine the drainage area (sq. mi.), main channel slope (ft./mi.), storage area (swamps, lakes, ponds, reservoirs in sq. mi.), and mean basin elevation (ft.). Wherever possible, the designer should use current USGS or MassHighway photogrammetric maps. The USGS Method consists of the following steps:

- From Exhibit 8-5, locate the area of the state for the site; and
- From Exhibit 8-6, determine if the study site is at a gaged site or on a gaged stream.

Exhibit 8-5
Gaging Station Network Used in Flood-Frequency Analysis

Source: *Estimating Peak Discharges of Small Rural Streams in Massachusetts,* USGS.

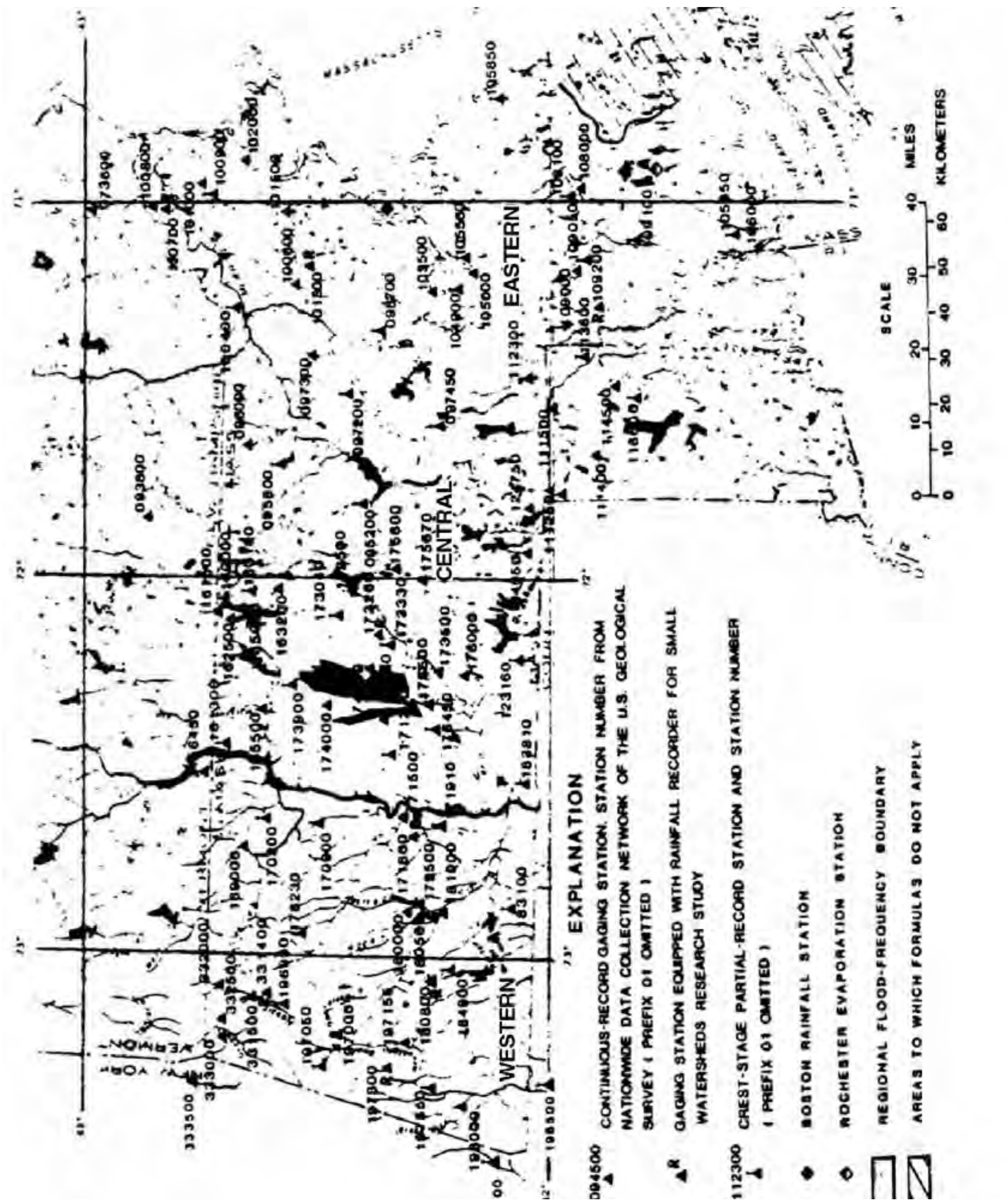


Exhibit 8-6
Selected Basin and Flood Characteristics for Gaged Stations — Eastern Region

Row No.	Station No.	Station Name	Station Location: Latitude (decimal degrees)	Station Location: Longitude (decimal degrees)	Drainage Area (mi2)	Years of Observed Peak Flow Record	Years for Historic Peak Adjustment*	Peak Discharge from Station Frequency curve, in cubic feet per second, with indicated exceedance probability: 0.5	0.3	0.1	0.04	0.02	0.01
1	01073600	Dudley Brook Near Exeter, NH	42.9936	71.0233	4.97	13	0	144	228	297	404	499	609
2	01093800	Stony Brook Tributary Near Temple, MH	42.8600	71.8333	3.6	12	0	136	198	246	315	373	437
3	01095200	Houghton Brook Near Oakdale, MA	42.4158	71.8033	0.69	12	0	20	26	31	38	43	49
4	01095800	Easter Brook Near Leominster, MA	42.5500	71.7100	0.92	11	0	36	57	75	104	129	159
5	01096000	Squannacook River Near West Groton, MA	42.6300	71.6600	64.9	26	0	1290	1910	2410	3140	3770	4470
6	01097200	Health Hen Meadow Brook at Stow, MA	42.4500	71.5000	3.89	11	0	45	73	98	137	173	216
7	01097300	Nashoba Brook Near Acton, MA	42.5100	71.4100	12.7	12	0	143	234	314	440	555	692
8	01097450	Jackstraw Brook at Westborough, MA	42.2539	71.6039	1.11	12	0	29	43	55	72	87	105
9	01098700	Hayward Brook at Wayland, MA	42.3611	71.3475	2.32	11	0	30	48	63	86	106	130
10	01100100	Richardson Brook Near Lowell, MA	42.6633	71.2672	4.32	13	0	126	156	178	206	228	251
11	01100600	Shawsheen River Near Wilmington, MA	42.5681	71.2153	36.5	12	0	478	719	918	1220	1480	1780
12	01100700	East Meadow River Near Haverhill, MA	42.8114	71.0331	4.93	12	18	105	150	184	230	266	305
13	01100800	Cobbler Brook Near Merrimac, MA	42.8486	71.0194	0.77	13	0	51	74	94	122	146	173
14	01100900	Parker River Tributary Near Georgetown, MA	42.7342	70.9728	0.65	11	0	17	34	50	79	109	146
15	01101000	Parker River at Byfield, MA	42.7500	70.9500	21.6	30	0	197	290	365	475	570	677
16	01101300	Maple Meadow Brook at Wilmington, MA	42.5375	71.1614	3.99	12	20	61	88	107	133	154	177
17	01101500	Ipswich River at South Middleton, MA	42.5700	71.0300	43.4	38	0	357	511	631	804	949	1110
18	01102000	Ipswich River Near Ipswich, MA	42.6600	70.8900	124	45	90	994	1450	1770	2210	2550	2900
19	01103500	Charles River at Dover, MA	42.2600	71.2600	184	39	90	1120	1590	1960	2520	3000	3540
20	01104900	Mill Brook at Westwood, MA	42.2058	71.2406	1.52	11	0	30	49	67	96	123	155
21	01105000	Neponset River at Norwood, MA	42.1800	71.2000	35.2	36	90	317	470	600	803	986	1200
22	01105550	Plantingfield Brook at Norwood, MA	42.2047	71.1869	1.52	11	0	129	164	189	223	251	280
23	01105850	Furnace Brook Near Marshfield, MA	42.1083	70.7314	1.61	12	0	37	62	84	119	152	192
24	01105950	Kirby Brook Near Head of Westport, MA	41.6006	71.0736	3.69	11	38	131	236	334	498	656	849
25	01106000	Adamsville Brook at Adamsville, RI	41.5583	71.1297	7.91	35	0	153	217	266	336	393	457
26	01108000	Taunton R at State Farm, NR Bridgewater, MA	41.9300	70.9500	260	46	0	2280	3000	3510	4220	4780	5370
27	01108100	Snows Brook Near Bridgewater, MA	41.9481	70.9936	1.41	11	21	44	98	158	277	409	590
28	01109000	Wading River Near Norton, MA	41.9500	71.1800	42.4	50	0	444	639	794	1020	1220	1440
29	01109050	Threemile River Tributary Near Oakland, MA	41.9272	71.1547	0.5	11	0	15	22	28	36	43	51
30	01109100	Taunton River Trib Near Fall River, MA	41.7586	71.1169	0.25	12	0	42	51	58	67	73	80
31	01109200	West Br Palmer River Near Rehoboth, MA	41.8794	71.2550	4.34	11	51	155	225	278	349	404	469

* years of combined record length for the calibrated stations, numbers 12, 16, and 31

Source: Estimating Peak Discharges of Small Rural Streams in Massachusetts, USGS

Exhibit 8-6 (Continued)
Selected Basin and Flood Characteristics for Gaged Stations — Central Region

Row No.	Station No.	Station Name	Station Location: Latitude (decimal Degrees)	Station Location: Longitude (decimal degrees)	Drainage Area (mi2)	Storage area (%)	Years of Observed Peak Flow Record	Years for Historic Peak Adjustment*	Peak Discharge from Station Frequency curve, in cubic feet per second, with indicated exceedance probability: 0.5	0.2	0.1	0.04	0.02	0.01
1	01111250	Dry Arm Brook Near Wallum Lake, RI	41.9728	71.7508	1.74	10.7	10	0	60	76	88	103	116	130
2	01111400	Chepachet River at Chepachet, RI	41.9228	71.6581	17.4	8.95	11	40	290	451	584	787	965	1170
3	01111500	Branch River at Forestdale, RI	42.0000	71.5600	91.2	4.48	37	90	1440	2180	2760	3590	4280	5050
4	01112300	Bungay Brook Near Sheldonville, MA	42.0247	71.4567	2.66	22.7	11	0	92	125	150	186	215	248
5	01113600	Blackstone R Trib. No. 2 at Berkeley, RI	41.9242	71.4136	1.04	5.81	11	0	31	37	41	47	51	55
6	01114500	Woonasquatucket River at Centerdale, RI	41.8600	71.4900	38.3	9.45	35	0	512	774	988	1310	1590	1910
7	01116600	Pocasset River Near North Scituate, RI	41.8369	71.5303	1.34	6.57	10	0	26	45	61	88	114	145
8	01123160	Wales Brook Tributary Near Wales, MA	42.0800	72.1975	0.71	0.20	12	0	24	37	47	62	76	91
9	01124050	Tufts Branch at Dudley, MA	42.0531	71.9394	1.06	1.70	13	0	51	84	113	159	203	254
10	01124750	Browns Brook Near Webster, MA	42.0567	71.8303	0.49	2.19	15	21	26	45	63	90	117	153
11	01161300	Millers Brook at Northfield, MA	42.6853	72.4531	2.33	0.54	12	21	105	189	264	389	506	647
12	01161500	Tarbell Brook Near Winchendon, MA	43.7125	72.0858	18.2	11.1	59	144	240	374	488	666	827	1010
13	01162000	Millers River Near Winchendon, MA	42.6800	72.0800	83.0	6.47	58	144	996	1480	1900	2530	3110	3780
14	01162500	Priest Brook Near Winchendon, MA	42.6800	72.1200	19.4	2.47	58	144	353	586	778	1070	1320	1610
15	01163100	Wilder Brook Near Gardner, MA	42.5950	72.0147	2.50	14.4	11	0	41	52	59	70	78	86
16	01163200	Otter River at Otter River, MA	42.5883	72.0414	34.2	14.0	12	0	398	525	617	744	846	954
17	01165000	East Branch Tully River Near Athol, MA	42.6422	72.2611	50.4	2.32	32	144	715	1170	1590	2290	2950	3770
18	01165500	Moss Brook at Wendell Depot, MA	42.6000	72.3600	12.3	2.52	59	97	258	429	567	7171	947	1140
19	01171200	Scarboro Brook at Dwight, MA	42.3289	72.4464	2.92	1.67	11	0	71	101	124	157	184	215
20	01172500	Ware River Near Barre, MA	42.3906	72.0608	55.0	4.95	11	0	649	1070	1430	2000	2520	3140
21	01173040	Pleasant Brook Near Barre, MA	42.4289	72.0764	1.11	5.55	10	0	38	61	82	113	142	176
22	01173260	Moose Brook Near Barre, MA	42.3978	72.1475	4.54	16.1	12	42	90	123	146	180	206	236
23	01173330	Fish Brook Near Gilbertville, MA	42.3233	72.1864	1.01	0.0	11	0	39	65	87	122	155	193
24	01173500	Ware River at Gibbs Crossing, MA	42.2353	72.2792	199	2.07	45	90	2010	3370	4810	7520	10400	14400
25	01173990	Middle Br Swift R at North New Salem, MA	42.5458	72.3194	4.73	2.53	11	0	96	153	201	276	342	418
26	01174000	Hop Brook Near New Salem, MA	42.4800	72.3300	3.39	0.74	28	0	150	203	241	294	336	381
27	01174500	East Branch Swift River Nr Hardwick, MA	42.3900	72.2400	43.70	8.39	39	107	623	1010	1350	1910	2430	3060
28	01174900	Cadwell Creek Near Belchertown, MA	42.3356	72.3700	2.81	0.53	14	0	112	160	197	251	296	346
29	01175500	Swift River at West Ware, MA	42.2678	72.3331	188	1.14	29	104	1660	2370	2960	3850	4630	5520
30	01175600	Caruth Brook Near Paxton, MA	42.3167	71.9711	2.35	13.8	11	0	79	121	154	206	251	302
31	01175670	Sevenmile River Near Spencer, MA	42.2650	72.0053	8.58	4.59	15	0	152	221	277	358	429	507
32	01176000	Quaboag River at West Brimfield, MA	42.1800	72.2600	151	3.86	63	111	1050	1580	2160	3270	4490	6160
33	01176450	Roaring Brook Near Belchertown, MA	42.2353	72.4050	2.77	1.73	12	0	90	147	197	276	348	433
34	01183810	Longmeadow Bk at PDSDE Rd Nr Longmeadow, MA	42.0394	72.5922	4.15	1.65	13	0	72	103	128	164	194	228

*years of combined record length for the calibrated stations, numbers 10, and 22

Source: Estimating Peak Discharges of Small Rural Streams in Massachusetts, USGS.

Exhibit 8-6 (Continued)

Selected Basin and Flood Characteristics for Gaged Stations — Western. Region

Row No.	Station No.	Station Name	Station Location: Latitude (decimal Degrees)	Station Location: Longitude (decimal degrees)	Drainage Area (mi2)	Main channel slope (ft/ml)	Mean basin elevation (ft)	Years of observed peak flow Record	Years for historic peak Adjustment	Peak discharge from station frequency curve, in cubic feet per second, with indicated exceedance probability: 0.5	0.2	0.1	0.04	0.02	0.01
1	01156450	Connecticut R Tributary Nr Vernon, VT	42.7836	72.5325	1.12	122	600	11	0	45	70	91	121	147	177
2	01169000	North River at Shattuckville, MA	42.6400	72.7300	88.4	65.6	1440	36	0	3910	6210	8110	11000	13500	16400
3	01170200	Allen Brook Near Shelburne Falls, MA	42.6128	72.6672	0.73	81.1	880	11	0	24	45	66	102	137	180
4	01170900	Mill River Near South Deerfield, MA	42.4692	72.6419	6.37	134	550	12	0	141	194	234	290	336	386
5	01171500	Mill River at Northampton, MA	42.3200	72.6600	54.0	94.8	870	37	0	1990	2920	3620	4610	5430	6330
6	01171800	Basset Brook Near Northampton, MA	42.3025	72.6878	5.56	39.9	400	12	46	116	178	228	302	366	436
7	01171910	Broad Brook Near Holyoke, MA	42.1997	72.6864	2.26	80.6	460	11	0	66	90	108	132	152	174
8	01178230	Mill Brook at Plainfield, MA	42.5158	72.9250	4.47	56.4	1680	12	0	185	247	291	352	400	452
9	01179500	Westfield River at Knightville, MA	42.2878	72.8647	162	41.7	1470	31	64	6300	10500	14100	19700	24800	30900
10	01180000	Sykes Brook at Knightville, MA	42.2900	72.8700	1.64	118	1110	29	38	57	114	171	270	369	493
11	01180500	Middle Br Westfield R at Goss Heights, MA	42.2586	72.8731	52.6	79.0	1420	54	98	2730	4640	6420	9410	12300	15900
12	01180800	Walker Brook Near Becket Center, MA	42.2636	72.0467	3.01	138	1570	15	22	163	252	319	415	498	594
13	01181000	West Br Westfield R at Huntington, MA	42.2400	72.9000	93.7	54.9	1420	40	98	4440	7840	10800	15600	19900	25000
14	01183100	Seymour Brook Trib at Granville, MA	42.0647	72.8617	0.66	311	960	12	21	34	69	105	170	238	324
15	01184900	Haley Pond Outlet Near Otis, MA	42.2042	73.0322	0.27	64.8	1610	11	0	13	19	23	30	35	41
16	01196990	Windsor Brook Trib at Windsor, MA	42.5114	73.0769	0.29	138	1900	11	0	24	36	45	58	69	81
17	01197000	East Br Housatonic R at Coltsville, MA	42.4700	73.2000	57.1	47.7	1680	40	221	1550	2570	3380	4560	5580	6700
18	01197050	Churchill Brook at Pittsfield, MA	42.4914	73.2822	1.16	432	1660	11	0	32	60	84	126	164	212
19	01197155	Housatonic R Trib No. 2 at Lee, MA	42.3058	73.2303	0.73	449	1320	10	0	35	64	92	138	183	237
20	01197300	Marsh Brook at Lenox, MA	42.3497	73.2989	2.19	161	1240	12	0	82	107	125	150	169	189
21	01197550	Housatonic R Trib at Risingdale, MA	42.2325	73.3464	0.69	4.74	1190	13	0	16	28	39	55	71	89
22	01198000	Green River Near Great Barrington, MA	42.1900	73.3900	51.0	54.2	1180	21	27	1160	2060	2890	4240	5520	7060
23	01198500	Blackberry River at Canaan, Conn.	42.0240	73.3420	45.9	64.5	1150	**	**	1480	2850	4240	6750	9340	12700
24	01331400	Dry Brook Near Adams, MA	42.5889	73.1133	7.53	188	1760	12	31	505	826	1080	1550	2000	2510
25	01331500	Hoosic River at Adams, MA	42.6103	73.1256	46.3	12.6	1580	44	0	1110	1690	2160	2880	3510	4230
26	01332000	North Br Hoosic R at North Adams, MA	42.7000	73.0900	39.0	77.4	1840	45	107	2200	3560	4710	6510	8120	10000
27	01332500	Hoosic River near Williamstown, MA	42.7058	73.1806	132	19.2	1660	35	0	3700	5610	7140	9390	11300	13500
28	01333000	Green River at Williamstown, MA	42.7089	73.1972	42.6	33.0	1620	26	0	1300	2070	2700	3660	4490	5450
29	01333500	Little Hoosic R at Petersburg, NY	42.7600	73.3400	56.1	118	1550	24	27	1910	3060	4020	5460	6740	8190
30	01362100	Roeliff Jansen Kill Nr Hillsdale, NY	42.1536	73.5219	27.5	54.0	1040	14	0	767	1300	1760	2480	3140	3910

- years of combined record length for the calibrated stations, numbers 6, 12 and 24.

Source: Estimating Peak Discharges of Small Rural Streams in Massachusetts, USGS.

- Compute the appropriate basin characteristics, including an estimate of the usable man-made storage.
- From Exhibit 8-7, use the appropriate equation for an ungaged site, gaged site, or a site on a gaged stream.

Example 1: Ungaged Site (USGS)

Given: Drainage area = 13.5 sq. mi. (A)
Main channel length = 7. 5 mi.
Storage area = 1.4 sq. mi.
Mean basin elevation = 560 ft. (E)

Problem: Determine the peak discharge for a 50-year design for each region of the state.

Solution: Eastern — From Exhibit 8-7:

Q_{50} = $118.1\ A^{0.645}$

Q_{50} = $(118.1)\ (13.5^{0.645})$

Q_{50} = 633 cfs

Central — A storage index (St) must be determined:

$$St = \left(\frac{\text{Storage Area}}{\text{Drainage Area}} \times 100 \right) + 0.5$$

$$St = \left(\frac{1.4}{13.5} \times 100 \right) + 0.5 = 10.9$$

From Exhibit 8-7:

Q_{50} = $141.9A^{0.785}\ St^{-0.217}$

Q_{50} = $(141.9)(13.5^{0.785})(10.9^{-0.217})$

Q_{50} = 652 cfs

Western — A main channel slope (S1) must be determined between the points 10% and 85% of the total length above the design site. The topographic quadrangle map yields elevations of 480 feet (mile 0.8) and 840 feet (mile 6.4) at these points, Therefore:

$$S1 = \frac{840 - 480}{6.4 - 0.8} = 64.3\ \text{ft./mi.}$$

Exhibit 8-7
Equations for USGS Method

Site Characteristic	Area of State	Equations			Definition of Terms
Ungaged Site	Eastern	$Q_2 = 36.30A^{0.682}$ $Q_5 = 55.38A^{0.670}$ $Q_{10} = 72.12A^{0.660}$		$Q_{25} = 96.71A^{0.651}$ $Q_{50} = 118.1A^{0.645}$ $Q_{100} = 143.1A^{0.638}$	Q_t = the peak discharge, in cubic feet per second, for the specified design flood frequency, t, A = the drainage area, in square miles, Sl = the main-channel slope, in feet per mile, St = the storage index which is the area of lakes, ponds, and swamps expressed as a percentage plus 0.5, and E = the mean basin elevation, in feet.
	Central	$Q_2 = 41.11A^{0.743}St^{-0.097}$ $Q_5 = 65.17A^{0.751}St^{-0.139}$ $Q_{10} = 84.98A^{0.760}St^{-0.166}$		$Q_{25} = 114.9A^{0.775}St^{-0.195}$ $Q_{50} = 141.9A^{0.785}St^{-0.217}$ $Q_{100} = 172.7A^{0.797}St^{-0.237}$	
	Western	$Q_2 = 0.933A^{0.970}Sl^{0.158}E^{0.429}$ $Q_5 = 1.05A^{0.969}Sl^{0.178}E^{0.469}$ $Q_{10} = 1.23A^{0.969}Sl^{0.187}E^{0.480}$		$Q_{25} = 1.31A^{0.969}Sl^{0.205}E^{0.505}$ $Q_{50} = 1.41A^{0.970}Sl^{0.215}E^{0.520}$ $Q_{100} = 1.51A^{0.971}Sl^{0.225}E^{0.533}$	
Gaged Site	All	$Q_{t(w)} = \dfrac{(Q_{t(s)} \times N) + (Q_{t(r)} \times E)}{N + E}$			$Q_{t(w)}$ = the weighted discharge for design frequency, t, $Q_{t(s)}$ = the station value given in Table 10-2.02C for the peak at t, $Q_{t(r)}$ = the flood-peak estimate at t, from the regression equations, N = the number of years of observed peak data given in Table 10-2.02C, used to compute the station frequency curve (the greater of the observed and historical periods), and E = the equivalent years of record for the flood estimating equations.
		E for 25-Yr	E for 50-Yr	E for 100-Yr	
	Eastern	5	6	7	
	Central	9	11	11	
	Western	10	10	10	
Site on Gaged Stream	All	$Q_{t(u)} = \left(\dfrac{A_u}{A_g}\right)^x Q_{t(g)}$			$Q_{t(u)}$ = the peak discharge at ungaged site for design frequency, t, $Q_{t(g)}$ = the weighted average discharge at gaged site for t, computed using equation for gaged site, A_u = the drainage area of ungaged site, A_g = the drainage area of gaged site, and x = the exponent for each flood region.
		Exponent "X"			
	Eastern	0.66			
	Central	0.75			
	Western	0.96			

Reference: USGS publication.

Source: *Estimating Peak Discharges of Small Rural Streams in Massachusetts*, USGS

Example 3: Sites on Gaged Streams (USGS)

Given: Site on Fish Brook
Drainage area = 0.75 sq. mi.
Storage = 0.0

Problem: Compute the peak discharge for a 50-year design.

Solution: The ratio of the drainage area of the ungaged site to the area of the gaged site must be about 0.6 to 1.4 to use the USGS method:

Au/Ag = .75/1.01 = 0.74

From Exhibit 8-7:

$$Q_{t(u)} = (A_u/A_g)^{x} Q_{t(g)}$$

$$Q_{50(u)} = (0.75/1.01)^{0.75}(161) = 128 \text{ cfs}$$

8.3.2.2 Rational Method

The formula for the Rational Method is:

$$Q = CiA$$

Where:
Q = peak discharge, cfs
C = runoff coefficient
i = average rainfall intensity, in./hr, for a storm duration equal to the time of concentration, T_c
A = drainage area, acres

This method is a simplified model of the hydrologic process. Therefore, it should only be used for small drainage areas, and preferably for areas with the same general basin characteristics. It should be used to determine the peak discharge for pavement drainage design.

The following assumptions are inherent in the Rational Formula:

- The peak flow occurs when the entire watershed is contributing to the flow.
- The rainfall intensity is the same over the entire drainage area.
- The rainfall intensity is uniform over a time duration equal to the time of concentration, Tc. The time of concentration is the time

required for water to travel from the hydraulically most remote point of the basin to the point of interest.

- The frequency of the computed peak flow under the Rational Method is the same as that of the rainfall intensity, i.e., the 10-yr rainfall intensity is assumed to produce the 10-year peak flow under the Rational Method.
- The coefficient of runoff is the same for all storms of all recurrence probabilities.

Because of these inherent assumptions, the Rational Formula should only be applied to drainage areas smaller than 50 acres.

Runoff Coefficient (C)

The runoff coefficient is a general representation of the drainage basin characteristics. These include antecedent precipitation, soil moisture, infiltration, detention, evaporation, and ground slope and cover. The coefficient "C" can be determined in one of two ways. Exhibit 8-8 provides coefficients based on the overall character of the drainage area. The second method develops a composite coefficient based on the percentages of different surface types in the drainage area.

To determine C for a design frequency of 10 years or less, follow this procedure:

1. Document the predominant types of surfaces within the drainage area. Estimate the percentage each represents.
2. Select a C for each type of surface from Exhibit 8-9.
3. Calculate a weighted C value for the drainage area.

If a design frequency greater than 10 years is needed, use Exhibit 8-10 to determine a C_a. The modified Rational formula is:

$$Q = C_a CiA$$

Where: $C_a \times C$ must be less than or equal to 1.0.

Exhibit 8-8

Recommended Runoff Coefficients (C) for Rational Method

(By Overall Character of Area)

Description of Area	Runoff Coefficients
Business	
Downtown	0.70 to 0.95
Neighborhood	0.50 to 0.70
Residential	
Single-Family	0.30 to 0.50
Multi-Family, Detached	0.40 to 0.60
Multi-Family, Attached	0.60 to 0.75
Residential (Suburban)	0.25 to 0.40
Apartment	0.50 to 0.70
Industrial	
Light	0.50 to 0.80
Heavy	0.60 to 0.90
Parks, Cemeteries	0.10 to 0.25
Playgrounds	0.20 to 0.35
Railroad Yard	0.20 to 0.35
Unimproved	0.10 to 0.30
Woodland	0.15 to 0.25
Cultivated	0.40 to 0.60

Source: Design Manual for Storm Drainage, ASCE 1960

Exhibit 8-9

Recommended Runoff Coefficients (C) For Rational Method

(For Surface Type)

Character of Surface	Runoff Coefficients
Pavement	
Asphaltic and Concrete	0.70 to 0.95
Brick	0.70 to 0.85
Roofs	0.75 to 0.95
Lawns, Sandy Soil	
Flat, 2 Percent	0.05 to 0.10 0.
Average, 2 to 7 Percent	10 to 0.15
Steep, 7 Percent	0.15 to 0.20
Lawns, Heavy Soil	
Flat, 2 Percent	0.13 to 0.17
Average, 2 to 7 Percent	0.18 to 0.22
Steep, 7 Percent	0.25 to 0.35

Source: Design Manual for Storm Drainage, ASCE 1960

Exhibit 8-10
Recommended Ca Values (Rational Method)
(For Greater Than 10-year Design Runoff)

Recurrence Interval (Years)	C_a
2 to 10	1.0
25	1.1
50	1.2
100	1.25

Note: The product of C x Ca should not exceed 1.
Source: WPCF Manual of Practice No. 9, Design and Construction of Sanitary and Storm Sewers.

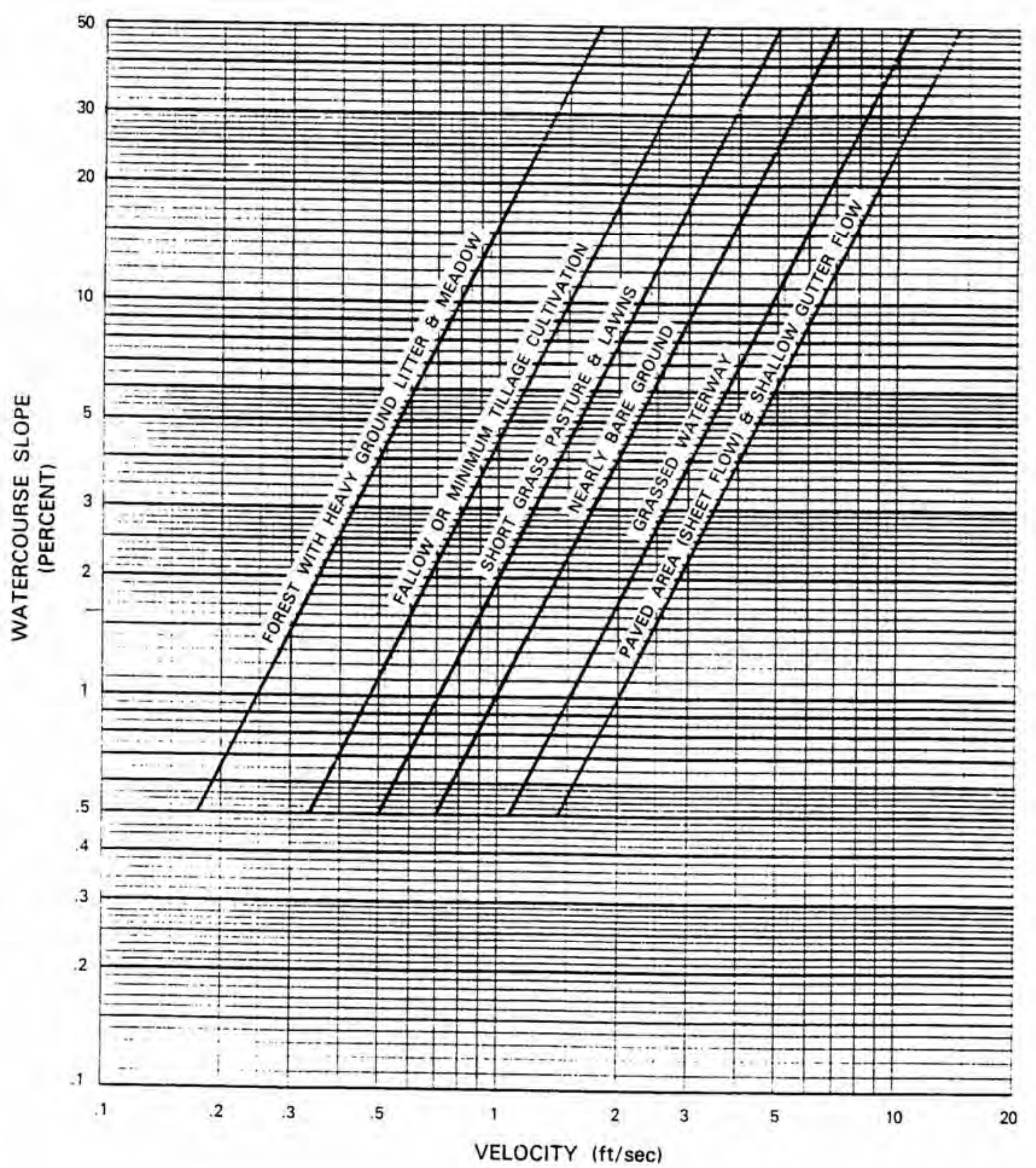
Rainfall Intensity (I; in inches/hour)

Rainfall intensity in the Rational Method is a function of: 1) selection of design flood frequency (see Exhibit 8-2) and 2) time of concentration (T_c), or the time required for the runoff to travel from the hydraulically most distant part of the watershed to the design site. It is usually computed by determining the water travel time through the watershed. The hydraulically most distant location will not necessarily be the linearly most distant site.

To determine i, follow this procedure:

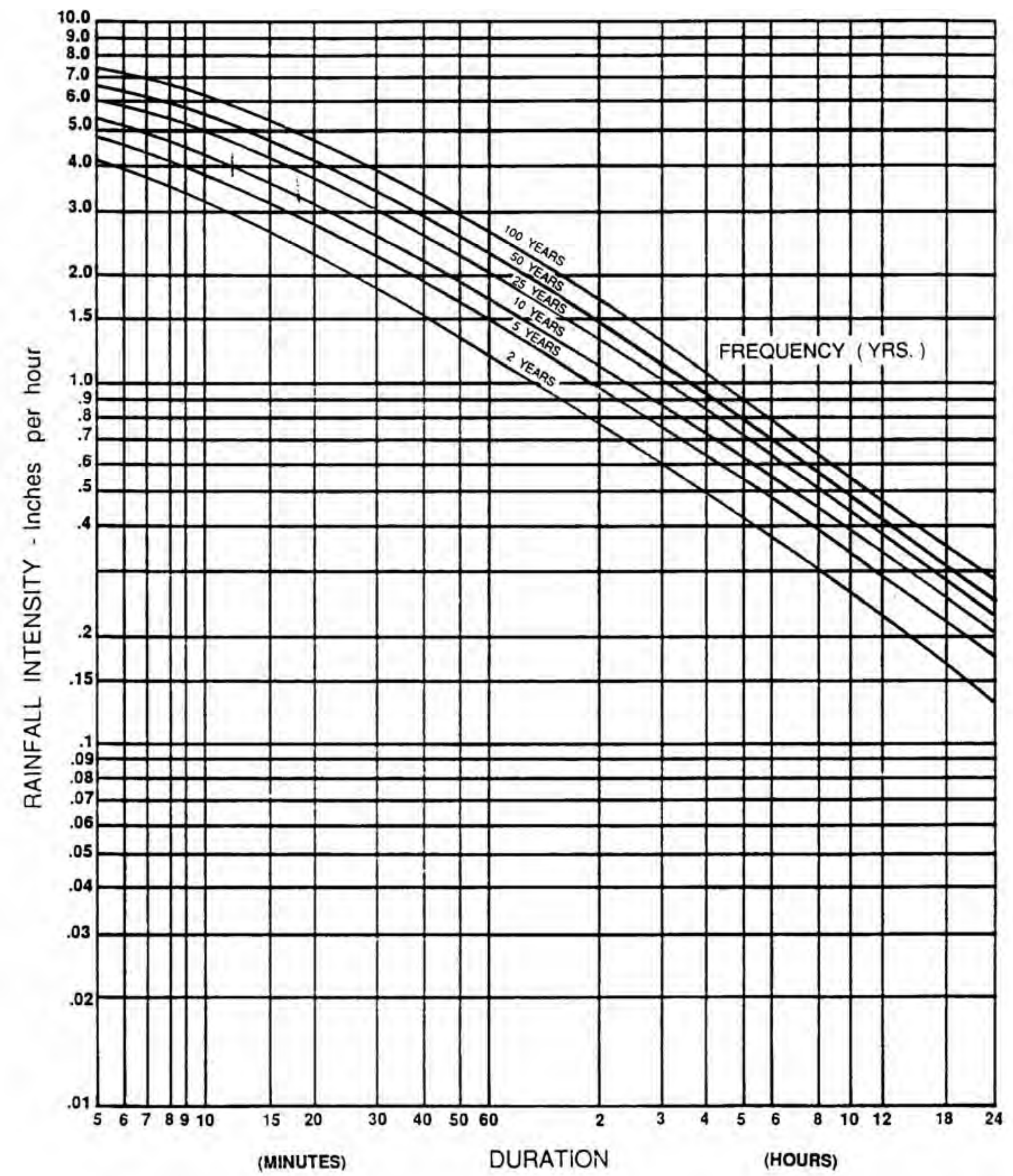
- To calculate T_c, use Exhibit 8-11. For pavements T_c is normally assumed to be 5 minutes for the first inlet only. T_c is based on the slope of the water course and the type of surface cover. The designer should check several overland watercourses or flow routes to determine T_c. See the example for a T_c calculation. For an alternate method for computing T_c, the designer should refer to the procedure in FHWA-NHI-01-021 *Urban Drainage Design Manual* (HEC-22).
- Exhibits 8-12 to 8-16 provide intensity-duration-frequency (I-D-F) curves for Boston, Barnstable, Worcester, Springfield, and Pittsfield. The designer should select the station closest to the design site.
- Enter the selected I-D-F curve with the calculated T_c and turn at the selected design flood frequency. Read i from the vertical axis.

Exhibit 8-11
Average Velocities for Overland Flow



Source: TR55 - Urban Hydrology for Small Wetlands, NRCS

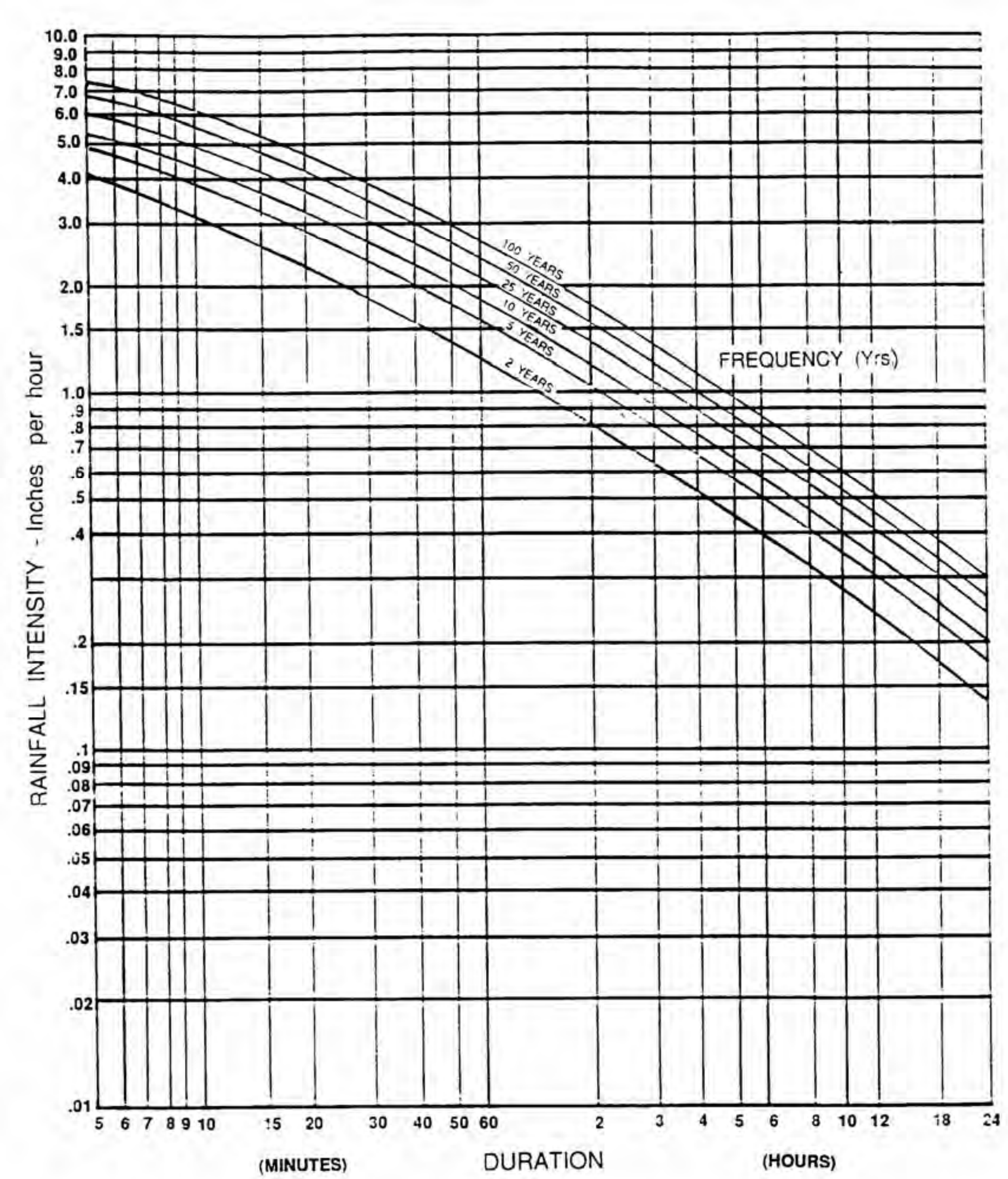
Exhibit 8-12
Intensity - Duration - Frequency Curve for Boston, MA



Source: TR55 - Urban Hydrology for Small Wetlands, NRCS

Exhibit 8-13

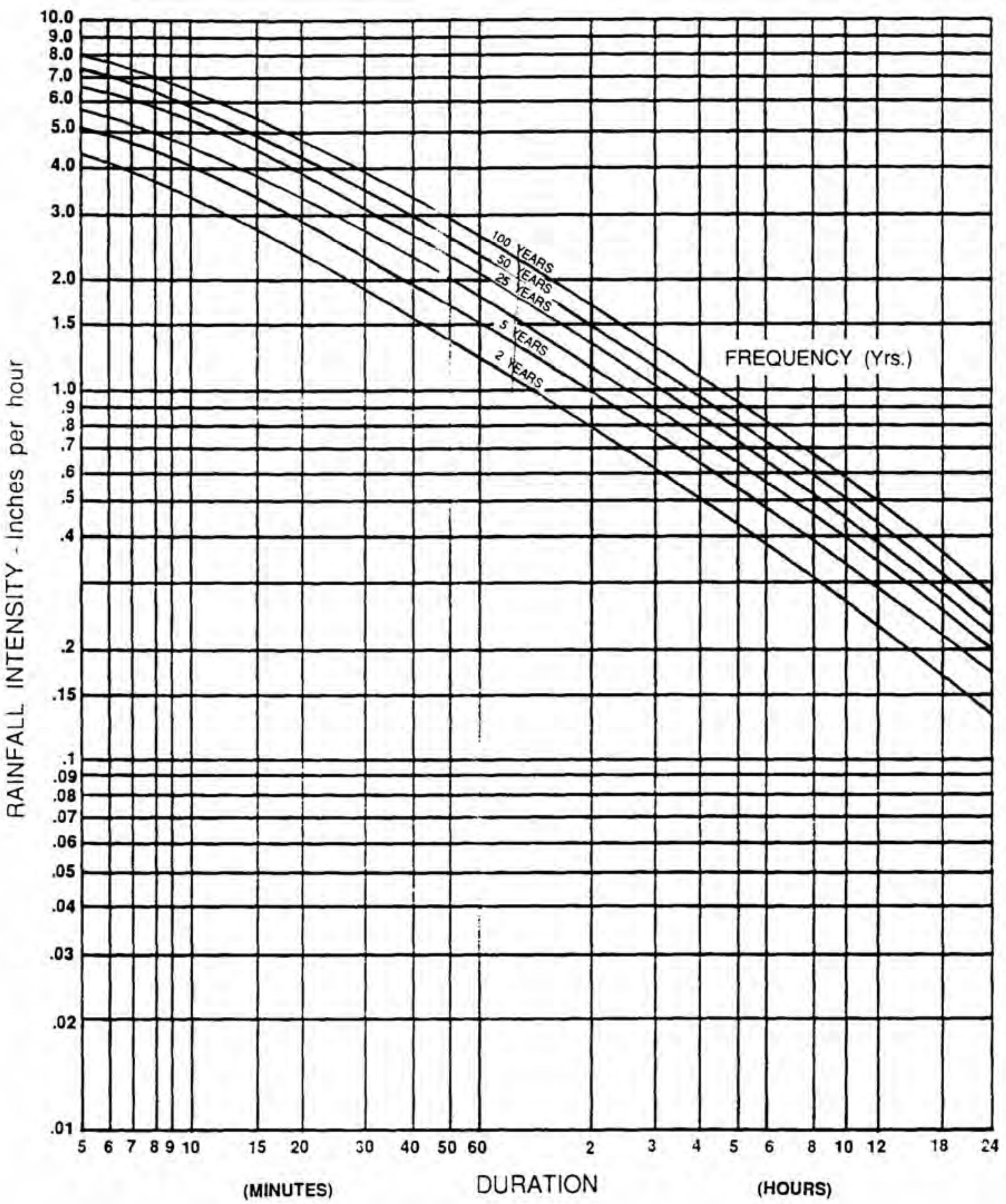
Intensity - Duration - Frequency Curve for Barnstable, MA



Source: TR55 - Urban Hydrology for Small Wetlands, NRCS

Exhibit 8-14

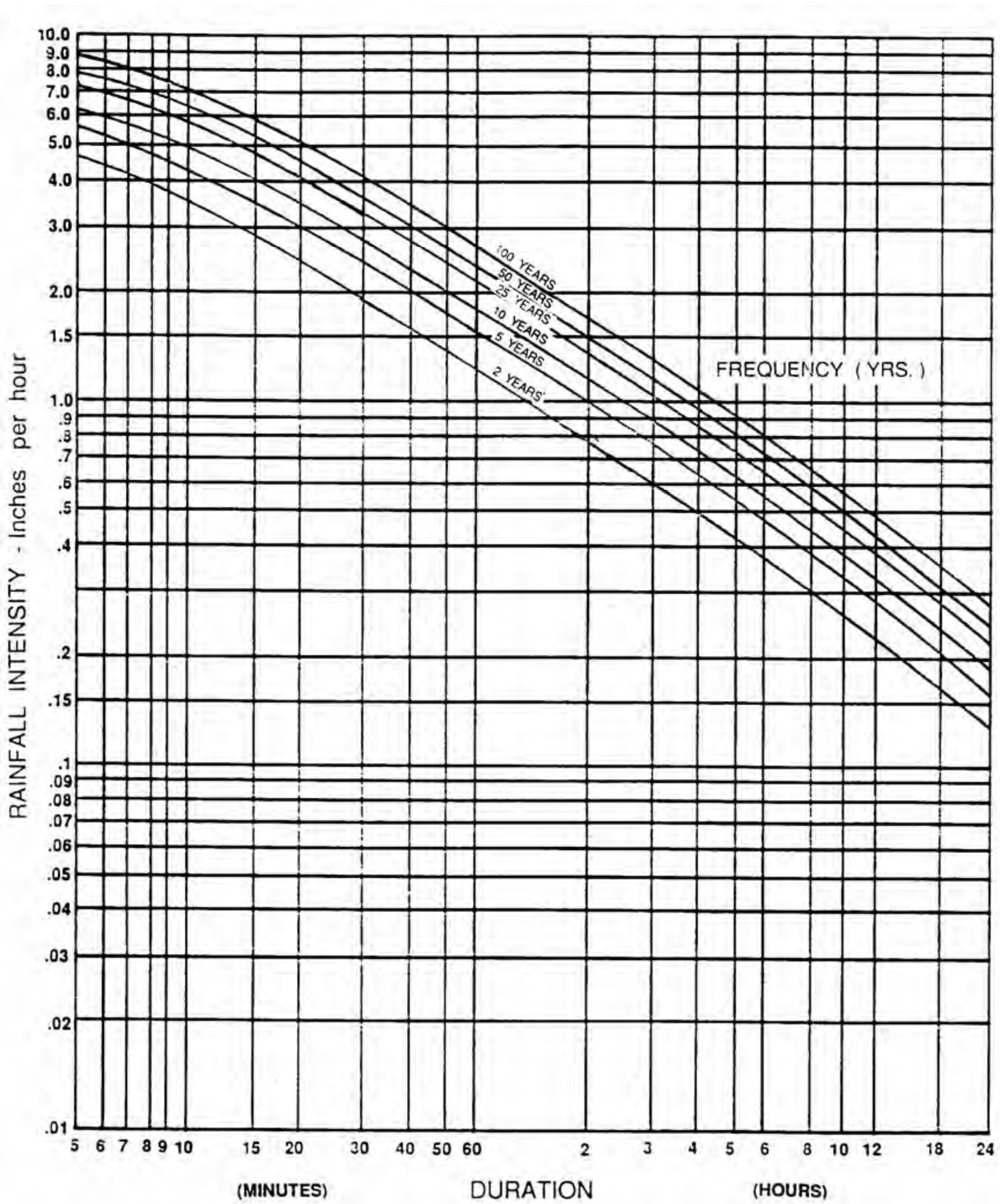
Intensity – Duration – Frequency Curve for Worcester, MA



Source: TR55 - Urban Hydrology for Small Wetlands, NRCS

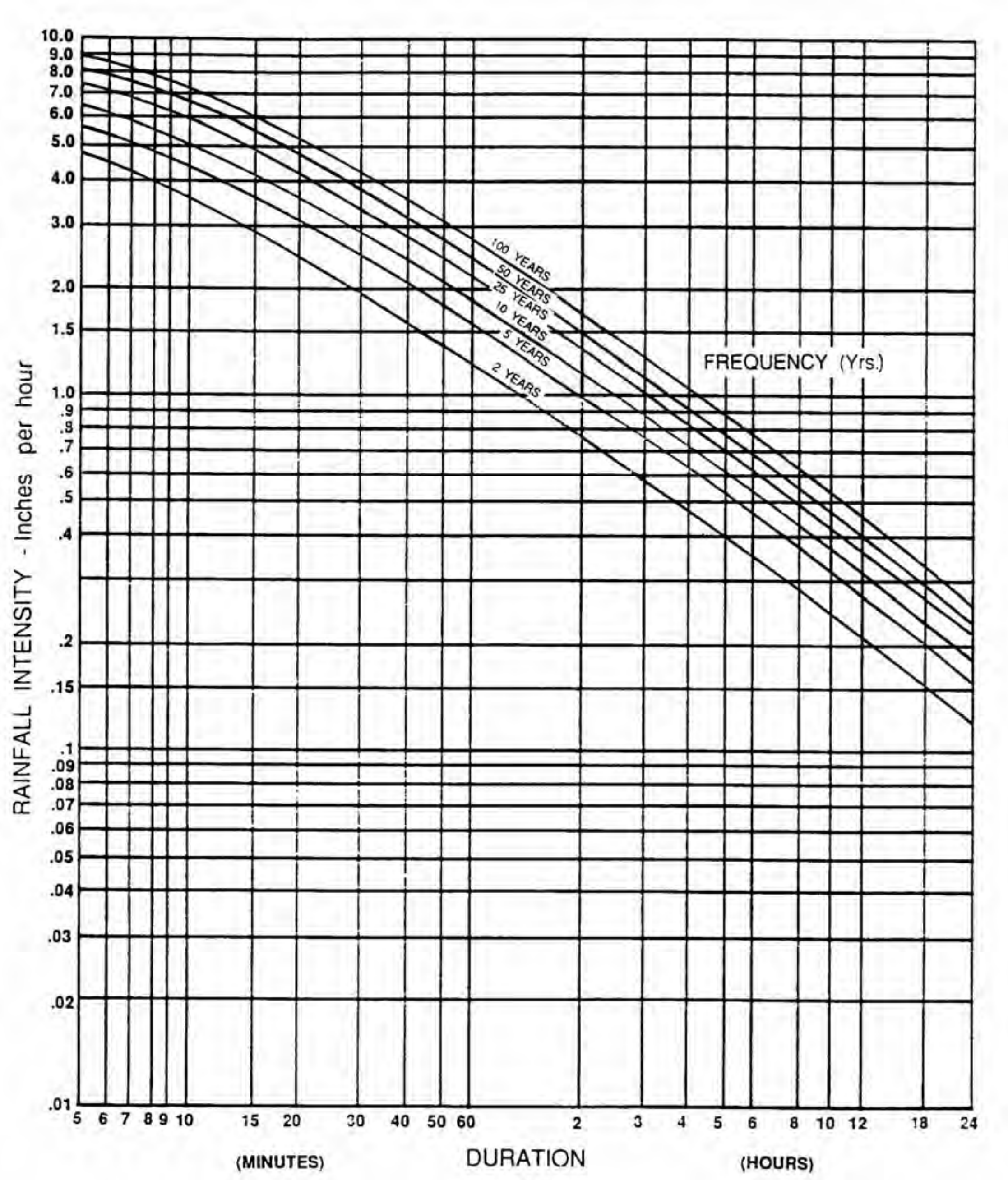
Exhibit 8-15

Intensity - Duration - Frequency Curve for Springfield, MA



Source: TR55 - Urban Hydrology for Small Wetlands, NRCS

Exhibit 8-16
Intensity – Duration – Frequency Curve for Pittsfield, MA



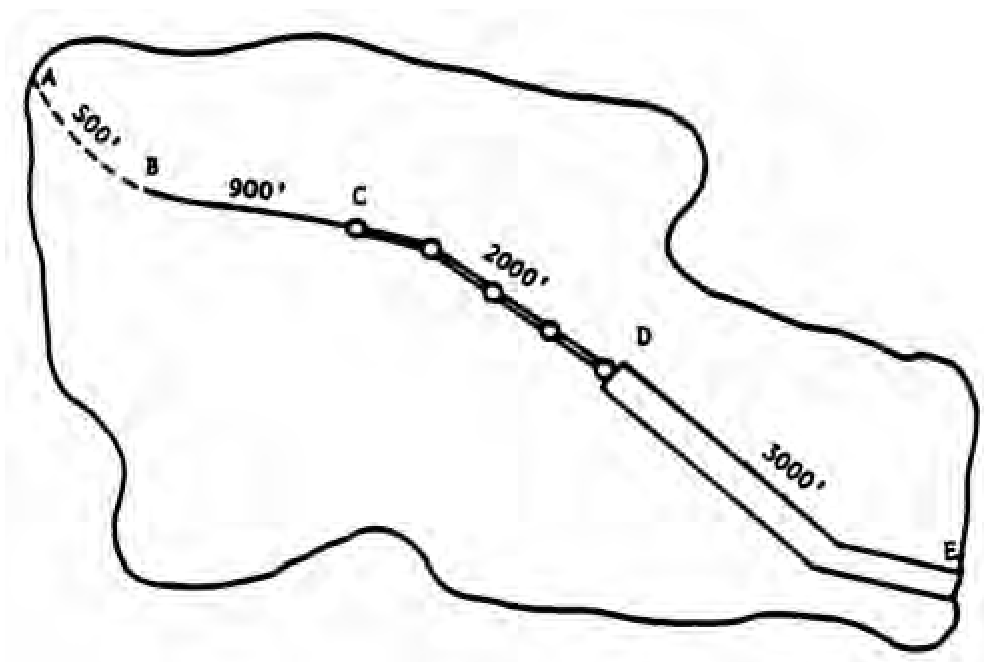
Source: TR55 - Urban Hydrology for Small Wetlands, NRCS

Example 1: (T_c)

Given: The figure below illustrates an urbanized watershed. The following describes the watershed:

Reach	Description	Slope (%)	Length (ft)
A-B	Overland (forest)	7.0	500
B-C	Overland (shallow gutter)	2.0	900
C-D	Storm drain(D = 36”, n = .015)	1.5	2000
D-E	Open channel, gunite, trapezoidal	0.5	3000

Problem: Determine T_C from A to E.



Solution: Compute the travel time (Tt) for each segment of the watercourse and sum up the times:

1. A-B — From Exhibit 8-11 for a slope of 7% and forest cover, read V = 0.7 ft./sec.

Tt = length/velocity = 500/0.7 = 714 sec.

2. B-C — From Exhibit 8-11 for a slope of 2% in a shallow gutter, read V = 2.8 ft./sec.

   Tt = 900/2.8 = 321 sec.

3. C-D — Use Manning's equation for a pipe flowing full to find V = 10 ft./sec. (see Section 8.3.1).

   Tt = 2000/10 = 200 sec.

4. D-E — Use Manning's equation for open channel flow to find V = 8.2 ft./sec. (see Section 8.3.1).

   Tt = 3000/8.2 = 366 sec.

The total travel time for the watercourse is 714 + 321 + 200 + 366 = 1601 sec. Therefore:

Tc 1601/60 = 26.7 min.

Example 2 (Rational Method)

Given: The location is a suburban residential area in Norfolk County with a closed storm drainage system. The road is a two-lane bituminous concrete facility, 30 feet curb-to-curb, and crowned in the center. The grade is 3%. The first inlet will be located 300 feet from the vertical crest. The following data describes the drainage basin to the first inlet:

A = 2 acres
Tc = 8 minutes

Problem: Determine peak discharge delivered to the inlet for a 10-year design flood frequency.

Solution: For the first inlet in storm drain design, two calculations are necessary. The designer should determine the discharge for the pavement and the discharge for the entire drainage area. The larger of the two will be selected. This is further discussed in Section 8.3.4. The discharge for the pavement is:

A = (30/2)(300) = 4500 sq. ft. = .103 acre

C = 0.9 (from Exhibit 8-9)
Tc = 5 min.
i = 5.3 in./hr (from Exhibit 8-12 for 10 year frequency)
Q = CiA = .9 x 5.3 x .103 = .49 cfs

The discharge for the drainage basin is:

C = 0.35 (from Exhibit 8-8)
i = 4.7 in./hr.
Q = CiA = .35 x 4.7 x 2 = 3.29 cfs

The drainage basin produces the greatest discharge and should, therefore, be used for the design discharge into the first inlet.

8.3.2.3 Natural Resource Conservation (NRCS) Method

The NRCS method (formerly the SCS method) is named "The Modified Soil Cover Complex Method," as described in Appendix B of *Guidelines for Soil and Water Conservation in Urbanizing Areas of Massachusetts*, October, 1977. The NRCS Method is also described in detail in Technical Release No. 55, *Urban Hydrology for Small Watersheds*, U.S. Soil Conservation Service, revised 2003 The retention characteristic of the soil is expressed as a "curve number" (CN). A series of charts are used to determine the peak discharge (Q) in cfs based on:

- Drainage area (in acres),
- Curve number (determined by soil type and land use),
- Watershed slope (flat, moderate, or steep), and
- 24-hr precipitation for the design frequency.

The basic NRCS approach incorporates several parameters as listed in Exhibit 8-3. In addition, the designer can make adjustments for varying slopes, storage (swamps, ponds, etc,), and watershed shape factors when using the NRCS method to calculate the peak discharge, the following procedure should be used:

- Determine the size of the drainage area.
- Estimate the average slope of the watershed (flat: 0-3%; moderate: 3-8%; steep: >8%).

- Select the appropriate CN based on the land use, hydrologic soil group, and hydrologic conditions. (See Exhibits 8-17 and 8-18 for CN values). Soil classification maps can be obtained at the Natural Resources Conservation Service (NRCS) main office in Amherst, Massachusetts, or at the NRCS regional office
- Determine the 24-hr precipitation for the design year and location within the state.
- Determine the peak runoff from the appropriate chart in the NRCS method
- Make any necessary adjustments for slopes, storage, or shape factor.

Example: (NRCS)

Given: Watershed Area = 100 acres near Springfield
Average Slope = Moderate
Hydrologic Soil Group = B Woods with fair hydrologic condition

Problem: Determine the peak discharge for a 10-year design frequency.

Solution: Q is calculated as follows:
CN = 60 (Exhibit 8-18)
Rainfall = 4.6 in, determined using Exhibit 8-19)
Q = 38 cfs (determined using Exhibit 8-20)

Note that Exhibit 8-20 is only for a CN = 60 with moderate slopes.

The NRCS Method can also be used to develop flood hydrographs and calculate runoff volumes necessary for designing peak discharge controls. The designer should consult Technical Release No. 55, *Urban Hydrology for Small Watersheds*, U.S. Soil Conservation Service, revised June 1986, when developing flood hydrographs, calculating runoff volumes and designing peak discharge controls. The TR-55 and TR-20 computer programs are available from the U. S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) at http://www.wcc.nrcs.usda.gov/hydro/hydro-tools-models.html. Computer software for the NRCS Method is also available from Applied Microcomputer Systems, Haestad Methods and other computer software companies.

Exhibit 8-17
Runoff Curve Numbers for Urban Areas[1]

Cover Description		Curve Numbers for Hydrologic Soil Group			
Cover Type and Hydrologic Condition	Average Percent Impervious Area[2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas:					
Newly graded areas (pervious areas only, no vegetation)[5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in Table 2-2c).					

1 Average runoff condition, and Ia = 0.2S.
2 The average percent impervious area shown was used to develop the composite CNs. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CNs for other combinations of conditions may be computed using figure 2-3 or 2-4.
3 CNs shown are equivalent to those of pasture. Composite CNs may be computed for other combinations of open space cover type.
4 Composite CNs for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CNs are assumed equivalent to desert shrub in poor hydrologic conditions.
5. Composite CNs to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4, based on the degree of development (impervious area percentage) and the CNs for the newly graded pervious areas

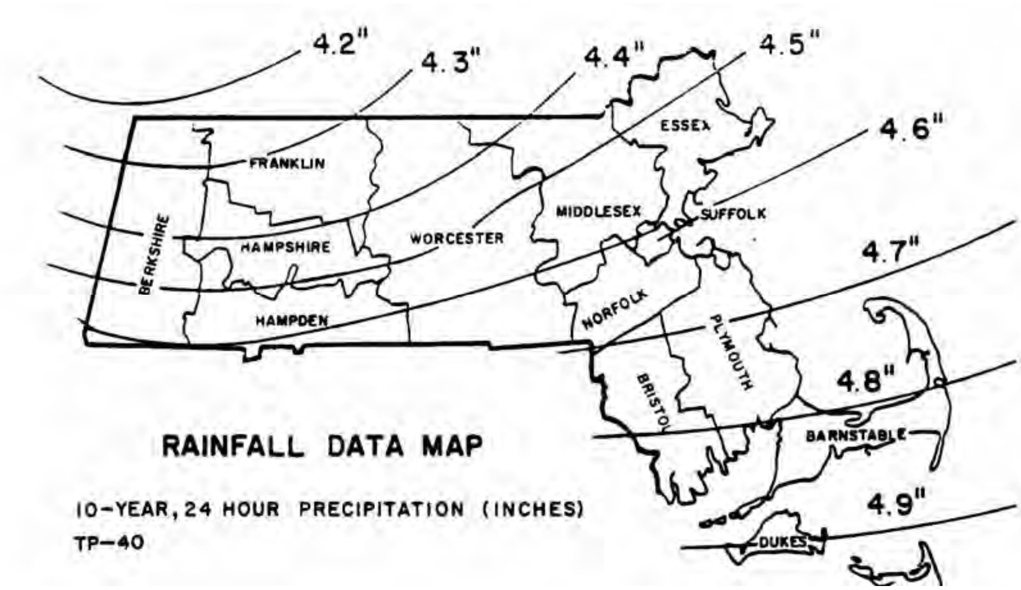
Source: TR55 - Urban Hydrology for Small Wetlands, NRCS

Exhibit 8-18
Runoff Curve Numbers For Other Agricultural Lands[1]

Cover Description		Curve Numbers for Hydrologic Soil Group			
Cover Type and Hydrologic Condition	Hydrologic Condition	A	B	C	D
Pasture, grassland, or range — continuous forage for grazing[2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow— continuous grass, protected from grazing and generally mowed for hay	—	30	58	71	78
Brush— brush-weed-grass mixture with brush the major element[3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30[4]	48	65	73
Woods— grass combination (orchard or tree farm)[5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods[6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30[4]	55	70	77
Farmsteads — buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

1 Average runoff condition, and Ia = 0.2S.
2 Poor: <50% ground cover or heavily grazed with no mulch. Fair: 50 to 75% ground cover and not heavily grazed. Good: >75% ground cover and lightly or only occasionally grazed.
3 Poor: <50% ground cover. Fair: 50 to 75% ground cover. Good: >75% ground cover.
4 Actual curve number is less than 30; use CN = 30 for runoff computations.
5 CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.
6 Poor: Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.
7 For CNs for cultivated agricultural lands such as row crops see TR55
Source: TR55 - Urban Hydrology for Small Wetlands, NRCS

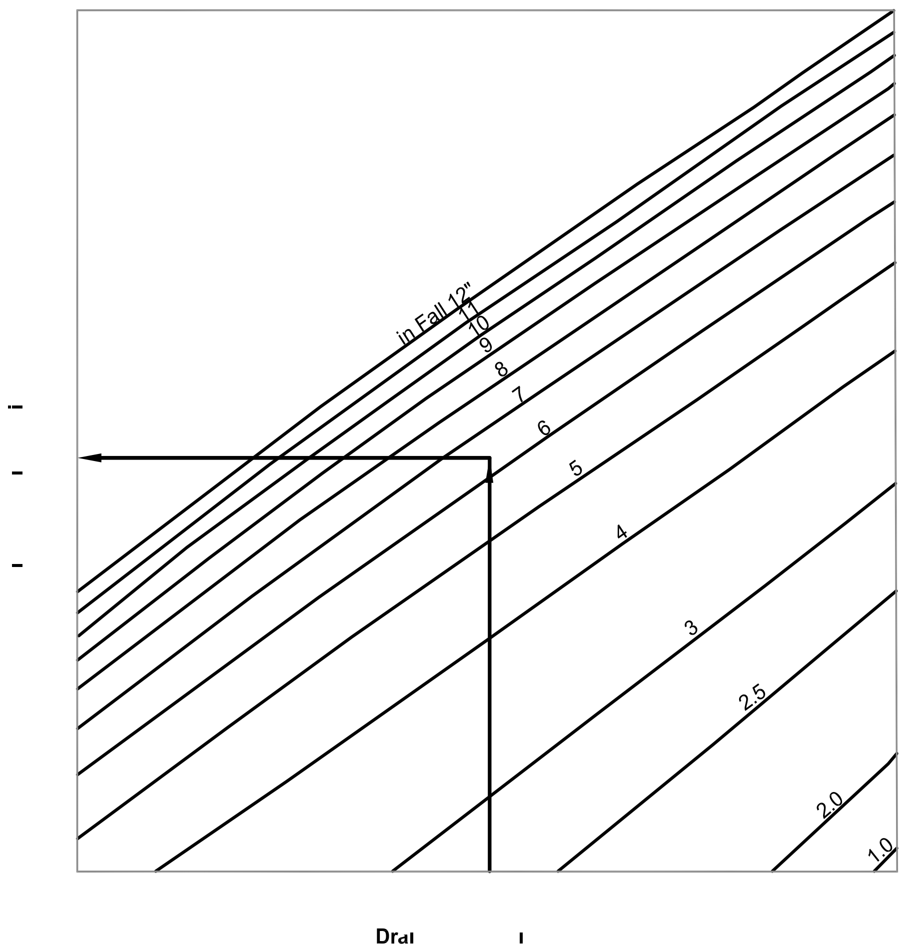
Exhibit 8-19
Rainfall Data Map



Reference: Guidelines for Soil & Water Conservation in Urbanizing Areas of Massachusetts, NRCS

Exhibit-20

Peak Discharge Determination



Slopes – Moderate Curve Number 60 24 Hour Rainfall from US WM TP 40
Source: Guidelines for Soil & Water Conservation in Urbanizing Areas of Massachusetts, NRCS.

8.3.3 Effects of Storage

Storage has the effect of reducing the peak discharge, thus reducing the required sizes of the drainage structures. Each of the hydrologic methods used, except the Rational Method, accounts for natural storage (swamps and ponds) that is spread throughout the drainage area. The NRCS Method has adjustment factors for natural storage near the design site. Natural (or man-made) storage at the upper reaches of the watershed area is usually ignored, depending on the level of the detail required by the hydrologic evaluation. The designer must consider any future changes in the existing upstream watershed, that it is anticipated would reduce existing storage capacity in the future.

The effects of man-made storage areas, such as reservoirs and flood control systems, should also be evaluated. The designer should refer to the procedure in Chapter 8 of FHWA-TS-84-202 *Drainage of Highway Pavements* and the *MassHighway Drainage Manual*

The NRCS Method can be used to develop flood hydrographs and estimate runoff volumes that can be used in evaluating the storage capacity of existing drainage systems particularly at the inlet side of existing culverts.

The NRCS Method can also be used to size proposed detention basins that can provide additional storage in order to mitigate increases in peak discharge. The designer should use the *MassHighway Storm Water Handbook* to determine whether detention areas will need to be designed in order to mitigate increases in peak discharge as part of the project.

Detention storage facilities are designed to reduce peak discharge and detain runoff for short periods of time. The following information, at a minimum, is required to prepare a detention storage facility design:

- Inflow hydrograph for all selected design storms.
- A stage-storage curve defining the relationship between the depth of water and the storage volume of the proposed facility.
- A stage-discharge curve defining the relationship between the depth of water and the discharge or outflow for all outlet control structures to be used on the proposed facility.

A general procedure for performing a detention storage facility design is presented below:

- Step 1: Compute inflow hydrograph for runoff from the 2, 10 and 100 year design storms. Both pre- and post-development hydrographs are required.
- Step 2: Perform preliminary calculations to evaluate the detention storage requirements for the hydrographs from Step 1. If the storage requirements are satisfied for runoff from the 2 and 10

year design storms, runoff from intermediate storms is assumed to be controlled.

- Step 3: Determine the physical dimensions necessary to hold the estimated volume from Step 2, including freeboard. The maximum storage requirement calculated from Step 2 should be used.
- Step 4: Size the outlet structure. The estimated peak stage will occur for the estimated volume from Step 2. The outlet structure should be sized to convey the allowable discharge at this stage.
- Step 5: Perform routing calculations using inflow hydrographs from Step 1 to check the preliminary design using the storage routing equations. If the routed post-development peak discharges from the 2 and 10 year design storm exceed the pre-development peak discharges, or if the peak stage varies significantly from the estimated peak stage from Step 4, then revise the estimated volume and return to Step 3.
- Step 6: Consider emergency overflow from the runoff due to the 100 year or larger design storm and established freeboard requirements.
- Step 7: Evaluate the downstream effects of detention outflow to ensure that the routed hydrograph does not cause downstream flooding problems.
- Step 8: Evaluate the control structure outlet velocity and provide channel and bank stabilization if the velocity would cause erosion problems downstream.

This procedure can involve a significant number of reservoir routing calculations to obtain the desired results. The designer should refer to Chapter 8 of FHWA-TS-84-202 *Drainage of Highway Pavements* and the *MassHighway Drainage Manual* when designing detention storage facilities.

8.4 Hydraulic Design

This section of Chapter 8 discusses the design of drainage courses and structures.

8.4.1 Roadside Drainage (Open Channels)

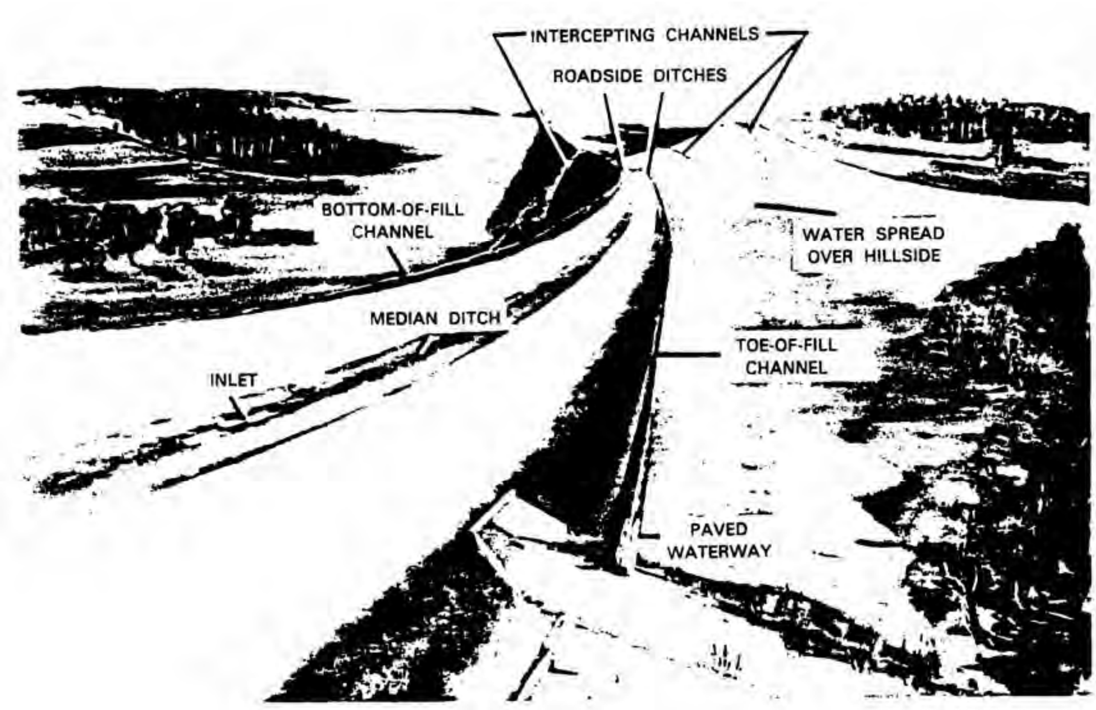
Roadside drainage channels remove and divert surface runoff from the highway right-of-way. Normally, they are the least expensive means to provide highway drainage.

Roadside drainage channels and median swales can also be used to lengthen the time of concentration by creating longer flow paths and using rough and vegetated channel linings. Drainage channels and median swales can also be used to create opportunities for infiltration and detention through the use of vegetation, natural substrates and check dams.

Exhibit 8-21 illustrates several types of roadside drainage channels. These are:

- ***Roadway Channels*** — provided in cut sections to remove the storm runoff.
- ***Bottom-of-Slope Channels*** — provided at the bottom of a slope to convey the storm runoff from roadway channels to a discharge point.
- ***Intercepting Channels*** — provided longitudinally at the top of a cut to intercept runoff from the hillside before it reaches the roadway.
- ***Paved Waterways*** — usually steeply inclined open channels having an armored invert which convey water to a lower level.
- ***Median Swales*** — shallow, depressed areas in medians which drain the median area of a divided highway.
- ***Gutters*** (not shown in figure) — channels at the pavement or shoulder edges which drain the roadway surface.

Exhibit 8-21
Types of Roadside Drainage Controls



Source: Design Charts for Open Channel Flow, HDS #3, FHWA, 1973.

References for roadside drainage design include:

- *Design Charts for Open Channel Flow,* Hydraulic Design Series No. 3 (HDS #3), Federal Highway Administration, 1973.
- *Design of Roadside Drainage Channels*, Hydraulic Design Series No. 4 (HDS #4), Federal Highway Administration (FHWA), 1983.
- *Design of Stable Channels With Flexible Linings*, Hydraulic Engineering Circular No. 15 (HEC #15), October, 1975.

8.4.1.1 Definitions

There are many important definitions to understand in hydraulic design:

Steady Flow — exists when the quantity of water passing any section is constant with time. At any point, the rates of inflow and outflow must be constant and equal.

Unsteady Flow — exists when there are variations in the discharge with time.

Uniform Flow — results from a constant channel cross section, grade, and roughness. The depth, slope, and velocity will remain constant over a given length of channel. The slopes of the channel bottom, hydraulic gradient, and energy gradient are equal.

Non-Uniform Flow — occurs when the depth of flow changes along the length of the open channel.

Specific Energy — the total energy head at a cross section measured from the bottom of the channel. It is the sum of the potential head (depth) and the velocity head (kinetic energy).

Hydraulic Grade Line — the line defined by the water surface in the open channel. The slope of the line is the hydraulic gradient.

Velocity Head — the kinetic energy of the flow which equals the average velocity squared divided by two times the gravitational constant g.

Energy Grade Line — the line defined by a distance of the velocity head above the hydraulic grade line. The slope of the line is the energy gradient.

Critical Flow — exists when the discharge is maximum for a given specific energy head or, conversely, when the specific energy head is minimum for a given discharge.

Critical Depth — the depth of flow at which the discharge is maximum for a given specific energy, or the depth at which a given discharge occurs with minimum specific energy.

Critical Velocity — the mean velocity when the discharge is critical flow.

Critical Slope — that slope which will sustain a given discharge at uniform critical depth in a given channel.

Subcritical Flow — flow which occurs when the depth is greater than critical depth and the velocity is less than critical velocity.

Supercritical Flow — flow which occurs when the depth is less than critical depth and the velocity is greater than critical velocity.

8.4.1.2 Channel Capacity

The open channel must be designed to accommodate the peak discharge for the design frequency. The Manning equation is used to calculate the flow velocity:

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

The capacity of the channel is determined by:

$$Q = AV$$

Combining the two equations yields:

$$Q = A \frac{1.49}{n} R^{2/3} S^{1/2}$$

Where:
- Q = flow discharge (cu. ft./sec.)
- V = mean velocity (ft./sec.)
- A = cross-sectional area of wetted area (ft.^{2})
- N = Manning coefficient of channel roughness
- WP = wetted perimeter (ft.)
- R = hydraulic radius (ft.) = A/WP
- S = slope of energy gradient (ft./ft.)

The Manning equation is used for open channel flow and unsubmerged culverts. The design of the pressure flow through culverts is discussed in Section 8.4.2. For most roadside drainage design, the designer can assume steady, uniform flow.

Use the following procedure to determine the capacity of the channel:

1) Select the basic channel cross section (trapezoidal, rectangular, etc.). See discussion in Section 8.4.1.3.

2) Determine the channel slope.

3) Select the channel lining (grass, jute mesh, or paved). See discussion in Section 8.4.1.6.

4) Determine the roughness coefficient "n" (Exhibit 8-22). Ordinarily, use a value about midway in the range. Grass-lined channels must be evaluated separately.

5) Determine the required depth of the selected channel to accommodate the design storm frequency. Use one of these approaches:

   a) HDS #3 provides charts for the direct solution of the Manning equation for rectangular, trapezoidal, triangular, grass-lined trapezoidal, circular pipe, pipe arch, and oval concrete pipe channels. Examples 1 and 2 illustrate how to use the charts.

   b) For open channel sections not found in HDS#3, the designer must use a nomograph for the solution of the Manning equation. A trial-and-error procedure is necessary. Example 3 illustrates its use.

   c) After the three examples, the following are provided as design aids for the necessary calculations:

   i) Exhibit 8-25 "Hydraulic Elements of Channel Sections"
   ii) Exhibit 8-26 "Partial Area of Flow in a Circular Channel"
   iii) Exhibit 8-28 "Depth of Flow in a Trapezoidal Channel"

6) If possible, open channels (except paved waterways) should be designed for subcritical flow. Calculate dc, Vc, and Sc for the channel section and discharge. See Example 3 for determining these values when not using the standard charts. Determine if flow is subcritical or supercritical. In general, flow depths within ± 10% of dc should be avoided.

7) Calculate the design flow velocity where erodible linings are used. Compare with the maximum permissible velocities in Exhibits 8-23 and 8-24. See discussion in Section 8.4.1.6.

8) Once all of the above criteria have been satisfied, add a minimum of 2 feet, where practical, to the flow depth for freeboard for subcritical flow. For supercritical flow, the lining material should extend to the top of the channel or to a minimum of 2 feet above the flow depth. For roadside ditches, the ditch bottom in a cut section should be at least level with or 6 inches below the subgrade.

Exhibit 8-25 provides equations for the area, wetted perimeter and hydraulic radius of various channel shapes. Exhibit 8-26 provides adjustment coefficients for partial flow in circular pipes

Exhibit 8-22
Manning Roughness Coefficient, n[1]

	Manning's n range[2]
I. Closed conduits:	
A. Concrete pipe	0.011–0.013
B. Corrugated-metal pipe or pipe-arch:	
1. 2⅔ by ½-in. corrugation (riveted pipe):[3]	
a. Plain or fully coated	0.024
b. Paved invert (range values are for 25 and 50 percent of circumference paved):	
(1) Flow full depth	0.021–0.018
(2) Flow 0.8 depth	0.021–0.016
(3) FLow 0.6 depth	0.019–0.013
2. 6 by 2-in. corrugation (field bolted)	0.03
C. Vitrified clay pipe	0.012–0.014
D. Cast-iron pipe, uncoated	0.013
E. Steel pipe	0.009–0.011
F. Brick	0.014–0.017
G. Monolithic concrete:	
1. Wood forms, rough	0.015–0.017
2. Wood forms, smooth	0.012–0.014
3. Steel forms	0.012–0.013
H. Cemented rubble masonry walls:	
1. Concrete floor and top	0.017–0.022
2. Natural floor	0.019–0.025
I. Laminated treated wood	0.015–0.017
J. Vitrified clay liner plates	0.015
II. Open channels, lined[4] (straight alinement):[5]	
A. Concrete, with surfaces as indicated:	
1. Formed, no finish	0.013–0.017
2. Trowel finish	0.012–0.014
3. Float finish	0.013–0.015
4. Float finish, some gravel on bottom	0.015–0.017
5. Gunite, good section	0.016–0.019
6. Gunite, wavy section	0.018–0.022
B. Concrete, bottom float finished, sides as indicated:	
1. Dressed stone in mortar	0.015–0.017
2. Random stone in mortar	0.017–0.020
3. Cement rubble masonry	0.020–0.025
4. Cement rubble masonry, plastered	0.016–0.020
5. Dry rubble (riprap)	0.020–0.030
C. Gravel bottom, sides as indicated:	
1. Formed concrete	0.017–0.020
2. Random stone in mortar	0.020–0.023
3. Dry rubble (riprap)	0.023–0.033
D. Brick	0.014–0.017
E. Asphalt:	
1. Smooth	0.013
2. Rough	0.016
F. Wood, planed, clean	0.011–0.013
G. Concrete-lined excavated rock:	
1. Good section	0.017–0.020
2. Irregular section	0.022–0.027
III. Open channels, excavated[4] (straight alinement,[5] natural lining):	
A. Earth, uniform section:	
1. Clean, recently completed	0.016–0.018
2. Clean, after weathering	0.018–0.020
3. With short grass, few weeds	0.022–0.027
4. In gravelly soil, uniform section, clean	0.022–0.025
B. Earth, fairly uniform section:	
1. No vegetation	0.022–0.025
2. Grass, some weeds	0.025–0.030
3. Dense weeds or aquatic plants in deep channels	0.030–0.035
4. Sides clean, gravel bottom	0.025–0.030
5. Sides clean, cobble bottom	0.030–0.040
C. Dragline excavated or dredged:	
1. No vegetation	0.028–0.033
2. Light brush on banks	0.035–0.050
D. Rock:	
1. Based on design section	0.035
2. Based on actual mean section:	
a. Smooth and uniform	0.035–0.040
b. Jagged and irregular	0.040–0.045
E. Channels not maintained, weeds and brush uncut:	
1. Dense weeds, high as flow depth	0.08–0.12
2. Clean bottom, brush on sides	0.05–0.08
3. Clean bottom, brush on sides, highest stage of flow	0.07–0.11
4. Dense brush, high stage	0.10–0.14
IV. Highway channels and swales with maintained vegetation[6,7] (vaules shown are for velocities of 2 and 6 f.p.s.):	
A. Depth of flow up to 0.7 foot:	
1. Bermudagrass, Kentucky bluegrass, buffalograss:	
a. Mowed to 2 inches	0.07–0.045
b. Length 4-6 inches	0.09–0.05
2. Good stand, any grass:	
a. Length about 12 inches	0.18–0.09
b. Length about 24 inches	0.30–0.15
3. Fair stand, any grass:	
a. Length about 12 inches	0.14–0.08
b. Length about 24 inches	0.25–0.13
B. Depth of flow 0.7-1.5 feet:	
1. Bermudagrass, Kentucky bluegrass, buffalograss:	
a. Moved to 2 inches	0.05–0.035
b. Length 4 to 6 inches	0.06–0.04
2. Good stand, any grass:	
a. Length about 12 inches	0.12–0.07
b. Length about 24 inches	0.20–0.10
3. Fair stand, any grass:	
a. Length about 12 inches	0.10–0.06
b. Length about 24 inches	0.17–0.09
V. Street and expressway gutters:	
A. Concrete gutter, troweled finish	0.012
B. Asphalt pavement:	
1. Smooth texture	0.013
2. Rough texture	0.016
C. Concrete gutter with asphalt pavement:	
1. Smooth	0.013
2. Rough	0.015
D. Concrete pavement:	
1. Float finish	0.014
2. Broom finish	0.016
E. For gutters with small slope, where sediment may accumulate, increase above values of n by	0.002

Source: Design Charts for Open Channel Flow, HDS #3, FHWA, 1973

Exhibit 8-22 (Continued)
Manning Roughness Coefficient, n[1]

	Manning's n range[2]
VI. Natural stream channels:[8]	
A. Minor streams[9] (surface width at flood stage less than 100 ft):	
1. Fairly regular section:	
a. Some grass and weeds, little or no brush	0.030–0.035
b. Dense growth of weeds, depth of flow materially greater than weed height	0.035–0.05
c. Some weeds, light brush on banks	0.035–0.05
d. Some weeds, heavy brush on banks	0.05–0.07
e. Some weeds, dense willows on banks	0.06–0.08
f. For trees within channel, with branches submerged at high stage, increase all above values by	0.01–0.02
2. Irregular sections, with pools, slight channel meander; increase values given in 1a–e about	0.01–0.02
3. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stage:	
a. Bottom of gravel, cobbles, and few boulders	0.04–0.05
b. Bottom cobbles, with large boulders	0.05–0.07
B. Flood plains (adjacent to natural streams):	
1. Pasture, no brush:	
a. Short grass	0.030–0.035
b. High grass	0.035–0.05
2. Cultivated areas:	
a. No crop	0.03–0.04
b. Mature row crops	0.035–0.045
c. Mature field crops	0.04–0.05
3. Heavy weeds, scattered brush	0.05–0.07
4. Light brush and trees:[10]	
a. Winter	0.05–0.06
b. Summer	0.06–0.08
5. Medium to dense brush:[10]	
a. Winter	0.07–0.11
b. Summer	0.10–0.16
6. Dense willows, summer, not bent over by current	0.15–0.20
7. Cleared land with tree stumps, 100–150 per acre:	
a. No sprouts	0.4–0.05
b. With heavy growth of sprouts	0.06–0.08
8. Heavy stand of timber, a few down trees, little undergrowth:	
a. Flood depth below branches	0.10–0.12
b. Flood depth reaches branches	0.12–0.16
C. Major streams (surface width at flood stage more than 100 ft): Roughness coefficient is usually less than for minor streams of similar description on account of less effective resistance offered by irregular banks or vegetation on banks. Values of n may be somewhat reduced. Follow recommendation in publication cited[8] if possible. The value of n for larger streams of most regular section, with no boulders or brush, may be in the range of	0.028–0.033

Source: Design Charts for Open Channel Flow, HDS #3, FHWA, 1973.

1. Estimates are by Bureau of Public Roads unless otherwise noted.
2. Ranges indicated for closed conduits and for open channels, lines or excavated, are for good to fair construction (unless otherwise stated). For poor quality construction, use larger values of n.
3. Friction Factors in Corrugated Metal Pipe, by M.J. Webster and L.R. Metcalf, Corps of Engineers, Department of the Army: published in Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, vol. 85, No. HY9, Sept. 1959, Paper No. 2148, pp. 35-67.
4. For important work and where accurate determination of water profiles is necessary, the designer is urged to consult the following references and to select n by comparison of the specific conditions with the channels tested:
   Flow of Water in Irrigation and Similar Channels, by F.C. Scobey, Division of Irrigation, Soil Conservation Service, U.S. Department of Agriculture, Tech. Bull. No. 652, Feb. 1939; and
   Flow of Water in Drainage Channels, by C.E. Ramser, Division of Agricultural Engineering, Bureau of Public Roads, U.S. Department of Agriculture, Tech. Bull. No. 129, Nov. 1929.
5. With channel of an alignment other than straight, loss of head by resistance forces will be increased. A small increase in value of n may be made, to allow for the additional loss of energy.
6. Handbook of Channel Design for Soil and Water Conservation, prepared by the Stillwater Outdoor Hydraulic Laboratory in cooperation with the Oklahoma Agricultural Experiment Station; published by the Soil Conservation Service, U.S. Department of Agriculture, Publ. No. SCS-TP-61, Mar. 1947, rev. June 1954.
7. Flow of Water in Channels Protected by Vegetative Linings, by W.O. Ree and V.J. Palmer, Division of Drainage and Water Control, Research, Soil Conservation Service, U.S. Department of Agriculture, Tech. Bull. No. 967, Feb. 1949.
8. For calculation of stage or discharge in natural stream channels, it is recommended that the designer consult the local District Office of the Surface Water Branch of the U.S. Geological Survey, to obtain data regarding values of n applicable to streams of any specific locality. Where this procedure is not followed, the table may be used as a guide. The values of n tabulated have been derived from data reported by C.E. Ramser (see footnote 4) and from other incomplete data.
9. The tentative values of n cited are principally derived from measurements made on fairly short but straight reaches of natural streams. Where slopes calculated from flood elevations along a considerable length of channel, involving meanders and bends, are to be used in velocity calculations by the Manning formula, the value of n must be increased to provide for the additional loss of energy caused by bends. The increase may be in the range of perhaps 3 to 15 percent.
10. The presence of foliage on trees and brush under flood stage will materially increase the value of n. Therefore, roughness coefficients for vegetation in leaf will be larger than for bare branches. For trees in channel or on banks, and for brush on banks where submergence of branches increases with depth of flow, n will increase with rising stage.

Exhibit 8-23
Permissible Velocities for Channels with Erodible Linings[1]

Soil Type and Lining (earth; no vegetation)	Clear Water (f.p.s.)	Water Carrying Fine Silts (f.p.s.)	Water Carrying Sand and Gravel (f.p.s.)
Fine sand (noncolloidal)	1.5	2.5	1.5
Sandy loam (noncolloidal)	1.7	2.5	2.0
Silt loam (noncolloidal)	2.0	3.0	2.0
Ordinary firm loam	2.5	3.5	2.2
Volcanic ash	2.5	5.5	2.0
Fine gravel	2.5	5.0	3.7
Stiff clay (very colloidal)	3.7	5.0	3.0
Graded, loam to cobbles (noncolloidal)	3.7	5.0	5.0
Graded, silt to cobbles (colloidal)	4.0	5.5	5.0
Alluvial silts (noncolloidal)	2.0	3.5	2.0
Alluvial silts (colloidal)	3.7	5.0	3.0
Coarse gravel (noncolloidal)	4.0	6.0	6.5
Cobbles and shingles	5.0	5.5	6.5
Shales and hard pans	6.0	6.0	5.0

1 As recommended by Special Committee on Irrigation Research, American Society of Civil Engineers, 1926.
Source: Design Charts for Open Channel Flow, HDS #3, FHWA, 1973.

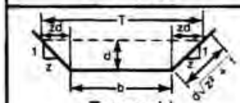
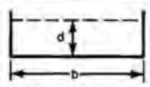
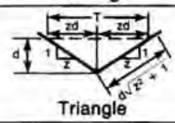
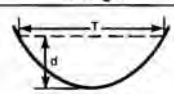
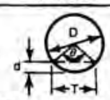
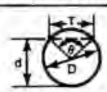
Exhibit 8-24
Permissible Velocities for Channels Lined with Grass[1-2]

Cover	Slope Range (%)	Erosion Resistant Soils (*f.p.s.*)	Easily Eroded Soils (*f.p.s.*)
Bermuda grass	0-5 5-10 Over 10	8 7 6	6 5 4
Buffalo grass Kentucky bluegrass Smooth broome Blue grama	0-5 5-10 Over 10	7 6 5	5 4 3
Grass mixture	0-5 5-10	5 4	4 3
Lespedeza sericea Weeping lovegrass Yellow bluestem Alfalfa Crabgrass	0-5	3.5	2.5
Common lespedeza[3] Sundangrass[3]	0-5[4]	3.5	2.5

1 From Handbook of Channel Design for Soil and Water Conservation (see footnote 6, Table 1, above.)
2 Use velocities over 4 f.p.s. only where good covers and proper maintenance can be obtained.
3 Annuals, used on mild slopes or as temporary protection until permanent covers are established.
4 Use on slopes steeper than 5 percent is not recommended.
Source Design Charts for Open Channel Flow, HDS #3, FHWA, 1973.

Exhibit 8-25

Hydraulic Elements of Channel Sections

Section	Area a	Wetted Perimeter p	Hydraulic Radius r	Top Width T
 Trapezoid	$bd + zd^2$	$b + 2d\sqrt{z^2 + 1}$	$\frac{bd + zd^2}{b + 2d\sqrt{z^2 + 1}}$	$b + 2zd$
 Rectangle	bd	$B + 2d$	$\frac{bd}{b + 2d}$	b
 Triangle	zd^2	$2d\sqrt{z^2 + 1}$	$\frac{zd}{2\sqrt{z^2 + 1}}$	$2zd$
 Parabola	$\frac{2}{3}dT$	$T + \frac{8d^2}{3T}$ 1	$\frac{2dT^2}{3T^2 + 8d^2}$ 1	$\frac{3a}{2d}$
 Circle–< ½ full 2	$\frac{D^2}{8}\left(\frac{\pi\theta}{180} - \sin\theta\right)$	$\frac{\pi D\theta}{360}$	$\frac{45D}{\pi\theta}\left(\frac{\pi\theta}{180} - \sin\theta\right)$	$D \sin\frac{\theta}{2}$ or $2\sqrt{d(D-d)}$
 Circle–> ½ full 3	$\frac{D^2}{8}\left(2\pi - \frac{\pi\theta}{180} + \sin\theta\right)$	$\frac{\pi D(360-\theta)}{360}$	$\frac{45D}{\pi(360-\theta)}\left(2\pi - \frac{\pi\theta}{180} + \sin\theta\right)$	$D \sin\frac{\theta}{2}$ or $2\sqrt{d(D-d)}$

1. Satisfactory approximation for the interval $0 < \frac{d}{T} \leq 0.25$

   When $\frac{d}{T} > 0.25$, use $p = \frac{1}{2}\sqrt{16d^2 + T^2} + \frac{T^2}{8d}\sinh^{-1}\frac{4d}{T}$
2. $\theta = 4\sin^{-1}\sqrt{d/D}$
3. $\theta = 4\cos^{-1}\sqrt{d/D}$

Insert θ in degrees in above equations

Source: Handbook of Hydraulics, H.W. King, 1954

Exhibit 8-26
Partial Area of Flow in a Circular Pipe (Values of C)

d / D	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0		.0013	.0037	.0069	.0105	.0147	.0192	.0242	.0294	.0350
.1	.0409	.0470	.0534	.0600	.0668	.0739	.0811	.0885	.0961	.1039
.2	.1118	.1199	.1281	.1365	.1449	.1535	.1623	.1711	.1800	.1890
.3	.1982	.2074	.2167	.2260	.2355	.2450	.2546	.2642	.2739	.2836
.4	.2934	.3032	.3130	.3229	.3328	.3428	.3527	.3627	.3727	.3827
.5	.393	.403	.413	.423	.433	.443	.453	.462	.472	.482
.6	.492	.502	.512	.521	.531	.540	.550	.559	.569	.578
.7	.587	.596	.605	.614	.623	.632	.640	.649	.657	.666
.8	.674	.681	.689	.697	.704	.712	.719	.725	.732	.738
.9	.745	.750	.756	.761	.766	.771	.775	.779	.782	.784
1.0	.785									

Source: *Handbook of Hydraulics*, H.W. King, 1954.
A = $C D^2$
D = Diameter of Pipe
d = Depth of Flow
C = Coefficient
A = Flow Area

Note: The vertical d/ D column should be read for the tenths value, and the horizontal d/ D row should be read for the hundredths value. For example, if d/ D = .56 use .5 in the column and .06 in the row to read C = .453.

Example 1: (Trapezoidal Channel)

Given: Cross Section: Trapezoidal channel with b = 4'; 2:1 front and back slopes
Slope = 0.04 ft./ft.
Q = 100 cfs

Problem: Determine necessary channel depth, critical flow conditions, and lining requirements.

Solution: The procedure outline in Section 8.4.1.2 is followed:

Step 1: Given

Step 2: Given

Step 3: A paved lining is necessary for a 4% slope. Asphalt (smooth) will be used.

Step 4: n = 0.013

Step 5: Use Exhibit 8-27 to determine flow information. The figure is only valid for n = 0.03. Therefore, the auxiliary Qn and Vn scales must be used for
n = .013:

$$Qn = 100 \times .013 = 1.3$$

Move vertically from 1.3 on the Qn scale to the slope of 0.04. Read d = 0.95 ft. Move horizontally to the Vn scale and read Vn = .23. Therefore:

$$V = .23/.013 = 17.7 \text{ ft./sec.}$$

Step 6: dc and Vc are independent of the value of n. Move vertically from Q = 100 to the critical curve. Read dc = 1.95ft. and Vc = 6.5 ft./sec. The normal depth is less than dc, and the normal velocity is greater than Vc. Therefore, flow is supercritical. Also note that d is not within ±10% of dc. To determine Sc, relocate dc = 1.95 for Q = 100. Move along this dc, line until Qn = 1.3 line is intersected. Read S_c .0027.

Step 7: Not applicable.

Step 8: For supercritical flow, the minimum depth of the paved lining is:

$$d_{min} = 0.95 + 2.0 = 2.95 \text{ ft.}$$

Note: As an alternative, Exhibit 8-28 can be used to calculate the depth. The following would be known:

Q = 100	Z = 2
n = .013	S = .04
b = 4	

The horizontal scale would be read at 0.16. Move vertically until the Z = 2 line is intersected. Move horizontally and read d/b = .24. Therefore:

$$d = 4 \times .24 = 0.96 \text{ ft.}$$

Exhibit 8-27

Trapezoidal Channel - Example 1

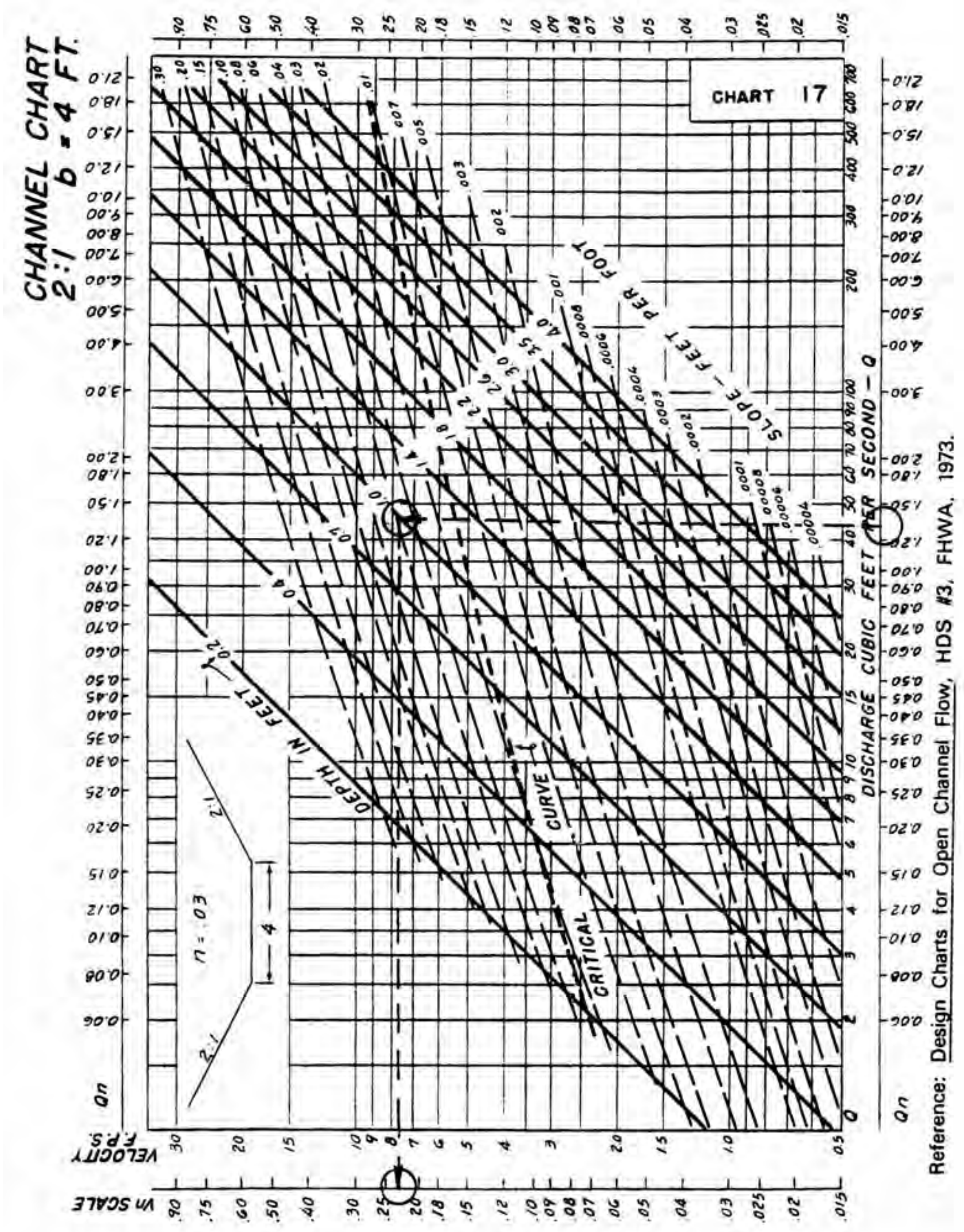
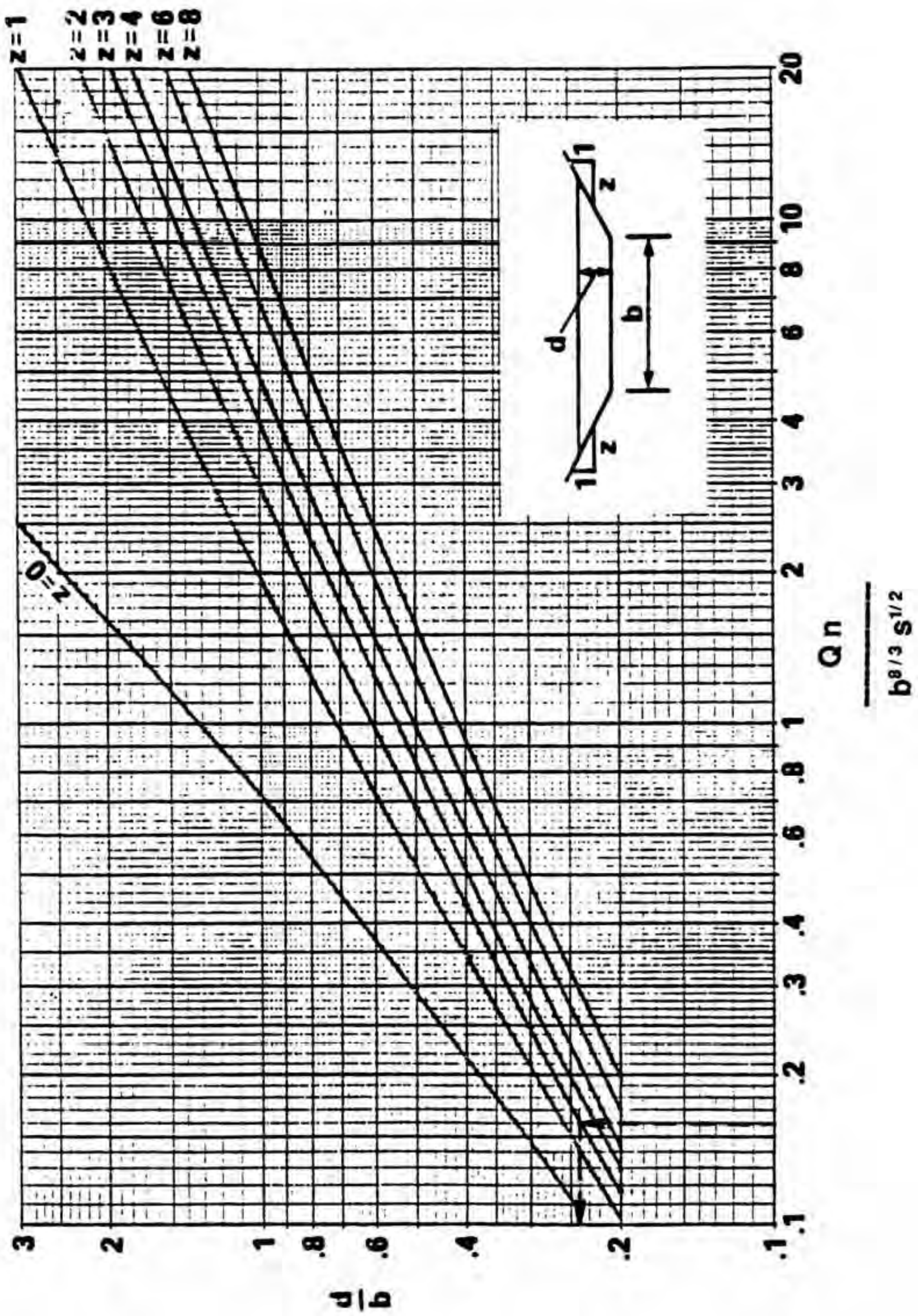


Exhibit 8-28
Depth of Flow in a Trapezoidal Channel



Source: Highway Drainage, FHWA, 1983.

Example 2: (Trapezoidal Grass-Lined Channel)

Given: Cross Section: Trapezoidal channel with b = 4'; 4:1 front and back slopes

Slope = 0.005 ft./ft.
Q = 50 cfs

Problem: Determine necessary channel depth, critical flow conditions, and acceptability of grass lining.

Solution: The procedure outlined in Section 8.4.1.2 is followed:

Step 1: Given

Step 2: Given

Step 3: Use a lining of good Bermuda grass sod for easily eroded soil.

Step 4: For grass-lined channels, n varies with the product of velocity (V) and hydraulic radius (R). This is incorporated into the design charts.

Step 5: Use Exhibit 8-29 to determine the flow information. Use the retardance (C chart) for channel capacity. Move vertically from 50 on the discharge scale until S = .005 is intersected. Read d = 1.9 ft. and V = 2.3 ft./sec.

Step 6: Move vertically from 50 on the discharge scale until the critical flow curve is intersected. Read dc = 1.2 ft. and Vc = 5.0 ft./sec. The flow is subcritical for the discharge. Also note that the depth is not within ±10% of dc.

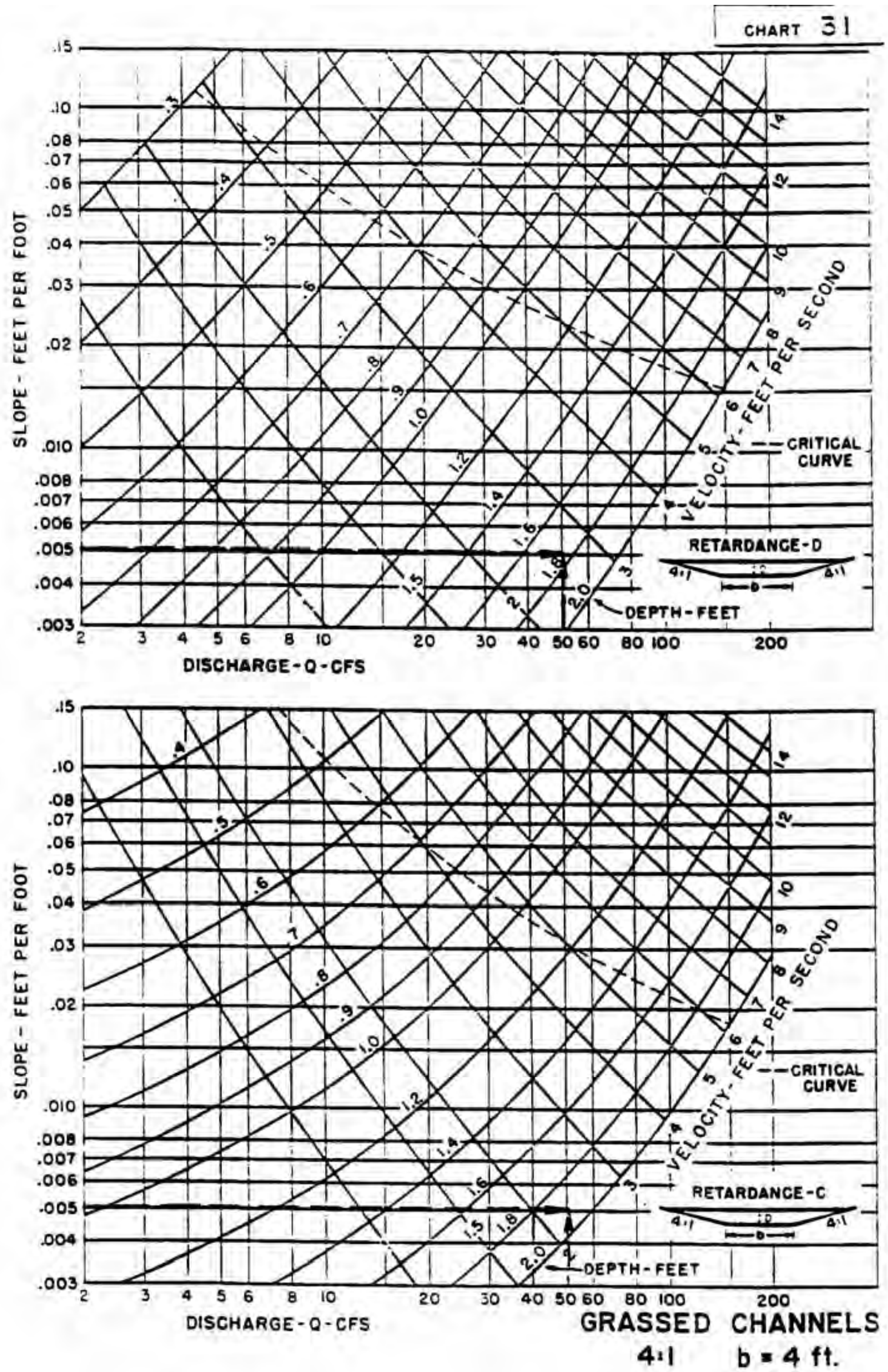
Step 7: Use the retardance (D chart) to calculate flow velocity to determine the erosion possibility. Move vertically from 50 on the discharge scale until S = .005 is intersected. Read V = 2.7 ft./sec. Exhibit 8-24 provides a maximum permissible velocity of 6 ft./sec. Therefore, the grass lining will protect against erosion.

Step 8: For subcritical flow, the minimum channel depth is:

$$d_{min} = 1.9 + 2.0 = 3.9 \text{ ft.}$$

Note: The retardance to flow from a grass-lined channel depends on the height of the grass and the condition of the stand. These are characteristics beyond the control of the designer. Therefore, to be conservative retardance C should be used for channel capacity and D for flow velocity. (D is a lower resistance to flow than C.)

Exhibit 8-29
Grassed Channels - Example 2



Reference: Design Charts for Open Channel Flow. HDS #3, FHWA, 1973.

Example 3: (Using Manning Nomograph)

Given: Cross Section: circular channel with D = 2'
Slope = 0.04 ft./ft.
Q = 13 cfs

Problem: Determine necessary channel depth, critical flow conditions, and lining requirements.

Solution: The step-by-step solution follows.

Step 1: Given

Step 2: Given

Step 3: A lining is necessary for a 4% slope. Asphalt (smooth) has been chosen.

Step 4: n = 0.013

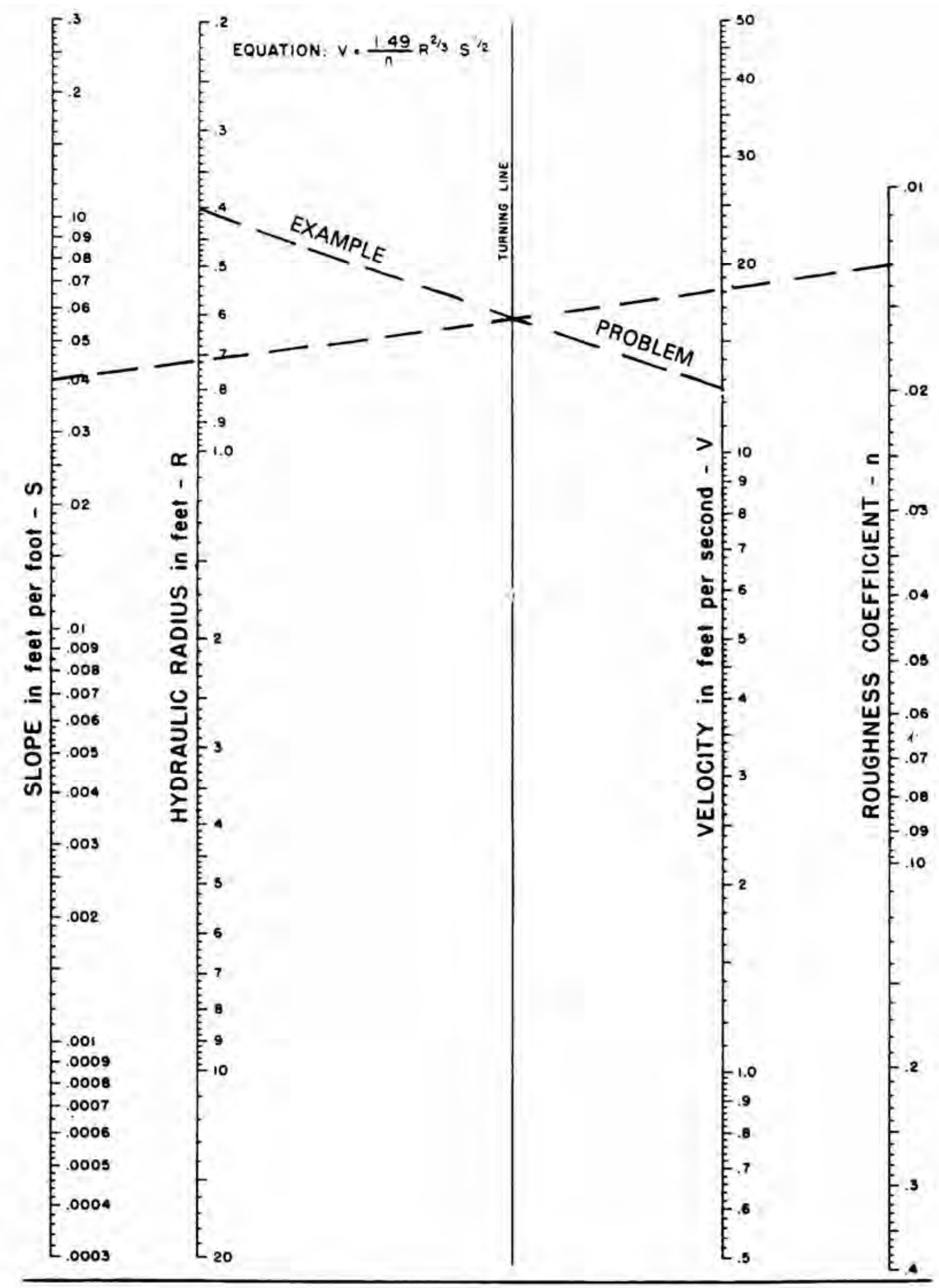
Step 5: Use Exhibit 8-30 to determine the necessary depth of channel. Use Exhibit 8-25 for the equations for area, wetted perimeter, and hydraulic radius for a circular pipe flowing less than half full.

TRY d = 0.8ft: Θ = 156.93 deg.
A = 1.17 sq. ft.
WP = 2.74 ft.
R = .427 ft.
From the nomograph V = 12.8 ft./sec.
Q = 14.98cfs TOO HIGH

TRY d = 0.7 ft: Θ = 145.08 deg.
A = .98 sq. ft.
WP = 2.53ft.
R = .387 ft.
From the nomograph V = 12.0 ft./sec.
Q = 11. 8 cfs TOO LOW

Exhibit 8-30

Nomograph for Solution of Manning Equation - Example 3



Source: Design Charts for Open-Channel Flow, HDS #3, FHWA.

TRY $d = 0.73$ ft: $\Theta = 148.67$ deg.

$A = 1.04$ sq. ft.

$WP = 2.595$

$R = .401$ ft.

From the nomograph $V = 12.4$ ft./sec.

$Q = 12.9$ cfs GOOD

Therefore: $d_n = 0.73$ ft. The nomograph shows the solution for the third try.

Step 6: Use Charts No. 15-20 in Hydraulic Engineering Circular 5 to determine dc. From Chart 16 for circular pipes, Q = 13 cfs, and D = 2':

d_c 1.3 ft.

V_c is found by:

$V_c = Q/A_c$, where A_c = Area of flow at d_c

From Exhibit 8-26, $d/D = .65$. This yields $A_c = 2.16$ sq. ft.

Therefore, $V_c = 13/2.16 = 6.02$ ft./sec.

Since d is below critical depth and V is above critical velocity, the flow in the channel is supercritical.

S_c is solved from the Manning equation.

$S_c = .0405$ ft./ft.

Step 7: Not applicable.

Step 8: For supercritical flow, the minimum depth of the paved lining is to the top of the circular channel.

8.4.1.3 Channel Cross Section

Following are the standard MassHighway cross sections for roadside drainage:

- **Trapezoidal** — This is the standard ditch section for a roadside channel. See the *MassHighway Construction Standards*.
- **Semi-Circular** — An ACCM pipe is typically used for intercepting channels at the top of slopes. See the *MassHighway Construction Standards*.
- **Parabolic** — A 4-inch deep parabolic ditch section (PWW), using bituminous or cement concrete, is also used. See the *MassHighway Construction Standards.*

8.4.1.4 Channel Gradient

The desired minimum grade is. 0.005 ft./ft. To avoid sedimentation, the gradient should remain constant and increase in the downstream direction.

8.4.1.5 Channel Alignment

The designer should avoid abrupt changes in alignment. If possible, alignment changes should be made where flow is subcritical. Refer to HEC #15 (p. 11-12) for a detailed discussion of the hydraulic analysis associated with changes in alignment.

8.4.1.6 Channel Linings

Channel linings protect the channel section from erosion and reduce maintenance. Channel linings should also be selected to maximize filtration and infiltration. The use of grass, cobbles or stone over impervious surfaces such as concrete or asphalt in encouraged. MassHighway's criteria for roadside ditch linings are:

- Grades up to 2% — grass or sod
- Grades 2-3% — jute mesh with loam and seed or other suitable material
- Grades over 3% — either paved or approved lining

On grades over 3% the designer should investigate the use of state of the art development in channel linings and make a recommendation as to the type of channel lining to be used. In this investigation the designer should consider the aesthetics and natural environment, as well as drainage criteria.

For open channels other than roadside ditches, if the calculated velocity exceeds the maximum permissible velocity (Exhibits 8-23 and 8-24), then a more erosion-resistant lining should be used.

Exhibit 8-31 provides a summary of the characteristics of channel linings typically used in Massachusetts. Channel linings and riprap sizing is further discussed in Hydraulic Design Series (HDS) #4 and Hydraulic Engineering Circular (HEC) #15.

Exhibit 8-31
Characteristics of Channel Linings

Characteristic	Grass	Cement Concrete	Bituminous Concrete	Stone	ACCM (Semi-Circular)
n Value	Depends on type and height of grass	n = .013	n = .015	Variable, depending on size of stone and placement	n = .024
Construction Cost	Low	High	Medium to High	Low if stone is locally available	Medium
Maintenance	Frequent	Low	Low	Low	Low
Other	▪ flexible ▪ self-healing ▪ requires protection until established ▪ use when possible	▪ rigid ▪ subject to heaving, undermining, and/or buoyancy ▪ scour protection at outfalls may be required	▪ semi-flexible ▪ subject to undermining and/or weed growth ▪ scour protection at outfalls may be required	▪ flexible ▪ very adaptable for design ▪ may require filter blanket base ▪ energy absorber and velocity reduction	▪ rigid ▪ subject to heaving

Source: Roy Jorgensen Associates, Inc.

8.4.2 Culverts

A culvert is a structure (culverts are not classified as a bridge if their span is less than 20 feet) which provides an opening under the roadway. Culvert cross sections include rectangular (box), circular, arch, and oval. Materials include concrete, steel and aluminum. Some existing culverts may be constructed of stone masonry. Culvert design and construction is standard for small sizes which are prefabricated by manufacturers. Structural-plate pipe arches and precast concrete box culverts may be used for larger culverts. The *MassHighway Construction Standards* provide the design details for box and pipe culverts.

The basic references for the design of culverts are:

- *Hydraulic Charts for the Selection of Highway Culverts*, Hydraulic Engineering Circular No. 5 (HEC #5), Federal Highway Administration, June, 1980.
- *Capacity Charts for the Hydraulic Design of Highway Culverts*, Hydraulic Engineering Circular No. 10 (HEC #10), Federal Highway Administration, November, 1972.
- *Hydraulic Design of Improved Inlets for Culverts*, Hydraulic Engineering Circular No. 13 (HEC #13), Federal Highway Administration, August, 1972.
- *Hydraulic Design of Highway Culverts*, Hydraulic Design Series No. 5 (HDS #5), Federal Highway Administration, September 1985.

In addition, the following computer programs are available for the hydraulic design of culverts:

- FHWA-TS-8O-245 Culvert Design System, December, 1980 (for IBM 370/155 with OS/MVS operating system).
- FHWA Hydraulics Engineering:
  - HY-2 — Hydraulic Analysis of Pipe-Arch Culverts, available for all major computer systems.
  - HY-4 — Hydraulics of Bridge Waterways, available for all major computer systems.
  - HY-6 — Analysis of Culverts, available on IBM 360 computer program.
  - HY-8 — Culvert Analysis, Version 6.1, IBM PC or compatible DOS 2.1 or higher.

All of these computer programs can be modified for use on other, more current computer systems. These computer programs are available at: http://www.fhwa.dot.gov/engineering/hydraulics/software.cfm Culvert design software is also available from Haestad Methods and other computer software companies.

8.4.2.1 Design Responsibility

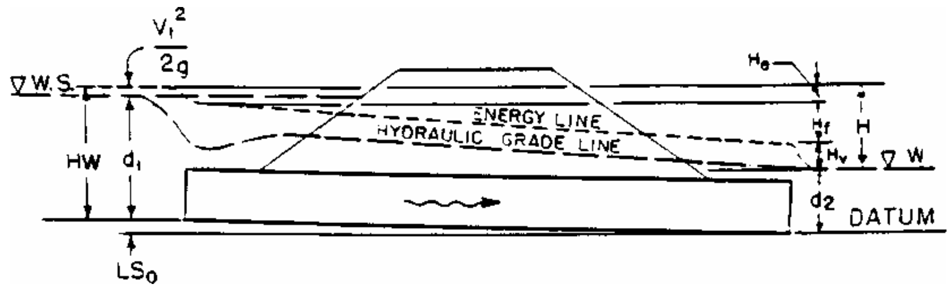
The Design Engineer will design most culverts; however, the designer may refer large culverts which present unusual problems to the Hydraulic Section.

8.4.2.2 Definitions

Terms used in culvert design are defined below and shown in Exhibit 8-32.

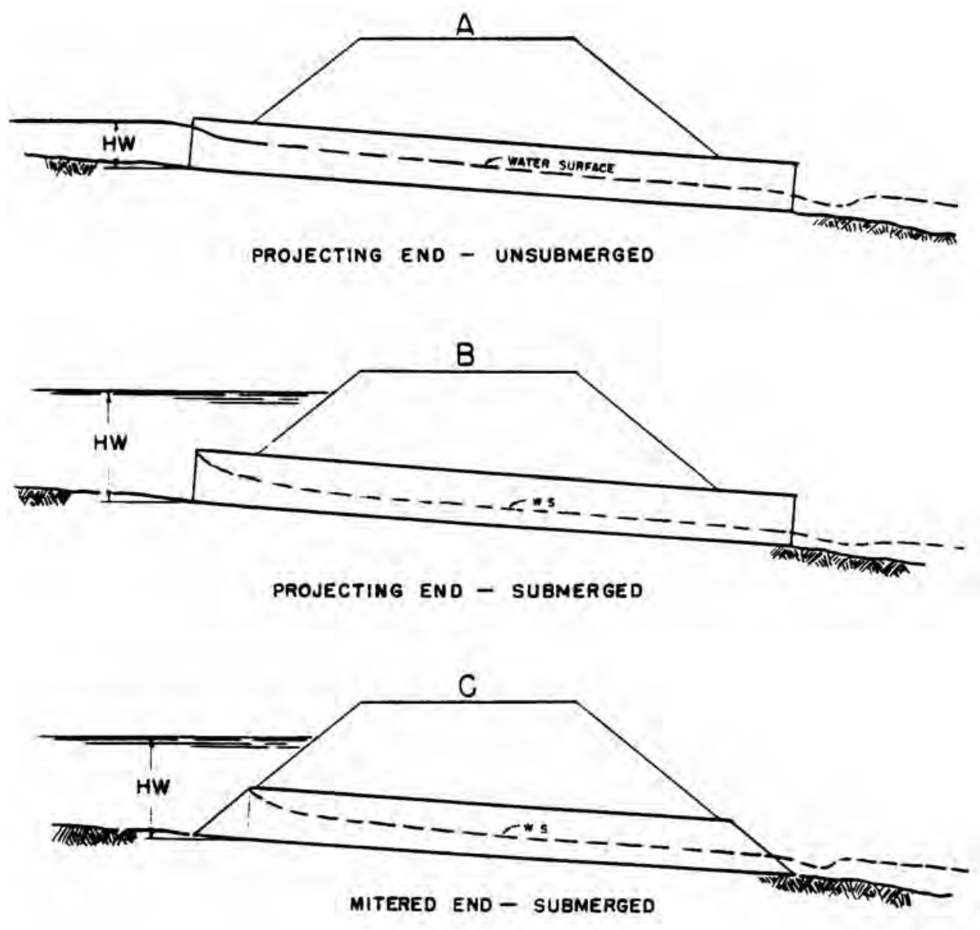
- ***Headwater (HW)*** — the vertical distance between the invert at the culvert inlet and hydraulic gradeline (water surface). For a given set of conditions (discharge, culvert size, etc.), a certain HW depth will develop to provide the required head to force the discharge through the culvert.
- ***Allowable Headwater (AHW)*** — the maximum allowable ponding elevation at the culvert entrance, as a measured from the culvert invert.
- ***Freeboard —*** the distance between the AHW and some Source point (e.g., the edge of the pavement surface).
- ***Tailwater (TW)*** — the vertical distance between the invert at the culvert outlet and HGL (depth of water). TW will often be determined by conditions downstream from the culvert.
- ***Hydraulic Grade Line (HGL)*** — the elevation to which water would rise in small vertical pipes attached to the culvert wall. The HGL is sometimes called the pressure line.
- ***Energy Grade Line (EGL)*** — the line defined by a distance of the velocity head above the HGL.
- ***Inlet Control*** — discharge capacity which is controlled by the conditions at the culvert entrance, including the depth of headwater and entrance geometry (barrel shape, cross-sectional area, and type of inlet edge). See Exhibit 8-33.
- ***Outlet Control*** — discharge capacity which, in addition to the entrance conditions, is controlled by the culvert characteristics and outlet conditions, including culvert length and slope and depth of tailwater. Culverts in outlet control may flow full or part full for all or part of the culvert length. See Exhibit 8-34.

Exhibit 8-32
Culvert Definition Sketch



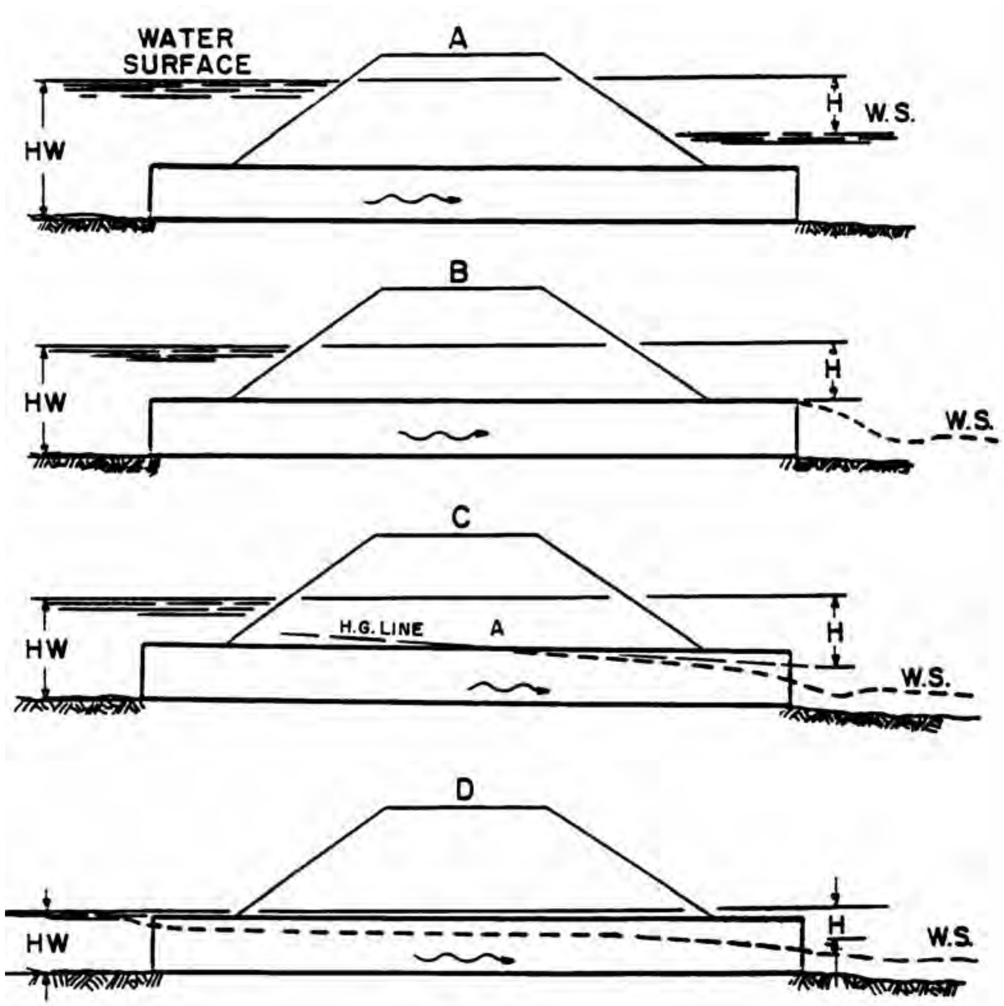
Source: Hydraulic Charts for the Selection of Highway Culverts. HEC #5, FHWA. Hydraulic

Exhibit 8-33
Inlet Control



Source: Hydraulic Charts for the Selection of Highway Culverts. HEC #5, FHWA. Hydraulic

Exhibit 8-34
Outlet Control



Source: Hydraulic Charts for the Selection of Highway Culverts. HEC #5, FHWA. Hydraulic

8.4.2.3 Basic Design Criteria

The basic design criteria for culvert design is described in the following paragraphs.

- ***Allowable Headwater —*** The minimum desirable freeboard is 2 feet between the AHW and the roadway overtopping elevation.

  The allowable headwater will be limited by one or more of the following:

  - ❑ Non-damaging to upstream property;

- ❑ Below the traffic lanes of interest or no higher than the shoulder or 1.6 feet below the edge of shoulder;
- ❑ Equal to an HW/D no greater than 1.5;
- ❑ No greater than the low point in the road grade; and
- ❑ Equal to the elevation where flow diverts around the culvert.

In addition, the designer should also consider:

- ❑ Existing and future land use in the watershed;
- ❑ Potential pavement damage when water rises above the subbase elevation;
- ❑ FEMA 100-year flood requirements;
- ❑ DEP Bordering Land Subject to Flooding and Bordering Vegetated Wetlands requirements;
- ❑ Debris;
- ❑ The need to create lower-than-existing headwater ponding in flood-prone or sensitive areas upstream from the culvert; and
- ❑ Overbank flooding and resultant overtopping of the highway at a roadway low point away from the culvert location.

- ***Minimum Size —*** 15-inch diameter for driveways and median culverts; 18-inch diameter for roadway cross culverts and 24-inch diameter for interstate roadways.
- ***Safety —*** Preferably, cross culvert end sections should be extended beyond the roadside recovery area as presented in Chapter 5. If within the recovery area, the end section should be designed to fit the embankment side slope. Otherwise, guardrail may be warranted. Roadside and median culverts within the recovery area should also be designed to fit the embankment slope, if practical. The desirable slope for these cases is 10:1; it should not be steeper than 6:1.
- ***Stream Stability —*** When new culvert crossings of rivers or major streams are planned, the designer should conduct an assessment of the existing stream and river conditions that affect the road alignment, culvert placement and design. The assessment should include a geomorphic analysis of the affected stream and a determination as to whether the stream is aggrading, degrading or stable. In preparing the geomorphic analysis the designer should

consult *Stream Stability at Highway Structures*, Hydraulic Engineering Circular No. 20 (HEC #20), Federal Highway Administration, November 1995.

- ***Wildlife Accommodation —*** The U. S. Army Corps of Engineers Programmatic General Permit for Massachusetts requires that all new waterway crossings be designed to facilitate fish passage. The designer should refer to Chapter 14 – Wildlife Accommodation Sections 14.3.1 and 14.3.2. for the guidelines for new culverts. When new culvert crossings are planned on rivers or streams that support one or more species of fish, or in known amphibian or other wildlife crossings, the designer should consider the installation of open bottom arch culverts or partially embedded box culverts.

- ***Outlet Velocity —*** The outlet velocity should be checked to make sure that it will not result in erosion or scour of the downstream channel bottom. See Section 8.4.3 for the design of energy dissipators.

8.4.2.4 Capacity Factors

The capacity of culverts operating with inlet control is determined by culvert size, inlet geometry, and headwater. The capacity of culverts operating with outlet control is determined by culvert size, inlet geometry, headwater, tailwater, and culvert slope, roughness and length.

Inlet treatment will affect the entrance losses at the headwater. The standard types of treatment include (in order of increasing efficiency): projecting pipes; cut to fit the embankment slope (either by mitering or with a standard end section); and headwalls (with a beveled edge or with wingwalls). Following is general MassHighway policy for culvert inlets:

- ***Box Culverts —*** A wingwall with headwall should normally be provided. The range of angles is 30 degrees to 75 degrees (typically 45 degrees) as measured from the longitudinal axis of the culvert.

- ***Concrete Pipes —*** A grooved end (bevel) should be provided. The decision to provide a headwall or to project the end is based on the highway cross-section.

- ***Corrugated Metal Pipes —*** The decision to provide a headwall, mitered or standard end section, or projected, will be based on the highway cross-section and safety (See Section 8.3.2.3.). Mitered or projected end sections may require stone protection to prevent erosion and scour.

Inlet geometric improvements can significantly increase the capacity of culverts operating with inlet control. They provide some improvement to those operating with outlet control. HEC #13 discusses these improvements in detail. Three types of inlet improvements can be considered: bevel-edged, side-tapered, and/or slope-tapered.

8.4.2.5 Use of Hydraulic Engineering Circulars

The following circulars are culvert design aids used by the MHD:

- ***Hydraulic Engineering Circular (HEC) #5 —*** This circular provides nomographs for determining culvert size operating with inlet or outlet control (box, circular, oval, or arch culverts; made of concrete, corrugated metal, or structural plate corrugated metal). A trial-and-error procedure is necessary to determine the required culvert size for a given set of conditions. These conditions include:

  - ❑ Allowable headwater;
  - ❑ Discharge (cfs);
  - ❑ Entrance type; and
  - ❑ Culvert length, slope and roughness (outlet control only).

The designer must calculate the required culvert size assuming both inlet control and outlet control.

- ***HEC #10*** — This circular provides capacity charts which allow a direct solution for culvert sizing and headwater. Solutions can be found for box culverts with a square end or with wingwalls, for circular or oval concrete pipe with square- or groove-edged entrances, and for circular or pipe arch, standard or structural plate corrugated metal with projecting or headwall entrance. To determine culvert size, the following information is needed:

  - ❑ Discharge (cfs);
  - ❑ Allowable headwater;
  - ❑ Entrance condition;
  - ❑ Culvert length (ft.);
  - ❑ Culvert slope (ft./ft.); and

- Culvert shape and material (to select proper nomograph).

Both inlet and outlet control curves are provided on the chart. The limitations of HEC #10 are reflected in the procedures outlined in Section 8.4.2.6 for using the circulars.

Examples 1 and 3 illustrate the use of Hydraulic Engineering Circulars #10 Example 2 and 4 illustrate the use of HEC #5. Both HEC #5 and HEC #10 are often equally applicable to a culvert design.

- ***HEC #13*** — This circular provides design charts and procedures for calculating the increased capacity of improved inlet geometry. These include bevel edges, side tapers, and slope tapers. The procedures are applicable only for culverts in inlet control and only for rectangular or circular shapes. The *HEC #13* analysis may be useful when HEC #5 or *HEC #10* determine that an existing culvert is inadequate. An improved inlet may avoid the need to replace the culvert.

8.4.2.6 Procedures for Determining Culvert Size

Procedure 1 (Tailwater Check for HEC #10)

Step 1: Determine the design discharge and AHW.

Step 2: Estimate the size of culvert needed or evaluate the existing culvert.

Step 3: Calculate the TW depth. Use the procedures in Section 8.3.1 for open channel flow to determine the depth of flow, unless a downstream condition will determine the TW.

Step 4: If TW is greater than the height of the culvert, *Hydraulic Engineering Circular #10* cannot be used; *HEC #5* must be used. See Procedure 4 and Examples 2 and 4.

Step 5: If TW is less than the culvert height, calculate the critical depth (dc) for the culvert outlet. Use Charts 15-20 in *HEC #5*

Step 6: If TW is less than dc, either *HEC #10* or *HEC #5* can be used to determine the adequacy of the culvert capacity. See Procedure 2 and Examples 1 and 3 for *HEC #10*.

Step 7: If TW is between dc and the culvert height, *HEC #10* or *HEC #5* can be used. However, also see Procedure 3.

Procedure 2 (Headwater Check for HEC #10)

Step 1: Determine the required HW depth for the design discharge and type and size of culvert. See Examples 1 and 3.

Step 2: If HW is less than 2D (D = culvert height), the answer from *HEC #10* is reliable. Go to Step 4.

Step 3: If HW is greater than 2D, the solution from *HEC #10* is unreliable. Use *HEC #5* to analyze the culvert (Procedure 4).

Step 4: Compare the HW from Step 2 to the AHW. If HW > AHW, a larger culvert or improved inlet treatment must be tried. If HW is equal to or slightly less than AHW, the selected culvert is adequate. If HW is considerably less than AHW, a smaller or less expensive culvert should be tried (e.g., a proposed headwall for a corrugated metal pipe may be eliminated to see if the pipe projected end will work).

Procedure 3 (From Step 7 of Procedure 7 for HEC #10)

Step 1: Determine the required HW depth from HEC #10 for the design discharge and type of culvert. See Examples 1 and 3.

Step 2: Calculate L/100S. If this is equal to or greater than 1/2 of the value on the solid-line inlet curve on the chart, add the following to the HW: I/2(TW -dc). Go to Step 4.

Step 3: If L/100S is less than 1/2 of the value on the solid-line inlet curve, HW from the chart can be used. Go to Step 4.

Step 4: Compare the TW to the HW (modified) from Step 2 or the HW from Step 3. If TW is greater, then HEC #10 cannot be used. Use HEC #5 (Procedure 4).

Procedure 4 (Use of Hydraulic Engineering Circular 5)

Step 1: Document given information on the HEC #5 form. Examples 2 and 4 illustrate completed forms.

Step 2: Estimate the size of the culvert by using the inlet control nomograph and assume HW/D = 1.5. Arbitrarily pick a culvert type (e.g., box).

Step 3: Assume inlet control. Find the HW from the appropriate nomograph. If HW exceeds AHW, try larger culvert sizes until an HW<AHW is found.

Step 4: Assume outlet control for culvert size from Step 3.

Step 5: Calculate HW by:

$HW = H = h_o - LS_o$

where: HW = headwater (at inlet), ft.

H = head loss determined from nomograph, ft.

h_o = tailwater, ft. (see Step 6)

S_o = culvert slope, ft./ft.

L = culvert length, ft.

To find H, the entrance loss k_e must be found. See Table 1, P. 5-49 of *HEC #5.*

Step 6: For TW $\geq$ culvert height, then h_o = TW

For TW $\leq$ culvert height, then:

$$h_o = \frac{d_c + D}{2} \text{ or TW, whichever is greater}$$

Where:

d_c = critical depth (Charts 15-20), ft.

D = culvert height, ft.

Step 7: Compare HW for inlet control and for outlet control. The higher value governs and indicates the flow control for the culvert.

Step 8: If inlet control governs, this is the minimum size culvert of that type. Go to Step 10.

Step 9: If outlet control governs, compare HW and AHW.
If HW > AHW, try a larger size culvert of the same type.
If HW < AHW, try a smaller size culvert of the same type.
If HW = AHW (or is slightly less), then this is the solution for that type culvert. Go to Step 10.

Step 10: Once a size determination has been made for one type of culvert, the designer should follow that same procedure for other types. The final selection will be based on the least costly type which is best adaptable to the site.

The pages that follow provide four examples of the use of these circulars for culvert design.

Example 1: (HEC #10)
Given: $Q50 = 60$ cfs
$L = 400$ ft.
$S_o = 0.005$ ft./ft.
AHW = 8 ft.
TW = 1.5 ft.
Existing culvert = 36-in. diameter reinforced concrete pipe with a square-edged entrance.

Problem: Determine the hydraulic acceptability of the existing culvert.

Solution:

Procedure 1 (TW Check):
The TW (1.5 ft) is less than the culvert height. The critical depth (dc) from Chart 16 in HEC #5 is dc = 2.3 ft. TW is less than dc; therefore, the charts in HEC #10 may be used (Step 6).

Procedure 2 (HW Check):
Chart 11 from HEC #10 is reproduced as Exhibit 8-35. Calculate:

$$\frac{L}{100S_O} = \frac{400}{(100)(.005)} = 800$$

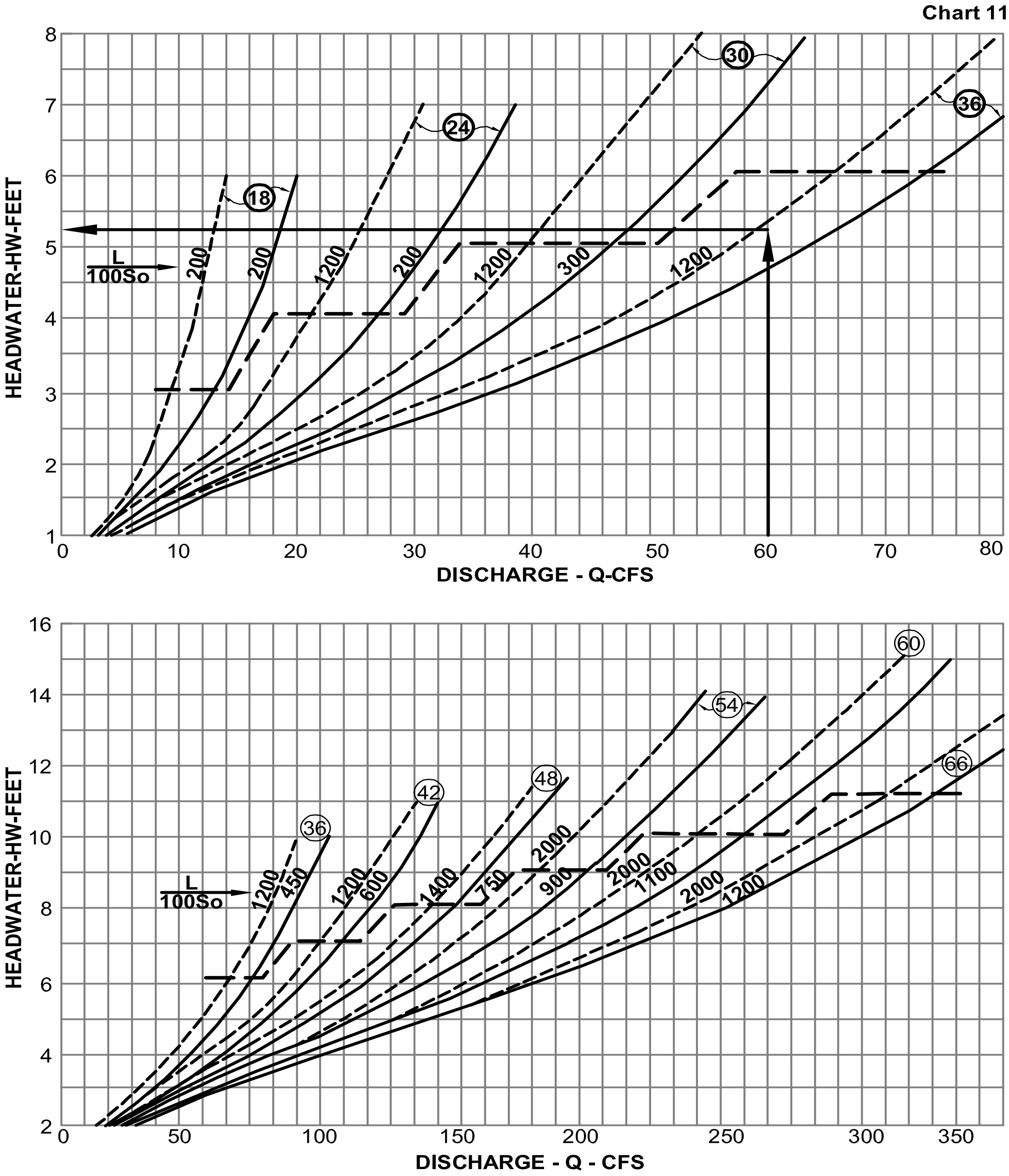
The 36-inch pipe range is from 450 to 1200 (upper graph). 800 is slightly less than between these limits. Find Q = 60 on the horizontal scale and move up until the 800 value is found for 36 in. Move to the vertical scale and read HW = 5. 3 ft. This is less than AHW = 8 ft. Therefore, the 36-inch pipe is acceptable. Also note that the 36-inch size is the smallest acceptable size for the given AHW.

Now that the design HW has been found, the designer must check the HW. Calculate:

$$\frac{HW}{D} = \frac{5.3 \times 12}{36} = 1.77$$

Exhibit 8-35

Example 1 - HEC #10



Culvert Capacity Circular Concrete Pipe Square-Edged Entrance 18" to 66"

Source: Capacity charts for the Hydraulic Design of Highway Culverts, HEC #10, FHWA.

The value is less than 2 (shown as dashed line on Chart 11); therefore, the answer from HEC #10 is reliable (Step 2).

Example 2: (HEC #5)

Given: Q_{50} = 300 cfs
L = 150 ft.
S0 = .008ft./ft.
AHW = 8 ft.
TW = 3 ft.

Problem: Determine the necessary culvert size and type for the given conditions.

Solution: Exhibit 8-36 has been filled in for this example. Procedure 4 is followed:

Step 1: The given data is documented on the HEC #5 form.

Step 2: Chart 1 from HEC #5 is reproduced as Exhibit 8-37. Assuming HW/D = 1.5 yields a box culvert about 5.5 x 5.5 ft.

Step 3: Using Chart 1 for inlet control for a 5 x 5 ft. box culvert, (solution not shown) yields HW/D = 1.8 and HW = 9 ft. This exceeds AHW. A 6 x 6 ft. size with a 45-deg wingwall (solution shown) yields HW/D = 1.12 and HW = 6.7 ft. This is acceptable.

Step 4: Use Chart 8 for outlet control (Exhibit 8-38).

Step 5: First find H. ke = 0.2 (Table 1, beveled edge). Locate L = 15O ft. on the ke = 0.2 line. Connect this point with 6 x 6 on the dimension line. Note the intersection with the turning line. Connect this point with Q = 300 on the discharge line. Read H = 1.8 ft (solution shown).

h_o = 5.1 ft. (from Step 6)
LS_o = 150 x .008 = 1.2 ft.
therefore, HW = 1.8 + 5.1- 1.2 = 5.7ft.

Step 6: Calculate ho. TW culvert height. Find dc from Chart 15 in HEC #5. dc 4.2 ft; therefore, ho = 5.1 ft.

$$h_o = \frac{4.2 + 6}{2} = 5.1 \text{ ft. or } h_o = TW = 3 \text{ ft.}$$

Exhibit 8-36

Example 2 - HEC #5 Documentation Form

PROJECT: ____________ DESIGNER: ____________ DATE: ____________

HYDROLOGIC AND CHANNEL INFORMATION

Q_{50} = 300 cfs

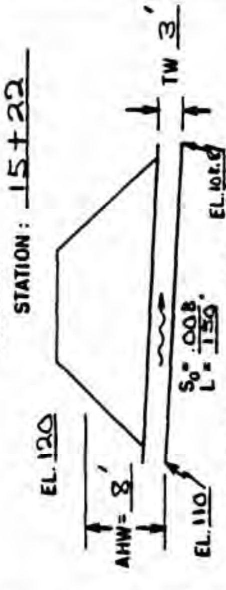
Q_1 = ______ TW_1 = ______

Q_2 = ______ TW_2 = ______

(Q_1 = DESIGN DISCHARGE, SAY Q_{25}
Q_2 = CHECK DISCHARGE, SAY Q_{50} OR Q_{100})

SKETCH

STATION: 15+22



MEAN STREAM VELOCITY = 8'/sec
MAX. STREAM VELOCITY = 12'/sec

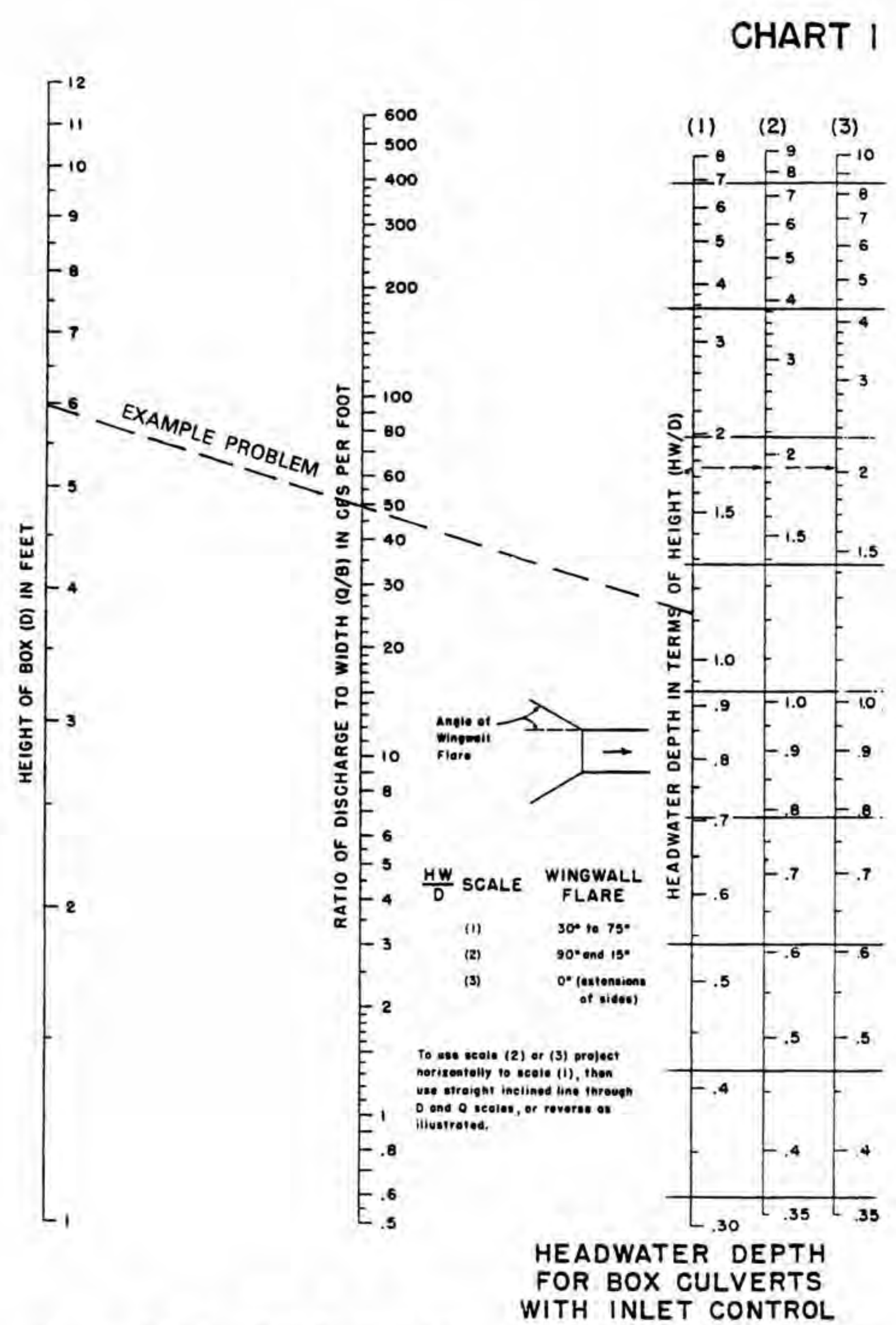
CULVERT DESCRIPTION (ENTRANCE TYPE)	Q	SIZE	HEADWATER COMPUTATION: INLET CONT. HW/D	INLET CONT. HW	OUTLET CONTROL HW=H+h_o−LS_o: K_e	H	d_c	$\frac{d_c+D}{2}$	TW	h_o	LS_o	HW	CONTROLLING HW	OUTLET VELOCITY	COST	COMMENTS
Conc. Box w/ 45° WW	300		Ass 1.5				Find		B≈5.5'							—
"	"	5x5	1.8	9												No Gd for In. Cont.
"	"	6x6	1.12	6.7	0.2	1.8	4.2	5.1	3	5.1	1.2	5.7	6.7	11.9		Good
Conc. Pipe w/ Gr. End, Proj.	"	72"	1.29	7.74	0.2	2.7	4.7	5.4	3	5.4	1.2	6.9	7.7	12.6		Good
C.M. Pipe w/ Headwall	"	72"	1.4	8.4												No Gd for In. Cont.
"	"	84"	1.01	7.1	0.2	2.3	4.6	5.8	3	5.8	1.2	6.9	7.1	11.2		Good

SUMMARY & RECOMMENDATIONS:

Use least expensive which is best adaptable to site

Reference: Hyrdaulic Charts for the Selection of Highway Culverts, HEC #5, FHWA.

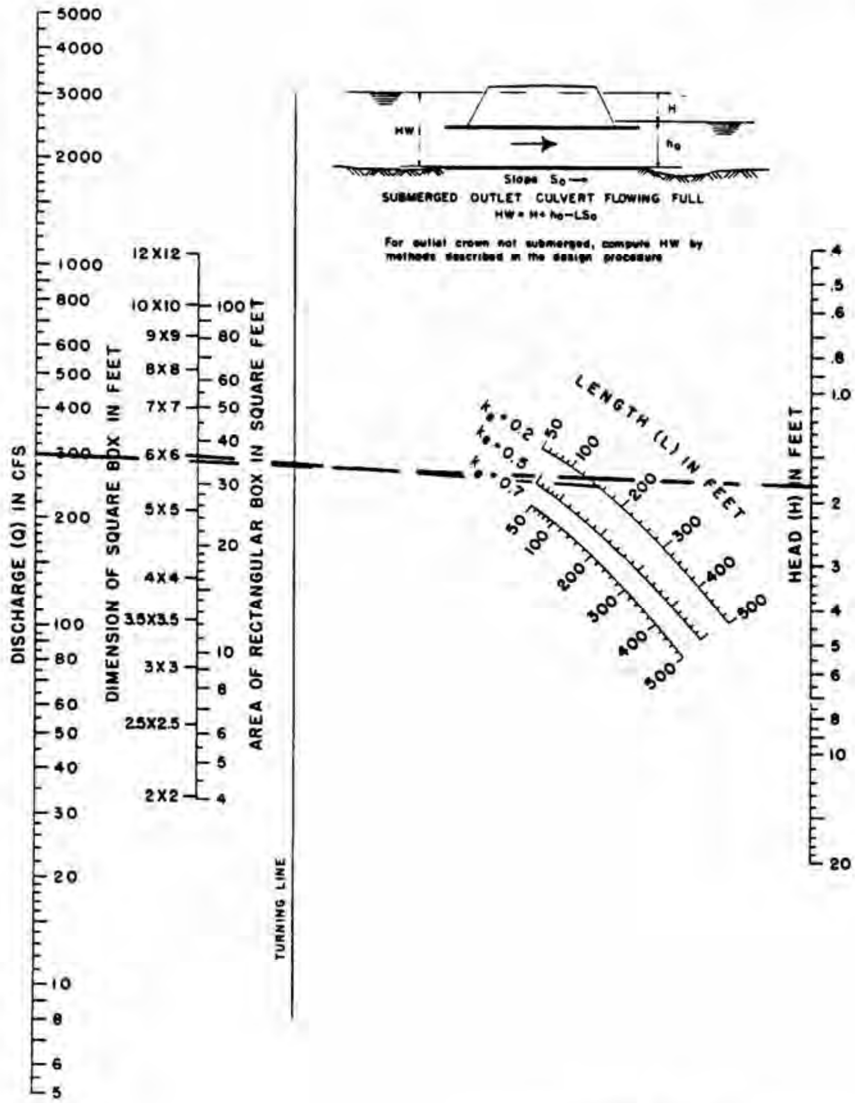
Exhibit 8-37
Example 2 - HEC #5



Reference: Hyrdaulic Charts for the Selection of Highway Culverts, HEC #5, FHWA.

Exhibit 8-38
Example 2 - HEC #5

CHART 3



HEAD FOR
CONCRETE BOX CULVERTS
FLOWING FULL
$n = 0.012$

Reference: Hyrdaulic Charts for the Selection of Highway Culverts, HEC #5, FHWA.

Example 3 (HEC #10)

Given: Same data as for Example 2.

Problem: Determine the necessary culvert size and type for a box culvert and compare answer to HEC #5.

Solution:

Procedure 1 (TW Check):
From Chart 15 in HEC #5, dc = 4.3'for a 6'x 6'box culvert and Q = 300 cfs. TW = 3 ft. and is less than dc. Therefore, HEC #10 may be used.

Procedure 2 (HW Check):
Chart 9 from HEC #10 is reproduced as Exhibit 8-39. Calculate:

$$\frac{L}{100S_O} = \frac{150}{(100)(.008)} = 187.5$$

For a 6' x 6' box culvert, L/100So = 1300 on Chart 9. Whenever the value for the culvert under design is less than the chart value, the culvert is in inlet control and the lowest chart value for that type and size culvert applies (see p. 8-4 and 8-6 in HEC #10). For Q = 300, this yields HW = 6.8 ft. for a 6' x 6' culvert. This compares with HW = 6.7 from HEC #5.

Note that for a 5' x 5' culvert, Chart 9 yields HW = 8.9 ft., which is unacceptable (HEC #5 yielded HW = 9.0 ft.). Therefore, both HEC #5 and HEC #10 yield the same answer (6' x 6' box culvert).

Example 4: (HEC #5, Submerged Outlet)

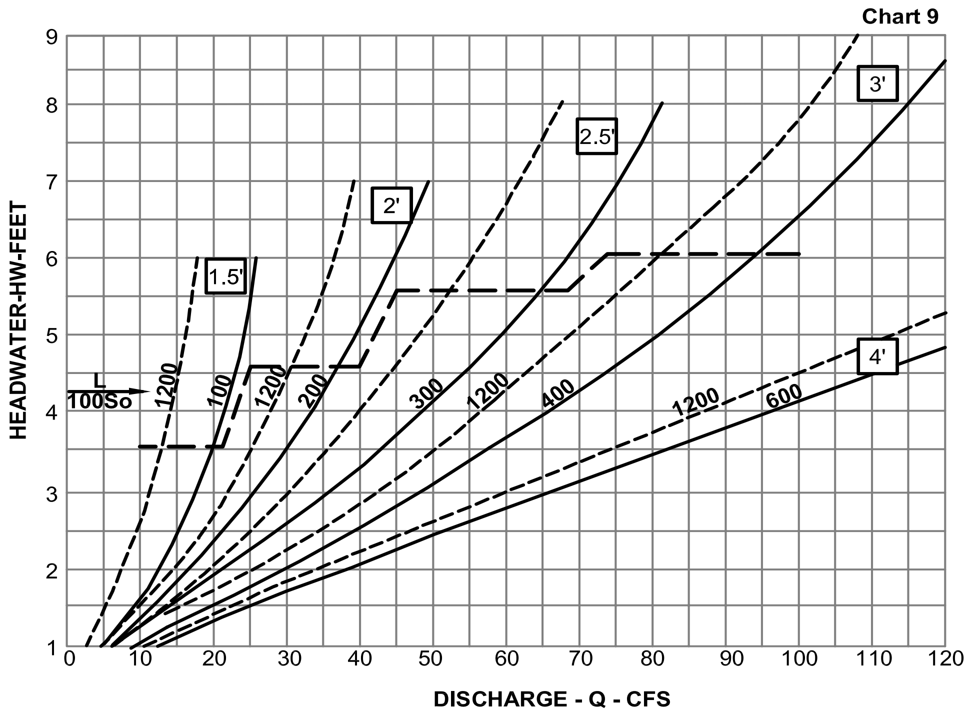
Given: Q = 250 cfs
L = 200 ft.
S_O = 006 ft./ft.
AHW = 7 ft.
TW = 7 ft.

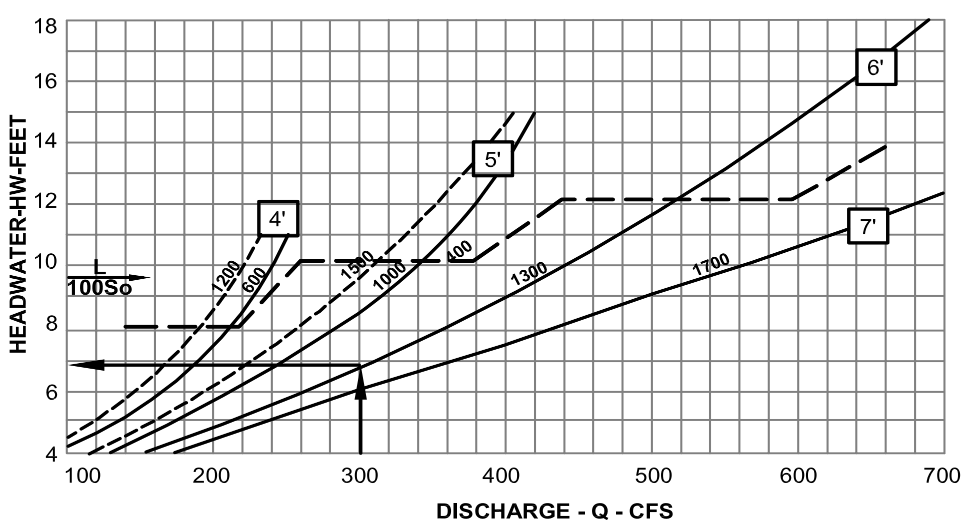
Problem: Determine the necessary size for a concrete pipe culvert.

Solution: Exhibit 8-40 has been filled in for this example. Procedure 4 is followed:

Exhibit 8-39

Example 3 - HEC #10





Culvert Capacity Square Concrete Box 30° To 75° Wingwall Flare 1.5'x 1.5' To 7'x7'

Source: Capacity charts for the Hydraulic Design of Highway Culverts, HEC #10, FHWA

Exhibit 8-40

Example 4 - HEC #5 Documentation Form

PROJECT: ______________ DESIGNER: ______________
DATE: ______________

HYDROLOGIC AND CHANNEL INFORMATION

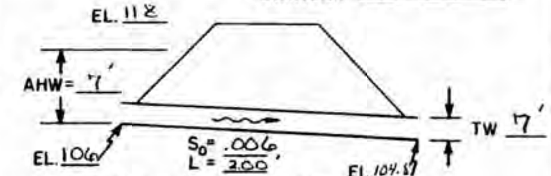
Q_{50} = 250 cfs

Q_1 = ______ TW_1 = ______
Q_2 = ______ TW_2 = ______

(Q_1 = DESIGN DISCHARGE, SAY Q_{25}
Q_2 = CHECK DISCHARGE, SAY Q_{50} OR Q_{100})

SKETCH

STATION: 17 + 32



MEAN STREAM VELOCITY = 8'/sec
MAX. STREAM VELOCITY = 11'/sec

CULVERT DESCRIPTION (ENTRANCE TYPE)	Q	SIZE	HEADWATER COMPUTATION: INLET CONT. HW/D	HW	OUTLET CONTROL HW=H + h_0 − LS_0: K_e	H	d_c	$\frac{d_c+D}{2}$	TW	h_0	LS_0	HW	CONTROLLING HW	OUTLET VELOCITY	COST	COMMENTS
Conc Pipe w/ Sq. Ed. w/ HW	250	72"	1.22	7.32									7.3	—		No Gd w/ In. Cont.
Conc. Pipe w/ Gr. End w/HW	"	72"	1.12	6.72	.2	2.1	4.3	5.2	7	7	1.2	7.9	7.9	—		No Gd w/ Out. Cont.
Conc. Pipe w/ Gr. End w/HW	"	84"			.2	.98	4.2	5.6	7	7	1.2	6.8	6.8	12.9		Good

SUMMARY & RECOMMENDATIONS:

Use 84"-diameter concrete pipe w/ groove end w/ headwall

Reference: Hyrdaulic Charts for the Selection of Highway Culverts, HEC #5, FHWA.

Step 1: The given data is documented on the HEC #5 form.

Step 2: Chart 2 from HEC #5 is reproduced as Exhibit 8-41 for inlet control. Assuming HW/D = 1.5 yields a 60-inch diameter pipe.

Step 3: Using Chart 2 for inlet control and a square edge with headwall (solution not shown) yields HW/D = 2.0 and HW = 10.0 ft. This exceeds AHW. A 72-in. diameter pipe with a square edge with headwall (solution shown) yields HW/D = 1.22 and HW = 7.32ft. This also exceeds AHW. If a groove end with headwall is used (solution shown), this yields HW/D = 1.12 and HW = 6.72 ft. This is acceptable.

Step 4: Chart 9 from HEC #5 (Exhibit 8-42) is used for outlet control.

Step 5: First find H. k_e = 2 for a groove edge. Locate L = 200 ft. on the k_e = 0.2 line. Connect this point with 72 on the diameter line. Note the insertion with the turning line. Connect this point with Q = 250 on the discharge line. Read H = 2.1 ft. (solution not shown).

h_o = 7 ft. (from Step 6)

LS_o = 200 x .006 = 1.2 ft.

Therefore, HW = 2.1 + 7 = 1.2 = 7.9 ft.

Step 6: Calculate h_o. Since TW> culvert height, h_o = TW = 7 ft.

Step 7: HW for outlet control exceeds HW for inlet control. Therefore, outlet control governs.

Step 8: Not applicable.

Step 9: The HW = 7.9 ft. exceeds the AHW. Therefore, try D = 84".

Solution of H = 0.98 ft. is shown on Chart 9.

HW = .98 + 7 - 1.2 = 6.8 ft.

This is less than the AHW and is therefore acceptable.

Step 10: Not applicable.

Exhibit 8-41

Example 4 - HEC #5

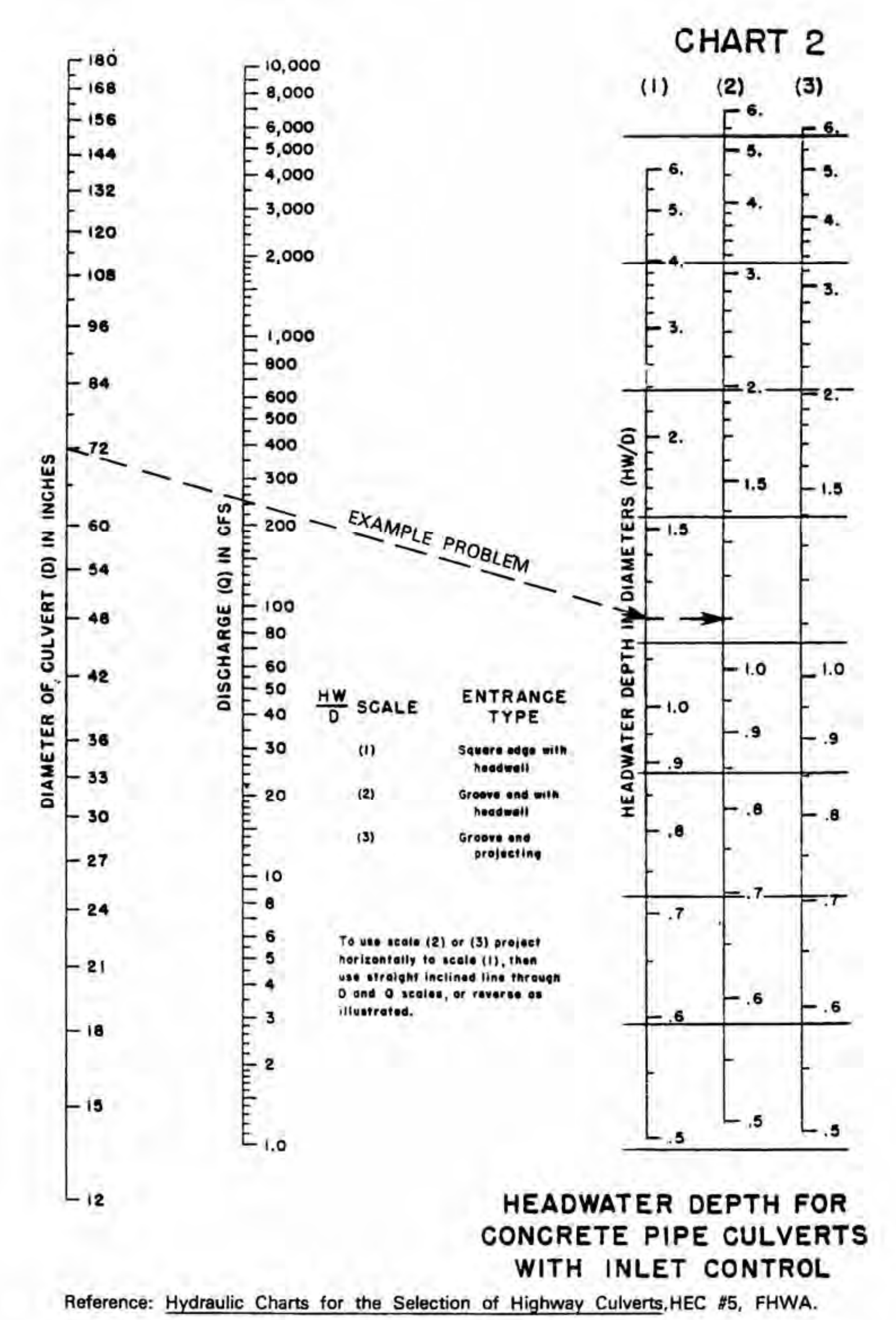
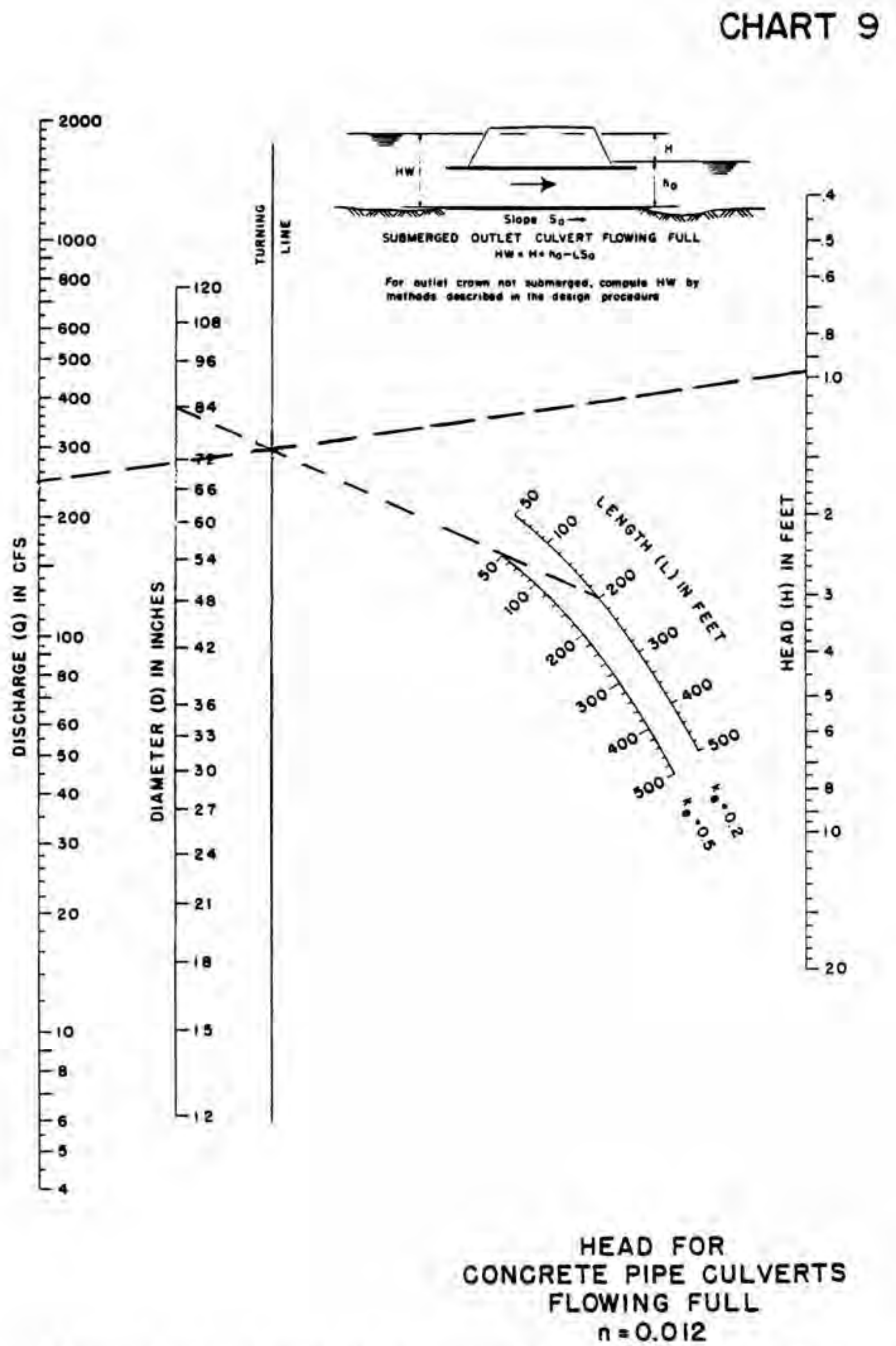


Exhibit 8-42
Example 4 - HEC #5



Reference: Hyrdaulic Charts for the Selection of Highway Culverts, HEC #5, FHWA.

8.4.3 Energy Dissipators

Open channels and culverts may significantly increase the erosion of the natural channel bed at their outlet. This is particularly true of culverts. Erosion and scour will occur if the outlet conditions produce excessive flow velocities. In these cases, either altering the design of the culvert or providing an energy dissipator should be evaluated. Otherwise, the culvert may fail. The basic source for the design of energy dissipation is *Hydraulic Design of Energy Dissipators for Culverts and Channels*, Hydraulic Engineering Circular No. 14 (HEC #14), Federal Highway Administration, December, 1975.

If needed, the type of energy dissipator will depend on the following:

- discharge volume and velocity;
- culvert size, slope, roughness, and outlet geometry;
- natural channel material;
- tailwater depth; and
- Froude number (F) range.

When the design of an energy dissipater is required for new culvert crossings on rivers or streams that support one or more species of fish, or on a known amphibian or other wildlife crossing, the designer should refer to Chapter 14 - Wildlife Accommodation since these devices may impact the ability of wildlife to pass through the culvert.

The highest outlet velocities will be produced by long, smooth-barrel culverts on steep slopes. These culverts are the most likely candidates for energy dissipators. However, protection may also be necessary for culverts on mild slopes. Tailwater (TW) is also a major factor. High TW will reduce the outlet velocity and, therefore, the erosion potential. In addition, the erodibility of the natural stream material at the outlet will influence the amount of scour.

The Froude number is:

$$F = \frac{V}{\sqrt{g d_m}} = \frac{V}{V_c}$$

where: dm = mean depth of flow, ft.

g = 32.2 ft./sec.^{2}

V = mean velocity, ft./sec.

V_C = critical velocity, ft./sec.

The Froude number represents subcritical (F < 1), critical (F = 1), or supercritical (F > 1) flow. In the selection of energy dissipators, F will indicate which type is best for the hydraulic conditions (see Table XII-1 in HEC #14).

8.4.3.1 Applicability

The designer must estimate the potential erosion or scour at the culvert outlet to determine the need for culvert modifications or an energy dissipator. If an existing culvert is being re-evaluated, a field inspection of the outlet should be made to examine the existing erosion. The soils information, maintenance history, culvert characteristics, and discharge history (if available) should be reviewed.

The designer should estimate the potential scour of new and existing culverts by the procedures in Chapter V of HEC #14. The method provides an estimate of the depth, width and length of scour based on the tailwater depth, culvert dimensions and a time variable. The procedure is inexact and meant to serve as only an approximate means to estimate scour.

8.4.3.2 Culvert Modifications (New or Existing)

If the designer concludes that scour will occur, he should first consider altering the culvert characteristics to correct the problem. Possibilities include:

- Increase the culvert size to reduce outlet velocity. This may be effective on mild slopes, but is generally ineffective on steep slopes.
- Increase the number of culvert barrels.
- Provide a wingwall in conjunction with a square-edged headwall. This is applicable for culverts in outlet control where subcritical flow is present throughout the structure. Under specific circumstances, it may also be applicable to supercritical flow.
- Consider corrugated metal pipe with a higher "n" value to reduce the flow velocity.

8.4.3.3 Types of Energy Dissipators

If the culvert cannot be modified, or if the design options of a proposed culvert are limited, an energy dissipator should be used at the outlet or within the culvert barrel. Many general types exist, as illustrated in Exhibit 8-43.

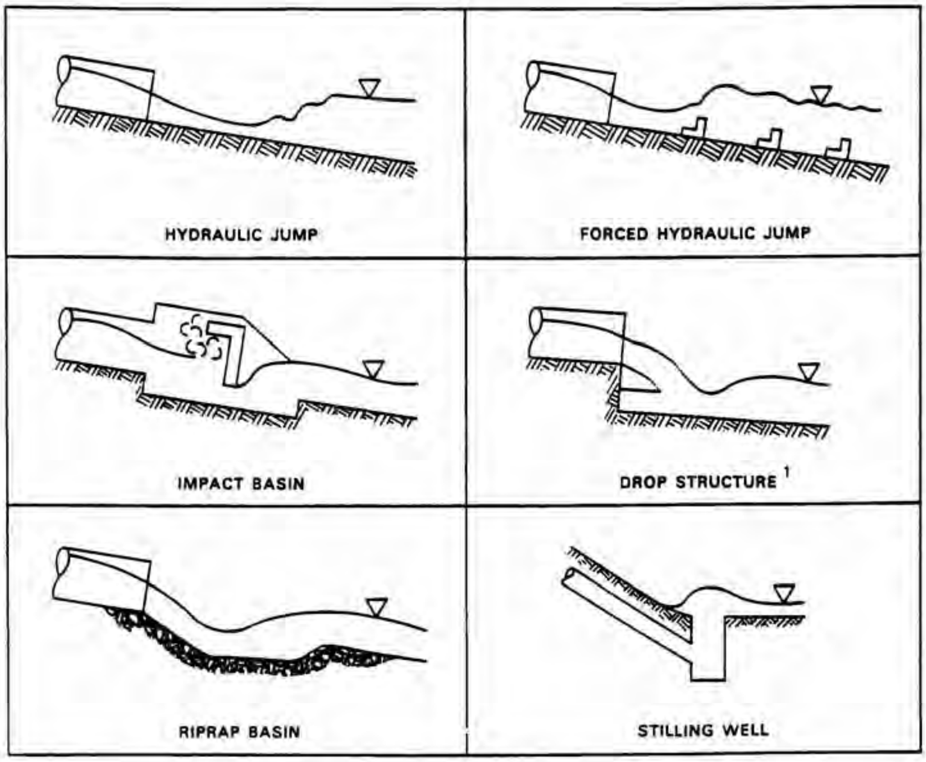
- **Hydraulic jump** — Natural stilling basins at the culvert outlet may be used to convert the kinetic energy of supercritical flow into potential energy of subcritical flow. This will reduce the flow velocity and increase the depth of flow.
- **Forced hydraulic jump** — Several roughness elements (blocks, sills, etc.) may be used to force the water flow from supercritical to subcritical. They may be used inside a culvert (inlet control only), at the culvert outlet, or in an open channel (for slopes up to 15%).
- **Impact basins** — Vertical baffles are used at the culvert outlet to dissipate the kinetic energy. Various designs are applicable to a wide range of culvert types and sizes.
- **Drop structures** — A steep slope for culverts or open channels may be converted to a series of gentle slopes with intermittent vertical drops into a stilling basin. This arrangement will prevent the erosive high velocities from developing.
- **Riprap basins** — Large angular and rounded stones are used at the culvert outlet to dissipate the kinetic energy. A filter blanket should be used as a foundation for the stone. Riprap should be sized in accordance with HEC #14
- **Stilling wells** — These dissipate the kinetic energy by forcing the flow to travel upward to reach the downstream channel.

8.4.3.4 Design Procedure

The following procedure should be used to select and design an energy dissipator. HEC #14 describes the analytical details:

- Determine the pertinent data for the outfall (discharge volume and velocity; culvert size, slope and roughness; outlet conditions).
- Determine the potential for scour at the outfall. See Chapter V of HEC #14.
- Evaluate the practicality of modifying the existing culvert to eliminate the potential scour. See Section 8.4.3.2.

Exhibit 8-43
Energy Dissipators



[1] A drop structure would typically be a series of these arrangements.

Reference: Hydraulic Design of Energy Dissipators for Culverts and Channels, Demonstration Project No. 31, FHWA.

- If modification is impractical, evaluate several types of energy dissipators considering costs, limitations, and effectiveness of each type.
- Select the dissipator which is most economical and adaptable to the site.
- Conduct the detailed design of the dissipator.

8.4.4 Storm Drain Systems

A storm drain system is a closed system which conveys storm runoff. Catch basins, gutter inlets, manholes, collector pipes, and the main trunk line form the system. It is often used in urban and suburban areas where roadside ditches are unacceptable. The basic references for the design of a storm drain system are:

- *FHWA-TS-84-202, Drainage of Highway Pavements*, Hydraulic Engineering Circular No. 12. (HEC #12), Federal Highway Administration, March, 1984.
- *FHWA-NHI-01-021,Urban Drainage Design Manual*, Hydraulic Engineering Circular No. 22 (HEC #22), Federal Highway Administration, August, 2001.
- *WPCF Manual of Practice No. 9, Design and Construction of Sanitary and Storm Sewers*, Water Pollution Control Federation and the American Society of Civil Engineers, 1969.
- *FHWA-RD-74-77, Hydraulic Characteristics of Two Bicycle-Safe Grate Inlet Designs*, Federal Highway Administration, November, 1974.
- *FHWA-RD-78-4, Bicycle-Safe Grate Inlets Study*, Volumes 1 & 2, Federal Highway Administration, May, 1978.

8.4.4.1 Definitions

- **Hydraulic grade line (HGL)** — A line representing the potential energy of the water flow. In closed pipes, it is also called the pressure line.
- **Hydraulic gradient** — The slope of the HGL.
- **Energy Grade line (EGL)** — A line representing the total energy (potential plus kinetic) of the water flow.
- **Velocity Head** - The difference between the HGL and EGL is the velocity head:

$$H_V = V^2/2g$$

where V = velocity, (ft./sec.)

- **Energy gradient** — The slope of the EGL, usually parallel to the hydraulic gradient.

Exhibit 8-44 illustrates the HGL and EGL. The figure also shows an improper and proper design for a surcharge system with a submerged outlet. (See Section 8.4.4.9 for a further discussion.)

8.4.4.2 Pavement Drainage

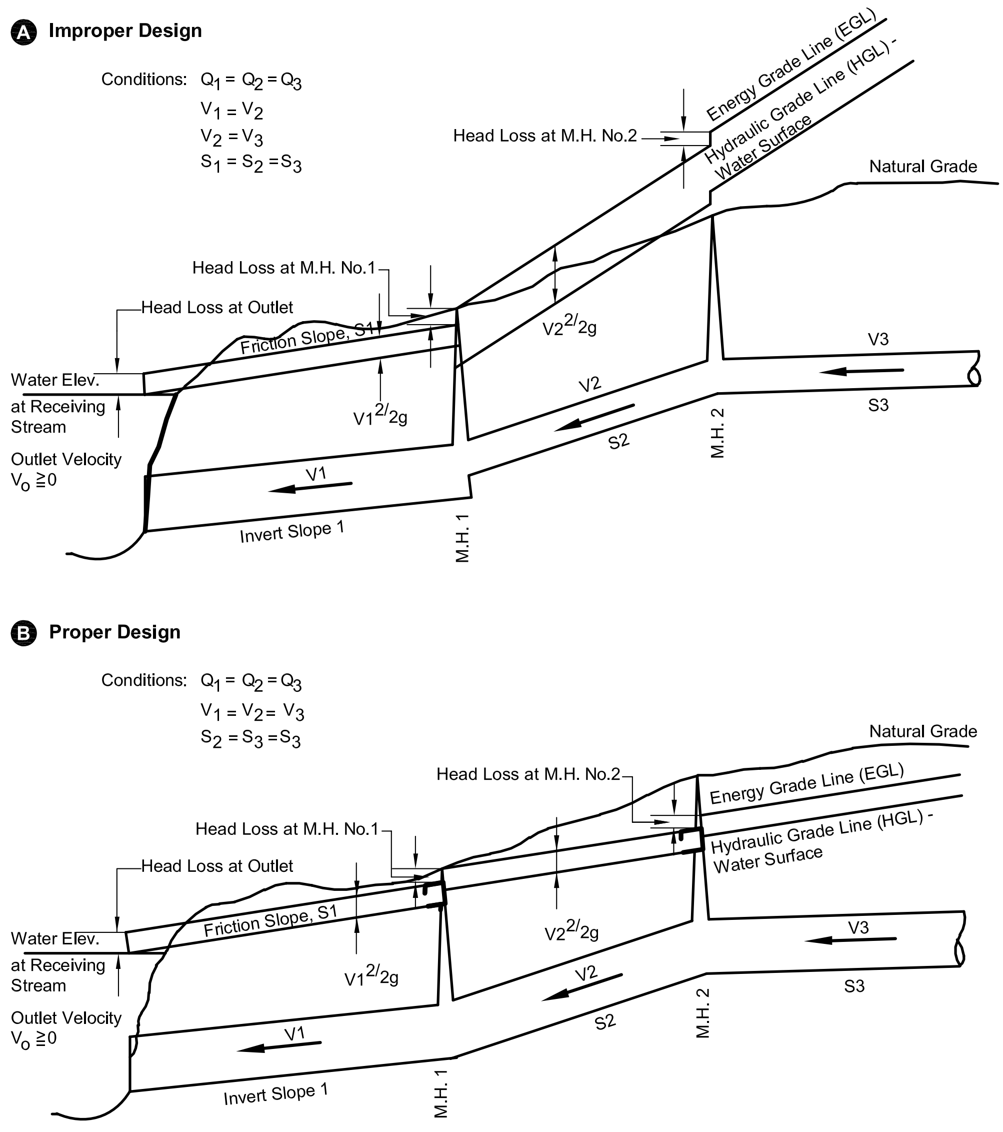
Storm discharge from pavements will contribute a large part of the water the storm drain system must handle. The amount of discharge for the selected design frequency will depend on the rainfall intensity and the pavement grade, width, and cross slope. The designer must select a tolerable spread (T) on the pavement to evaluate pavement drainage (See Exhibit 8-45). The spread will depend on the pavement discharge and the capacity and spacing of the gutter inlets. (See Section 8.4.4.3) These criteria apply:

- **Interstate/Freeway/Expressway/Arterials** — On high volume roadways with speeds greater than 45 mph not more than the shoulder should be flooded during a 10-year runoff frequency. On high volume roadways with speeds less than 45 mph not more than the shoulder plus 3 feet should be flooded during a 10-year runoff frequency, except a 50-year frequency should be used for underpasses or other depressed roadways where ponded water can only be removed through the storm drain system.
- **Collectors** — On roadways with speeds greater that 45 mph not more than the shoulder should be flooded during a 10-year runoff frequency. On roadways with speeds less that 45 mph or underpasses not more than half of a through traffic lane should be flooded during a 10-year runoff frequency.
- **Local Roads** — On roadways with high ADTs not more than half a through lane should be flooded during a 5 or 10-year runoff frequency. On roadways with low daily traffic not more than half of a through traffic lane should be flooded during a 2 or 5-year runoff frequency. On underpasses or depressed roadways not more than half a through lane should be flooded during a 10-year runoff frequency.

This criteria applies to shoulder widths of 6 feet or greater. Where shoulder widths are less that 6 feet, a minimum design spread of 6 feet should be considered.

The Rational Method (Section 8.3.2.2) is used to calculate the discharge from pavements. The minimum time of concentration (Tc) is assumed to be 5 minutes, which is then used as the rainfall duration for the first inlet structure. An example for calculating the pavement discharge is provided in Section 8.3.2.2.

Exhibit 8-44
Energy and Hydraulic Grade Lines for a Properly and Improperly Designed Storm Sewer

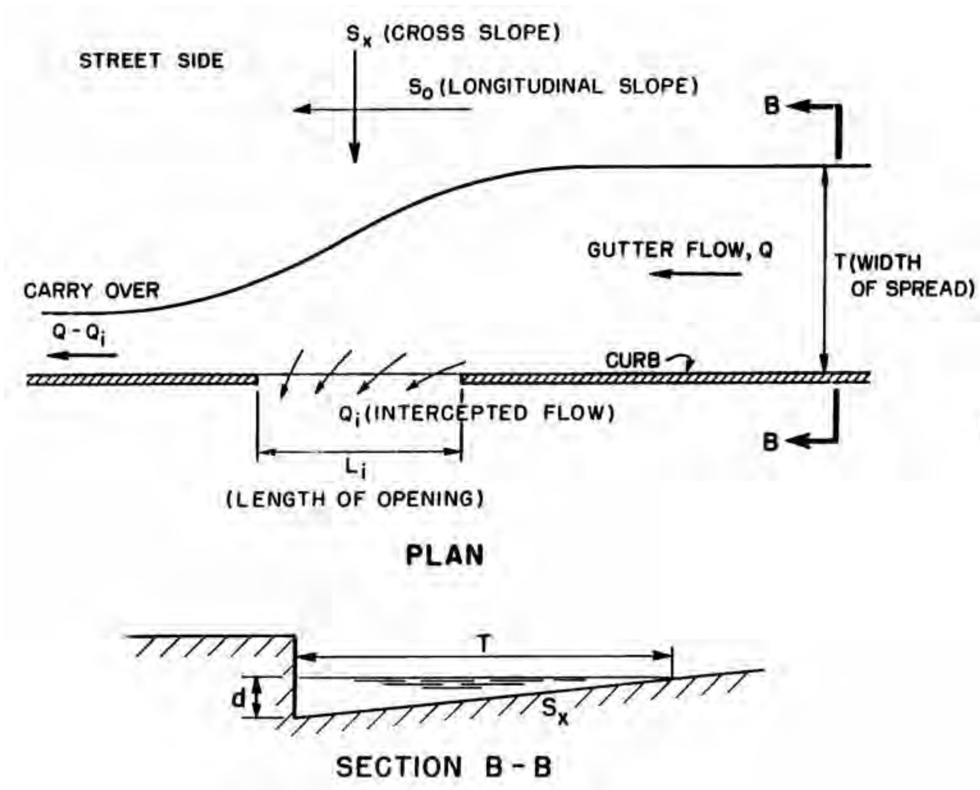


Note A: EGL elevations above M.H. No.2. Therefore during design storm, water would issue from sewer. Design should be revised.

Note B: By increasing the size of pipe 2 & 3 the friction slope was reduced such that the HDL does not exceed the top of M.H. No.2 and M.H. No. 3.

Source: *Hydraulic Manual*, Oregon Department of Transportation

Exhibit 8-45
Width of Spread



Source: Drainage of Highway Pavements, HEC#12, FHWA

8.4.4.3 Inlet Structures

MassHighway uses three types of inlets to collect storm runoff, as described below:

- **Catch basins** — A grate is used to intercept storm runoff which is delivered to an underground structure (usually an inside diameter of 4 feet) with a 2-3 foot sump. Deep sump catch basins with 4-foot sumps should be used to help remove suspended solids from the storm water. Hoods may also be used to trap oil and grease. The designer should consult the MassHighway Storm Water Handbook for locations where deep sump catch basins or hoods are required. Catch basins can be constructed using concrete block, or precast concrete. Three types of grates are used — the parallel-bar grate, the Massachusetts cascade grate, and rectangular bar grates. Parallel bar grates should only be used on limited access highways where bicycles are not allowed; the cascade grate is used on all other highways on continuous grades. At low points, rectangular bar rates should be used because they efficiently accept flow from both directions and are safe for bicycles. The MassHighway Construction Standards provide the design details for the catch basin and grates. A curb inlet may also be used where curbing is required. The efficiency of these grates is shown in Exhibit 8-46.

- **Gutter inlet** — A grate is used to intercept storm runoff which is delivered to an underground structure (2-feet square) without a sump. It is designed for locations where utilities make a full-size catch basin impossible. They can be either brick or concrete as described in the *MassHighway Construction Standards*. When a gutter inlet is used, a catch basin with a 2-3 foot sump and manhole frame and cover should be installed between the inlet and trunk line manhole. A curb inlet may also be used where curbing is required.
- **Drop inlet** — A grate and side-opening “throat” are used with a 2- to 3-foot sump. These are typically used in ditches. A raised type is used where run-off-the-road vehicles cannot hit the drop inlet; a flush type is used where the inlet can be a hazard. *MassHighway Construction Standards* provide the design details.
- **Spacing** — Catch basins should be spaced so that the tolerable ponding on the travel lane is not exceeded. General guidelines for spacing are as follows:
  - 300± feet on tangent, or closer as required for intersections.
  - 200-250 feet on the inside of superelevated curves. The closer spacing should be used for wider pavements.
  - 250 feet on highway grades over 6%.

The methodology discussed under "Capacity" should be checked to determine if closer catch basin spacings are warranted. The final decision will be based on engineering judgment and economic considerations.

Exhibit 8-46
Grate Inlet Efficiency (E)

	Allowable Width of Spread (T)								
Grate	2'	3'	4'	5'	6'	7'	8'	9'	10'
Parallel Bar	.95-1.00	.92-.99	.83-.94	.74-.86	.66-.78	.59-.71	.54-.65	.49-.60	.45-.56
Mass. Cascade	.91-1.00	.87-.99	.79-.93	.70-.85	.63-.77	.56-.70	.51-.64	.46-.59	.43-.55

Source: MassHighway

In addition to spacing, other location criteria also apply to catch basins:

- It is preferable to use catch basins as “end of line” devices with each catch basin connected to a drain manhole rather than connected to another catch basin in series.
- At low points on major highways, six inlets are used: one on each side of the roadway at the low point and one on each side of the low point at locations approximately 0.3 feet above the low point. At low points on minor highways, four inlets are used: one on each side at the low point and one on each side 20 to 25 feet from the low point on the lesser of the two upgrades.
- Uphill of intersections and pedestrian crosswalks.
- On superelevated curves, before the superelevation transition begins.
- On the uphill side of bridges.

Capacity (Gutter and Inlet). The designer should analyze the capacity of the gutter and grates to determine if additional catch basins are required. The procedure for determining inlet spacing on continuous grades is:

Step 1: Select the allowable ponding width (T) as measured from the curb. As an additional check, the designer should ensure that the depth of water in the gutter will not overtop the curb.

Step 2: Select the pavement cross slope (Sx), typically l/4"/ft (.021) for travel lanes and 3/8"/ft (.031) for shoulders.

Step 3: Calculate Z: Z = 1/SX

Step 4: Select n, the Manning roughness coefficient, for the pavement and gutter surface. Use Exhibit 8.22. Calculate Z/n.

Step 5: Calculate the depth of flow (d) at the curb:

$$d = T/Z$$

Compare this depth to the curb height.

Step 6: Determine the runoff flow (Qt) in the gutter. Use chart presented with the Example Problem that follows.

Step 7: Calculate the capacity of the inlet (Qi). Use Exhibit 8-45.

$$Qi = EQt$$

Where: Qi = capacity of grate inlet, cfs

E = inlet efficiency (or percent of capture

Qt = total gutter flow immediately before grate inlet, cfs

Source: FHWA-TS-84-202

Step 8: Locate the first inlet. Select a trial location and use the proper hydrologic method (Section 8.2) to determine where the flow equals Qt from Step 6. The designer should calculate the discharge separately for the pavement drainage and for the total drainage area to the first inlet. The higher of these two values will be used. Regardless of this calculation, the first inlet should be placed no more than 300 feet from the crest of the vertical curve.

Step 9: Calculate the flow bypassing the inlet. This will be:

$$Qb = Qt - Qi$$

Step 10: Determine the distance downstream from the first inlet where Qi is generated from the pavement drainage. This will provide a reasonable estimate of catch basin spacing where all of the flow would be intercepted by the inlet.

Example:

Given: The site discussed in Example 2 for Section 8.2.2.3 "Rational Method" will be evaluated to determine catch basin spacing. The key information from that example, which calculated the discharge into the first inlet 300 feet from the vertical crest, follows:

Highway:	30-ft. curb-to-curb
	So = 3%
	Sx = .031
Drainage Basin:	A = 2 acres
	Q = 3.29 cfs
Pavement Drainage:	Q = .49 cfs

Problem: Determine catch basin spacing for the cascade grate for a 10-year design frequency and 6 feet of ponding. Use standard MHD catch basin.

Solution: The step-by-step solution follows.

Step 1: Given

Step 2: Given

Step 3: $Z = 1/.031 = 32.26$

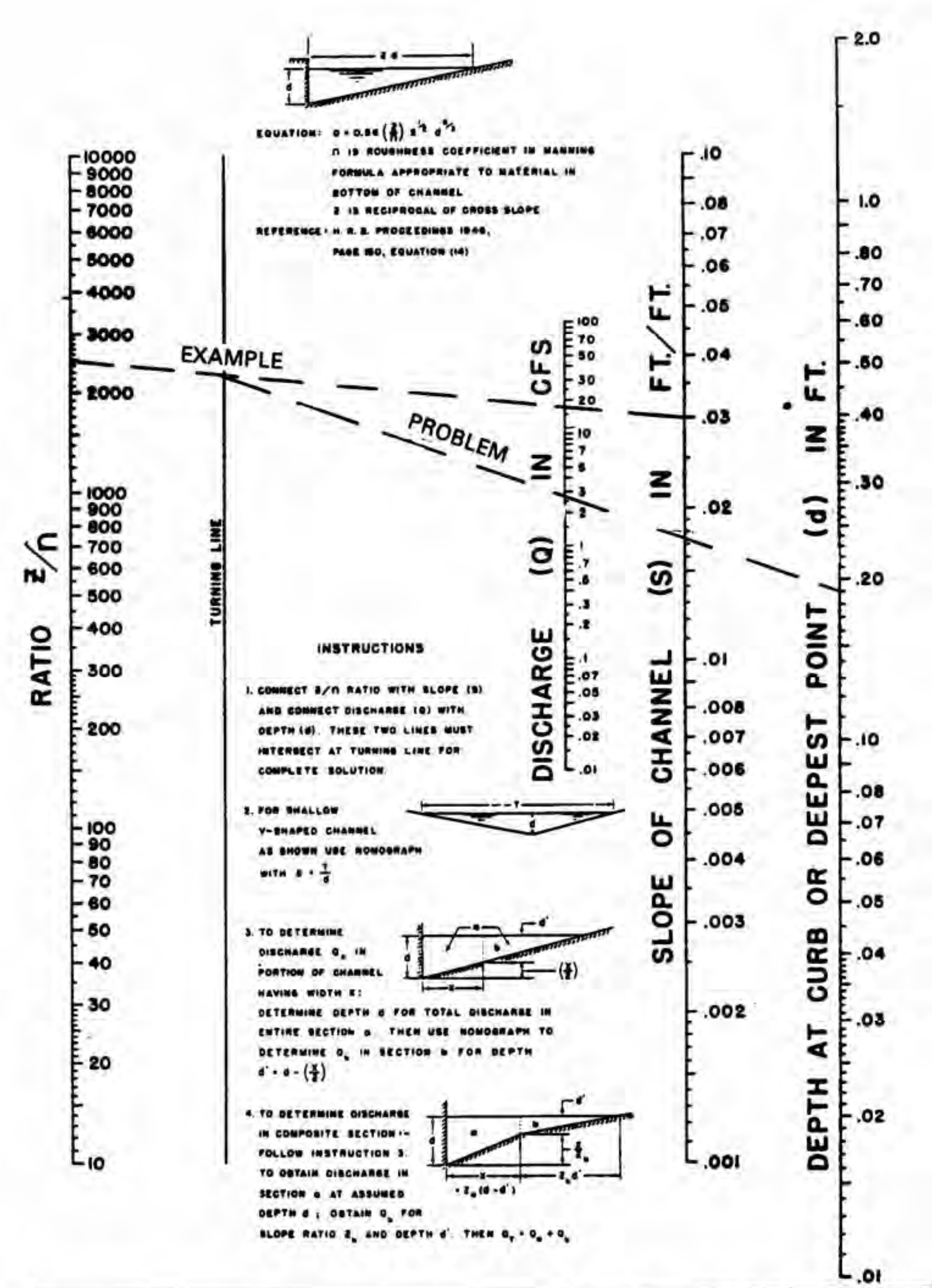
Step 4: $n = .013$; $Z/n = 2482$

Step 5: $d = 6/32.26 = .19$ ft.

Step 6: From Exhibit 8-47 , Qi = 2.7 cfs. This is the maximum allowable gutter flow within the given constraints of longitudinal slope, cross slope, and allowable ponding.

Step 7: Use Exhibit 8-46 to determine the flow captured by the cascade inlet. For a 3% slope and 6 ft. of ponding, E = .73 (approximately).
Qi = .73 x 2.7 = 1.97 cfs.

Exhibit 8-47
Gutter Capacity - Example Problem



NOMOGRAPH FOR FLOW IN TRIANGULAR CHANNELS

Source: Drainage of Highway Pavements, HEC#12, FHWA

Step 8: Determine if the first inlet location is correct (300 ft. from vertical crest). From the example in Section 8.2.2.3, the drainage basin delivers 3.29 cfs to the first inlet. This exceeds the allowable maximum discharge of 2.7 cfs from Step 6.

Therefore, the first inlet must be relocated closer to the vertical crest. This would be to approximately where the area of the drainage basin to the inlet is about (2.7/3.29) x 2 = 1.64 acres.

Note: For 3.29 cfs, the ponding would be about 6.8 ft.

Step 9: Qb = 2.7-1.97 = .73 cfs.

Step 10: Each successive inlet should be spaced so that no more than 1.97 cfs is generated by the pavement drainage. For this example, the distance would be approximately 1,200 ft. However, closer catch basin spacing would be used because of intersections and/or the 300-ft "rule of thumb."

8.4.4.4 Manholes

Manholes are underground structures and provide access for maintenance to the storm drain system. They are typically located at junctions, at intermediate points on long tangent pipe runs, where the conduit changes sizes, and at changes in grade or alignment.

The spacing of manholes should be in accordance with the following criteria:

Size of Pipe	Maximum Distance
12 – 24 inch	300 feet
30 -36 inch	400 feet
42 – 54 inch	500 feet
60 inch and greater	1000 feet

Deflection angles in the trunk line produce head losses at the manhole, which will increase the HGL. Deflection angles up to 90 degrees are acceptable if the head losses are calculated for the HGL computation (see Section 8.4.4.9). As general guidance, pipe diameters up to 36 inches may have deflection angles up to 60 degrees at manholes. These angles are measured between the centerlines of the inflow and outflow trunk line.

Where inlet or lateral pipes connect to the trunk line at a manhole, the maximum deflection angle should be no more than 60 degrees. This is measured between the centerlines of the inflow (lateral) pipe and the outflow pipe. Drop manholes are necessary where the difference in the trunk line flow exceeds 3 feet. The *MassHighway Construction Standards* provide the design details for standard manholes.

8.4.4.5 General Design Criteria for Trunk Line System

The following design parameters apply to the drainage trunk line system.

- **Design Discharge**. The storm drain system should be designed for the same frequency as the pavement drainage and should meet these criteria:
    - The pipe system should flow full for the calculated total flow, wherever possible.
    - Ideally, the system should operate under pressure with a free outfall. A system operating under surcharge with a submerged outflow is allowable.
    - Preferably, the HGL should not rise to within 2.0 feet of any manhole cover or top of any inlet for the design discharge; in no case, should the HGL rise to within 0.75 foot of the cover.
    - The HGL should not rise to a level that would flood any subdrain outfalling into the storm drain system.
    - The hydraulics of the lateral pipes preferably will not be influenced by the HGL of the trunk line.
- **Location**. If possible, the trunk line should not be located beneath the travel way — but preferably in the median, in the shoulder, or behind the curb. Inlets should not be located over the trunk line.
- **Outfall**. The outfall should meet these criteria:
    - It should be into a natural drainage course, preferably downstream of the roadway.
    - It should be located so as to allow for overland flow before any storm water reaches any wetland resource area associated with the natural drainage course.

- Its flow should not significantly increase the flow of the drainage course. The designer should consult the *MassHighway Storm Water Handbook* for locations where peak discharge controls are required.
- When feasible, it should be a free outlet during the design discharge period.
- The outflow velocity should be low enough to prevent scour and erosion in the natural drainage course. Erosion control should be provided at the outlet consisting of a riprap apron or vegetated swale stabilized with erosion control fabric depending on the outlet velocities. An energy dissipator may be warranted in some cases. See Section 8.4.3.
- If located within the roadside recovery area, the outlet design should provide a flared end section rather than a headwall so as not to present a hazard to an errant motorist.

- **Pipe Design**. All pipes should meet these criteria:
  - The material can be concrete, corrugated metal, corrugated polyethylene, ductile iron, or cast iron pipe.
  - Preferably, pipes will be placed at a 5-foot depth to avoid frost penetration. Exhibit 8-48 provides the recommended covers for various concrete pipe sizes and types.
  - Corrugated metal and polyethylene pipe shall be placed in accordance with the manufacturer's recommendations for providing cover over the pipe.
  - All pipes should be laid in a straight line. Where this is not cost effective for larger pipe sizes, bends can be considered.
  - The minimum size of trunk line pipe is 12 inches; for lateral pipes, it is also 12 inches.
  - Pipe joints should be gasketed, mortared or other acceptable joint provided based on the pipe material to prevent infiltration or exfiltration.
- **Gradient**. The minimum desirable slope is 0.4%.
- **Velocity**. These criteria apply:

- The minimum velocity should be 3 ft./sec. when flowing at a depth of approximately 1/3 of the diameter.
- The maximum velocity should be 10 ft./sec. In extreme cases, higher velocities will be permitted.

Exhibit 8-48

Recommended Cover (Reinforced Concrete Drain Pipe)

Diameter	III Modified	Extra Strength	Class III	Class IV	Class V
Inches	Min-Max	Min-Max	Min-Max	Min-Max	Min-Max
6		24 in. to 23 ft			
8		24 in. to 17 ft			
10		24 in. to 13 ft			
12	36 in. to 12 ft	24 in. to 13 ft	18 in. to 12 ft	12 in. to 20 ft	6 in. to 35 ft
15	36 in. to 12 ft	24 in. to 13 ft	18 in. to 12 ft	12 in. to 20ft	6 in. to 35 ft
18	36 in. to 12 ft	24 in. to 13 ft	18 in. to 12 ft	12 in. to 20 ft	6 in. to 35 ft
21			18 in. to 12 ft	12 in. to 20 ft	6 in. to 35 ft
24			18 in. to 12 ft	12 in. to 20 ft	6 in. to 35 ft
27			18 in. to 12 ft	12 in. to 20 ft	6 in. to 35 ft
30			18 in. to 12 ft	12 in. to 20 ft	6 in. to 35 ft
36			18 in. to 12 ft	12 in. to 20 ft	6 in. to 35 ft
42			18 in. to 12 ft	12 in. to 20 ft	6 in. to 35 ft
48			18 in. to 12 ft	12 in. to 20 ft	6 in. to 35 ft
60			18 in. to 12 ft	12 in. to 20 ft	6 in. to 35 ft
72			18 in. to 12 ft	12 in. to 20 ft	6 in. to 35 ft

1. *Maximum* cover shown is measured from *finish* grade.
2. Minimum cover shown is measured from subgrade for construction traffic.
3. Heavy weight cast iron pipe is required for subgrade cover less than 6 inches for laterals. For trunk line, use Class V reinforced concrete pipe.

Source: *Hydraulics Manual,* Oregon Department of Transportation.

8.4.4.6 Procedure — Field Work

Before the designer begins any design for the storm drain system, the following basic information should be obtained:

- From topographic maps, determine the drainage basin characteristics from the proposed drainage system.
- Walk the area to locate possible outfalls and potential problem areas.
- Locate all existing underground utilities, both horizontally and vertically.

- Determine basic highway data (e.g., pavement widths, cross slopes, grades, existing drainage, etc.).

The designer should also refer to Section 8.2.3.

8.4.4.7 Procedure — Preliminary Layout

The designer should prepare at least one alternate layout for the storm drain system to determine the best design. The preliminary layout should be made on the proposed or existing road plan. A preliminary layout will include:

- Plot of roadway profile;
- Location of all underground utilities shown on the plan with elevations at critical crossings;
- Location of the trunk line;
- Location of the curb line and the direction of the gutter flow;
- Location, type and spacing of inlet structures;
- Location of manholes;
- Location of outfalls; and
- Location of storm water management systems including detention, infiltration or water quality measures in accordance with the MassHighway Storm Water Handbook.

8.4.4.8 Procedure — Full-Flow or Partial-Flow System

Exhibit 8-49 provides the work sheet to document the data for storm drain systems designed to flow full or partial. A description of each column in follows:

Note: For the "Discharge" information for the first inlet only, the designer will be entering data based on the results of Step 8 in the grate capacity procedures (Section 8.4.4.3). This step requires that the designer use the pavement drainage or drainage basin discharge to the inlet, depending on which analysis yields the higher flow.

- Column 1: Enter the number for the inlet which will drain to the upstream end of the trunk line (TL) segment.
- Column 2: Enter the street name.

- Column 3: Enter the centerline station number and offset from the centerline for the manhole at the beginning of the TL segment.
- Column 4: Enter the same data for the manhole at the end of the TL segment.
- Column 5: Enter the size in acres for the entire drainage area to the inlet.

Exhibit 8-49
Worksheet for Storm Drain Design

Project ______ City/Town ______ Design Frequency ______ Sheet ____ of ____

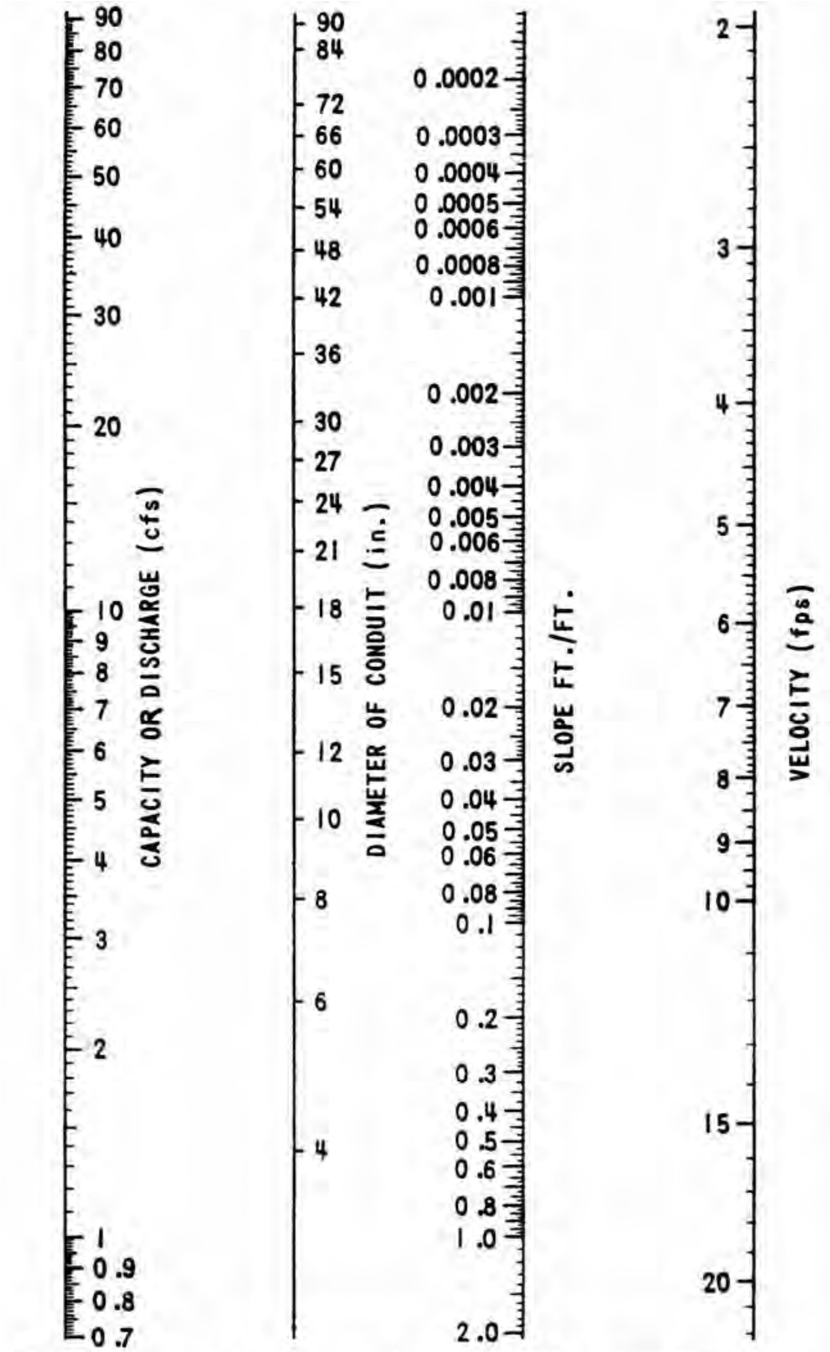
Designed by ______ Date ______ Checked by ______ Date ______

	Manhole Location			Discharge						Pipe Data					Vertical Control			
		Centerline Station and Offset													Invert Elevation		Top of MH Elevation	
Inlet No.	Street Name	From	To	Drainage Areas (acres)	Coefficient (c)	Tc or Pipe Flow Time (min)	Total Tc (min)	Rainfall Intensity (i) (in./hr)	Design Discharge (cfs)	Length (ft)	Slope (ft/ft)	Diameter (in)	Full-Flow Capacity (cfs)	Full-Flow Velocity (fps)	Upper	Lower	Upper	Lower
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)

Source: MassHighway

- Column 6: Enter a composite runoff coefficient (see Section 8.3.2.2).
- Column 7: Enter the pipe flow time (Tc) from the previous TL segment. This is found by dividing the TL length (Column 11) by the TL velocity (Column 15) and dividing by 60 to yield a time in minutes.
- Column 8: Enter the cumulative time of concentration. This will be the sum of the Column 7 value and Column 8 from the preceding TL segment.
- Column 9: Enter the rainfall intensity for the calculated T_C and design runoff frequency.
- Column 10: Calculate and enter design discharge (Q) from the Rational formula.
- Column 11: Enter the length of the TL segment.
- Column 12: Enter the slope of the pipe segment. Usually, the slope of the above pavement can be assumed on a trial basis. If the final slope varies, this must be documented in the final work sheet.
- Column 13: Determine and enter the pipe size. Use Exhibit 8-50 for concrete pipes and Exhibit 8-51 for corrugated metal pipe. Lay a straight edge connecting Q (Column 10) on the discharge scale to the slope (Column 12) on the slope scale. Read the size of the pipe above the straight edge.
- Column 14: Determine and enter the capacity of the pipe size from Column 13. Use either Exhibit 8-50 or 8-51. Connect the pipe size with the slope and read the capacity.
- Column 15: Read and enter the velocity of the pipe flow when flowing full.
- Column 16: Enter the elevation of the pipe invert at the upper end of the TL segment.
- Column 17: Enter the surface elevation for the lower pipe invert.
- Column 18: Enter the surface elevation of the manhole at the upper end of the TL segment.
- Column 19: Enter the surface elevation of manhole at the lower end.

Exhibit 8-50
Concrete Pipe Flowing Full

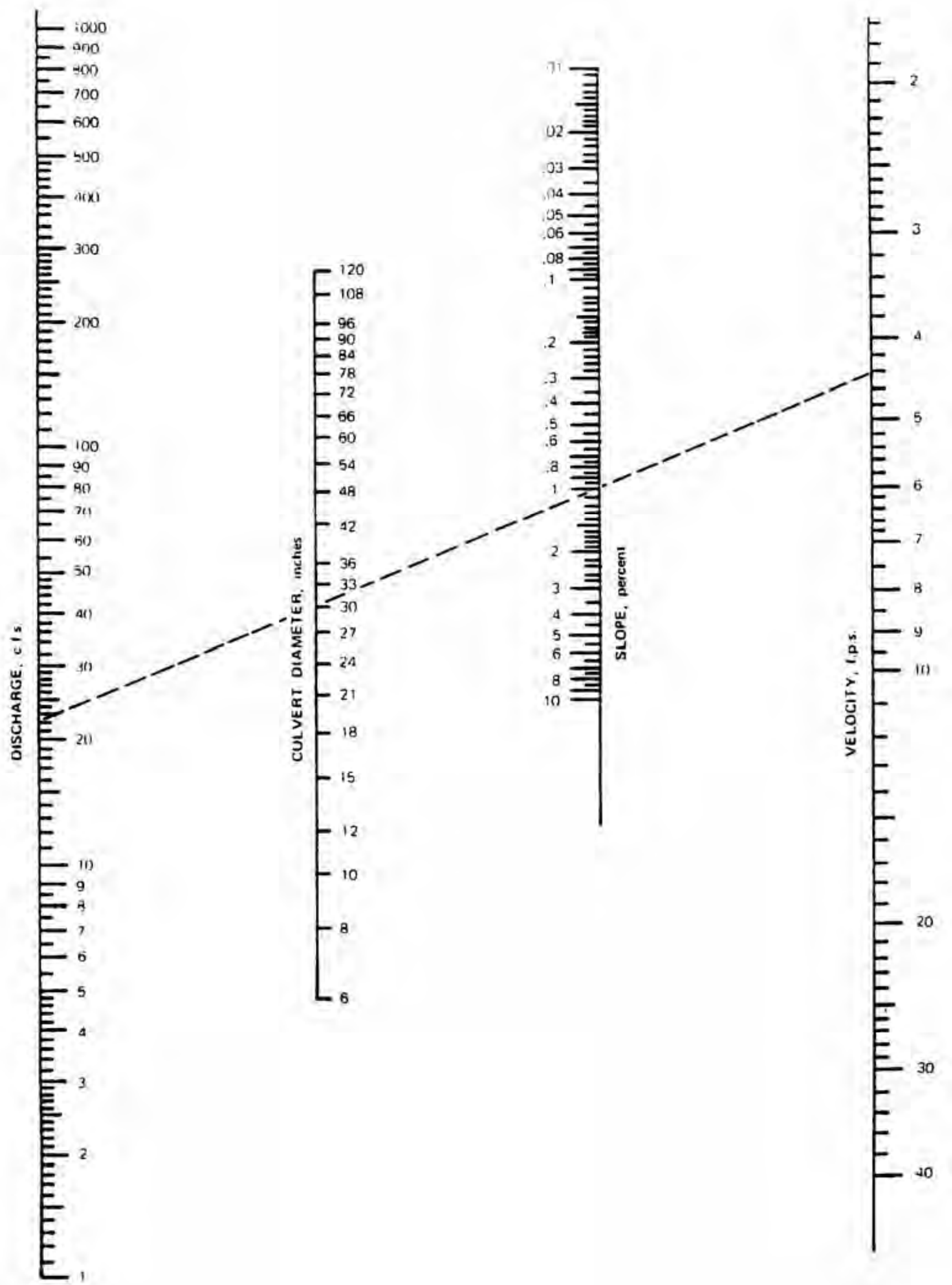


Nomograph based on Manning's formula for circular pipes flowing full in which n=0.013.

Source: Hydraulic Manual, Oregon Department of Transportation

Exhibit 8-51

Circular Corrugated Pipe Flowing Full



Source: Hydraulic Manual, Oregon Department of Transportation

8.4.4.9 Procedure — Hydraulic Gradeline Check

After the storm drain system has been laid out, the designer must check the elevation of the HGL. The HGL will preferably not be closer than 2.0 feet to the surface of any manhole or inlet structure. At a minimum, it will not be closer than 0.75 feet. This procedure applies to storm drain systems with either a free or submerged outlet.

Exhibit 8-52 should be used to document the calculations for the HGL elevation. A description of each column follows:

- Column 1: Enter the street name.
- Column 2: Enter the centerline station number and offset from the centerline for the manhole at the downstream end of the TL segment.
- Column 3: Enter the same data for the manhole at the upstream end.
- Column 4: Enter the design discharge for pipe segment.
- Column 5: Enter the pipe diameter.
- Column 6: Enter the pipe length.
- Column 7: Enter the pipe velocity.
- Column 8: Enter the velocity head ($V^2/2g$).
- Column 9: Enter the HGL for the downstream end of the pipe (tailwater) as measured from the pipe invert. For the lowermost pipe segment in the system, this will be:

A. Submerged: Water surface

$$HGL = \frac{d_c + D}{2} \quad \text{(not to exceed D)}$$

B. Free Outfall:

Where: dc = critical depth (see Chart 16 of HEC #5), ft.

D = pipe diameter, ft.

For all other pipe segments, the tailwater HGL will equal the HGL from Column 16 of the preceding or downstream pipe.

Exhibit 8-52
Worksheet for HGL Computations

Project ______ City/Town ______ Design Frequency ______ Sheet ______ of ______

Designed by ______ Date ______ Checked by ______ Date ______

Manhole Location			Pipe Data						HEC #5		Manhole Head Losses				Vertical Controls (Elevations)			
Street Name	Centerline Station and Offset																	
	From	To	Discharge (cfs)	Diameter (in.)	Length (ft)	SO FT/FT	Velocity (fps)	Vel. Head (ft)	Tailwater HGL (ft)	Headwater (ft)	KM	Manhole Loss (ft)	KD	Deflection Loss (ft)	Pipe Invert (Upstream Manhole)	HGL (Upstream Manhole)	Surface (Upstream Manhole)	Freeboard (ft)
(1)	(2)	(3)	(4)	(5)	(6)	(6A)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)

Source: MassHighway

- Column 10: Using the procedures in Section 8.4.2.6 for HEC #5, determine the required headwater for the given pipe conditions. Make these assumptions:

  A. Inlet Control: Use Chart 2 and a groove end with a headwall for a concrete pipe. Use Chart 5 with a headwall for a corrugated metal pipe.

  B. Outlet Control: Use Chart 9 with ke = 0.2 for a concrete pipe. Use Chart 11 with ke = 0.25 for a corrugated metal pipe. Enter the headwater as measured from the pipe invert.

- Column 11: Enter the loss coefficient (usually 0.2) for the manhole (Km)

- Column 12: Enter the head loss for the manhole. This will be calculated using the velocity head for the inflow pipe into the manhole. (Column 8 for the upstream pipe.) Therefore, $Hm = Km (V^2/2g)$.

- Column 13: Enter the loss coefficient (KD) for any deflections of the trunk line at the manhole. Use Exhibit 8-53.

- Column 14: Enter the head loss for any deflections. This will be calculated using the velocity head for the inflow pipe into the manhole. (Column 8 for the upstream pipe.) Therefore, $HD = KD (V^2/2g)$.

- Column 15: Enter the elevation of the pipe invert at the upstream manhole, as measured from an appropriate datum.

- Column 16: Enter the HGL elevation in the upstream manhole. The distance from the pipe invert to the HGL is (adjusted headwater):

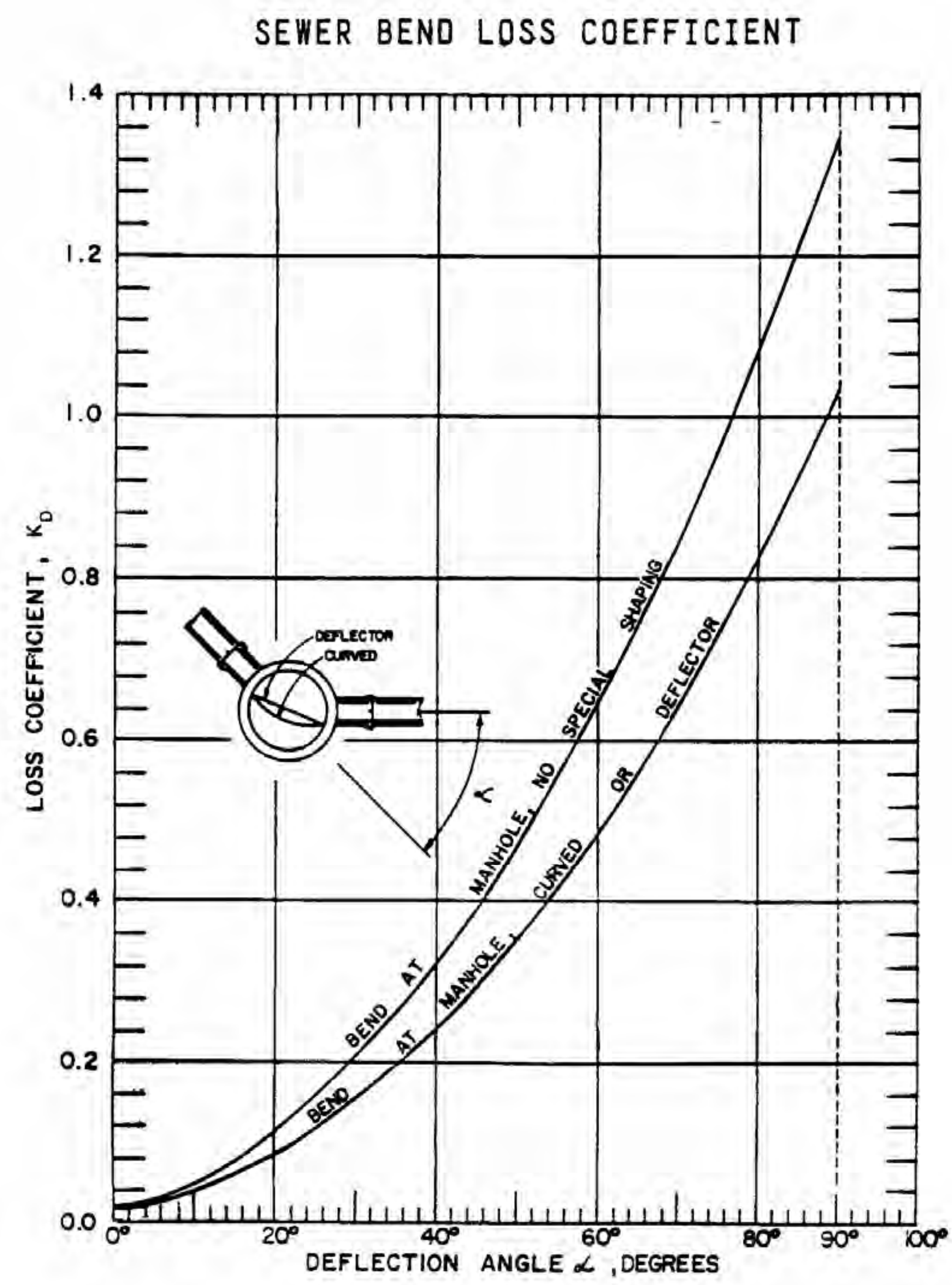
  HWadj = HW (Column 10) - Velocity Head (Column 8, upstream pipe) + Hm (Column 12) + HD (Column 14).

- Column 17: Enter the surface elevation of the upstream manhole.

- Column 18: Enter the freeboard for the upstream manhole. This will be the manhole surface elevation (Column 17) minus the manhole HGL.

  If the freeboard in Column 18 is less than 2.0 feet, the system should be redesigned. It must be redesigned if the freeboard is less than 0.75 feet. Typical changes include providing larger pipe sizes, flattening pipe slopes, or reducing deflection angles at the manholes.

Exhibit 8-53
Manhole Bend Losses



Source: Urban Storm Drainage, Denver Regional Council of Governments

Example:

Given: Exhibit 8-54 illustrates the schematic of a storm drain system. Exhibit 8-55 provides the elevation data for the system.

Problem: Determine the proper sizes for each segment of the trunk line assuming a free outfall and a submerged outfall where TW = 4 feet.

Solution: After Exhibits 8-54 and 8-55 follow:

- A completed worksheet for the storm drain design,
- A completed worksheet for the HGL computation (free outfall), and a completed worksheet for the HGL computation (submerged outfall).

Note that for both HGL computations, the first pipe in the system was undersized according to the initial sizing procedures.

Computer software for the design of storm drainage systems is available from Haestad Methods and other computer software companies.

Exhibit 8-54
Example Problem - Storm Drain System

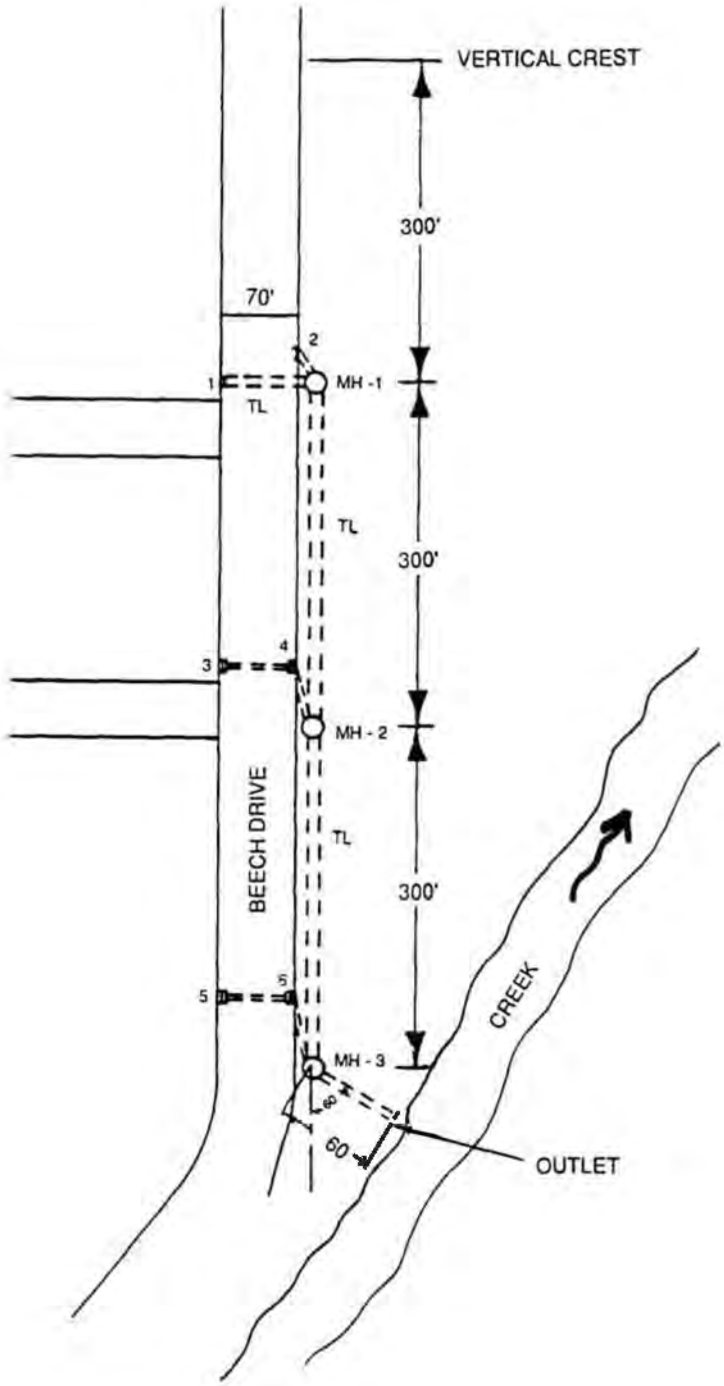
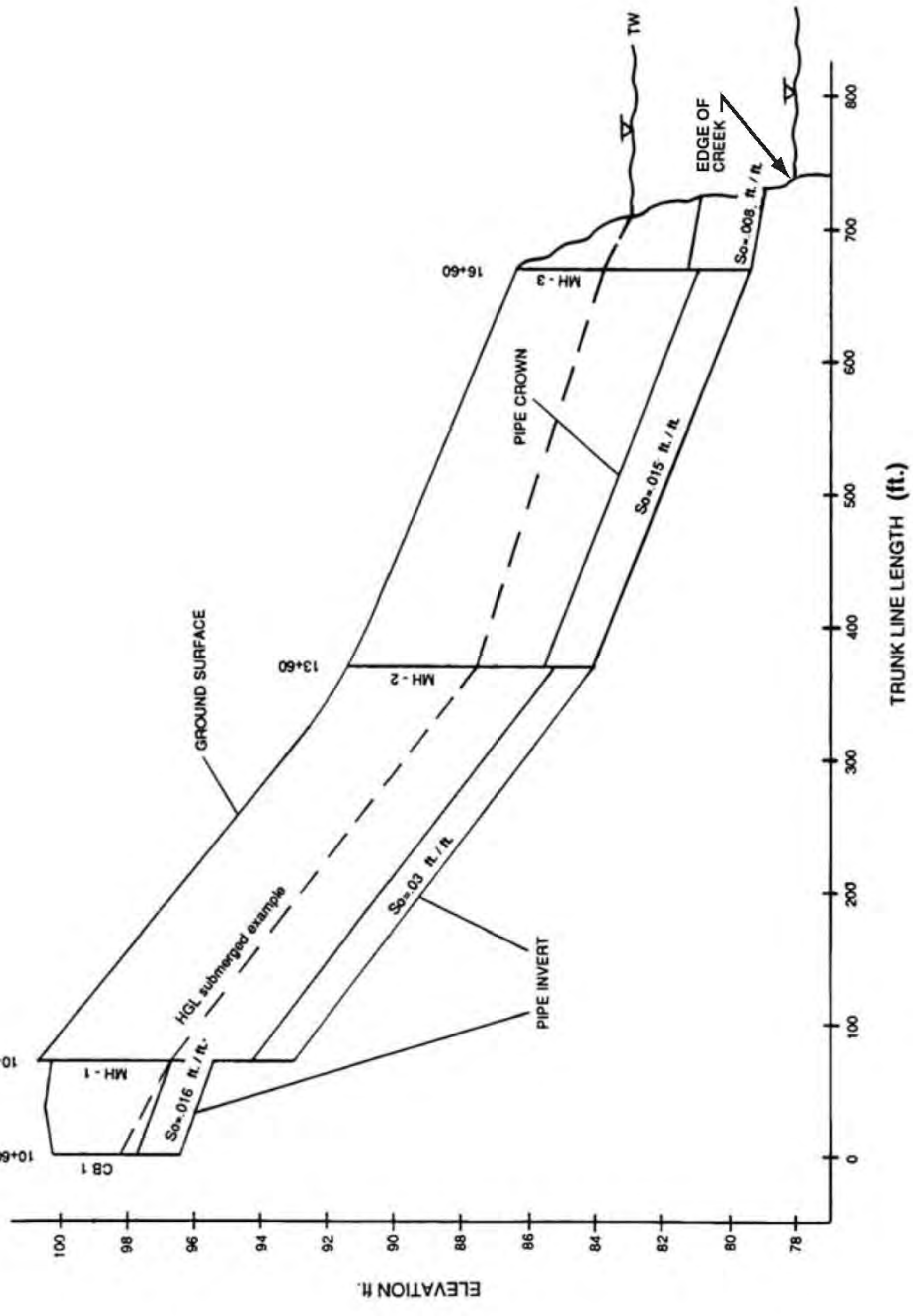


Exhibit 8-55
Example Problem - Storm Drain System



Storm Drain Design Worksheet

Project Beech Drive City/Town Boston Design Frequency 10 yrs Sheet 2 of 3

Designed by Brad Martin Date 3/29/88 Checked by Mary Coughlin Date 3/31/88

Manhole Location			Pipe Data					HEC #5		Manhole Head Losses				Vertical Controls (Elevations)			
Street Name	Centerline Station & Offset From	Centerline Station & Offset To	Discharge (cfs)	Diameter (in)	Length (ft)	Velocity (fps)	Vel. Head (ft)	Tailwater HGL (ft)	Headwater (ft)	K_M	Manhole Loss (ft)	K_D	Deflection Loss (ft)	~~Pipe Invert (Upstream Manhole)~~ HGL ABOVE UPSTREAM PIPE INVERT	HGL (Upstream Manhole)	Surface (Upstream Manhole)	Freeboard (ft)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Beech Dr.	Outlet	16+60 35' Lt	14.0	21	60	–	–	4	4.57	.2	.17	.49	.41	4.32	83.82	86.40	2.58
↓	16+60 35' Lt	13+60 35' Lt	12.7	18	300	7.3	8.3	4.32	4.52	.2	.26	–	–	3.49	87.49	91.50	4.01
↓	13+60 35' Lt	10+60 35' Lt	11.1	15	300	9.1	1.29	3.49	3.49	.2	.14	1.04	.73	3.66	96.66	100.80	4.14
↓	10+60 35' Lt	10+60 35' Rt	8.2	15	70	6.7	.70	1.28	2.23	–	–	–	–	2.23	98.73	100.30	1.57
↓	10+60 35' Lt	10+60 35' Rt	8.2	18	70	4.7	.34	1.19	1.70	–	–	–	–	1.70	98.20	100.30	2.10

Worksheet for HGL Computations
(Free Outlet Example)

HGL Computation Worksheet

Project Beech Drive City/Town Boston Design Frequency 10 yrs Sheet 1 of 2

Designed by Mary Coughlin Date 3/29/88 Checked by Brad Martin Date 3/31/88

Inlet No.	Manhole Location			Runoff						Pipe Flow					Vertical Control			
	Street Name	Centerline Station & Offset		Size (acres)	Coefficient (c)	Tc or Pipe Flow Time (min)	Total Tc (min)	Rainfall Intensity (i)	Design Runoff (cfs)	Length (ft)	Slope (ft/ft)	Diameter (in)	Capacity Flowing Full (cfs)	Velocity Flowing Full (fps)	Invert Elevation		Top of MH Elevation	
		From	To												Upper	Lower	Upper	Lower
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
1	Beech Dr.	10+60 35' Rt	10+60 35' Lt	4.10	.4	7.10	7.10	4.9	8.0	70	.016	15	8.2	6.7	96.5	95.38	100.3	100.8
2	↓	10+60 35' Lt	13+60 35' Lt	4.34	.43	.17	7.27	4.8	9.0	300	.03	15	11.1	9.1	93.00	84.00	100.8	91.50
3 & 4	↓	13+60 35' Lt	16+60 35' Lt	4.82	.47	.55	7.82	4.7	10.7	300	.015	18	12.7	7.3	84.00	79.50	91.50	86.40
5 & 6	↓	16+60 35' Lt	Creek Outlet	5.30	.51	.68	8.50	4.6	12.4	60	.008	21	14.0	5.8	79.50	79.02	86.40	–

8.4.5 Subdrainage Design

In addition to surface drainage of roadway runoff, proper drainage of subsurface water is an important element of roadway design, as described in the subsequent sections.

8.4.5.1 Purpose

Subdrainage systems remove water from beneath the surface of pavements or side slopes. Excess water from precipitation or groundwater can lead to failure of the pavement structure or slope. Water can enter the pavement subgrade through cracks in the surface, by lateral infiltration, or from groundwater. Groundwater action leads to the problems commonly known as frost heave and spring thaw. Water can enter the pavement structural section through gravity drainage or artesian flow. The longitudinal pipes of a subdrainage system intercept the water and drawdown the water table to below the pavement structure.

The basic references for subdrainage design are:

- FHWA-RD-30, *Guidelines for the Design of Subdrainage Drainage Systems for Highway Structural Sections*, Federal Highway Administration, June 1972.
- FHWA-TS-80-224, *Highway Subdrainage Design*, Federal Highway Administration, August, 1980.
- MS-15, *Drainage of Asphalt Pavement Structures*, The Asphalt Institute, August, 1981.

8.4.5.2 Typical System

The typical subdrainage system consists of:

- **Drainage blanket (permeable base)** — An open-graded aggregate subbase used to intercept and/or transfer the water to drain pipes.
- **Longitudinal drains** — Perforated pipes running beneath the roadway to collect the subsurface water. Intermittent outlets are provided.
- **Transverse drains** — Lateral pipes or stone bleeders used to carry the subsurface water away from the pavement structure or side slope

8.4.5.3 Application

The soils analysis of the proposed project site may indicate either a high groundwater table and/or soils with low permeability. In these cases, a subdrainage system should normally be used. Side hill cuts and ledge areas will likely require treatment.

Subdrains are usually located:

- Laterally, at the transition from cut to fill;
- Laterally, on the uphill side of a bridge approach;
- Laterally, on steep grades (5% or greater) where new pavement meets old pavement;
- Longitudinally, in cut areas where side slope stabilization may be a problem; and
- Laterally and longitudinally beneath a raised median.

On reconstruction projects, the designer and Pavement Design Engineer should examine the existing pavement and side slope conditions to determine the need for subdrainage design. Problems such as pavement cracking, water seepage through pavement cracks, and side slope sloughing or failure may indicate the need for subdrainage. Where subdrainage is required, the following measures may be considered:

- Complete removal of the existing pavement structure and the installation of a new system; or
- Provision of longitudinal and/or lateral drains beneath a new or reconstructed shoulder.

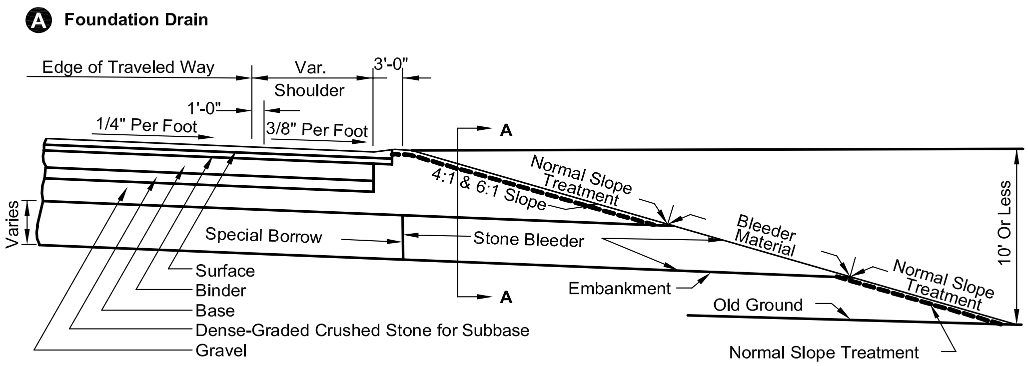
In addition to subdrains, the designer should also consider deepening shallow ditches, removing debris, or installing a closed surface drainage system on a reconstruction project. Shallow side ditches can allow flowing or standing water to seep beneath the shoulder and into the pavement structure.

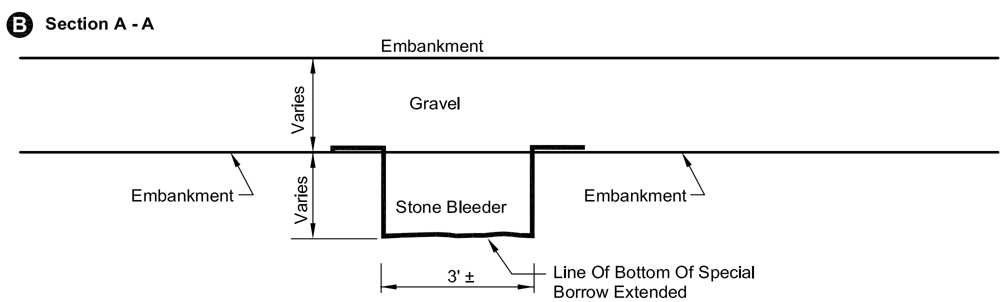
All uphill ends of subdrain pipes will be connected to a clean-out structure. Normally, the perforated pipe diameter is 8 inches, except in extraordinary circumstances where 12 inches is used. The *MassHighway Construction Standards* illustrate the construction of the subdrain.

Where possible the water collected in the subdrain system should be re-infiltrated through an infiltration trench, french drain or other system in a location where it will not be detrimental to the roadway.

Exhibits 8-56 through 8-59 illustrate typical MassHighway designs in fill, cut, and median sections.

Exhibit 8-56
Stone Bleeders on Fills



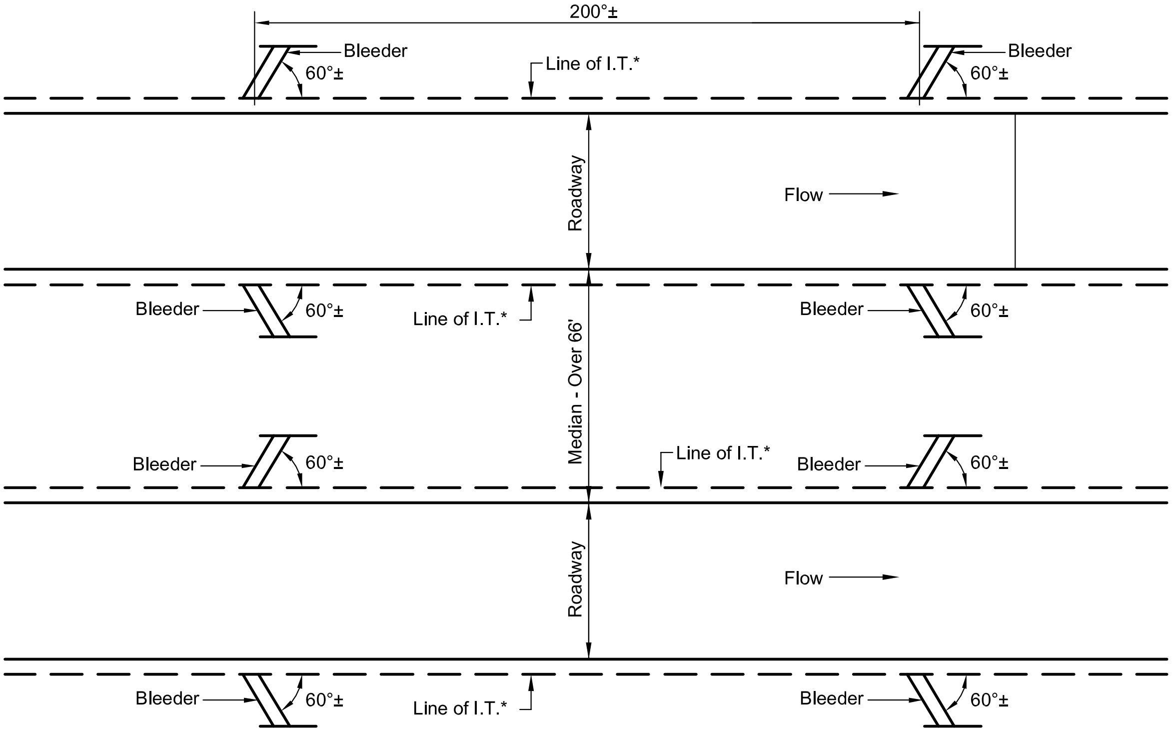


Source: MassHighway

Notes:

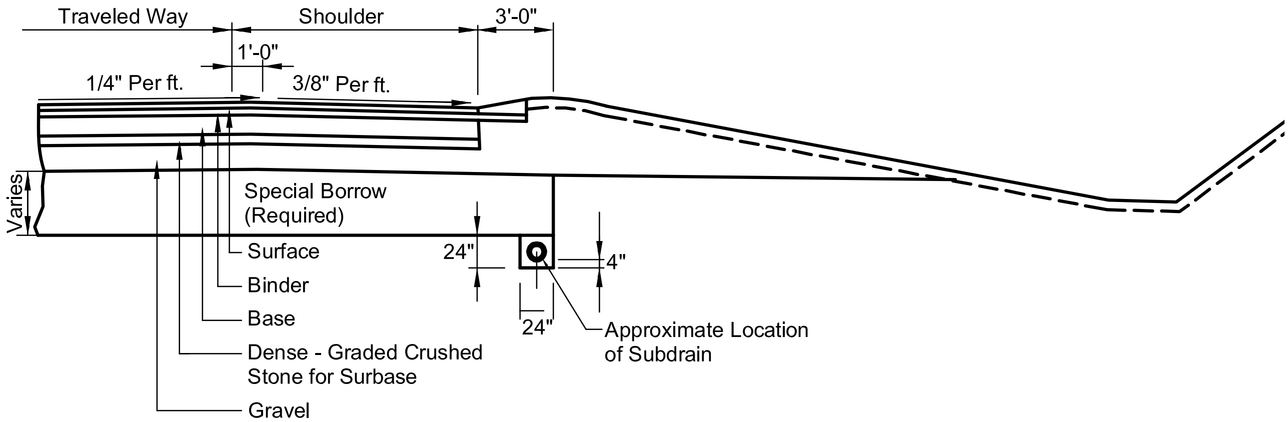
1. Bleeders are to be placed at 200 ft intervals, at low points, and at approximately 50 feet before and after each low point and/or as directed by the Engineer
2. See special provisions for bleeders, special borrow
3. Bleeders are not placed on 2:1 fill slopes. Special borrow is extended to slope.

Exhibit 8-57
Location of Foundation Drains



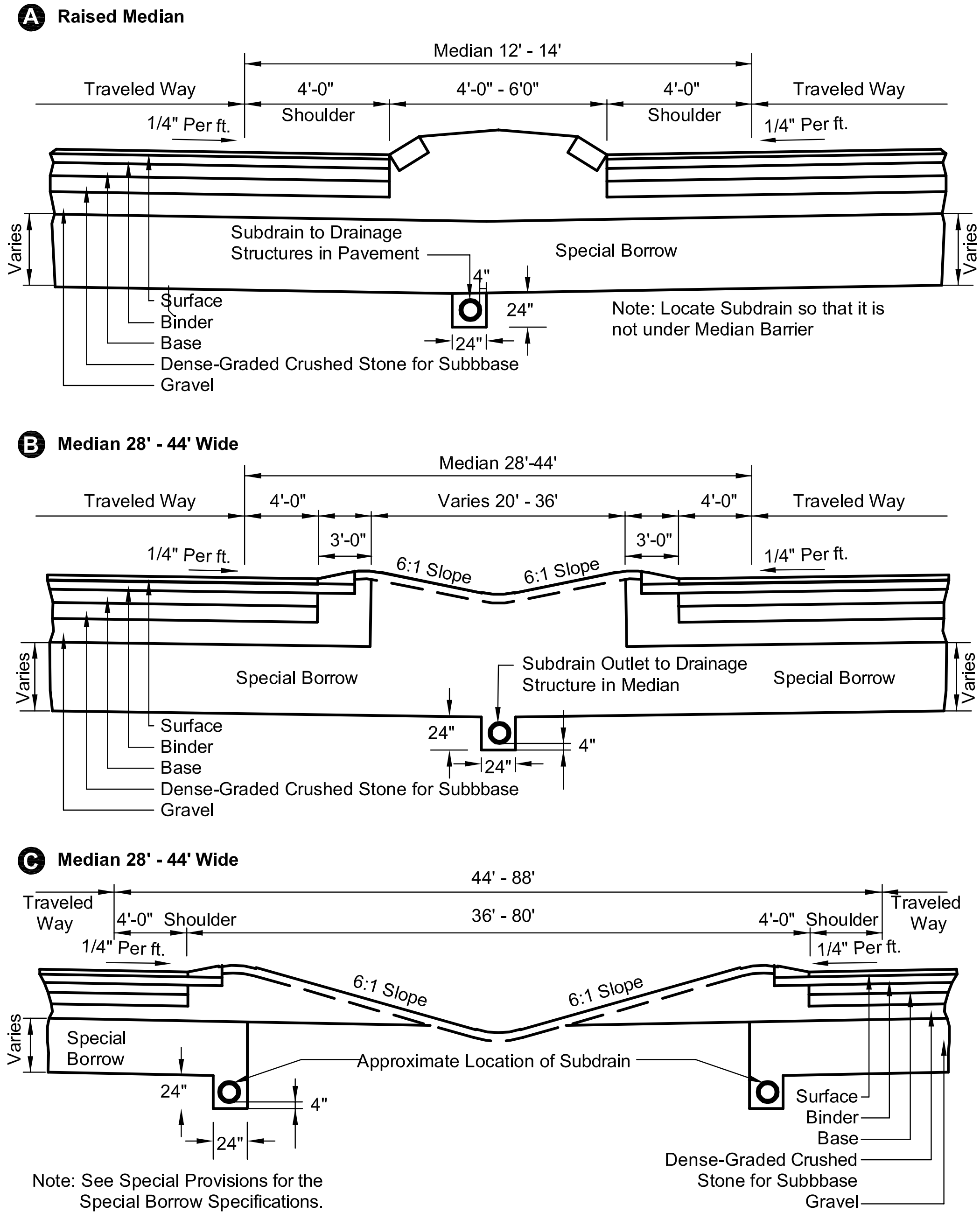
Source: MassHighway
Notes:
Bleeders are to be placed at 200 foot intervals, at low points, and at approximately 50 feet before and after each low point, and/or as directed by the engineer
* End of special borrow.

Exhibit 8-58
Subdrains in Earth Cuts



Source: MassHighway
Notes:
1. See special provisions for special borrow specification.
2. See construction standard 102.1.0 for treatment in rock cut, except that the subdrain should be placed in a "sump" as shown above.

Exhibit 8-59
Subdrains in Medians



8.4.6 Special Designs

On occasion, it may be necessary to use special hydraulic designs that may include:

- Siphons
- Bradley head inlets
- Flood control gates
- Debris control structures
- Detention basin outlet structures
- Sediment chambers

The designer should review any available technical publications which discuss these designs. The use of siphons to convey streams in cross-culverts is discouraged.

8.5 Erosion Control During Construction

During a highway construction project, soil erosion can be a major contributing factor to environmental pollution. In order to minimize the effect of sedimentation, scour, turbulence, washouts, etc. during construction operations, temporary measures and sometimes permanent controls must be provided.

Depending on the proximity of existing wetland resource areas, the project may be subject to the Wetlands Protection Act under MGL Chapter 131, Section 40. If that is the case than the design of erosion and sedimentation controls will need to be reviewed and approved by the local Conservation Commission.

In 1990, the U.S. Environmental Protection Agency (EPA) promulgated rules establishing the Phase I of the National Pollutant Discharge Elimination System (NPDES). Part of the Phase I rule addresses discharges from certain industrial activities including construction activities disturbing 5 acres or more of land. In 1999, the EPA issued the Phase II rule of the NPDES storm water program. Part of the Phase II rule reduces the threshold for soil disturbance at construction sites from 5 acres down to 1 acre. The Phase II rule went into effect on May 1, 2003. Roadway construction projects that exceed the soil disturbance threshold of 1 acre require the filing of a Notice of Intent (NOI) with the EPA under the Construction General Permit and the preparation of a Storm Water Pollution Prevention Plan (SWPPP) including erosion and sediment controls. In addition to affecting MassHighway construction activities, the NPDES Phase II rule applies to MassHighway as an “operator of MS4s” (as defined under the Phase II Rule). Phase II requires implementation of six minimum control measures including the following elements: 1) public education and outreach, 2) public participation/involvement, 3) illicit discharge detection and elimination, 4) construction site runoff control, 5) post-construction runoff control, and 6) pollution prevention/good housekeeping. This section addresses the requirements of construction site runoff control.

The type and design of the controls will vary with the environment that is to be protected and the specific cause of the potential environmental degradation. The protective measures may consist of, but not be limited to:

- Sedimentation basins for the protection of rivers, lakes, streams, and ponds.
- Temporary earth berms and slope drains to control heavy runoff, thus preventing washouts.
- Ditches at the bottom of slopes.
- Check dams at waterway crossings.
- Filters at drain inlets.
- Energy dissipators at culvert outlets (e.g., splash pads, bulk stone deposits, etc.).
- Silt fences.
- Hay bales.

The first priority in controlling erosion is to prevent displacement of the soil. When this is impractical, control measures should be designed to collect the displaced soil in a sediment control system. The most susceptible areas include cut-to-fill transitions, open channels, culvert inlets and outlets, steep slopes, borrow pits, and haul roads. Sandy and silty soils are the most susceptible to erosion; clay and gravel are the least susceptible. The designer should review the Soils Report to identify the type of soils likely to be exposed.

The construction plans and specifications may include various measures to prevent or minimize erosion and sedimentation:

- Sequencing the work in order to minimize the extent of land disturbance at one time.
- Permanent drainage features (channel linings, seeding, sodding, mulching, energy dissipators, etc.) should be constructed as soon as possible.
- All protection should closely follow the grading operation. Deep cuts and high fills should be mulched and seeded as the work progresses.
- Minimize the area and duration of exposed soil.
- Reduce the velocity and volumes of runoff on bare soil with check dams and diversions.
- Trap or filter out sediment before it leaves the construction area.

Many types of protective designs can be adapted to meet a particular condition. The temporary control measures generally include vegetation, water runoff diversion, sedimentation checks, and sedimentation basins. In some cases, the designer may have to develop innovative measures to control erosion and sedimentation.

Generally, the various schemes detailed in *Temporary Erosion and Pollution Control Measures*, Federal Highway Administration (February 1972) can be applied. Other references which can be used are:

- *Best Management Practices for Erosion and Sediment Control*, Federal Highway Administration, Region 15, December, 1978.
- *Suggestions for Temporary Erosion and Siltation Control Measures*, Federal Highway Administration, February, 1973.
- NCHRP Synthesis 70, *Design of Sedimentation Basins*, Transportation Research Board, June, 1980.

The designer should also refer to the DEP *Erosion Control Manual* and the *Massachusetts Erosion and Sediment Control Guidelines for Urban and Suburban Areas*, Prepared by Franklin, Hampden, Hampshire Conservation Districts, Northampton, MA for the MA Department of Environmental Protection 1997.

8.5.1 Vegetation

Vegetation applied soon after the grading operation is highly effective in erosion control. The vegetation can be temporary or (preferably) permanent. Temporary vegetation is practical when the final grading operation cannot be immediately completed, and the area will be exposed for a considerable length of time (more than one month).

Both permanent and temporary vegetation will require these considerations:

- Fertilization (temporary seeding requires about 400-700 lbs/acre);
- Mulch or binder (including straw, bituminous, and/or jute mesh);
- Topsoil, loam or plantable soil (4-in minimum thickness);
- Sod at critical locations (embankment grade breaks, ditch bottoms, and other susceptible areas); and
- Other special vegetative applications (see Chapter 13 for details).

8.5.2 Flow Diversion

8.5.2.1 Diversion Channel

These are temporary channels to divert water around an ongoing construction site for a permanent drainage structure. These keep the worksite dry and therefore minimize the chance for erosion. Diversion channels are normally used where structures larger than a 36-inch pipe are being installed in a natural stream. The construction sequence should be:

- Excavate and shape the diversion channel, leaving plugs or berms at both ends.
- Install channel linings as required.
- Remove plug from diversion channel (downstream first) and plug permanent channel location.
- Construct the permanent drainage structure.
- Remove plugs (downstream first) and divert flow to the new channel.
- Divert the flow through permanent structure.
- Salvage material and obliterate diversion channel.

The size of the diversion channel will depend on the discharge and channel shape, slope, and roughness. The procedures in Section 10.3.1 on open channels can be used to design the temporary ditch. A 2-year or 5-year runoff frequency should be used. Exhibit 8-60 illustrates the typical design of a diversion channel.

8.5.2.2 Temporary Slope Drain

These systems carry water from the work area to a lower elevation, typically down an embankment. They help prevent erosion of the slope until permanent protection is established. Slope drains may be metal pipes, half-round pipes, or paved ditches. They should be placed:

- Every 500 feet on a 2% grade;
- Every 200 feet on a 4% grade;
- According to field conditions on 5% or steeper grades; and
- At all low points.

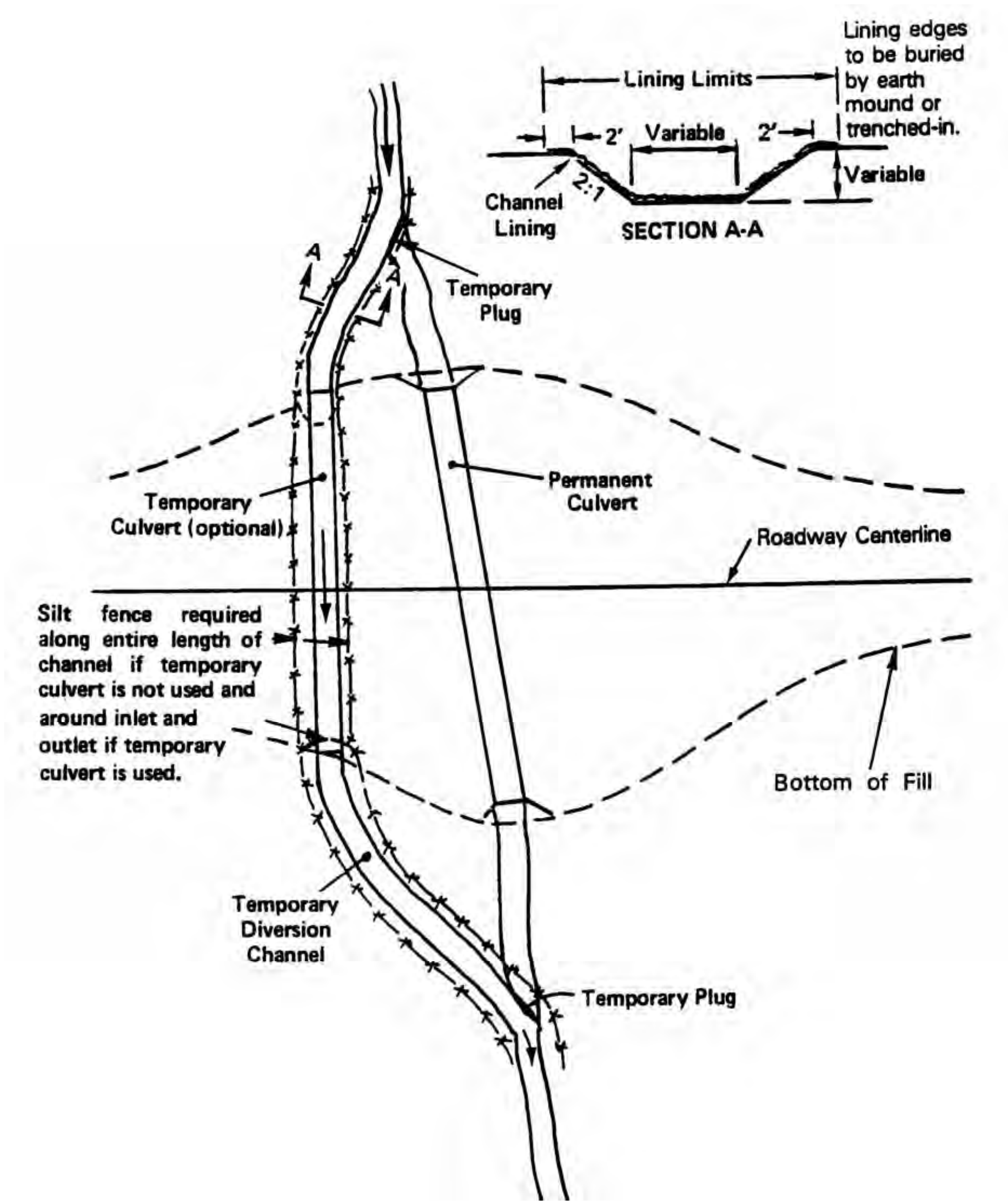
Minimum pipe sizes are 12 inches for metal pipes, and 18 inches for half-round corrugated metal pipes.

A protective treatment (stone revetment) should be provided at the outlet of a temporary slope drain. The inlet of a metal pipe should have a prefabricated metal inlet structure. Exhibit 8-61 and 8-63 illustrate a typical site and design for a temporary slope drain.

8.5.2.3 Temporary Berm

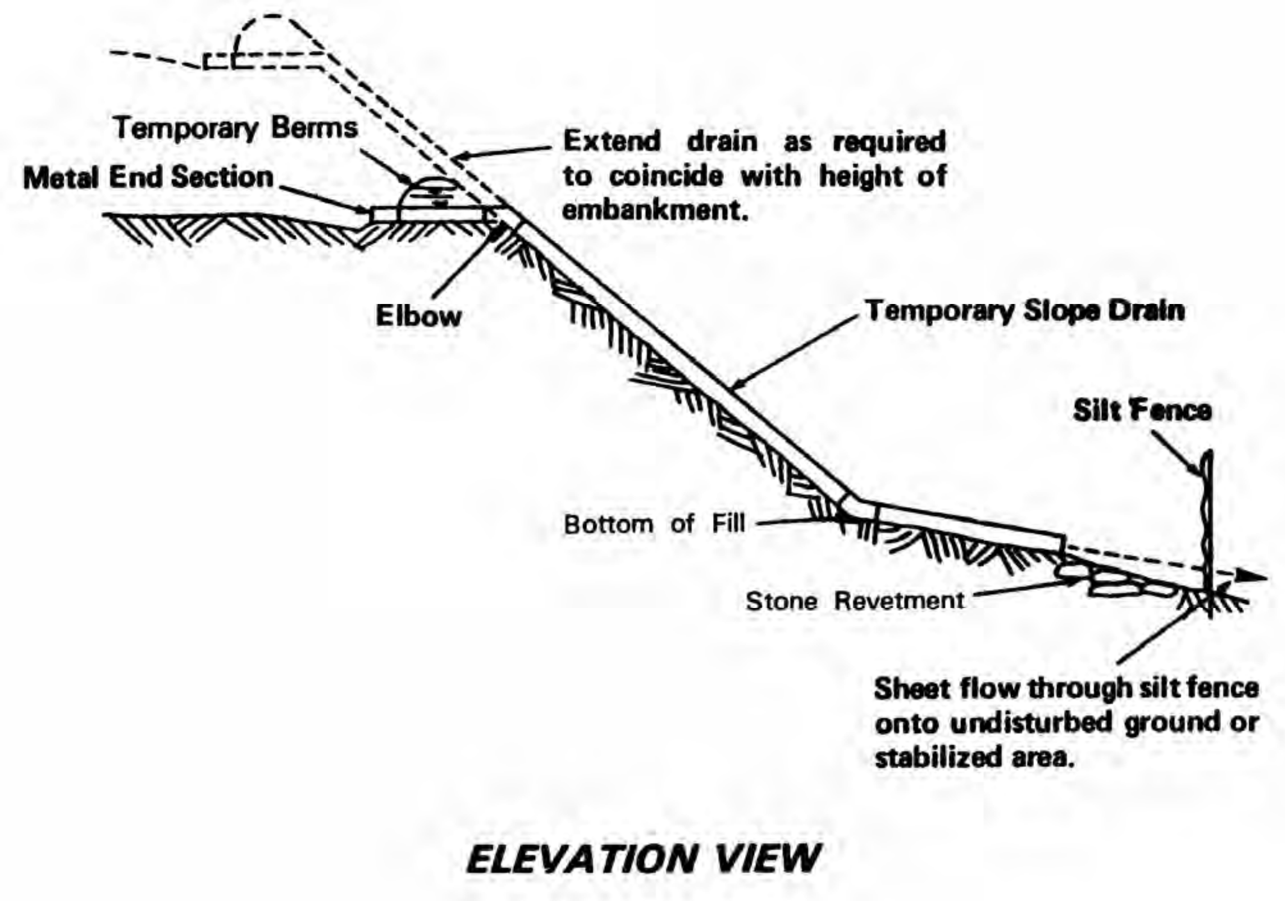
This is a ridge of compacted soil which intercepts and diverts runoff from small construction areas. It is often used in combination with a temporary slope drain at the top of a fill slope. Temporary berms can be constructed for overnight protection or for longer periods. Exhibit 8-64 illustrates a typical installation.

Exhibit 8-60
Temporary Diversion Channel



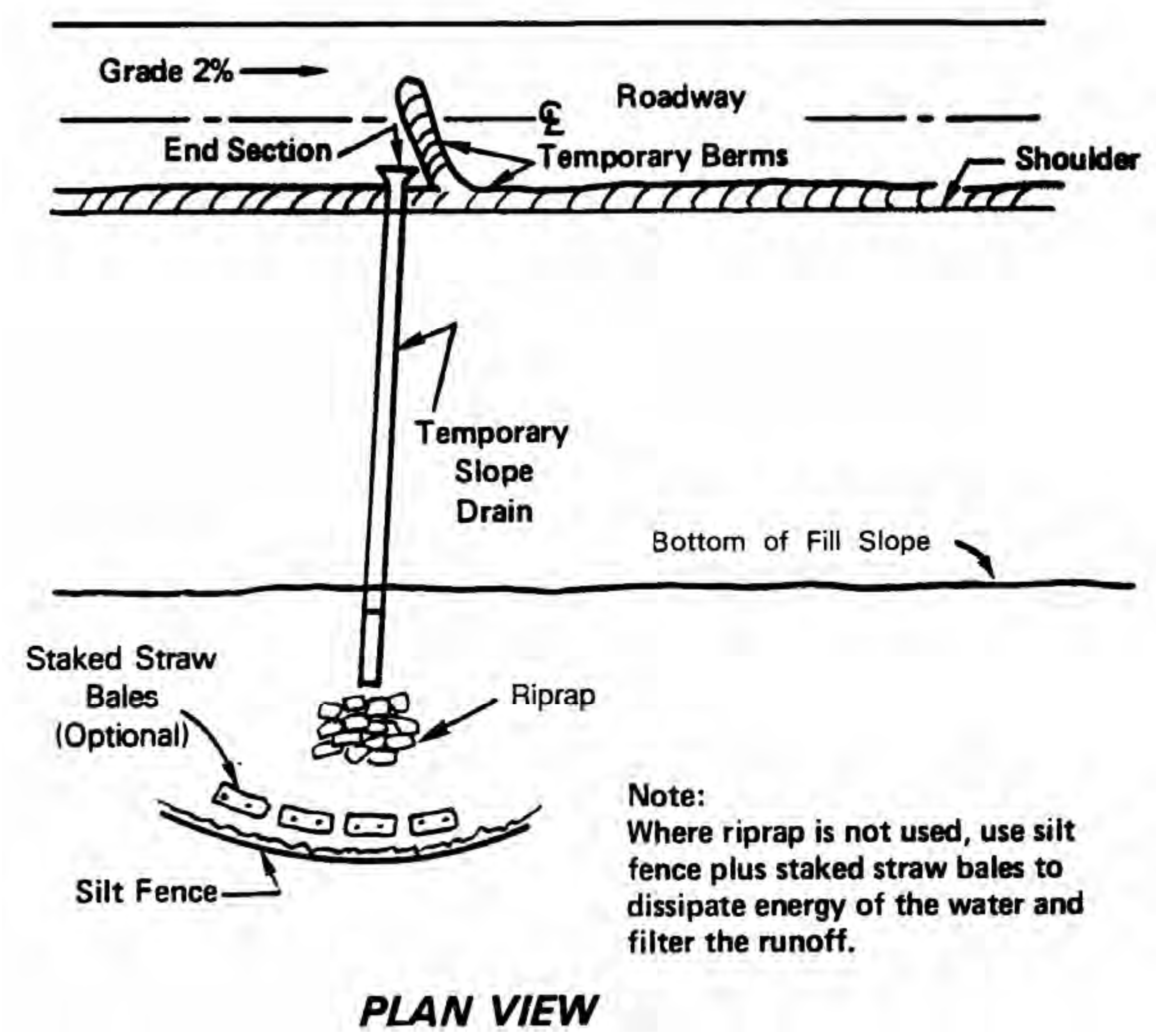
Source: *Best Management Practices for Erosion and Sediment Control*, FHWA

Exhibit 8-61
Typical Conditions Where Temporary Slope Drains are Acceptable



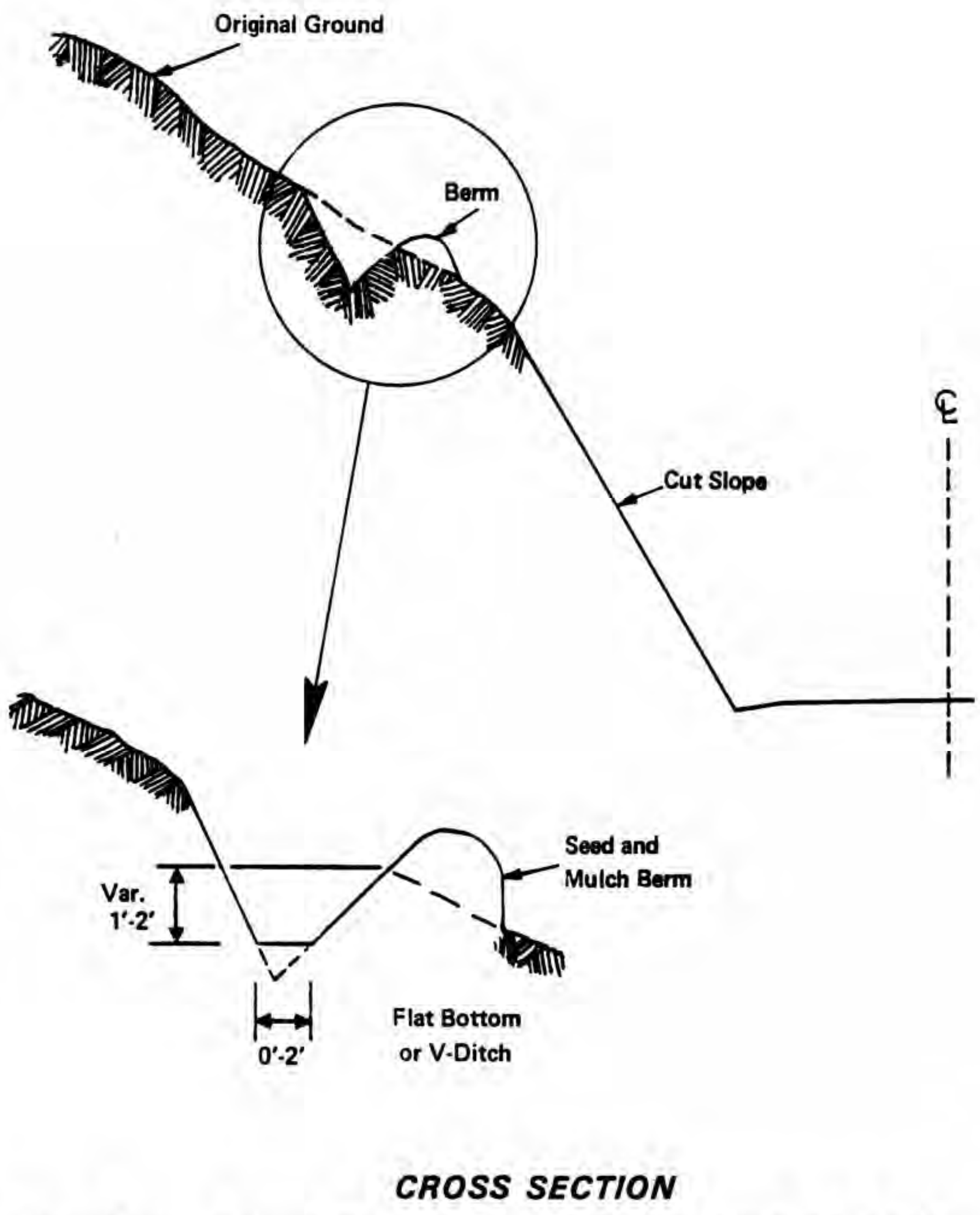
Source: *Best Management Practices for Erosion and Sediment Control*, FHWA

Exhibit 8-62
Typical Conditions Where Temporary Slope Drains are Acceptable



Source: *Best Management Practices for Erosion and Sediment Control*, FHWA

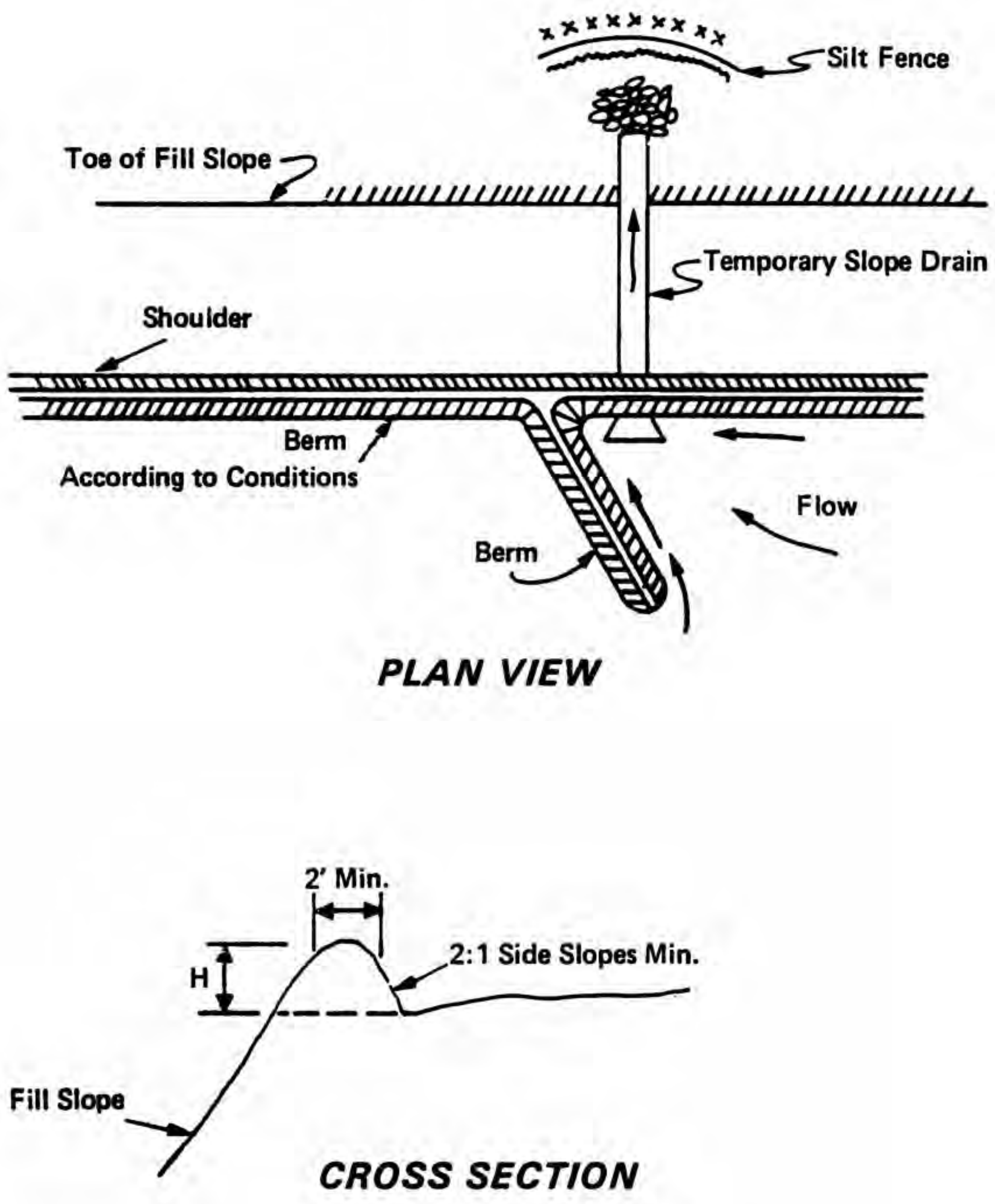
Exhibit 8-63
Temporary Diversion Ditch



Note: A temporary diversion ditch can also be used beyond the bottom of a fill slope.

Source: *Best Management Practices for Erosion and Sediment Control*, FHWA

Exhibit 8-64
Temporary Berms



Source: *Best Management Practices for Erosion and Sediment Control*, FHWA

8.5.3 Sedimentation Checks

Several types of sedimentation checks are available for use during construction, as described in the following sections.

8.5.3.1 Silt Fences

These are fences made with a geotextile filter fabric. They trap sediment before it leaves the construction area. Silt fences can be prefabricated with geotextile filter fabric material, which allows for easy installation. The fence is made of geotextile filter fabric, is a minimum of 36-inch high, and has wood at 6-10 foot spacing. Commercial filter fabrics should be used with the approximate permeability of a #50 sieve. Exhibits 8-65 to 8-67 illustrate typical installations of silt fences.

8.5.3.2 Hay Bales

These are used to reduce flow velocity and intercept the sediment before it leaves the construction area. Typical applications include:

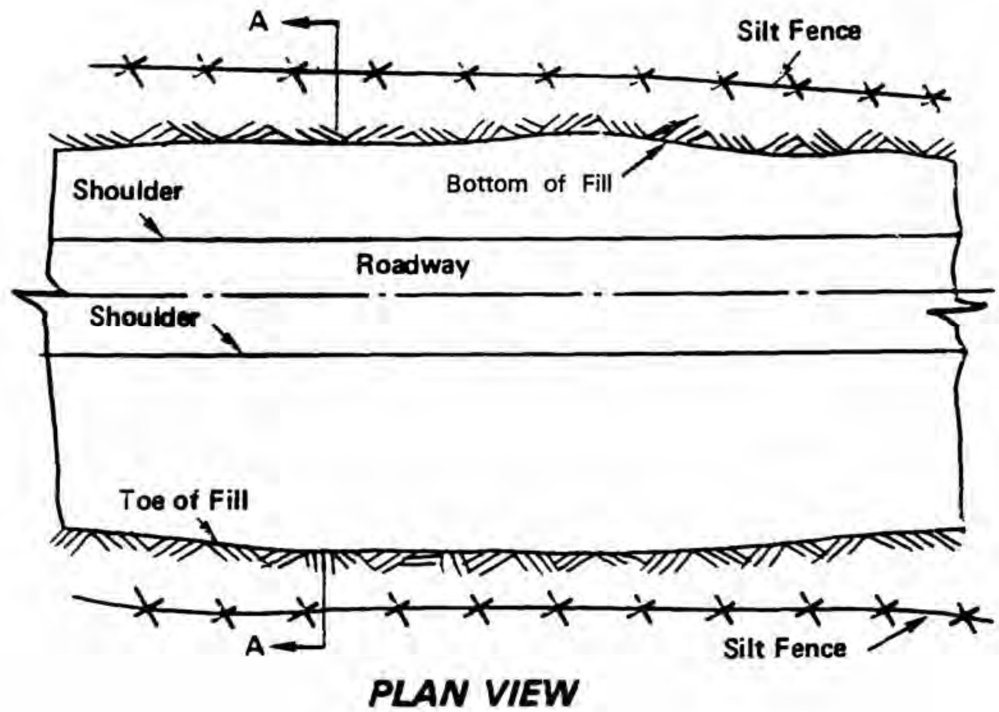
- Bottom of embankment
- Temporary slope drain outlet
- Filter cores for check dams
- Around storm drain inlets
- Behind silt fences

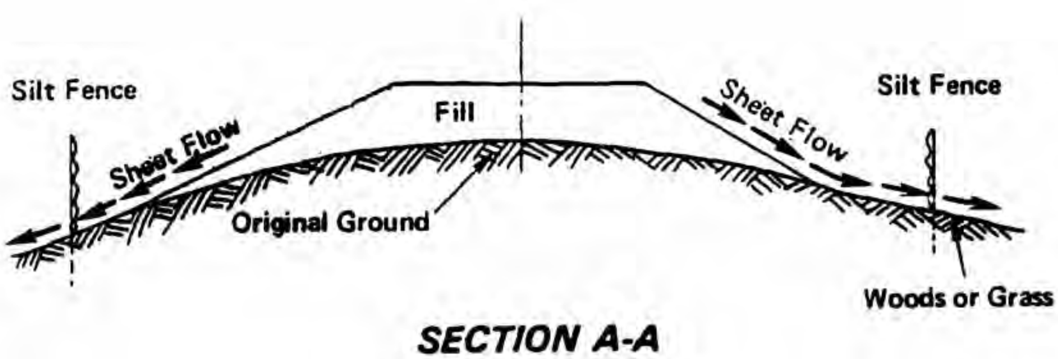
The hay bales should be tied with biodegradable twine. They should be anchored with 2” x 2” x 4’ wood stakes (two per bale). Hay bales will last three to six months and must be replaced when clogged with sediment or deteriorated. Exhibits 8-68 to 8-70 illustrate typical installations.

8.5.3.3 Check Dams

These are barriers made of filter cloth and hay bales which reduce flow velocity and trap the sediment. They are normally used below small drainage structures (less than 38-inch diameter pipe). Check dams may also be used below larger structures if a diversion ditch is impractical. Riprap may be necessary on the downstream side of the dam to protect the stream bed from scour.

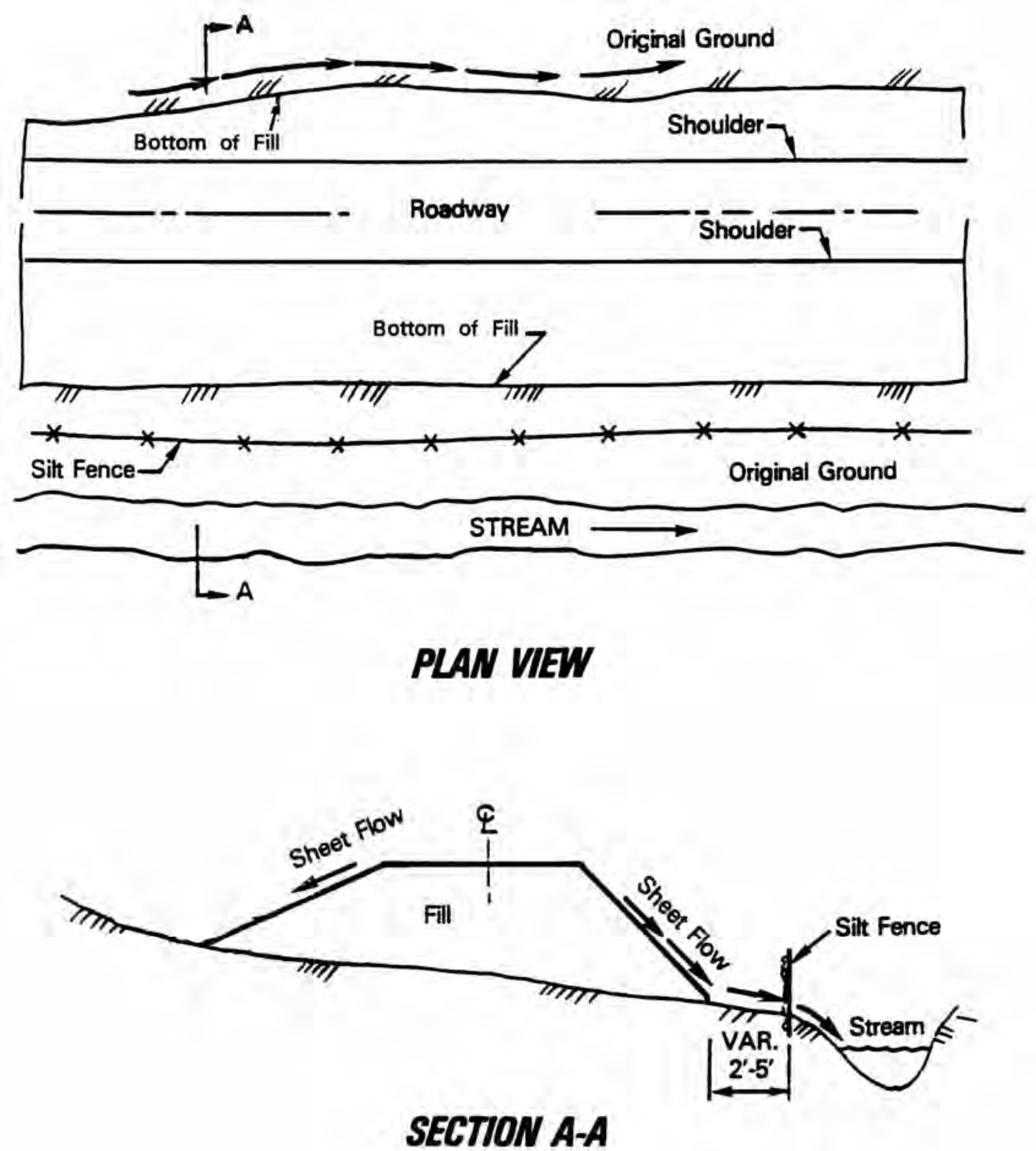
Exhibit 8-65
Typical Conditions Where Silt Fences are Applicable





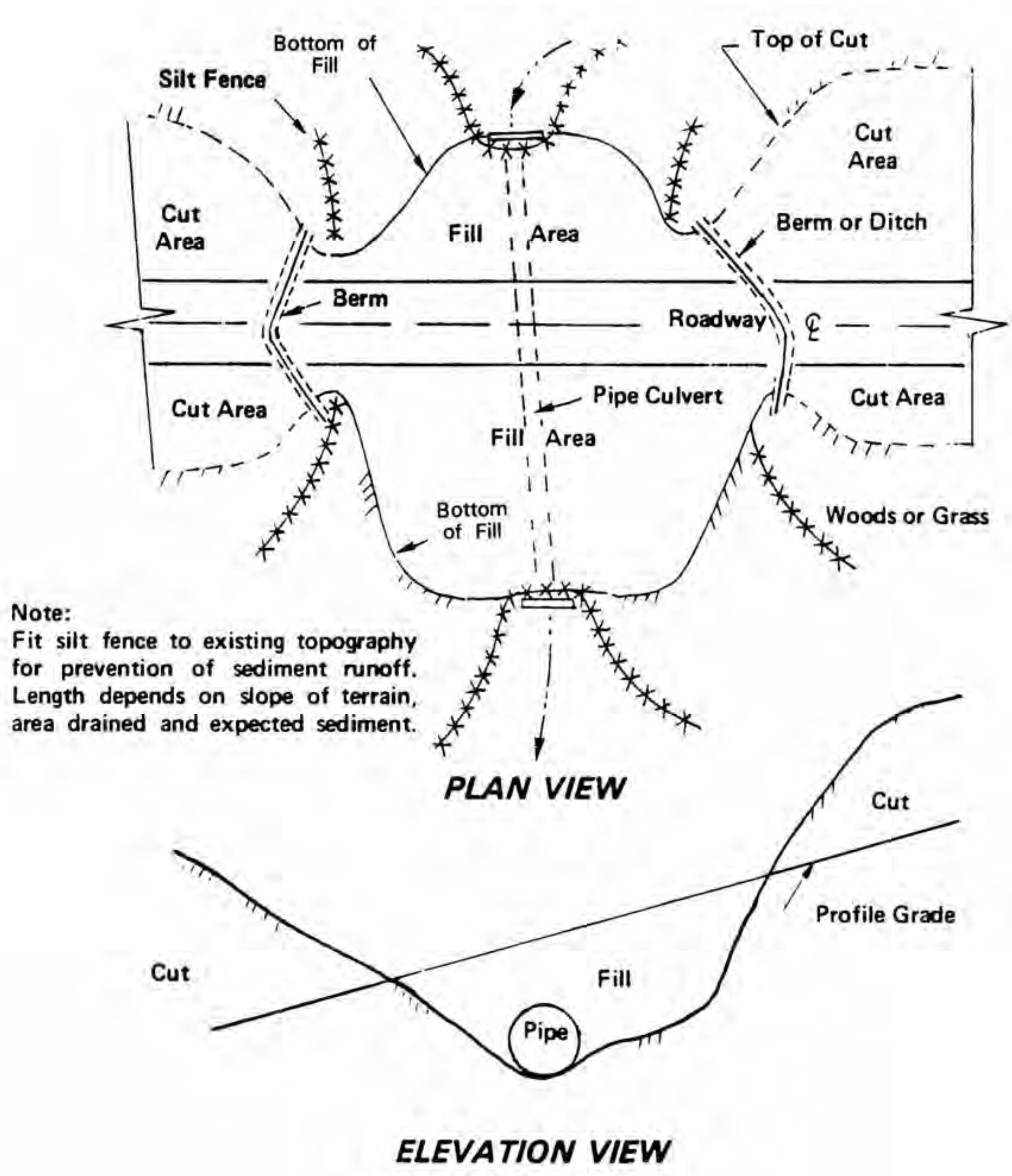
Source: *Best Management Practices for Erosion and Sediment Control*, FHWA

Exhibit 8-66
Typical Conditions Where Silt Fences are Applicable



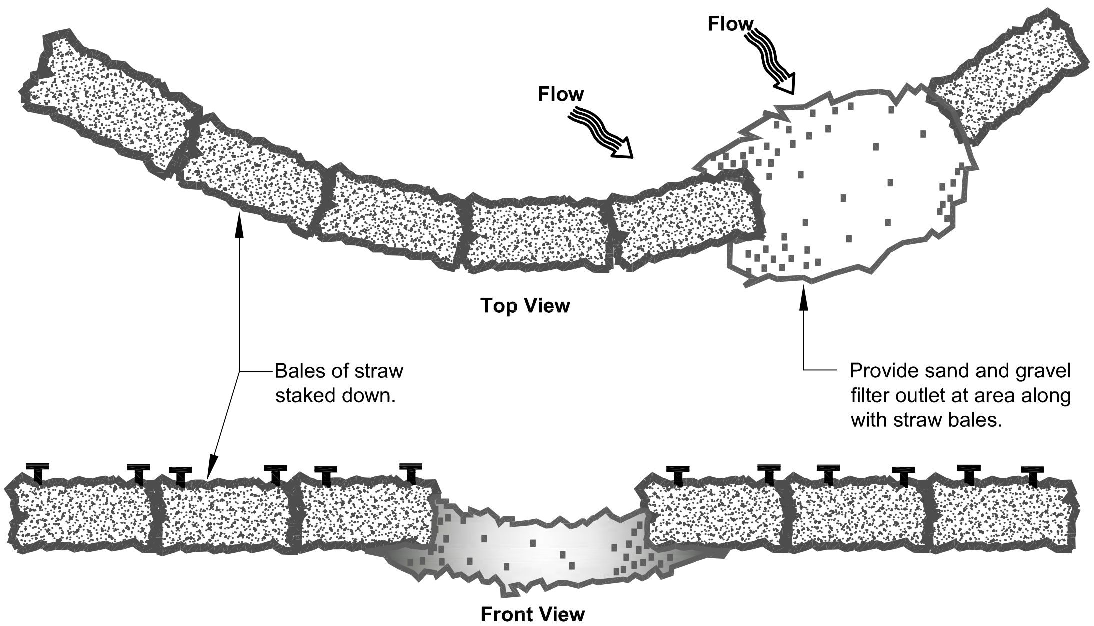
Source: *Best Management Practices for Erosion and Sediment Control*, FHWA

Exhibit 8-67
Typical Conditions Where Silt Fences are Applicable



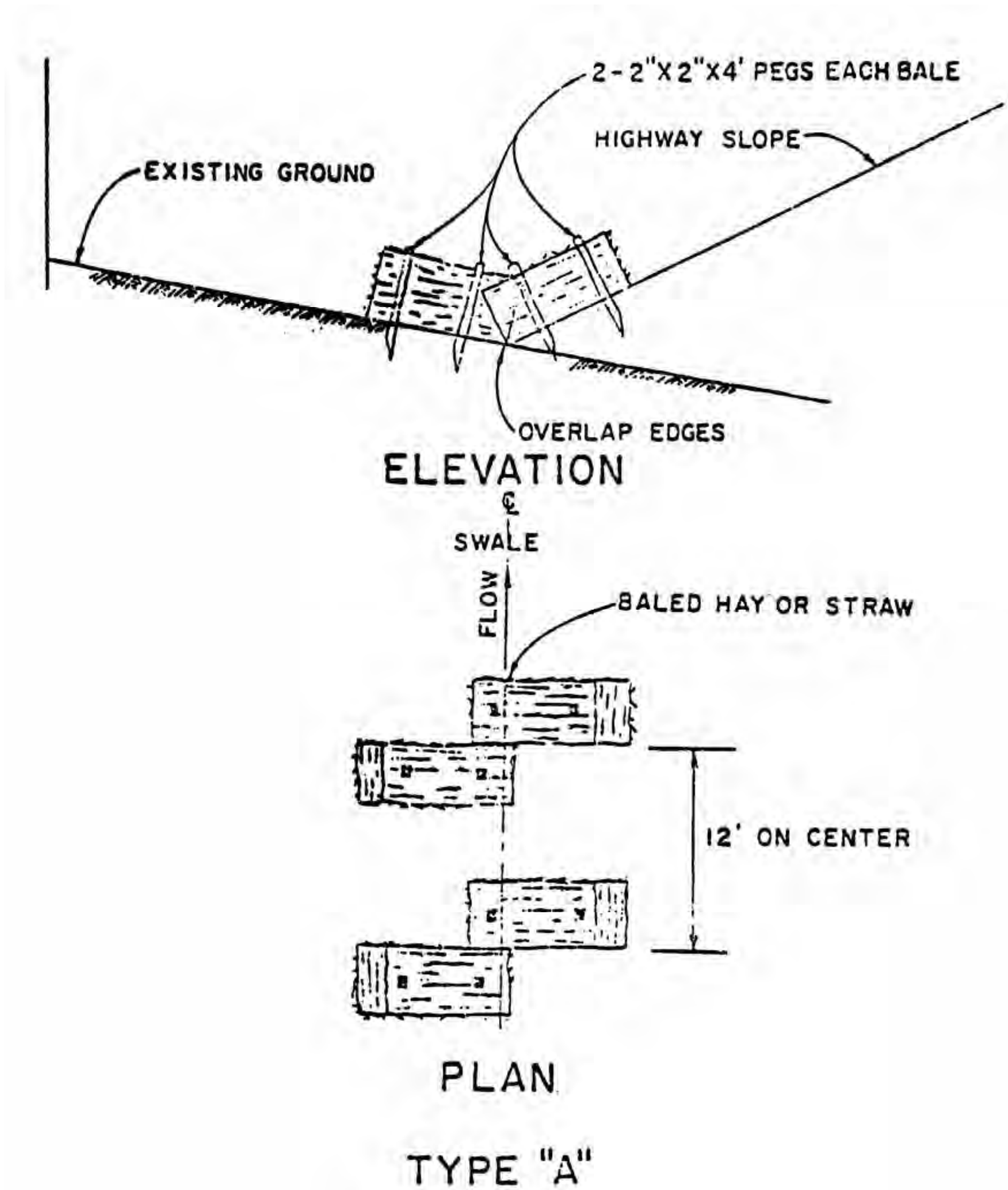
Source: *Best Management Practices for Erosion and Sediment Control*, FHWA

Exhibit 8-68
Hay Bale Dams Used Along Bottom of Slope



Source: *Temporary Erosion and Pollution Control Measures*, FHWA Region One.

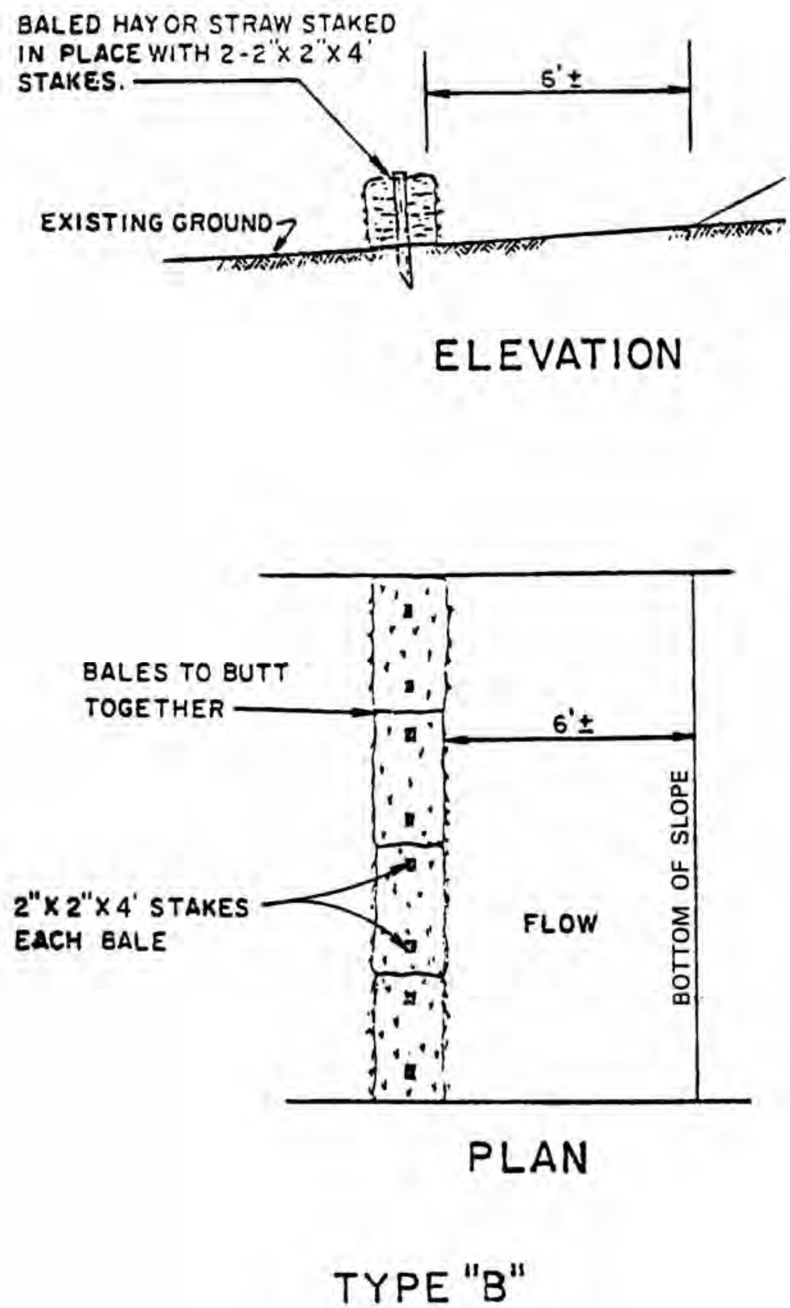
Exhibit 8-69
Baled Hay or Straw Erosion Checks



Notes: 1) To be used in locations where the existing ground slopes toward the embankment.
2) Measurement and payment will be by the bale in place with no removal item

Source: *Temporary Erosion and Pollution Control Measures*, FHWA Region One.

Exhibit 8-70
Baled Hay or Straw Erosion Checks



Notes: 1) To be used in locations where the existing ground slopes toward the embankment.
2) Measurement and payment will be by the bale in place with no removal item

Source: *Temporary Erosion and Pollution Control Measures*, FHWA Region One.

8.5.4 Sediment Basins

Sediment basins are detention areas used to intercept runoff and allow its sediment to settle out, They are installed to protect streams, rivers, ponds and lakes from the excess sediment produced during construction. The basin can be produced by excavation, in a natural depression, or with an impoundment berm of some type. Typical locations in natural drainage- ways include the bottom of embankments, the lower end of waste or borrow areas, or at the downgrade area of a cut section. Sediment basins typically consist of a darn or embankment, a pipe outlet, and an emergency spillway.

8.5.4.1 Types of Sediment Basins

Temporary Sediment Traps

These are small basins intended for short-term use (overnight to a few weeks) Typical dimensions might be 5 feet x 10 feet and 3 to 5 feet in height. Many temporary sediment traps might be used at a construction site. It can remain in peace until it obstructs construction operations or fills up with sediment deposits, when it can be replaced with another trap.

Temporary Sedimentation Basins

These are intended to remain operational during the entire construction period. Therefore, their locations must not interfere with construction operations. During its life, it may be cleaned out periodically.

Permanent Sedimentation Basins

These are designed for use during construction, but they are intended to remain as permanent facilities. A permanent basin may be used for storm water once it is cleaned out after construction.

8.5.4.2 Sedimentation Basin Design Criteria

The following criteria apply to the design of sedimentation basins:

- Sedimentation basins should be constructed before any grading operations begin, and should not interfere with construction activities.
- The basin should be accessible for easy clean out.
- The basin should not be constructed on any watercourse.

- In general, several small sediment traps will work better than a larger sedimentation basin.
- The size of a temporary sedimentation trap should be determined on a case-by-case assessment of the drainage area size and duration of use.
- The size of a sedimentation basin should be determined by:

$$V = 1815A$$

Where: V = volume of basin, cu. ft.
A = drainage area, acres
1815 = volume {in cubic feet) of 0.5 inch of runoff per acre

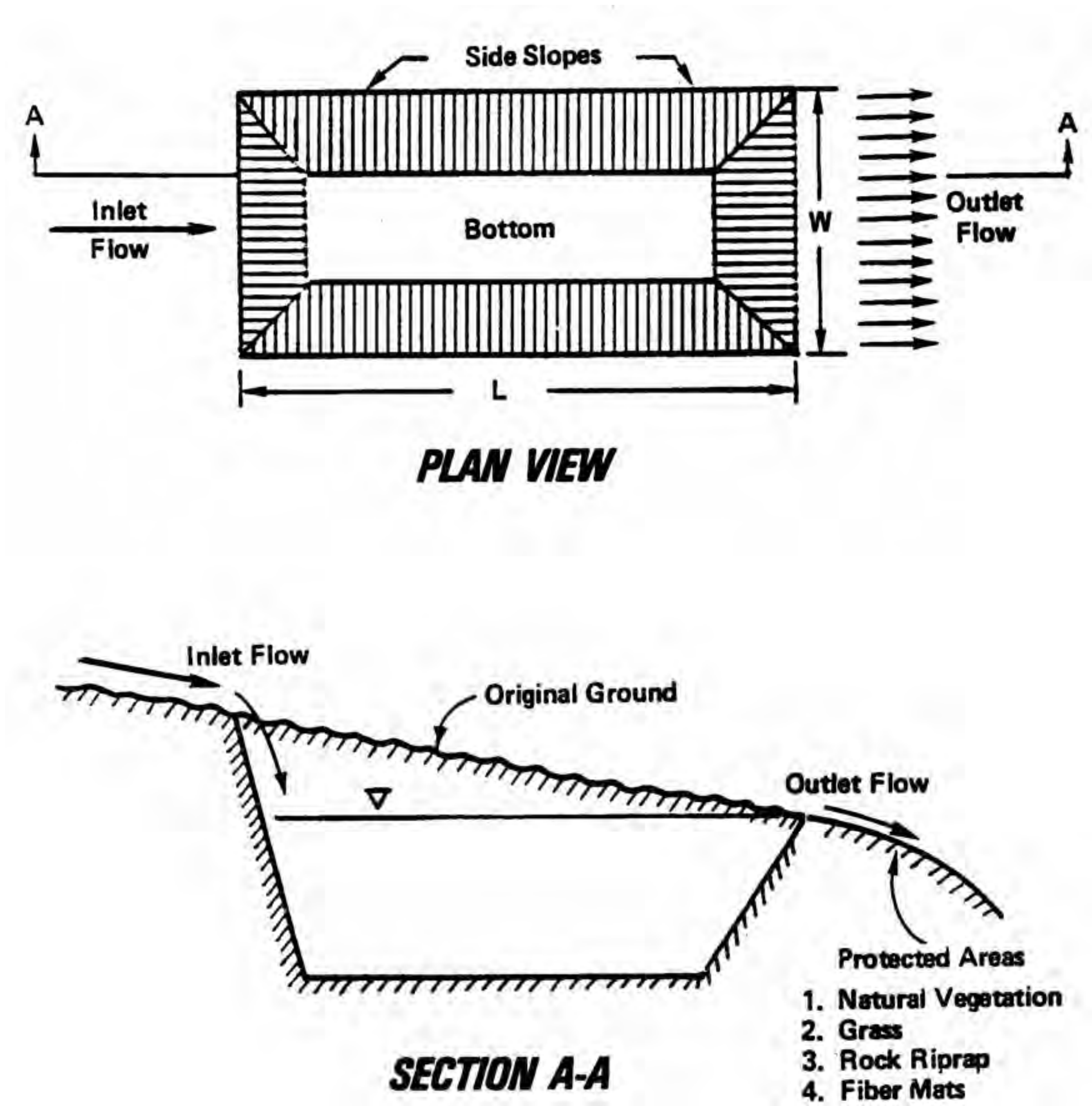
If the basin can eventually discharge into a reservoir used for drinking water, the storage capacity of the basin should increased and investigated on a case-by-case basis. The water level in the basin, based on the calculation, should come no closer than 1 foot to the top of the overflow spillway and preferably will be no closer than 2 feet. If practical, the length of the basin should be at least twice its width.

- The earth berm surrounding the basin should meet the following criteria:
  - The height of the berm should not exceed 10 feet.
  - The minimum top width is 8 feet for a10-foot height.
  - The recommended slope is 2:1 on each side.
  - The composition of the earth berm should be based on the recommendation the Soils Unit.
  - A grate or cage should be placed on top of the riser pipe for safety.

Additional information on the design of small earth dams can be obtained from Technical Release No. 60 *Earth Dams and Reservoirs* prepared by the U. S. Department of Agriculture, Soil Conservation Service, Engineering Division 1985.

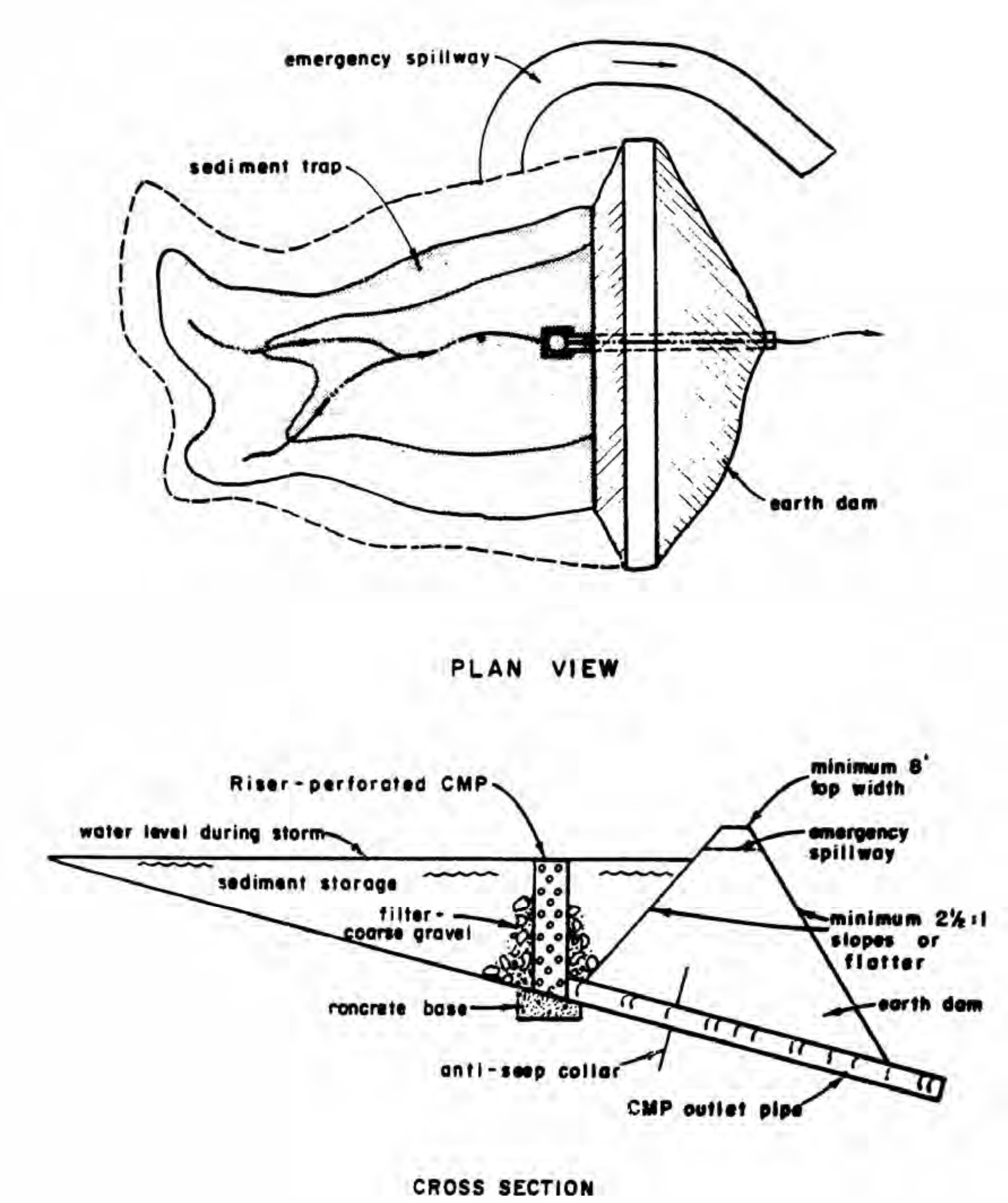
Exhibits 8-71 and 8-72 illustrate a typical excavated sedimentation trap and basin.

Exhibit 8-71
Typical Excavated Sediment Trap



Source: *Best Management Practices for Erosion and Sediment Control*, FHWA

Exhibit 8-72
Sediment Basin



Source: *Guidelines for Soil and Water Conservation,* Soil Conservation Service\

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Chapter 9

Pavement Design

Pavement Design

9.1 Introduction to the Pavement Design Process

Effective pavement design is one of the more important aspects of project design. The pavement is the portion of the highway which is most obvious to the motorist. The condition and adequacy of the highway is often judged by the smoothness or roughness of the pavement. Deficient pavement conditions can result in increased user costs and travel delays, braking and fuel consumption, vehicle maintenance repairs and probability of increased crashes.

The pavement life is substantially affected by the number of heavy load repetitions applied, such as single, tandem, tridem and quad axle trucks, buses, tractor trailers and equipment. A properly designed pavement structure will take into account the applied loading.

To select the appropriate pavement type/treatment and properly design a pavement structure, the Designer must obtain information and input from the Pavement Management System (PMS), the Pavement Design Engineer (PDE), and Research & Materials. The Designer must also apply sound engineering judgment. Steps in the design process include:

- **Review Pavement Management Data** to determine the appropriate scope of work and treatment type (i.e. new pavement, reconstruction, reclamation, resurfacing, or pavement preservation);
- **Evaluate existing pavement** to confirm the scope of work and determine preliminary design and appropriate construction strategy. Research roadway history and traffic data, verify existing pavement materials and structure. Perform field trips to make site inspections, prepare a pavement condition checklist, communicate with engineering and maintenance forces for history of roadway performance, groundwater problems and other background information;

- **Evaluate sub-base and sub-grade** for drainage characteristics and bearing capacity;
- **Make structural calculations**. The traffic, soils, and existing pavement data is used to calculate specific pavement course requirements;
- **Set specifications**. The pavement materials, construction methods, and finished project requirements must be both practical to attain and clearly defined. The Designer must ensure that the plans, specifications, and estimate clearly and unambiguously define the requirements.

The pavement design procedures contained in this chapter are based on the 1972 AASHTO *Interim Guide* as revised in 1981. These are the standard procedures to be followed for the design of all pavement structures subject to this chapter.

For HMA structural resurfacing on Interstate and other controlled access highways, the design procedures contained in the 1993 AASHTO *Guide for Design of Pavement Structures* may be utilized, subject to the review and approval of the Pavement Design Engineer (PDE). The 1993 AASHTO Guide features the following:

- Use of statistical reliability instead of the factor of safety design;
- Use of resilient modulus tests for soil support (a dynamic test) vs. CBR (a static test); and
- Introduction of environmental factors to evaluate the effects of spring thaw and frost heave.

New Pavement Design Methods are being implemented on a limited basis across the United States. The “AASHTO Mechanistic-Empirical Pavement Design Guide” (M-E Design Guide) was released in 2004 with the goal of improving the existing pavement design procedures. The M-E Design Guide transitions from the existing empirical-based pavement design procedures to mechanistic-empirical based procedures. It employs analytical modeling capabilities and incorporates the pavement field performance data collected under the Strategic Highway Research Project (SHRP). MassHighway is currently evaluating implementation of the M-E Design Guide as it is still undergoing validation and refinement.

The standard pavement cross-section details to be applied to pedestrian and bicycle facilities are provided in Chapter 11 and other applicable chapters in this Guidebook.

9.2 Pavement Types, Definitions, and Abbreviations

Different types of pavement are commonly used in the construction of roadways. There are three different types of pavement. These are:

- Flexible Pavement
- Rigid Pavement
- Composite Pavement

Each of these pavement types is presented below.

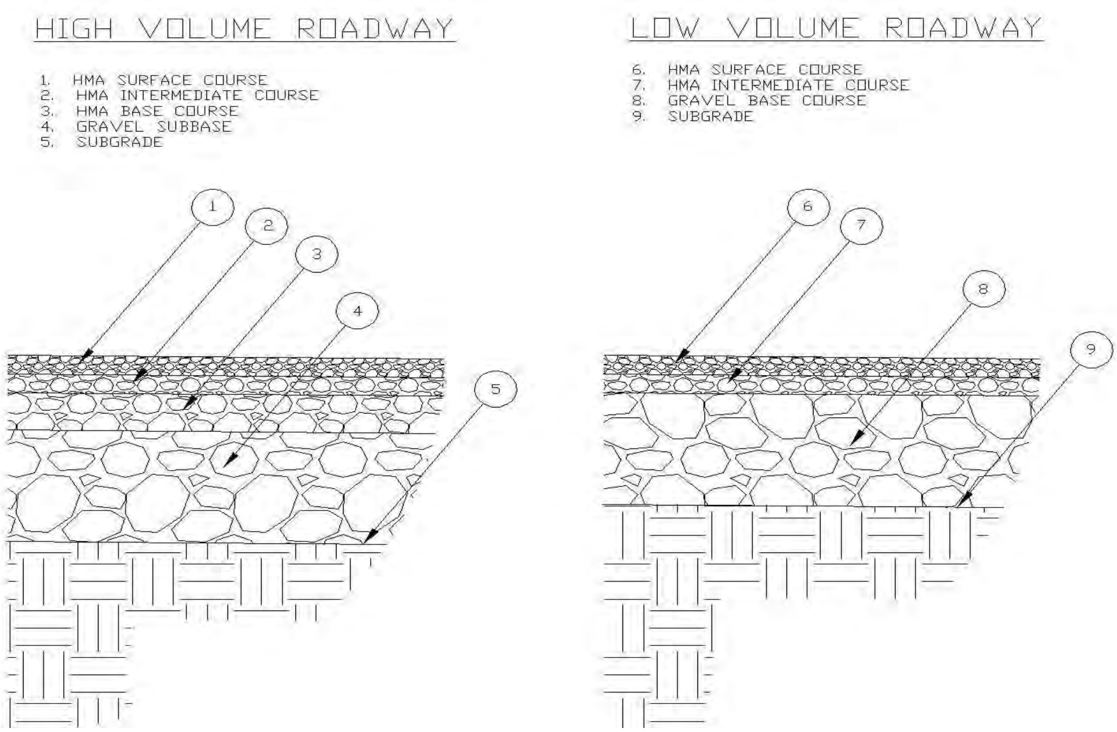
9.2.1 Flexible Pavement

This chapter outlines the design methods for ***flexible pavement*** (Hot Mix Asphalt (HMA) and also known as bituminous concrete). A flexible pavement structure consists of the following layers – the sub-base, base course, intermediate course, surface course, and where determined necessary, a friction course.

- The **sub-base** consists of granular material - gravel, crushed stone, reclaimed material or a combination of these materials.
- The **base course** is an HMA or concrete pavement layer placed upon the compacted sub-base. A gravel base course can be designed and specified for low volume roadways (<2,000 vehicles per day) depending upon loading and other design considerations.
- The **intermediate course** is an HMA pavement layer placed upon the base course.
- The **surface course** is the top HMA pavement layer and is placed upon the intermediate course.
- A **friction course** is a specialized thin-lift wearing course which, when specified, is placed over the surface course. Friction courses provide improved vehicle skid resistance, but do not provide any structural value to the pavement. Typically friction courses are placed on high volume limited access roadways.

Typical cross-sections illustrating the pavement courses for low traffic volume pavements and high traffic volume pavements are shown in Exhibit 9-1.

Exhibit 9-1
Pavement Courses for Flexible Pavement Structure



Source: MassHighway

9.2.2 Rigid Pavement

Because Massachusetts highways are primarily HMA , the design for **rigid pavements** is not detailed in this chapter. A rigid pavement is constructed of portland cement concrete (PCC) placed on a granular sub-base. PCC pavements are either plain and jointed or continuously reinforced. All newly constructed or rehabilitated rigid pavements shall be designed as directed and approved by the PDE.

9.2.3 Composite Pavement

A **composite pavement** consists of one or more HMA pavement courses over a PCC base. All newly constructed or rehabilitated composite pavements shall be designed as directed and approved by the PDE.

9.2.4 Other Pavement Concepts

Research is continuing into porous and permeable pavements that have the potential to improve safety, reduce runoff and diminish undesirable environmental impacts. Some noise-reducing pavements are based on a similar premise. Permeable pavements may be constructed as full-depth porous pavements or surface friction courses.

Full-depth porous pavements are constructed using specialized asphalt layers or Portland cement concrete surfaces that permit water to drain down to a specially constructed crushed stone base. This crushed stone base functions as a temporary stormwater storage area and allows the runoff to infiltrate into the sub-grade. While this design concept appears promising for low volume facilities and parking areas, the foundation needed to adopt it on larger facilities is not in place at this time.

Permeable surface friction courses such as Open Graded Friction Course (OGFC) permit water to drain from the driving surface below the tire-pavement interface. This reduces hydroplaning, tire spray and tire noise while improving skid resistance and visibility. Several types of OGFC have been placed on Interstate and limited access highways in Massachusetts.

Experimental pavements have been constructed which feature the use of colored aggregate in the pavement surface to improve the visual consistency of the roadway with its surroundings. Other projects have been built which feature the use of colored aggregate to improve the definition between the roadway and shoulder. These practices may be considered in special circumstances.

9.2.5 Pavement Design Terms and Definitions

The following terms and abbreviations are commonly used in pavement design.

- **Binder** – The liquid asphalt material in an HMA mixture that bonds the aggregate together.
- ***Equivalent Single Axel Load (ESAL)*** – The conversion of mixed vehicular traffic into its equivalent single-axle, 18-Kip Load. The equivalence is based on the relative amount of pavement damage.
- ***Daily ESAL (T_{18})*** – The average number of equivalent 18-Kip loads which will be applied to the pavement structure in one day.

Normally, a 20-year design period is used to determine the daily load. (See Exhibit 9-2).

- ***ESAL Applications per 1000 Trucks and Combination***s – A factor which reflects the relative mix of sizes (see Exhibit 9-2) and weights of trucks on various classes of highways (e.g., freeways, arterials, collectors, and local streets). Truck percentages typically exclude two-axle, four-tire pickup trucks, the effect of which may be ignored.
- ***Pavement Serviceability Index (PSI)*** – A measure of a pavement's ability to serve traffic on a scale of 0 to 5. It reflects the extent of pavement condition.
- ***Terminal Serviceability Index (Pt)*** – A pavement design factor which indicates the acceptable pavement serviceability index at the end of the selected design period (usually 20 years).
- ***Sub-grade*** – The undisturbed virgin substrate or embankment material which the pavement structure is placed upon.
- ***Bearing Ratio*** – The load required to produce a certain penetration using a standard piston in a soil, expressed as a percentage of the load required to force the piston the same depth in a selected crushed stone. Bearing Ration values are normally determined using the California Bearing Ratio (CBR) text method.
- ***Design Bearing Ratio (DBR)*** – The selected bearing ratio used to design the pavement. It is based on a statistical evaluation of the CBR test results on the soil samples.
- ***Soil Support Value (SSV)*** – An index of the relative ability of a soil or stone to support the applied traffic loads. It is specifically used for the pavement design method in the *AASHTO Interim Guide for Design of Pavement Structures*. The soil support value of the sub-grade is related to its CBR (DBR).
- ***Structural Number (SN)*** – A measure of the structural strength of the pavement section based on the type and thickness of each layer within the pavement structure.
- ***Layer Coefficient*** – The relative structural value of each pavement layer per inch of thickness. It is multiplied by the layer thickness to provide the contributing SN for each pavement layer.
- **Skid Resistance** – A measure of the coefficient of friction between an automobile tire and the roadway surface.

- ***Pavement Design Engineer (PDE)*** – MassHighway Pavement Design Engineer.
- ***Designer*** – The consultant under contract to MassHighway or the municipality, or the Designer within MassHighway.

Exhibit 9-2
Equivalent 18-Kip Axle Applications per 1,000 Trucks for Flexible Pavements

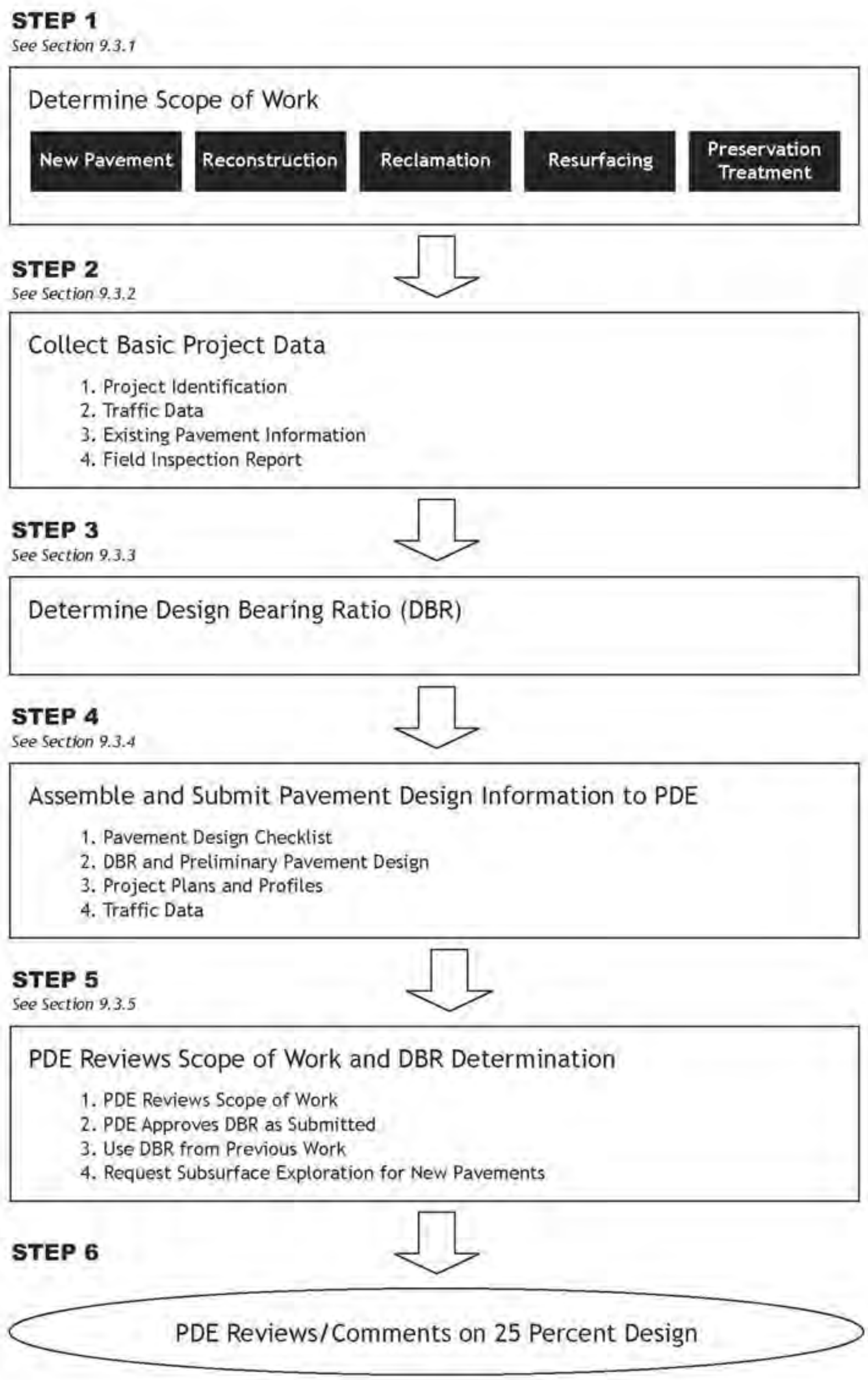
Highway Class	Equivalent Axle Applications
Freeways	1100
Major Arterials	880
Minor Arterial (Urban and Suburban)	880
Minor Arterial (Rural)	660
Collector (Urban and Suburban)	880
Collector (Rural)	660
Local Roads, Urban and Suburban	660
Local Roads, Rural	660

This table is effective January 1, 2006. It will be periodically updated to reflect the MassHighway weigh-in-motion readings.
Source: MassHighway

9.3 Typical Pavement Design Procedures for 25 Percent Submittal

Exhibit 9-3 illustrates the MassHighway pavement design steps associated with the 25 Percent submittal. All pavement designs are determined by the designer with the MassHighway Pavement Design Engineer (PDE) responsible for reviewing and approving all pavement designs. The major tasks in the design process are presented below.

Exhibit 9-3
25 Percent Design Activities



Source: MassHighway

9.3.1 Step 1 – Determine Scope of Work

The Designer will determine the appropriate scope of work for the pavement design. This can be a new pavement, reconstruction, reclamation, resurfacing, pavement preservation, pedestrian/bicycle facility, or a combination of work. The scope of work may or may not include widening or corrective work to the existing pavement. To determine the scope of work for existing pavements (i.e. all work other than new pavement) the Designer shall review current Pavement Management data. Pavement Management reports will normally identify the apparent scope of pavement treatment required.

9.3.1.1 New Pavement

New pavement is a pavement structure placed on a prepared sub-grade. It applies to new highway construction, to a relocated highway, or to the new part of a widened highway.

9.3.1.2 Pavement Reconstruction

Reconstructed pavement or full depth reconstruction results when an existing pavement structure is completely removed to the sub-grade and replaced with a new pavement structure. This type of work is needed when the existing pavement has deteriorated to such a weakened condition that it cannot be salvaged with corrective action. The type and extent of pavement distress will determine when pavement reconstruction is necessary.

9.3.1.3 Pavement Reclamation

Reclaimed pavement reuses an existing pavement structure through the pulverizing and mixing of the existing pavement and granular sub-base into a gravel base material to be overlaid with new HMA layers. The reclamation method is usually performed on site.

9.3.1.4 Pavement Resurfacing

Pavement resurfacing consists of placing the needed thickness of hot mix asphalt on an existing pavement. The resurfacing will return the pavement to a high level of serviceability and provide the necessary structural strength for the pavement design period.

9.3.1.5 Pavement Preservation

Pavement Preservation involves the application of properly timed surface treatments to ensure that pavements in good condition will remain in good condition. Preservation treatments extend the pavement service life, but generally provide no structural strength.

9.3.1.6 Pedestrian and Bicycle Facilities

Pavements for pedestrian and bicycle facilities shall be designed as presented in Chapter 11 and other applicable chapters of this Guidebook. All project designs must incorporate American with Disability Act (ADA) requirements

9.3.2 Step 2 - Collect Basic Project Data

The designer must collect the basic project data listed in the **Pavement Design Checklist** included in Appendix 9-A-1 to this chapter along with a **Field Inspection Report**, as described below.

9.3.2.1 Project Identification

Provide the project location information and project design engineer.

9.3.2.2 Traffic Data

At a minimum, the following traffic data is required:

- Current ADT, (ADT for year of proposed opening to traffic);
- Projected ADT (20 years);
- ADT truck percentage;
- Number of lanes;
- Divided/undivided; and
- Source of traffic data.

9.3.2.3 Existing Pavement Information

The thickness and type of each pavement layer (i.e., surface course, intermediate course, base course, sub-base) and sub-grade information shall be recorded. This data is necessary for proper design and analysis of the pavement structure for all types of projects. Base plans and profiles should also be obtained for purpose of pavement design.

9.3.2.4 Field Inspection Report

A field inspection report must also be prepared which includes the general condition of the roadway. The field report should note pavement deficiencies including type of distress, extent of distress and severity of distress (See Appendix 9-A-1). The report should also include other field observations such as; adequacy of drainage, presence of curbing, edging, berm or shoulder condition, sidewalks, curb cuts and driveways, and any other characteristic that may be pertinent to the analysis of the existing pavement and scope of work. The Designer should also research and document known problems with the existing pavement through discussion with field maintenance personnel.

9.3.3 Step 3 - Determine Design Bearing Ratio (DBR)

Exhibit 9-4 summarizes the recommended action to determine the Design Bearing Ratio based on the Daily ESAL (T_{18}). Projects having T_{18} values less than 15 should use the minimum design for the roadway's classification (refer to Exhibit 9-11). Projects having T_{18} values between 15 and 120 should use DBR values based on AASHTO soils classification as shown in Exhibit 9-5. Projects having T_{18} values greater than 120 will require AASHTO soils classifications and CBR testing. Soil classification data and CBR test data should be submitted to the PDE for DBR determination.

Exhibit 9-4
Design Bearing Ratio Determination

Value from Line (h) of Data Sheet 1 (T_{18})	Action
$T_{18} < 15$	Use Minimum Design (See Exhibit 9-11)
$15 < T_{18} < 120$	Assume DBR based on soil classification as determined by District lab (From Exhibit 9-5)
$T_{18} > 120$	Submit AASHTO soils classification and CBR test results to PDE for DBR determination and approval

Source: MassHighway

Exhibit 9-5
DBR Based on AASHTO Soils Classification

General Classification / Subgrade Rating	AASHTO Group Classification	DBR	SSV
Granular Materials / Excellent to Good	A1 - a	30	7.1
	A1 - b	20	6.2
	A2 - 4	15	5.4
	A2 - 5[1]		
	A2 – 6[1]		
	A2 – 7[1]		
	A – 3	10	4.4
Silt-Clay Materials / Fair to Poor	A2 – 4	8	3.9
	A2 – 5[2]	5	2.8
	A2 – 6[2]	3	1.6
	A2 – 7[2]	2	0.6
Virgin Gravel for Reconstruction		40	7.8
In-Site Gravel Base/Sub-base for Resurfacing		8.5	6.6

Source: MassHighway
1 Consult pavement design engineer (PDE)
2 Consider economics of replacing poor material

9.3.4 Step 4 - Assemble and Submit Pavement Design Information to PDE

The designer will submit all applicable information for the pavement design to the PDE including:

- The Pavement Design Checklist documenting the reasons for selecting the scope of work (see Appendix 9-A-1 to this chapter);
- The DBR value and preliminary pavement design;
- A set of project plans and profiles; and
- Traffic data.

9.3.5 Step 5- PDE Reviews Scope of Work and DBR Determination

9.3.5.1 PDE Reviews Scope of Work

The PDE will review the Designer's recommendation, scope of pavement work, the preliminary pavement design, traffic data and the pavement checklist documenting the engineered design solution. The PDE will provide comments on the scope of work and the preliminary pavement design.

9.3.5.2 PDE Approves DBR as Submitted

The Pavement Design Engineer must approve the Design Bearing Ratio used for the design. The PDE will approve, reject, modify or request additional sampling and testing.

9.3.5.3 Use DBR from Previous Work

If it is available and still applicable, the PDE will use the DBR used for the original pavement design or any previous pavement resurfacings.

9.3.5.4 Request Subsurface Exploration for New Pavements

If the Designer recommends a subsurface exploration to determine the soil gradation, properties and stratification data and the PDE has concurred, the Designer will submit a written request to MassHighway, Pavement Management Section and include the following information.

The Designer will prepare the requested soil exploration method and plan. The method and plan will include test pit, pavement cores, etc. the required number and their locations. This information is to be in written form and shown on project base plans and forwarded to MassHighway, Chief Engineer, to the attention: Pavement Design Engineer.

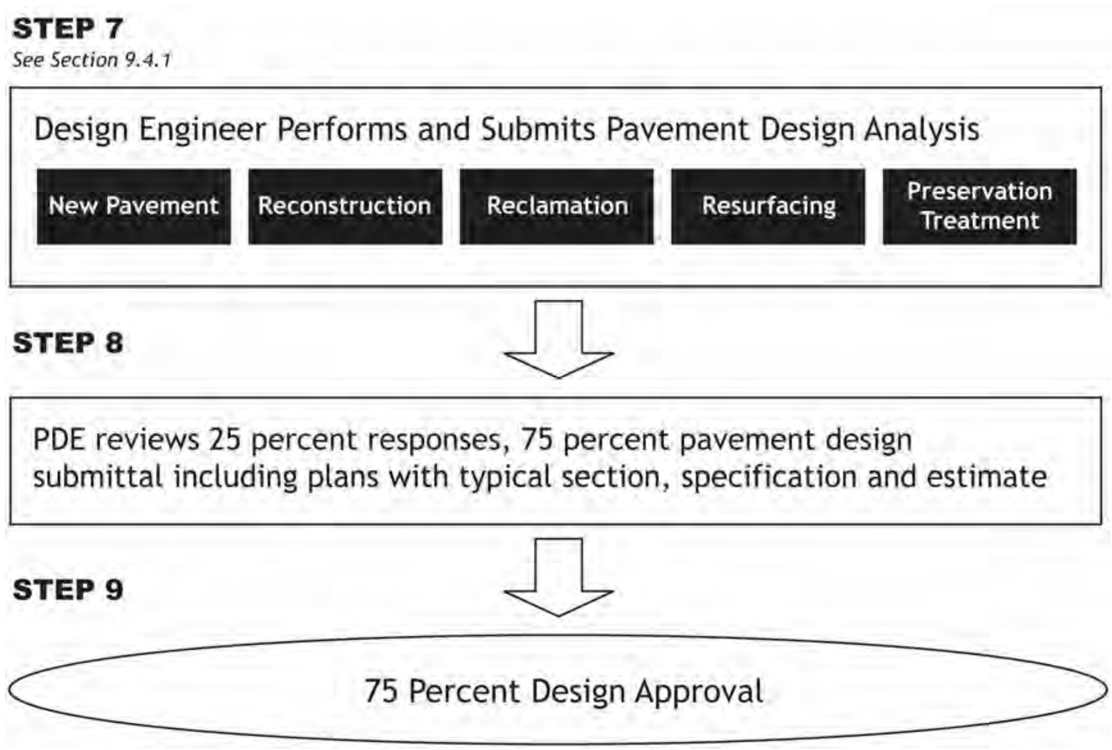
9.3.6 STEP 6 - PDE Reviews/Comments on the 25 Percent Design

The PDE will review and comment on the 25 Percent Design recommendation from the Design engineer.

9.4 Typical Pavement Design Procedures for 75 Percent Submittal

The activities described in the following sections should occur between the 25 percent and the 75 percent design submission. The 75 percent submittal should include responses to the 25 percent pavement design review and comments.

Exhibit 9-6
75 Percent Design Activities



Source: MassHighway

9.4.1 Step 7 - Design Engineer Performs and Submits Pavement Design Analysis

The design engineer will perform the detailed analysis to determine the type and thickness of each course in the pavement structure. The design engineer will submit the recommended detailed pavement design with completed data sheets to the PDE. The types of analysis are discussed further below.

9.4.1.1 New Pavements

On new pavements, the designer will determine the detailed full-depth design of the pavement. The detailed procedure is discussed in Section 9.5.

9.4.1.2 Pavement Reconstruction

On reconstructed pavement, the designer will determine the detailed full-depth design of the pavement. The detailed procedure is discussed in Section 9.5.

9.4.1.3 Pavement Reclamation

For reclaimed pavements, the Designer will determine the depth of reclamation required. A minimum 12” granular base or sub-base course must be provided beneath the HMA pavement courses. The detailed procedure is as outlined in Section 400 of the *Standard Specifications for Highways and Bridges*.

9.4.1.4 Pavement Resurfacing

On pavement resurfacing, the Designer will specify the depth of milling, if required, leveling course, if used, and the depth and mixture type for the HMA resurfacing course(s). The detailed procedure is discussed in Section 9.6. In addition, the Designer will determine any corrective work needed on the existing pavement.

9.4.1.5 Pavement Preservation

The design/selection of all pavement preservation treatments must be in accordance with the MassHighway *Pavement Preservation Guidelines*. The Designer shall submit the proposed treatment type and surface preparation requirements to the PDE for approval.

9.4.2 Step 9 - PDE Reviews Pavement Design Analysis

The PDE will review, comment and approve or request modifications to the pavement design recommendation from the Design engineer.

9.5 New and Reconstructed Pavements

This section specifies the MassHighway procedure for determining the detailed design of a new or reconstructed pavement. This procedure applies to HMA pavements only. MassHighway uses the AASHTO *Interim Guide for Design of Pavement Structures* as the basic design methodology. However, MassHighway has incorporated several modifications to the Guidebook's procedures to reflect specific conditions in Massachusetts and to simplify the procedure.

The ***Pavement Design Form – New or Reconstructed Pavements*** (cover sheet and data sheets 1 through 3) are included in Appendix 9-A-2 to this chapter. This form must be completed by the Designer and submitted to the PDE prior to the 75 Percent Submittal.

9.5.1 Pavement Design Cover Sheet

The following information must be recorded on the cover sheet:

- Enter the project identification data at the top of the cover sheet.
- Summarize the recommended pavement design by documenting the surface, base, and sub-base data. List the depths, type of layer, and recommended lifts.
- Describe the special borrow, if required for the project. Special borrow may be necessary where the existing sub-grade is susceptible to frost penetration within the typical frost penetration depth. If this subsurface condition exists, subsurface exploration and soil analysis may be warranted. The Designer will recommend the type and depth of special borrow to be used for frost control. Special Borrow is generally placed on freeways and arterial routes. Consideration for placement on other roads will depend on functional classification, traffic volumes, presence of utilities, construction methods, etc.

9.5.2 Data Sheet 1: Pavement Structural Design Data

Data Sheet 1 includes the following information:

- **Line (a)**: Enter the anticipated (current) ADT for date of opening.
- **Line (b)**: Enter the future ADT (see Chapter 3 for information on traffic volume forecasts). Generally the design period for pavements is 20 years; however there may be occasions when the traffic information submitted does not cover the design period. In these cases the future ADT is to be estimated by approved methods. Under certain circumstances, pavements may be designed for periods of less than 20 years.
- **Line (c)**: Calculate the average ADT during the design period.
- **Line (d)**: Calculate the average ADT in one direction.
- **Line (e)**: Enter the truck percentage for the ADT.

- **Line (f)**: Calculate the average daily truck volume in one direction.
- **Line (g)**: Enter the equivalent 18-Kip axle application per 1,000 trucks and combinations. (See Exhibit 9-2).
- **Line (h)**: Calculate the number of 18-Kip axle loads per day in one direction (T_{18}).

9.5.2.1 Design Bearing Ratio (DBR) Determination

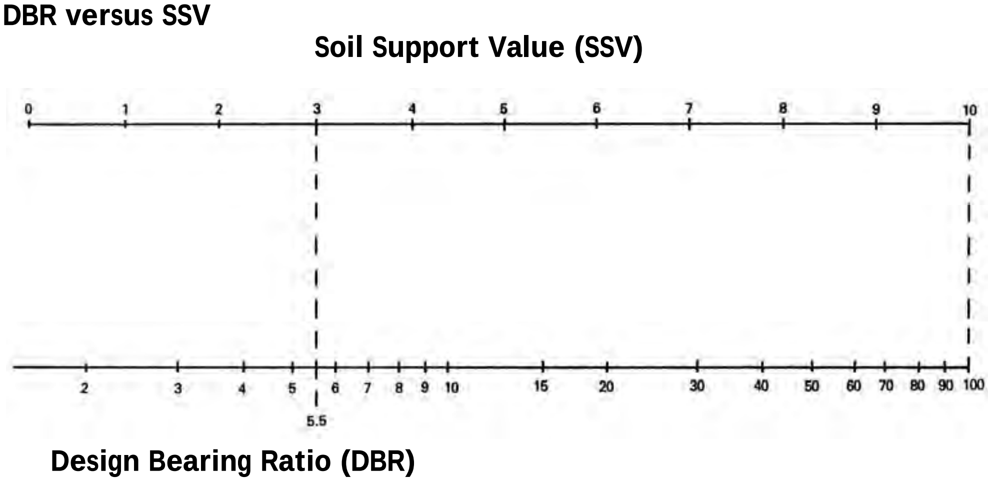
Use the value on Line (h) (T_{18}) and Exhibit 9-4 to determine the sub-grade or Sub-base DBR. As noted the PDE may be required to provide the DBR. In all cases, Designers make a general computation of the sub-grade or sub-base DBR for reviews by the Pavement Design Engineer. See Section 9.3 above.

9.5.3 Data Sheet 2: Determining Structural Number (SN)

The following steps are required to determine the structural number (SN):

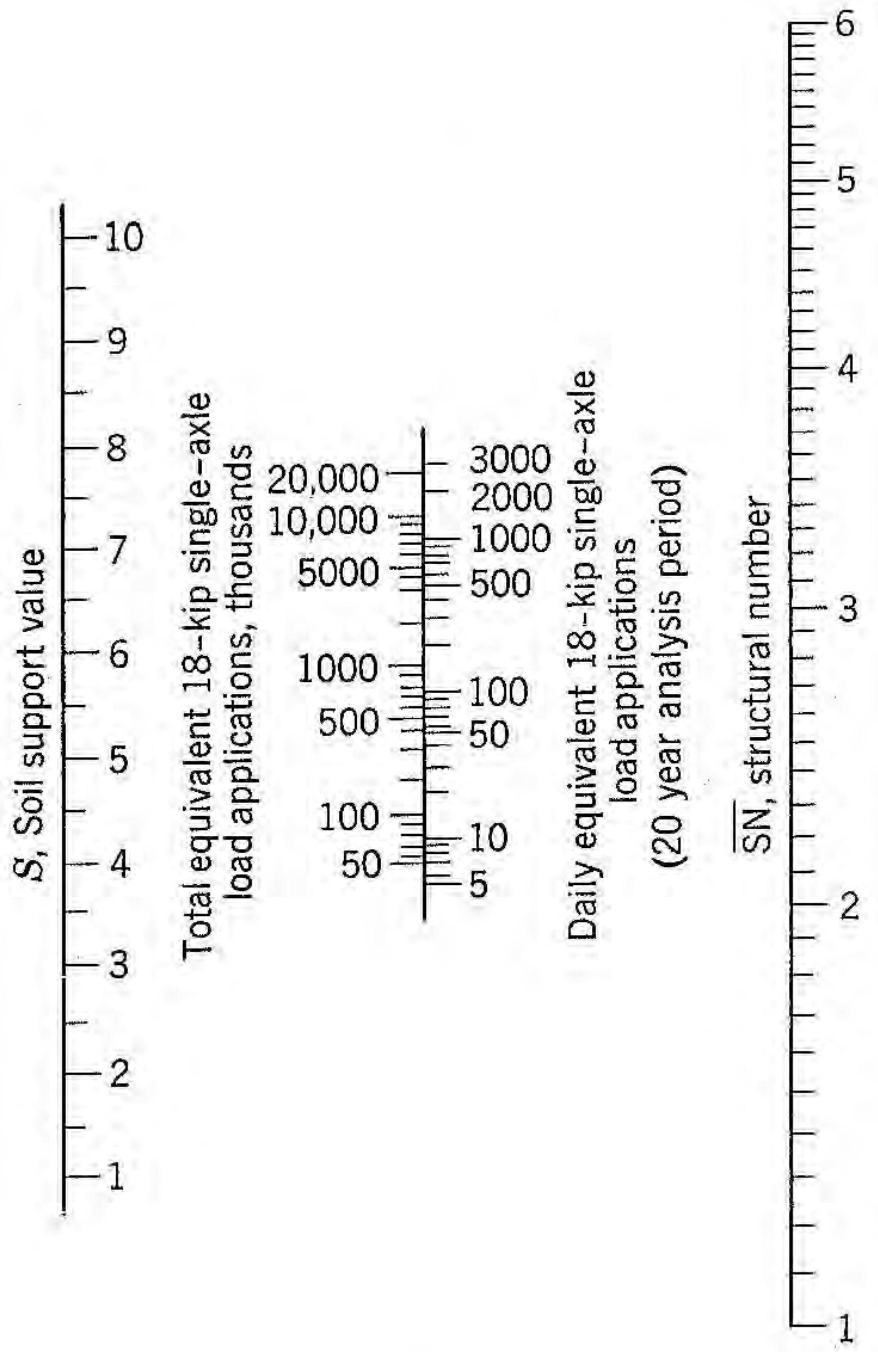
- **Step 1**: Determine the design lane equivalent daily 18-Kip applications based on the number of lanes.
- **Step 2:** Determine the DBR for the sub-grade from Exhibit 9-4 and 9-5. The sub-base DBR is 40 for the typical MassHighway sub-base on new or reconstructed pavements (gravel).
- **Step 3:** Determine the soil support value (SSV). Exhibit 9-7 illustrates the relationship between the DBR and SSV.
- **Step 4:** Determine the required structural number (SN) above the sub-base and above the sub-grade. Exhibit 9-8 should be used. Use the design-lane T_{18} from Step 1 for the daily equivalent 18-Kip single axle load. Use the SSV from Step 3 for the soil support value.
- **Step 5:** Increase the SN by 15 percent to determine the design SN to adjust for climatic and other environmental conditions.

Exhibit 9-7
DBR versus SSV



Source: MassHighway

Exhibit 9-8
Structural Number Nomograph (For Flexible Pavements P=2.5)



Note: The right side of the vertical line in the center provides the daily equivalent 18-kip single-axle load. It is only good for a 20-year analysis period. The left side provides the total load application and it can be used for any design analysis period.

Source: Interim Guide for Pavement Structures. AASHTO. 1972.

9.5.4 Data Sheet 3: Pavements Structural Number (SN)

By trial and error, the designer will select the most cost-effective design that provides the required SN for the highway conditions. The designer should also consider minimum and maximum lift thicknesses and the logistics of construction procedures when designing the pavement design combinations using this procedure.

- **Step 1:** Select each pavement layer component and the thickness of each layer.
- **Step 2:** From Exhibit 9-10 select the layer coefficient for each pavement layer.
- **Step 3:** Determine the contributing SN for each pavement layer by multiplying the layer coefficient by its thickness.
- **Step 4:** The minimum thicknesses of each layer are noted on Exhibit 9-11.
- **Step 5:** Check to ensure that the required SN is provided above the sub-base and the sub-grade. If not, increase the layer thickness as necessary. If the trial design exceeds the required SN, reduce the layer thicknesses.
- **Step 6:** Determine several alternate pavement designs which satisfy the SN requirements. The selected design will be based on economics.
- **Step 7:** Regardless of the calculations from the pavement design analysis, the minimum design thickness should not be less than those shown in Exhibit 9-11.

Exhibit 9-9
Layer Coefficients for New and Reconstructed Pavements

Pavement Course	Mixed Type	Minimum Design Thickness (inches)	Maximum Design Thickness (inches)	Mix Designation
Friction Course	Open-graded	0.75	1.25	Open-Graded Friction Course (OGFC)
Surface Course	A	1.5	2.0	SC – A[1]
	B	1.75	2.75	SC – B
	C	1.75	2.75	SC – C[2,3]
Intermediate Course	A	1.75	3.0	IC – A
	B	1.75	3.0	IC – B
Base Course	A	3.25	5.0	BC – A
	B	2.0	3.0	BS – B
Leveling Course	Leveling Mix	0.75	1.25	LC - LM

Source: MassHighway
1 Use surface course A (SC - A) for roadways with ADT<10,000, low truck traffic and few intersections.
2 Use surface course C (SC – C) for high volume intersections based on existing pavement deficiency
3 Surface course C (SC – C) to be placed under OGFC.

Exhibit 9-10
Layer Coefficients for New and Reconstructed Pavements

Placement Component	Layer Coefficient (per inch)
Surface Course:	
— Hot Mix Asphalt Riding Surface and Binder	0.44
Base Course:	
— Hot Mix Asphalt	0.34
Sub-base:	
— Crushed Stone (Dense Graded)	0.14
— Gravel	0.11

Source: MassHighway

Exhibit 9-11
Minimum Pavement Thickness (New and Reconstructed Flexible Pavements)

Highway Type and Pavement Course	Thickness (inches)	Layer Coefficient	SN
HMA Surface Course			
Freeway	1.75	0.44	0.77
Arterial	1.75	0.44	0.77
Collector & Local	1.5	0.44	0.66
Low volume	1.5	0.44	0.66
HMA Intermediate Course			
Freeway	2.00	0.44	0.88
Arterial	1.75	0.44	0.77
Collector & Local	1.75	0.44	0.77
Low volume	2.5	0.34	0.85
HMA Base			
Freeway	4.50	0.34	1.53
Arterial	3.50	0.34	1.19
Collector & Local	3.25	0.34	1.10
Low volume	12” gravel base	0.11	1.32
Sub-base: Stone & Gravel			
Freeway	4” stone	0.14	.56
	8” gravel	0.11	.88
Arterial	4” stone	0.14	.56
	8” gravel	0.11	.88
Collector & Local	12” gravel	0.11	1.32
Total Structural Number			
Freeway	-	-	4.62
Arterial	-	-	4.17
Collector & Local	-	-	3.85
Low Volume			2.83

The above table is only valid when the conventional design calculations indicate a required pavement structure less than above. All pavement thicknesses shall be designed as detailed here. The use of crushed stone as part of the base course serves two purposes: it makes a firmer base for the paving machines and it reduces the amount of gravel required (gravel is in short supply in many areas of the State). Gravel also serves two purposes: structural support (although it is weaker than crushed stone) and drainage. Crushed stone is incompatible with drainage and, therefore, cannot fully replace gravel.
Source: MassHighway

9.6 Reclamation

For reclaimed pavements, the Designer will determine the depth of reclamation required. A minimum 12 inch granular base or sub-base course must be provided beneath the HMA pavement courses. The detailed procedure is as outlined in Section 400 of the *Standard Specifications for Highways and Bridges*. The Designer must complete the Pavement Design Form – New and Reconstructed Pavements in accordance with Section 9.5 above.

9.7 Pavement Resurfacing

A pavement resurfacing can be used if the Designer determines that an existing pavement is in reasonably good condition. A pavement resurfacing may be in conjunction with roadway widening and/or corrective work to the existing pavement. The ***Pavement Resurfacing Design Form*** and a completed example (cover sheet and data sheets 1 to 3) is included in Appendix 9-A-3 to this chapter. The depth of HMA resurfacing will be determined by the following procedure.

9.7.1 Pavement Resurfacing Design Cover Sheet

The following must be recorded on the Pavement Resurfacing Design Coversheet:

- Enter the project identification data at the top of the cover sheet.
- Document the existing pavement structure before resurfacing.
- Record the recommended pavement resurfacing thickness.

9.7.2 Data Sheet 1: Pavement Structural Design Data

Data Sheet 1 should be completed using the following procedure:

- **Line (a)**: Enter the current ADT.
- **Line (b)**: Enter the future ADT, (see Chapter 3 for information on traffic forecasts) usually for 20 years beyond the current. Note that the traffic data available may not correspond to the dates in Lines (a) and (b). If not, the designer should assume a uniform straight-line increase between the data. This assumption can then be used to determine the traffic volumes in Lines (a) and (b).
- **Line (c)**: Calculate the average ADT during the design period.
- **Line (d)**: Calculate the average ADT in one direction.
- **Line (e)**: Enter the truck percentage for the ADT.
- **Line (f)**: Calculate the average daily truck volume in one direction.
- **Line (g)**: Enter the equivalent 18-Kip axle application per 1,000 trucks and combinations (See Exhibit 9-2).
- **Line (h)**: Calculate the number of 18-Kip axle loads per day in one direction (T_{18}).

- **Line (i)**: Calculate the design lane equivalent daily 18-Kip applications based on number of lanes.
- **Line (j)**: Enter the sub-grade DBR and SSV. These will be provided by the PDE as discussed in Section 9.3 and Exhibits 9-4 and 9-5.
- **Line (k)**: Determine the required SN above the sub-grade from Exhibit 9-8.
- **Line (l)**: Determine the design SN by increasing the SN by 15 percent.

Exhibit 9-12
Layer Coefficients for Existing Pavements

Pavement Component	Layer Coefficient (per inch)
Surface Course:	
Hot Mix Asphalt	0.44
Sand Asphalt	0.40
Base Course:	
Hot Mix Asphalt	0.34
Asphalt Treated Penetrated Stone	0.24
Crushed Stone / Macadam	
Sand Bound Crushed Stone	0.14
Sandy Gravel	0.07
Sub-base:	
Crushed Stone (Dense Graded)	0.14
Gravel	0.11
Sand / Sandy Clay	0.05 to 0.10

These are the layer coefficient values for when the pavement was new. They must be reduced according to the Reduction Factors in Exhibit 9-13.
Source: MassHighway

Exhibit 9-13
Reduction Factors for Existing Pavement

Description of Existing Pavement	Reduction Factor (RF)
HMA surface exhibits appreciable cracking and crack patterns, little or no spalling along the cracks, some wheel path deformation, and is essentially stable.	0.5 - 0.7
HMA surface exhibits some fine cracking, small intermittent cracking patterns, and slight deformation in the wheel paths, and obviously stable.	0.7 - 0.9
HMA surface generally uncracked, little or no deformation in the wheel paths, and stable	0.9 - 1.0

This is based on a visual survey of the type and extent of distress. If the pavement distress and deterioration is worse than described in the table, consideration should be made for the removal and reconstruction of the pavement.
Source: MassHighway

9.7.3 Data Sheet 2: Actual SN of Existing Pavement

The following steps are required to complete Data Sheet 2:

- **Line (a)**: Enter the SSV of the existing pavement elements. The SSV for the penetrated crushed stone base, the sand bound crushed stone base, and the gravel sub-base are usually assumed as shown. However, if laboratory-determined DBR results are available, these values should be used. Enter the SSV for the sub-grade from Line (j) of Data Sheet 1.
- **Line (b)**: Determine the SN of the existing pavement. Follow these steps:
  - Exhibit 9-10 provides the layer coefficient for each layer component for a new pavement.
  - The coefficients in Exhibit 9-12 should be multiplied by a reduction factor (RF) from Exhibit 9-13. The RF will be based on a visual survey of the type and extent of distress in the existing pavement. The RF will apply even if corrective work is performed on the existing pavement.
  - The contributing SN for each layer is calculated by multiplying its depth by the layer coefficient and RF.
  - The total SN is found by summing the SN of each pavement layer.

  (Note: If Portland Cement Concrete is part of the existing pavement, the PDE will determine its contributing SN.)
- **Line (c)**: Determine the actual SN above each layer of the existing pavement. The SN for each layer is entered in the appropriate column. The "Total SN" reflects the cumulative SN above each pavement layer.

9.7.4 Data Sheet 3: Determination of Resurfacing Thickness

The following steps are needed to complete Data Sheet 3:

- **Line (a)**: Determine the required SN above each layer of the existing pavement using Exhibit 9-8. The values from Line (i) on Data Sheet 1 and from Line (a) of Data Sheet 2 are used in the figure. The SN values from Exhibit 9-8 are increased by 15 percent to determine the design SN.
- **Line (b):** Determine the SN deficiency for each layer for the existing pavement. The required SN from Line (a) of Data Sheet 3 is entered in

the first column. Enter the value from Line (c) of Data Sheet 2 in the second column. The first column SN minus the second column SN yields the SN difference, which is entered in the third column. (Note: A negative value indicates there is no SN deficiency for that pavement layer.)

- **Line (c):** The largest SN deficiency from the table in Line (b) is used to determine the thickness of the pavement resurfacing. The SN per inch is 0.44 for the Hot Mix Asphalt surface course. Regardless of the calculation, the minimum overlay thickness is 1 ¾ inch for modified top course.

9.8 Limited Access Highway Pavement Resurfacing Design

Due to the high traffic volumes and loadings on limited access highways, MassHighway maintains the ability to perform non-destructive testing and evaluate the pavement and subsurface conditions for these roadways. When designing structural resurfacings on limited access highways, the PDE may elect to use non-destructive testing to determine the appropriate resurfacing. The following general parameters are considered the minimum standards for these roadways:

9.8.1 Design Method

Both a layered component analysis and non-destructive testing analysis should be reviewed to calculate the effective existing SN.

9.8.2 Serviceability

An initial serviceability no greater than 4.5 should be assumed. A terminal serviceability no greater than 2.75 should be selected.

9.8.3 Reliability

Traffic disruption and congestion associated with construction operations result in significant user costs. Increased design reliability helps reduce these user costs. Thus, reliability levels approaching 99.9 percent are used to design structural resurfacings on the Interstate Highway System. Reliability levels approaching 99.5 percent should be used to design structural resurfacings on other limited access highway.

9.8.4 Back-calculation

Non-destructive testing must be analyzed to determine the resilient modulus of the soil. Because differing stress states occur between field conditions and lab conditions, a correction factor must be used to convert field-determined modulus values to lab values for design calculations. For granular soils, a resilient modulus correction factor (C) of 0.33 shall be used.

Depending upon the project, the back-calculated resilient modulus values of the sub-grade could vary significantly. Extremely high modulus values could be indicative of subsurface irregularities such as shallow bedrock or groundwater. To minimize the possibility of such erroneous modulus values, only modulus values within one standard deviation of the mean should be used to calculate the average resilient modulus for design purposes.

9.8.5 *1993 AASHTO Pavement Resurfacing Design*

Once the non-destructive testing has been analyzed and the future traffic loadings have been determined, the PDE will determine the required future structural number.

9.9 Pavement Preservation

The design/selection of all pavement preservation treatments must be in accordance with the MassHighway *Pavement Preservation Guidelines*. The Designer shall submit the proposed treatment type and surface preparation requirements to the PDE for approval.

9.10 Typical Pavement Design for Low Volume Roads

In this revision of the Guidebook, the minimum pavement cross section has been reduced for low volume roads (2,000 AADT maximum). This new minimum cross section has eliminated the use of HMA base course and provides for the placement of Gravel Base Course in its place. These revisions are reflected in Exhibit 9-10 Minimum Pavement Thickness (New and Reconstructed Flexible Pavements).

9.10.1 Design Procedures

For the purpose of designing pavements on low volume roadways, the Designer should begin with the minimum low volume roadway cross section as shown on Exhibit 9-11. This design should be adequate for virtually all roadways less than 1,000 AADT and most roadways less than 2,000 AADT and 3percent truck traffic. If the design calculations indicate that a greater thickness is required, then the Designer should adjust the pavement layer thickness accordingly.

9.11 For Further Information

- *Interim Guide for Design of Pavement Structures*, AASHTO, 1972 (Revised 1993).
- Layered Pavement Design Method for Massachusetts, Massachusetts Department of Public Works and Massachusetts Institute of Technology, January, 1965.

9-A-1

Pavement Design Checklist

Pavement Design Checklist

I. Project Identification

City/Town ______________________________ Project Number ______________________________
Street/Rte. No. ______________________________ Functional Class ______________________________
From Station ______________________________ To Station ______________________________
From (Landmark) ______________________________ To (Landmark) ______________________________
Date ______________________________ Design Engineer ______________________________

II. Traffic Data

Current ADT (year)______________________________ Future ADT (Year)* ______________________________
T (ADT) ______________________________ T (PEAK HR.)______________________________
No. of Lanes ______________________________ Divided/Undivided ______________________________

III. Existing Pavement Information

Year Initially Constructed______________________________ Overlaid ______________________________
Source Information ______________________________

Existing Pavement Structure:

Layer	Depth	Type
Surface Course:	____________	____________
Intermediate Course:	____________	____________
Base Course:	____________	____________
Sub-base:	____________	____________
Sub-grade:	____________	____________

III a. Document Existing Pavement Conditions and Distress

Type	Extent (percentages)	Severity			Depth Inches
[ ] Alligator Cracking		High	Medium	Low	
[ ] Block Cracking					
[ ] Other Cracking (tranverse, longitudinal, reflective)					
[ ] Lane/Shoulder Dropoff					
[ ] Potholes					
[ ] Rutting (wheelpaths)					
[ ] Alligator Cracking					
[ ] Other ___________					
[ ] Other ___________					

Notes: 1. If existing pavement is PCC, provide a separate description of pavement
2. Provide photographs as needed to demonstrate pavement distress

* Minimum 20 yr. protection

IV. Field Inspection Report

a. Proposed Corrective Work to Existing Pavement

[ ] Milling / Cold Planing
[ ] Leveling Course*
[ ] Reclamation
[ ] Reconstruction or Full Depth Construction
[ ] Heater/Scarifier

[ ] Subdrainage Pipes
[ ] Full Depth Patching/Pothole Repairs
[ ] Crack Filling*
[ ] Preventive Maintenance
[ ] Other ______________________________

Discussion on above corrective work or other special site conditions:

____
____
____
____
____
____

b. Proposed Scope of Work

[ ] New Pavement
[ ] Reconstructed Pavement or Full Depth Construction
[ ] Reclaimed Pavement or Recycling
[ ] Surface (in place)
[ ] Cold-Mix
[ ] Hot-Mix

[ ] Pavement Overlay
[ ] Preventive Maintenance
[ ] Geometric Improvements
[ ] With corrective work to existing pavement
[ ] Without corrective work to existing pavement
[ ] Other

Discussion on above proposed scope of work or other special site conditions :

____
____
____
____
____

Briefly discuss reasons for proposed work, including estimated costs and any special site conditions which may limit the practical choices.

Discussion:

____
____
____
____
____

* Only done under certain circumstance and with the approval of PDE

9-A-2

New or Reconstructed Pavement Form

COMMONWEALTH OF MASSACHUSETTS
MassHighway

PAVEMENT DESIGN
NEW AND RECONSTRUCTED PAVEMENTS

City/Town	____________		
Route No.	____________	**Highway System**	____________
From Station	____________	**To Station**	____________
No. of Lanes	____________		
Date Pavement Designed	____________	**Pavement Designer**	____________

RECOMMENDED PAVEMENT STRUCTURE

Surface Course:

Intermediate Course

Base Course:

Sub-base:

Sub-grade:

NEW AND RECONSTRUCTED PAVEMENTS

DATA SHEET 1: PAVEMENT STRUCTURAL DESIGN DATA

City/Town ____________________ **Route No.** ________________

From Station ____________________ **To Station** ________________

No. of Lanes ___ **Highway System** ____________ **Date** ___________

Current ADT ____

Terminal Serviceability Index (T.S.I) = 2.5

(a) Day of Opening A.D.T. (Date year)[1] ________

(b) Future A.D.T. (Date (a) + 20 years)[2] ________

(c) Mean A.D.T. = $\frac{[(a) + (b)]}{2}$ ________

(d) Mean A.D.T. in One Direction = $\frac{(c)}{2}$ ________

(e) A.D.T. Truck Percentage ("T" A.D.T.) ________

(f) Mean Truck A.D.T. In One Direction (d) x (e) ________

(g) ESAL Application per 1000 Trucks and Combinations Exhibit 9-2 ________

(h) Number of ESALs Per Day in One Direction ________

$\frac{(f) \times (g)}{1000}$ (T_{18})

Comments:
____

____

____

____

____

1 Anticipated traffic when facility is opened to travel.
2 Under certain conditions this may change to a larger or shorter period.

NEW AND RECONSTRUCTED PAVEMENTS

DATA SHEET 2: DETERMINATION OF STRUCTURAL MUMBER (SN)

Design Lane ESAL Applications (T_{18})

For 2-Lane Undivided Highway

Design Lane T_{18} = 1.00 x Total T_{18}* = 1.00 x ……..... = ________________

For 4 (Total Lanes) Lane Divided Highway

Design Lane T_{18} = 0.90 x Total T_{18}* = 0.90 x ……..... = ________________

Design 6 or More (Total Lanes) Divided Highway

Design Lane T_{18} = 0.80 x Total T_{18}* = 0.80 x …………= ________________

Design DBR + SSV Exhibits 9-4, 9-5 & 9-7, Sections 9.3 & 9.4

Subbase ____________ DBR = ____________ SSV = ____________

Subgrade ____________ DBR = ____________ SSV = ____________

Design Structural Number (SN)

Apply Design SSV and Design Lane T_{18} from above to Design Nomograph (Exhibit 9-8)

	From Exhibit 9-8	+15%
Above Subbase ……………=		
Above Sugrade …………... =		

*From Line (h) of Data Sheet 1.

NEW AND RECONSTRUCTED PAVEMENTS

DATA SHEET 3: PAVEMENT STRUCTURAL NUMBER (SN)

$$SN = D_1a_1 + D_2a_2 + D_3a_3 + D_4a_4 + D_5a_5$$

Surface Course

Material: ______________ D_1a_1 = ____________________________

Intermediate Course

Material: ______________ D_2a_2 = ____________________________

Base Course

Material: D_3a_3 =

Total SN Above Sub-base = ____________________________

Sub-base (Foundation)

Material: __________________ D_4a_4 = ____________________________

__________________ D_5a_5 = ____________________________

Total SN Above Sub-grade = ____________________________

Where: D_1 = Surface Course Thickness, inches

D_2 = Intermediate Course Thickness, inches

D_3 = Base Course Thickness, inches

D_4 = Sub-base Course Thickness, inches

D_5 = Sub-base Course Thickness, inches

a_1 = Coefficient of Relative Strength, Surface Course

a_2 = Coefficient of Relative Strength, Intermediate Course

a_3 = Coefficient of Relative Strength, Base Course

a_4 = Coefficient of Relative Strength, Sub-base Course

a_5 = Coefficient of Relative Strength, Sub-base Course

Comments: ____

____

____

____

____

9-A-3

Overlay Design Form

COMMONWEALTH OF MASSACHUSETTS
MassHighway

PAVEMENT RESURFACING OVERLAY DESIGN

City/Town	________________		
Route No.	________________	**Highway System**	________________
From Station	________________	**To Station**	________________
No. of Lanes	________________		
Date Pavement Designed	________________	**Pavement Designer**	________________

EXISTING PAVEMENT STRUCTURE

Depth	Existing HMA Pavement Course
________________	HMA surface course
________________	HMA intermediate course
________________	HMA base course or Penetrated Stone
________________	Sub-base
________________	Sub-grade

PROPOSED MILLING

_______**Proposed Milling Depth**
_______**Existing HMA Depth After Milling Depth**

RECOMMENDED PAVEMENT DESIGN OVERLAY THICKNESS

Depth	HMA Description

PAVEMENT RESURFACING OVERLAY DESIGN

DATA SHEET 1: PAVEMENT STRUCTURAL DESIGN DATA

Terminal Serviceability Index Nomograph = 2.5

(a) Current A.D.T. (Date ________)	________________
(b) Future A.D.T. (Date ________)	________________
(c) Mean A.D.T. $= \frac{[(a) + (b)]}{2}$	________________
(d) Mean A.D.T. in One Direction $= \frac{(c)}{2}$	________________
(e) A.D.T. Truck Percentage	________________
(f) Mean Truck A.D.T. In One Direction (d) x (e)	________________
(g) ESAL Application per 1000 Trucks and Combinations Exhibit 9-2	________________
(h) Number of ESALs Per Day in One Direction $\frac{(f) \times (g)}{1000}$ (T_{18})	________________
(i) ESALs on Design Lane: (h) x 1.00 for 2 lanes; (h) x 0.90 for 4 lanes; (h) x 0.80 for 6 or more lanes	________________
(j) Sub-grade Design Bearing Ratio and Soil Support Value	________________
(k)* Structural Number (SN) Required above this Subgrade	________________
(l)* Increase SN by 15% for Design SN	________________

*These values are developed on Data Sheet #3.

PAVEMENT RESURFACING OVERLAY DESIGN

DATA SHEET 2: ACTUAL SN OF THE EXISTING PAVEMENT STRUCTURE

a) Soil Support Values of Existing Granular Base and/or Sub-base

Dense Graded or Penetrated Crushed Stone Sub-base =

Gravel Base and/or Sub-base =

Sub-grade =

(b) Actual Structural Number (SN) of Each Layer of the Existing Pavement Structure

(1) Depth		(2) Coefficient Exhibit 9-10	(3) RF Exhibit 9-11	SN ((1)X(2)X(3)
	HMA			
	Dense Graded or Penetrated Crushed Stone Sub-base			
	Gravel Base/Sub-base			
			Total SN =	

(c) Actual Structural Number (SN) Above Each Layer of the Existing Pavement Structure

Above Top Of:	SN* HMA	SN* Pentrat. Stone	SN* Sand-Bd. Stone	SN* Gravel	Total SN*
Dense Graded-Penetrated Crushed Stone Sub-base					
Gravel Base and/or Sub-base					
Sub-grade					

*From Table (b) Above
**Accumulated SN Values from layers Above
***Gravel Base (for low volume design < 2000 adt)

PAVEMENT RESURFACING OVERLAY DESIGN

DATA SHEET 3: DETERMINATION OF HMA OVERLAY THICKNESS

(a) Required Structural Number (SN) Above Each Layer of the Existing Pavement Structure

	SN	+15%
Above Top of Dense Graded or Penetrated Crushed Stone Sub-base =		
Above Top of Gravel Base and/or Sub-base =		
Above Top of Sub-grade =		

(b) SN Deficiency to be Corrected with the HMA Overlay Thickness

Above Top Of:	Required SN*	Actual SN**	SN Difference
Dense Grade or Penetrated Crushed Stone Sub-base			
Gravel Base and/or Sub-base			
Sub-grade			

*From (a) Data Sheet #3
**From (c) Data Sheet #2

(c) Thickness of Hot Mix Asphalt Overlay

$$\text{Depth} = \frac{\text{Largest SN Difference}}{0.44} =$$

9-A-4

Sample Problems and Completed Forms

A4.1 New or Reconstructed Pavement Design
Sample Problem and Completed Form

Approximately 6,000 feet of Broadway Street (Route 107) is being reconstructed in Revere. The area has seen commercial and industry development and an increase in traffic volumes. Broadway is a two-lane urban facility. The following data is given.

- 2005 ADT = 21,640
- 2025 ADT = 22,480
- T (ADT) = 5%

Problem:
Determine the pavement structural design for a 20-year period.

Solution:

Data Sheet 1
Lines (a) to (g) on Data Sheet 1 are completed as instructed. Exhibit 9-2 is used to select the ESAL applications per 1000 trucks and combinations. The urban roads value of 800 is used and entered on Line (g). Therefore, Line (h) is 440.

DBR Determination
Line (h) (T_{18}) exceeds 120. Therefore, according to Exhibit 9-4, PDE must determine the DBR for the subgrade.

Data Sheet 2
- **Step 1:** The design lane equivalent for a two-lane undivided highway is 1.00 x Line (h) which, in this case, is 440.
- **Step 2:** PDE determines that the subgrade DBR is 9.
- **Step 3:** Using Exhibit 9-7, The subgrade SSV = 4.2; The subbase SSV = 7.8.
- **Step 4:** Using Exhibit 9-8, the required SN above the subbase is 2.6; above the subgrade it is 4.15.
- **Step 5:** Increasing these values by 15% yields SN design values of 2.99 and 4.77.

Data Sheet 3
Use the trial-and-error procedure to determine the most economical design which satisfies the SN requirements for the subbase and subgrade. The following design is selected:

1 ¾-inches of HMA surface course standard 1 ¾-inches of HMA intermediate course dense
4 ½-inches HMA base course standard
4 inches of dense graded crushed stone over
10 inches of gravel sub-base

A completed summary sheet and completed data sheets follow.

COMMONWEALTH OF MASSACHUSETTS
MassHighway

PAVEMENT DESIGN
NEW AND RECONSTRUCTED PAVEMENTS

City/Town	Revere		
Route No.	Broadway St. (Rte.107)	**Highway System**	Urban Collector
From Station	54+00I	**To Station**	114+00I
No. of Lanes	2 Travel Lanes		
Date of Pavement Design:	2/24/05	**Pavement Design By:**	Pavement Designer

RECOMMENDED PAVEMENT STRUCTURE

Surface Course:	1 ¾-inch HMA Surface Course over
Intermediate Course:	1 ¾-inch HMA Intermediate Course over
Base Course:	4 ½-inch HMA Base Course placed in one layer over
Sub-base:	4-inch Dense Graded Crushed Stone Sub-base over 10-inch gravel sub-base
Sub-grade	Undisturbed existing sub-grade

NEW AND RECONSTRUCTED PAVEMENTS

DATA SHEET 1: PAVEMENT STRUCTURAL DESIGN DATA

City/Town	Revere	**Route No.**	107
From Station	54+00	**To Station**	114+00
No. of Lanes	2 **Highway System**	Urban Collector	**Date** 2/2/4/05
Current ADT	2005		

Terminal Serviceability Index (T.S.I) = 2.5

(a) Day of Opening A.D.T. (Date 2005)*	21,640
(b) Future A.D.T. (Date (a) + 20 years)**	22,480
(c) Mean A.D.T. = $\frac{[(a) + (b)]}{2}$	22,060
(d) Mean A.D.T. in One Direction = $\frac{(c)}{2}$	11,030
(e) A.D.T. Truck Percentage ("T" A.D.T.)	5
(f) Mean Truck A.D.T. In One Direction (d) x (e)	550
(g) ESAL Application per 1000 Trucks and Combinations Exhibit 9-2	800
(h) ESALs Per Day in One Direction $\frac{(f) \times (g)}{1000}$ (T_{18})	440

Comments:

*Anticipated traffic when facility is opened to travel.
**Under certain conditions this may change to a larger or shorter period.

NEW AND RECONSTRUCTED PAVEMENTS

DATA SHEET 2: DETERMINATION OF STRUCTURAL MUMBER (SN)

Design Lane ESAL Applications (T_{18})

For 2-Lane Undivided Highway

Design Lane T_{18} = 1.00 x Total T_{18}* = 1.00 x 440 = 440

For 4 (Total Lanes) Lane Divided Highway

Design Lane T_{18} = 0.90 x Total T_{18}* = 0.90 x ……..... = __________

Design 6 or More (Total Lanes) Divided Highway

Design Lane T_{18} = 0.80 x Total T_{18}* = 0.80 x …………= __________

Design DBR + SSV Exhibits 9-4, 9-5 & 9-7, Sections 9.6 Exhibit 9-7

Subbase	Gravel	DBR =	40	SSV =	7.8
Subgrade		DBR =	9	SSV =	4.2

Design Structural Number (SN)

Apply Design SSV and Design Lane T_{18} from above to Design Nomograph (Exhibit 9-8)

	From Exhibit 9-8	+15%
Above Subbase ……………=	2.6	2.99
Above Sugrade …………... =	4.15	4.77

*From Line (h) of Data Sheet 1.

NEW AND RECONSTRUCTED PAVEMENTS

DATA SHEET 3: PAVEMENT STRUCTURAL NUMBER (SN)

$$SN = D_1a_1 + D_2a_2 + D_3a_3 + D_4a_4 + D_5a_5$$

Surface Course

Material:	1 ¾” HMA	D_1a_1=	1.75 x .44 =	0.77

Intermediate Course

Material:	1 ¾” HMA	D_2a_2=	1.75 x .44 =	0.77

Base Course

Material:	4½” HMA	D_3a_3=	4.5 x .34 =	1.53

Total SN Above Subbase = 3.07 > 2.99

Subbase (Foundation)

Material:	4” crushed stone	D_4a_4=	4 x .14 =	0.56
	10” gravel	D_5a_5=	10 x .11 =	1.10
	Total SN Above Subbase	=		4.73 ~4.77

Where: D_1 = Surface Course Thickness, inches

D_2 = Intermediate Course Thickness, inches

D_3 = Base Course Thickness, inches

D_4 = Sub-base Thickness, inches

D_5 = Subbase Thickness, inches

a_1 = Coefficient of Relative Strength, Surface

a_2 = Coefficient of Relative Strength, Intermediate

a_3 = Coefficient of Relative Strength, Base

a_4 = Coefficient of Relative Strength, Sub-base

a_5 = Coefficient of Relative Strength, Subbase

Comments:

Overlay Design
Sample Problem and Completed Form

Approximately 2460 feet of Route 3 in Hingham is being resurfaced overlayed. Route 3 is a four-lane urban freeway facility. The existing pavement exhibits some moderate severity cracking , raveling of longitudinal joints and patch repairs. The last resurfacing of this road was in 1989. The following data is given.

- 2005 ADT = 52,000
- 2025 ADT = 66,000
- T (ADT) = 6%

Existing Pavement:

- 6 inch hot mix asphalt
- 4½ inch penetrated crushed stone base
- 12 inch gravel subbase
- 2 inch proposed milling

Problem:

Determine the depth of hot mix asphalt overlay for a 20-year design period.

Solution:

Data Sheet 1

- Line (a)- Line (f): Completed as instructed
- Line (g): Exhibit 9-2 yields a value of 1000
- Line (h): This calculation yields a T_{18} = 1768
- Line (i): For a four-lane facility, the design lane ESAL is (0.9 x T_{18}), or 1593
- Line (j): The PDE provides a subgrade DBR of 11, which yields SSV = 4.5
- Line (k): Exhibit 9-8 yields an SN 3.67 above the subgrade
- Line (l): Increasing by 15% yields a design SN of 4.22

Data Sheet 2

- Line (a): The subgrade SSV = 4.5 is entered.
- Line (b): Exhibit 9-12 is used to select the layer coefficients for the existing pavement. The existing pavement is in generally good condition. Therefore, a reduction factor of 0.9 is selected from Exhibit 9-13. The calculations are shown on the completed data sheet
- Line (c): The actual SN above each pavement layer is entered s shown on the completed data sheet

Data Sheet 3

- Line (a): Exhibit 9-8 is used to determine the required SN above each layer of the existing pavement. These are increased by 15% as shown.
- Line (b): The SN deficiency for each layer of the existing pavement is shown on the completed data sheet
- Line (c): The largest SN deficiency is 1.75 for the subgrade. This is used to determine that a 4 inch overlay is needed to provide acceptable pavement performance over the 20-year period.

A completed summary sheet and completed data sheets follow.

COMMONWEALTH OF MASSACHUSETTS
MassHighway

PAVEMENT RESURFACING OVERLAY DESIGN

City/Town	Hingham		
Route No.	3	**Highway System**	Freeway
From Station	85+00	**To Station**	109+60
No. of Lanes	4		
Date Pavement Designed	Date	**Pavement Designed By:**	Pavement Designer

EXISTING PAVEMENT STRUCTURE

Depth	Existing HMA Pavement Course
1 ½"	HMA Surface Course
	HMA Intermediate Course
4 ½"	HMA Base Course
4½"	Dense Graded or Penetrated Crushed Stone
	Sub-base
12"	Sub-grade

PROPOSED MILLING

2" PROPOSED MILLING DEPTH
4" EXISTING HMA DEPTH AFTER MILLING

RECOMMENDED OVERLAY THICKNESS TO BE PLACED OVER MILLED SURFACE

2" HMA SURFACE COURSE
2" HMA INTERMEDIATE COURSE

PAVEMENT RESURFACING OVERLAY DESIGN

DATA SHEET 1: PAVEMENT STRUCTURAL DESIGN DATA

Terminal Serviceability Index Nomograph = 2.5

(a) Current A.D.T. (Date 2005)	52,000
(b) Future A.D.T. (Date 2025)	66,000
(c) Mean A.D.T. = [(a) + (b)] / 2	33,000
(d) Mean A.D.T. in One Direction = (c) / 2	29,500
(e) A.D.T. Truck Percentage	6%
(f) Mean Truck A.D.T. In One Direction (d) x (e)	1768
(g) ESALs per 1000 Trucks and Combinations Exhibit 9-2	1000
(h) Number of ESALs Per Day in One Direction (f) X (g) / 1000 (T_{18})	1768
(i) ESALs on Design Lane: (h) x 1.00 for 2 lanes; (h) x 0.90 for 4 lanes; (h) x 0.80 for 6 or more lanes	1593
(j) Sub-grade Design Bearing Ratio and Soil Support Value	DBR = 11:SSV= 4.5
(k)* Structural Number (SN) Required above this Subgrade	3.7
(l)* Increase SN by 15% for Design SN	4.26

*These values are developed on Data Sheet #3.

PAVEMENT RESURFACING OVERLAY DESIGN

DATA SHEET 2: ACTUAL SN OF THE EXISTING PAVEMENT STRUCTURE

a) Soil Support Values of Existing Granular Base and/or Sub-base

Dense Graded or Penetrated Crushed Stone Sub-base	= 9.0
Gravel Base and/or Subbase	= 6.6
Subgrade	= 4.5

(b) Actual Structural Number (SN) of Each Layer of Existing Pavement

(1) Depth		(2) Coefficient Exhibit 9-10	(3) RF Exhibit 9-11	SN ((1)X(2)X(3)
4"	Hot Mix Asphalt	0.44	0.9	1.6
4½"	DGCS or Penetrated Crushed Stone Sub-base Base	0.24	0.9	0.97
12"	Gravel Base and/or Sub-base	0.11	0.9	1.19
			Total SN =	3.7

(c) Actual Structural Number (SN) Above Each Layer of Existing Pavement

Above Top Of:	SN* HMA	SN* Pentrat. Stone	SN* Sand-Bd. Stone	SN* Gravel	Total SN*
DGCS or Penetrated Crushed Stone Sub-base Base	1.6				1.6
Gravel Base and/or Sub-base	1.6	1.0			2.6
Sub-grade	1.6	1.0		1.2	3.7

*From Table (b) Above
**Accumulated SN Values from layers Above
Gravel Base (for low volume design < 2000 adt)

PAVEMENT RESURFACING OVERLAY DESIGN

DATA SHEET 3: DETERMINATION OF OVERLAY THICKNESS

(a) Required Structural Number (SN) Above Each Layer of Existing Pavement

		SN	+15%
Above Top of Penetrated Crushed Stone Base	=	2.62	3.01
Above Top of Gravel Base and/or Sub-base	=	3.67	4.22
Above Top of Subgrade	=	4.78	5.50

(b) SN Deficiency to be Corrected With an Overlay

Above Top Of:	Required SN*	Actual SN**	SN Difference
Penetrated Crushed Stone Base	3.01	1.58	1.43
Gravel Base and/or Sub-base	4.22	2.56	1.66
Sub-grade	5.50	3.74	1.75

*From (a) Data Sheet #3

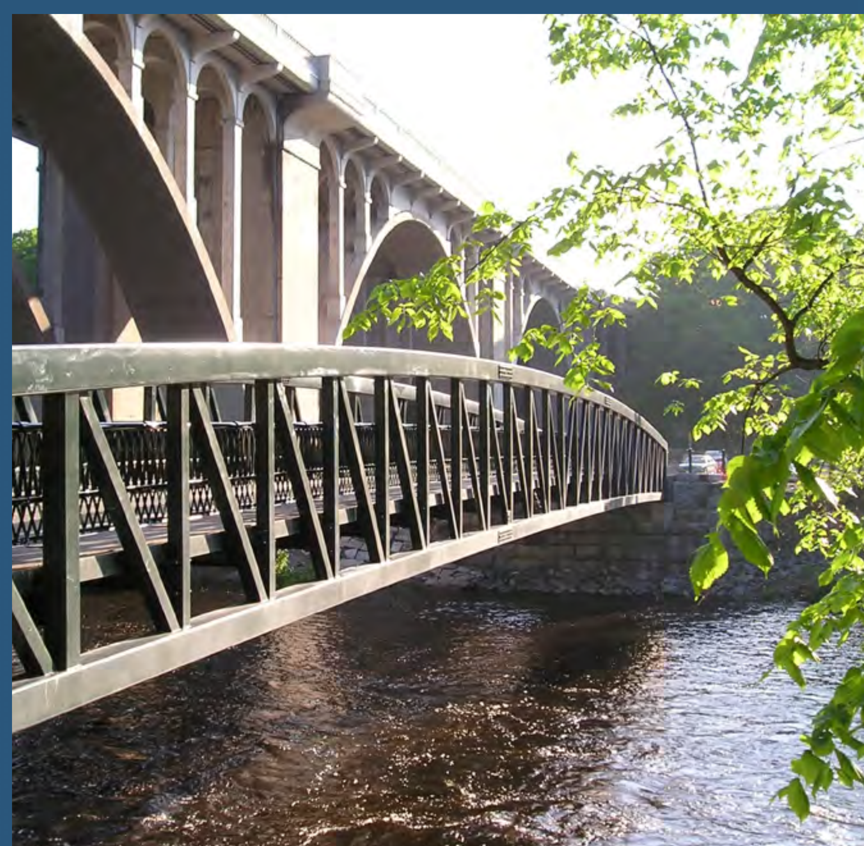
**From (c) Data Sheet #2

(c) Thickness of Hot Mix Asphalt Overlay

$$\text{Depth} = \frac{\text{Largest SN Difference}}{0.44} = \frac{1.75}{0.44} = 3.98 \text{ inches} \quad \text{use 4 inches}$$

Chapter 10

Bridges



Bridges

10.1 Introduction

The primary function of bridges is to carry pedestrians, bicycles, and/or vehicles over various types of transportation facilities or natural features. Bridges come in a wide variety of configurations and structure types. This chapter provides a brief introduction into the topic of bridge planning and design including discussion of applications of bridges, contextual influences on bridge design, preliminary design guidelines, major bridge elements, and the inventory and management of bridges.

For detailed information on bridge design, please refer to the *MassHighway Bridge Manual* which, along with Chapter 2 of this Highway Design Manual, also provides information on process and roles and responsibilities.

10.2 Applications of Bridges

The various bridge applications are described in the following sections.

10.2.1 Pedestrian and Bicycle Facility Bridges

Bridges can be constructed to carry pedestrian and bicycle traffic over an obstacle, usually vehicular traffic, a railroad, or a watercourse. Given that extra travel distance is more acceptable for vehicular travel than for pedestrians and cyclists, it may be appropriate to include a separate bicycle and pedestrian crossing at locations where the existence of schools, churches, parks and open spaces, and other land uses generate large volumes of pedestrians or cyclists. Other factors affecting the decision to provide a pedestrian or bicycle bridge include:

- A large number of children crossing;
- Unacceptable traffic conflicts due to roadway width, high traffic speeds, and high traffic volumes; and
- Cost.

Pedestrian routes on bridges have the same requirements for accessibility for people with disabilities as other sidewalks. Slopes can follow the roadway alignment but cross-slopes cannot exceed 2 percent in the built condition (1.5 percent in design). Curb cut ramps are required at intersections. Where a bridge is not along the roadway right-of-way, its slope cannot exceed 8.33 percent in the built condition.

Preliminary design features such as vertical and horizontal clearance and cross-section should be considered. Pedestrian passages under a roadway are discouraged unless the highway lanes are on a fill section of 15 feet or more. This type of structure presents problems for drainage and lighting and creates a condition where policing is difficult.

10.2.2 Highway Grade Separations

A grade separation where a roadway passes over an intersecting roadway or railroad is called an ***overpass*** or over-crossing. A grade separation where a roadway passes under an intersecting roadway or railroad is called an ***underpass*** or under-crossing. These definitions apply for the roadway in question and are the opposite for the crossing roadway.

Most grade separations and interchanges are located on freeways or major arterials. These structures allow the highway to safely accommodate high volumes of traffic through intersections. Some controlling factors in the planning of a highway grade separation include highway geometry and the available right-of-way. Highway grade separations are often combined with ramp systems to form interchanges described in Chapter 7.

To present consistent visual cues to drivers, grade separation structures should conform to the highway alignment and cross section, and also provide the required vertical clearance. Its profile must be limited to grades that allow sufficient stopping sight distance. The transition from roadway to grade separation should be designed such that the driver 's behavior is not altered. Other considerations that should be integrated into the design of highway structures include the following:

- Generous lateral clearances to structural elements and other features;

- Structural elements of the bridge should be shielded from potential impact by errant vehicles either through grading of roadway medians and off-shoulder slopes, or through the provision of barrier systems and impact attenuators as described in Chapter 5;
- The design should support projections of activity levels by all users, consistent with state, regional and local plans and policies (see Chapter 3);
- Aesthetically pleasing highway architecture should be considered;
- Underpass structures should be as open as practical to allow light penetration, air circulation, and maximum visibility. In the case of long underpasses or tunnels, consideration must be given to the inclusion of rescue assistance areas, fire suppression, and ventilation;
- Bridges over navigable rivers should be as open as possible to recreational (canoe/kayak) passage.
- All structures should be designed with shoulders, curbing, lighting and other highway elements that exist on the approaching roadway or that may be expected to be provided on the approaching roadway with future improvements. Bridges should also include sidewalks and bicycle accommodation even where such facilities are not provided on the approaching roadway. These facilities are needed to provide pedestrian and bicycle access across barriers, such as water, railroads and highways and to assure facilities consistent with potential future roadway and sidewalk improvements on the approaching roadway.

With respect to highway operations, there is no minimum spacing or limit to the number of grade-separated cross streets, however, considerable savings can be achieved by terminating some of the less important cross streets or combining nearby streets into single crossings.

Engineering studies should be conducted to determine the effects of termination and the mitigation required to maintain continuity, safety and access requirements for area roads. In some instances, frontage roads may be installed along the mainline to provide connectivity for users from terminated street to through cross streets. Factors that may affect the number and spacing of cross streets include:

- Network connectivity and development characteristics;
- Activity levels (pedestrian, bicycle and traffic volumes);
- Location of schools, recreational areas, hospitals and other public facilities; and
- Emergency service routes.

The availability of adequate right of way may limit the possible structure types. Moreover, the construction process can also be adversely affected by the lack of right of way and can require staged construction. Additionally, considerations such as the bridge span length, soil characteristics, and skew may also affect the structure's design.

In some instances, particularly in developed areas, the grades of local roads cannot be changed due to the surrounding context. In these situations, it may be necessary to depress or raise the entire through roadway into a boat section, tunnel or viaduct. These facilities are much more expensive to construct than simple overpasses and underpasses and may require drainage pump stations, control of groundwater, underpinning of nearby structures, special lighting, and video systems for security monitoring.

10.2.3 Railroad Grade Separations

Structures that carry a roadway over railroad traffic are referred to as ***railroad overpasses***. Conversely, ***railroad underpasses*** are structures that pass roadways under railroads. Some considerations when planning a railroad overpass or underpass include the selection of the structure type, the horizontal and vertical clearance to the centerline of the track, the available right-of-way, drainage, train movements, and required coordination with the railroad company.

The selection of the type of structure, either overpass or underpass, usually depends on the existing topographical conditions. Railroad underpasses often present drainage problems, sometimes requiring the use of pump stations which can be costly and require ongoing maintenance.

Proper clearances are an important consideration in the early planning phase. In order to determine vertical clearance, it is important to determine the top of high rail elevation for approximately 500 ft. in each direction from the roadway and for a greater distance if a change in railroad grade is proposed.

Crossings of railroad right-of-way usually requires negotiating an agreement with the railroad company. In many cases, the structure must span the entire railroad right-of-way rather than just the active tracks. Train movements can also affect the construction process. Construction schedule and construction crew safety need to be addressed during the preliminary design phase.

10.2.4 Crossings of Streams, Rivers, and Other Natural Features

Bridges and culverts provide crossings over streams, rivers, and other natural features. Hydraulic analysis should take place early in project development to uncover unusual problems that become much more difficult to address at later stages. This is particularly important with respect to highway location. As discussed in Chapter 2, crossings of watercourses often require extensive permitting processes at the local, state, and federal level. When encountering streams, rivers, and other natural features the designer should reference the Massachusetts River and Stream Crossing Standards and Chapter 14 of this Guidebook. Where they exist, opportunities to replace substandard crossings should be considered.

Culverts are usually pre-manufactured sections that can operate either with a submerged inlet (under pressure) or with free surface flow. The roadway cross-section is usually constructed on fill placed over the culvert. Culverts exceeding 20 feet in length along the roadway centerline are classified as bridges; however, despite this classification culvert design standards should be followed.

Bridges are structures usually constructed in-place (although pre-manufactured elements are commonly used) which carry traffic directly on a deck surface. Bridges do not form inlet conditions or act as pressurized conduits since the flow line of a bridge is rarely fixed and the material along the flow line of a bridge is usually the same as the stream it crosses.

Bridges and culverts are vulnerable to damage from floods. To minimize the risk of damage, the hydraulic requirements of a stream crossing must be recognized and considered in all phases of project development, construction, and maintenance. Therefore, hydrologic and hydraulic analyses are required for all new bridges, bridge replacements, bridge widenings, and roadway profile modifications that may adversely affect the flood plain. These analyses are discussed further in Chapter 8. Typically the hydrologic and hydraulic analyses should include an estimate of peak discharge (sometimes complete runoff hydrographs), existing and proposed condition water surface profiles for design, check flood conditions, and consideration of the potential for stream stability problems and maximum predicted scour depth. These analyses should also consider recreational water users by ensuring that they are not precluded from using the waterway due to limits on vertical clearance under the bridge. The designer should also consider routes for recreation access to the waterway during the design process.

Both new and replacement bridges and culverts can also be used to improve the connectivity of habitat in certain locations, whether or not they are placed for a hydraulic function. The design of both bridges and culverts should consider the effects on wildlife habitat, fish passage, and other considerations described in Chapter 14.

10.3 Contextual Influences on Bridge Design

Bridges are highly visible elements of the transportation infrastructure in the surrounding landscape. Often they traverse environmentally and ecologically sensitive sites, culturally or visually significant areas, or are visually prominent features in communities and other developed settings. Although bridges can have negative impacts on these environments, they can also be designed in such a way that they are pleasing or welcome additions to the landscape.

Designing a suitable bridge requires that the designer pay careful attention to the details starting with an understanding of the setting in which the structure will be built and ending with the detailing of the bridge structure itself. Bridges can be designed to blend into the surrounding natural or built environment, if that is what is desired. Alternatively, bridges can serve as signature elements of the community by standing out from their surroundings. In either case, the designer must remember that the bridge can last many decades. The designer has the power to make the bridge a long-standing source of pride or of dissatisfaction. The role of the bridge in the built environment should be determined during the project development process with input from a broad range of interested individuals and groups.

10.3.1 Understanding the Context

The designer must understand the context of the site which the bridge will be built. If it is in a natural area, the designer should map the topography and natural features of the site. Usually a bridge in a natural setting will be designed to fit into its setting rather than have the setting altered to fit a bridge structure. In urban areas, the designer needs to understand the community patterns in the vicinity of the bridge and the bridge characteristics suitable for the community setting. Specific issues with both natural and developed settings are described below.

10.3.1.1 Environmental Resources

Bridges often cross sensitive environmental resources such as wetlands, streams, and rivers. Although replacement of bridges (such as through the footprint bridge program) are exempt from the some permitting requirements, construction activities in these areas is usually regulated at the local, state, and federal level, as described in Chapter 2, and the permitting requirements for these projects can be extensive. MassHighway has established a footprint bridge program to of replace bridges roughly within their existing location to help expedite replacement of existing deficient structures.

Bridges can – and should – be designed to fit into the context in which they are placed.

The design of bridge projects needs to be based on an understanding of these resource areas and the potential short and long term impacts that the bridge may have on their hydrologic and ecological value. Design decisions such as crossing location, span length, substructure layout, and width can be adjusted to minimize impacts to these resources, regardless of the applicable regulatory requirements. Project design should also consider methods to provide erosion control and streambank restoration.

Although bridges may impact these resources, they may also be included in a project design to reduce the impacts that causeways or other filling of the resource area could have. As described in Chapter 14, the inclusion of bridges and culverts in roadway projects can maintain habitat connectivity for many different types of environments, and reduce habitat loss especially for crossings of open watercourses.

10.3.1.2 Community Resources

In a developed or urban setting, the bridge is typically part of a grade separation. This change in elevation can result in either embankments or walls that create visual and functional barriers between different parts of the community. In some cases, the barrier effect of a grade separation can intensify the barrier effect of the roadway itself. On the other hand, longer grade separations, such as an elevated or depressed high-speed, high-volume roadway through a developed area can improve community connectivity if the crossings of the facility are well-designed and at appropriate locations.

Pedestrian and bicycle facility grade separations can have similar effects as the grade separation of two roadways. For these facilities to be successful, they must be well-integrated into the surrounding pedestrian and bicycle network to prevent extra travel due to long ramp systems needed to achieve the grade separation. Additionally, these facilities are usually used to cross freeways, or other high-speed, high-volume roadways where pedestrians and bicycles are prohibited by regulation. In other situations, properly designed surface crossings of roadways generally provide the desired connectivity for pedestrians and bicycles.

Grade separations of roadways or pathways and railroads is generally desirable. In many cases, railroads are developed along consistent grades and are often on embankments or below the surrounding grade. In these situations, grade separation is especially desirable to improve the safety and operating characteristics of both the roadway/pathway and the railroad. In locations where substantial modifications to the existing grades are required, the design considerations mentioned above are applicable. Similarly, paths built along railroad rights-of-way can often maintain grade separations at roadway crossings without adversely impacting the surrounding area.

The considerations for grade separation of transportation facilities are also discussed in Chapters 6, 7, and 11.

Bridge crossings of streams and watercourses can improve community connectivity and are less frequently associated with negative community impacts. However, in most cases, the aesthetics of the bridge crossings are very important due to their high visibility in the built environment, as discussed below.

10.3.2 Aesthetics

The visual quality of bridges can vary widely based on the type of structure, bridge profile and location, and the construction materials and details used. The aesthetics of a bridge start with the design of the structure itself. Those bridges that are considered to be the best examples of aesthetically-pleasing bridges are the ones whose primary structural systems represent the basic structural mechanics of how the structure carries the applied loads to the foundations. Therefore, a well-designed and aesthetically-pleasing bridge is not one that is based on an abstract physical form, but, rather, one that expresses the natural, physical properties to which people intuitively relate.

The expression of structure alone is not sufficient to make a bridge aesthetically successful. In order for a bridge to be truly successful, it must be attractive on the following three levels at which the public experiences a bridge:

- The overall bridge and how it relates to its setting;
- The human-level experience of a pedestrian, or bicyclist, or boater traveling over, under or beside the bridge; and
- The driver-level experience of someone driving over or under the bridge.

Each of these requires a level of detail to which a person can relate and with which a person can be visually engaged. Failure to adequately address the aesthetic expectations at any one of these levels will result in a bridge that people will find fault with, no matter how aesthetically successful the bridge may be on the other levels.

Aesthetics on all levels are achieved by attention to detail and consideration of how each element of the bridge relates to the others. The design of the bridge must present a coherent overall vision of what each component part does and all architectural surfaces should be consistent with this vision. A bridge's aesthetics are vastly improved when all of the component parts (piers, abutments, railings, and the superstructure) are designed to work together and complement each other visually.

Therefore, the decisions that the designer makes regarding the structure type and substructure configuration will determine the aesthetics of the bridge more effectively than the application of superficial decoration after the basic bridge has been designed. MassHighway's standard details contained in the *Bridge Manual* have been developed with this philosophy in mind.

10.3.3 Historically Significant Bridges

Older bridges have potential historical significance, which adds to their value as community assets, but also complicates the process of rehabilitation or reconstruction of structurally deficient or functionally obsolete bridges.

State and federal statutes recognize the importance of preserving significant elements of our cultural and engineering heritage. Historically significant bridges are listed or eligible to be listed in the National Register of Historic Places. A bridge that is of a rare type, is unusual from an engineering perspective, or has historic significance because of location or association with an important event or person is a candidate for classification as a historically significant bridge (historic bridge). A bridge that is 50 years of age or older may also be a candidate for the list.

As described in Chapter 2, historically significant bridges are addressed under the provisions of Section 4(f) of the Transportation Act of 1966 and may be demolished or moved only if it can be demonstrated that "there is no feasible and prudent alternative" to this taking of the historic property. Options that do not require the demolition of the bridge must be thoroughly considered including the no build option, as well as construction of a new structure at a new location or parallel to the existing facility. These alternatives need to be examined, evaluated, and thoroughly documented before any decision is made to demolish the bridge or to designate it for removal and transport to another location for non-vehicular reuse. Alternatives that keep the bridge in some level of vehicular service must also be examined; that is, rehabilitating the bridge in a way that does not destroy its historic integrity or retaining the historic bridge as part of a one-way pair or as an alternate scenic crossing.

The Federal Highway Administration (FHWA) makes the final determination about whether the conditions of Section 4(f) have been met, and whether it has been demonstrated that there is no feasible and prudent alternative to the action that will remove and dispose of the historic bridge. Additional cost and additional displacements do not necessarily render an alternative imprudent or infeasible.

Historic bridges that do not meet the criteria for vehicular use may be preserved for other uses. Preservation options include use for non-vehicular transportation purposes at the existing or relocation site, or use as a historical exhibit or monument at the existing or relocation site. Preservation for bicycle/pedestrian use or as a historic monument at the existing site may be a viable option if the replacement structure's horizontal alignment can be adjusted to bypass the historic bridge.

10.4 Preliminary Design Guidelines

Chapter 2 of the *MassHighway Bridge Manual* provides detailed guidelines and checklists for preliminary bridge engineering. The purpose of the guidelines is to ensure that sufficient information about the project parameters (obtained through site investigations, material testing, limited structural analysis, review of utility systems in the area, and hydraulic and geotechnical studies) is available to make an informed decision regarding the scope of a bridge project and the type of structure to be pursued. Chapter 2 of the *Bridge Manual* describes types of bridge projects (either new/replacement or rehabilitation), contextual and aesthetic considerations, guidelines for bridge type selection for new and replacement bridges, and guidelines for bridge rehabilitation projects.

10.5 Major Design Elements

A bridge consists of a superstructure and a substructure. The ***superstructure*** includes the bridge deck and beams. The ***substructure*** includes the cap and foundations of the abutments and the cap, columns, and foundations for bridge piers or support columns.

10.5.1 Superstructure

The superstructure is critical in the performance and cost effectiveness of a bridge. Many types of superstructures are commonly used. Choosing an appropriate superstructure depends on factors such as:

- Span length
- Vertical clearance
- Hydraulics (freeboard)
- Speed of construction
- Economics
- Aesthetics
- Accommodation of utilities

Span length requirements and vertical clearance are generally the controlling criteria when choosing the superstructure. Span lengths are determined based on bridge location, geography, and structural limitations. Vertical clearance is based on bridge location and federal and state requirements. Design criteria concerning span lengths, clearances, and other design features are discussed in the *MassHighway Bridge Manual*.

10.5.2 Substructure

The structural elements used in the superstructure often influence the design of the substructure. The substructure generally consists of either single or multiple reinforced concrete columns. Available construction space, right-of-way limitations, bridge width, clearance, stage construction, and aesthetics are often factors in this decision. The column configuration and subsurface conditions determine an appropriate foundation type. Choice of foundation type should remain as flexible as possible in preliminary design to allow an economic design in the detailed plan preparation stage.

10.5.3 Horizontal and Vertical Alignment

Bridge structures should be on a tangent alignment if such can be accomplished without sacrificing the overall geometric design of the highway. Tangent alignment affords easier plan preparation and easier bridge construction thereby resulting in lower structure cost. In areas where it is not feasible to build structures on a tangent alignment, curved structures are possible. Where curved structures are built, their geometry should fit the curve geometry for the roadway sections. Tightly curved alignments can significantly restrict the type of superstructure. Basic design criteria for horizontal alignment can be found in Chapter 4 of the Guidebook.

The vertical curvature of structures should generally conform to curvatures on sections of roadway for the same conditions of traffic and terrain described in Chapter 4 of this Guidebook. For bridge decks that would otherwise be flat, a small crest vertical curve is recommended throughout the bridge length to prevent an illusion of sag and to improve deck drainage. Basic design criteria for vertical alignment can be found in Chapter 4 of the Guidebook.

10.5.4 Cross-Section

The type of structure best suited to grade separations is one that blends smoothly into the surrounding environment and provides a seamless connection for all users of the transportation facility. For example, where motorists take practically no notice of a structure which they are crossing, driver behavior is the same or nearly the same as at other points on the highway, and sudden, erratic changes in speed and direction are unlikely. However, a different cross section on the structure from that on the approaching roadways may be appropriate where future changes in the roadway cross section are desirable. As noted earlier in Section 10.2.2, the structure should provide desirable bicycle and pedestrian accommodation irrespective of existing bicycle and pedestrian accommodation along the remainder of the corridor.

For any structure, a constant clear roadway width and a uniform protective railing or parapet should be provided. The multimodal accommodation and cross-section features found along the adjacent roadway segments should be included on the bridge cross-section. It is not usually necessary for the bridge deck to be substantially wider than the approaching roadway but the design of the bridge structure should include consideration of possible future widening such as by providing a wider abutment. Generally, the width of the travel way and shoulder lanes should be consistent with the existing or planned future cross section of the adjacent roadway. In terms of additional width, a 2-foot setback from the shoulder or bike lane to bridge rails or parapet walls is required. Additionally or alternatively, approximately 1 to 2 feet of additional sidewalk width is desirable to account for shy distance from the railing or parapet wall when sidewalks are provided.

For reconstruction and rehabilitation projects (such as footprint bridges), the designer should provide multimodal accommodation as close as possible to that found along adjacent roadway segments. During reconstruction or rehabilitation it is often possible to modify the structure to provide, or to allow for the easy addition of, pedestrian and bicycle accommodation on the bridge. Additionally, if multimodal accommodation is available along a corridor, except for a bridge, the designer should evaluate whether retrofitting the existing bridge to provide accommodation is possible in lieu of replacing the structure.

10.5.5 Curbs and Railings

Curbs, suitable barrier rails or combination railings are often provided between the roadway and sidewalk. The use of barrier rail to separate vehicle from pedestrian traffic is governed by the following criteria:

- Barrier rail between the roadway and sidewalk is recommended when the design speed equals or exceeds 50 mph.
- If the design speed equals or exceeds 40 mph but less than 50 mph, appropriate barrier rail may be considered where bridge-specific conditions will allow it without interference to pedestrian movements, traffic flow, or other features.
- Curbs are normally used on bridges in conjunction with sidewalks. If curbs are used, curb height should meet or exceed that of the approach roadway.
- Independent of the presence of a sidewalk, bridge railings or barriers is required on all bridges to prevent pedestrians, bicyclists and motor vehicles from falling off the bridge deck. Where appropriate, open railings should be used to provide views of water bodies or the surrounding landscape.

10.6 Inventory and Management of Bridges

MassHighway administers the state and federal reconstruction/ replacement program for bridges over 20 feet in length. MassHighway conducts necessary bridge inspections that place bridges into the following three categories:

- Meeting standards,
- Functionally obsolete, and
- Structurally deficient.

Structurally deficient structures have a defect in the structure that requires corrective action. There are different categories of deficiencies and urgency of repair. Functionally obsolete facilities have no structural deficiencies but do not meet standards to adequately serve current user demands.

MassHighway uses PONTIS, a system used by most state transportation departments, to record, organize and analyze bridge inventories and inspections. Based on this listing, MassHighway, with input from local cities and towns, and consideration of factors such as average daily traffic (ADT), selects bridges for reconstruction or replacement. The objective of MassHighway is preservation - to fix it now rather than later. MassHighway also inspects locally-owned bridges on a regular basis and provides a report to the city or town.

10.7 For Further Information

- *Bridge Design Manual*, Massachusetts Highway Department, 2005
- *Massachusetts River and Stream Crossing Standards*, University of Massachusetts – Amherst, 2004.

Chapter 11

Shared Use Paths and Greenways

Shared Use Paths and Greenways

11.1 Introduction

This chapter describes the design considerations for shared use ***paths and greenways.*** Paths and greenways are found in a variety of settings throughout the Commonwealth including: trails in agricultural or wilderness areas; paths along active or abandoned railroad corridors; paths following highway corridors; paths and promenades along waterfront areas; paths following utility corridors; and paths and trails through neighborhood open-space networks and parkland.

Shared use paths are facilities for non-motorized users that are independently aligned and not necessarily associated with parallel roadways. Shared use paths are designed to accommodate a variety of users, including walkers, bicyclists, joggers, people with disabilities, skaters, pets and sometimes equestrians. These users can be on the facility for a variety of purposes including recreation, commuting, and local travel. A shared use path can accommodate various users in one or more treadways. A ***treadway*** is defined as a portion of the pathway designated for a particular user or set of users.

In contrast to shared use paths, the discussion of ***greenways*** in this chapter focuses on recreational facilities through backcountry or other remote areas. These facilities are generally unpaved trails and can serve hikers, mountain bikers, equestrians, or other off-road users. This chapter does not discuss other types of trails such as all-terrain vehicle trails, dirt bike trails, or snowmobile trails. The common distinctions between shared use paths and greenways is illustrated in Exhibit 11-1.

Exhibit 11-1
Distinction between Shared Use Path and Greenway

Similarly, this chapter does not discuss the design of sidewalks and on-road bicycle facilities. These design features are integrated into the roadway cross-section and are described in Chapter 5. This chapter provides general guidance on the design of shared use paths and greenways. The designer should refer to AASHTO's 2004 *Guide for the Planning, Design, and Operation of Pedestrian Facilities* and 1999 *Guide for the Development of Bicycle Facilities* for more detailed design guidance for these facilities. The *Manual on Uniform Traffic Control Devices (MUTCD)* 2000 edition also provides information on signing and pavement markings for bicycle facilities.

11.1.1 Design Considerations

In the design of any type of path or trail, care should be taken to design elements that are compatible within the context of the project. Path materials, barrier-types, landscaping, signage, walls and fencing should be properly selected to complement the character of the area in which the path is built.

11.2 Path Networks and Greenway Systems

The diversity of paths and trails provides transportation and recreation designers with a wide variety of facility types to satisfy the needs and wants of users. However, shared use paths and trails are not a substitute for adequate on-street facilities. Shared use paths and trails are a complementary, non-motorized extension to the street network and should not preclude shared use of streets either by regulation or design. Where pedestrian or bicycle use is prohibited or difficult to accommodate on a roadway, alternative access for pedestrians and bicyclists via convenient paths to all linkages and destinations served by the roadway is a possible solution. A well-planned and designed network of shared use paths and trails can achieve the following objectives:

- Provide shortcuts between generators of pedestrian and bicycle activity;
- Provide pedestrian and bicycle access to areas served only by highways on which pedestrian and bicycle travel is prohibited;
- Provide pedestrian and bicycle access to areas not well-served by roads;
- Provide a training ground or alternative experience for bicyclists who are not comfortable with on-road cycling; and,
- Provide an integrated recreation facility that is in itself a destination for users and a valued community resource.

11.2.1 Path Networks

Shared use paths can be of any length from short connections between streets to long corridors following features like rivers or railroad corridors. A path network should be integrated with other pedestrian and bicycle facilities and connected to popular destinations including parks, schools, colleges, employment centers, and commercial centers. Connections with the street system should be carefully designed and signed to indicate street names and path destinations. Path networks should also be accessible from parking lots and transit services for those who are using one of these other modes as a component of their trip on the path. Where possible, paths should be integrated with nearby transit stations. A path network should be designed to:

- Achieve a context-sensitive facility that fits the environment through which it passes and achieves a high level of aesthetics;
- Include uniform design elements to present a consistent, safe facility for the user;
- Provide separation from motor vehicle traffic;
- Provide convenient access points and connections matching the origins and destinations of path users;
- Provide a high level of safety and security;

- Highlight the natural, scenic, historic, and cultural qualities of the area through which it passes;
- Minimize the number of street and driveway crossings to the extent possible; and,
- Provide safe crossings of streets and driveways where they are needed.

11.2.2 Greenway Systems

Greenway systems are usually less developed than shared use paths. In most cases, a greenway or trail system is associated with a particular resource area, such as a park or forest. Nonetheless, opportunities for connection to the pedestrian and bicycle facilities on surrounding roads and access to parking lots or transit stops are important considerations in the development of a greenway or recreational trail system.

11.3 Accessibility of Shared Use Paths and Greenways

Shared use paths and trails provide important transportation options and outdoor recreational opportunities. Shared use paths should be designed to meet the needs of the widest possible range of users, including people with disabilities. In this light, most pathways that serve as transportation facilities for pedestrians and bicyclists must meet accessibility requirements. The accessibility of a shared use path depends not only on the design of the path itself, but also on the design of associated facilities, including:

- Parking areas,
- Path entrances,
- Path destinations, and
- Resting and other wayside facilities.

All designs must comply with 521 CMR, *The Rules and Regulations of the Massachusetts Architectural Access Board,* which has jurisdiction over:

- Walkways: *An interior or exterior pathway with a prepared surface intended for pedestrian use, including but not limited to general pedestrian areas such as plazas, courts and crosswalks. Walkways include but are not limited to all walks, sidewalks, overpasses, bridges, tunnels, underpasses, plazas, courts and other pedestrian pathways,* ...(521 CMR 22.1).

The requirements of 521 CMR include specification for width, grade, level changes, surface, drainage, gradings, and intersections.

A significant issue that designers face is that walkways outside a public right of way must conform with the slope limitation requirements for walkways (maximum 5%) and ramps (maximum 8.33%, with level landings every 30 feet and continuous handrails). In addition, the pathway material must be 'firm, stable, and slip resistant." These requirements may be difficult to meet in some settings. FHWA's *Designing Sidewalks and Trails for Access, Part II: Best Practice Design Guide* provides design details and alternative treatments for making paths accessible to all users. Where 521 CMR cannot be met, designers should recommend a variance request in consultation with MassHighway as well as the local disability commission(s) and the regional independent living center. The Massachusetts Architectural Access Board is authorized by law to grant variances when full compliance is "*impracticable," i.e. is…technologically unfeasible, or… would result in excessive and unreasonable costs without any substantial benefit to persons with disabilities.* (521 CMR 5.44).

11.4 Shared Use Path Design

A shared use path is physically separated from motorized vehicle traffic by open space or a barrier. Shared use paths are typically developed on a continuous right-of-way and experience minimal cross flow by motor vehicles. Users of these facilities may include bicyclists, inline skaters, roller skaters, wheelchair users (both non-motorized and motorized), and pedestrians, among others. It is important to identify the intended users of a path early in the design process to the extent possible, to provide appropriate accommodation and address potential conflicts.

A mix of users on a shared use path is not always a desirable situation because the potential for conflicts is high. For example, commuting bicyclists are slowed by users on recreational strolls. The safety and enjoyment of a path can decline when conflicts among users occur. For these reasons, the designer should avoid creating situations in which sidewalks are used as shared use paths. Conflicts between users stem from many sources including:

- Personal expectations;
- Overcrowding;

- Clashes between different users;
- Various levels of ability and experience; and
- Differences in speed.

The most effective way to address these potential conflicts is to accommodate different types of users through design, coupled with user courtesy and education. When paths are intended to be shared by a number of different users, their design should ensure that adequate visibility and sight-distance are provided. Design treatments to improve paths so that they are safer for everyone include:

- Horizontal and vertical alignment to ensure clear lines of sight for pedestrians and bicyclists, especially around horizontal curves;
- Shoulders at least 2-feet wide to provide stopping and resting areas off the path, allow for snow storage, help to prevent root damage, and to allow passing and widening at curves;
- Avoidance of view obstructions such as signs, poles, benches, landscaping, etc., at the edge of the trail;
- Use of a bicycle design speed suitable to the path setting and providing guidance for appropriate speeds; and
- Signing and marking, such as a centerline stripe or keep right signs, as described in the *Manual on Uniform Traffic Control Devices*.

Major design elements of a shared use path are discussed in the following sections.

11.4.1 Path Width, Side Clearance and Vertical Clearance

MassHighway and FHWA require that bike paths designed or constructed with state or federal funds follow the design standards of AASHTO. There are, however, situations where flexibility in design may be needed such as where there are environmental and/or geographic constraints. But the guidelines set forth in AASHTO and summarized below should be used as a starting point for the design, with the individual conditions of the project examined to determine any potential need for deviations from these standards. Public input should also be considered as the design is developed.

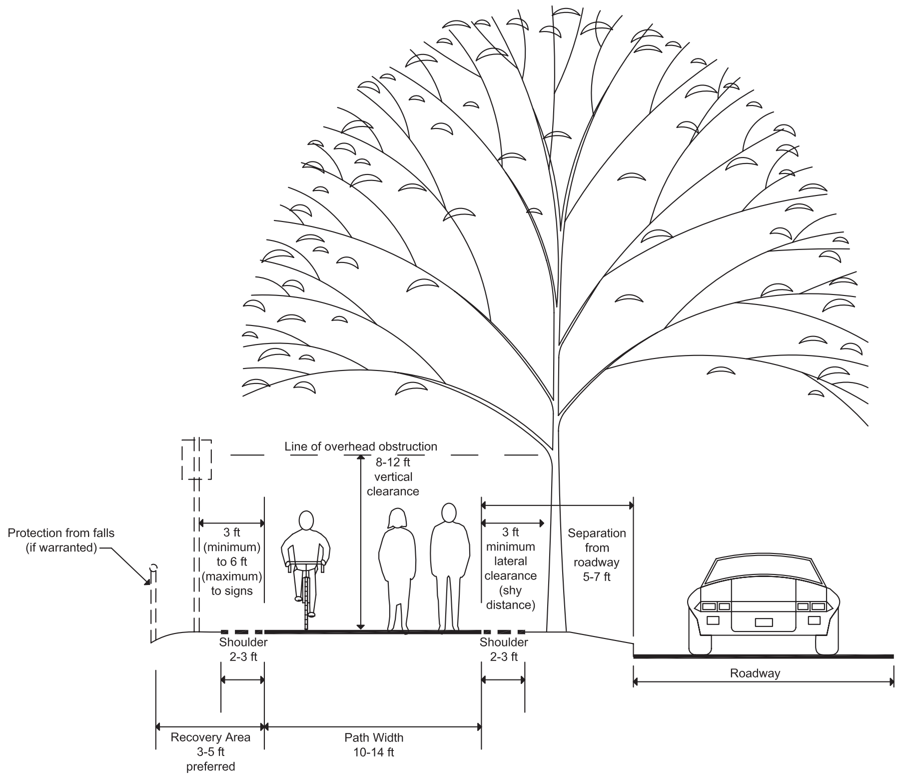
11.4.1.1 Path Width

Shared use paths are most commonly designed for two-way travel. In most cases, the users are accommodated in a single treadway, although multiple treadways with separation are possible as described below. As illustrated in Exhibit 11-2, under most conditions, the minimum width for a two-directional shared use path is 10 feet. Under most conditions it is desirable to increase the width of a shared use path to 12 feet, or even 14 feet to accommodate substantial use by bicycles, joggers, skaters, and pedestrians, and to provide access for maintenance vehicles. In certain instances, a reduced width of 8 feet may be acceptable where there are severe environmental, historical, and/or structural constraints.

11.4.1.2 Shoulders and Side Clearance

A minimum 2-foot wide graded shoulder should be maintained adjacent to both sides of the path. The graded area can be either paved or unpaved. Non paved surfaces could be constructed using grass, stone dust, or other stabilized materials. A minimum 3-foot clearance should be maintained from the edge of the path to signs, trees, poles, walls, fences, guardrails, or other obstructions. Where the path is adjacent to canals, ditches, or slopes steeper than 1 vertical :3 horizontal (1:3), a wider separation should be considered. A 5-foot separation from the edge of the path to the top of slope is desirable under these circumstances. Where a slope of 1:2 or greater exists within 5 feet of a path and the fill is greater than 10 feet, a physical barrier such as dense shrubbery, railing, or chain link fence should be provided along the top of slope. Other situations may also dictate the need for a physical barrier, such as the height of the embankment or an unsafe condition at the bottom of slope.

Exhibit 11-2
Shared Use Path Dimensions



Source: Adapted from the VTrans Pedestrian and Bicycle Facility Planning and Design Manual

Separation Between Shared Use Paths and Roadways

Shared use paths are not a substitute for street improvements, even if there is sufficient space to locate the path adjacent to the roadway. Some operational problems with paths adjacent to roads are:

- Bicyclists will be riding against the normal flow of traffic, contrary to the rules of the road. When a path ends, bicyclists riding against traffic may continue riding on the wrong side of the street.
- At intersections, motorists entering or crossing the roadway often do not notice bicyclists approaching from the right, as they are not expecting any traffic from that direction.
- Barriers used to separate motor vehicle traffic from path users can obstruct sight lines along both facilities and can reduce access to and across the path.
- Snow plowed from the adjacent roadway can obstruct the path.

When two-way shared use paths are located adjacent to a roadway, wide separation between a shared use path and the adjacent highway is desirable. This demonstrates to both the bicyclist and the motorist that the path functions as an independent facility for bicyclists and others. This separation area also acts as a “recovery zone” for path users. A 7-foot separation between the edge of the shoulder and the shared use path is recommended with the minimum being 5 feet. When this is not possible, a suitable physical barrier (considered to be one that does not obstruct sight lines, as identified in Section 11.4.3) is recommended. Such barriers serve both to prevent path users from making unwanted movements between the path and the highway shoulder and to reinforce the concept that the path is an independent facility.

Future signs, mailboxes, and other side obstructions should be considered when designing separation between the shared use path and roadway. Care should also be taken in providing adequate clearance along and between the path and adjacent parcels for future expansion and necessary buffers to adjacent land uses.

11.4.1.3 Vertical Clearance

The vertical clearance to obstructions should be a minimum of 8 feet, which meets the requirements of 521 CMR and ADAAG. In some instances, vertical clearance may need to be greater to permit passage of maintenance and emergency vehicles. In underpasses and tunnels, 10 feet is desirable for adequate vertical shy distance (the vertical clearance at which a bicyclist would feel comfortably separated from an obstruction) and passage by maintenance vehicles. Where equestrian users are expected, clearance of at least 12-feet should be provided. See Section 11.4.10.2 for a discussion of vertical clearances for underpasses.

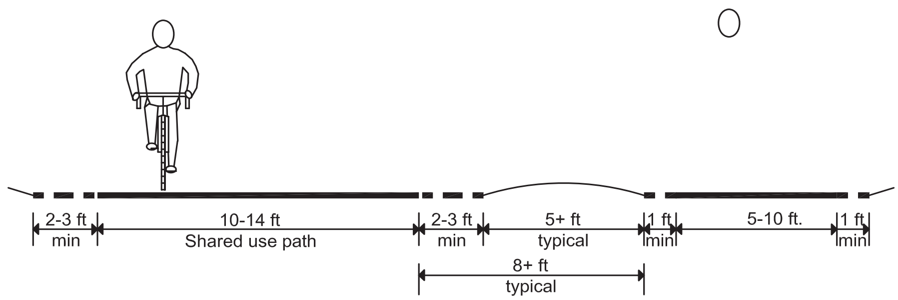
11.4.2 One-Way Paths/Multiple Treadways

If a one-way shared use path is necessary to make a key connection, the minimum width should be 6 feet. A one-way path would rarely be designed and only in a special situation, such as to circumvent mature trees or connect to parallel paths. It should be recognized that one-way paths often will be used as two-way facilities unless effective measures are taken to assure one-way operation. Without such enforcement, it should be assumed that shared use paths would be used as two-way facilities by both pedestrians and bicyclists and designed accordingly.

In some cases it may be desirable to provide multiple treadways as part of a shared use path to separate user types to reduce potential conflicts,

as illustrated in Exhibit 11-3. Multiple treadways can be a successful design approach for heavily used corridors. In most applications of multiple treadways, a sidewalk or path suitable for pedestrians is provided separately from a path for bicyclists. Generally, the minimum width for the sidewalk is 5 feet and the minimum width for the bikeway is 10 feet.
Wider treadways are possible, and sometimes desirable, for both uses.

Exhibit 11-3
Cross-Section of Shared Use Path with Multiple Treadways



Source: Adapted from the VTrans Pedestrian and Bicycle Facility Planning and Design Manual

The designer should take measures to ensure, however, that the purpose of each is clear to the users. This approach is also suitable where equestrian users are expected.

11.4.3 Barrier Height and Placement

The placement of physical barriers adjacent to a shared use path serves many purposes including safety and security, protection from falls, screening for adjacent land uses and separation of paths from other transportation facilities. The design of barriers is dependent upon their intended function, safety, proximity to the path, and aesthetics. The designer should determine the need to provide protection along a shared use path on a case-by-case basis after evaluating the following factors:

- If adequate recovery area is provided, then the need for a barrier is lessened.
- The greater the height of the drop-off, the greater the need for protection. A protective barrier may be required when a vertical

drop from the path surface to the base of the slope is greater than 4 feet.

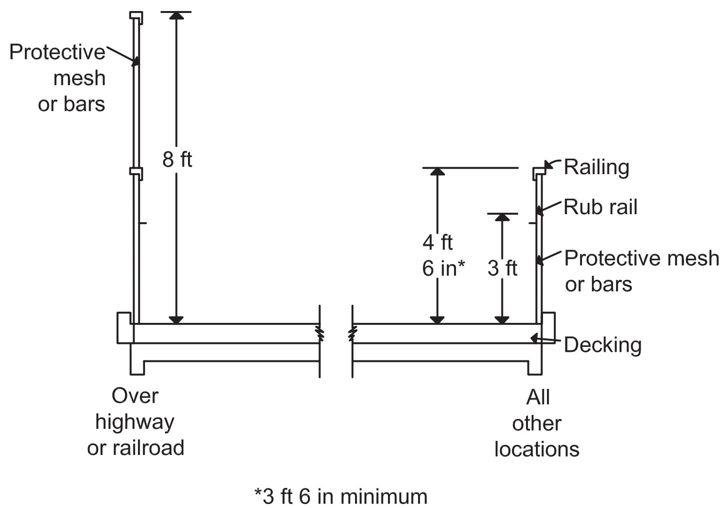
- 521 CMR requires *ramps and landings with drop-offs shall have edge curbs, walls, railings, or projecting surfaces that prevent people from slipping off the ramp. Edge curbs shall be a minimum of two inches high.*
- Where the side slopes are greater than 1:3, the need for a barrier is increased, unless the slope material is forgiving, or a recovery area is provided.
- If the material used on the side slope is grass, shrubbery, or another non-abrasive material, then the need for a barrier is lessened. If the material is likely to result in increased injury severity then the need for a barrier is increased.

Where used, the *AASHTO Guide for the Development of Bicycle Facilities* recommends that the barrier should be a minimum of 3.5 feet high to prevent bicyclists from toppling over it. A barrier between a shared use path and adjacent highway should not impair sight distance at intersections and should be designed to not be a hazard to motorists or bicyclists. A variety of barrier types are possible including:

- Fences – a variety of types.
- Walls – retaining walls.
- Vegetation – cushioning vegetation (such as shrubs, pine trees, etc.) capable of stopping a fall, spaced at most 6 feet on-center within 10 feet of the grade drop. This barrier type will require maintenance to ensure that the vegetation does not eventually encroach on the path.
- Guardrail/Concrete Barrier – placement of a rail on the top may be necessary to reach the required height. These barriers should meet the requirements of NCHRP Report 350 if separating a path from a roadway.

Rub-rails to prevent snagging of handlebars are recommended at a height of approximately 3-feet from grade, as illustrated in Exhibit 11-4. Other types of fencing with rub rails might be more architecturally appropriate, including split or round rail fencing. Additionally, the barrier systems should be smooth and free of protruding objects such as bolts. One method for reducing these hazards is to countersink washers and nuts into support posts, or mount a wood rail along the back side of the barrier. It is also important to flare the ends of the barrier where possible so the blunt ends do not pose a hazard. Another common mistake is to end the barrier too abruptly once past the hazard area. Consideration should be given to the possibility of a cyclist going off the path and behind the barrier toward the hazard.

Exhibit 11-4
Barrier Elements



Source: Adapted from VTrans Pedestrian and Bicycle Facility Planning and Design Manual

11.4.4 Design Speed

Shared use paths should be designed for a selected speed that is at least as high as the preferred speed of the faster bicyclists. In general, a minimum 20 mph design speed should be used. When a downgrade exceeds 4 percent or where strong prevailing tailwinds exist, a design speed of 30 mph or more is advisable. Lower design speeds, in the range of 10 to 15 mph, are appropriate for shared use paths through parks or other settings where the interactions between bicyclists and other users are frequent and unpredictable.

11.4.5 Cross-Slopes and Superelevation

Shared use pathways must meet the requirements of 521 CMR, *The Rules and Regulations of the Massachusetts Architectural Access Board* and the *Americans with Disabilities Act Guidelines* (ADAAG). Both of these standards require that cross slopes on pedestrian pathways and sidewalks not exceed 2 percent to avoid the dangers that greater cross slopes can create for people using wheelchairs, walkers, canes, etc. Thus, for most shared use paths, the maximum superelevation rate will be 2% in the built condition (1.5% in design). When transitioning a 2% superelevation, a minimum 25-foot transition distance should be provided between the end and beginning of consecutive and reversing horizontal curves.

11.4.6 Horizontal Curvature

The curvature of a path is dependent upon the design speed, lean angle and cross-slope of the path. Exhibit 11-5 summarizes the resulting curve radii for a range of design speeds using a 15-degree lean angle.

Exhibit 11-5
Minimum Curve Radii

Design Speed (mph)	Minimum Radius (feet)
12	36
15	56
20	100
25	156
30	225

Source: Guide for the Development of Bicycle Facilities, AASHTO, 1999.

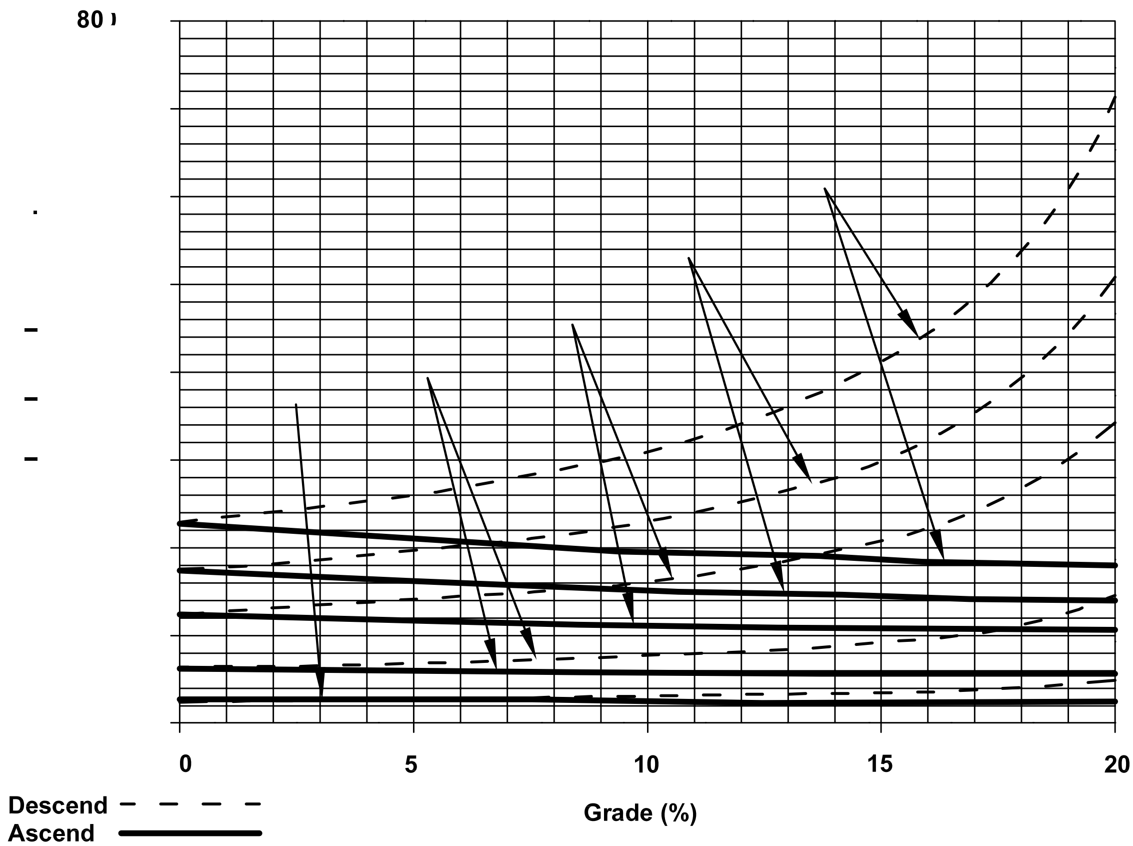
It should be noted that 521 CMR does not allow curved ramps.

11.4.7 Sight Distance

To provide bicyclists with an opportunity to see and react to the unexpected, a shared use path should be designed with adequate stopping sight distances. Minimum stopping sight distance for various design speeds, vertical and horizontal curves, and grades need to be considered to ensure safe breaking distance on a shared use path. The 1999 *AASHTO Guide for the Development of Bicycle Facilities* provides methodologies, tables and graphs of stopping sight distance for various combinations of grade and design speed. Similar tables are provided for calculating the minimum length of crest curves to provide adequate stopping sight distance. This information is presented in Exhibit 11-6.

Bicyclists frequently ride side-by-side on shared use paths, and on narrow paths bicyclists have a tendency to ride near the middle of the path. For these reasons, and because of the higher potential for head-on bicycle crashes, lateral clearances on horizontal curves should be calculated based on the sum of the stopping sight distances for bicyclists traveling in opposite directions around the curve.

Exhibit 11-6
Minimum Stopping Sight Distance



Source: Guide for the Development of Bicycle Facilities, AASHTO, 1999.

Exhibit 11-6
Minimum Stopping Sight Distance (Continued)

A	English Units. Minimum Length of Crest Vertical Curve (L) Based on Stopping Sight Distance S = Stopping Sight Distance (ft)														
(%)	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300
2												30	70	110	150
3								20	60	110	140	180	220	260	300
4						15	55	95	135	175	215	256	300	348	400
5					20	60	100	140	180	222	269	320	376	436	500
6				10	50	90	130	171	216	267	323	384	451	523	600
7				31	71	111	152	199	252	311	376	448	526	610	700
8			8	48	88	128	174	228	288	356	430	512	601	697	800
9			20	60	100	144	196	256	324	400	484	576	676	784	900
10			30	70	111	160	218	284	360	444	538	640	751	871	1000
11			38	78	122	176	240	313	396	489	592	704	826	958	1100
12		5	45	85	133	192	261	341	432	533	645	768	901	1045	1200
13		11	51	92	144	208	288	370	468	578	699	832	976	1132	1300
14		16	56	100	156	224	305	398	504	622	753	896	1052	1220	1400
15		20	60	107	167	240	327	427	540	667	807	960	1127	1307	1500
16		24	64	114	178	256	348	455	576	711	860	1024	1202	1394	1600
17		27	68	121	189	272	370	484	612	756	914	1088	1277	1481	1700
18		30	72	128	200	288	392	512	648	800	868	1152	1352	1568	1800
19		33	76	135	211	304	414	540	684	844	1022	1216	1427	1655	1900
20		35	80	142	222	320	436	569	720	889	1076	1280	1502	1742	2000
21		37	84	149	233	336	457	597	756	933	1129	1344	1577	1829	2100
22		39	88	156	244	352	479	626	792	978	1183	1408	1652	1916	2200
23		41	92	164	256	368	501	654	828	1022	1237	1472	1728	2004	2300
24	3	43	96	171	267	384	523	683	864	1067	1291	1536	1803	2091	2400
25	4	44	100	177	278	400	544	711	900	1111	1344	1600	1878	2178	2500

when $S > L$, $L = 2S - \frac{900}{A}$

Shaded area represents S = L

when $S < L$, $L = \frac{AS^2}{900}$

L = Minimum Length of Vertical Curve (ft)
A = Algebraic Grade Difference (%)
S = Stopping Sight Distance (ft)

Height of cyclist's eye – 4-1/2 ft
Height of object – 0 ft

Minimum Length of Vertical Curve = 3 ft.

Source: Guide for the Development of Bicycle Facilities, AASHTO, 1999.

Where it is not possible or feasible to provide significant sight distance, consideration should be given to widening the path through the curve, installing a yellow center line stripe, installing a “Curve Ahead” warning sign in accordance with the MUTCD, or some combination of these alternatives. The designer can also consider clearing obstructions along the inside of the curve of the path to increase the available sight distance. AASHTO provides guidance on the appropriate clearance areas.

11.4.8 Grade

Where a bicycle path follows the existing terrain, Exhibit 11-7 offers guidance on the maximum grade lengths. Grades greater than 5 percent are undesirable because the ascents are difficult for many bicyclists and the descents cause some bicyclists to exceed the speeds at which they are competent or comfortable. Steep grades also do not meet pedestrian accessibility requirements.

Exhibit 11-7
Maximum Grade Lengths for Bicycles

Grade (%)	Maximum Length (ft)
5 to 6	800
7	400
8	300
9	200
10	100
11+	50

Source: Guide for the Development of Bicycle Facilities, AASHTO, 1999.

Grades for pathways used by pedestrians cannot exceed 5% unless treated as a ramp, with a maximum slope of 8.33% in the built condition. Even when shared with bicyclists, these pedestrian pathway slopes must be met, or a variance from 521 CMR granted from the Massachusetts Architectural Access Board. Variances should only be recommended with support from MassHighway, the local disability commission(s), and the regional Independent Living Center.

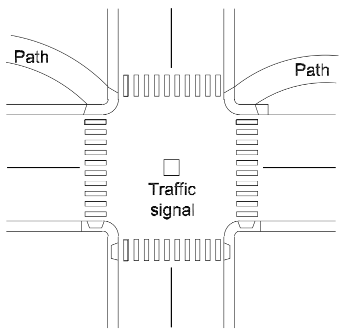
11.4.9 Path-Roadway Intersections

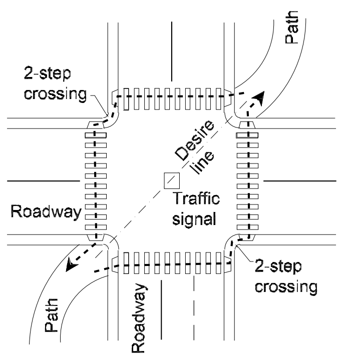
Intersections between paths and roadways are often the most critical issue in shared use path design. Good intersection design provides clear indication to those approaching the intersection what path they should follow and who has the right of way, including pedestrians and bicyclists, whose movements are constricted by their lesser speed and visibility. Typical arrangements of path crossings at intersections are shown in Exhibit 11-8. Some basic principles to be followed when designing intersections are:

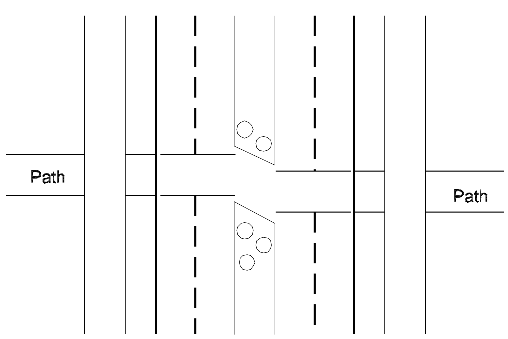
- Unusual conflicts should be avoided;

- Intersection design should create a path for bicyclists that is direct, logical and as close to the path of motor vehicle traffic as possible.
- Bicyclists following the intended trajectory should be visible and their movements should be predictable.
- Potential safety problems associated with the difference between auto and bicycle speeds should be minimized.

Exhibit 11-8
Path Crossings at Intersections







Source: Adapted from VTrans Pedestrian and Bicycle Facility Planning and Design Manual

Shared use paths should cross roadways as close to an intersecting road as practical. This allows for good sight distances for both motor vehicle operators and bicyclists.

Refer to 521 CMR when designing bicycle pathways.

As the path approaches the crossing it should be aligned with the destination of the crossing on the other side of the road. The crossing should also be as perpendicular as possible to the road being crossed. Curb cut ramps that comply with 521 CMR should be appropriately aligned and be the same width as the path (at least 36” plus the side flares). Stopping Sight Distance and Intersection Sight Distance should be evaluated and sound engineering judgment must be used in locating crossings. See Section 11.4.7 and Section 3.7 in Chapter 3 for appropriate guidance on sight distances.

Midblock crossings of paths with curb cut ramps and detectable warnings are also possible where adequate spacing from adjacent intersections is present. In many cases, it is desirable to provide a crossing island in the middle of a roadway when higher speeds or traffic volumes are present. These islands can increase the visibility of the crossing, slow motor vehicle speeds on the cross-street, and to provide a refuge for crossing path users. The islands should include curb cut ramps or cut-throughs with detectable warnings.

11.4.9.1 Traffic Control at Path Crossings

Traffic control at path-roadway crossings should be treated so that the intersection looks and functions like a regular road intersection. Path crossings can occur as signalized or unsignalized intersections, depending on the particular attributes of the location. Warrants for signalization are discussed in the MUTCD and Warrant #4 should be used as guidance for path crossings as bicycles are considered pedestrians under these circumstances. Additional guidance developed for the Florida Department of Transportation suggests that traffic signals be considered where paths cross roadways with volumes greater than 10,000 vehicles per day. The same research suggests that either traffic signalization or grade separation be considered when a path crosses a roadway with greater than 20,000 vehicles per day (see Section 11.4.9.2 below). Motor vehicle speeds along the crossing corridor are also an important factor in this analysis.

Where signals are provided, the path should be provided with adequate “green time” to allow pedestrians and cyclists to cross the street. At locations with push-buttons, the signals should respond quickly to activation so that the likelihood of signal adherence is increased and a higher level of service is provided to the path. The 2002 federal Access Board's *Draft ADA Accessibility Guidelines for Public Rights of Way* require audible signals where pedestrian signals are provided.

At unsignalized locations, adequate sight distance should be provided along the roadway approaches to the path and the path approaches to the roadway. In most cases, advance warning signs indicating that a bicycle path is crossing the roadway should be provided along the road in accordance with the MUTCD. In most cases, STOP signs are provided on the path approaches to the intersection and STOP AHEAD signs along the path may be appropriate if visibility to the crossing along the path is limited. STOP bars and centerlines should be provided on the path approaches to the crossing. The path crossing of the street should be marked as a crosswalk since it carries a mix of non-motorized users. Removable bollards or other appurtenances may be placed on the path just prior to roadway intersections to discourage path use by motorized vehicles and to act as a visual alert to path users that a crossing is imminent.

Due to the potential conflicts at these junctions, careful design is of paramount importance to the safety of path users and motorists. Each intersection is unique and will require sound engineering judgment on the part of the designer as to the appropriate solution. The AASHTO *Guide for the Development of Bicycle Facilities* provides examples and guidelines for various intersection treatments. Path crossings of roadways are also discussed further in Chapter 6.

11.4.9.2 Grade Separation of Path Crossings

There is often a desire to grade separate the crossings of highly-utilized paths and busy roads. In these cases, both underpasses and overpasses are options. The topography of the surrounding area usually will govern which type of grade separation is selected. In level terrain, an underpass usually requires shorter ramp sections since the path clearance under a road ranges between 8 and 12 feet. Road or railroad clearance under a path, on the other hand, can range from 17 to 23 feet. If the path is designed with a maximum five-percent slope, then the transitions for an overpass can be twice as long as those for an underpass (as much as 500 feet in each direction). On the other hand, overpasses are generally open and have fewer security concerns.

While there are no clear “warrants” for grade separation of path crossings of roadways. The designer should consider a number of factors including:

- The suitability of the existing topography for grade separation;
- The effectiveness of signage or traffic signal control as an alternative for the crossing given the context of the location;
- Any changes in alignment that may be necessary to achieve the grade separation;
- The opportunities or limitations placed on path connectivity to the surrounding area by the grade separation;
- The context in which the path is set, in consideration of safety and security issues;
- The volume, mix of vehicles, and speed of cross-traffic on the roadway; and
- The volume and mix of path users.

If the grade separation adds out-of-direction travel to the path alignment or inconvenience, users will likely cross the roadway at grade, potentially eliminating the safety benefit of the grade separation. Furthermore, for shared use paths, pedestrians generally prefer at-grade treatments, so adequate provisions may be necessary for these crossings even if grade separation is provided.

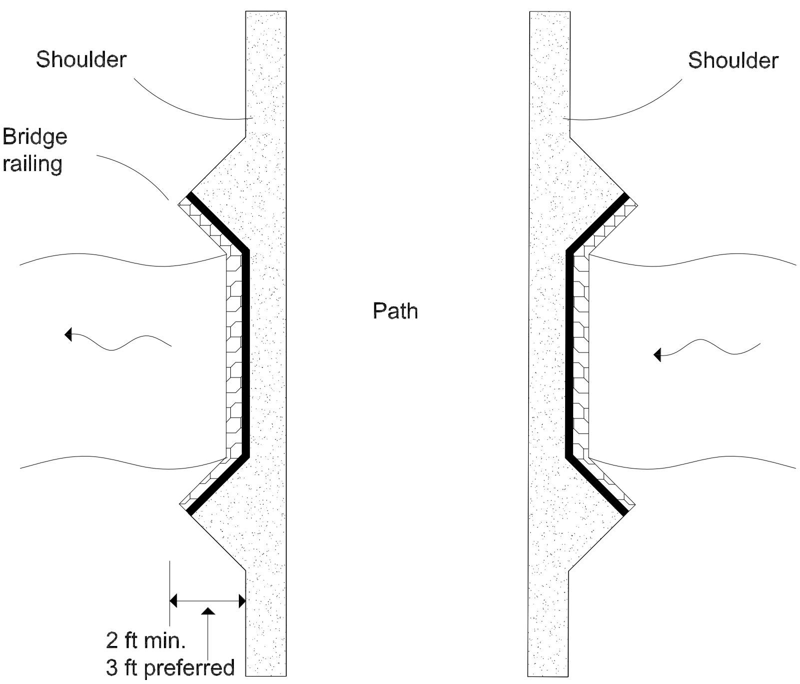
11.4.10 Bridges, Overpasses, and Underpasses

A shared use path may also cross a natural feature, such as a stream or river on a bridge. Design elements of these structures are described below.

11.4.10.1 Bridges and Overpasses

On crossing structures, the minimum clear width should be the same as the shared use path approach plus a minimum 2-foot wide clear shoulder on both sides of the path. The bridge railings should also be flared with an apron to direct path users onto the structure, as illustrated in Exhibit 11-9. Vertical transitions to and from the bridge should follow the grade guidelines discussed earlier in this chapter. The maximum slope and cross slope standards in 521 CMR apply to bridges and overpasses. Therefore any slope greater than 5% must be treated as a ramp, with handrails and level landings; and any slope greater than 8.33% is not allowed without a variance from the Massachusetts Architectural Access Board.

Exhibit 11-9
Bridge Treatments for a Path



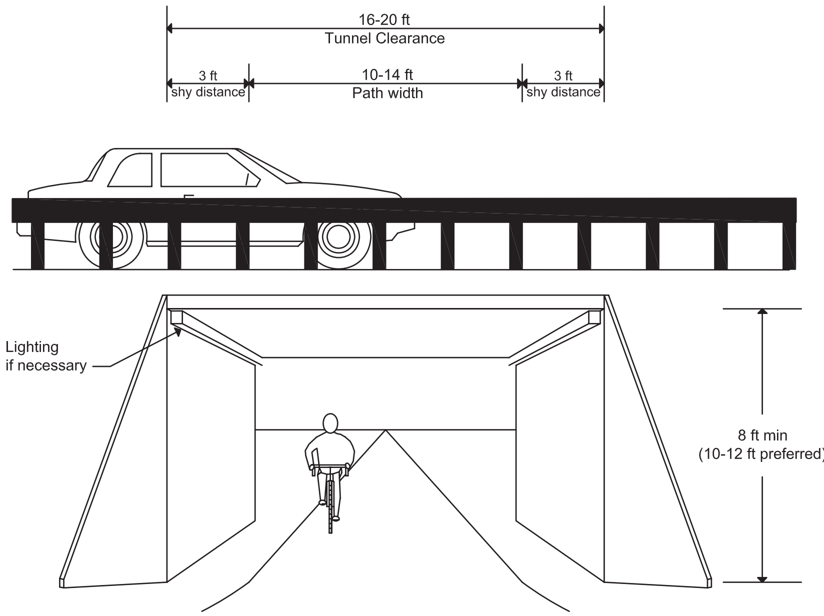
Source: Adapted from VTrans Pedestrian and Bicycle Facility Planning and Design Manual

The *AASHTO Guide for the Development of Bicycle Facilities* recommends that railings, fences, or barriers on both sides of a path on a structure should be a minimum of 42 inches (3.5 feet) high. In situations where the structure crosses a high speed or high volume road or objects are subject to being thrown off the structure, it is recommended that the path be enclosed with fencing. Enclosing a path may also be desirable in other areas such as a waterway crossing. However, to the extent feasible, clear views along the path crossing should be preserved to retain the aesthetics of the path's environment.

11.4.10.2 Underpasses and Vertical Clearance

Much like for bridges and overpasses, 2-foot wide clear shoulder should be provided on both sides of the path. Vertical clearance of at least 8 to 12 feet should be provided, depending upon the anticipated users of the path, as described earlier in this Chapter. A typical arrangement of a path underpass is illustrated in Exhibit 11-10. See also Section 11.4.1.3 for a discussion of vertical clearances for obstructions.

Exhibit 11-10
Path Underpass



Source: Adapted from the VTrans Pedestrian and Bicycle Facility Planning and Design Manual

11.4.11 Signing and Marking

Adequate signing and marking are essential on shared use paths, especially to alert bicyclists to potential conflicts and to convey regulatory messages to both bicyclists and motorists at highway intersections. Both advanced crossing and crossing warning signs are needed on roadways to provide appropriate warning to the motorists of the upcoming path intersection. In addition, guide signing on a path, such as to indicate directions, destinations, distances, route numbers, mile markers (to aid in emergency response), and names of crossing streets, should be used in the same manner as they are used on highways. Where the Massachusetts Architectural Access Board has granted variances for steeper slopes on walkways, it is useful to provide signage indicating the length and difficulty of the trail. This will allow people with disabilities or limited stamina to decide how much time do they need, which route they want to take, and what assistance might be needed to experience the sites of the trail.

Occasional signs with maps of the entire path route and indicating important destinations should be placed at major entry points to the path.

In general, uniform application of traffic control devices, as described in the MUTCD, provides minimum traffic control measures that should be applied. Warning signs, directional signs, and other devices along the path should also meet the MUTCD guidelines. The application of traffic control at path/roadway crossings is described in Section 11.4.9.

11.4.12 Surfacing

When selecting paving and surfacing materials, long-term durability, safety, availability, cost and maintenance are important selection criteria. All paths need to provide a firm, stable, slip-resistant surface in a wide variety of use and weather conditions. In general, surfacing materials for paths in urban areas should be paved or consist of other “hard-surface” materials. Paved pathways function best in areas with high use and those that will be cleared of snow in the winter. “Stone dust” and other unpaved paths may be suitable in areas with lower levels of use, where the mix of users is more suitable for an unpaved path, or where aesthetic or contextual factors suggest that an unpaved treatment is appropriate. Unpaved paths are best located in natural and historic surroundings where they fit well with the character of their environment. Unpaved materials are not suitable for inline skaters or bicyclists who travel at higher speeds.

Where pedestrians are intended pathway users, accessibility of the surface is a key factor. Both 521 CMR and ADAAG require that the surface be:

- Firm, stable, and slip-resistant.
- Without slopes and cross slopes greater than the maximum allowed. The Massachusetts Architectural Access Board measures compliance of slopes in 24 inch increments using a digital level. This can be a difficult standard to meet at first construction and over the life of the pathway.
- Without level changes of greater than ¼”. Rippled asphalt and tree roots protruding through pathway surfaces create dangerous conditions for people with disabilities.

- Without low-hanging branches or other obstacles that protrude into the accessible route between the heights of 27” – 80”. These are dangerous conditions for people with disabilities.

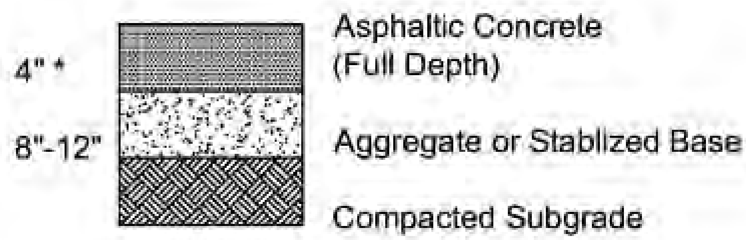
For paved paths, a subbase of compacted aggregate or structurally-suitable soil is important to ensure the long-term durability of the pavement. Exhibit 11-11 illustrates a typical pavement design for a path. In most cases, a 4-inch bituminous concrete riding surface placed over an 8 to 12-inch aggregate base is recommended, especially if the path needs to support occasional maintenance or emergency vehicles. The designer must consider the site-specific soil, environmental, and use characteristics of the path when determining the appropriate pavement design.

Some surface treatments may be appropriate to introduce a particular theme or gain a certain aesthetic quality for a shared use path. Both the Massachusetts Architectural Access Board and the ADAAG require that accessible elements be maintained. For example, if stone dust is used as an accessible surface and rain washes a section of it out, the AAB and ADAAG require maintenance to repair the section to meet their minimum accessible design standards. Finally, where a paved path intersects gravel roadways and driveways, 10-foot paved aprons on the roadway or driveway approaches are recommended to keep debris off the path and minimize pavement damage.

Where landscaping or natural vegetation is located near a path, root barriers can reduce root intrusion and resulting pavement buckling or other surface irregularities, as illustrated in Exhibit 11-12. Prevention of intrusion from tree roots and other vegetation should be given high priority during the design phase to prevent surface distortion that can be become a dangerous condition for people with disabilities and bicyclists and a deterrent to future path usage.

Path shoulders should also provide a smooth area that resists erosion, root intrusion, debris spreading and other undesirable effects. Grassed shoulders are very common along shared-use paths, but require mowing and other regular maintenance. Stone dust shoulders are another option that the designer may consider.

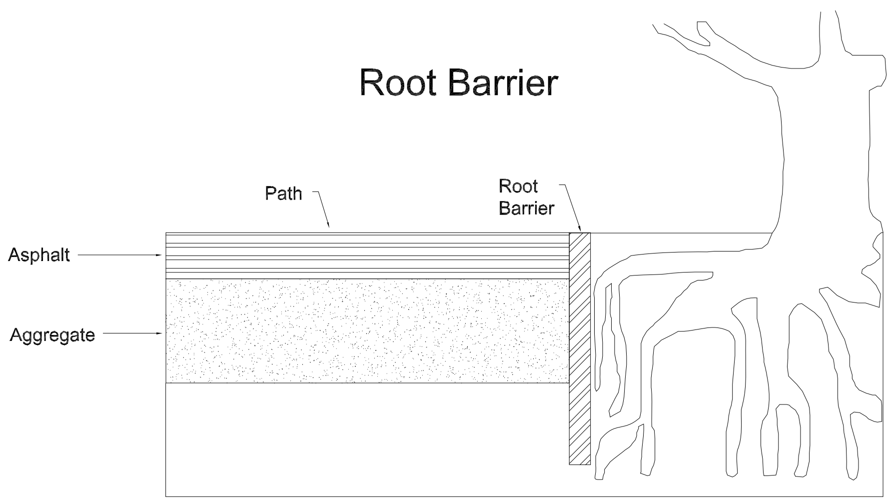
Exhibit 11-11
Typical Path Pavement Design



* The thickness of the asphalt layer can be increased at locations where heavy vehicle access (maintenance and emergency vehicles) are expected to be on or crossing the pathway.

Source: Adapted from WSDOT Pedestrian Facility Guidebook

Exhibit 11-12
Root Barriers



Source: Adapted from WSDOT Pedestrian Facility Guidebook

11.4.13 Landscape Selection and Maintenance

Selecting appropriate landscaping vegetation and then maintaining the landscaped vegetation that is chosen and installed are important aspects of path and trail design. Refer to Chapter 13 for more discussion of landscaping.

11.4.14 Drainage

The maximum allowable pavement cross slope of 2 percent adequately provides for drainage. However, lower design cross-slopes may be needed to ensure compliance with 521 CMR and AADAG regulations in the built condition. Sloping in one direction instead of crowning is preferred and usually simplifies the drainage and surface construction. A smooth surface is essential to prevent water ponding and ice formation. On unpaved paths, particular attention should be paid to drainage to avoid erosion. Where the path is constructed on a hillside, ditches of suitable dimensions to contain the flow of water from the uphill side of the path should be constructed. To prevent erosion, paved waterways should be provided at low points and berm should be provided on the edge of steep slopes along the shoulder and resulting drop-off. In areas with underground drainage systems, catch basins should be located outside of the path and flush with its surface. Bicycle-safe, wheelchair-safe, and crutch-safe drainage grates should be used exclusively.

11.4.15 Lighting

Lighting for shared use paths is important and should be considered where night usage is expected, such as paths serving college students or commuters, and at highway intersections. Lighting should also be considered through underpasses or tunnels and when nighttime security could be an issue.

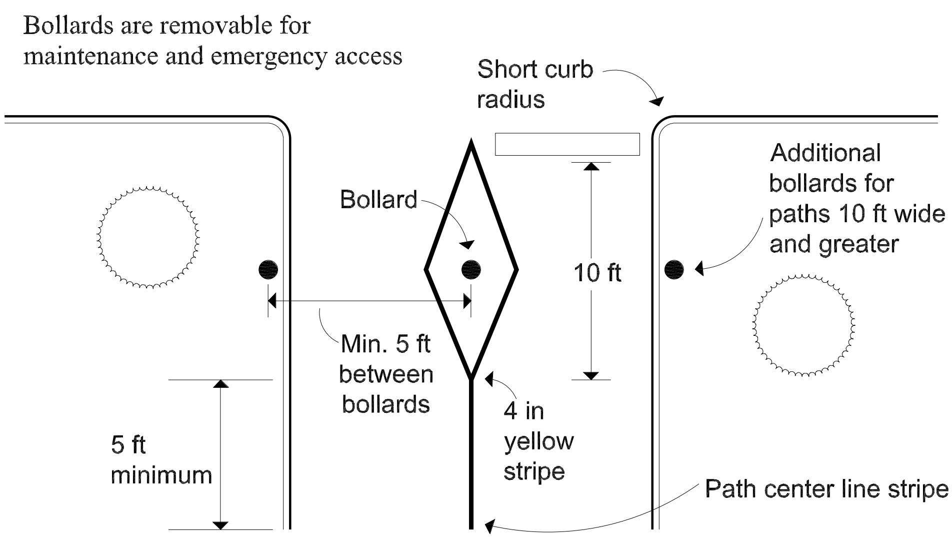
11.4.16 Restriction of Motor Vehicle Traffic

Shared use paths may need some form of physical barrier at highway intersections to prevent unauthorized motor vehicles from using the facilities. Provisions can be made for a lockable, removable (or reclining) barrier post to only permit entrance by authorized vehicles.

Bollards are the most common type of barrier used to control motor vehicle access to a path. These bollards should be marked with reflective materials to ensure their visibility at night. The recommended minimum height for bollards is 30 inches. Bollards need to be adequately spaced to allow easy passage by bicyclists, bicycle trailers, pedestrians and wheelchair users (to meet AAB and ADAAG standards, a minimum width of 36 inches must be provided) Typically, one bollard located in the center of the path is sufficient to control motor vehicle access to the path. As illustrated in Exhibit 11-13, if more than one bollard is needed, the additional bollards should be placed at the path's edges. A minimum of 36" clear width should be maintained.

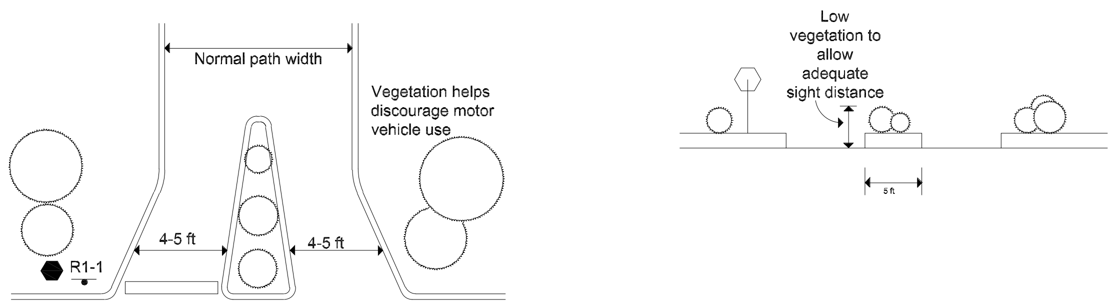
Other entrance treatments can be designed to discourage motor vehicle access, maintain emergency access, and act as an entrance treatment to a shared use facility. One example of an alternative treatment is a short splitter island with low landscaping that can be traversed by an emergency vehicle and does not obstruct sight lines, as illustrated in Exhibit 11-14. Gates and other devices also serve as ways to control vehicular access to paths. Regardless of the type of physical barrier used, it should be maintained to ensure that it does not become a safety issue.

Exhibit 11-13
Bollard Placement



Source: Adapted from VTrans Pedestrian and Bicycle Facility Planning and Design Manual

Exhibit 11-14
Splitter Island Treatment



Source: Adapted from VTrans Pedestrian and Bicycle Facility Planning and Design Manual

11.4.17 Bicycle Parking

Bicycle racks are an integral part of accommodating bicycle transportation. Bicycle racks should be located where they are convenient to the users and where they will not interfere with pedestrian and vehicular traffic. Providing bicycle racks helps discourage users from locking bikes to railings, street trees, and other furnishings. General guidelines are presented below:

- The appropriate number of spaces needed should be assessed with respect to the associated building or land use.
- Typical inverted "U" systems are preferred, but any similar rack that meets the following criteria may be used:
  - Rack must enable the frame and one or both wheels to be secured, preventing the bike from tipping over
  - The rack should be anchored so that it cannot be stolen with bikes attached
  - Two locking points available for theft-protection

For parallel storage, arrange rack elements 30 inches on center to allow space for two bicycles to be secured to each rack element.

11.5 Greenways

Design guidelines for hiking and other recreational trails are not as well established as those for shared use paths. Trails in parks and other open spaces are commonly designed to provide experiences for differing levels of accessibility. The levels of accessibility served may depend on the setting. For example, in urban parks, a full range of accessible recreation opportunities, including paths and trails, is typically expected by the public. However, in rural and remote areas, full accessibility is not generally expected, and trails and pathways that serve varying levels of accessibility are commonly provided. Some paths may serve as accessible routes of travel, while others may have steeper gradients and unpaved surfaces. Individuals can then choose a path or trail that provides the recreation experience and degree of challenge they desire.

The federal Access Board is in the process of developing specific standards for accessibility for recreational trails, and these are expected to reflect user expectations for greater accessibility as well as preservation of natural terrain and wilderness experiences. In the meanwhile, 521 CMR, *The Rules and Regulations of the Massachusetts Architectural Access Board*, applies to any pathway constructed for pedestrian use. Where there is a conflict between 521 CMR and the intended use of the trail, the designer should recommend that a variance be requested from the Board, and include input from people with disabilities in the design area, as well as the local independent living center.

Universal Access to Outdoor Recreation, *A Design Guide*, developed by the USDA Forest Service, provides extensive design guidance related to outdoor recreation trails. It includes a trail rating system and suggests that trails be signed to indicate the level of accessibility, as shown in Exhibit 11-15. Additional information and guidance can be found in the federal Access Board's 1999 Regulatory Negotiation Committee on Accessibility Guidelines for Outdoor Developed Areas: Final Report.

General guidelines for the development of recreational trails, adapted from the Forest Service guidelines are presented in Exhibit 11-16. Where these do not meet current 521 CMR requirements, a variance should be requested from the Massachusetts Architectural Access Board before proceeding. As with all variances requested from this Board, the designer should have input from people with disabilities, including people from the local commission(s) on disability and the regional independent living center.

Exhibit 11-15
USDA Forest Service Accessibility Guide Signs

Source: WSDOT Pedestrian Facility Guidebook

Exhibit 11-16
Recreational Trail Guidelines

	Level of Difficulty		
Design Element	Easy	Moderate	Difficult
Surfacing	Paved	Compacted	Varies
Clear Width	4 feet	3 feet	2.5 feet
Sustained Slope	5 percent	8.33 percent	12.5 percent
Maximum Grade and Distance	8.33 percent/30 feet	14 percent/50 feet	20 percent/50 feet
Maximum Cross-Slope	2 percent	3 percent	5 percent
Passing Interval Spacing	200 feet	300 feet	400 feet
Rest Area Intervals	400 feet	900 feet	1,200 feet
Maximum Surface Irregularity	0.5 inch	1 inch	3 inches

Adapted from US Forest *Service Universal Access to Outdoor Recreation, A Design Guide*
Source: WSDOT Pedestrian Facilities Guidebook

11.6 Rail Trails

Railroads developed a vast network of transportation corridors throughout the region. Many of these corridors no longer serve railroad activities and many still do. Regardless of the actual presence of railroad activity in a corridor, railroad rights-of-way (ROW) are often seen as opportunities for the development of shared use paths. The design elements of shared use paths described earlier in this chapter are applicable to rail trails. Although not discussed in detail below, rail trails can also be developed as more primitive trails, or for use by motorized vehicles such as snowmobiles.

11.6.1 Inactive ROW

Inactive ROW serve as ideal candidates for the development of formalized shared use paths and for informal use by other users such as snowmobiles and cross-country skiers. The railroad ROW is generally suitable for reuse as a shared use path because the geometric features of the railroad, such as grades, alignment, clearances, etc. are also favorable for use by pedestrians, bicyclists, and others. The key differences between developing a shared use path on an inactive railroad ROW versus a new alignment include:

- Property issues are sometimes complicated along railroad rights-of-way, especially those that have been long-abandoned by the railroad.
- Existing structures, road crossings, and other features may be suitable for re-use.
- The ROW may provide access to new recreational or other resources, not well served by the roadway network.
- The ROW may be highly separated from the surrounding urban or natural environment, facilitating through movement, but complicating connections to surrounding attractions and destinations.
- There is a reasonable expectation of hazardous material contamination, especially in former railroad yard areas.
- Redevelopment of the ROW may pose a real opportunity for economic growth and revitalization of adjacent properties.

11.6.2 Rails with Trails

The development of shared use paths adjacent to active railroads is often more controversial than the reuse of inactive ROW. Railroad companies may not enthusiastically embrace the concept of a shared use path adjacent to their facility. Railroad corridors are usually private property and are viewed as frequented by trespassers, who are often responsible for vandalism or accidents. There is often a concern that development of a path will increase the amount of this undesirable activity. With this in mind, it is understandable that railroad owners and operators may be hesitant to support path development near their facilities, however, introducing formal trail use within the ROW can actually lead to a reduction in undesirable activities as well as a reduction in illegal dumping by abutters or outsiders.

With these concerns in mind, there is often width within a railroad ROW that is not being actively used for railroad purposes. These corridors can be opportunities for path development. The key considerations in the development of paths within active railroad corridors are the ability to provide adequate separation between the railroad activity and the shared use path as discussed below.

11.6.2.1 Separation from Railroad Operations

According to the FHWA's *Rails-with-Trails: Best Practice Report*, the minimum setback between the path and the railroad should take into consideration the speed and frequency of trains in the corridor, maintenance activities, separation techniques, existing problem areas, and good judgment. In areas where recommended setbacks cannot be achieved, additional right-of-way should be acquired, or additional separation measures should be established to improve security and ensure safety.

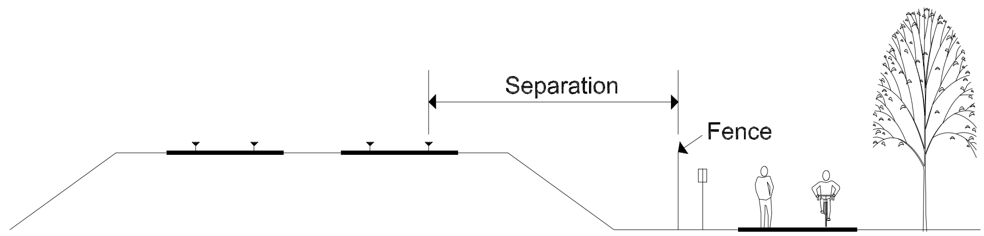
As an absolute minimum, the path cannot fall within the train's envelope of operation, which is the space required for the train and its cargo to overhang due to any combination of loading, lateral motion, or suspension failure. Separation between the track and the path is illustrated in Exhibit 11-17. Recommended values are presented in Exhibit 11-18. Exceptions to these recommendations are possible on a negotiated, case-by-case basis with the track owner/operator.

Methods to provide additional width for path development within a constrained existing railroad ROW are possible through selection of the path location or modification of the ROW cross-section. These methods are illustrated in Exhibit 11-19 and include:

- Locate the path at the bottom of the slope;
- Locate the path in an adjacent utility corridor;
- Widen the embankment;
- Excavate and retain the side-slopes;

- Cantilever the path at rail trail bridge crossing, or provide a separate crossing independent of the rail bridge; or
- Use a low retaining wall.

Exhibit 11-17
Separation Between Track and Path



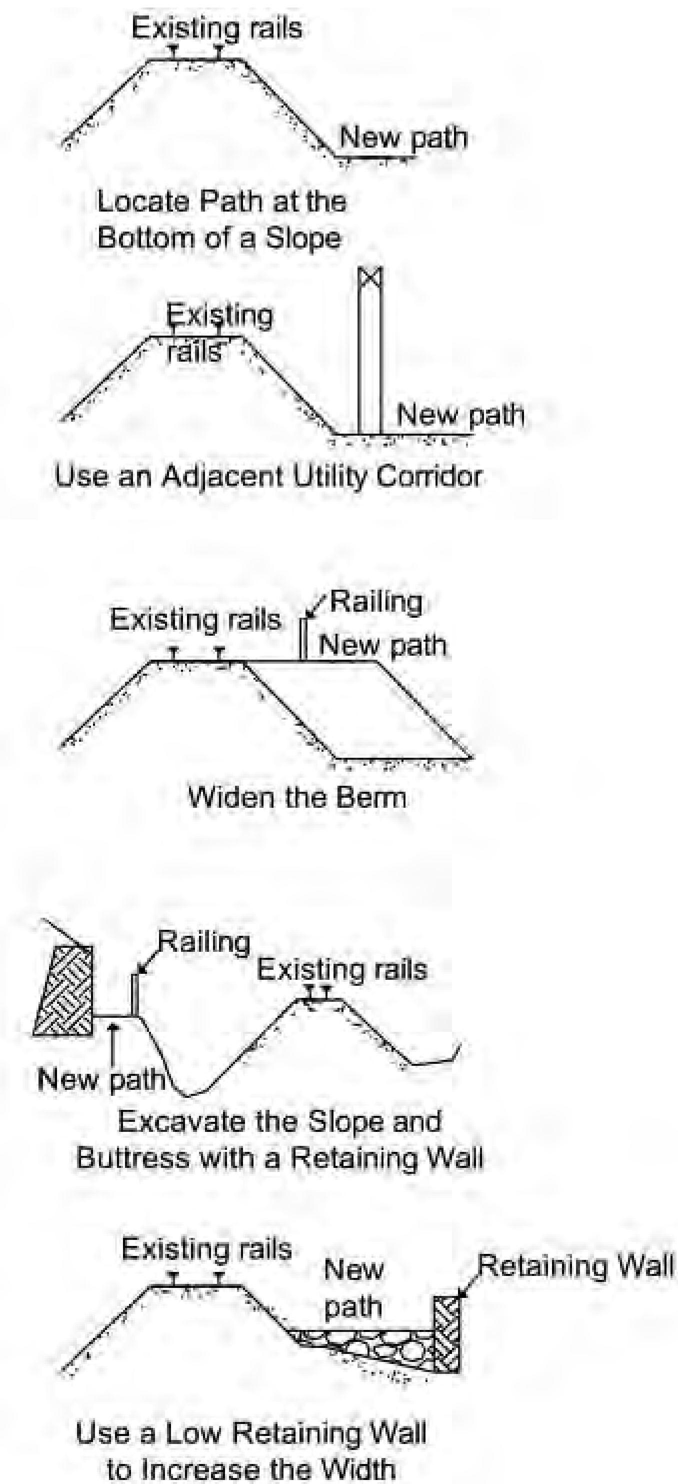
Source: Adapted from the VTrans Pedestrian and Bicycle Facility Planning and Design Manual

Exhibit 11-18
Recommended Separation between Active Rail Lines and Paths

Type of Rail Operation	Setting Characteristics	Recommended Minimum Separation
High Volume/ High Speed 11 trains or more per day Max speed over 45 mph	Typical Conditions	25 feet with fence, 15 feet with a solid barrier
	Constrained Areas (cut/fill, bridges, etc.)	15 feet with fence or other physical barrier
	Vertical Separation of at least 10 feet	20 feet
Medium Volume/ Medium Speed Fewer than 11 trains per day Max speed 45 mph	Typical Conditions	25 feet 15 feet with a physical barrier
	Constrained Areas	11 feet with a physical barrier
	High Trespassing Areas	11 feet with a physical barrier
Low Volume/ Low Speed Fewer than 1 train per day Max speed 35 mph	Typical Conditions	25 feet desired 11 feet minimum
	Constrained Areas	11 feet with a physical barrier

Adapted from FHWA Rails with Trails: Lessons Learned
Source: VTrans Pedestrian and Bicycle Facility Planning and Design Manual

Exhibit 11-19
Methods to Provide Additional Width for Path Development



Source: Adapted from the VTrans Pedestrian and Bicycle Facility Planning and Design Manual

11.7 Maintenance

Maintenance is an important consideration for all transportation facilities including on-road bicycle facilities and shared use paths. Good maintenance practices, such as periodic sweeping, surface repairs, tree pruning, mowing, trash removal, litter pick-up, new pavement markings, etc., are important elements of a routine maintenance schedule. In addition, both the Massachusetts Architectural Access Board and the Americans with Disabilities Act require that accessible elements be maintained to meet their minimum standards.

Path maintenance operations are often undertaken by the locality or governing agency and their importance and the associated costs should be considered during the planning stages of the project. The entity who is to take on these responsibilities should be established early in the process. In some instances, nonprofit groups, civic groups, and private organizations (i.e. bike clubs) partner with the locality by assisting in the smaller maintenance tasks. Key maintenance activities are discussed below.

11.7.1 Sweeping and Debris Removal

Sand and gravel accumulation on a path can pose a serious hazard to cyclists and skaters. Paths should be periodically swept to avoid accumulation of debris. The sweeping schedule should be established based on the path conditions and needs. At a minimum, it is recommended that a path be swept six times per year.

11.7.2 Pavement Quality and Striping

Path users are particularly sensitive to pavement irregularities and paths should be regularly maintained to ensure that cracks, potholes and other pavement defects are corrected. Additionally, most paths require periodic restriping to ensure the visibility and effectiveness of pavement markings. Missing and damaged signs should also be replaced.

11.7.3 Snow Removal

Snow removal is required if a path will be used in the winter months. Many paths are used for walking, jogging, and cycling year-round. To accommodate these uses, snow should be placed well beyond the path (or marked shoulder lane) edge to avoid ice formation and other hazards. Fences and barriers should be sufficiently set-back to allow effective snow removal.

In some cases, snow may not be removed to allow use of the path for cross-country skiing. A management decision should be made in consultation with the local entity and user groups to determine the preferred winter time use.

11.8 For Further Information

For further information on the design of paths and trails consult the following publications:

- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004.
- *Guide for the Development of Bicycle Facilities*, AASHTO, 1999.
- *Guide for the Planning and Design of Pedestrian Facilities,* AASHTO, 2004.
- *Manual on Uniform Traffic Control Devices*, Federal Highway Administration, 2003.
- *Virginia Bicycle Facility Resource Guide*, Virginia DOT, 2002.
- *Vermont Pedestrian and Bicycle Facility Planning and Design Manual*, Vermont Agency of Transportation, 2002.
- *Pedestrian Facilities Guidebook: Incorporating Pedestrians into Washington's Transportation System*, Washington State Department of Transportation, Puget Sound Regional Council, County Road Administration Board, Washington Association of Cities, 1997.
- *Design Manual*, Washington State Department of Transportation, 2004.
- *Rails with Trails, Lessons Learned*, Federal Highway Administration, 2002.
- *Trail Intersection Guidelines*, prepared for Florida Department of Transportation, University of North Carolina Highway Safety Research Center, 1996.
- Universal *Access to Outdoor Recreation: A Design Guide*, United States Department of Agriculture – US Forest Service (Draft) 2005.
- Accessible Rights of Way: A Design Guide, Architectural and Transportation Barriers Compliance Board, (Draft) 1999.
- ADA Accessibility Guidelines for Buildings and Facilities (ADAAG).

- MassHighway Policy Directive P-98-003 Bicycle Route and Share the Road Signing Policy
- MassHighway Specifications for Installation, Signing, and Surface Markings for Bicycle Sensitive Detectors at Traffic Signals.

Chapter 12
Intermodal Facilities and Rest Areas

Intermodal Facilities and Rest Areas

12.1 Introduction

This chapter describes design considerations for Park & Ride/Transit Centers and Rest Areas/Tourist Information Centers. **Park and Ride** lots provide a collection point for travelers to transfer between the automobile mode and transit, or between the single occupant vehicle (SOV) and high occupancy vehicle modes. Other modes potentially supported by a Park and Ride facility include pedestrian, bicycle, paratransit, intercity bus transit, airport service, and intercity and commuter rail. In addition to the services offered at park-and-ride lots, **Transit Centers** tend to offer a higher degree of travel services, route choices, and mode choices.

Rest Areas are as areas that provide a location for travelers to relax and take a break from highway travel. Rest areas often serve multiple purposes, providing comfort stations, and in some cases, food and beverage services. **Tourist Information Centers**, also provide a location for travelers to rest and provide information on nearby services and attractions. These centers could be included within Rest Areas or constructed separately.

12.2 Park & Ride Facilities

Park & ride facilities are constructed to provide a convenient area for commuters to park and carpool or take public transportation. In tourist-oriented areas, they can also serve as Tourist Information Centers (described in section 12.4 below) and meeting places for travelers. The following section describes characteristics of successful park & ride lots and key design considerations.

12.2.1 Success Factors

Key design considerations for developing successful park & ride lots include:

- A location on a major highway serving commuters that is convenient to residential areas, bus routes, and/or feeder highways to the major commuting route;
- A location upstream of points of congestion along the commuting highway;
- A location in proximity to good quality transit services (high frequency and speed);
- A location near or within commercial developments such as movie theaters, shopping malls, restaurants, stadiums, and hotels (as well as other public or private developments). These land uses often have a surplus of parking during the workday (the establishment's "off-peak" time). This parking could be sufficient to serve the needs of commuters or travelers during the day and patrons of the establishment at night and on weekends.
- The presence of retail services near the park & ride facility and ambient lighting and security;
- Quality design elements such as effective lot circulation, easy access and egress, ample parking, bicycle accommodation, attractive landscaping, lighting, bus shelters, phones, and security; and
- Proper maintenance of these quality design elements, including snow removal, also contributes to success.

12.2.2 Design Considerations

The design of a park and ride facility should consider expected parking demand, parking facility design standards, circulation patterns, and drainage facilities. Key design considerations for park & ride lots are discussed in the following sections.

- **Site Selection**: In addition to the factors that make a park & ride lot attractive for users, the designer needs to consider site terrain, drainage, subgrade soils, and the available space compared to the required lot size. The designer should also consider impacts to any surrounding streams, wetlands, or environmentally sensitive areas, as well as impacts to abutters and compatibility with surrounding land uses. All measures should be taken to avoid historically, culturally, or environmentally sensitive areas or minimize impacts to them if a facility must be located near them.

- **Multi-modal Access**: The designer should attempt to incorporate park and ride facilities into existing transit, bicycle, and pedestrian systems and should consider expected uses of the facility, including transit access, pedestrian access, bicycle accommodation, vehicular access, and parking layout. Bus loading, passenger drop-off and pick-up, and parking should be separated from each other and clearly marked. For facilities with transit service, dedicated busways should be provided and short term parking and drop-off/pickup space should be located near the bus loading area.
- **Safe Pedestrian and Bicycle Circulation**: Pedestrian connections, crosswalks, and paths must be provided throughout the lot to the transit area and nearby buildings. Within the parking areas, spaces should be aligned 90 degrees to the direction of pedestrian travel ensuring clear routes that maximize visibility. Consideration should be given to providing a separate walking route between parking bays that aligns with a transit center entrance or bus loading area. If bicyclists are expected to commute to the lot, a bicycle area with covered racks or lockers should be provided. Bicycle parking should be provided at a rate of 1 space for every 10 to 20 vehicle spaces, depending on location.
- **Site Access/Egress**: Separate driveway exits and entrances should be provided, preferably on different streets if possible. The entrance driveways should be on the upstream side of the traffic flow nearest the lot, and the exit driveway on the downstream side. It is desirable to provide at least one exit and one entrance for every 500 parking spaces provided. Individual driveways serving a greater number of parking spaces should be reviewed for possible signalization. All exits and entrances should be designed according to the criteria in Chapter 6 (At Grade Intersections). These criteria include capacity, turning radii, and auxiliary lanes on the intersecting highway or street.
- **Parking:** The number of parking spaces to be provided in a new or expanded park-and-ride facility should be determined using information generated by the Office of Planning. The size of the drop-off/pickup area and the number of associated short-term spaces should be determined according to projected demand. Best practice calls for right-angle parking with sufficient aisle width for

two-way travel. However, where space is limited, angle parking with one-way travel is acceptable. There are specific requirements for accessible parking spaces for cars and vans, including the number, size, and location of these spaces as well as vertical clearance for van spaces. Refer to 521 CMR and ADAAG for specific parking standards. Where accessible parking is more than 200 feet from a building entrance, an accessible drop-off area must be provided. In addition, refer to the AASHTO *Guide for the Design of Park-and-Ride Facilities* for guidance in parking layout and recommendations for parking stall dimensions based upon the angle of parking. Consideration should also be given to the need for any parking regulatory signs such as “No Overnight Parking”.

- **Bus Bays and Circulation**: Where possible, linear bus bays are preferred, with a separation between bus layover and passenger loading areas. All required turns within the parking lot (e.g., to and from bus loading area and around islands) should be designed to accommodate the applicable vehicle. Refer to Chapters 3 and 6 of this manual and the AASHTO *Guide for the Design of Park-and-Ride Facilities* to determine appropriate bay dimensions and turning radii. Adequate level areas adjacent to where buses stop to discharge or pick-up passengers are needed to accommodate a wheelchair getting on or off a bus.
- **Sidewalks and Walkways**: It is recommended that any sidewalks be at least 7 feet wide. Loading areas should be at least 12 feet wide. Wheelchair ramps are required for access onto sidewalks and loading areas.
- **Grading and Drainage**: Where buses will use the park-and-ride lot, the grade should not exceed 7 percent. A maximum grade of 5 percent is preferred. Grades may be steeper in facilities where only cars will use the lot. Chapter 8 should be used for the detailed drainage design of the parking lot. This includes design storm frequency pavement discharge, and capacity of drainage inlets. The drainage design should not allow ponding on pedestrian routes, bicycle routes, or any access roadways or parking areas. To provide proper drainage, the minimum gradient should be 1 percent. Water quality and peak discharge rate attenuation should also be addressed.
- **Signage**: Directional signs, bicycle route markings and signing, and traffic control should be designed in accordance with the Manual on

Uniform Traffic Control Devices (MUTCD). Local policies for informational signs should be considered.

- **Lighting & Security**: The entire parking lot should be lighted, however care should be taken to prevent spillover into adjacent neighborhoods. The uniformity ratio should not exceed 6:1. The area should be well lit and free of landscaping that can obstruct a user's view of his/her surroundings. The designer should provide adequate security measures which may include:

  - Video Surveillance;
  - Random Police Patrols;
  - Provision of Emergency Call Boxes; and
  - Provision of Safety Information Brochures to patrons.

  Additionally, co-location of park & ride facilities with active commercial sites, or other compatible uses can increase the "eyes on the street" and improve lot security.

- **Landscaping:** The designer should include landscaping in the plans for the park-and-ride lot. If islands are incorporated in the design, these can be convenient locations for trees and other landscaping elements. Safety, lighting, plowing, and landscape maintenance should also be considered in the placement and choice of trees and shrubs.

- **Amenities**: Where a loading area for buses or trains will be provided, a shelter should be included in the design. The size of the shelter should be approximately three to five square feet per person waiting to board. It is desirable to include lighting, benches, trash receptacles, and route information in loading areas. Bus shelters must be accessible to people with disabilities. Both 521 CMR and ADAAG have specific requirements for approaching, entering, and using shelters.

- **Solid Waste Management:** The designer should provide information on plans for collection of trash and recycling at the proposed facility.

Some of these design considerations can also be applied to the development "joint use" facilities such as at shopping centers although their application will be limited for existing facilities and by the needs of the joint user.

12.3 Transit Centers

Transit Centers serve as major multi-modal nodes connecting various regional, express, circulator and local bus services with each other and providing vehicular, bicycle and pedestrian access to these services. Transit centers are designed specifically to facilitate transferring between bus routes and between bus and other travel modes. They are often located within major activity centers. Transit centers will operate most successfully if good directional and informational signs are in place. Way finding systems should incorporate multi-media information so that people with hearing, sight, or mobility limitations can navigate between transportation modes. Accessible routes should coincide with the routes of the general public.

Typically, the design and operation of a Transit Center is the responsibility of a Transit Agency. The design guidelines of the transit agency should be followed with respect to layout and design. Design considerations specified earlier for park & ride facilities should also be considered for Transit Centers. Particular consideration should be given to:

- Allowances for minimum clearances and turning radii of transit vehicles;
- Acceleration/deceleration, grade, sight distance issues;
- Appropriate roadway and driveway widths; and
- Allowances for underside road clearance at driveways, speed humps, raised pedestrian paths, and railroad crossings

The designer must especially consider the need for multimodal safety and accommodation as discussed below.

12.3.1 Multi-Modal Safety & Accommodation

The design of a transfer facility should include safety measures that prevent conflicts between modes while not restricting the ability to easily transfer between modes. This can be achieved by providing separate access driveways for transit, non-transit modes, and pick-up/drop-off, and providing separate areas for bus loading and unloading and layover.

A continuous sidewalk network and pedestrian circulation pathway should be provided throughout the facility, including connections to park and ride lots, as applicable. Pedestrian desire lines (the natural pedestrian path) should not be blocked by landscaping or other impediments.

Maximum visibility of pedestrian crossings of vehicular routes should be provided through pavement markings, medians, or varying crossing heights. The Transportation Research Board's *Transit Capacity and Quality of Service Manual* and ADAAG and 521 CMR regulations should be consulted for procedures in designing pedestrian walkways and waiting areas.

Finally, planning for proper storage and access of bicycles is important to support the needs of the surrounding community. Protected bike racks or lockers should be provided in a secure, visible location that does not interfere with pedestrian and auto traffic.

12.4 Rest Areas

Rest Areas are developed primarily to provide safety and convenience to the traveling public along freeways and major arterials in Massachusetts. While the need for rest areas is determined on a case by case basis, planning for rest areas should consider:

- Attractiveness of location;
- Topography;
- Distance from other rest areas;
- Distance between interchanges; and
- Availability of water and utilities.

All rest areas should comply with the "Recreational Facility" section of 521 CMR.

12.4.1 Site Selection

A typical rest area requires approximately 25 acres of land within the highway right-of-way to accommodate the site functions. Where possible, rest areas should be located on both sides of the highway to avoid motorists stopping to use a rest area on the opposite side of the highway. To reduce this likelihood, measures such as advanced signage and median fencing should be considered. Additionally, Rest Areas on opposite sides of the highway should be spaced approximately 0.25 miles apart, with the motorist reaching the rest area in their travel direction prior to seeing one on the opposite side of the highway. Rest areas in the middle of the highway are not recommended because they disrupt mainline flow by requiring left-hand exiting from the highway and left-hand entering to the highway.

In addition to new locations, the designer should investigate the use of existing facilities or co-locating rest areas with other roadside facilities such as weigh stations. Once the need for a rest area is determined and the location selected, MassHighway should be consulted as to scenic quality of the area, roadway access to the area, and whether the area can sustain the proposed development (based on topography and utility connections). Generally, attempts should be made to locate the rest area away from adjacent residential and industrial land uses but near connections to municipal water and sewer systems. If no municipal water and sewer systems are available, the designer should provide MassHighway with alternate water and sewer plans. Alternatives for locations where utilities are not available include composting toilets, solar or wind power generation, or on-site sewerage treatment/storage/ disposal, designed in conformance with local and state regulations.

12.4.2 Design Considerations

Once a site has been selected, the rest area must be designed in detail. Several features need to be considered, including exits and entrances, parking, facilities, utilities, landscaping, safety and handicap access. All rest areas must be designed to properly accommodate people who require mobility aids with curb cuts, ramps, handicap and van accessible parking, and rest room features. All buildings must be accessible.

These considerations are described in the following sections.

- **Exits and Entrances**: The rest area junctions should be designed to the standards appropriate for the adjacent highway. These are described in Chapter 7. At a minimum, entrance and exit ramps should be located approximately 3,000 feet from adjacent highway interchanges. The ramps should be designed to slow traffic from highway speeds to those suitable for the pedestrian environment of the rest area (less than 30 miles per hour).
- **Parking**: The number of parking spaces should be commensurate with the expected usage of the rest area. The usage, in turn, will be a function of the size and type of facility provided (e.g., a large information facility will generate a greater percent stopping than a

smaller one). Parking should be provided for at least 50 passenger cars and 40 trucks. However, where space is restricted the number of parking spaces should be calculated as shown in Exhibit 12-1.

Exhibit 12-1
Minimum Parking Requirements

Minimum Required Truck Stalls		Passenger Cars	
Percent trucks * DHV =		Percent Passenger Cars* DHV =	
* 0.15 entering vehicles =		* 0.09 entering vehicles =	
* 0.5 Dwell Time/Turnover =		* 0.34 Dwell Time/Turnover =	

DHV = Design Hour Volume
Note: Passenger Stall requirements should be increased by 25 percent for Welcome Centers.
Source: Adapted from the Illinois Department of Transportation

Separate parking areas should be provided for passenger vehicles and for trucks and buses. There are specific requirements for accessible parking spaces for cars and vans, including the number, size, and location of these spaces as well as vertical clearance for van spaces. Refer to 521 CMR and the ADAAG for specific parking standards. Where accessible parking is more than 200 feet from a building entrance, an accessible drop-off area must be provided. Because of the one-way operation of rest areas, angle parking is generally recommended. Parking should be prohibited on entrance and exit ramps to the facility to ensure that adequate visibility and horizontal clearance is maintained along these ramps. Consideration should also be given to the need for any parking regulatory signs such as parking time limits.

- **Facilities**: Rest areas may provide a building with rest rooms, tourist and public information services, picnic tables and shelters, benches, sidewalks, pet accommodations, drinking fountains, vending machines, and trash collectors. If facilities are provided, they shall comply with 521 CMR and ADAAG requirements.
- **Restroom Facilities:** Entranceways to restrooms should provide an unobstructed walkway. Elevated planters, walls, shrubs, and bushes should not obscure the approaching patron's view of his/her surroundings. The area should be well lit. In general, restrooms buildings require approximately 3,000 square feet to accommodate traveler needs. Rest rooms should provide approximately 700

square feet for every eight fixtures provided. The number of fixtures needed can be calculated as shown in Exhibit 12-2. Restrooms should comply with 521 CMR and ADAAG.

Exhibit 12-2
Minimum Rest Room Requirements

		Notes
Two-way ADT =	______	
* 0.6 percent =	______	60/40 directional distribution
* 0.11 =	______	11 percent of ADT occurs during peak hour (DHV)
*2 =	______	2 person average vehicle occupancy
* 0.85 =	______	
P/RU =	☐	total person/rest room use

	Rest Room Amenities						
	Men				Women		
P/RU	Urinals	Toilets	Wash Basins	Hand Dryers	Toilets	Wash Basins	Hand Dryers
<250	4	2	2	2	6	2	2
>250	4	4	4	4	8	4	4
>500	6	4	4	6	10	4	6

Source: Adapted from the Illinois Department of Transportation

- **Other Amenities:** When considering other amenities, the following should be considered:
  - ❑ The number of picnic tables provided should equal approximately 0.008 times the projected roadway design hour volume and 5 percent of the tables, or a minimum of one table, should be accessible for a wheel chair user and on an accessible route (see 521 CMR “Recreational Facilities” and 521 CMR “Accessible Route” for clarification).
  - ❑ The number of trash receptacles provided should equal approximately 0.0008 times the projected roadway design hour volume or a minimum of two.

  Picnic tables and other recreation areas at rest areas should be located so that entering and exiting traffic does not pose an undue hazard to users of the facility.

- **Utilities**: Where permanent sanitary facilities are provided, an adequate water supply, sewage disposal system, and power supply will be required. These considerations may dictate the size of the rest area. Other utilities that may be needed include lighting and telephones.
- **Landscaping**: The rest area should be landscaped to take advantage of existing natural features and vegetation. Paths, sidewalks, and architectural style should fit naturally into the existing surroundings. If extensive regrading is required, architectural mounds or undulations should be considered both for aesthetics and other functions (safety, noise, and visual barrier). Designated dog walking areas should be provided away from areas designated for human use such as picnic areas to avoid safety and sanitary issues.

12.5 Tourist Information Centers

Tourist Information Centers are operated primarily for the purpose of providing information, directions, maps, and brochures to the general public. These centers may be combined within rest areas or constructed separately. If constructed separately, they may or may not include restrooms and food and beverage services. In addition to the design guidance given in section 12.4.2, the following should also be considered:

- At a minimum, the center must be staffed at least eight hours per day, seven days per week. Seasonal operation is permitted. Proper maintenance of facilities is critical to ensuring a good visitor experience.
- The Center should have parking spaces for at least 10 mid-sized passenger vehicles at least one of which is van accessible.
- At a minimum, 28 square feet of floor space shall be designated solely for tourist information.
- Each Center should provide an accessible public pay phone, a public text telephone, and an illuminated, weather protected MassHighway map,
- Each Center may provide wireless or wireline internet access.
- Other operational details as described in MassHighway's *Supplemental Private Sign Policy*.

12.6 For Further Information

- *Guide for Park and Ride Facilities*, AASHTO, 2003.
- *Supplemental Private Sign Policy*, MassHighway, 2003.
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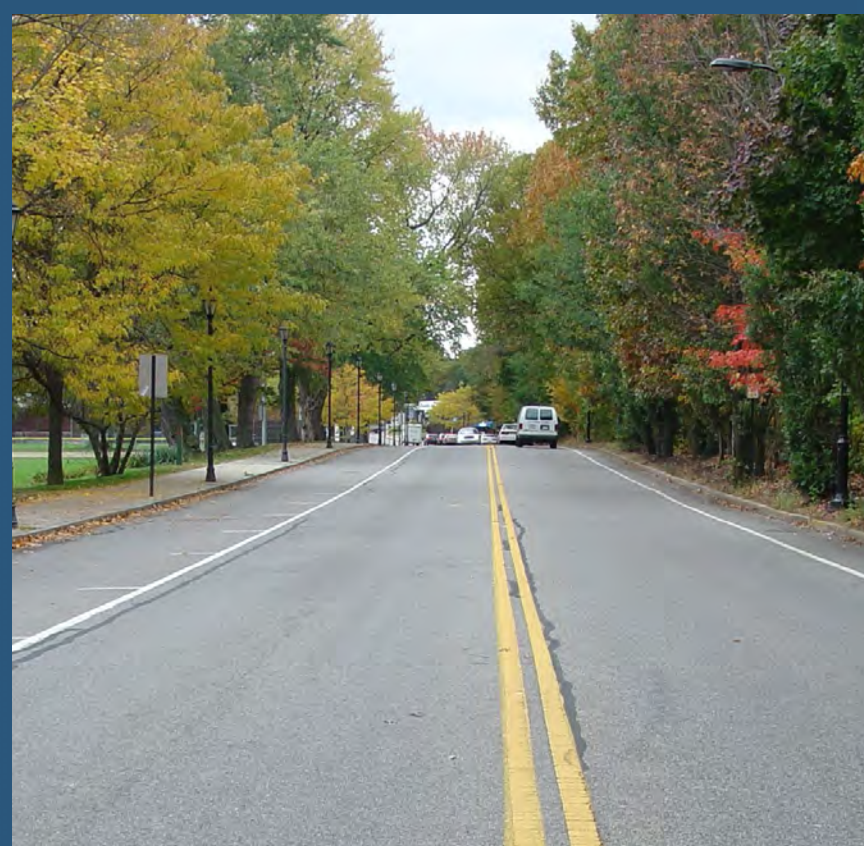
Chapter 13
Landscape and Aesthetics



Landscape and Aesthetics

This chapter provides an overview of landscape planning and design, an integral part of transportation project development. The chapter provides guidance on landscape objectives, corridor considerations, design, plant material section, and protection/preservation techniques. The chapter also describes the project documentation typically required for landscape elements.

13.1 Landscape Design Objectives

The goal of roadway landscape design is to integrate the road into the landscape context. This goal is guided by three objectives: (1) protection of natural and cultural resources, (2) restoration and rehabilitation of landscapes damaged or compromised by transportation improvements, and (3) enhancement of the corridor such that it becomes not merely a functional facility, but a community asset. Achieving these objectives involves evaluating the features of the corridor, and the corridor as a whole, to determine project impacts and how to best integrate the facility into the larger community and environmental context.

Protection and Preservation

Some features, such as wetlands, waterways, historic landmarks and districts, and parks, are protected by regulation. Yet there may be locally significant elements – pathways, architectural details, monuments, groves of trees – that may not meet regulatory thresholds, but may support adjacent ecosystems, or define the atmosphere of a village or town.

Plants, especially trees, provide climatic benefits, air filtration, erosion control and slope stability, storm water retention, and natural habitat. They also enhance the visual quality of the roadway corridor. Project planning and design should seek to preserve and protect existing plants, important cultural features, and ecosystems that make up the corridor.

Restoration and Rehabilitation
When impacts to the landscape are unavoidable, project design should, to the extent feasible, seek to restore or repair landscapes damaged by construction. For natural systems, the intent of such restoration is not merely to replace lost elements, but to replace specific lost functions. This may mean restoring habitat, water buffers, edge systems, hydrologic connections and soil functions. Streetscape restoration, like ecological restoration, involves more than simply replacing individual elements that have been lost. Therefore, the overall character of the street context must be evaluated in project planning and restored to the extent feasible.

Enhancement
Often landscaping is part of a civic improvement or a beautification initiative that has been incorporated into a transportation project. The local community is typically involved in design decisions for these projects and is committed to the future care of the streetscape elements. Project enhancements may include sidewalk improvements, furnishings, lighting, and street trees. New elements should be properly integrated with and linked to existing streetscape elements and should contribute to creating a sense of place and town identity.

13.2 Corridor Considerations

There are many requirements and considerations involved in safely accommodating the multiple uses of roadway corridors while respecting environmental conditions and meeting public expectations.

13.2.1 Public Expectations

The roadway landscape is the interface between the functional area of a road and the community through which it passes. Project planning and design must address a broad constituency with sometimes competing interests. For example, vehicles, including bicycles, require certain minimum widths for travel; neighborhood residents may desire street trees; and pedestrian accommodation requires minimum vertical as well as horizontal clearances. All of these factors will influence the streetscape opportunities for a roadway.

13.2.2 Safety

The over-riding spatial design considerations for roadway landscaping are those that address the safety of the corridor. The principle considerations are:

- ***Sight Lines*** must be maintained near intersections and driveways. No obstructions, such as plant material, signs, lights, signals, and other furnishings should block sight lines. Chapter 3 provides guidance as to the necessary sight distances.
- ***Clear Zones*** provide a recovery area adjacent to the roadway. Trees that will attain trunk diameters of 4 inches (measured 2 feet above ground) or more at maturity should not be located within the clear zone. See Chapter 5 for specific clear zone guidance.
- **Buffers** provide separation between higher speed vehicular traffic and pedestrian traffic. They serve to increase the comfort and safety of pedestrians walking on sidewalks. Measures, including landscape, to provide buffers and improve walkability are discussed in Chapters 5 and 16.

13.2.3 Environment

The environmental conditions of a site determine which plants will survive and thrive. Roadside conditions are typically harsh, limiting the palette of plants for landscape restoration and streetscapes. The following conditions should be analyzed to guide location and selection of species (See Section 13.4 for specific guidance on species selection).

- Climate and microclimate of the roadside vary from site to site and within sites. Slope angle and orientation will dramatically affect ground temperatures and water demands of plant material. Desiccating winds increase with closer proximity to the roadway.
- Soil quality of existing soils and proposed fills must be assessed as to drainage characteristics, compaction potential, organic content and fertility, as well as potential exposure to salt run-off and other soil contaminates.
- Existing hydrology will determine erosion considerations and species choices. Wetland areas will require additional protective measures, as described in Chapter 8.

- Existing vegetation should be evaluated with regard to plant communities, invasive species, native species, and the function that that vegetation serves (wetland buffer, screening, habitat area, erosion control, etc.). Indirect construction impacts on existing vegetation, such as changes in light or exposure, should also be addressed.
- Existing habitat should be assessed prior to choosing species for restoration. Habitat preservation and restoration should avoid inadvertently attracting species closer to roadway. Habitat considerations along roadways are further discussed in Chapter 14.

13.2.4 Utilities

Roadsides often serve as utility corridors. Underground and overhead wires and conduits are among the most common features. However, electric boxes, manholes, fire hydrants, lighting, and other fixtures must also be evaluated for clearance and access requirements. Underground utilities may require setbacks for the purpose of access and maintenance, although excavation of underground service is typically infrequent.

With the exception of the occasional high voltage utility corridor, overhead clearances are primarily a concern in urban and other developed areas. Utility poles, wires, and streetlights present special challenges for landscape design.

13.2.5 Roadway Maintenance

Landscape design must anticipate the type of maintenance that will be required. Responsibility for maintenance varies depending on roadway jurisdiction. Section 13.3.2.2 provides design guidance to accommodate maintenance in natural conditions. Maintenance for streetscape areas, as discussed in Section 13.3.1, is typically the responsibility of local municipalities.

13.3 Landscape Design Guidance

This section provides general design guidance. Design decisions are ultimately based on specific site conditions and may, in certain instances, require different solutions than those recommended. For this reason, this section classifies roadside landscapes into *streetscapes* and *natural sites.*

13.3.1 Streetscapes

Many of the roadway projects in Massachusetts pass through densely settled areas. These "streetscapes" are primarily pedestrian environments. This section focuses on the pedestrian landscape bound by the limits of right-of-way, and comprised of sidewalks and crosswalks. It may include decorative pavement, street trees, decorative lighting, and, where appropriate, other furnishings such as bicycle racks, benches, and trash receptacles.

13.3.1.1 Sidewalks

Occupying the border between the vehicular travel ways and private property, the sidewalk is a zone of many uses. In addition to pedestrian use, it usually carries underground and/or overhead utilities, streetlights and signs, as well as other sidewalk furnishings, including mailboxes, utility cabinets, and hydrants.

Sidewalk design must be attentive to the need for equitable access for a broad range of physical abilities, meeting the requirements of the Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities (ADAAG) and Massachusetts Architecture Access Board regulations (521 CMR). These requirements are discussed throughout the Guidebook and their specific influence on landscape design is summarized below:

- **Clearances**. Sidewalks must provide a clear path, a minimum of 5 feet wide. Short portions of this path may be narrowed to 3 feet to avoid fixed objects. Accommodating these clearances typically requires consolidation of street furnishings, including utility poles, lighting, and street trees to one side or the other of the walking path.
- **Gradient**. Sidewalks are allowed to follow the prevailing grade of the roadway. When other walkways are proposed, the constructed profile of walkway without a railing must not exceed 5 percent. Cross slopes should be designed to 1.5 percent, so as not to exceed the regulatory maximum of 2 percent. These cross section constraints restrict the type of materials and surfaces to those that can maintain these grades.
- **Surfaces**. Accessible surfaces should be slip resistant, with vertical deviations (such as at joints) not exceeding 1/8 inch. As with gradient thresholds, these constraints restrict the location and types of decorative pavement used.

- **Ramps at crossings**. Individual wheelchair ramps must be provided at both ends of all street crossings. They must be traversable from all approaches, and must provide level landings at top and bottom (See Chapter 6 for additional details). Landscape features such as street trees, lighting, and decorative pavement must be integrated such that they do not obstruct or hinder access to these transition areas.

13.3.1.2 Aesthetic Pavement Surfaces

Pavements for sidewalks are typically concrete or hot mix asphalt. Occasionally, decorative pavements are desired to reflect architectural materials and details in historic districts, to beautify significant downtown locations, or to highlight pedestrian zones. In general, the designer should:

- Limit irregular or rustic surfaces to non-traversable areas, such as the buffer zone, or “furniture zone” between the pathway portion of sidewalk and the street, or for non-traversed portions of medians;
- Where highlighted or decorative walks are desired, consider textured pavement and color admixtures.

Where unit pavers are used for pathways, the designer should:

- Provide a concrete or otherwise rigid base to ensure a smooth surface, and provide an adequate bituminous setting bed (minimum 3/4 inch) to ensure a durable bond.
- Avoid irregular or rustic materials such as cobble or rustic molded bricks. Use only highly durable modular units that fit together evenly and without gaps. Chamfer of pavers should be no greater than 1/8 inch.
- Apply unit paving only where pavement line is continuous. Minimize breaks requiring cutting and hand fitting of units.
- Anticipate utility fixtures and develop templates to fit whole units around fixtures without gaps.
- Wheelchair ramps should be constructed out of non-slip cement concrete. Integrate modular pavement with ramp conditions without transitional breaks and gaps.

Decorative pavement can be expensive to construct and presents challenges to maintain. Its application should be limited to projects that have explicitly identified the enhanced treatment as a priority and where there is local municipal commitment to maintenance, including proper repairs when pavements are disturbed or damaged.

13.3.1.3 Street Trees

Compared with other investments in civic improvements, street trees are relatively inexpensive and yield substantial community and environmental benefits. The desire for and feasibility of planting trees as part of a transportation project should be identified in the early stages of project development. Street tree plantings are frequently provided as part of state highway projects, but maintenance becomes the responsibility of local municipalities. For this reason, street tree planting design must consider not only conventional traffic issues of sight lines and clear zones, but also the horticultural requirements of plant material. An assessment of the planting area must take into account soil area, volume and type, availability of water, tree species, and microclimate.

Historically, trees have often been planted in strips too narrow and pits too small to adequately support long-term growth. Do not replant in these existing sites without carefully considering whether the soil volume, soil quality, microclimate, moisture levels and other site considerations are appropriate for the species selected, as described below.

Back-of-Curb Planting

Locating trees along the traffic side of sidewalks provides a buffer between the sidewalk and the street and may provide a visual traffic-calming cue to drivers. The planning and development of streetscapes should aim to provide sufficient area for tree planting, while accommodating pedestrian and utility demands. Considerations for back-of-curb planting include:

- Due to the many demands that may need to be met within the limited corridor space available – space for utility structures, pedestrian and bicycle accommodation, parking areas, and travel lanes – there is often insufficient area left for tree planting in back of the curb. Existing or proposed overhead and underground utility lines place further constraints on planting behind the curb.
- Typical urban forestry practices recommend at least 6 feet, preferably more, for the width of a street tree lawn. However, this

amount of available area is rarely found, especially in dense urban corridors.

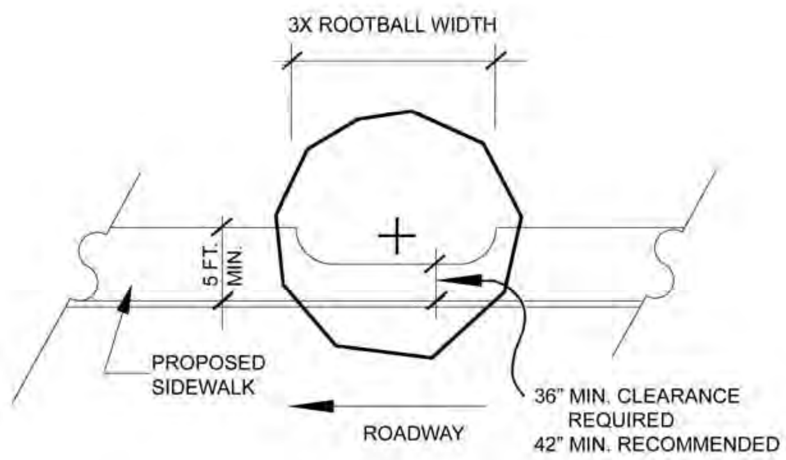
- If the width of the planting strip is less than 6 feet, or where the planting surface area is less than 60 square feet per tree, planting design should include documentation as to how species selection, soil modifications, irrigation or other designed modifications will support planting design.
- Tree strips as narrow as 3.5 feet may be viable. However, with smaller planting areas, municipalities should expect diminished tree growth and health, shorter plant life spans, and increased maintenance.
- Different species have different soil volume and moisture requirements. Choose species most likely to survive in the microclimate, site and soil conditions of the planting area.
- Shared root space provides a benefit to trees. Link tree pits or tree lawns to create spaces with greater soil area and volume.
- Municipalities may need to provide irrigation where there is insufficient soil volume to provide the moisture that the trees will require.
- In general, planting strips less than 3.5 feet wide are too narrow for trees. These strips do not contain sufficient soil volume for most species, do not provide sufficient area to protect tree trunks and roots from pedestrians, bicycles and parked cars, and, due to roots seeking soil outside the planting area, do not provide optimum long term conditions for sidewalks.

Back-of-Sidewalk Planting

Where sidewalk conditions (including accessible pathway requirements) limit the feasibility of back-of-curb planting, and where abutting land use allows, current urban forestry practices recommend back-of-sidewalk planting. Under these circumstances, the design process should include agreements with adjacent owners, especially where installation will encroach on private property.

Where right-of-way limits fall close to or on the back of the sidewalk, a portion of the sidewalk and sub-grade may be cut out to accommodate the root ball, provided there is adequate passage between the back of the curb and the back of the sidewalk, as shown in Exhibit 13-1.

Exhibit 13-1
Back of Sidewalk Tree Planting



Source: MassHighway

While planting in back of the sidewalk does not provide a physical buffer between the sidewalk and the street and may appear to compromise the conventional image of the tree-lined street, there are several significant benefits:

- Trees planted in areas with larger volumes of soil are more likely to survive and grow faster than trees in individual tree pits or strips because the roots have greater access to moisture and nutrients.
- Trees on back of sidewalk are much less likely to lift sidewalk pavement.
- Conflicts with overhead utilities along the sidewalk are avoided.
- Trees are less likely to be injured by vehicles and car doors.
- Trees will be less likely to obscure traffic signs and lights.
- Setback plantings are out of the way of future street repair such as curb resetting or installation.

Other Street Planting Strategies

Where sidewalk space is constrained and back-of-sidewalk planting is not possible, other considerations include:

- Locate trees where conditions are more favorable.

- Design subsurface planting pits that extend beneath and provide structural support to sidewalks, allowing sufficient room for root growth.
- Tree grates may help expand the tree planting area in confined pedestrian environments. There are specific ADA/ADAAG requirements for tree grates that limit the size of grate openings (and thereby limit available moisture). In general, tree grates are over-used as a decorative element. They are expensive and tend to restrict the growth of the tree over time. Uneven settlement around frames and eventual expansion of tree root mass can create trip hazards.

General Location and Design Guidelines

- The outside face of the tree trunk at its estimated mature size should be at least 1.5 feet behind face of curb.
- Locate trees and select species such that the canopy will not block signs, signals, or street lights.
- Locate trees so that trunks do not obscure sight lines at intersections and curb cuts.
- Where there is on-street parking, coordinate tree locations with parking stalls to minimize conflicts with car and truck doors.
- In commercial areas, allocate space for bicycle parking to deter people from locking bikes to trees.
- Avoid planting under utility wires. Otherwise, choose appropriate species/cultivars: low growing, columnar, or finely branched trees that can be pruned without causing major damage to the tree.
- Locate trees away from hydrants, electric boxes, lights, and other utility structures that may need to be accessed.
- Inventory subsurface utilities. In general, most tree roots are found in the top 2 to 3 feet of soil. However, excavation for sidewalks, root balls, backfill and drainage must be considered. Tree roots do not generally migrate toward underground lines, however, where soil surface area and volume is limited, roots may follow moisture and air along drainage and sewer lines underneath streets and sidewalks.

- Sidewalk pathways typically require a 7-foot vertical clearance, which may dictate species selection and/or selective pruning of trees upon or after installation.
- Vertical considerations for roadways include 8-foot clearances for bicycle traffic and as much as 14 feet clearance to avoid interference with buses. Pruning after installation may accommodate these conditions.

13.3.1.4 Median and Island Plantings in Urban Areas

Occasionally communities desire median or island plantings to enhance the visual quality of the roadway corridor. These locations are extremely challenging, particularly in high volume locations. The environmental stresses and maintenance demands are, along with safety considerations, greater than on the roadside. Clear commitment from the local community to maintain plantings is essential. General guidelines include:

- Median plantings in urban areas should be limited to areas where design speeds are less than 45 mph and where plants will not present a hazard or obscure sight distances or traffic signs and signals.
- From a horticultural standpoint, soil cross section for planted medians should be at least 10 feet for trees, 6 feet for shrubs.
- Selected trees should be upright, narrow, and high branching, in order to minimize interference with vehicles and pedestrians. Smaller tree species, including multi-stem trees tend to perform better than shade trees, but must not obstruct sight lines.
- Typically, the frequency of curb cuts and intersections will require maintaining sight lines across most, if not all, of the median, limiting shrubs and perennials to plants less than 3 feet high, including curb and earthwork height.
- Plants should be located as far from the curb as possible to prevent injury from salt, sand and snow.
- Raised earthwork on medians increases soil volume and raises plants above the roadway, providing greater protection from salt and sand.
- Where snow storage or traffic conditions may result in back-of-curb erosion, provide an 18 to 24-inch wide paved apron behind the curb.

Community commitment to maintenance is essential. Median areas are highly visible and highly susceptible to trash build up. Weeds must be regularly removed, plants watered, grass mowed, and branches routinely pruned. Planting and surfacing materials should be selected to avoid the emergence of weeds, minimizing the need for frequent manual weeding or herbicide application.

13.3.1.5 Lighting

Construction and maintenance requirements for roadways may limit the types of fixtures used. Communities are typically responsible for additional maintenance and installation costs of non-standard fixtures and lights. Aesthetic considerations include the detail and finishes of the posts and lamp housings, the post height, brackets, and the color quality of the light. The following general guidelines apply to the installation of street lighting, which is also discussed in Chapter 16:

- Top-mounted decorative lights can be obscured by adjacent street trees.
- It is advisable for light fixtures to cast the light downward to avoid obscuring the night sky and contributing to light pollution.
- Shorter lights are more to human scale, but provide a reduced spread of light. To provide adequate lighting, they must be installed at closer intervals. This increases installation, operation, and maintenance costs.
- In determining compatibility of illumination and planting, consider pole heights, light cones, the shape of the tree, and the horizontal location of poles relative to tree trunks.

13.3.1.6 Bicycle Racks

Bicycle racks are an integral part of accommodating bicycle transportation. Bicycle racks should be located where they are convenient to the users and where they will not interfere with pedestrian and vehicular traffic. Providing bicycle racks helps discourage users from locking bikes to railings, street trees, and other furnishings. General guidelines are presented below and additional references are provided in Section 13.7:

- The appropriate number of spaces needed should be assessed with respect to the associated building or land use.

- Ideally, the rack area should be protected from the elements
- Typical inverted “U” or post and ring systems are preferred, but any rack that meets the following criteria may be used:
  - Rack must enable the frame and one or both wheels to be secured, preventing the bike from tipping over.
  - The rack should be anchored so that it cannot be stolen with bikes attached.
  - For parallel storage, arrange rack elements 30 inches on center to allow space for two bicycles to be secured to each rack element.

13.3.1.7 Benches

When appropriately sited and properly constructed, benches create more attractive and comfortable human environments. Their design and construction should be appropriate to the character of the site. Backless benches allow two viewing perspectives. Benches should be located where people are likely to sit to wait, people-watch, rest, or look out at scenic views. They should not block pedestrian movement or impede wheelchair access. Avoid placing benches where they will not be used.

13.3.1.8 Trash Receptacles

Municipalities desiring receptacles must consider quantity and placement if they have limited resources to empty the receptacles. A period of monitoring may be necessary to determine the appropriate number of receptacles needed. In addition, receptacle design should consider capacity needs, security, weight, and vandalism, as well as lids to limit litter and rodent problems.

13.3.1.9 Information Signs

Information signs are necessary to guide people unfamiliar with the local area. Local zoning regulations are valuable in controlling the appearance, size and location of signs. Signs should be visible and conveniently located, but should not interfere with vehicular or pedestrian circulation. Less signage is better than excessive signage, which creates clutter and tends to be ignored.

13.3.2 Natural Site Landscape Treatments

Natural sites, as distinct from *streetscapes*, are those locations (urban and rural) where the principal objectives and concerns involve natural systems. Landscape design for natural sites encompasses surface stabilization of cuts and fills; containment and filtration of storm water runoff; tree replacement and reforestation; buffering of roadside ecosystems and habitats; screening views to and from the road; mitigating wind and snow drift; and habitat enhancement. Typical landscape conditions at natural sites are illustrated in Exhibit 13-2. In general, design for natural sites is primarily comprised of appropriately selecting and placing plant material. See Section 13.4, regarding plant selection.

13.3.2.1 Design Constraints

The principal constraints governing plant placement in natural sites are clear zones and sight lines, maintenance considerations, frequently dry and windy microclimate conditions, and relatively poor soil conditions along the roadside.

Planting in Clear Zones

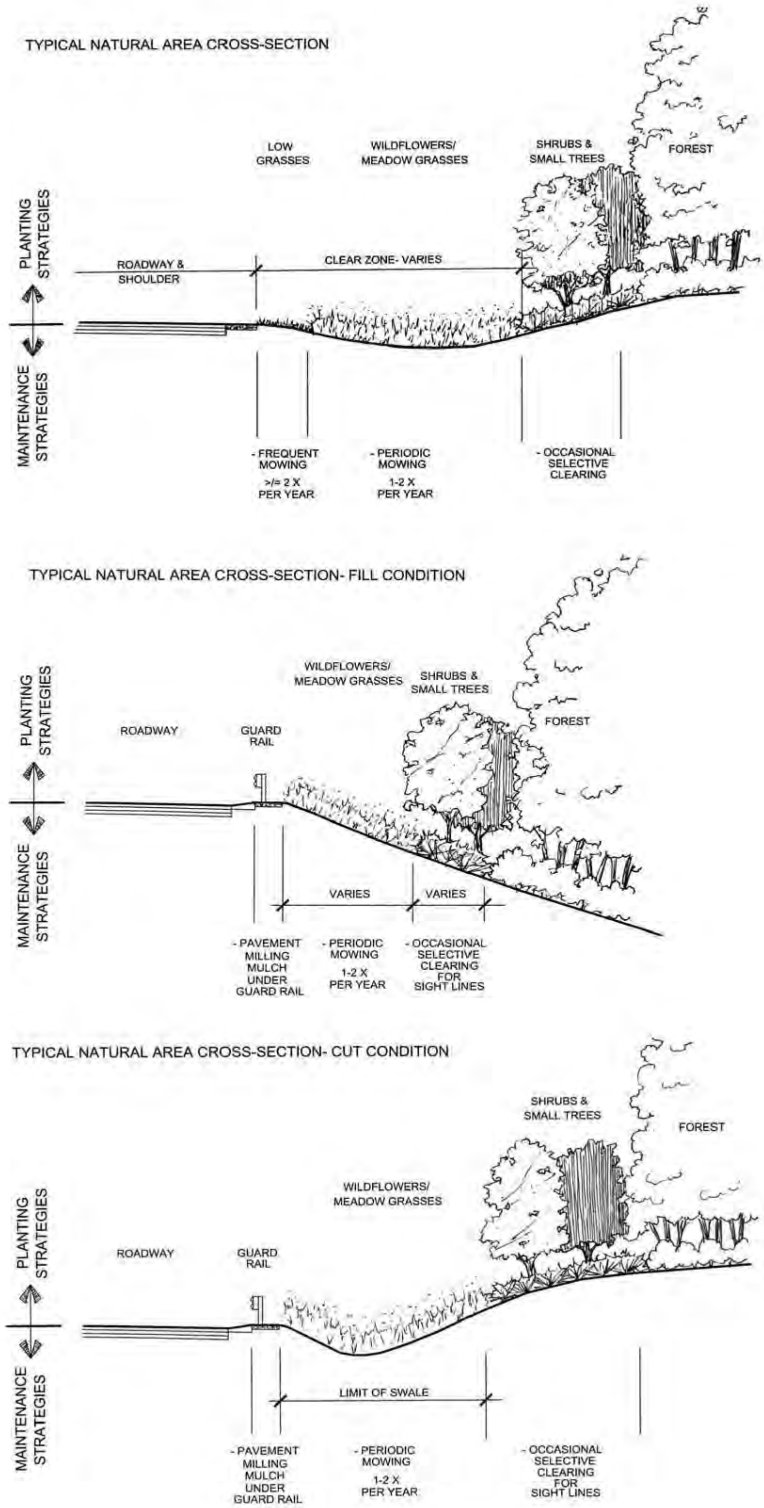
Technically, shrubs may be planted in the clear zone, although shrub masses are susceptible to successional growth of larger trees over time. Native grasses and perennials are good options for clear zone areas that are infrequently mowed.

Maintaining Sight Lines

Sight distance requirements on curves, and at interchanges and intersections limit the placement, height, and spread of plant material used. Sight distance requirements will depend on design speed, road geometry, and traffic controls. As with clear zones, low shrubs are technically feasible, but over time larger trees will have to be removed from shrub beds. Shrubs and perennials must be low growing. Larger trees should be set back to prevent branch encroachment and prevent blocking of traffic signs and signals, particularly for interstates and heavily traveled arterials.

Exhibit 13-2

Typical Landscape Cross-Sections at Natural Sites



Source: MassHighway

13.3.2.2 Design to Accommodate Roadway Maintenance

Successful integration of the road into the natural landscape requires anticipating typical maintenance practices. General planting guidance for maintenance of natural sites includes:

- Clear zones are typically mowed at least once a year, while 8- to 10-foot maintenance strips adjacent to the pavement may be cut more frequently. Grasses provide the typical groundcover. Native grasses and wildflowers are ideal where mowing is limited to once per year in the fall.
- In general, in natural areas, avoid planting woody material within 8 to 10 feet of the roadway edge, even behind barriers This area is typically mowed more frequently and may also be used for snow storage.
- Slopes steeper than 3H:1V are typically protected by guardrail. These slopes will not be mowed except for the area immediately behind the guardrail and may be planted with grasses, wildflowers, shrubs or trees.
- Plantings along the roadside must be able to tolerate salt runoff and salt spray from de-icing operations. Runoff tends to reach about 5 to 10 feet. While salt spray effects have been measured over 100 feet from interstates, the most noticeable impacts are on evergreens within 30 to 40 feet of the pavement on higher speed roadways.
- Locate large trees away from the road and use appropriate shrub and understory edge species in areas that are closer to the roadway.
- Avoid locating evergreen trees on the south side of east-west tangents to reduce potential roadway icing due to shade.
- Plant in groups to facilitate mowing and use perimeter mulching to help suppress weed growth during establishment.
- Locate plantings to ensure easy and safe access by maintenance teams.
- Reduce mowing areas by planting or allowing naturally occurring woody species to grow in expansive open areas.
- Use pavement milling mulch with weed barrier to suppress vegetation under and within 3 feet of the back of traffic barriers.

13.3.2.3 Buffers and Screening

Landscaping can provide a buffer between the road and adjacent land. Frequently this buffer is intended as a visual and aesthetic screen, either of the highway itself, or of undesirable views from the highway.

Earthwork landforms and berms can provide sound attenuation and add variety and shape to the landscape, but may require as much as 5 feet of cross section width for every foot of elevation. While trees and shrubs offer very little sound attenuation compared to structures, they provide substantial visual and psychological relief from traffic impacts.

When designing vegetative screening, use a diverse palette of plant material rather than a continuous wall of one species and size. Where space is adequate, provide a mix of evergreens and deciduous trees and shrubs, creating a mixed woodland strip. Where space is narrow, screening should be a mix of evergreen species and sizes.

- **Habitat Edge/Buffer** - In natural sites, a vegetated roadside edge provides a buffer for forests and other habitat areas. Plantings provide edge cover, screen wind and snow, and filter air and trash from roadway traffic. The vegetated edge also provides habitat for edge species and food and cover for wildlife movement along the roadway corridor, as further discussed in Chapter 14.
- **Water Resource Protection** - Plants are a critical part of water protection. They function as a physical barrier, protecting water from litter and other pollutants as well as slowing the flow of water to allow it to gradually filter through the soil, preventing erosion and flooding. Plants immediately along the water edge shade and cool waterways, protecting the habitat of fish and other wildlife.
- **Shading and Screening** - Trees on a rural roadway provide shade and reduce glare, lessening driver fatigue. Shrubs in the medians help screen headlights of opposing traffic. Trees can also be used to screen undesirable roadside views such as landfills, scrap yards, and other industrial uses. Evergreens provide winter screening.
- **Wind and Snow Breaks**. - Trees can prevent snowdrift and serve as windbreaks. Evergreens and dense deciduous shrubs are best for this use.
- **Framing Views**. Planting trees in rows or clusters focuses views and defines corridors. Plantings can also be used to draw attention to scenic views or historic landmarks.

- **Aesthetic Interest** - Shrubs and wildflowers provide visual accents, and large swaths of plantings create visual impact. A variety of plantings with seasonal interest and irregular plantings diversify roadway edges and reduce the monotony of a continuously forested edge. Reducing mowed areas and mowing times allows wildflowers to grow creating more interesting clear zones and open areas.

13.3.2.4 Medians in Natural Sites

In addition to the safety requirements of preserving clear zones and sight distances, medians in natural sites have many of the same environmental constraints as those in urban areas. However, they offer some additional design considerations.

- Shrub plantings and berms in the medians provide visual interest and screen headlight glare from opposing traffic. They also help reduce snow drifting.
- Rural medians provide an opportunity for storm water storage, conveyance and filtration. Plant selection and location should anticipate these functions. The *MassHighway Storm Water Handbook* and Chapter 8 of this Guidebook provide more information on these topics.

13.3.2.5 Steep Slope Conditions

Steeper slopes tend to be dryer due to increased run-off and (if south-facing) increased solar exposure. Planting recommendations, including maintenance considerations, include:

- Specify slope plant material in smaller sizes to facilitate transplanting.
- Plant in close groups on slopes to decrease wind damage to plants and to enhance root shading.
- Locate trees and shrubs away from channel bottoms and slope toes to avoid areas of flooding, poor drainage, and salt accumulation.
- South facing slopes require heat and drought tolerant species. North facing slopes require species that thrive in shade and a cooler microclimate.

13.3.2.6 Reinforced Slopes

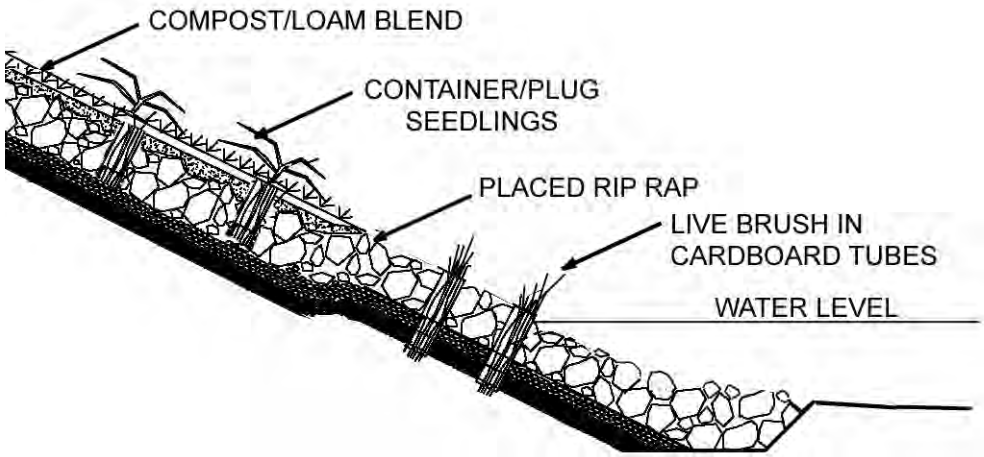
Protected resource areas and narrow right-of-way areas often require retaining walls or specially reinforced slopes to limit the area of impact. There are a variety of geotechnical solutions using wall unit systems and geotextiles to help stabilize steep slopes. Geotechnical evaluation of fills and cuts is necessary when considering alternatives.

Biotechnical stabilization integrates plant material with layered geogrid reinforced systems, riprap, and/or gabion systems. This method provides the benefits of bioengineered vegetative systems with the more predictable benefits of non-living structures and measures. The addition of deeply rooting plant material to the stabilization system can lead to longer term stability than is provided by strictly structural solutions. Further, the addition of vegetation provides ecological/habitat value, improves aesthetics, and reduces heat, glare, slope runoff amounts and rates, ice buildup and potential movement of structural elements over time.

To incorporate plants with geogrid systems, the facing of these slopes will require wrapping the slope face with rolled erosion control materials to ensure surface stability during plant establishment. Plants must be sufficiently drought and heat tolerant to withstand the steep slope conditions. In a similar fashion, gabion terraces may be inter-planted with seedlings or dormant plant material. A diverse palette of rapidly growing nurse (cool season) grass species mixed with durable native (warm season) grasses and wildflowers species, and rooted and dormant tree, shrub and vine species should be considered for any slope reinforcement site. The solar orientation (slope aspect) should guide the selection of appropriate plant species.

Where placed stone or riprap is used for steep slopes or bridge abutments, loam pockets and tube plantings can provide vegetative cover and wildlife habitat. When planting in pockets, potential dislodgement of plants and soil can be avoided through various preventative measures. Techniques can include tying woody stems to embedded rocks or other structural members and wrapping soil surface with sturdy, biodegradable erosion fabric, as illustrated in Exhibit 13-3.

Exhibit 13-3
Bioengineering Stabilization with Stone



Source: MassHighway

13.3.2.7 Bio-engineering and Stream Bank Stabilization

Bioengineering is the combined use of plant material and various natural and manufactured structural materials to stabilize, restore and/or reconstruct slopes, stream banks and shorelines. Because bioengineering seeks to mimic natural slope stabilization processes, rocks, boulders, logs, and dead brush may be used in combination with plantings. Existing soils may be enhanced with placed topsoil, marsh base and/or compost or leaf mulch. Biodegradable fabric is frequently used to hold soil in place prior to installation of plants. The term bioengineering covers a broad range of stabilization techniques, and therefore, allows for more site-specific treatment than strictly structural/conventional solutions. In some instances, bioengineering can provide more long-term stability than conventional solutions than structures alone.

As plants establish, the slopes become increasingly stabilized. However, there are some factors which must be considered:

- Bio-engineering depends on the performance of living material, which is difficult to predict, particularly during the initial establishment stage.
- Availability of water for irrigation, particularly in upland sites, may be limited.

- Bio-engineering tends to be labor-intensive, requiring hand placement of numerous plant stems at regular intervals.
- Some methods of bio-engineering require planting of dormant cuttings, which can only be implemented during certain seasons (usually very early spring).
- Proper stream bank repair requires an understanding of the specific stream type and stage of morphology.
- Bioengineering for stream stabilization is generally limited to bank slopes of 2:1 or flatter and has varying effectiveness depending on the morphology of the stream.
- Because they are constructed of living material, bioengineered systems must be monitored and maintained for at least a year or more following installation to ensure proper establishment of desired plant material and the control of invasive plant species.

Specifications on stream bank stabilization in the vicinity of bridge abutments and other critical slopes is provided by FHWA Highway Engineering Circular 23 (*HEC 23 Bridge Scour and Stream Countermeasures*).

13.3.2.8 Storm Water Management Facilities

Consistent with the goal of preservation, roadside design should pursue storm water management strategies that minimize the disturbance of existing vegetation and encourage vegetated filtration areas. However, standards for water quality may still require the construction of “Best Management Practices” in the form of filtration channels, detention/retention basins, and other storm water management practices. The *MassHighway Storm Water Handbook* provides guidance for the evaluation of storm water management demands and appropriate designs for roadway projects.

While constructed basins and channels improve filtration of runoff, they frequently become a dominant part of the highway terrain and substantially shape the roadside landscape. Basins should be designed to minimize disturbance to existing vegetation and topography, with a natural curvature that blends into the surrounding context. Planting can help integrate basins into the landscape. Configure basins to allow for appropriate screening and buffering of adjacent areas, particularly in residential locations. Avoid locating woody plants where sediment will accumulate, or on constructed retaining berms where planting may compromise the structure. Design should anticipate access for maintenance including sediment removal. Woody plants are not recommended in the basin area or on constructed embankments holding water.

13.3.2.9 Wetland Replacement

Thorough guidelines for wetland replacement are beyond the scope of this Guidebook. There is substantial guidance within the regulatory literature as to the performance objectives of wetland replacement. Basic guidelines include:

- Proposed replacement areas must fulfill the intent of replacing lost resources and functions.
- In addition to typical wetland requirements for adequate hydrology and proper soils, replacement areas in highway environments must be designed to anticipate additional environmental stresses and pressures from invasive plants associated with the roadside environment.
- Soils need to be evaluated as to potential seed content, including invasive plants. New soils should be manufactured from seed free components.
- Selected plant material must be self-sustaining and tolerant of salt and wind. Plant material may need to be planted in greater quantities and smaller sizes to compensate for transplant conditions.
- Plant selection should be based on a survey of existing material, should seek to restore native plant communities, and should not include any invasive or potentially invasive species.
- Grading, plant selection, and location must integrate and blend with upland conditions and existing hydrologic conditions.
- Wetlands are very susceptible to invasive species. Replacement projects must be inspected and managed after planting to ensure plant establishment and to control invasive material.

13.3.3 Noise Walls

Noise walls are installed where traffic noise exceeds or is expected to exceed established threshold levels. The introduction of these structures along the roadway can substantially depreciate the visual quality of the roadway corridor and become a mixed blessing to abutting land uses. Noise walls can particularly exacerbate the climatic stresses on roadside plants since the flat surfaces can substantially increase reflected solar gain, desiccating winds, and snow throw and salt spray accumulation. Design considerations for noise walls include:

- Provide noise walls only where they are needed, and consider terrain and abutting land uses.
- Typically, noise wall location is dependent on optimizing sound attenuation while minimizing wall height and construction cost.
- Where other factors do not prevail, wall should be sited such that it blends into the terrain and with existing vegetation.
- As setback from the highway increases, the opportunity for providing a sustainable planted roadside buffer also increases. Walls may also be constructed so as to weave through existing vegetation. Walls with more vegetation on the highway side are less susceptible to graffiti, however, the large scale of sound walls presents an imposing structure near residential areas.
- Walls within 20 feet of the traveled way will be limited to hardy vines and groundcovers on the roadway side.

13.3.3.1 Wall Design Aesthetics

Sound attenuation specifications control the materials, proportion and geometry of sound walls. Materials and installation costs further limit the alternatives available for the design. Aesthetic treatment lies in mitigating the effects of the large surface area, as described below.

- Architectural design that emphasizes and articulates posts can break up the surface of the wall and provide the appearance of a more decorative wall.
- Modular construction that breaks the surface into smaller units can relieve the monotony of continuous wall surfaces
- Using natural materials or simulated natural materials provides visual relief. The natural appearance and the layered pattern of the lumber makes wood an attractive option.
- Composite masonry units can be molded into a variety of forms that mimic stone masonry walls. However, where the reveal of the “grout” lines is shallow, shadow lines can disappear and the visual effect is lost to views from the road.

13.3.4 Bridges

Chapter 10 provides an overview of bridge design considerations. This section pertains to plant material around bridges and interchanges. Whether bridged interchanges are in predominantly natural or urban settings, the grade separation typically creates slope areas that benefit from landscaping. However, access to these areas can be limited, making maintenance difficult.

13.3.4.1 Interchanges

- Where bridges occur over roadways, plantings can blend the mass of the bridge into its environment. Plants also serve as ornamental features that enhance the interchange. In general, plant material should be selected and located to enhance the architectural lines of the bridge, rather than to screen the bridge.
- Locate plant material so that branches and stems do not obscure sight distances to and from ramps. Depending on interchange geometry, bridge abutments may govern available sight distances.
- Plant locations should allow access for periodic bridge inspection.
- Locate shade trees to avoid branch encroachment over bridge deck and locate plant material away from walls to allow for snow storage.
- Avoid over-planting or filling interchanges with trees and shrubs. These areas are frequently used as future construction staging areas and may be used for storm water storage.
- Planting hedges in interchange open space (outside of sight line and clear zone limits) can provide screening of headlights and reduce snow drifting.
- Planting materials should be diverse and massed to complement the design of the interchange. An irregular grouping of trees and shrubs with open spaces for wildflowers and grasses allows views and creates a more diverse and dynamic landscape.

13.3.4.2 Waterways

Where bridges carry traffic over waterways, landscaping may also be used to blend the bridge into the natural context and to restore adjacent areas used for temporary bridges and staging areas. Where existing patterns dictate, wildlife passages may be warranted, and surface treatment and landscape materials should integrate these passages with existing pathways, as described in Chapter 14.

Slope stabilization, including protection against scour, should be installed to look as natural as possible. This can be achieved by tapering armored stone aprons from bridge abutments out toward the bank so that they blend into the existing stream bank, rather than constructing abrupt edges that are perpendicular to the contour of the bank. Bio-stabilization techniques can further blend the armored surface with the natural riverbank form and habitat.

13.3.5 Traffic Barriers

As described earlier, traffic barriers are often used in steep slope conditions. They are also used in many other roadway settings to separate high-speed traffic flows and to shield other hazards. Barriers are described in more detail in Chapter 5 and options are available to increase the compatibility between the visual appearance of traffic barriers and the qualities of the setting. The designer needs to select a barrier system that meets the necessary safety requirements, can be obtained within the project budget, and can be effectively maintained. For additional information on aesthetic barrier treatments, the designer should refer to the 2002 AASHTO *Roadside Design Guide* and FHWA's *Flexibility in Highway Design*.

13.4 Plant Material Selection

Selecting the appropriate species is an essential part of creating a successful roadside landscape. Plants should be selected based not only on how they will thrive in that particular site, but also on how they may interact with and impact surrounding ecological systems. Good plant selection will create sustainable plant communities and transition areas, benefiting human and ecological systems. Poor selection can lead to plant failure which can result in soil loss, compromised highway structures, and the encroachment of invasive species, causing long-term negative impacts to surrounding as well as distant ecological systems.

13.4.1 General Plant Material Selection Guidelines

General guidance for species selection includes:

- **Hardiness** - Plants should be hardy to the region in which they will be planted. Roadsides have extremes of microclimates: south facing slopes get full sun and heat, north facing slopes are cool and shaded, areas close to the road have high wind conditions and salt spray. In urban environments, asphalt, building masses, automobiles, and reflective surfaces generate radiant heat, creating a microclimate hotter and drier than the general climate.

- **Existing Plant Species and Communities** - Surrounding vegetation should be assessed to determine what species are doing well in the site's general soil and climate conditions. Determine whether there are invasive species in the surrounding area that may out-compete new plantings. Surrounding vegetation can also be used as a clue to pH and moisture levels when selecting new species.
- **Soil Quality** - Soil should be evaluated for texture, pH, moisture and soil biology. Most soils close to the road are infertile, dry, compacted, and contain salt and other pollutants. New soils brought in after construction have better soil quality in terms of texture and density, but they tend to lack necessary soil organisms. The designer should select plant species appropriate to anticipated conditions.
- **Diversity of Species** - A diverse selection of plants, including native species that are already existing in the landscape should be used. Mixing different sizes and types of plants (i.e., shrubs, evergreens, deciduous trees, and groundcovers) helps create an interactive plant community. While the diversity opportunities are much more limited on streetscapes than in naturalized areas, diversity of species remains important. There are many benefits to choosing a variety of species, including pest or disease resistance within the population. Choosing cultivars that are more tolerant of drought and more resistant to pests and diseases is also important.
- **Plant Sizes and Densities** - Plant sizes (in age) should be relatively small. Quantities and spacing (particularly for reforestation type plantings) should be close due to the stresses and mortality during establishment. Varying ages prevents all trees from maturing and having to be replaced at the same time, thus maintaining general canopy cover at all times. Where conditions permit, smaller species can be planted between or in front/back of larger shade trees. The following general species selection considerations apply:
    - Do not use invasive and potentially invasive species.
    - Use native species, particularly in ecologically sensitive areas, when possible.

- Choose trees that are low maintenance (no spraying, pruning, fruit litter).
- Choose trees that are tolerant of specific site conditions (narrow spaces, overhead wires, salt, compacted soil, low soil volume, pollution).

13.4.1.1 Native Species

Native species are defined as species that occur in a region as result of natural forces rather than as having been brought in by humans, either intentionally or accidentally. A species may be native to a large area, such as North America, or may be native only to a small area, such as Cape Cod. The plant's native range, or region, is typically associated with environmental factors such as climate, soils, and topography. When choosing native species, it is recommended to choose plants as locally "native" as possible.

In an effort to restore native plant communities and retain native wildlife, planting of native species is recommended. The 1994 *Executive Memorandum on Environmentally Beneficial Landscaping* directs federally funded projects, to the extent practical, to use regionally native plants for landscaping and to minimize adverse effects on natural habitats, including reducing the use of fertilizer and pesticide.

In addition to environmental benefits, native species reflect the region's ecological characteristics. For instance, sugar maples or New England Asters along a New England roadside give a sense of place and identity to the roadway or streetscape. In general, native species are better adapted to the native climate and soils of a region. However, roadsides and other developed or exposed areas may not have typically "native" conditions. Therefore, species should be chosen with regard to the specific site conditions.

Special attention should be paid to sensitive areas and efforts should be made to plant native species in ecologically sensitive areas along waterways, wetlands, and areas noted for rare and endangered species.

Less common native species may not be available at the nurseries. Some native plants are not commonly used and therefore not readily available. When specifying native plants for a project, choose species and sizes that are available to avoid substitutions with non-native species at planting time.

13.4.1.2 Invasive Non-Native Species

Exotic or non-native species are those that have been introduced into a region by humans. Many early introductions came from European settlers who brought plants with them for human and animal consumption, for medicine, to make products, and for ornamental use. Some non-native species were accidental introductions, arriving with ships, in packaging, or with cattle. Many new weed species continue to enter the United States as seed contaminants.

Executive Order 13112 on Invasive Species requires Federal agencies to the extent practical to prevent the introduction of invasive species, respond to and control populations in a cost-effective and environmentally sound manner, to monitor invasive species populations, and to restore native species and habitat conditions in ecosystems that have been invaded.

Invasive species are common along roadsides because they survive and thrive in harsh climates and poor soils. Traffic, construction, and roadside vegetation management, including mowing, also contribute to the spread of these species along the roadway corridor. Invasive species have not only spread along the roadways, but have also spread into minimally managed environments and are displacing native species. Managing invasive species for roadside visibility, safety and general maintenance has proven expensive and difficult. While no longer planting these species will not eliminate them from the environment, it may help to contain the population. See Exhibit 13-4 for list of invasive species.

No invasive species should be planted. The most commonly planted invasive species that should no longer be used include: Burning Bush (*Euonymous alatus*), Barberry (*Berberis thunbergii*), and Norway Maple (*Acer platanoides*). Cultivars of these species have been found to revert back to the species and should not be used. Existing vegetation should be identified and measures taken to prevent the spread of invasive plants during and after construction.

13.4.1.3 Potentially Invasive Plants

Plants that have been found to be potentially invasive should be avoided, particularly in sensitive areas such as near waterways. In particular, species that spread by seed should be avoided as highway traffic, wind, and maintenance activities provide means for seeds to travel. Also, many roadways are along rivers and waterways, allowing for further spread of these species.

Exhibit 13-4
Selective List of Invasive or Potentially Invasive Ornamental Plants

Invasive Species (Do Not Use)	
Acer platanoides	Norway maple
Acer pseudoplatanus	Sycamore maple
Ailanthus altissima	Tree of heaven
Berberis thunbergii	Japanese barberry
Celastrus orbiculatus	Oriental bittersweet; Asian or Asiatic bittersweet
Elaeagnus umbellata	Autumn olive
Euonymus alatus	Winged euonymus, burning bush
Frangula alnus	European buckthorn, glossy buckthorn
Hesperis matronalis	Dame's rocket
Iris pseudacorus	Yellow iris
Lonicera japonica	Japanese honeysuckle
Lonicera morrowii	Morrow's honeysuckle
Lonicera x bella [morrowii xtatarica]	Bell's honeysuckle
Lythrum salicaria	Purple loosestrife
Phalaris arundinacea	Reed canary-grass
Phragmites australis	Common reed
Rhamnus cathartica	Common buckthorn
Robinia pseudoacacia	Black locust
Rosa multiflora	Multiflora rose
Likely Invasive (Do Not Use)	
Berberis vulgaris	Common barberry; European barberry
Euphorbia cyparissias	Cypress spurge
Ligustrum obtusifolium	Border privet
Lonicera tatarica	Tatarian honeysuckle
Miscanthus sacchariflorus	Plume grass; Amur silvergrass
Potentially Invasive (Avoid)	
Lonicera maackii	Amur honeysuckle

Source: "*The Evaluation of Non-Native Plant Species for Invasiveness in Massachusetts*," Massachusetts Invasive Plant Advisory Group, 2005

13.4.2 Plant Selection for Streetscapes

Vegetation and individual street trees play an important role along streetscape corridors. They enhance the ecological environment, which in turn enhances the environment for the community by improving microclimate, air quality and aesthetics. While more sparsely located, street trees and shrubs should also be considered as part of a larger system in that they function as links for animals migrating or seeking food within a larger habitat corridor.

As discussed in Section 13.3.1, streetscape environments are complicated by having multiple users, utilities, intersections, sidewalk accessibility requirements, and limited planting areas. Microclimate conditions on streetscapes are often harsh due to heat radiation from light reflected from buildings, windy conditions, or heavy shade from buildings. Soil conditions are generally poor. Soil volume in tree pits may be inadequate for healthy growth of most tree species and existing soil compaction or potential soil compaction due to pedestrian traffic are typically problems. Urban activities also create limitations: car doors opening, bus/truck clearance, and sign and safety visibility requirements. Overhead wires, utility poles, hydrants, mailboxes, and light fixtures further restrict the types of trees that can be used.

13.4.2.1 Recommended Species for Urban Conditions

General species guidelines for urban areas include:

- Use a variety of species, rather than just one or two species.
- Columnar cultivars should be considered for narrow areas.
- Trees that reach mature heights of 25 to 30 feet are better for areas where there are overhead utilities. The small upper branches of these trees may be pruned, but the heavy limbs, capable of breaking wires, remain well below the wires.
- Where soil conditions and overhead clearances allow, larger shade trees that can be limbed up may be preferable to smaller trees.
- Avoid species and cultivars that drop fruit or have excessive leaf litter, species that require frequent pruning or irrigation, and species with thorns.

Specific species recommended for streetscape environments are presented in Exhibit 13-5.

Exhibit 13-5
Suggested Street Trees

Botanical Name	Common Name	Cultivars	Size	Characteristics
Large Trees (mature size more than 40')				
Acer rubrum	Red Maple	'Red Sunset', 'Armstrong', 'Bowhall', 'Columnare'	40-75'	Does not tolerate heavily polluted areas, dry soils. Prefers acid soils.
Celtis occidentalis	Common Hackberry		40-60'	Wind tolerant, salt and drought resistant. Subject to pests and disease.
Fraxinus pennsylvanica	Green Ash	'Marshall's Seedless', 'Summit'	50-60'	Tolerant of heat, cold, wet and dry soils. Subject to borers and scale. Select male cultivars.
Ginkgo biloba	Ginkgo	'Autumn Gold', 'Princeton Sentry'	50-80'	Tolerates extremes of soil, heat and pollution. Choose male clones only.
Gleditsia triacanthos var. inermis	Thornless Honeylocust	'Skyline', 'Shademaster'	30-70'	Very adaptable to soils and tolerant of salt, drought, and soil compaction. Over-used. Subject to pests and disease.
Platanus x acerifolia	London Planetree	'Bloodgood', 'Columbia', 'Liberty', 'Yarwood'	70-100'	Tolerates wide range of soils. Select anthracnose resistant cultivars. Best where has large space.
Quercus palustris	Pin Oak	'Crownright', 'Sovereign'	60-70'	Fairly tolerant of city conditions. Intolerant of high pH soils. May need to be limbed up.
Quercus robur	English Oak	'Fastigata'	40-50'	'Fastigiata' is good for restricted areas, but red and pin oak are better choices where space allows. Mildew can be a problem.
Quercus rubra	Northern Red Oak		60-80'	Tolerates range of soils, withstands pollution. Intolerant of high pH.
Tilia cordata	Littleleaf Linden	'Corinthian', 'Glenleven', 'Greenspire'	60-70'	Tolerates pollution and pruning. Susceptible to salt, as well as aphids and Japanese beetle.
Ulmus americana	American Elm	'Princeton', 'Valley Forge', 'New Harmony'	60-80'	Withstands extremes of soil conditions, salt tolerant. Subject to pests and decay. Select Dutch elm resistant cultivars.
Ulmus parvifolia	Chinese Elm	'Allee', 'Athena', 'Milliken'	40-50'	Adaptable to wide range of soil, tolerant of urban conditions. Resistant to Dutch elm disease, elm leaf beetle and Japanese beetle.
Ulmus sp.	Elm hybrids	'Frontier', 'Regal', 'Homestead'	40-50'	Tolerant of urban conditions. Select resistant cultivars. Susceptible to elm leaf beetle.
Zelkova serrata	Japanese Zelkova	'Green Vase'	50-80'	Tolerant of soils, wind, drought, pollution. Good resistance to Dutch elm disease, elm leaf and Japanese beetle.

Source: MassHighway

Exhibit 13-5 (Continued)
Suggested Street Trees

Botanical Name	Common Name	Cultivars	Size	Characteristics
Medium Trees (mature size approximately 30-40')				
Acer campestre	Hedge Maple		25-35'	Very adaptable, tolerant of dry soils, soil compaction and air pollution. Withstands severe pruning.
Koelreuteria paniculata	Golden Raintree	'Fastigiata'	30-40'	Tolerant of heat, drought, wind, compacted soils, and air pollution. Possibly weak
Pyrus calleryana	Callery Pear	'Aristocrat', 'Chanticleer'	30-35'	Adaptable to soils, tolerates dryness and pollution. Overplanted. Use only disease/pest resistant cultivars, narrow cultivars for restricted space.
Small Trees (mature size less than 30')				
Acer ginnala	Amur Maple		15-20'	Adaptable to wide range soils, tolerant of wind and drought. Select single stem. May need to be limbed up.
Amelanchier sp.	Serviceberry	'Autumn Sunset', 'Cumulus'	15-25'	Adaptable to soil, not pollution tolerant. Subject to insects and diseases. Select resistant cultivars and single stem.
Malus sp.	Crabapple	'Donald Wyman', 'Cardinal', 'Prairifire',', 'Snowdrift', 'Zumi'	15-30'	Tolerant of drought, salt, air pollution. Wide variety of sizes and shapes. Select disease/pest resistant cultivar. Fruit litter. Low branching.
Syringa reticulata	Japanese Tree Lilac	'Ivory Silk', 'Regent', 'Summer Snow'	25-30'	Adaptable to difficult sites. Resistant to mildew, borers and scale.
*List is not a comprehensive urban tree list. Trees in list may not be appropriate for all conditions.				

Source: MassHighway

13.4.3 Plant Selection for Natural Sites

Generally, natural sites involve larger expanses of land, more extensive vegetation and associated wildlife, and significant water bodies. There is a wider range of species that can be selected for these areas, however, plants located close to the roadway must be able to tolerate climate conditions of exposure, high winds, salt spray, and full sun. Unless new soil has been brought in, soils close to the road are typically infertile, very dry or fluctuating between wet and dry, and often contain salt and other contaminants. Typical of naturalized roadside environments, there is little maintenance either to get plants established or to ensure their survival once established. The following functions and restoration goals should be considered when choosing plant species:

- **Erosion Control** - Deep-rooted species, such as warm season grasses and perennials are recommended for erosion control. They hold soil in place, can absorb run-off, and help water infiltrate the soil. Quick growing species are good for immediate erosion control.
- **Water Protection** - Using plants to benefit hydrologic systems is important to protect water bodies, wetlands, and aquifers. Deep-rooted species in particular, including native grasses and perennials, help water infiltrate through the soil and absorb excess nutrients.
- **Habitat Restoration** - All plants provide habitat. However, different species offer different kinds of habitat. Shrubs offer different forms of cover and food than trees, and evergreens offer different habitat environments than deciduous plants as well as providing winter cover. Consider a variety of types of plants (trees, shrubs, groundcovers) to provide a range of food and cover throughout the year. Planting native species helps support habitat for native wildlife. Edge conditions, such as where forest meets open areas, provide cover and a protective buffer from the road. When restoring roadway edge conditions it is important to consider species in terms of horizontal layering and vertical layering. This means choosing plants that fill all layers: trees which provide food, shade, and viewing posts; understory trees and shrubs which provide food and cover for small animals; grasses and perennials which provide food and cover for insects, birds and small animals; and groundcovers which protect creatures that move along the earth surface.
- **Pioneer Plants** - The roadside conditions after construction may be significantly disturbed and altered such that native species or species established in the surrounding environment will not thrive in the newly constructed roadside environment. In such cases, imitating typical succession patterns by using a mix of the surrounding species with fast growing, pioneer species that thrive in infertile soils - such as cherries, poplars, sumac, birches, and silver maples - helps create a forest type microclimate. These pioneer species grow fast, providing shade and cover for those species that are more difficult to get established.

13.4.3.1 Cultivating Grasses and Wildflower Meadows

Natural sites along the road offer an ideal opportunity for cultivating wildflowers. Clear zones within the roadside right-of-way must be maintained as grassland, ensuring the long-term establishment of grasses and perennials. Reducing mowing and incorporating more native grasses and wildflowers provides more food and shelter along these corridors than the traditional, continually mowed areas.

Wildflowers and grasses not only benefit insects and wildlife, but they create a more visually interesting and attractive roadside throughout the seasons, helping to alleviate driver fatigue. Wildflowers, either perennial or annual, can also be used to accentuate certain areas and to mark gateways. There are basically two strategies for cultivating wildflowers along the roadside: reducing areas that are mowed and by seeding. Both methods require reducing mowing to a once-a-year mowing schedule. This is important not only so that the blooms can be enjoyed throughout the seasons, but also to allow the wildflowers and grasses to set seed for the following year.

Benefits of cultivating grass and wildflower meadows include:

- Mowing less will also reduce air pollution and mowing expenses.
- Flowers and seeds provide a greater source of food attracting insects and birds.
- The diversity of herbaceous species will likely increase due to a reduction in mowing. This in turn may encourage greater diversity of wildlife.
- The reduced mowing cycle will encourage the growth and dispersal of New England natives such as goldenrods, asters and milkweeds, all of which provide an important food source for native wildlife.
- Taller herbaceous material provides better cover for birds and small mammals that nest and move along the highway corridors. Mowing later in the season allows many species of grassland birds and mammals to nest and to successfully raise their young.

Seeding Native Grasses and Perennials

Roadsides are an excellent place to begin re-vegetating by seeding perennials and native warm-season grasses. Highly disturbed areas or areas with new soil provide an ideal site for establishment since there is less competition from weeds and cool season grasses. It is also easier to control what competition there is until the warm season grasses are established.

Native warm season grasses tend to be more aesthetically attractive than cool season grasses because, unlike the cool season species whose flower stalks topple in summer, the stems and seed heads of these later-flowering grasses persist well into winter, maintaining their ornamental appeal.

Perennials and native grasses have several benefits over annuals and cool season grasses, but are more difficult to get established. Unlike annuals and cool season grasses, which usually spread by rhizomes, native perennials and warm season grasses tend to grow very deep root systems, sometimes down to 12 feet deep. However, in order to establish the initial root system, they partition more energy to the roots, resulting in slow aboveground growth of perhaps only 2-3 inches after the first season. It is because of this deep root system that once established, perennials and warm season grasses are longer lasting and more drought tolerant. The deep roots also provide additional benefits such as:

- Erosion Prevention—the deep fibrous root systems hold the soil.
- Improved water quality—deep roots absorb more water than sod and help to prevent runoff, which might result in less fertilizers and pollutants ending up in the water supply.
- Improve soils—the greater root bio-mass provides increased organic matter in soils and more rapid infiltration rates.

Due to establishment of extensive root systems, perennials and warm season grasses can take three to five years before they flower. Native and perennial species should not be chosen if the goal of the seeding project is quick cover and/or quick color.

In order to prepare the site to eliminate competition from existing species or seeds in the soil, a site will need to be sprayed with herbicide or repeatedly tilled to eliminate as many weeds and dormant seeds as possible. Soils generally do not need to be amended and no fertilizers are necessary.

Seeding Annual Wildflowers

Annuals typically have a very showy display in year one and maybe year two, but generally need to be reseeded in order to maintain such a display. Annuals are best used as a short-term means of accentuating “gateways” and other highly visible locations. They can also be incorporated with perennials in order to get blooms in the first and second years, before perennials typically bloom.

Restoration by Reduced Mowing

Medians and roadside areas should be mowed according to clear zone and sight line requirements and to maintain a neat and cared-for look. As part of a program to reduce mowing costs and to create beneficial aesthetic and ecological changes along the roadways, expansive open areas and areas where sight distance is not a concern can be designated for no mowing at all. In these areas, native trees and shrubs should be allowed to establish and over time, through succession, reforest that area.

13.5 Plant Protection and Preservation

During initial project development, existing vegetation should be assessed as to whether it should be preserved and if so, what steps should be taken to protect it. All vegetation should be assessed, not only trees. For instance, a dense stand of native grass not only serves a highly important function in terms of habitat and erosion control, but such a stand takes considerable time to become established, and therefore should be protected. Vegetation should be considered as to how it fits into the larger landscape and larger ecosystem: groups of trees or vegetation are often important parts of a larger forest or vegetated corridor.

Not all vegetation should be preserved. In some cases, the vegetation is not desirable: it may be overly mature, diseased, damaged or may be an invasive species. In such cases, the vegetation should be removed and replaced.

13.5.1 Trees

Trees are the most noticeable vegetation along roadways, particularly in the urban/suburban streetscape environment, and their removal usually has the biggest impact—both ecologically and visually. In assessing whether a tree should be preserved or removed, it is important to understand the basic structure of trees and how they function, as illustrated in Exhibit 13-6.

Roots

Trees get their water, oxygen, and most mineral nutrients through their root systems. Roots are therefore absolutely critical to the health of the tree. Roots also anchor the tree, preventing it from toppling. Most of tree preservation should focus on protecting the roots of the tree.

Tree roots typically grow along the top 18 inches of soil and extend well beyond the canopy of the tree. They tend to grow along the surface of the soil because that is where they have access to oxygen and water.

In order for oxygen and water to penetrate the soil and for roots to be able to grow and obtain oxygen, water and nutrients, the soil must have good structure. Good soil structure is characterized by the amount and size of pore spaces created by soil particles and organic matter. These pore spaces allow water, air and microbes to penetrate and move through the soil. Vehicular traffic, pedestrian traffic, tillage (especially when wet) and the storage of heavy equipment will ruin the soil structure, compacting the pore spaces and damaging tree roots. Most trees will die in compacted soil because they cannot get the oxygen, water and nutrients required for survival.

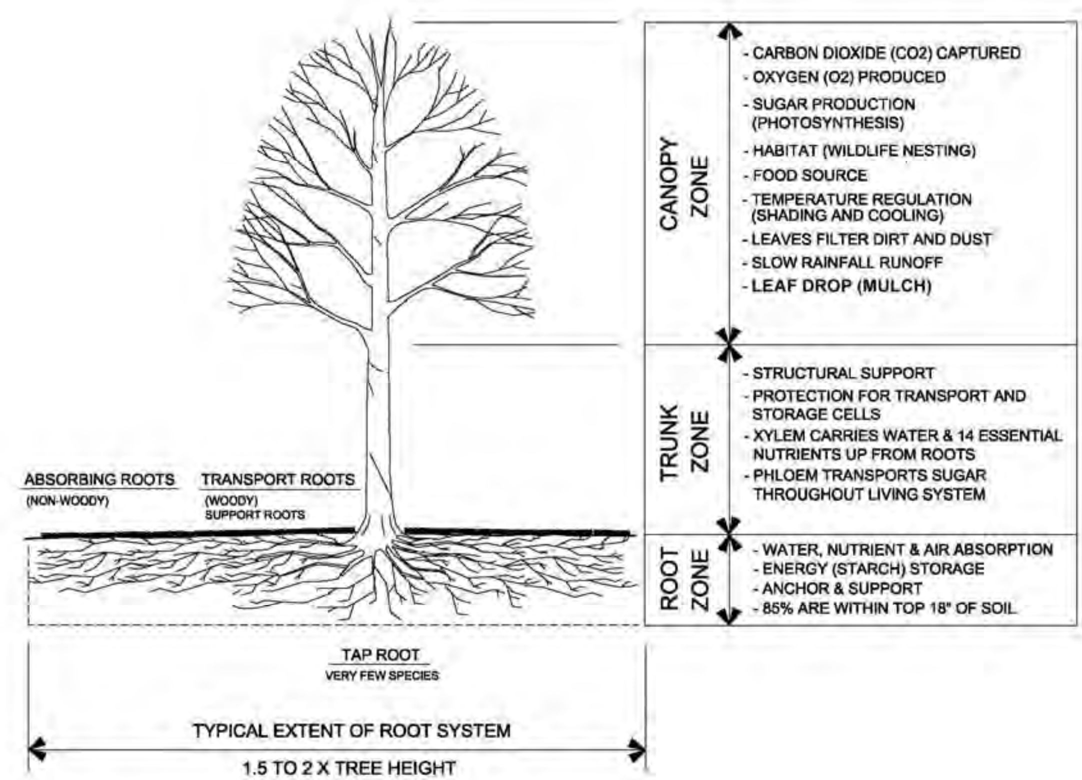
Trunk/Stem

The trunk of a tree serves two functions: it provides the means of transporting mineral nutrients, sugars and water between the roots and the canopy of the tree, and provides the structural support to hold the tree. The bark of the trunk protects the transport and storage cells. Protecting the bark and the trunk is important for protecting the means of transporting nutrients and water so that the tree can grow and survive. Wounds to the bark, the trunk, or major stems that do not close properly can cause decay.

Canopy and Branches

The tree canopy, through the process of photosynthesis, converts, water, CO_2 and nutrients into energy to support the growth of the tree. Significant damage to the canopy can compromise this conversion process. Substantial loss of limbs, either through damage, pests, or poor pruning practices, can also leave the tree prone to decay and failure.

Exhibit 13-6
Tree Structure and Functions



Source: MassHighway

13.5.2 Evaluation of Construction and Project Impacts

Construction impacts should be evaluated as to how they will affect the long-term health of the surrounding vegetation, particularly with regard to trees as they have the most extensive root systems. The following construction impacts should be avoided:

- **Changes in grade** - As little as 2 inches of soil placed on top of the root zone can smother roots by preventing the flow of water and oxygen into the soil. Removing soil may damage and expose root systems.

- **Damage to a significant portion of the root system** - If more than one-third of roots will be removed or otherwise significantly impacted, the tree should be considered for removal.
- **Soil compaction** - Vehicle and excessive foot traffic, as well as equipment or materials storage, will destroy soil by compacting it and closing soil pore spaces. This prevents water and air from moving through the soil, destroying roots and vital soil microbes. Protective measures should be taken to protect soil during construction. Storing equipment or material over root zone areas can cause moisture or aeration deprivation.
- **Damage close to tree trunk** - Removal or damage to the large roots close to the base of the trunk will have a significant impact on the tree. Damage to the trunk will interfere with the flow of nutrients and leave the tree susceptible to disease and decay.
- **Improper or excessive pruning** - Loss of too much tree canopy will interfere with photosynthesis and nutrient uptake, weakening the tree. Excessive loss of canopy also reduces the visual quality of trees and lessens its value in terms of providing shade and screening.
- **Excavation outside of tree root zones that alters subsurface water availability** - Changes to the surrounding area may cause changes in moisture levels creating conditions that no longer are appropriate to the existing tree species.
- **Increased exposure from unavoidable clearing** - Trees in a forested area typically have small canopies (low live crown ratio) and few lower limbs (i.e., pines). Once surrounding vegetation is removed, they may become structurally unsound. Such trees are also not aesthetically appealing.

13.5.3 Assessing Vegetation for Preservation

Accurate site information is essential in determining which plants, particularly trees, can be preserved and which will require removal. Project planners and designers should take measures to anticipate impacts from both construction activities and the project itself by visiting the site during the early stages of planning. Survey information is helpful in providing plant locations, but it does not replace a site visit. For instance, survey information often does not show the diameter of the tree trunk and therefore does not necessarily show the extent of impact the tree will suffer from changes in sidewalk or street re-alignment. Survey information also does not relay information about the health, age or structure of the tree.

During the project planning process, designers should identify on plans trees that might be affected and determine whether to protect or remove and replace existing vegetation. Trees and other vegetation should be evaluated for preservation in terms of the following considerations:

- **Species characteristics** - All species have characteristics that allow them to adjust to change or tolerate damage to different degrees. Some species are much more tolerant of disturbance and tolerate a much wider range of conditions. Some species are short lived and are not worth putting extra effort into preserving. Consideration should be taken as to:
  - life span
  - how well the species adapts to disturbance
  - resistance to decay and compaction
  - tendency to fail when exposed to wind
  - habitat value
  - invasiveness
  - historic or cultural value
- **Size** - The larger the plant size, the larger the area of root zone requiring protection.
- **Age** - Older plants may be less tolerant of construction impacts and will require larger protection zones.
- **Overall health of tree or community of plants** - Healthy plants will withstand removal of more roots, provided there are no stabilization problems. Plants that are diseased, damaged, or have pests should be considered for removal and be replaced.
- **Structure of plant** - Plants that show signs of decay or potential for decay, have been improperly pruned, or street trees that are poor specimens should be considered for removal.
- **Live crown ratio** - This is the ratio of the length of the live crown to the height of the tree. Trees with live crown ratio greater than 50 percent are the best candidates for preservation. Tall trees with

small crowns are structurally unstable. Many forest trees have low live crown ratios due to closer proximity of other trees. Forest pine trees in particularly, have low live crown ratios.

- **Crown integrity**. Crown should have healthy foliage, which typically signifies a healthy tree.
- **Pruning history (cut leaders, topped)**. Improperly pruned trees are susceptible to decay.

13.5.4 Plants Requiring Removal

In some cases there may be instances where tree or plant removal may be desirable, such as:

- When plants are weed species or invasive, as described in Section 13.4.1.2.
- When trees are structurally unsound, show signs of decay, have small crowns, and/or have small root systems.
- When plants are diseased or pest ridden since they will be more susceptible to failure under stress.
- When construction impacts are too significant for species to survive, or species has low tolerance of impacts.

13.5.5 Determining Tree Protection Zone

If it is desirable to retain a tree, there are several guidelines to determine the tree protection zone that will be required. These limits will indicate boundaries for permanent protection measures, such as walls, as well as temporary construction measures, such as fencing. Trees should be protected to the edge of tree canopy, or 1.5 times the drip line for narrow-canopied trees. Using trunk diameter is another method that may be more appropriate: for every inch of trunk diameter at 4.5 feet above grade, allow 1 to 1.5 feet of space from the trunk. This method is not dependent on the tree canopy, which may be small or irregular and not reflect the root zone area. In general, a minimum of 6 feet should be protected around a tree regardless of its diameter.

Other factors (determined as part of the plant evaluation) should also be considered. For instance, older trees may be more likely to die due to root loss and should have a larger root zone protection area. Some species are more likely to fail due to root loss and these should also have larger root zone protection area. In general, to determine tree protection zone:

- Evaluate species tolerance of the tree: good, moderate, or poor.
- Identify tree age: young, mature, or over-mature.
- Estimate distance from trunk that should be protected based on canopy size or trunk diameter.

13.5.6 Design Measures to Preserve & Protect Trees

If a tree is to be preserved, design measures should focus on preventing injury to trees, particularly to the root zones, during construction and after construction. Design strategies include:

- Shifting sidewalk or roadway geometry or reducing cross section to avoid the tree.
- Narrowing sidewalk to minimum accessibility thresholds in immediate vicinity of existing trees.
- Adjusting the profile (up to accessibility constraints) such as raising the sidewalk to existing grade rather than excavating to construct the walk.
- Using retaining walls and/or steepened slopes to minimize cuts or fills over existing root systems. For example, one can steepen the grade as it gets closer to the tree root zone area. Not only does this reduce the impact to the tree, but will also reduce the amount of cutting or filling in that area and reduce associated costs.

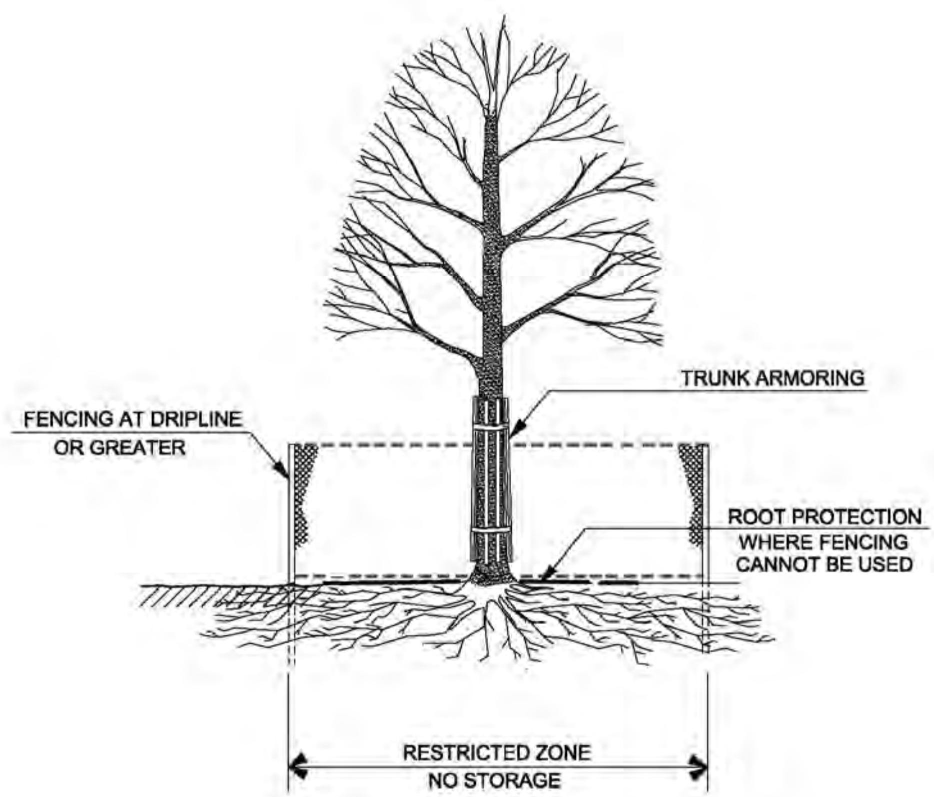
13.5.7 Construction Measures to Preserve & Protect Trees

Protecting plants is an important part of construction staging and operations. The following measures can be employed to protect plants during construction, as illustrated in Exhibit 13-7:

- Fencing should protect as much of the root zone area as possible. Fencing should enclose the entire root area of the plant or groups of plants to the edge of canopy. No activities should be allowed within this zone including no vehicular or foot traffic and no storing of machinery or supplies.
- Pruning of broken branches or roots by a certified arborist.
- Irrigation of disturbed roots.

- Avoiding staging areas around trees and protect tree roots close to staging area.
- Providing trunk armoring along with fencing if construction comes close to tree trunk.
- Mulching root zones to keep soil moist and protect roots.
- Providing wood chips where storage or foot traffic cannot be avoided: A layer of 4 to 12 inches of wood chip mulch can help prevent compaction of soil in the root zone.
- Bridging the root zone area when it cannot be fenced off. Plywood or steel plates supported by railroad ties or on top of wood chip mulch to cover the root zone area can be used so that the weight of a vehicle or equipment is distributed over the sheeting, not the ground.

Exhibit 13-7
Tree Protection



Source: MassHighway

13.6 Plans and Documentation

Documentation of projects is essential and additional information on project planning and design is provided in Chapters 2 and 18. Not all of the documentation recommended below is required for all projects. The type of project, its complexity, and the extent of change to the landscape will determine the extent of documentation.

From the standpoint of landscape and context analysis, photographic documentation is the most useful, simplest, and least expensive form of documentation. In addition to publicly-available orthographic aerials, digital photography has made the cost of collecting and distributing images negligible.

A further benefit of digital photography is the ability to readily edit and illustrate, in either elaborately rendered or simple diagrammatic form, the type and extent of changes for a given proposal.

13.6.1.1 Preliminary Development

The following are recommended design considerations during project planning and at the preliminary design stage:

- Aerial orthophotos.
- A comprehensive site photo documentation set.
- Large or complex projects should be superimposed on corresponding aerial orthophoto.
- Additional diagrammatic information may be included on aerial photograph to annotate graphic data for better understanding of context.

13.6.1.2 25 Percent Submittals

The following activities should be completed in preparation for the 25 Percent submittal:

- Early environmental coordination.
- Overlay of project on environmental layers.
- Digital site photo documentation.
- Narrative of site changes and estimated impacts.
- Photo documentation of existing structures (i.e., bridges).

- For Design Public Hearings, plan superimposed on aerial orthophoto, including approximate limit of impacts, such as grading.
- For complex or controversial projects, visual simulation showing changes.
- For projects where landscape is integral to the purpose or is substantially affected, a narrative of impacts and proposals.
- For streetscape/enhancement projects, approximate locations and type of landscape materials, including preliminary species list.

13.6.1.3 75 and 100 Percent Submittal

The following activities should be completed in preparation for the 75 and 100 Percent submittals:

- Construction drawings showing location and specific species of plants and other features.
- Tree protection shown on construction plans. Landscape plans shall show locations with symbol tags of proposed plants.
- Include a Summary plant list with botanical and common names, plant sizes and item numbers. Include a Comments column indicating, (as required) height to lowest branch, cultivation (container size, b&b, bare root, cutting, etc.), or other information.
- All planting sheets shall include key showing symbols and names of plants on that sheet.
- Where different types of seeding are used for different areas, call out non-typical locations on construction plans, landscape plans, or area detail, as appropriate.
- Estimate of landscape materials including quantities and sizes.
- Special provisions as required.
- Plans and CAD files as described in Chapter 18.

13.7 For Further Information

- AASHTO. 2004. *A Policy on Geometric Design of Highways and Streets: 2004.* Washington, D.C.: American Association of State Highway and Transportation Officials.
- AASHTO. 1990. *A Guide for Highway Landscape and Environmental Design.* Washington, D.C.: American Association of State Highway and Transportation Officials.
- AASHTO. 2004. *A Guide for Achieving Flexibility in Highway Design.* Washington, D.C.: American Association of State Highway and Transportation Officials.
- American Association of Nurserymen. Latest Edition. *American National Standard for Nursery Stock*.
- Bloniarz, David V. 1991. Street Trees, Overhead Utility Distribution, and Physical Infrastructure: Design Implications, Maintenance Costs, and Proposed Alternatives. Amherst: University of Massachusetts.
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- Dirr, Micheal A. 1990. *Manual of Woody Landscape Plants: Their Identification, Ornamental Characteristics, Culture, Propagation and Uses*. Champaign, IL: Stipes Publishing Company.
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- NRCS and Ducks Unlimited Canada. 1998. *Vegetating with Native Grasses in Northeastern North America*. Washington, DC: USDA.
- NRCS. 1992. National Engineering Field Handbook, Chapter 13, *Wetland Restoration, Enhancement, or Creation*; Chapter 16, *Streambank and Shoreline Protection*; Chapter 18, *Soil Bioengineering for Upland Slope and Protection and Erosion Reduction*. Washington, DC: USDA Soil Conservation Service.
- Franklin, Hampden, Hampshire Conservation Districts for NRCS. 1998. *Western Massachusetts Streambank Protection Guide: A Handbook for Controlling Erosion in Western Massachusetts Streams*. Northampton, MA.
- Sorrie, Bruce A. and Somers, Paul. 1999. *The Vascular Plants of Massachusetts: A County Checklist*. Westborough, MA: Massachusetts Division of Fisheries and Wildlife Natural Heritage & Endangered Species Program.
- Bassuk, Nina L. and Trowbridge, Peter J. 2004. Trees in the Urban Landscape: Site Assessment, Design, and Installation. New York: John Wiley and Sons, Inc.
- Craul, Phillip J. 1999. Urban Soils: Applications and Practices. New York: John Wiley & Sons, Inc.
- Harker, Donald.1999. Landscape Restoration Hand Book. New York: Lewis Publishers.
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- Harker, Donald.1999. *Landscape Restoration Hand Book*. New York: Lewis Publishers.
- Harris, Charles W. and Dines, Nicholas T., eds. 1998. *Time-Saver Standards for Landscape Architecture: Design and Construction Data.* New York: McGraw-Hill Publishing Co.
- www.bicyclinginfo.org
- www.mnla.com/invasive_plants.htm
- www.nps.gov/plants/alien
- http://tncweeds.ucdavis.edu
- www.invasivespecies.gov/council/main.html
- www.mass.gov/dcr/stewardship/forestry/urban/urbanFAQs.htm#planting
- www.mass.gov/dcr/stewardship/forestry/urban/urbanFAQs.htm#duringConstruction

Chapter 14
Wildlife Accommodation

Wildlife Accommodation

This chapter describes the potential effects of roads on wildlife, descriptions of wildlife accommodation that can be incorporated along new and existing roadways, and wildlife crossing structure guidelines. A great deal of information is available on effects of roads on wildlife, but practical solutions to successfully mitigate adverse effects are much scarcer. In most cases, crossings have been installed on a project-by-project basis, and have been designed for specific habitats, topography, and species. These data are beginning to emerge, and the *References* section at the end of this chapter provide links and studies to assist in appropriate accommodation design for wildlife and fish passage.

Many roads and other forms of linear transportation infrastructure were originally designed to transport vehicles with little understanding about the diverse terrestrial and aquatic landscapes that were traversed. Roads were often located along rivers, through wetlands, or in valleys to avoid steep grades and minimize construction costs. In recent years, a combination of shrinking wildlife habitat, reduced ability for wildlife to move between habitats, and increased wildlife-motor vehicle conflicts has generated a need for transportation agencies to address potential impacts to fisheries and wildlife habitat.

Studies have shown that mortality from vehicles is a threat to wildlife populations when population numbers are already low or when critical habitats occur near roadways. MassHighway recognizes the importance of reducing impacts to wildlife and improving habitat connectivity. However, the emphasis on public safety is paramount and cannot be overstated. As a transportation agency, the function of MassHighway is first and foremost to provide safe and efficient transportation infrastructure for motorists, bicyclists, and pedestrians.

When conflicts arise, safety must come first. For example, in northern New England, one in every 75 motor vehicle collisions with moose (Alces alces) results in a human fatality, as does one in every 2,500 collisions with white-tailed deer (Odocoileus virginianus).

While the moose population in Massachusetts is still small (currently, MassWildlife estimates there are 500 to 700 moose in the state), white-tailed deer are overabundant in some parts of the state. Public safety must take precedence over protection of both deer and moose. In some circumstances, the appropriate measure may be to exclude instead of accommodate wildlife. Sometimes the mortality effects of continued access to the roadway are greater than the fragmentation effects of excluding wildlife. However, in areas of statewide or regional importance for landscape-scale connectivity, exclusion should be coupled with alternative accommodations (passage structures) to avoid fragmentation and facilitate wildlife movement.

The science of road ecology, broadly defined as the study of *"the interaction of organisms and their environment linked to roads and vehicles"* (Forman *et al.* 2003), is still developing. Only in the past few decades has the relevance of the road in a landscape context, and its effects on the adjacent corridor, become a focus of study. Understanding road ecology requires participation and input from biologists, hydrologists, transportation planners, and engineers.

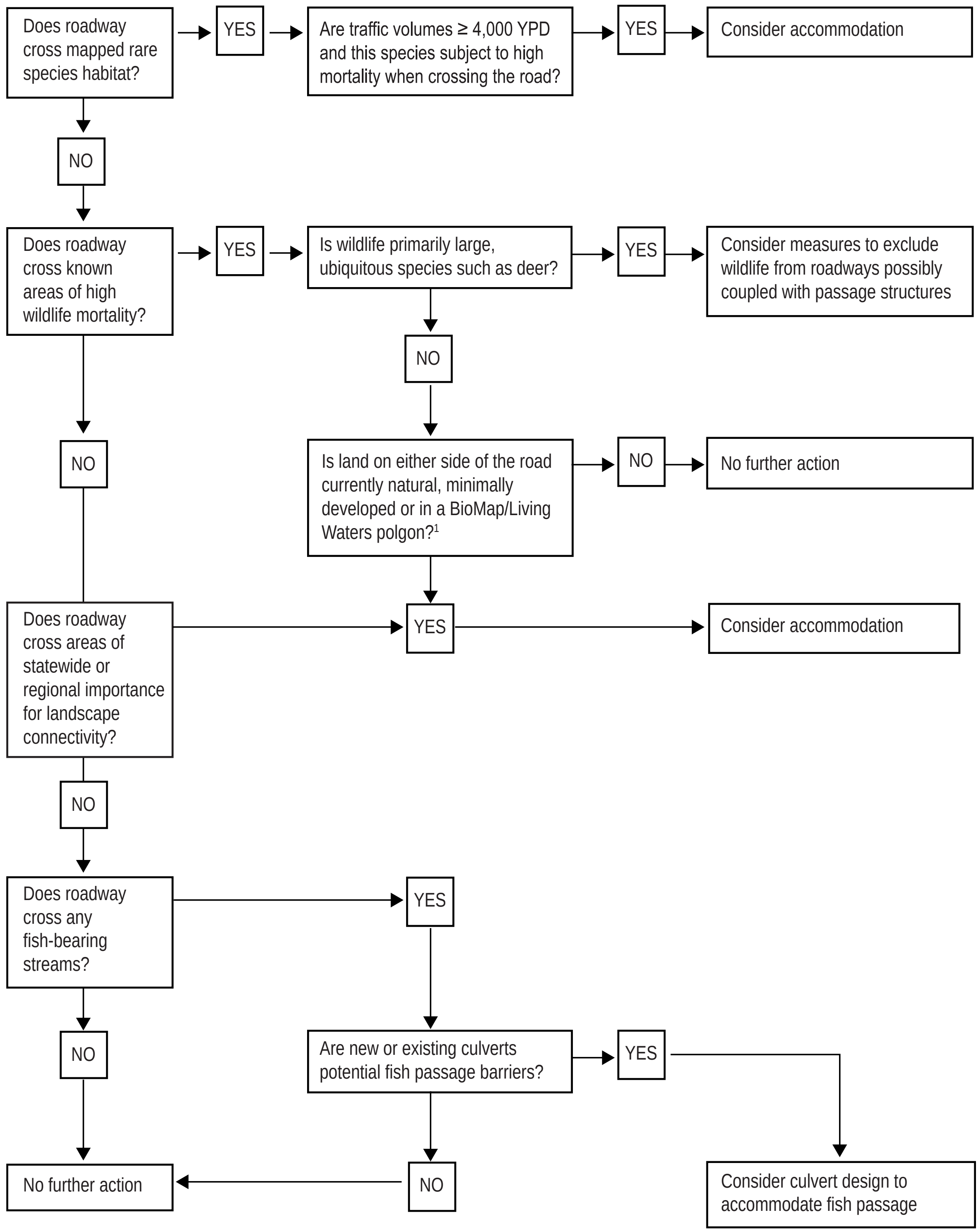
In a landscape context, roadway networks connect communities but often separate natural habitat components as they cross mountains, valleys, streams, forests, and farmland. Rainfall infiltration and drainage patterns may be altered when it encounters a roadway, and runoff from roads may result in reduced water quality in receiving waters. Habitats near roads may change through the introduction of non-native species along a linear right-of-way. Microhabitats adjacent to roads are often vastly different from nearby macrohabitats in terms of temperature, vegetation structure and composition, and substrates.

Worldwide, much data has been generated on the effects of roads on fisheries and wildlife species, and more data continues to emerge. What to do about the effects of roads on wildlife is not as clear, and research continues to be critically important in understanding what solutions work from a landscape and species perspective.

When prioritizing wildlife accommodation strategies, it is necessary to distinguish between common and rare wildlife. One of the most highly publicized examples of retrofitting a highway to accommodate wildlife is in Florida, where underpasses and bridge widenings were constructed along Interstate 75 between Naples and Miami. The crossings were built to facilitate both water movement into Everglades National Park and to reduce road kill of the federally listed Florida panther *(Puma concolor* *coryi)* along a 40-mile segment of highway. Construction of the underpasses reduced panther road kill, and evidence of several other species using the underpasses has also been documented.

In Massachusetts, most state-listed reptiles and amphibians are more likely to need accommodation than other species, primarily because of a dependence on at least two distinct habitat types (*i.e*. uplands and wetlands) that are frequently separated by roads. Studies have shown that roads have substantial adverse effects on some species, such as the state-listed Blanding's turtle *(Emydoidea blandingii).* Female Blanding's turtles may travel up to a mile in search of a suitable nest site, and are likely to cross at least one road to do so. A flow chart illustrating scenarios suitable for wildlife accommodation is provided as Exhibit 14-1.

Exhibit 14-1
Wildlife Accommodation Requirement Scenarios

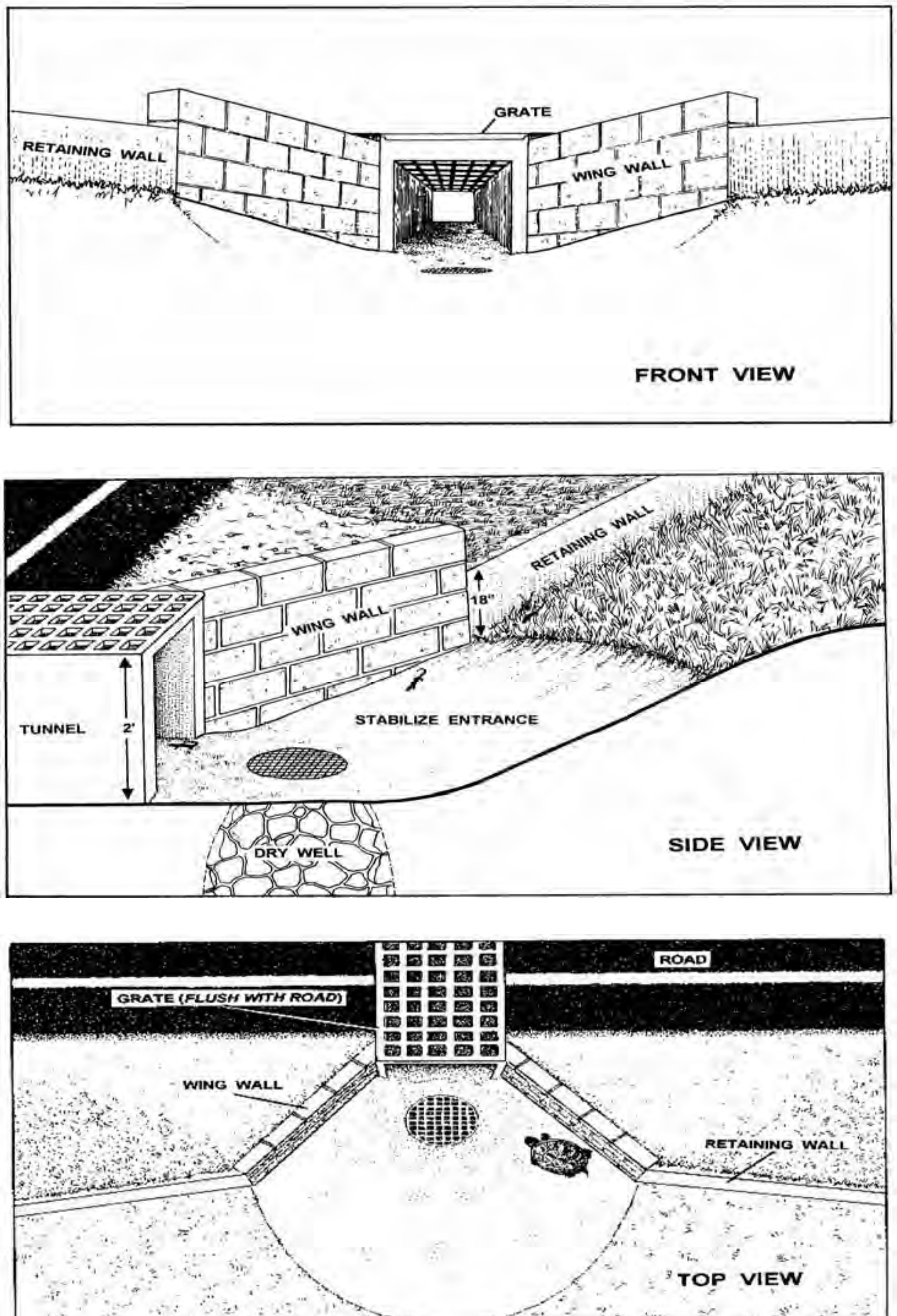


Source: MassHighway[1]

[1] BioMap Living Waters MASSGIS layers.

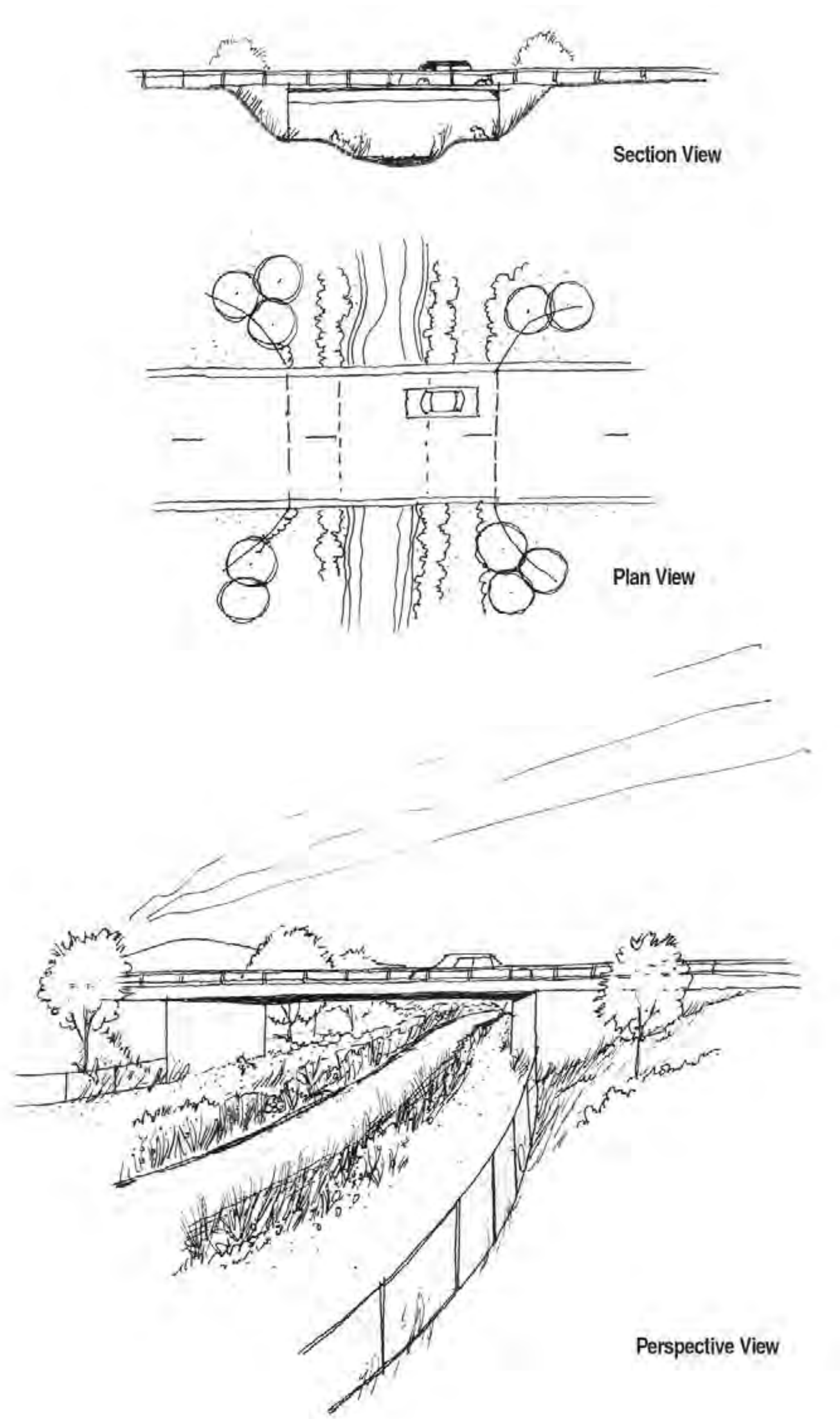
Exhibits 14-2, and 14-3 provide schematics for types of wildlife crossings that can be feasibly used when upgrading roadways.

Exhibit 14-2
Wildlife Crossings - Amphibian Tunnel



Source: Tamara Sayre; used with permission from S. Jackson, UMass Amherst."

Exhibit 14-3
Wildlife Crossings – Extended Bridge



Source: MassHighway

With 313 people per square kilometer, Massachusetts is the third most densely populated state in the country (behind New Jersey and Rhode Island). Public and private roads are knitted across habitats from the Berkshires to the coastal plain, and connect the 351 municipalities across the Commonwealth. Given the high density of existing roads, and the state's Smartgrowth policy, the focus of wildlife accommodation will be retrofitting existing roads.

Measures to minimize or mitigate the potential impacts include enhancing or creating habitat near roads through means such as wetland replication, installing vegetated berms, and incorporating native plantings along rights-of-way. Responsive mowing regimes along roadway rights-of-way and "living fences" can also be considered. Wildlife crossings are another strategy and can be incorporated into reconstructed roadways.

14.1 Types of Effects

Some roads may create adjacent habitat valuable to some forms of wildlife, and mechanisms to facilitate wildlife movement are already in place, primarily in the form of bridges. However, both existing and new roads may affect wildlife and habitat in a number of ways. Several studies have shown that some species avoid roadways and adjacent areas because of increased noise, pollution, visual disturbance, and predators using roadways as corridors.

Traffic speed and density also contribute to wildlife avoidance and barrier effects. Species that require at least two habitat types to complete their life cycle (such as breeding amphibians and reptiles) may continue to attempt to cross roads, resulting in higher mortality from vehicles.

Other types of effects may not be as noticeable but can be detrimental to wildlife populations. These can include habitat loss, habitat fragmentation, altered habitat quality, population fragmentation, and disruption of processes that maintain regional populations. The effects of roadways on wildlife are briefly described in the following sections.

14.1.1 Wildlife-Vehicle Collisions

Wildlife-vehicle collisions are a worldwide phenomenon that injure or kill millions of animals annually. Collisions with large mammals such as deer, moose, and black bear *(Ursus americanus)* also result in human injury and even fatality, with high annual property damage costs. In Massachusetts, there were 33 moose-vehicle collisions in 2003, resulting in one human fatality. In 2004, the number of collisions increased to 52.

Wildlife mortality from vehicles affects species to different degrees, from hoofed species such as deer and moose, to winged species such as songbirds and raptors, to smaller species such as amphibians, reptiles, and invertebrates including dragonflies and butterflies. Wildlife mortality from vehicles has a greater effect on animals with large home ranges and those that must migrate to different habitats in order to complete their life cycle than on those with smaller home ranges. For example, amphibians that live in uplands and breed in vernal pools, and turtles that live in wetlands and nest in uplands, frequently must cross roads to reach suitable nesting or breeding habitat.

Some long-lived wildlife species with low reproductive rates such as turtles are particularly vulnerable to population declines due to the loss of adults to road mortality. Also, populations with few individuals are more affected because of the relative importance of each individual in maintaining a healthy population. Temporal and seasonal variations are also evident. More white-tailed deer are struck by cars at dawn and dusk than any other time of day, and moose accidents are most likely to occur in the spring and fall. Large amphibian migrations occur in early spring. Female turtles cross roads to reach nesting areas in June.

Wildlife mortality from vehicles is also influenced by traffic volumes, traffic speed, roadway width, adjacent landscape, and wildlife behavior and physiology. To date, the literature presents conflicting information on traffic volumes, but most researchers agree that increasing traffic volumes pose greater threats to wildlife up to a certain critical point at which wildlife avoid roads altogether. Research suggests that roads with less than 1,000 vehicles per day (vpd) may cause road avoidance in smaller species, but crossing movements will still occur frequently. Roads with greater than 10,000 vpd likely pose an impenetrable barrier to wildlife, deterring most wildlife from crossing and killing many that do attempt to cross.

Research indicates that some wildlife are affected more by traffic speed than volume. For example, one study concluded that rabbits and songbirds experienced higher mortality rates at speeds greater than 40 miles per hour (mph). In Pennsylvania, deer-vehicle collisions decreased when the speed limit was reduced.

The surrounding context and roadway design features also influences mortality. For example, deer-vehicle collisions in Pennsylvania were lower with a higher number of residences and buildings near roads, when there was a greater distance to wooded areas, and when the minimum sight distance was increased.

14.1.2 Habitat Loss

Habitat is lost when an area previously providing food, cover, shelter, or breeding habitat is developed. As with road mortality, different species have different responses to habitat loss. Species that are long-lived, with low reproductive rates, have large home ranges, and low densities such as many large carnivores are at greater risk than other species.

14.1.3 Habitat Fragmentation

Fragmentation is defined as the subdivision of once large and continuous tracts of habitat into smaller patches. It results from agriculture, urbanization, and transportation or other right-of-way modifications. In general, fragmentation of habitat is viewed as detrimental when considering the original native, climax species composition and abundance, natural history, and relative ecological stability of unmanaged plant and animal populations.

Some species are sensitive to patch edges where they may have to complete with habitat generalists or are vulnerable to predators and brood parasites that are common along forest edges. Other species are “area-sensitive” in that they will not use habitat patches (such as forest, grassland or marsh) unless it is above a particular size threshold. Most species use more than one “patch,” or habitat type, in a landscape, and their survival depends on their ability to move successfully between patches in a landscape. Fragmentation can lead to several ecological processes that adversely affect wildlife populations including edge effects, barrier effects, and loss of genetic diversity.

14.1.3.1 Reduction in Patch Size

Fragmentation of large areas of forest, grassland or wetland habitat is likely to reduce the number of species occupying those habitat patches. In part this is because smaller patches are not able to support enough individuals to maintain viable populations for all species likely to be found in large patches. In addition there are many area-sensitive bird species that simply avoid smaller areas of otherwise suitable habitat.

14.1.3.2 Edge Effects

In fragmented habitats, there is a proportional increase of habitat edge. Habitat edge is the transitional zone from one habitat community to another, such as the zone between pasture and forest, and generally signifies habitat that is more susceptible to edge effects such as predation, and parasitism. The species richness of these areas is often higher than that of either bordering habitat because edges contain species from both habitats. However, species that are more successful near edges may negatively affect forest interior species and contribute to indirect effects of fragmentation.

Edge effects include a range of beneficial and detrimental ecological consequences that are associated with habitat diversity, the most common of which are increased predation and parasitism. Predation effects nearer the edge are most likely attributable to larger predators such as crows *(Corvus brachyrhynchos)*, blue jays *(Cyanocitta cristata)*, raccoons *(Procyon lotor)*, and snakes that tend to use and follow forest edges. In addition, brown-headed cowbirds *(Molothrus ater)* are commonly found in edge habitats, particularly in agricultural areas and are nest parasites of many songbirds, laying their eggs in other birds' nests.

Edges may also have detrimental effects by allowing invasive plants species to colonize newly disturbed areas adjacent to roadways, decreasing habitat quality. In addition, indirect effects of transportation improvements such as altered microclimates near edges may further decrease suitability for the original occupants of a forest such as butterflies, damselflies, and other insects.

14.1.3.3 Barrier Effects

Many species require more than one habitat type to successfully carry out breeding, feeding, or other required functions. The barrier effect created by infrastructure is a physical or psychological restriction on movements or migration by some feature within a corridor that wildlife is either unwilling or unable to cross. Studies have indicated that some small mammals are reluctant to cross a gravel cart path. Connectivity to other patches, or habitat types, in the landscape may be reduced by roads, constituting a barrier effect.

Isolation of populations due to the barrier effect of roads may lead to reduced genetic diversity. Researchers in Germany found that a bank vole (Clethrionomys glareolus) population separated by a highway experienced significant genetic variation, but not within populations separated by a county road. Barriers may also lead to reduced ability for individuals such as young of the year to colonize new areas, and can also cause difficulties for reproducing adults to locate one another.

The permeability of a road (*i.e.,* the degree to which it presents a barrier to wildlife) is influenced by the adjacent roadside habitat and the occurrence of safe locations for wildlife to cross. For example, a roadway with a wide cleared roadside will be relatively more impermeable to a forest-dwelling species than a road with suitable forested habitat adjacent to the road. However, the cleared roadside may benefit other species by providing a visibility zone to drivers and wildlife attempting to cross roads.

Barrier effects may also result in species being unable to complete a portion of their life cycle. For example, mole salamanders (Ambystomidae) spend the majority of their lives in forested uplands and wetlands and breed only in seasonal pools known as vernal pools. If an impermeable road separates the two habitats, the ability to successfully reproduce and maintain a population may be reduced or eliminated.

14.1.3.4 Population Fragmentation

Smaller isolated populations of plant and animal species are more susceptible to genetic deterioration as a result of inbreeding, depression and genetic drift, possibly resulting in extinction.

14.1.4 Altered Habitat Quality

Most effects of roads on habitat quality are negative, though in some cases they can prove beneficial to wildlife. Reduced habitat quality has been documented for birds adjacent to high-volume roads, primarily from noise associated with passing vehicles which may interfere with the ability of breeding males to successfully establish territories and attract females. However, other research found no difference in the number of breeding birds adjacent to highways from numbers at a greater distance, presumably because the roadside and median provided acceptable breeding habitat.

As introduced above, not all habitat modifications are negative. Beneficial habitat adjacent to roads can be created for amphibians in roadside ditches, perching sites for raptors, and as corridors for various wildlife. Beneficial habitat increases in value when roadsides and medians are planted with native species and are mowed less frequently. Of course, the habitat benefits of unmowed roadsides must be carefully balanced with safety effects of such conditions. The creation of attractive habitat along a roadside can also have negative consequences for wildlife.

Amphibians may attempt to breed in roadside ditches or detention ponds where conditions are not suitable for successful reproduction. Wildlife attracted to roadside habitats or food sources (carrion) may be subject to higher mortality.

In addition to terrestrial habitats, aquatic ecosystems may be indirectly affected by transportation improvements due increased water runoff. Increased runoff may increase erosion, causing decreased water quality through sedimentation and higher pollutant loading. Highway runoff may also affect vegetation composition and aquatic species, especially in areas of heavy traffic. For example salt laden runoff from roads and highways can facilitate the invasion of Phragmites into wetlands. Drainage system design can help to mitigate these impacts.

14.2 Types of Wildlife Accommodation

Research has suggested six policy initiatives that should be considered as goals and guidelines to address wildlife issues. To the extent possible, MassHighway will consider these initiatives in roadway design and maintenance. Clearly, some of these principles are outside the scope of MassHighway's activities and influence, but are presented to provide a contextual overview. Most roadway design and maintenance will be on existing roads, which minimizes applicability of some of these initiatives.

- Conduct landscape-based analyses to identify important "connectivity zones" and set priorities for mitigation

- Evaluate road-stream crossings for their barrier effects and prioritize structures for replacement
- Perforate road corridors for frequent wildlife and water crossings to reduce the road-barrier effect and habitat fragmentation.
- Depress roads and use soil berms and vegetation to reduce traffic disturbance and noise effects on wildlife and adjacent residential areas.
- Collect and consolidate traffic, including trucks, and channel it onto primary roads to reduce the dispersion of both noise and barrier effects on lower classification roadways.
- Improve engineering designs or road surfaces, tires, motors, and vehicles (aerodynamics) to reduce the ecological effects of noise.
- Use cleaner fuel and “life-cycle” vehicular materials (by designing vehicle parts to be recycled) to reduce greenhouse gases as well as pollutants of soil, water, and air.
- Consider exclusion fencing to keep wildlife off high-volume roadways.

Several techniques have been used in the United States to mitigate the impacts of transportation facilities on wildlife and habitat, though most measures have been shown to have limited success. The value of monitoring accommodation strategies is critical to understanding what works, and future studies may indicate different success rates.

Mitigation techniques that attempt to alter human behavior include:

- Signage
- Animal detection technology
- Public education and awareness
- Roadway lighting
- Reduced speed limits

Mitigation techniques that attempt to alter wildlife behavior include:

- Habitat alteration
- Fencing

- Modified Jersey barriers
- Wildlife crossing structures
- Hazing
- Whistles
- Mirrors and reflectors

Devices such as high frequency whistles attached to vehicles, increased highway lighting, reflectors (e.g., Swareflex®) placed along highway shoulders, and hazing are being used by some states in an attempt to scare wildlife away from oncoming traffic. However, results of studies on the effectiveness of these techniques indicate they are ineffective in reducing deer-vehicle collisions, and are not discussed further in this chapter. Descriptions of the most feasible and effective methods to accommodate wildlife in Massachusetts are described below.

14.2.1 Signage

Installing wildlife crossing signs where traditional wildlife pathways intersect highways can alert drivers to potential encounters with wildlife. Although the ability of these signs to reduce vehicle collisions with animals has not been proven, they at least heighten the awareness of drivers to wildlife mortality problems. Variability in signage increases the possibility of motorist observance.

For example, Maine placed signs along roads during high deer and moose activity periods and found that collision frequency was lower than in areas where signs were left in place year-round. In addition to seasonal signage, some states in northern new England have instituted “fatality signs.” These signs are updated on a regular basis to reflect the current number of motorist fatalities from moose and deer collisions.

14.2.2 Public Education and Awareness

Public education can take the form of educational videos distributed at driver education classes and distribution of maps at rest areas, visitor centers, and welcome centers along major roadways, and local Registries of Motor Vehicles, that detail types of common crashes, likely causes, and ways to avoid being in a wildlife-related crash.

14.2.3 Reduced Speed Limits

Maine evaluated data through 1998 for moose and deer crashes, and found that most crashes occur on roads with speed limits of 50 to 55 mph, indicating that many crashes are caused by drivers whose decision distance is greater than the distance that can be seen under headlight illumination.

14.2.4 Habitat Alteration

Habitat alteration presents two potentially conflicting objectives: to attract or repel wildlife from roadsides and medians while at the same time allowing motorists adequate visibility to avoid hitting wildlife that venture too close to the roadway. Alteration can consist of removing vegetation along roadways, planting species adjacent to roadways that are undesirable to wildlife, or planting native species to provide habitat for some wildlife and reduce the spread of non-native vegetation along a transportation corridor.

Roadsides and medians are usually mowed for safety reasons. Untrimmed vegetation reduces visibility adjacent to roads (potentially increasing risks to wildlife, pedestrians, and bicyclists) and also reduces sight distance to oncoming vehicles and roadway geometry.

Changes to mowing regimes can be considered where benefits to wildlife such as rare birds or insects or rare plants growing in the verges may be realized. For example, in central Wisconsin, the state-endangered Karner blue butterfly *(Lycaeides melissa samuelsis)* is dependent on wild lupine *(Lupinis perennis),* a plant that is commonly found adjacent to roads.

The Department of Defense instituted a protocol where lupine populations adjacent to roads at Fort McCoy are staked out each year, and mowing crews lift their blades to avoid cutting them during routine maintenance. Other possibilities to consider for mowing regimes include timing and frequency. Mowing roadsides outside of breeding bird population dates (generally early May through late June) can benefit breeding birds that use roadside verges and medians. Lessening the frequency of mowing not only costs less but increases plant species diversity.

Washington State, among others, employs a three-tiered approach to roadside vegetation management. There are three zones adjacent to a road, and vegetation is cut at different rates and to different heights.

The purpose of this is to allocate maintenance resources most effectively, but it is also useful for ecological management as well.

Additionally the limited use of herbicides in areas of critical habitat can reduce impacts to adjacent wildlife populations. In areas where such treatments are required, chemicals with low toxicity to animal populations of concern should be used. Design techniques, such as careful plant species and construction materials selection can also be used to reduce the need for these treatments.

14.2.5 Modified Jersey Barriers

First designed in New Jersey, Jersey barriers are concrete dividers that are typically used on divided highways as a means of keeping two-way traffic separate or to prevent access to a restricted area (e.g. during highway construction). Where installed in the median, they may increase some wildlife mortality by trapping small and medium-sized mammals. Jersey barriers have been modified (and are in use on Route 6A on Cape Cod, and along sections of Route 24 and Route 3) so that “scuppers” allow passage of small species through the barrier, as well as promoting more efficient drainage. Jersey barriers can also be installed at the outer edges of a highway to keep wildlife off roadways.

14.2.6 Fencing

Fencing is a common practice used to keep wildlife off highways. For high-volume roadways such as interstates, fencing should be considered as an exclusionary measure for wildlife such as deer and moose. Exclusion fencing may also benefit small mammal populations by providing forage and cover habitat near highways. Fencing is typically 7 to 10-foot high chain link or rectangular mesh but can be smaller for reptiles and amphibians. If smaller species are the target, fencing is usually buried and angled to prevent animals from climbing over.

For wildlife crossings (described below) to be successful, studies indicate that areas adjacent to the road must be fenced to direct animals to crossing structures, and to prevent them from crossing over the roadway. For deer, fencing should be at least 7 feet high (preferably 8 feet high) upright chain link “outrigger” fencing (sloped) to prevent deer from approaching close enough to jump over the fence.

For amphibians and reptiles, fencing can be constructed of silt fence or concrete retaining wall. Installing silt fence is significantly less expensive than constructing a retaining wall, but requires considerably more maintenance to be successful. Fencing must be maintained to be successful. Gaps resulting from poor construction, erosion, or crawl holes dug by animals reduce efficacy, as wildlife will exploit fence gaps.

14.2.7 Wildlife Crossing Structures

Crossing structures are designed to safely move wildlife either over or under a roadway, maintaining natural population movements and reducing road kill. Several factors, such as location, hydrology, light, openness ratio (cross-sectional area of a culvert divided by its length), and cover are important in designing successful wildlife crossing structures. Overall, crossing structures should maintain landscape connectivity rather than redirect wildlife movements. Therefore, they should be placed in known wildlife migration/travel routes.

Geographic Information Systems (GIS) analysis is a landscape-based tool that can be used to determine the most valuable habitat for wildlife and wildlife movement by characterizing landscape features such as vegetation, riparian corridors, development, and topography. Determining species distribution and corridors of movement and understanding target species biology is critical in designing effective wildlife crossing structures. A community/ecosystem approach rather than species-specific approach has been found to be most effective in maintaining habitat connectivity and ecological functions.

Most researchers agree that location is the most critical aspect of design, particularly for species of low mobility (small mammals, reptiles and amphibians). Wildlife crossing structure success also depends on noise levels, substrate, vegetative cover, moisture, temperature, and light, as well as roadway width, openness, traffic volumes and human disturbance.

Openness is negatively correlated with use by small mammals, indicating that large openings without cover from predators were avoided by small and medium-sized mammals (except coyotes *(Canis latrans*) and shrews), possibly because of higher predation associated with larger culverts. However, lagomorphs (rabbits and hares) and carnivores are inhibited by low openness. Distance to cover, such as shrubs or trees, was also negatively correlated to small and medium-sized mammal use. This correlation indicates that these species (particularly voles, weasels *(Mustela* spp.), and coyotes rely on the increased cover when moving about.

For species with low mobility (amphibians and reptiles), crossings should not be more than 500 feet apart. Crossings can be placed closer to each other if cost and context permit. If crossings are considered for wildlife with large home ranges [bobcat *(Lynx rufus)*, deer, moose, fisher *(Martes pennanti*)], they should be placed no more than 1 mile apart. Again, crossings may be constructed closer to each other if possible. For long projects, spacing should be prioritized according to habitat suitability and future potential development. A variety of crossing structures is recommended to provide passage for several species.

14.2.7.1 Culvert Replacement and Stream Restoration

Replacement of undersized culverts with bridges or "stream simulation" culverts can restore river and stream continuity and facilitate passage by fish and other aquatic organisms. Stream restoration may occur as part of a culvert replacement (to address scour or aggradation that may have occurred due to the undersized structure) or in other areas such as eroding or previously riprapped banks or stream sections that were artificially straightened to accommodate a road or highway.

14.2.7.2 Wildlife Underpasses

Wildlife underpasses can be large or small, depending on the target wildlife species. They can take the form of amphibian tunnels, ecopipes, wildlife culverts, and oversized stream culverts. Amphibian tunnels are widely used in Europe to facilitate annual amphibian migrations under roads, but to date have not been used extensively in the United States. One of the first amphibian tunnels was constructed beneath Henry Street in Amherst, Massachusetts to minimize road kill of spotted salamanders as they migrated to and from breeding sites (see Figure 14-2). Another larger tunnel, greater than 10-feet wide was constructed under Route 57 in Agawam.

Although best-suited to new construction, wildlife underpasses can be considered in roadway reconstruction where circumstances warrant. They can also be used to replace existing in–stream structures in culvert replacement situations. Providing such crossing opportunities, particularly in areas adjacent to late successional forest, may facilitate forest ecological functions involving small mammals (e.g. the dispersal of seeds and fungal spores).

Migrating amphibians are hesitant to enter tunnels with a microclimate that is significantly different from their surroundings, including differences in light, air flow, and humidity levels. Concrete tunnels are preferred over steel or plastic. Culverts should be at least 2 feet by 2 feet, and should be grated to allow ambient light, air and moisture to enter and pass freely through the tunnel.

Ecopipes are small, dry tunnels (1-foot to 1.3-foot diameter) used to facilitate movements of small and medium-sized mammals. They have been installed in the United Kingdom and the Netherlands, and appear to be successfully used by badger *(Meles meles)* and otter *(Lutra lutra)*. Wildlife culverts are similar to ecopipes but are installed over waterways. They are up to 4 feet wide and have raised dry ledges, or shelves, on one or both sides of the waterway that allow wildlife to cross under the road and adjacent to the river or stream. The shelves also ensure that the appropriate stream channel configuration is maintained, which prevents possible morphological streambank degradation.

Oversized stream culverts or extended bridges are options in replacement culvert or bridge situations along waterways where target species include both upland wildlife and aquatic species (see Figure 3). Extended bridges maintain terrestrial habitat connectivity by providing an unsubmerged area adjacent to the waterway. Abutments extend beyond water’s edge to provide a natural bank under the bridge – animals can cross under the bridge instead of over the road.

Construction of a concrete shelf above the floodplain will encourage use by terrestrial species; care should be taken to not alter stream hydrology. Bankfull width must be maintained for the stream to continue to convey the appropriate water volume and bedload material (i.e. material transported by a stream).

Dry drainage culverts have been used in Canada, the United States, Europe, and Australia. They are useful to small and medium-sized mammals, ungulates, and possibly reptiles, and can be constructed in uplands particularly in areas of high quality wildlife habitat, or areas with nearby wetlands. Results of wildlife crossing monitoring highlighted the importance of dry drainage culverts for small mammal movement.

14.2.7.3 Wildlife Overpasses

These buried highway sections that function by providing a wildlife “bridge” over a highway have been constructed in Canada and Europe, and one is proposed to be constructed along I-70 in Colorado. They are generally only feasible in areas of new construction and where substantial areas of high-quality wildlife habitat occur on both sides of the roadway. They are usually constructed at high points in the landscape over roadway to connect habitat, and can be planted with grasses, shrubs, and small trees.

14.2.7.4 Viaducts

Viaducts are elevated roadway spans over entire valleys, floodplains, wetlands, or gorges and provide unrestricted wildlife movements. They are excellent for a multi-species design approach, but are the most expensive option for all wildlife crossing structures. They are only appropriate in new design scenarios and on large projects.

14.3 Wildlife Accommodation Guidelines

Many states recognize that roads can result in a series of adverse effects to wildlife, and are beginning to formalize initiatives and policies to address these impacts. In the Northeast, Maine has developed a task force to address large mammal-vehicle collisions, as well as a fish passage policy. Vermont is in the process of developing a wildlife crossing initiative. Currently, most states address wildlife accommodation on a project-by-project basis. In general, if the road crosses an area of statewide or regional importance for landscape connectivity wildlife accommodation should be considered.

As described earlier in this chapter, efforts to accommodate wildlife will be primarily on reconstructing existing roads and bridges. Wildlife accommodation should be focused on rare species that require conservation (*e.g*. state-listed reptile and amphibian species) instead of more ubiquitous wildlife such as deer (see Figure 14-1).

Wildlife accommodation should be prioritized so that areas of high-value habitat are connected, and areas that do not provide habitat on both sides of a roadway should not be included. Accommodations for wildlife should be considered where high crash statistics indicate a problem exists for wildlife. Anecdotal or statistical evidence of high crash locations may be available from local DPWs, the state Division of Fisheries and Wildlife, and other natural resource agencies. Aquatic animals should also be provided passage across roadway corridors. The designer should provide bridges or culverts that maintain stream continuity and allow fish passage, including migratory passages for diadromas fish.

14.3.1 Design Guidelines

This section lists potential accommodations for wildlife that could be used for typical MassHighway projects. They are intended to assist readers with deciding what types of accommodation should be considered for a project. This menu should be used in conjunction with the flow chart provided in Exhibit 14-1.

14.3.1.1 Footprint Bridge Program

This program was undertaken in 1991 to replace debilitated bridges along essentially the same alignment, resulting in fewer environmental impacts. For projects that qualify for this program, the following accommodation measures should be considered:

- Stream restoration
- Extended bridges

14.3.1.2 New Bridges

New bridge construction includes projects that would construct a new bridge on a new alignment. The following accommodation measures should be considered:

- Extended bridges
- Viaducts

14.3.1.3 Roadway Widening, Reconstruction, and Maintenance Projects

Roadway widening includes projects that add a least one lane to a roadway. Reconstruction projects include those projects that add shoulders or a bicycle lane, widen an existing road to meet current design standards, and propose sidewalks. Maintenance projects are those that qualify for the Footprint Roads Program that was initiated in 2003 to allow some roads to be reconstructed without widening to current design standards.

If projects do not include stream crossings, the following measures should be considered:

- Signage
- Public education and awareness
- Reduced speed limits

- Habitat alteration
- Modified jersey barriers (on divided highways)
- Fencing
- Dry drainage culverts
- Amphibian tunnels

For those widening and reconstruction projects that include stream crossings, the following measures should be considered in addition to the above measures:

- Culvert replacement
- Stream restoration
- Extended bridges

When practical, drainage and stormwater measures should be brought up to standard as part of reconstruction.

14.3.2 Other Guidelines

In Massachusetts, there are published guidelines and manuals that focus on proper stream crossing installations, particularly culverts. Each is briefly described below.

14.3.2.1 Massachusetts River and Stream Crossing Standards

In 2004, the multidisciplinary River and Stream Continuity Steering Committee developed technical standards to facilitate the implementation of stream crossings. General and optimal standards for new and retrofit culverts are described. The guidelines are excerpted here and referenced at the end of this chapter.

The goals of the Committee were to develop standards that would address fish passage, riparian wildlife, and river and stream continuity. The guidelines should be considered for permanent roads that cross perennial streams (or intermittent streams that provide fish habitat), and where amphibians and/or reptiles are known to cross in high concentration. Guidelines were developed for new and replacement culvert installation as summarized below.

General Guidelines - New Culverts

These standards should be implemented when new crossings are planned over rivers or streams that support one or more species of fish, or in areas with known amphibian or other wildlife crossings.

- Bridge span preferred
- If box culverts are used, structure should be embedded (sunken) at least two feet (minimum of 2 feet or 25 Percent whichever is greater)
- Natural bottom substrate should be provided within culverts that generally matches upstream and downstream substrates
- *Spans channel width (a minimum of 1.2 times the bankfull width)*
- Designed to provide water depths and velocities at a variety of flows that are comparable to those found in upstream and downstream natural stream segments (e.g. low flow channel)
- Openness ratio of >10 inches. Openness ratio is the cross-sectional area of a structure divided by its crossing length (with all dimensions measured in meters). For a box culvert, openness = (height x width)/length

Standards for Culvert Replacement

Whenever possible replacement culverts should meet the design guidelines for general standards (see Standards for New Crossings above) If it is not possible or practical to meet all of the General Standards, replacement crossings should be designed to meet the General Standards for crossing width (1.2 times bankfull width), meet other General Standards to the extent practical, and avoid or mitigate the following problems.

- Inlet drops
- Outlet drops
- Flow contraction that produces significant turbulence
- Tailwater armoring
- Tailwater scour pools
- Physical barriers to fish passage

As indicated by long profiles, scour analyses and other methods, design the structure and include appropriate grade controls to ensure that the replacement will not destabilize the river/stream. To the extent practicable conduct stream restoration as needed to restore river/stream continuity and eliminate barriers to aquatic organism movement

14.3.2.2 U.S. Army Corps of Engineers Programmatic General Permit Conditions

On January 20, 2005, the U.S. Army Corps of Engineers (ACOE) reissued the Programmatic General Permit (PGP) for Massachusetts. The PGP Condition 21 requires:

- Designing new permanent waterway crossings to not obstruct aquatic life movement.
- New permanent crossings must conform to the General standards of the Massachusetts River and Stream Crossing Standards (see Section 14.3.2.1) unless otherwise authorized by ACOE.
- For new stream crossings, open bottom arches, embedded culverts or bridge spans are required to qualify as a Category 1/non-reporting project.

The ACOE permitting process allows projects meeting the PGP's Category 1 definition and the PGP's general permit conditions to process without application or notification to the Corps. These projects are referred to as Category 1 – Non-Reporting Projects. If these designs are impractical, applicants must consult with the ACOE.

14.4 Conclusions

Roads have been traditionally viewed solely as a means of transporting humans and goods. As the understanding of road ecology grows, a multidimensional view of roads emerges, which takes into consideration not only the safety and efficiency of roadway networks to humans, but the ability to maintain ecological processes as well. Careful consideration of these ecological processes during planning for roadway upgrades and reconstruction will require close collaboration between planners, engineers, landscape designers, biologists, and maintenance staff.

Monitoring wildlife accommodations should be a priority. A recent success for rare wildlife in Massachusetts was achieved along relocated Route 44 in Carver. This 8-mile section of new state highway between Carver and Plymouth crossed an area providing high-value habitat to state-listed spotted turtles *(Clemmys guttata)* and eastern box turtles *(Terrapene c. carolina).* A two-year pre-construction study conducted as partial mitigation for rare species habitat impacts showed that an entrance ramp would bisect two habitats used extensively by spotted turtles and, although all permits had been obtained, MassHighway redesigned a portion of the project. An intermittent stream that flowed under the entrance ramp proved to be a major migration route for the turtle population to travel between habitats, and it was redesigned from a 24-inch pipe to a 6-foot by 6-foot box culvert. The culvert was sunk approximately 6 inches below the streambed, and had an openness ratio of 0.8. A post-construction study of the turtle population documented use of the culvert by several turtles, indicating that the population integrity remains intact.

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Chapter 15

Access Management

Access Management

This chapter discusses access management techniques that have potential application to highways and streets. The chapter is organized to describe the context in which access management is commonly used; MassHighway's role in managing access, including guidelines and driveway design; other access management techniques; and, land use strategies that local jurisdictions can use as part of an access management program.

Access management applies roadway and land use techniques in order to preserve the safety, function, and capacity of transportation corridors. The objective is to ensure roadway safety and efficient operations while providing reasonable access to the adjacent land uses. Access management can also improve the environment for pedestrians, bicycles, and motor vehicles in all settings and on all roadway types by reducing and consolidating driveway conflict points.

In addition to the guidance provided in this Chapter, TRB's *Access Management Manual* and NCHRP's *A Guidebook for Including Access Management in Transportation Planning* provide more information on the development of access management programs including:

- Principles and effects of access management;
- Access management techniques and their potential advantages, disadvantages, and applications;
- The interrelationship with land development and how to address access management in the context of comprehensive planning and land development regulation;
- The rationale for spacing standards and how to choose appropriate standards for connections, signals, corner clearance at intersections, and interchange areas;

- Information on the location and design of access features, such as driveways, medians, auxiliary lanes, and service roads; and
- Legal considerations that guide program development and implementation.

15.1 Relationship to Context

The application of access management tools varies according to the area through which the roadway passes and the function of the roadway itself. Access management can be an important component of new facility plans since the designer has more flexibility in the location and design of driveways. Access management techniques can also be applied on retrofits of existing facilities where the designer, through regulatory or negotiated processes, can reduce the number and improve the characteristics of access to properties along the corridor. In Massachusetts, the vast majority of access management activities involve retrofits of existing facilities.

15.1.1 Area Types

Access management can be applied anywhere. It can be particularly helpful if an access management program is developed for an area prior to its development to systematically plan for access, or limits to access, along a corridor. Within rural developed and suburban zones, development is often comprised of significant commercial development of medium to large-sized lots, which are favorable to an access management program. In village, town center and urban locations, where constraints exist, there may be less applicability of access management techniques.

15.1.2 Roadway Type

Access management describes a wide range of regulatory and design techniques to ensure that both access to property and regional mobility are provided by roadway facilities. Degrees of access control that influence access management, and their relationship to different roadway types, are described below.

15.1.2.1 Access Control

A consideration in access management is the concept of access control. ***Access control*** defines the degree to which properties are connected to a roadway. The following degrees of access control are possible:

- **Controlled Access** – Freeways or other major arterials where access to the roadway is limited to interchange points or major intersections.
- **Limited Access** – Typically arterials where intersections are widely spaced and driveway connections are limited (often to right-in, right-out operations or widely spaced signalized intersections). Driveways to properties may be consolidated to limit connections to the roadway. Major intersecting streets may be signalized or handled at interchanges. Minor intersecting streets may be limited to right-turn in right-turn out operations or may be grade-separated.
- **Full Access** – Typically arterials or collectors where access is provided to adjoining properties without restrictions on turning movements. Driveway spacing and other design guidelines are typically applied. Intersecting streets usually provide the full complement of turning movements.
- **Uncontrolled** – Typically collectors and local roads where access controls are not employed.

15.1.2.2 Access Management, Access Control, and Functional Classification

Often, access management plans are developed for arterial roadways that serve local and regional travel and freight movement as part of a corridor upgrade or planning study. Although most commonly applied to arterials, access management techniques are also applicable to collectors which carry higher speed, higher volume flows. Access management tools are infrequently applied on local streets. Access management can be an integral part of planning for safety or addressing high crash locations on all types of facilities.

Access management can be used to improve the relationship between the adjacent land use and the functional classification of the road. The designer may have the ability to design access points to the facility that are consistent with the roadway's functional classification, as described below:

Access management can be an integral part of planning for safety or addressing high crash locations on all types of facilities.

- **Freeways** – Roadways with controlled access. Access is limited to interchange points and intersecting roads are treated using one of the methods described in Section 15.3.6.
- **Major Arterials** – Limited access or full access may be provided. Access management is an important element of the design and

driveway spacing and configuration should minimize impact to regional traffic flow. The designer should work with adjacent land owners to develop driveway spacing and layout consistent with purpose of the roadway using the guidelines and tools discussed in this chapter.

- **Minor Arterials and Major Collectors** – In most cases, full access is provided. These roadways fall within the middle of the functional classification system and provide a combination of access to land and regional mobility. Access points are likely to be more frequent than on major arterials and greater impedance to regional traffic flows is expected on these roadways. Nonetheless, the access management techniques remain important for these roadways and the designer should meet the driveway spacing and corner clearance guidelines described in this chapter.
- **Minor Collectors** – Full access or uncontrolled access is usually provided. Minor collectors provide the highest degree of land access of the facilities in which MassHighway is typically involved. Parcel access is often more important than regional mobility on these roadways. As described above, however, benefits for all users can be obtained by providing well-designed access points.
- **Local Roads** – Access is usually uncontrolled. The primary function of local roads is to provide access to the adjacent land use. Access and driveway design is usually performed to meet the guidelines of the local jurisdiction.

15.2 The Commonwealth's Role in Managing Access

Access management must consider road design principles as well as land use planning principles to be effective. As such, it requires a joint effort between MassHighway and the appropriate communities. While MassHighway is responsible for providing a safe transportation network, local jurisdictions are responsible for orderly growth patterns that minimize the impacts of land use on the transportation system.

15.2.1 Access Guidelines

MassHighway has an active role in access management with the responsibility to issue permits for all new curb cuts and for modifications of existing curb cuts on state-owned routes (MGL Chapter 81, Section 21). Design standards for the provision of access onto state highways have been in place for decades and have been updated several times.

The goal established by MassHighway for the review and issuance of access permits is to provide for safe and efficient access while maintaining safety and the operational integrity of the highway. A design review has also been developed to ensure that driveways are properly designed so that the safety of all users is maintained.

The MassHighway District Highway Director is responsible for maintaining the function and operations of roadways with respect to access in his/her District. In this capacity, the District Highway Director has discretionary access permitting authority to permit or deny access if it is not designed adequately (through his/her Permit Engineer). Details on the process for when access permits are needed and how they are obtained is available from each MassHighway District Office.

MassHighway strives to provide well-designed access as part of its projects; however, a more effective access management program requires the development of a more systematic approach that considers roadway classification, traffic volumes, speeds, and local land use policies, as discussed in this chapter.

15.2.2 Monitoring, Reviewing and Responding to New Development

MassHighway's Public/Private Development Unit (PPDU) monitors development proposals that may affect state highways. Many development projects require permits from MassHighway for access or indirect access to its facilities. The review and approval of development projects occurs at the local level following local regulations expressed in zoning codes, development guidelines, and administrative procedures. MassHighway's focus is on the safety and operational impacts to public ways. Larger projects exceeding the review thresholds included in state regulation are also reviewed under the Massachusetts Environmental Policy Act (MEPA) provisions.

Both local and MEPA development review procedures usually require an assessment of the impacts on nearby roadways of new development proposals. These transportation impact and access studies (TIASs) often result in commitments for access design and offsite roadway improvements. The development project proponent should consult the *Guidelines for EIR/EIS Traffic Impact Assessment* (1989, as amended) by the Executive Office of Transportation and the Executive Office of Environmental Affairs, as well as other statutes, regulations, executive orders or policy directives that govern roadway and traffic issues.

These review procedures, either under MEPA or local regulation, provide numerous opportunities for public review and comment on development projects themselves and associated roadway improvements. Depending upon the outcome of these review processes, MassHighway's PPDU works with developers and their consultants to ensure that access points and offsite improvements are designed and constructed to meet standards, including the context sensitivity and multimodal accommodation goals of this Guidebook. In many cases, the developer constructs improvements to roadways once the designs are reviewed and approved by MassHighway and other responsible parties such as the municipal planning, public works, or building departments.

Larger projects that require completion of an Environmental Impact Report (EIR) by the Executive Office of Environmental Affairs, also require a Section 61 Finding, issued by MassHighway relative to access, prior to the issuance of an access permit. The Section 61 Finding specifies the driveway access and off-site mitigation measures necessary for initial occupancy of the project. Additional mitigation measures and the construction timing of the measures relative to phased development of a project may also be specified in the Section 61 Finding to ensure that the anticipated impacts from the development do not adversely impact the transportation system.

15.2.3 Driveway Design

Driveways are points of access from public streets to private property and, therefore, are not intersections as defined in Chapter 6. The requirements for making turning movements between public streets and driveways, however, are similar to the turning movements required at intersections. Intersection design criteria are presented in Chapter 6.

Driveways are intended for low-speed vehicle operation, and therefore should have corner radii reflecting low speeds. Where higher speeds are required, due to the nature of the public street or due to traffic volumes on the driveway (as in a commercial parcel), design guidelines for intersecting streets, as discussed in Chapter 6, are applicable. Single-lane driveways are appropriate for two-way traffic for all single family residential uses, as well as for small aggregations of residential units such as free-standing apartments. For aggregations of residential use of around ten dwelling units or greater, a two-lane driveway (24 feet in width) becomes appropriate. For small commercial uses with employee-only traffic (i.e., no retail customers or frequent visitors) a single-lane driveway is adequate. For commercial uses with retail customers and regular visitors, a two-lane driveway is preferable. Guidelines for Basic Driveway Dimensions are provided in Exhibit 15-1.

Exhibit 15-1
Basic Driveway Dimension Guidelines

	Residential	Commercial	Industrial
Nominal Width (feet)			
One-Way	10	15	20
Two-Way	10	30	40
Right Turn Radius or Flare (R)			
Minimum (feet)	5	15	20
Minimum Spacing			
From Property Line	R	R	R
Minimum Angle	45°	45°	30°

To allow reasonable entrance and exit speeds without causing vehicle under-ride and edge clearance problems, the vertical profile of the driveway cannot exceed certain limits. Maximum grades for residential driveways are 10 to 15 percent and for commercial 5 to 8 percent. Vertical curves at least 10 feet in length may be used to connect the tangent slopes.

Where an open channel is used for roadside drainage, the channel should intercept the driveway at approximately a 90-degree angle. The driveway side slope, including the pipe end section for the channel, should not exceed 1:6 and, preferably, will be 1:12. If construction will make radical changes on unpaved driveways, it may be necessary to pave the surface for proper drainage and erosion prevention. In all cases, the driveway should be paved to a point established in the field by the District Permit Engineer.

Sidewalks, bikeways, and parking lanes must be considered in the geometric design of driveways. A minimum 4 foot wide flush wheelchair path of no more than 1.5 percent cross slope must be provided where a driveway crosses a sidewalk.

Elements of driveway design that minimize the negative impact of driveways on pedestrian travel on sidewalks are:

- Minimum width of driveways, using single-lane driveways wherever possible.
- Minimal change to grade and cross slope of the sidewalk, even if this requires a break in the driveway grade.
- For low volume driveways, the sidewalk across the driveway may be at the same level as the adjoining sidewalk. Heavier volume driveways should be treated as an intersecting roadway with the sidewalk ramping down to the roadway surface.
- Continuation of the sidewalk paving material across the driveway, rather than continuity of the driveway paving material across the sidewalk. Where the paving materials are the same, the sidewalk should be outlined with joints or saw cuts across the driveway.

Turning and storage lanes should be considered on high-speed, high-volume driveways. Chapter 6, Intersections, and Section 15.3 discuss the design and warrants for these lanes.

15.2.3.1 Driveway Spacing and Consolidation

Separation of conflict areas is recognized as an effective way to improve pedestrian, bicycle, and vehicle safety. Extensive safety studies have confirmed that crash rates increase as the spacing of unsignalized access points decrease. This is especially true for commercial entrances and exits. Vehicles entering or leaving the road at driveway locations generally operate at slower speeds than the prevailing traffic, which increases crash potential and slows roadway travel. Managing driveway spacing often enhances operations and safety for the entire corridor.

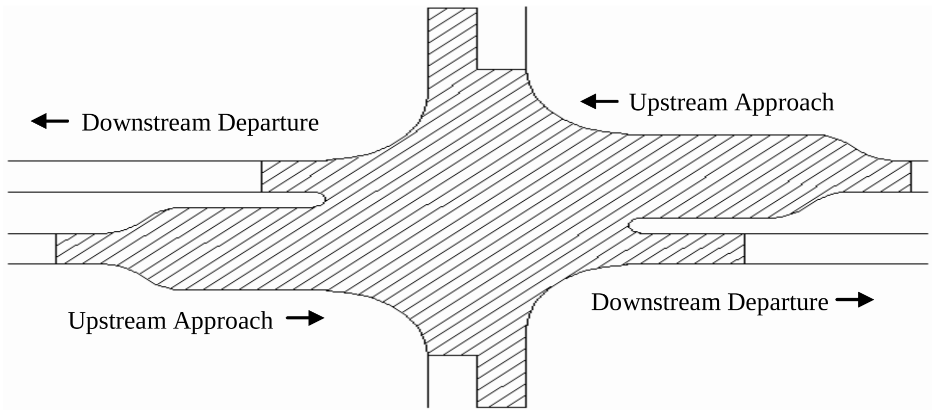
Minimum driveway spacing guidelines for the construction of new driveways are based on posted speed and roadway type, and need to consider:

- Stopping and intersection sight distances;
- The functional areas of upstream and downstream intersections;
- The influence of right-turns on through traffic; and
- Egress capacity

TRB's *Access Management Manual* presents detailed spacing guidelines for the various roadway types and environmental conditions. A brief description of each follows:

- **Sight Distances -** Stopping sight distance and intersection sight distance are important considerations in driveway location and design. A discussion of these design criteria is provided in Chapter 3, Section 3.7 of this Guidebook.
- **Functional Area –** All access points, signalized and unsignalized, have functional areas that often extend beyond the immediate physical intersection. This area is comprised of auxiliary lane vehicle storage (or queue) space, and a decision and maneuvering distance approaching an intersection, as well as merging and acceleration space departing an intersection, as illustrated in Exhibit 15-2.
- **Right-turn Influence** – Driveways that are spaced too closely can impact through traffic operations when a driver must monitor more than one right turn merging movement (called right-turn conflict overlap), or when upstream through traffic is required to brake and slow down for right-turning vehicles (referred to as the driveway's influence distance).
- **Egress Capacity** – Closely spaced driveways can interfere with each other and restrict egress capacity. This can be a result of increases in decision-making time and the influence of vehicle maneuvering and acceleration at adjacent access points.

Exhibit 15-2
Intersection Functional Boundary



Ideally, driveway spacing as wide as possible is desirable, both from intersections and from other driveways. However, the small property parcel size in most settled areas and the right of parcel owners to gain access to the adjoining street often dictates a minimum spacing.

In certain areas, provisions need to be made for access to existing parcels of land. However, where multiple existing parcels develop as a single entity, as in the case of a shopping center, coordinated and shared access is preferable. Furthermore, indirect access via secondary roads should be seen as a way to help implement the minimum standard. Finally, elimination, consolidation, or reconstruction of sub-standard access points should be incorporated into redevelopment projects and corridor improvements.

For new residential subdivisions on major arterials, a consolidated point of access from an internal road network is preferable for all house lots. Ideally, new lots should not be provided direct access from major arterials. If lots front on arterials, the advantages and disadvantages of loop driveways should be considered. Their advantage in eliminating cars backing out onto the roadway may be offset be the negative effects of doubling the number of driveway openings. Furthermore, connections should be made to surrounding developments to facilitate bicycle and pedestrian, as well as motor vehicle access.

Driveway closures are another way of eliminating conflicts with an arterial that has too many entering access points. Rather than closing a driveway, access can be restricted to right-in and right-out turns only to improve the overall safety of the arterial. Existing properties with multiple points of access onto major arterials are well-suited for this type of treatment.

15.2.3.2 Corner Clearance

Corner clearance is a related issue to driveway spacing and addresses the distance from roadway intersections to the nearest driveway entrance. A primary safety concern at or near controlled intersections is the reduction of interferences from side-street activity. Whenever practical, driveways should not be situated within the functional boundary of at-grade intersections (see Exhibit 15-2). This can become a significant concern since inadequate corner clearance can result in backups from the intersection extending across driveway entrances and blocking ingress and egress.

Although there are insufficient data, most access management research has concluded that:

- Crashes appear to increase as corner clearances decrease;
- Retrofitting corner clearances is both difficult and expensive; and
- A preferred proactive approach involves establishing a desired access location in conjunction with minimum frontage requirements that meets or exceeds the desired corner clearances.

Corner clearance should be provided on the main roadway and on the intersecting side streets. It is applied to both the upstream approach and downstream departure side of an intersection. The standards for each roadway classification are quite different. A restrictive median can reduce corner clearance requirements. Additional distance may be needed to provide for increased vehicle queuing at signalized intersections. MassHighway guidance for recommended minimum corner clearances is provided in the *Access Management Manual*.

Additional guidance for the minimum spacing of driveways from freeway ramps is provided in Chapter 7.

15.3 Access Management Techniques

A wide array of techniques can be used to manage roadway access. Appropriate measures vary according to roadway classification and existing context.

15.3.1 Turning Treatments

Removing turning vehicles from through lanes reduces the conflicts associated with the speed changes necessary to make turns (acceleration and deceleration). As such, turn lanes can improve safety and reduce delays at access locations. The majority of driveway-related crashes involve turns to or from the major road.

15.3.1.1 Left Turns

Left-turn lanes provide a safety benefit.

The safety benefits of left-turn lanes are well documented. The median crash rate reduction resulting from installation of left-turn lanes is 50 percent, although right-angle crash rates show mixed results at unsignalized intersections (NCHRP Report 420). Left-turn lanes also benefit highway operations by delay reductions to through traffic.

Several left-turn warrant methodologies have been developed that indicate the need for a turn lane based on the volume of left-turning vehicles as a function of the volume of opposing traffic. The National Highway Institute (NHI) suggests that such warrants may be appropriate for rural highways. The 2000 Highway Capacity Manual indicates the need for left-turn lanes where space permits when left-turn volumes exceed 100 vehicles per hour (vph), and recommends dual left-turn lanes when volumes exceed 300 vph.

Various standards also exist regarding the length of left-turn lanes. The standards are generally a function of vehicle speed and traffic volume, and are designed to allow turning vehicles to leave the travel lane, decelerate, and make the turning movement, accounting for queuing at the intersection.

The length of turn lanes and tapers should be based on MassHighway left-turn warrants, intersection operations, and design criteria (see Chapter 6).

15.3.1.2 Right Turns and Use of Paved Shoulder

Similar warrants and design standards exist for right-turn lanes. Right turn lanes should be considered at new commercial entrances and the entrances to new residential subdivisions where heavy turning volume is anticipated. Where numerous commercial or residential driveways exist in close proximity, consideration should be given to using an expanded right shoulder as a continuous turn/auxiliary lane. Since right-turn lanes can cause a shift in the roadway curb or edge and can result in traffic crossing over bike lanes on the roadway, care should be taken to ensure that such a treatment does not create an impediment to bicycle or pedestrian accommodations.

15.3.2 Median Treatments

The selection of an appropriate median type can be critical in providing for safe and efficient travel along a major arterial. In selecting a median type, a balance is often needed between providing access to adjacent properties and ensuring adequate throughput capacity and travel speeds.

By separating oncoming traffic, and by managing turning movements, non-traversable medians offer the most significant potential to improve roadway safety and operations. The provision of a non-traversable median that separates opposing traffic effectively limits left-turns on a roadway. Safety data have shown the crash rate reduction attributable to installation of medians is up to 35 percent (NCHRP Report 420). Wide non-traversable medians prevent cross-over crashes, provide shelter for vehicles making left-turns from or to a side street, and provide refuge for pedestrians or bicyclists crossing the street.

In four-lane roadway sections, research has shown that the selection of an appropriate median type is dependent on a number of factors, including number of access points, intensity of use of these access points, speed limit, presence of pedestrians, environment (developed, developing, rural),and the provision of adequate shoulders.

Two-way, left-turn lane (TWLTL) roadway sections as a median treatment can be appropriate in: 1) volume conditions less than 25,000 vehicles per day, 2) roadway sections with high driveway densities and low to moderate volumes, and 3) sections with high left-turning volumes relative to the overall traffic flow. Residential and low-density commercial areas are the prime examples of this type of roadside development. In both cases, TWLTL sections generally are posted for travel speeds between 25 and 45 miles per hour.

The design of a TWLTL section can also minimize safety concerns if shoulders are provided and the width of the center left-turn lane is adequately sized. A 12-foot minimum (16-foot maximum) is suggested for a center two-way left-turn lane. The center turn lane is a shared space, so drivers tend to enter this area cautiously. Therefore, in areas with higher driveway densities, driver transitions into the turn lane will tend to occur at slower speeds. In addition, in these areas, the provision of a wider center turn lane (14 to 16 feet) is likely to result in fewer vehicles partially blocking the through travel lane. On long corridors, TWLTL sections should broken by median islands to prevent the lane being used as a passing or travel lane and in locations with pedestrian crossings.

As discussed in Chapters 5 and 11, segments of non-traversable median interspersed with left-turn lanes is often preferable to the use of a TWLTL section to provide pedestrian accommodation and to reduce the perceived width of the street. Additionally textured, colored pavements and other features can be combined with TWLTLs to improve their function.

15.3.3 Signal Spacing and Timing

The spacing of signalized intersections dramatically impacts safety and traffic operations. Management of signal spacing includes planning for the frequency of signals, as well as the uniformity of their spacing. This technique is useful in managing access in some of the developed and developing corridors, particularly where several traffic signals already exist.

Optimal spacing depends on travel speed and cycle length. Research data indicate that as speed and cycle length increase, so does desired spacing.

Minimum signal spacing should be one-half mile in developing areas, and one-quarter mile in developed areas. In all cases, signal timing should be coordinated to facilitate traffic flow. For undeveloped sections of a corridor, two-mile spacing should be considered.

Along developing sections of highways, development should be carefully planned to avoid the proliferation of new traffic signals, and to ensure that minimum spacing standards are maintained. Local zoning plays a significant role in managing the intensity of development and redevelopment that will occur.

As areas experience infill and redevelopment, existing driveways and circulation patterns should be reconfigured to complement the signal system to the maximum extent. This may involve closing existing driveways, rerouting traffic to secondary streets, and providing connections between parcels. Roundabouts might also provide a technique for reducing the number of signalized location (see Chapter 16, Traffic Calming for a discussion of roundabouts).

15.3.4 Inter-Parcel Connections and Internal Roadway Systems

Inter-parcel connections for both pedestrians and motorists can limit short trips on the main route. These often take the form of simple driveway and sidewalk connections between commercial sites, so that traffic moving from one to the other need not access the arterial.

Large residential developments can also be planned to provide a minimum number of access points on the main highway by internalizing private driveways on local subdivision streets, which in turn connect to a feeder road that has direct and full access onto the main highway. It is important to also plan for future growth of residential development by planning for interconnections of the development with adjacent (potentially undeveloped) properties. This will help avoid a single-entry cul-de-sac serving each development and ensure that the best and fullest use of the existing access point on the main highway is utilized.

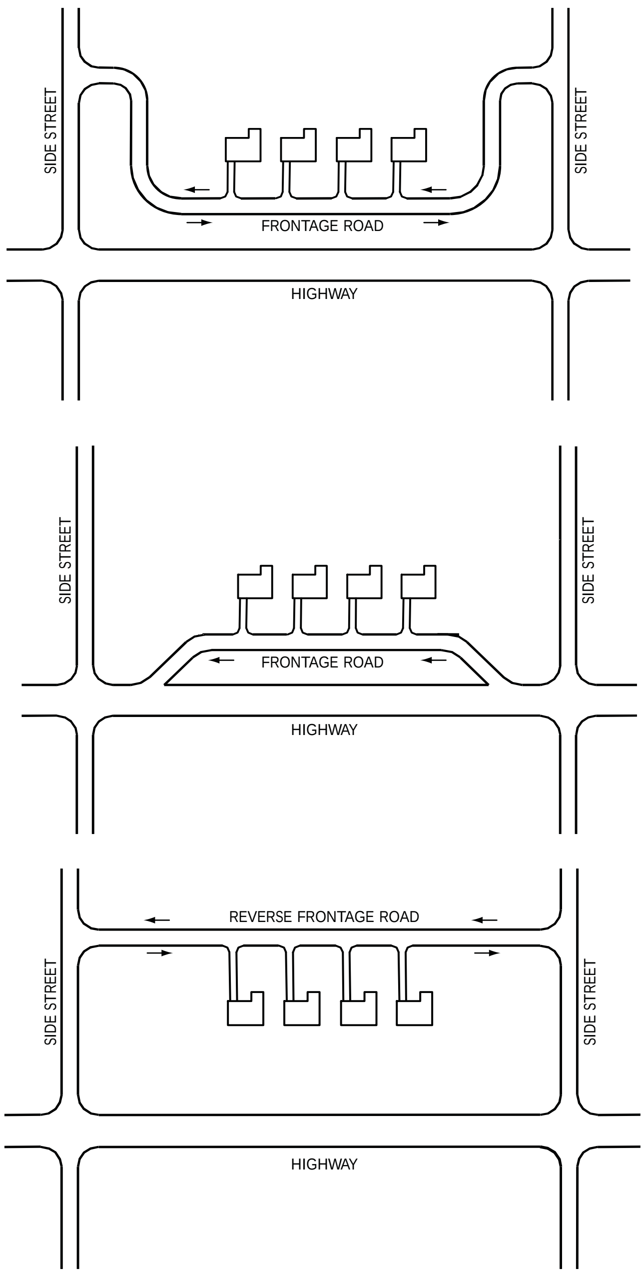
In some communities, commercial and large residential developments are allowed only to have indirect access onto a major roadway or restricted right-in/right-out access, with the full access point on the side street. This is also done when a driveway is anticipated to have an adverse effect on traffic safety and operations.

15.3.5 Frontage Roads

An effective treatment to consolidate the number of access points, and therefore conflict points, on an arterial highway can be achieved through the construction of a frontage road or a reverse frontage road. These concepts are depicted in Exhibit 15-3.

A frontage road is a local street (one-way or two-way) that serves multiple land uses (properties) and provides one to two points of access onto the main roadway. A frontage road can be constructed without taking existing buildings fronting the roadway when the buildings are setback far enough to accommodate the roadway and maintain the minimum setback from the road required by zoning.

Exhibit 15-3
Frontage Road Concepts



Frontage roads have a place in serving commercial development as well as residential access needs. When carefully designed to facilitate access and maintain signal operations, frontage roads can be a viable access management technique for large commercial developments.

15.3.6 Full Access Control Highways

When full access control is proposed for an existing highway or a new freeway, each intersecting public or private way must be handled using one of the following options. The options listed below also apply to dedicated pedestrian and bicycle facilities.

- The intersecting facility can be dead-ended, thereby effectively terminating through traffic.
- The intersecting facility can be re-routed to maintain connectivity, often as a frontage road.
- The intersecting facility can be grade separated as either an underpass or an overpass, thereby maintaining through traffic, but effectively terminating access to the intersecting highway.
- The intersecting facility can be reconstructed as an interchange, thereby maintaining through traffic access to the intersecting highway.

The importance of the continuity of the crossing road or the feasibility of an alternate route will determine whether a grade separation without ramps or interchange is provided. An interchange should be provided on the basis of the anticipated demand for access to the minor road. The decision to provide a grade separation without ramps rather than an interchange is often based on the following considerations:

- Lacking a suitable relocation plan for the crossroad, a highway grade separation without ramps may be provided to maintain connectivity of low volume roadways. All users desiring to access one facility from the other are required to use other existing routes. In some instances, these users may have to travel a considerable distance, particularly in rural areas.
- A grade separation without interchange ramps may be provided to avoid having interchanges so close to each other that signing and operation would be difficult. This approach eliminates interference with large major road interchanges and increases safety and mobility by concentrating turning traffic at a few points where it is

feasible to provide adequate ramp systems. On the other hand, undue concentration of turning movements at one location should be avoided where it would be better to have additional interchanges.

- In rugged topography, the site conditions at an intersection may be more favorable for provision of a grade separation than an at-grade intersection. If ramp connections are difficult or costly, it may be practical to omit them at the structure site and accommodate turning movements elsewhere by way of other intersecting roads.
- Many times partial interchanges are constructed initially because the traffic volumes do not support a full interchange or the required right-of-way is not available when the interchange is first constructed. As time passes however, the need for a complete interchange develops or the right-of-way is obtained.

15.4 Land Use Controls

Because access management deals with the relationship between transportation and land use, it requires cooperation between MassHighway and local government agencies. Local governments are encouraged to identify corridor preservation goals and address land use access requirements in their comprehensive plans.

The Commonwealth, Regional Planning Agencies, and the municipalities should cooperate carefully to manage access along the arterial roadway network. Local land use plans and zoning ordinances that discourage highway dependent development and sprawl are supportive of MassHighway’s goals to protect and preserve the safety and function of the Commonwealth’s transportation network.

Some recommendations included in this section fall under the purview of MassHighway and others fall under control of the local governments. Consistent application of access management plans, by all parties and across jurisdictional boundaries, will produce greater success in preserving the highway system into the future.

The following sections describe approaches to managing access through land use controls at the local level and are included as examples of steps local governments can take to improve the relationship between local land uses and the regional highway system.

15.4.1 Zoning and New Development

Revisions to local zoning standards are often necessary to effectively implement access management. Zoning that targets development in areas with good multi-modal access, requires shared access along streets and highways, and encourages compact centers as opposed to strip development is helpful in managing access through land use control and improving the relationship between land use and access control.

Subdivision regulations and local ordinances should require minimum lot frontages, dimensions, and street layouts that recognize the intended function of the roadway (traffic flow versus property access). The higher the roadway classification, the fewer the number of access points that should be provided along the roadway. The ability of the municipalities to provide zoning restrictions to require minimum parcel frontages on important roadway corridors can significantly aid in the enforcement of driveway spacing standards (i.e., minimum parcel frontage standard consistent with driveway spacing guidelines). Chapter 7 of the *Access Management Manual* provides guidance on land use zoning, access controls and subdivision site plan review processes that are helpful in achieving the full benefit of a access management plan.

15.4.2 Highway Corridor Overlay District

One of the most effective tools in applying corridor-specific standards is the highway corridor overlay district (HCOD). This is a separate set of zoning regulations for parcels within a certain distance from a roadway, usually an arterial highway. An HCOD generally would not be used on lower classification roadways. The ordinance implementing an HCOD contains additional regulations that are over-riding, and in some cases, additive, to existing zoning regulations. HCODs involve standards governing access, visibility, and corridor aesthetics. They generally provide standards for number and location of access points, inter-parcel connections, size and location of signs, and landscaping and buffer requirements.

Several communities within the Commonwealth have successfully implemented HCODs; however, they are often implemented in response to an already congested roadway. Elements of a model overlay district that designed for incorporation into municipalities' zoning ordinances are overviewed below.

15.4.2.1 Intent

The HCOD should state its intended effects which are generally to enhance the safety, function, and capacity of designated highways. As major traffic routes, these highways represent significant community investments, and contribute to public health, safety, and welfare. They provide access to jobs and schools, facilitate delivery of emergency services, support the movement of goods and services, and enhance economic development. Furthermore, these corridors serve as first impressions of the community for visitors and the traveling public.

15.4.2.2 Applicability

The applicability of the HCOD should be clearly stated, as an example:

> *The HCOD shall also apply to redevelopment projects, as defined herein, regardless of whether such redevelopment requires site plan or subdivision review. As an overlay district, the HCOD shall complement the requirements of the underlying zone, which shall remain in effect. Wherever the requirements of the HCOD conflict with those of the underlying zone, the greater or more stringent standard shall apply.*
>
> *To ensure adequate coordination with MassHighway regarding highway access management and traffic improvements, no site plan or subdivision plat shall be approved without a written finding from the MassHighway District Highway Director that the proposed roadway, driveway, and circulation systems are consistent with the Access Management Plan.*

15.4.2.3 Access

The purpose of the HCOD is to manage vehicular and non-vehicular access. To achieve this goal, all site plans should include an access plan drawn to the same scale as the site plan. These plans should show the location and dimensions of all streets, driveways, crossovers, parking areas, access aisles, sidewalks, and any other relevant information. Access to the HCOD corridor should be provided by direct or indirect means, consistent with the following planning guidelines:

- Minimal number of access points;
- Required corner clearance of driveways from intersecting streets;
- Minimum sight distances along the highway for the design speed;

- Internal street layout and connections to the maximum extent feasible;
- Shared access to the maximum extent feasible;
- Good pedestrian and bicycle access to minimize conflicts with vehicular traffic; and
- Pedestrian circulation systems that connect uses within individual projects to adjacent parcels and activity centers.

In order to promote the orderly retrofit of existing developments that do not conform to the requirements of the HCOD, while encouraging reuse of previously developed properties, redevelopment standards should be defined in the language of the ordinance. Given the varying conditions of existing development, some administrative flexibility is required in applying standards to redevelopment.

15.4.2.4 Traffic Impact Analysis

As part of HCODs, consideration is often given to requiring a traffic impact analysis (for example, for all developments generating more than 1,000 average daily trips). The projected number of average daily trips should be based on trip generation rates as defined by the most recent publication of the Institute of Transportation Engineers "Trip Generation," or an acceptable substitute. In addition, a traffic impact analysis may be required for developments generating fewer daily trips when it is determined, in consultation with the MassHighway District Highway Director, that safety considerations warrant such analysis. The traffic impact analysis should identify level of service impacts of the proposed development and should be used to determine necessary improvements to support the development. The analysis should be conducted for the morning and evening peak commuter hours as well as for other peak hours applicable to the proposed use (e.g., a Saturday peak hour for retail development). At a minimum, the impact analysis shall address the following:

- Definition of pedestrian, bicycle, and motor vehicle access
- Turn lane and access improvements
- Internal site circulation
- Shared access/access to adjacent sites
- Impacts to intersections and median crossovers
- Potential need for signalization or roundabouts

15.4.2.5 Required Improvements

Required improvements, the need for which is generated by the proposed development, is determined in consultation with the MassHighway District Highway Director based on the traffic impact analyses. The developer shall be responsible for provision of the improvements.

15.4.2.6 Setbacks

In order to preserve and enhance highway safety and efficiency, setbacks are often specified in the language of the HCOD. Typically, setbacks are to remain free from all development, including buildings, parking areas, gas pumps, canopies, and similar structures and facilities. Where necessary to accommodate an approved circulation plan, access driveways are permitted within setbacks.

Setbacks can also be defined for the purposes of establishing streetscape improvements, or to provide for the future widening of a corridor when warranted.

15.4.2.7 Other Design Elements

To manage growth in a manner consistent with the intended traffic safety, operations, and corridor appearance objectives of the HCOD, design guidance for a number of other physical elements of the corridor, such as signage, lighting, and landscaping, are worthwhile considering.

Well planned and maintained signage, landscaping, and lighting will achieve several benefits in furtherance of this ordinance:

- Preserve and enhance traffic operations
- Enhance the pedestrian environment
- Preserve and enhance the visual quality of designated corridors

Site plans that include a landscaping plan drawn to the same scale as the site plan, and that show the location, size, and description of all landscaping materials in relation to structures, parking areas, and driveways should be required.

15.4.3 Retrofitting Existing Development

Effective access management requires both retrofit and policy actions. A comprehensive access management plan will include recommendations to improve existing problem areas, as well as requirements to ensure that new development does not degrade the future highway corridor function. The application of access management guidelines is not as straight-forward on existing roadways. While some land uses may be replaced in the future development, a best-fit (or retrofit) approach must be used to try to achieve the access management objectives with existing uses.

As an example, a new shopping center or residential development could provide an access road that connects to an existing church property that has poor access. This would allow for modification of the access to the church property. This is a proactive process that cannot be designed in advance but must be responsive as adjacent development occurs.

Major highway reconstruction projects should always review the potential for improvements to access management. A coordinated effort on the part of municipal officials and MassHighway is required to ultimately bring corridors up to desired standards.

15.5 For Further Information

- *Access Management Manual*, Transportation Research Board. Washington D.C., 2002.
- *A Guidebook for Including Access Management in Transportation Planning*, NCHRP Report 548, 2005.
- *Access Management Guidelines for Activity Centers*, NCHRP Report 348, 1992.
- *Impact of Access Management Techniques*, NCHRP Report 420, 1999.
- *Land Development Regulations that Promote Access Management*, NCHRP Synthesis 233, 1996.
- *Corridor Management*, NCHRP Synthesis 289, 2000.

Chapter 16

Traffic Calming & Traffic Management

Traffic Calming and Traffic Management

16.1 Introduction

This chapter describes a variety of measures that can be used to lower vehicle speeds, and redirect traffic flows. ***Traffic calming*** measures are physical road design elements intended to reduce vehicle speeds and improve driver attentiveness. ***Traffic management*** measures are the application of turn restrictions and other measures to redirect or restrict traffic flows. This chapter places a greater emphasis on traffic calming measures; however, traffic management strategies are also discussed.

Traffic calming incorporates three major categories of design measures:

- Narrowing the real or apparent width of the street.
- Deflecting (introducing curvature to) the vehicle path.
- Altering the vertical profile of the vehicle path.

These measures are used to reduce operating speeds on a roadway and to increase driver attentiveness. A major objective of traffic calming is to reinforce the desired operating speed through design of the facility, thereby self-enforcing the desired speed. The goal is to:

- Reduce the number of motorists exceeding the posted speed limit;
- Reduce the speed of all motorists to the desired operating speed; and
- In some cases, to support the reduction of posted speed limits.

Desirable operating speeds, regularly requested by those affected by traffic calming measures (typically residents, business owners/operators, employees, and business patrons), range from 15 to 30 miles per hour in residential settings and 20 to 35 miles per hour in commercial or institutional settings. The selection of appropriate design speeds is discussed further in Chapter 3 and needs to be informed by existing operating speeds and applicable speed limits.

Traffic calming should reduce the operating speed of the street (i.e. the speed which most motorists intuitively choose) to the target speed. In many cases, traffic calming is also used to increase the attentiveness of drivers by signaling a change from the prevailing roadway conditions. Additional attentiveness is achieved through:

- Reduction of operating speeds;
- Increase in noticing other important users of the street, specifically, pedestrians, bicyclists and motorists using on-street parking;
- Heightened awareness of a need for safe driving behavior; and
- Elimination of inducements to aggressive and dangerous behavior (for example, reducing pavement width to stop vehicle overtaking).

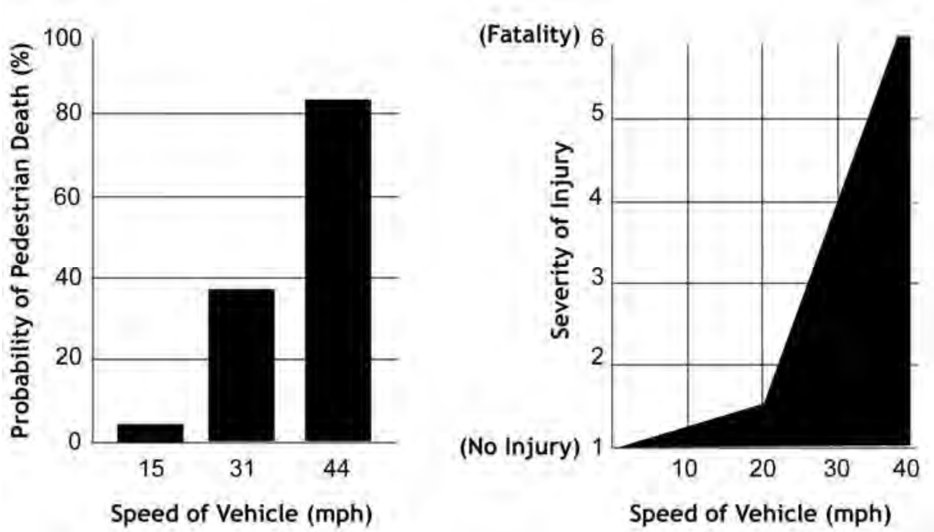
16.2 Potential Benefits and Impacts

When used in appropriate settings, the reduction in vehicle speeds obtained through traffic calming measures reduces both the frequency and severity of collisions. Further, traffic calming measures are also intended to increase driver attentiveness so that vehicles are less likely to collide. A number of studies support the correlation between reduced motor vehicle speed and reduced severity of collisions. For vehicle/pedestrian collisions, the severity of injuries increases sharply as vehicle speed increases, as illustrated in Exhibit 16-1. Traffic calming measures can improve pedestrian accommodation by:

- Reducing crosswalk distances, and the extent of pedestrian/motor vehicle conflict;
- Reducing motor vehicle speeds, their stopping distances, and the severity of pedestrian/motor vehicle conflicts;
- Increasing the attentiveness of motor vehicle drivers to the presence of pedestrians;
- Reducing the number of lanes of vehicular traffic, at least for short segments of streets;
- Increasing sidewalk space;
- Shielding sidewalks from moving motor vehicles with parked vehicles, trees, curbs, bicycle lanes and added sidewalk width; and

- Improving yielding to pedestrians due to the reduced sense of "lost" time for slowing and resuming speed when compared with higher speed environments.

Exhibit 16-1
Vehicle Speed and Pedestrian Fatality Rate



Source: Adapted from the Guide for the Planning Design and Operation of Pedestrian Facilities, AASHTO, 2004

The impact on safety for pedestrians is compounded since there are more suitable gaps for pedestrian crossings, complemented by improved yielding by drivers. The result is an increase in the ability for pedestrians to cross a traffic steam of any vehicular volume. The safety improvement is further compounded by the reduced probability and severity of injuries resulting from those collisions that do occur.

Traffic calming measures can improve bicycle accommodation by:

- Reducing motor vehicle speeds, reducing motor vehicle stopping distance, and the probability of bicycle/motor vehicle conflicts;
- Providing an opportunity to consider installation of bicycle lanes;
- Increasing the awareness of bicyclists;
- Reducing the severity of motor vehicle/bicycle collisions; and
- Reducing intersection size and the probability of motor vehicle/bicycle conflicts.

Traffic calming measures can improve motor vehicle accommodation by:

- Reducing motor vehicle speed, thus reducing the probability and severity of crashes;
- Reducing the frequency of vehicle overtaking on urban and neighborhood streets;
- Providing design features (for example, roundabouts) that self-enforce lower vehicular speeds; and
- Providing motor vehicle drivers with multiple reminders of safe and appropriate operating speed.

Although there are numerous possible benefits of traffic calming, there are several potential disadvantages that must be considered when developing a traffic calming design. Many of these potential disadvantages can be mitigated as described below.

- Traffic calming measures do not improve safety for motorists who fail to heed the indications of reduced design speed and operate a vehicle at speeds in excess of a road’s design speed. Advance signage can help to inform drivers of changes in proper operating speed when approaching traffic calming areas.
- Traffic calming and traffic management measures can slow emergency response since they often require slower operating speeds or diversions. It is important to coordinate traffic calming plans with local emergency response departments so that these impacts are minimized.
- Inappropriately designed or placed traffic calming and traffic management measures can impede transit vehicles. It is important to coordinate traffic calming plans with local transit agencies to avoid these impacts.
- Inappropriately designed or placed traffic calming and traffic management measures can impede large truck traffic. It is important to understand regional and local truck routes when developing traffic calming programs to avoid these impacts.
- Some traffic calming measures (particularly those involving horizontal and vertical deflection) can result in increased noise and headlight impacts to adjacent properties. Traffic calming design needs to be sensitive to these potential impacts.

16.3 Applicability to Settings and Roadways

Traffic calming measures are usually deployed in response to community concerns about high motor vehicle operating speeds and volumes. As a result, traffic calming measures are more often applied in developed settings such as urban areas, suburban town centers and villages, suburban high density areas, and rural villages. Typical characteristics of settings associated with traffic calming are:

- Concentrated generators of pedestrian activity; for example, school campuses, elderly housing, downtown retail districts, “Main Street” shopping areas, public assembly venues (stadiums, auditoriums), recreation destinations (parks, playgrounds), health care complexes, and large employers;
- Pedestrian activity, either constant or in surges, along and across the street;
- Neighborhood streets where the street serves both as a transportation facility and a community space;
- Sensitive land uses (historical, tourist, retail, civic, institutional) abutting the street; and
- Transition zones, from higher to lower speed, e.g., when approaching a rural village.

Traffic calming is most often applied to existing streets where vehicle operating speeds are in conflict with pedestrian activity and other aspects of the setting as described above. Some traffic calming measures (such as crossing islands and curb extensions) used as retrofit measures on existing streets can also be used as regular design elements on new or rebuilt streets.

The needs of the setting must be balanced with the regional mobility function of the roadway when considering traffic calming measures, similar to many other aspects of roadway design. Traffic calming measures discussed in this chapter are most appropriate for local roads and minor collectors. Additional measures suitable for local streets (but too restrictive for other types of streets) are not discussed in this chapter, but may be found in the references listed at the end of the chapter.

Traffic calming must strike a balance between local needs and local mobility.

In some circumstances, such as in a town center environment, where both high vehicular and high pedestrian volumes are present, traffic calming measures can be suitable for use on arterials. In some cases, these elements, such as crossing islands and curb extensions, can be incorporated directly as elements of good design for new roadways. However, intensive traffic calming programs are usually not applied to suburban and rural arterials since they primarily provide for regional travel and the settings for which traffic calming is desired are not usually found along arterials.

Traffic calming measures are not appropriate for freeways and expressways. The settings associated with traffic calming are not present along freeways and expressways. Exhibit 16-2 summarizes the applicability of various traffic calming measures to various roadway types under typical conditions. The specific measures are described in more detail in the following sections.

Exhibit 16-2
Traffic Calming and Traffic Management Applicability by Roadway Type

	Arterials	Major Collectors	Minor Collectors	Local Roads
Street Narrowing				
Narrow Lanes		Δ	■	■
Raised Curbs	■	■	■	■
Street Furniture	■	■	■	■
Street Trees	■	■	■	■
Street Lighting	■	■	■	■
Spot Narrowing	Δ	■	■	■
Medians and Crossing Islands	■	■	■	■
Curb Extensions	■	■	■	■
Road Diets	Δ	Δ	■	■
Building Siting	■	■	■	■
Horizontal Deflection				
Chicanes			■	■
Crossing Islands/Short Medians	■	■	■	■
Mid-Block Traffic Circles			Δ	■
Roundabouts	■	■	■	■
Lane Offsets		Δ	Δ	■
Profile Alterations				
Speed Humps		Δ	Δ	■
Raised Crosswalks		Δ	■	■
Raised Intersections		Δ	■	■
Textured Pavement	■	■	■	■
Traffic Management	Δ	Δ	Δ	Δ

■ Often used for new design or retrofit programs in traffic calming settings
Δ May be suitable

16.4 Spacing and Frequency of Measures

Traffic calming measures which alter the cross section of the street (for example, on-street parking for a block or more, continuous planting of street trees) are appropriate for extended lengths. Drivers are more likely to regard such features as an inherent characteristic of the street and not as measures “aimed” at their driving practices.

On the other hand, “spot” traffic calming measures, applicable to only a small segment of street (for example, roadway narrowing or speed humps) should be spaced so that the desired operating speed is maintained along the roadway segment in question. If measures are placed more frequently and require excessive slowing and accelerating or maneuvering, they can become annoying and less effective in controlling speeds. The particular spacing of elements depends greatly upon the context in which they are used. For example, with speed humps, the driver should be cued to their spacing so that a consistent speed is maintained. Often, speed humps should be visible from one to the next along a continuous segment of roadway to encourage a flat speed profile rather than rapid acceleration and deceleration at the speed humps.

In a comprehensive traffic calming plan, continuous street-length measures (on-street parking, tree planting) are used on streets, such as the major spine of the area. On other streets within the district, a spacing of one to two traffic calming measures per block is appropriate.

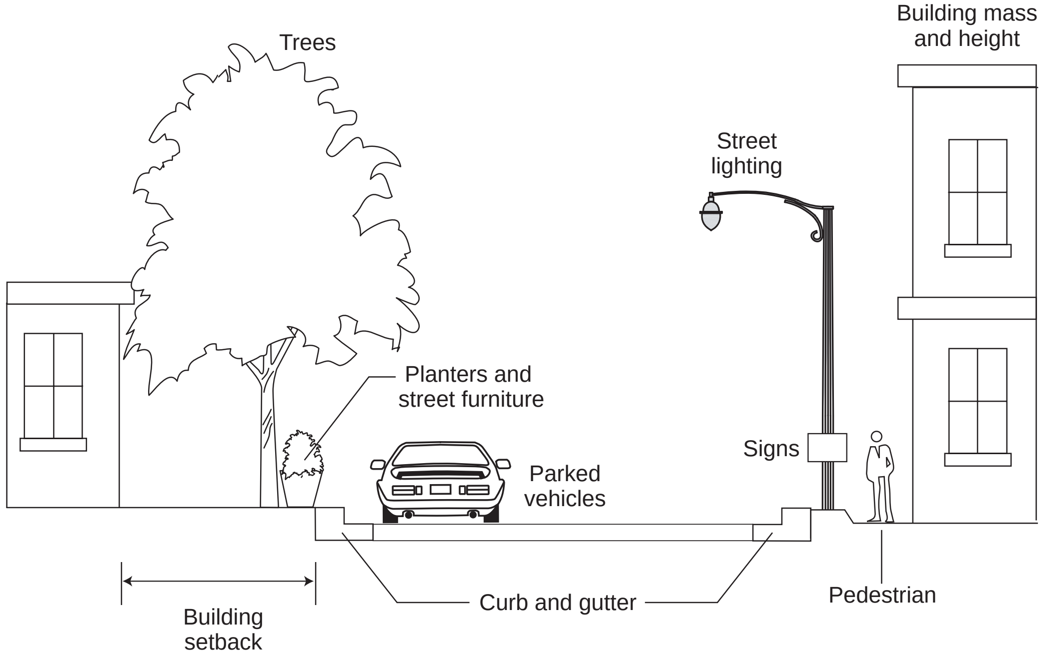
16.5 Measures to Narrow the Apparent Width

Reduction of the apparent street width can be an important traffic calming element. Elements that influence the apparent width of a street are illustrated in Exhibit 16-3, listed below, and discussed in the subsequent sections.

- Building placement along the street;
- The presence or placement of trees along the street;
- Street furniture including lights, benches, and other elements;
- Edge treatment of the pavement; and
- Pavement cross-section including on-street parking, spot narrowing, bike lanes, travel lanes, auxiliary lanes, medians, and islands.

An additional tool for narrowing the apparent width is the use of gateways, which are also described later in this section.

Exhibit 16-3
Elements of Apparent Street Width



Source: MassHighway

16.5.1 Building Placement

In commercial settings, the placement of buildings directly along the street (i.e., with no setbacks from the right-of-way) is a highly effective traffic calming measure. Building sites are, by definition, outside the public right-of-way. Their regulation is usually the prerogative of local government jurisdictions (city or town). Regulatory changes, by local governments, to encourage building placement adjacent to streets, particularly in commercial areas, are effective complements to traffic calming design.

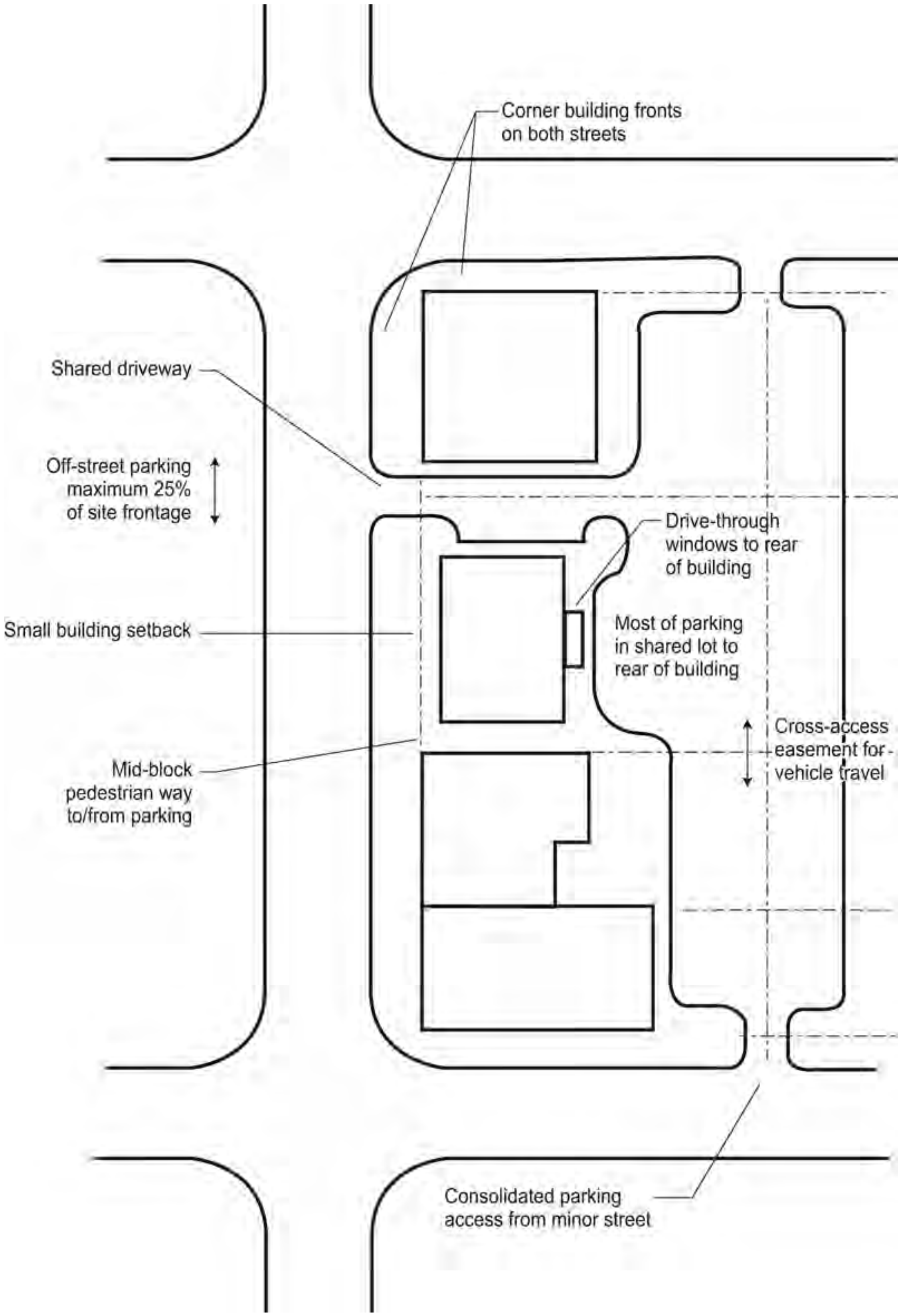
Placing buildings directly on the street involves no loss in vehicular service. The quantity, but not the placement, of off-street parking can remain the same for development, although in practice the improved walking atmosphere and the availability of on-street spaces reduces the demand for off-street parking. Drive-through windows can be placed to the rear of buildings, with no loss in vehicle access. In many instances, drive-through operations function better when serviced by the long drive aisles of joint parking areas located behind the building, rather than in small parking areas on individual parcels.

To properly support traffic calming in commercial settings, commercial buildings should be sited along the street as shown in Exhibit 16-4. Parking lots in front of buildings (i.e., along the street frontage) should be prohibited. On corner parcels, the building should occupy the corner itself, with visible off-street parking (if any) at parcel boundaries, as far from the corner as possible.

Features of building placement that contribute to traffic calming include:

- **Sense of enclosure** – With buildings fronting the street, typical street-side building mass (two story building or equivalent) encloses the street, from the driver's eye point, to a height of about 30 degrees from horizontal. This visual enclosure is always greater than that produced by buildings of the same height, but set back from the street.
- **Urban Characteristics** – Buildings sited along the street convey a broad set of signals signifying that the area is a setting requiring lower vehicle operating speeds. Some elements associated with a town or village center environment are the detailing of the building faces, signs and symbols on the buildings, merchandise visible in the building or displayed on the sidewalk, and on-street parking.
- **Pedestrians or expectation of pedestrians** – Building placement directly along the street puts multiple possible origins and destinations along the street edge. Front doors along a street, served by on-street parking, assure some level of pedestrian travel on the sidewalk. The presence of pedestrians, or the expectation that pedestrians might be present, is an important factor in reducing vehicle speeds and heightening attentiveness of drivers.

Exhibit 16-4
Building Siting Guidelines

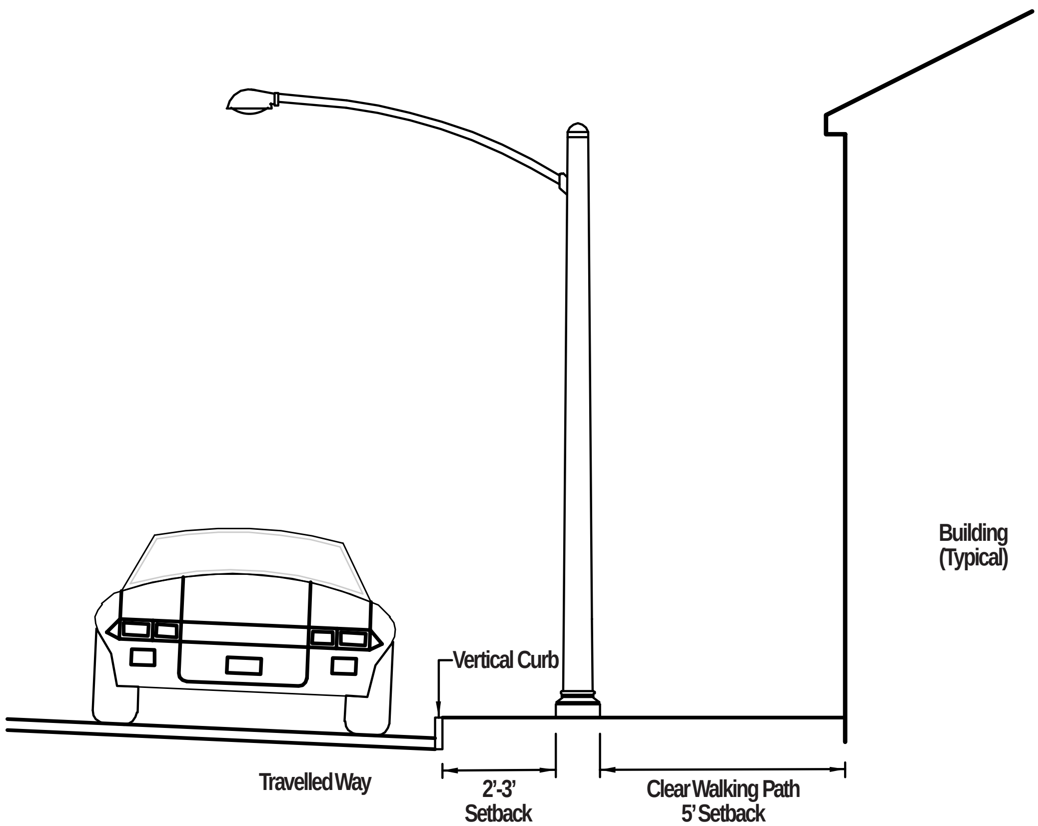


Source: Adapted from Congress for New Urbanism

16.5.2 Street Furniture

Street furniture elements include signs, signals, street lights, walls, fencing, and pedestrian furnishings such as benches, shelters and trash receptacles. In traffic calmed settings, it is desirable for street furniture to border the street and provide a separation between the pedestrian pathway and traffic. Poles and planters are normally located 2-3 feet from the back of curb, leaving room for the opening of car doors or for movement of pedestrians to/from parked automobiles, as shown in Exhibit 16-5. Benches, kiosks and shelters should allow sufficient space (6-8 feet from curb) for the comfort of their users.

Exhibit 16-5
Desirable Street Furniture Setbacks



Source: MassHighway

16.5.3 Street Lighting

Common street furniture elements are street lights, which affect the apparent width of the roadway in several ways:

Street lights in a town center setting

- By the size and placement of the street lights,
- By the height and pattern of light when illuminated, and
- Through the sense of enclosure created by overhead street lights.

A street lamp height of 12-15 feet supports a traffic calmed environment by signaling an area of special concern where pedestrians are present. Where street trees are present, the lamp height should be beneath the tree canopy, or between trees.

For the street lamp heights suggested above and desirable illumination levels, a longitudinal spacing of 50-75 feet is appropriate. Lighting fixtures should be appropriately shielded to minimize undesirable light pollution and the color emitted (white light is often preferred in developed areas) should be consistent with the setting.

In addition to possible traffic calming influences, street lights are an important feature of the urban design for a district. In many cases, municipal or district standards apply to the selection and placement of street light fixtures.

16.5.4 Street Trees

Tree trunks lining the roadside create a sense of enclosure and contribute to a reduced apparent width. The overhead tree canopy further adds to the perception of a narrowed road since the light/shade patterns on the pavement created by the trees contribute to a sense of texture on the pavement. Guidance for the planting of street trees is provided in Chapter 13.

16.5.5 Raised Curbs

Curbs are important in traffic calmed settings because they signal a lower design speed to motorists. Curbing is not normally paired with clear zones typical of rural areas and high speed environments. Further, a raised curb permits a placement of roadside objects (trees and street furniture) close enough to the travel lanes to have a pronounced traffic calming effect.

Short segments of streets with no curb within longer segments of curbed streets can also be a traffic calming measure. In such instances, the edge of the traveled way is delineated by pavement markings, change in pavement texture, or paving bands of a contrasting color and texture. The edge of the traveled way can be further delineated by bollards, planters or other street furniture. Curbless sections can also serve as “shared streets” which are designed to be fully part of the public realm and are integrated into the surrounding context. Examples of such shared streets are plazas in a town center, market places with street vending, streets regularly used for festivals, and places (e.g., in front of churches or city halls) of unusual civic interest.

16.5.6 Curbside Parking

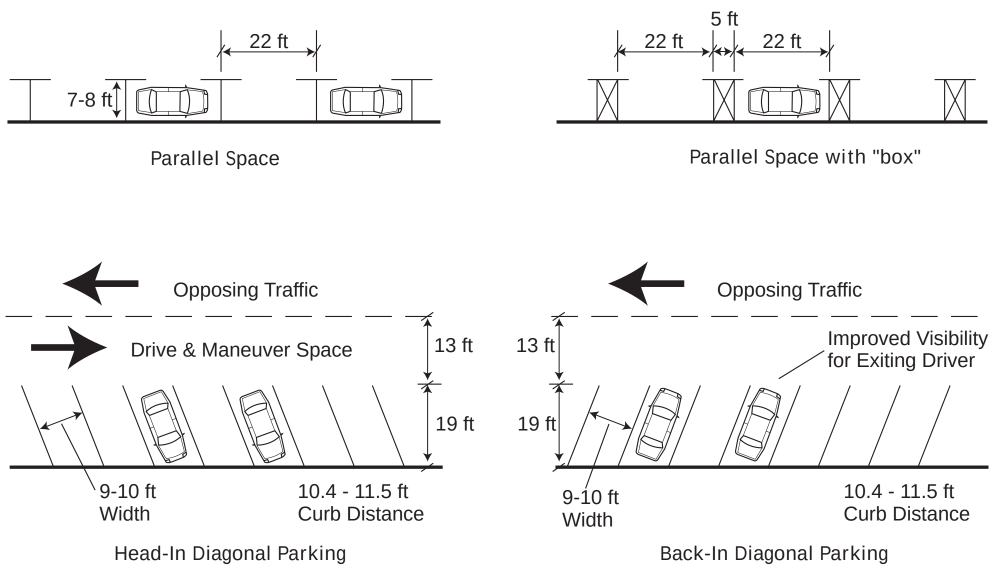
The sense of enclosure resulting from parked cars, the articulated appearance of parked cars, the entry/exit vehicular maneuvers, and the pedestrian traffic generated by occupants of parking/departing vehicles, all contribute to traffic calming on streets with parking. Curbside parking of all types should be considered in the context of bicycle use of the street since parking maneuvers and door openings are obstacles to bicyclists.

The dimensions for on-street parking, in contrast to those for moving vehicles, are not intended to change behavior, but rather are intended to make parking safe and efficient. Although spaces do not need to be striped, the typical dimensions for on-street parallel spaces are a width of 8 feet, and a length of 20-22 feet. In many locations, particularly with short sections of curb face interrupted by driveways or hydrants, the length of parking spaces can be increased without reducing the number of spaces. The selected width should also take into consideration whether bicycle lanes are present and the volume and composition of traffic on the street.

The parallel parking maneuver can be expedited and made more convenient to drivers by marking a “box” at one or both ends of the parking space, as illustrated in Exhibit 16-6. If parking is allowed, this treatment is particularly suited to roadways with higher traffic volumes. The box striping plan can help minimize the delays caused by the parking maneuver. With these boxes in place, the entering or exiting motorist has available the marked dimensions of the space (typically 22 feet, although smaller spaces are possible with this treatment) and also the length of both of the attached boxes (a total of 8-10 feet) to enter and exit the parking space.

Diagonal parking is not commonly used because of limitations in roadway width, but can be an element of traffic calming in areas with a high demand for parking and sufficient pavement width. The allocation of pavement (parking versus travel lanes) and the "friction" of parking maneuvers contribute to traffic calming.

Exhibit 16-6
Curbside Parking



Source: Adapted from Back-In Angle Parking in the Central Business District, John A. Nawn, 2003

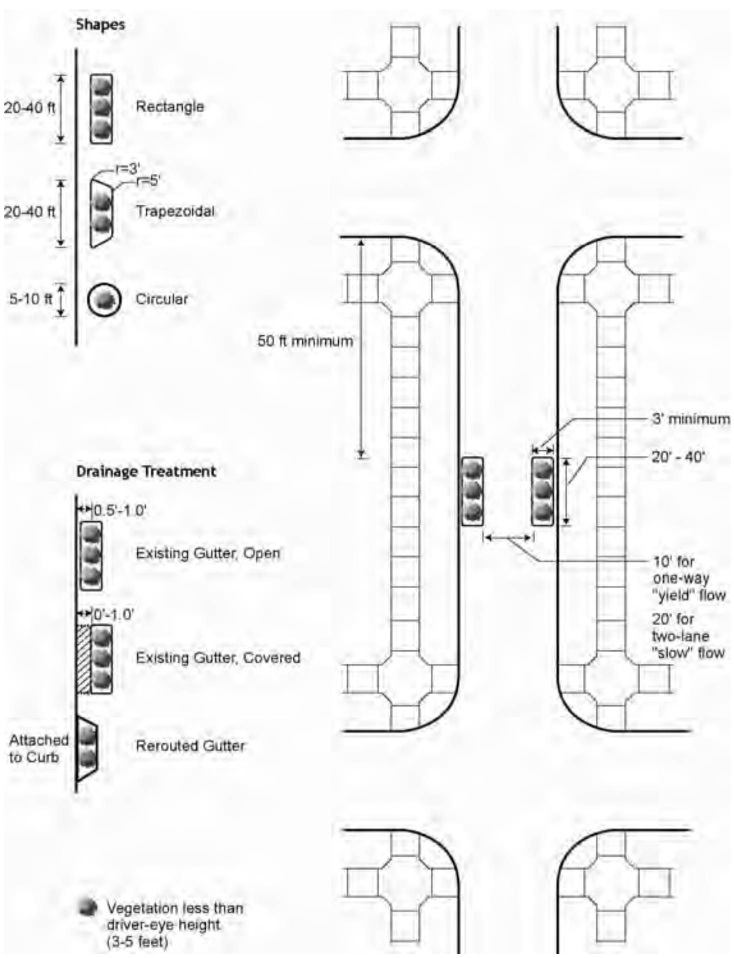
"Back-in" diagonal parking, shown in Exhibit 16-6 has recently been suggested as another approach to angle parking. Parking dimensions are the same as head-in diagonal parking. However, the back-in layout permits exiting drivers to have a clear view of on-coming traffic, bicyclists, and pedestrians in the street as they exit the space. Visibility leaving the space is superior to head-in parking, where exiting drivers are likely to have their view of on-coming traffic obscured by the adjacent vehicle. An additional advantage of back-in parking is that the open doors of the parked vehicles block passenger access to the street, and instead channel passengers toward the sidewalk, a safety benefit for all users and particularly for children. Finally, back-in parking places the cargo area (trunk, hatchback, truck bed) for almost all vehicles on the curb, and not in the street adjacent to traffic lanes.

The principal drawbacks of back-in parking, when compared with head-in parking are the need for a motorist to stop in the travel lane before backing into a space and increased potential for vehicle overhang on sidewalks. The overhang is a significant concern if the sidewalks are narrow. The provision of wheel stops can help address the overhang issues, although the rear-wheel overhang dimension varies widely across the motor vehicle fleet. Wheel stops can also pose a challenge for maintenance operations such as street sweeping and snow plowing.

16.5.7 Spot Narrowing of Pavement

Narrowing a street at mid-block locations, as illustrated in Exhibit 16-7, can capture much of the benefit of a far more extensive narrowing. Narrowing the street at mid-block locations serves to reduce the speed of vehicles not only at the narrowing itself, but also for the adjacent street segments, where motorists decelerate and return to normal running speed.

Exhibit 16-7
Mid-block Street Narrowing



16.5.8 Medians and Crossing Islands

Traversable medians, typically built of textured or contrasting materials such as stamped concrete, bricks, pavers, or cobblestones can be effective traffic calming devices particularly where periodic segments of raised median are included, as shown in Exhibit 16-8. These medians are flush with the travel lanes but are notably different, both in appearance and in feel to the driver. Traversable medians narrow the real and apparent width of the street, and provide deflection at end points, while still permitting unlimited driveway access across them. They can serve as left-turn lanes, and allow for passing of double-parked cars. Further, traversable medians offer opportunities for emergency vehicles to bypass stopped traffic. At intersections, the ends of the traversable medians can extend all the way through the crosswalk, thereby providing some pedestrian refuge.

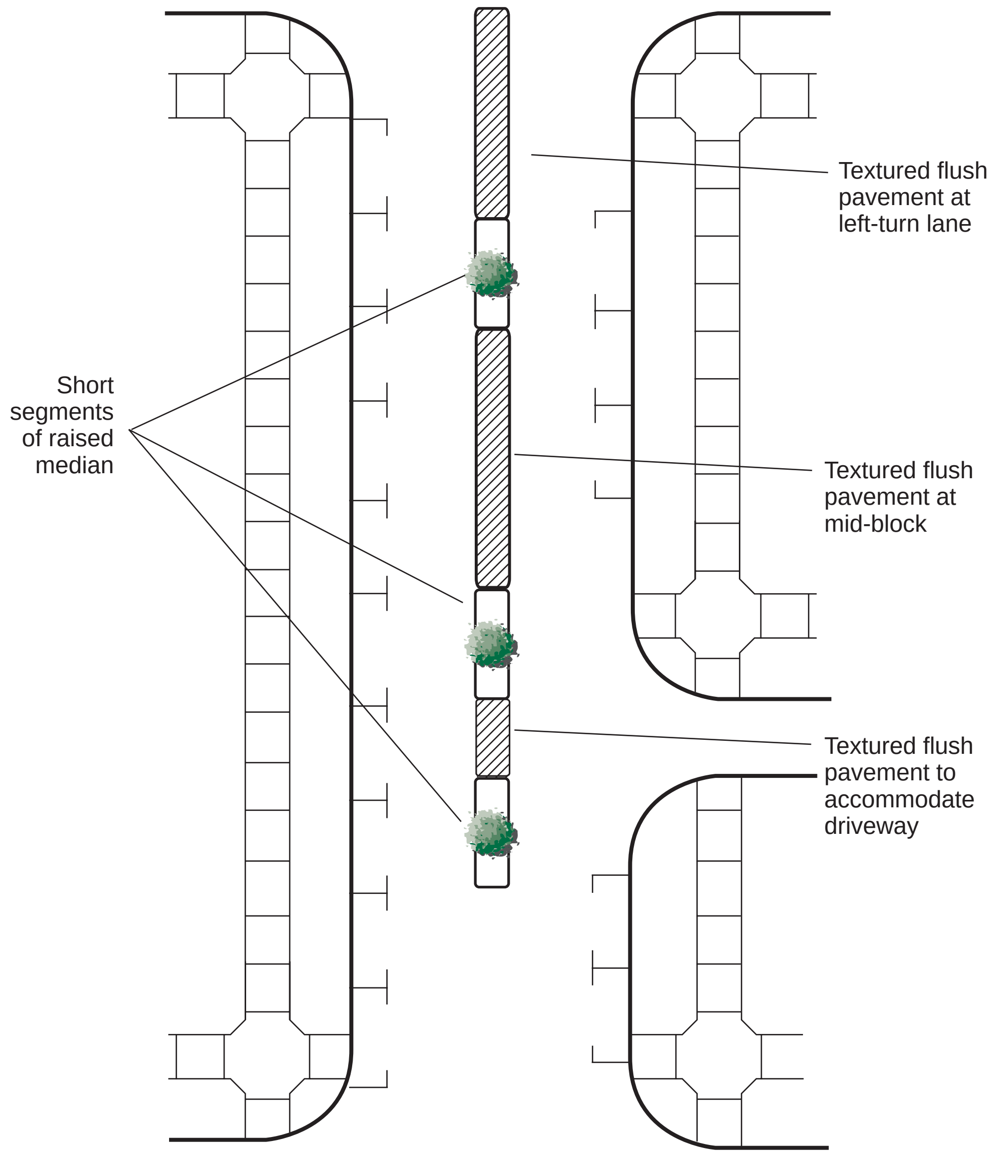
Pedestrian crossing islands are short divisional islands located at crosswalks. Pedestrian crossing islands may be located at intersection or midblock locations. These islands allow pedestrians and bicyclists to cross only one traffic stream at a time and provide some degree of protection from the vehicular traffic while waiting for a gap to finish their crossing.

These islands should include raised curbs with a cut-through at the pavement level for wheelchair users. The cut-through should be graded to drain quickly and should also have special provisions to assist the visually impaired in identifying the refuge island. The pedestrian crossing island should be at least 6 feet wide from the face of the curb to the face of the curb. The island should not be less than 12 feet long or the width of the crosswalk, whichever is greater.

Raised mid-block islands should be short in length, typically less than 70-90 feet. Longer islands are likely to cut off access to too many properties and do not add to the deflection. Ideally, these short segments of median are sited to avoid blocking property access, although confining the occasional driveway to right-in/right-out access may be reasonable. The minimum island size should be 50 square feet. Larger islands can sometimes support plantings if adequate soil volumes and irrigation are provided. See Chapter 3 for additional planting guidance.

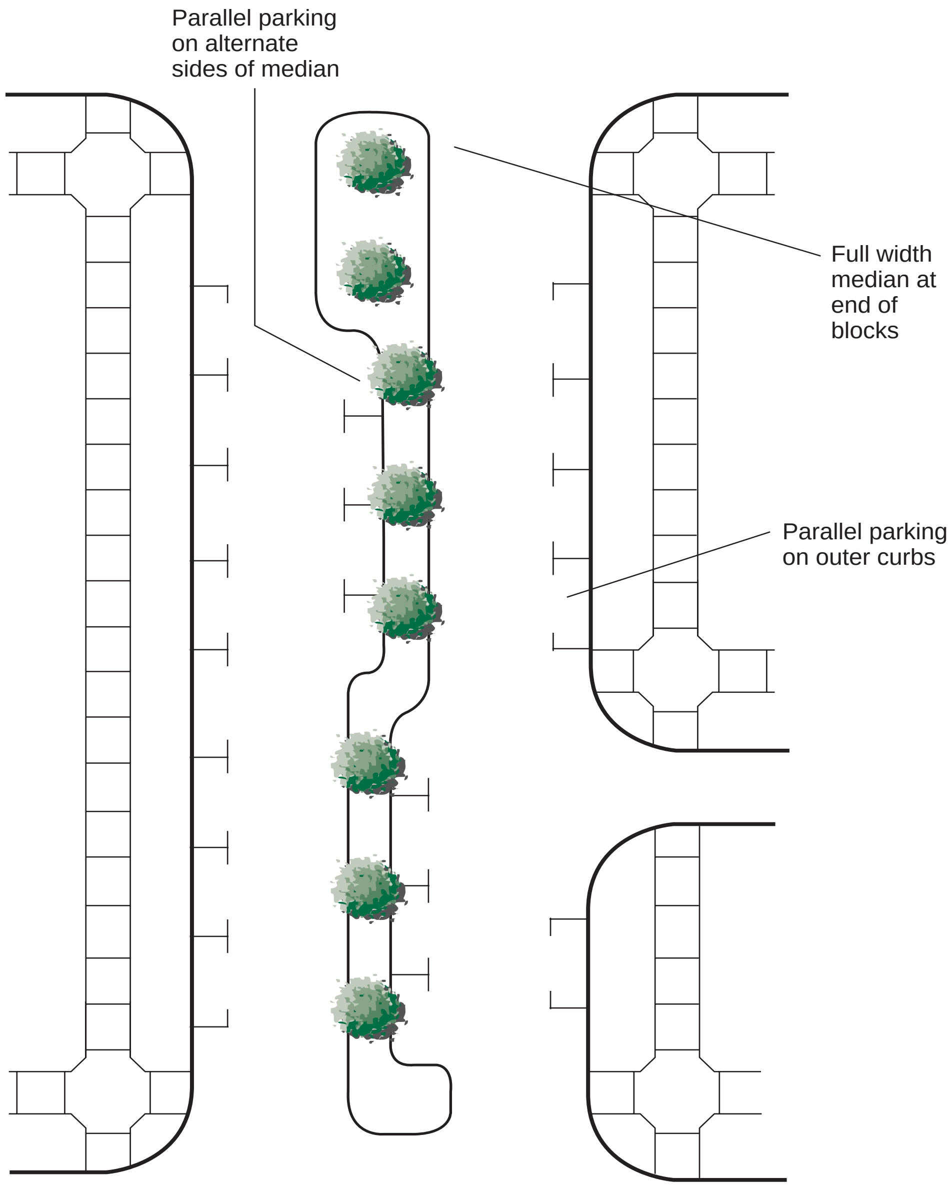
All raised islands should also include an approach nose, offset from the edge of the traffic lane and appropriately treated to provide motorists with sufficient warning of the island's presence. This can be achieved in various ways, such as illumination, reflectorization, marking, signage, and/or by the size of the island.

Exhibit 16-8
Median Islands



On divided streets, parking can be added along the median. Where the total street width permits only one lane of parking along the median, that parking lane can be alternated, as shown in Exhibit 16-9. With this approach a planted median can give the appearance of a double row of trees, although only a single row is present at any point along the street. The designer should refer to Chapter 13 for additional guidance on tree planting in the medians.

Exhibit 16-9
Parking on Median Islands



16.5.9 Allocation of Pavement Width and Road Diets

The pavement width of the street can be allocated in a manner that gives more space to pedestrians, bicycles, and parking, reducing the width of the motor vehicle traveled way. In some instances, the elimination of a travel lane on a four-lane roadway and conversion of another lane to a median with turning pockets can improve conditions for pedestrian and bicycle users without adversely affecting roadway capacity since the left-turns are accommodated within the median. Allocation of pavement width could also provide wider sidewalks if conditions suggest that additional space could better accommodate the existing or anticipated pedestrian activity. These types of measures have recently been referred to as “road diets” when applied to existing streets.

16.5.9.1 Bicycle Lanes

Adding an on-street bicycle lane, as shown in Exhibit 16-10, reduces the pavement width for motor vehicles, while at the same time providing for bicycle travel. The typical dimensions and placement of bicycle lanes are discussed in Chapter 5.

16.5.9.2 Travel Lane Width

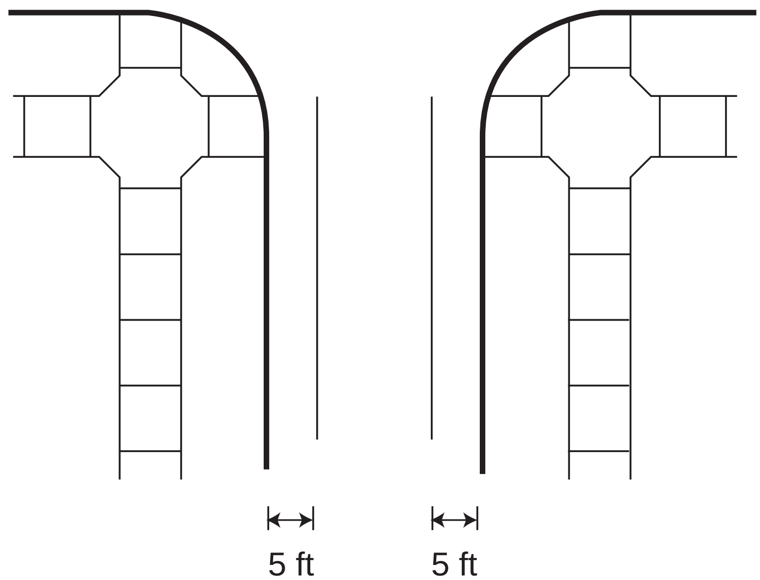
Minimal lane widths can reduce vehicle speeds, reduce pedestrian crosswalk distances, and maximize the space available for bicycle lanes and sidewalks.

Where traffic calming is intended, driving lane widths should be 10 feet, a width widely accepted as appropriate for residential and minor collector streets. A larger lane width (11 feet) is appropriate for outer (curb) lanes on streets where on-street parking is not present and on arterials or other roadways that carry large numbers of trucks and buses.

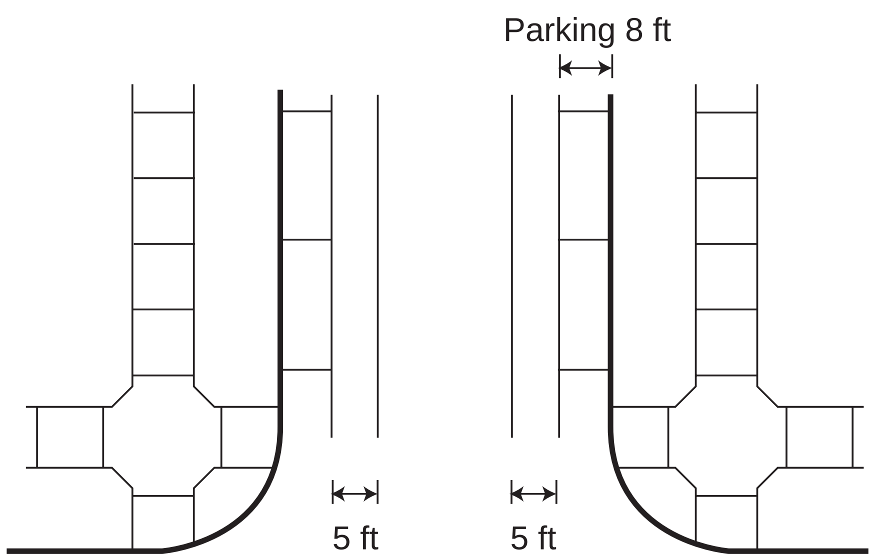
Lane layouts should also take into consideration space for bicycles, as described in Chapter 5. Traffic claming measures that reduce the travel lane width may reduce or eliminate the opportunities for motor vehicles drivers to overtake bicycles sharing the same lane. Where such overtaking is impossible, motor vehicle speed is likely to be determined by bicyclist speed. Thus, the presence of bicyclists becomes a significant element of traffic calming.

Exhibit 16-10
Bicycle Lanes

A. Streets without On-Street Parking



B. Streets with On-Street Parking



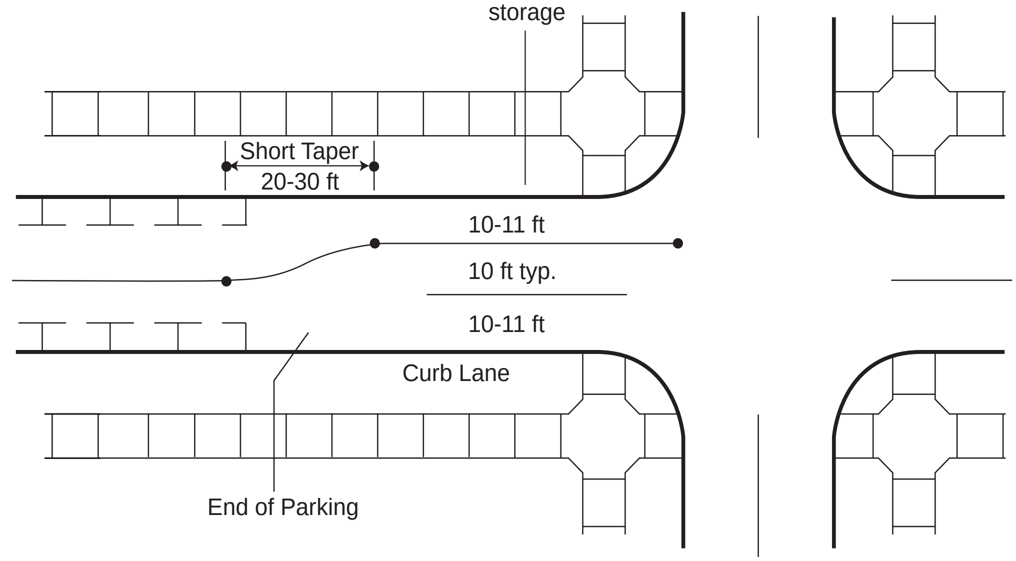
16.5.9.3 Auxiliary Lanes

Auxiliary (left turn and right turn) lanes should be used sparingly with traffic calming. Typically, rear-end collisions between a left-turning and at-speed following vehicle are less frequent and less severe due to the lower speeds of traffic in traffic-calmed settings. Further, the occasional blockage of through traffic by a left-turning vehicle should not be considered a detriment in a traffic calmed setting. Occasional and irregularly timed variations in traffic flow are an intended consequence of traffic calming.

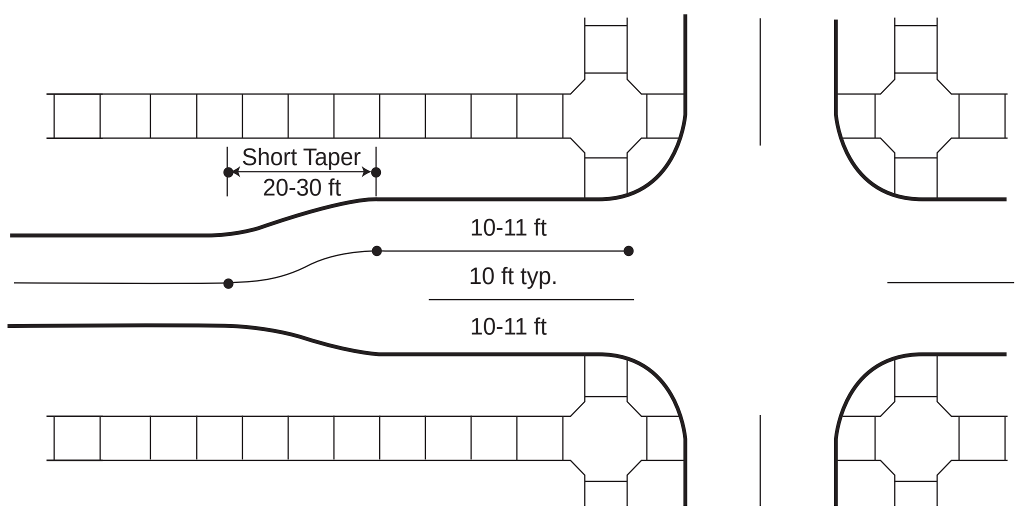
When on-street parking is present, as shown in Exhibit 16-11, left-turn lanes can generally be accommodated (when necessary) within the existing pavement width on the intersection approach leg by removing parking spaces on both sides of the street at the intersection. On streets without parking, the existing pavement width may not be adequate to accommodate a left-turn lane, and the approach may therefore have to be flared to accommodate the left turn lanes. Auxiliary lanes (typically left-turn lanes) should typically be 10 feet wide in traffic calmed areas.

Right-turn lanes are inadvisable in most traffic calmed settings. Their emphasis on vehicular accommodation, the additional crossing distance they create for pedestrians, and the increased possibility of vehicle conflicts with pedestrians are all likely to negate the goals for the traffic calmed street.

Exhibit 16-11
Left-turn Lanes, Traffic Calming Values



A. Within existing pavement width



B. Pavement width flared to accommodate left-turn lane

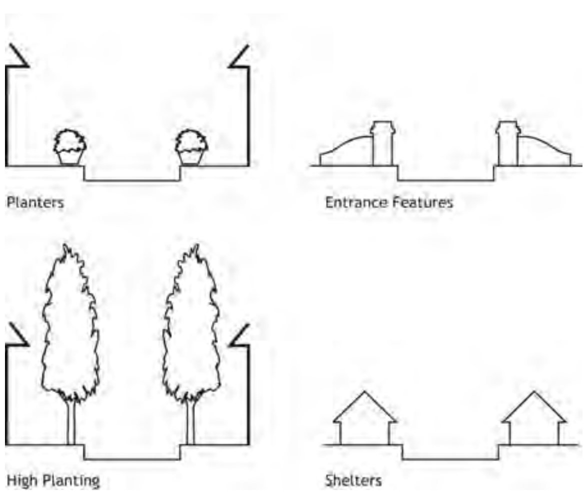
16.5.10 Gateways

Closure of a street (through gates, barricades, pavement removal) should not be considered as part of a traffic calming program. The unintended consequences of street closure – moving traffic problems to a new location, increasing vehicle miles of travel, contentiousness, and degrading emergency services – argue strongly against street closure as a remedy for neighborhood traffic problems.

However, street-side features that function as gates or portals are an effective traffic calming device. Gateway features, located close to the pavement edge, appear to narrow the road and therefore reduce the operating speed of approaching motorists. Gateways are usually interpreted as indicative of a special area, requiring increased attentiveness. Gateways are often associated with dead-end street systems, and can therefore be a signal to unfamiliar motorists that a route is not a likely cut-through route. In addition to their traffic calming function, gateway features can serve as transit waiting areas, information kiosks and mountings for signs and lighting.

As shown in Exhibit 16-12, it is appropriate for gateway features to be placed within the street right-of-way. Minimum clearance from the street is 2-feet from back of curb. When placed near or at an intersection, gateway designs should be checked to assure that an adequate intersection sight triangle is preserved as described in Chapter 3.

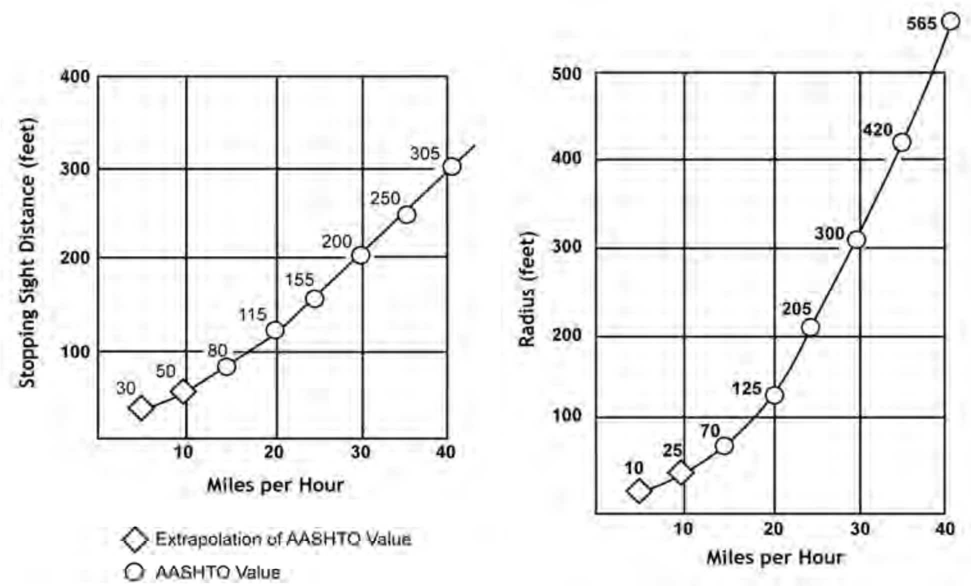
Exhibit 16-12
Gateways



16.6 Traffic Calming Measures Incorporating Deflection

Deflecting the vehicle from an otherwise straight path is an important traffic calming action that reduces vehicle speed. The relationship of sight distance and curvature to operating speed is a basic relationship for road design at all speeds as described in Chapter 3. For the lowest design speeds associated with traffic calming (5-15 miles per hour), it is necessary to extend the ranges of stopping sight distance and minimum radius, by extrapolating the values adopted for higher speeds, illustrated in Exhibit 16-13.

Exhibit 16-13
Low-speed Design Parameters



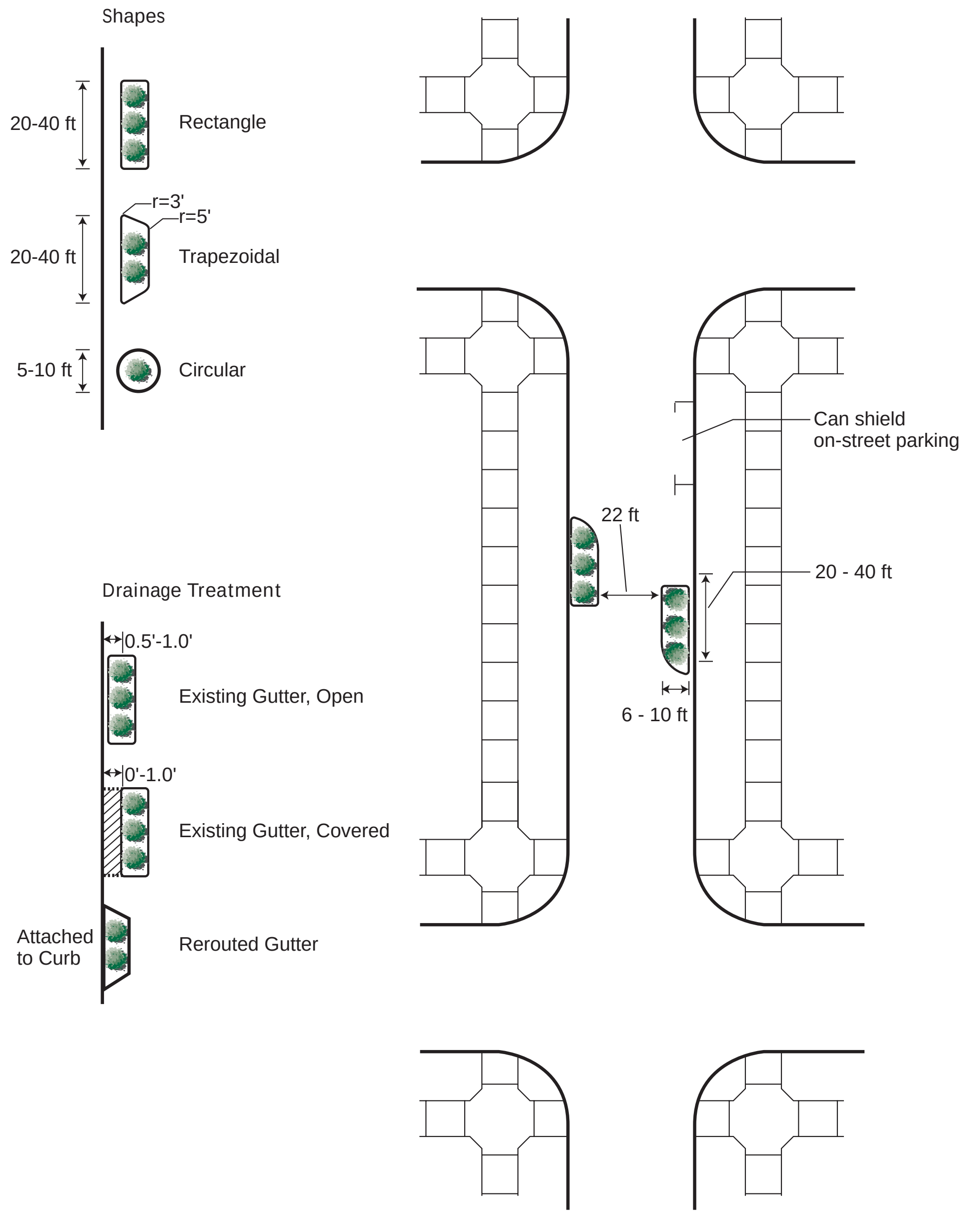
16.6.1 Mid-Block Deflection Measures

There are several possible approaches to introducing mid-block deflection to a vehicle path, as described below:

16.6.1.1 Chicanes and Lane Offsets

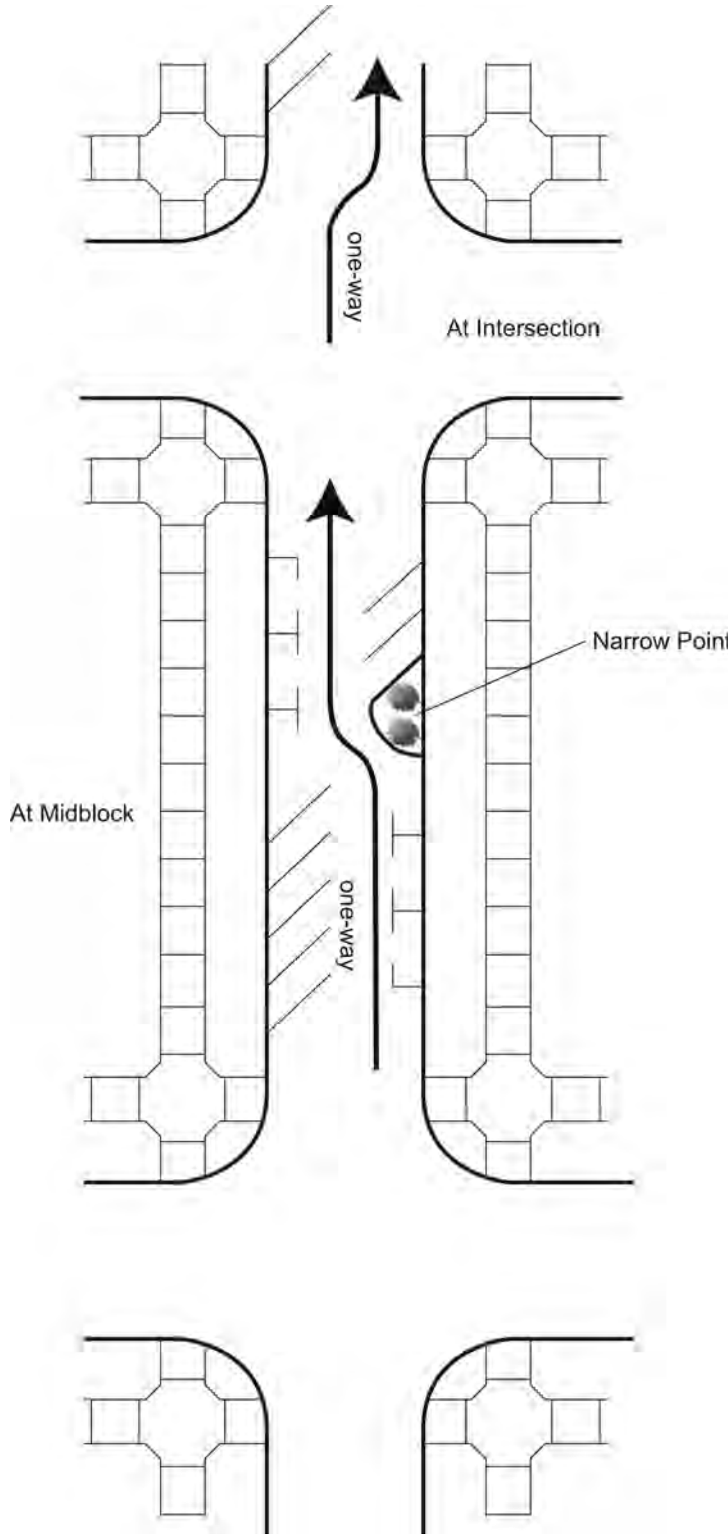
The simplest measure for deflecting traffic is the narrowing of one side of the street by an amount that requires the through traffic to deflect from its previously straight path, as shown in Exhibit 16-14. A series of such deflections, typically called chicanes, multiplies in effectiveness as it extends throughout the entire length of the block.

Exhibit 16-14
Mid-block Deflection



Mid-block deflection can also be obtained by alternating the parking (or type of parking) along the block faces as shown in Exhibit 16-15.

Exhibit 16-15
Lane Offsets from Parking



16.6.1.2 Short Medians/Crossing Islands

Measures to deflect traffic, such as medians and crossing islands, can also be centered in the street, as discussed previously in Section 16.5.8. Horizontal deflection can be achieved with crossing islands where there is on street parking by eliminating parking near the island. Curb lines can also be adjusted to accommodate the crossing islands.

16.6.1.3 Mid-Block Traffic Circles

Mid-block traffic circles are a traffic calming measure that assures a great deal of deflection in the vehicle path, and therefore a significant reduction in vehicle speeds. Unlike the roundabout intersection, the mid-block circle has no traffic control function, since there is no cross street traffic to be controlled. Beyond its traffic calming value, the highly visible central island of the mid-block circle can serve as a major demarcation point at a neighborhood boundary, as a setting for a monument or other display, or to deliberately terminate the view down the street in order to hide the scene beyond.

16.6.2 Intersection Measures

The principle of deflecting traffic in order to reduce its speed can be applied to intersections as well as non-intersection locations. Roundabouts provide a central island, which requires deflection for all movements. Deflection through intersections can also be provided by offsetting the through traffic lanes or through the use of crossing islands.

16.6.2.1 Lane Offsets at Intersections

Traffic lanes can be offset at an intersection, reducing speed through the intersection, as shown previously in Exhibit 16-15. On streets with parking on one side, the offset results from alternating the side of the street containing the parking. At “T” intersections with a left-turn bay provided, the left-turn lane requires an offset for through traffic in at least one direction of travel. On streets with diagonal parking on one side and parallel on the other, the offset at the intersection results from alternating the sides on which each type of parking is provided.

16.6.2.2 Crossing Islands

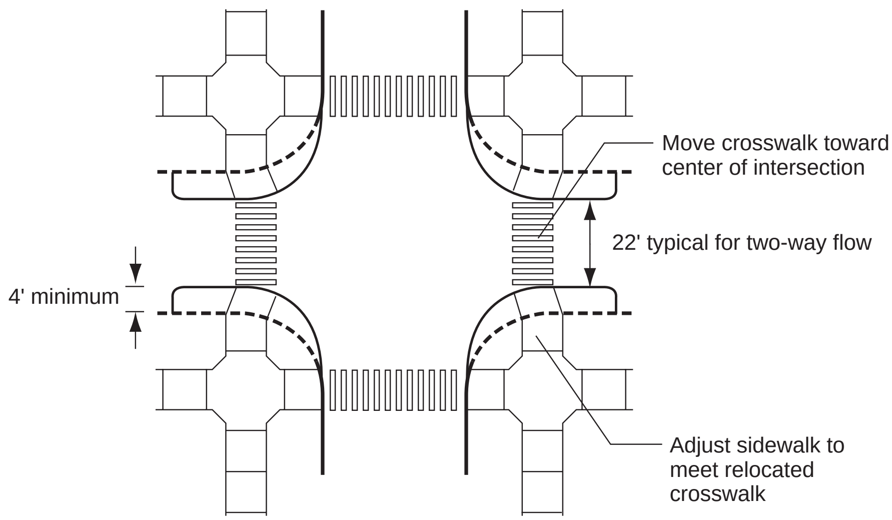
Crossing islands, as described in Section 16.5.8, can also be used at intersection locations.

16.6.2.3 Curb Extensions

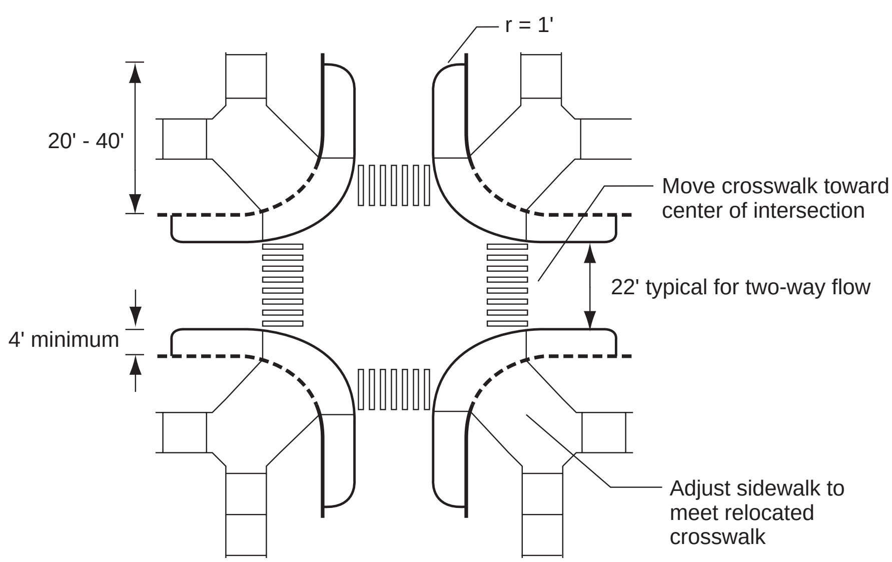
Narrowing the street at an intersection, through the use of curb extensions, is a versatile and widely used traffic calming measure, as shown in Exhibit 16-16.

Exhibit 16-16
Intersection Curb Extensions

A. Bulbouts on Both Streets



B. Bulbouts on One Street



In addition to slowing traffic due to reduced pavement widths, curb extensions delineate on-street parking, shield the ends of the parking lane from moving traffic, and discourage drivers from using an empty parking lane for overtaking other vehicles. They also prevent illegal parking at corners, thereby improving sight lines for all users.

Curb extension substantially reduce the pedestrian crossing distance while increasing the pedestrian space on the intersection's corners. Curb extensions can also benefit vehicular traffic, by moving the stop bar on the approach lanes further into the intersection, thereby reducing the intersection size and signal clearance intervals. The reduced intersection size can, in some instances, solve sight-distance deficiencies on the intersection approaches. Curb extensions can prevent parking close to intersections, and thus improve sight distance from cross streets. Also, curb extensions frequently reduce the "wasted" pavement at intersections (i.e., areas of pavement unusable by either vehicles or pedestrians near the corners). Fire hydrants are often located near intersections so that curb extensions result in no loss of legal parking.

Curb extensions can be used on one or both of the intersecting streets, or on any combination of approaches. The width of the roadway at the curb extension is typically no wider than necessary to accommodate the through lanes, providing 10 to 12 feet per lane plus additional offset of 1 to 2 feet from the edge of the traveled way. Curb extensions should only be used in conjunction with on-street parking so that they do not pose an unexpected hazard to bicyclists and motor vehicles.

With curb extensions, the increase in sidewalk area provides space for street furniture such as fire hydrants, information kiosks, benches and plantings. The additional sidewalk space is particularly useful where local regulations require buildings to be located adjacent to the sidewalk, thereby putting a premium on sidewalk space.

Typically, curb extensions are cost effective, since a single intersection treatment affects traffic in all directions on both intersecting streets. Because of their high visibility, curb extensions can be an important entrance feature for a neighborhood or a district of special interest.

16.6.2.4 Roundabouts and Mini-Traffic Circles

Two characteristic features of roundabouts—splitter islands on approaches and the central circle—provide a significant reduction in vehicle speeds and corresponding increases in driver attentiveness. The deflection provided by the splitter islands encourages a decrease in speed as drivers approach the intersection. Within the roundabout, the radius of the central island reinforces the low operating speed. At some roundabouts landscaping or man-made features within the central island terminate the view on approaching roadways, thereby contributing to reduction of the operating speed of approaching traffic. Guidelines for the design of roundabouts are given in Chapter 6 of this Guidebook.

Roundabouts are intersection control measures that provide speed reduction. (Photo Credit: Jan Conklin)

Because of its circular central island, the mini-traffic circle is frequently confused with roundabouts. However, the mini-traffic circle differs from a roundabout in important ways. Mini-traffic circles are typically smaller than roundabouts and do not merge traffic into a stream around a circulating roadway. Unlike the roundabout, the mini-traffic circle is not a traffic control device. Rather, at the mini-traffic circle, right-of-way is assigned by stop control (often all-way stop control). Mini-traffic circles usually do not have splitter islands on their approaches, although these are sometimes provided to absorb excess pavement width on approaches or to provide pedestrian refuge. For automobiles, operations at the mini-traffic circle are similar to those at a roundabout, with vehicles proceeding around in a counterclockwise direction. Large trucks (single unit (SU) trucks or larger) make right turns and through movements by entering the circle and proceeding counterclockwise. However, they make left turns by turning in front of the mini-traffic circle, after yielding right-of-way.

This pattern of movement can be hazardous where truck and buses are present on a regular basis. Mini-traffic circles can also pose significant challenges for emergency vehicles. As a result, mini-traffic circles are not recommended for most locations. Roundabouts and mini-roundabouts (designed using the same principles as a roundabout, but will a small central island) should be considered in lieu of mini-traffic circles.

16.6.2.5 Stop Control

Stop control, considered to be a traffic calming measure by many neighborhood groups, can be an appropriate traffic control decision under special circumstances. However, stop signs are traffic control devices that help to assign who has the operational right-of-way movement through an intersection and should not normally be considered a traffic calming tool. Warrants supporting the use of two-way and all-way stop are provided in the MUTCD. Some factors that may suggest use of all-way stop control include a lack of an obvious major and minor street, large volumes of turning movements, nearby pedestrian generators (park, school), and single through lanes in all directions.

Advocates of neighborhood traffic calming tend to overrate the effectiveness of stop control, and often request it at inappropriate locations. Excessive numbers of stops are difficult to enforce, and can be annoying to even careful motorists. Over the longer run misuse of stop control contributes to the erosion of motorist respect for traffic control devices in general, and is likely to decrease safety.

16.7 Measures to Alter the Street Profile or Texture

Traffic calming measures involving the profile and surface of the street include alterations to the profile of the street (humps and elevated segments of streets) and placing a textured pavement surface in parts of the street.

16.7.1 Speed Humps

Speed humps are intended to let vehicles operating at intended speeds pass with little discomfort to the driver, no bouncing of loads in trucks, and little noticeable stress (for example, bottoming out) of the vehicles. Because driver discomfort at humps rises rapidly as their design speed is exceeded, humps are an effective measure for controllig speeds.

Vehicle crossing a speed hump

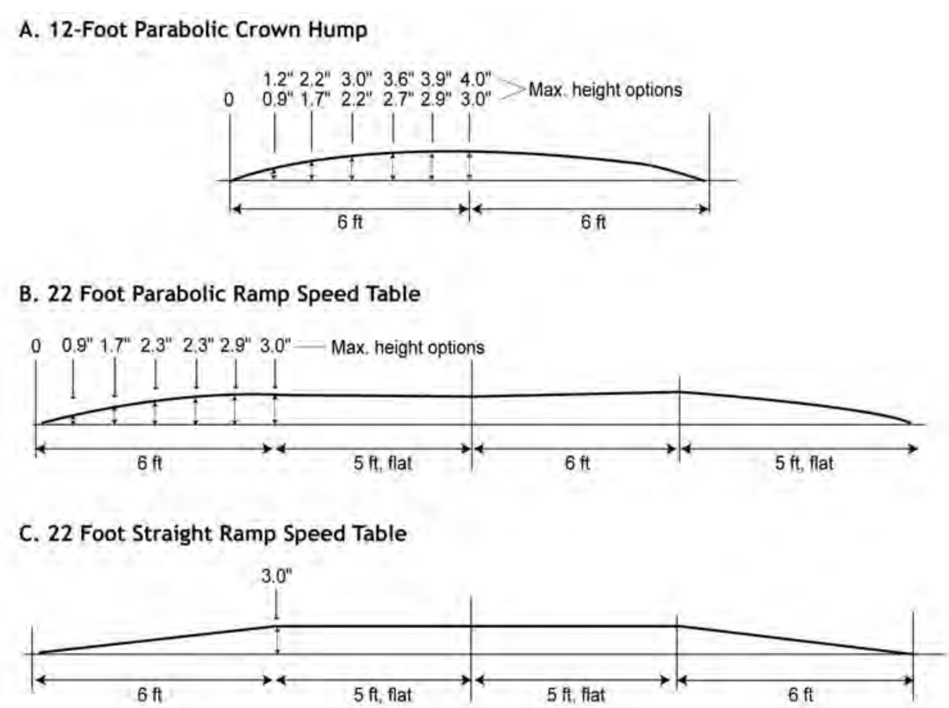
Speed humps can be appropriate for minor collectors and local roads. On higher-classified streets (major collectors or arterials), the target design speed of 15-20 miles per hour for humps is likely to be inappropriate and inconsistent with the function of such streets.

Speed humps may generate noise from vehicles braking and accelerating. Noise impacts on nearby residents can be mitigated through careful locating of the speed humps, or by spacing humps closely to encourage constant speeds.

16.7.1.1 Round-Top Speed Humps

Round-top speed humps are 12-14 feet in length, and rise to a height of 3-4 inches. A common profile, the parabolic crown, illustrated in Exhibit 16-17, permits comfortable crossing at design speed, but makes crossings increasingly uncomfortable as design speed is exceeded.

Exhibit 16-17
Speed Humps and Speed Tables



Round-top humps may be constructed from a wide variety of materials: asphalt, textured or colored asphalt, and poured and stamped concrete. Typically, the space between the end of the hump and the curb is left open, allowing the gutter drainage to continue functioning unhampered.

16.7.1.2 Speed Cushions

The speed cushion is a variety of flat-top hump that does not extend fully across the street, but rather affects only one side of the vehicle. Speed cushions provide much of the traffic calming impact of a flat-top hump, and also allow bicycle lanes and storm drainage to continue unhindered at the original street grade.

16.7.2 Raised Crosswalks (Flat-Top Speed Humps)

Flat-top speed humps, shown in Exhibit 16-17, are frequently used to complement pedestrian crossings, particularly where curb extensions are in place. When constructed of a pavement material differing from the adjacent street, flat-top speed humps are conspicuous to both drivers and pedestrians, thereby improving the pedestrian crossing safety. Flat-top humps at crosswalk locations also serve to protect the pedestrian crossing from intrusion by on-street parking. For flat-top humps, typical ramp lengths are 6 feet, and the typical length of the flat top is 10 feet, giving a total length of 22 feet. A simple straight ramp is typically used.

16.7.3 Raised Intersections

The concept of the flat-top hump can be extended to an entire intersection, raising the entire intersection to sidewalk height or nearly so. The raised intersection provides benefits to all crosswalks. Raised intersections employ many of the same design elements as raised crosswalks; however, the designer needs to pay special consideration to drainage issues and the demarcation of intersection corners through pavement changes, markings, or bollards.

16.7.4 Textured Pavement

Textured pavement encourages motorists to be aware of an area of special concern due to the appearance of the texture, vibration, more noticeable motion of the vehicle and tire noise. Pavement texture alone, at isolated locations, is not an effective traffic calming measure. Rather, textured pavement is more appropriate in support of other traffic calming measures such as mid-block narrowing, intersection curb extensions, or roundabouts.

Flexible pavement materials (i.e., asphalt) can be colored or stamped with patterns, and are often the material of choice for speed humps and crosswalks. Rigid pavement (i.e., concrete and stamped concrete) is regularly used for flat-top humps, and for crosswalks. Rigid materials, such as concrete pavers, are frequently used for full-intersection designs, raised intersections, crosswalks, and in connection with mid-block traffic calming measures such as narrowing and splitter islands. Paver-insets need to be constructed so that their long-term serviceability is ensured given the freeze-thaw cycles common in this region.

16.7.5 Rumble Strips

The use of rumble strips as a traffic calming measure is inappropriate, since these are typically used as a warning device at high-hazard locations, such as isolated, high-volume, rural intersections. Further, rumble strips are hazardous to bicyclists, and the noise generated by them is likely to be problematical in neighborhoods. A further reason to avoid rumble strips as a traffic calming measure is that they do not compel a reduced speed as do other traffic control measures, and drivers eventually learn to ignore them.

16.8 Traffic Management Measures

Traffic calming measures are intended to reduce operating speeds and increase driver attentiveness. On the other hand, *traffic management* measures are intended to reduce and redirect traffic movements, but are unlikely to have a significant influence on operating speeds.

Traffic management measures fall into two categories:

(1) Movements physically restricted by street design features, and

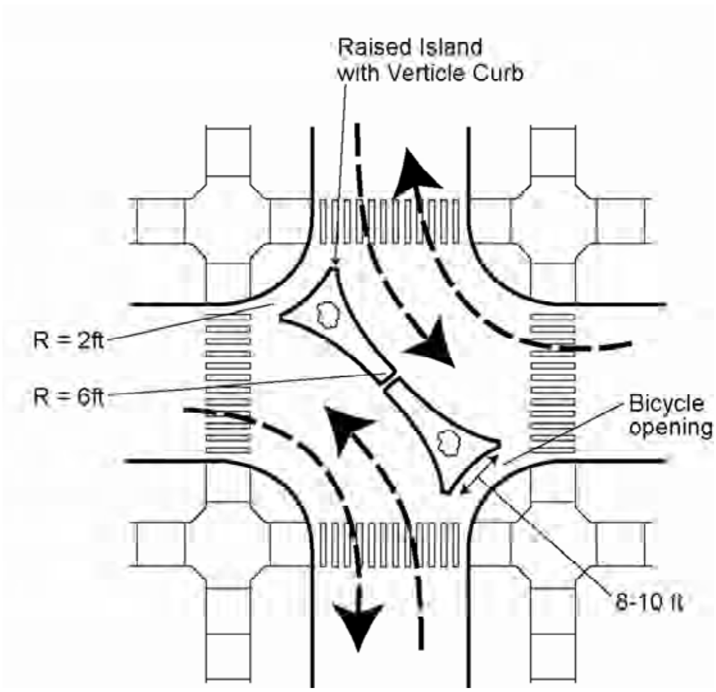
(2) Regulatory restrictions, conveyed primarily through signs.

16.8.1 Restriction of Vehicle Movements through Street Design

Several design measures are available to restrict specific movements at an intersection. For example, a segment of median extending across an intersection limits turning movements, from all approaches, to a right turn only. Further, a median eliminates the possibility of through trips on the cross street. This type of cross-street access restriction by medians could be appropriate where sight distance is inadequate for safe turning movements at the intersection, or where through traffic on the cross street is being discouraged. Other techniques such as the use of channelizing islands for particular movements can be used to restrict traffic movements at intersections.

On local streets, the diagonal street closure, shown in Exhibit 16-18, prevents through movement on both of the intersecting streets, but allows either a right or left turn from all approaches. Diagonal through-movement closure may be appropriate to discourage cut-through trips in neighborhood districts with a dense, well-connected network of streets. Diagonal street closures should also maintain connectivity for bicycle travel.

Exhibit 16-18
Diagonal Street Closure



Source: Traffic Calming State of the Practice, ITE, 1999

Completely blockading (i.e., completely closing) a street should not be considered as a traffic management measure. Street closures should be considered only in instances where such closure is vital for a public purpose (for example, major park or public institution) and then only when an ample, well-connected network remains. Restriction of vehicle movements at town lines is not permitted without the consent of the adjacent community.

16.8.2 Regulatory Measures to Restrict Vehicle Movements

Turn restrictions, on both right turns and left turns, have long been used at intersections to improve pedestrian or traffic flow, and such measures can be used as traffic management actions. Restrictions on turning movements (“no left turn” or “no right turn”), are commonly used to expedite traffic flow. Turning movement restrictions can be more efficiently policed than speed or stop control violations. The drawback of traffic management measures that rely on regulation is less for turn restrictions than most other types of regulatory action.

The all-way turn restriction, with neither right nor left turns permitted from any approach, is sometimes used at downtown intersections, where large volumes of pedestrians are present on all crosswalks. When used as a traffic management measure, an all-way turn restriction has the further impact of redirecting traffic away from areas of special concern, and channeling it toward intended routes.

Turn restrictions have value in traffic management when used to discourage the use of inappropriate routes. Turn restrictions that apply only during the peak hour, intended to prevent peak hour commuter cut-through traffic in neighborhoods, can also be effective.

16.9 Administering a Traffic Calming Program

Requests for traffic calming often come from neighborhood groups. Traffic calming programs should be planned in a design dialogue, conducted on-scene in the subject area, involving residents, property owners, and business operators in intensive hands-on work sessions. A successful program of traffic calming measures requires skilled gathering and interpretation of input and applying a large measure of judgment in developing the measures.

Formal traffic survey techniques are often ineffective in forming traffic calming programs. Requiring petitions from residents, business or property owners as a prerequisite for installing traffic calming measures is inadvisable. Petitions voluntarily submitted by stakeholder groups can be one of a number of useable inputs to the design of any traffic calming program and can be a measure of the community's perceived need for improvement and their willingness to fund it. However, such petitions should not be required. They are expensive, both in terms of funding and managerial attention required by the traffic calming program. Further, the petition process is often divisive, with the outcome likely to vary greatly depending on the wording of the petition and the outlook of the person collecting signatures.

Attempting to plan a program of traffic calming based on numerical scores or quotas is not advisable. Numerical scoring schemes will focus on those traffic characteristics that are easily measured (specifically, speeds, traffic volumes and collisions), thereby furnishing an incomplete and often misleading analysis of the need for traffic calming. Factors that are important to the community may not register in this type of numerical analysis. These important factors include the character of residential neighborhoods, historical value, type and value of retail business, neighborhood institutions and aesthetic character.

It is important to determine and discuss the benefits and impacts of various traffic calming measures with community members so that a well-founded traffic calming program can be prioritized and implemented. In some cases, gathering numerical data is expensive and time consuming, and can drain the traffic calming program of funds needed for producing the measures themselves. However, before-and-after studies and the use of low-cost, temporary measures (such as carefully arranged construction barrels) can be used to identify the effectiveness of existing or proposed traffic calming measures to build consensus around a traffic calming plan.

16.10 Traffic Calming and Tort Liability

Traffic calming measures are simply low-speed street design elements, following accepted design guidelines or reasonable extrapolations of them, as discussed earlier in this Chapter. Therefore, traffic calming measures can be defended against tort liability in the same manner as road design in general. The design should document the design decisions and their rationale by following the recommendations listed below:

- Provide a reasonable, written rationale for the traffic calming measure or program of measures. Typical rationales include neighborhood safety, historical preservation, retail viability, and proximity of important institutions (schools, for example).

- Observe good practice in designing the traffic calming measures.

- Monitor the safety performance of installed measures. Ongoing crash record systems are suitable for this monitoring.

- Address observed safety problems in a cost-effective manner, making prudent use of available funding. The “prudent use” test has long been a defense against tort liability at known or suspected safety problem locations, and can be extended to modifications needed at traffic calming measures.

16.11 For Further Information

- *Traffic Calming Guidelines*, Devon County Council, Exeter, England, 1991.
- *Traffic Calming – State of the Practice*, Institute of Transportation Engineers, Washington, D.C., August, 1999.
- *Traffic Calming, Planning Advisory Service Report Number 456*, American Planning Association, Chicago, IL, 1995.
- *Guidelines for the Design and Application of Speed Humps – A Recommended Practice*, Institute of Transportation Engineers Speed Humps Task Force, Washington, D.C., 1997.
- Traffic *Calming Guidelines*, FHWA, 2002 (www.fhwa.dot.gov/environment/tcalm)

Chapter 17
Work Zone Management

Work Zone Management

17.1 Introduction

Construction always has some impact on the users of the facility. The various activities required during construction normally cause some disruption to existing pedestrian, bicycle, and motor vehicle patterns. In all but a few instances, the public must have some form of access through or around the work site. The planning, design, and preparation of contract documents for modification of the normal traffic and pedestrian patterns during construction is commonly know as ***work zone traffic control***. ***Traffic management plans (TMPs)*** are the result of this planning and design.

The frequency of crashes in work zones is disproportionately higher than at other locations. Therefore, the primary consideration in work zone traffic control is safety for pedestrians, bicyclists, motorists, and personnel on the worksite. Maintaining the full carrying capacity and accommodation for all users is usually not possible during construction. Existing walkways, bicycle accommodation, and motor vehicle travel lanes are either narrowed, closed, or rerouted. Even when reductions, closures, and rerouting are not necessary, construction activity often reduces quality of service for roadway users because it can be distracting and cause temporary disruptions.

For significant projects, a TMP consists of a Temporary Traffic Control (TTC) plan and addresses the Transportation Operations (TO) and the Public Information (PI) aspects of the project.

Improving alternative routes of travel, providing temporary facilities, staging work to occur in off-peak hours, and providing police officer control are ways to reduce the impact of construction on roadway operations. These strategies need to be used in such a way as to maintain the safety of facility users and work crews.

This chapter describes some of the basic considerations associated with work zone management. Detailed information on the preparation of traffic management plans is provided in MassHighway's *Standard Details and Drawings for the Development of Traffic Management Plans,* and Part 6, *The TO component of the TMP includes the TMP strategies to mitigate the transportation operations and management impacts of the project.*

Temporary Traffic Control, in the *Manual on Uniform Traffic Control Devices* (MUTCD). A TMP should be prepared for every worksite.

Work zone management influences the accommodation and safety of all users of the facility. The objectives of the management plan should address the following issues:

- The safety of pedestrians, bicyclists, and motorists traveling through the work zone;
- Protection of work crews from hazards associated with moving traffic;
- Capacity of facilities and delays to users;
- Maintenance of access to adjoining properties; and
- Issues that may result in project delay.

17.2 Public Information

Accurate and timely reporting of project information is a valuable element in the overall strategy for managing a work zone. The use of resources such as MassHighway's *Project Information System* (ProjectInfo), newspapers, radio, television, changeable message signs, and traveler information systems such as *511, MassTraveler*, and *SmarTraveler* (as well as others) can greatly improve the public's acceptance of necessary delays and inconveniences. Key benefits of a public information program are:

- Advance notice might encourage users to seek an alternate route or make alternative arrangements;
- Advance notice might encourage users to travel at off-peak times, or when construction sites are dormant;
- Reduced traffic volumes and increased driver awareness might result in fewer crashes, safer working conditions, and fewer complaints;
- Motorist acceptance might reduce speeding and other aggressive driving behavior in work zones; and
- Advance notice might allow abutters and other impacted parties to ensure that their access needs are considered in the development of a traffic management plan.

The PI component of the TMP includes communications strategies to inform road users and the general public about the expected work zone impacts of the project.

17.3 Coordination

Projects are more successful in managing traffic and providing adequate safety when there is a clear understanding of roles and responsibilities. Coordination is important during both the design and the construction phases. A meeting including the project designer, resident engineer, law enforcement officials, contractor, and community representatives held early in the development of TMPs for major projects can help ensure that work zone management will be effective and that roles and responsibilities are clearly defined.

Early planning efforts should be undertaken to identify whether the population being affected has special access needs. Appropriate efforts should be made to accommodate those needs, especially for the physically disabled. In certain instances, this may require extraordinary measures, such as providing transportation around work areas.

During construction, agreement is necessary between the designer, the resident engineer, the contractor, and local or state police to ensure that traffic management plans and specifications will be effective and are implemented. Close coordination will assure that plans can be refined as needed or modified to effectively address unanticipated situations.

17.4 Work Zone Categories

The timing, duration of work, and type of construction operation are major considerations in developing a work zone management plan. The following classifications of work zones can be a helpful framework for addressing these considerations when developing a work zone management plan:

For individual projects or classes of projects that have less than significant work zone impacts, the TMP may consist only of a TTC plan.

17.4.1 Road Closures

Closing a roadway, while not often practical, is often the most efficient arrangement from a construction perspective and can isolate construction from the public, increasing the safety of the operation. For the public, closing a road for a short period may be less of an inconvenience than an extended period of construction activity on an open, restricted road. The designer can consider road closures if an alternate route is available. The alternate route should have sufficient capacity to carry the additional traffic volume and should provide substitute accommodation for pedestrian and bicycle users. In the case of road closures, it is usually necessary to maintain access to properties fronting the construction zone. If road closure is a reasonable option, the designer should take the following actions before closing a road:

- Obtain local agency approval to use local roads as detours.
- Meet with abutters, businesses, and other community members to discuss the road closure and find ways to mitigate the accessibility impacts.
- Determine the maximum number of days allowed for the closure and incorporate these provisions into the contract documents.
- Determine if additional traffic control or temporary improvements are needed along the detour route.
- Consider how contractor access will be provided to the worksite.
- Contact emergency services, school officials, and transit authorities to determine if there are impacts to their operations.
- Develop a notification program to the public so that the closure is not a surprise. As part of this program, the public should be advised of alternate routes that divert traffic away from the work zone.

17.4.2 Time Restrictions

Restricting construction activities to off-peak travel periods is a common management approach for work zones. Some construction and maintenance activities can be conducted at off-peak times, leaving the entire facility usable during peak times. Traffic volumes on highways vary greatly across the time of day and day of the week. Additionally, traffic flows tend to have predominant directions during different periods of the day. Similar temporal distributions are also exhibited by pedestrian and bicycle flows. Exhibit 17-1 indicates that decreased volumes during off-peak hours may allow one or more travel lanes to be closed for roadway work.

If construction activities can be contained within off-peak times, the impacts to roadway users can be reduced. However, construction activities that cause excessive noise, such as pile driving, are usually restricted at night in developed areas. Limitations on noise levels should be considered when considering overnight construction operations. Even though construction activity is limited to off-peak times, adequate work zone management techniques must be employed during those times.

Exhibit 17-1

Measured Average Work Zone Capacities

Number of Lanes		Estimated Capacity	
Normally Open	During Construction	Vehicles/hour/lane	Total vehicle/hour
2	1	1,340	1,340
3	2	1,490	2,980
3	1	1,170	1,170
4	3	1,520	4,560
4	2	1,480	2,980
4	1	1,170	1,170

Source: Adapted from Notes on Work Zone Capacity and Level of Service

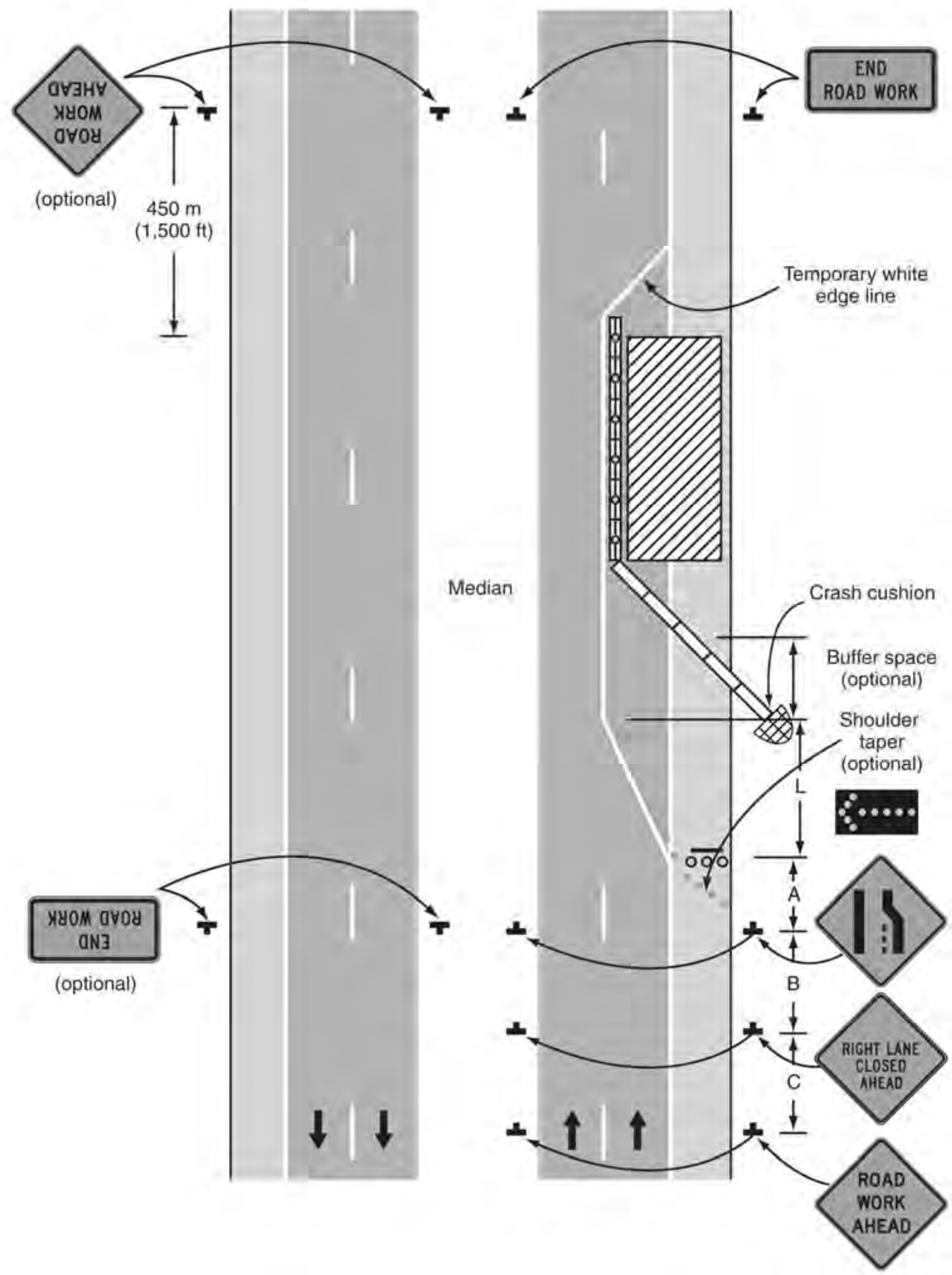
By comparing hourly traffic volumes (within a minimum of a 48-hour automatic traffic recorder (ATR) count) of the particular roadway to the above estimated capacities, it can be determined at what time of the day or night a certain number of lanes may be closed.

17.4.3 Stationary Work Zones

At long-term stationary work zones there is ample time to install, and benefit from, the full range of traffic control procedures and devices. Generally, larger channelizing devices are used, temporary detours and barriers can be provided, and inappropriate pavement markings can be replaced with temporary markings. The time required for the installation and removal of temporary barriers and markings can be justified when they will be in place for several days. Exhibit 17-2 shows an example of a work zone where a travel lane needs to be closed for an extended period of time. These temporary traffic control plans can be adapted to construction projects on various types of roadways by adjusting the spacing of the warning signs, as shown in Exhibit 17-3.

Exhibit 17-2

Long Term Stationary Work Zone



Source: Manual on Uniform Traffic Control Devices, 2003. Part 6 Temporary Traffic Control.

Exhibit 17-3

Suggested Work Zone Warning Sign Spacing

Roadway Type	Distance Between Signs (feet)		
	A	B	C
Local Streets	250-350	250-350	350-500
Collectors Streets	250-500	250-500	500
Arterial Roadways	500	1000	1,000-1,140
Freeways/Expressways	1,000	1,500-1,640	2,500-2,780

Note: Distances A, B and C refer to Exhibit 17-2
Source: MassHighway

For shorter duration projects, the work crews often set up and break down traffic control devices at the beginning and end of the work cycle, lasting from a few hours to a couple days. Simplified and moveable traffic control procedures are often used for these types of projects.

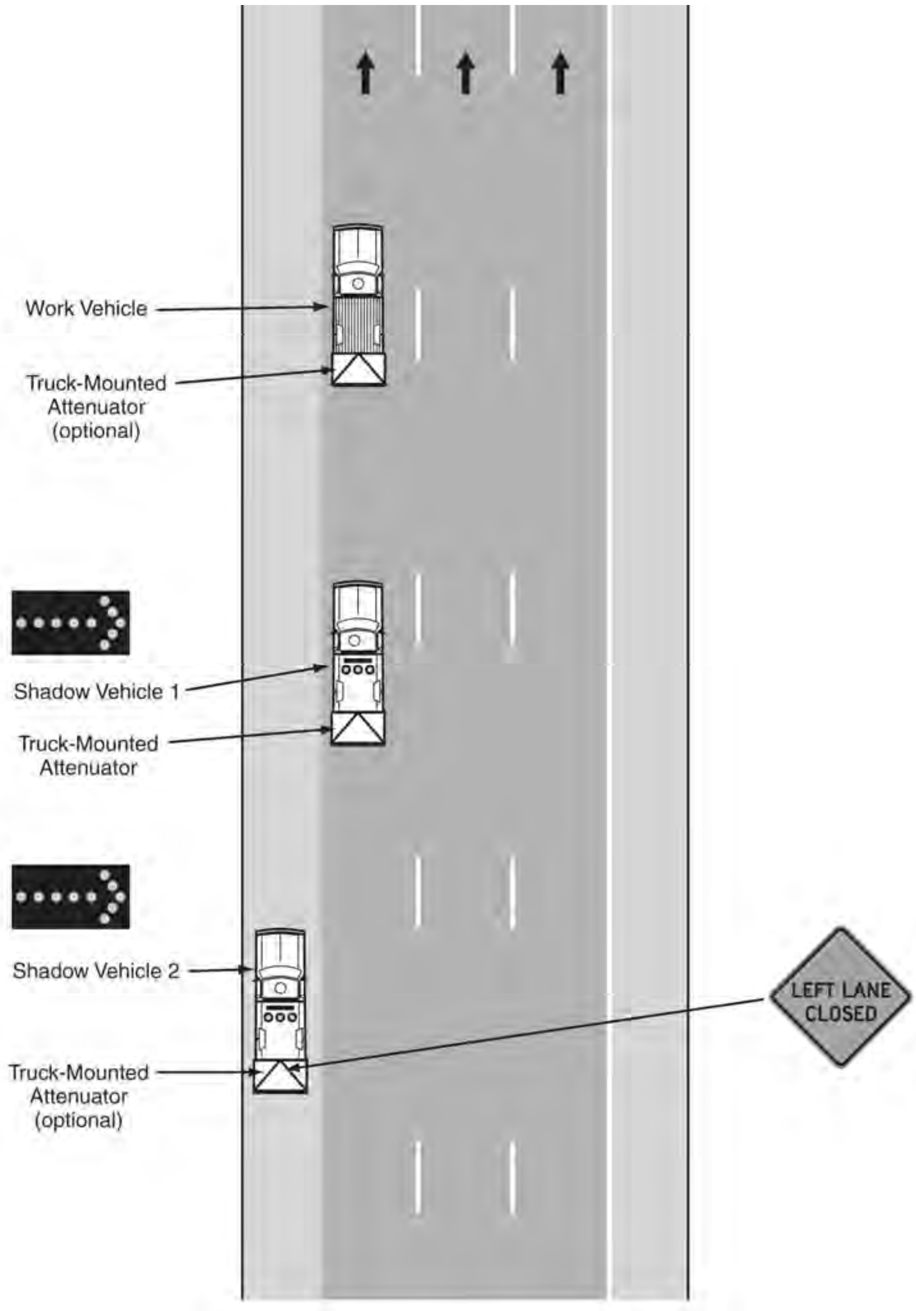
17.4.4 Mobile Work Zones

Mobile work zones are activities that progress along the road either intermittently or continuously. Mobile operations often involve frequent stops for activities such as litter cleanup, pothole patching, or utility operations. Warning signs, flashing vehicle lights, flags, and channelizing devices are often used for these operations.

When the operation moves along the road at low speeds without stopping, the advance warning devices are often attached to mobile units that move with the operation. As indicated in Exhibit 17-4, electronic signs and flashing arrow displays are effective management tools in these situations. Pavement milling and pavement placement, although moving, do not fall into this category and should be treated as stationary work zones.

Exhibit 17-4

Mobile Work Zone Operation



Source: Manual on Uniform Traffic Control Devices, 2003. Part 6 Temporary Traffic Control.

17.5 Work Zone Safety

Effective work zone traffic control strategies encompass the safety of all users and workers, and are not limited to providing clear guidance and warning to motorists. Work zone areas present constantly changing roadway conditions that are unexpected by most users. Unless properly managed, these conditions pose a risk to facility users and construction crews.

17.5.1 Worker Safety

Working on highway construction projects is one of the more hazardous work environments in the state. The risk of being struck by a vehicle traveling through a work zone increases with higher traffic volumes and speeds. Long delays can sometimes cause motorists to become impatient and act unpredictably. The designer should consider the risks faced by workers when developing a work zone management plan. In many cases, advisory signs (W13-1) warning motorists to reduce speeds are sufficient and the regulatory speeds (R2-1) are still valid. In areas more sensitive to speed reduction, reduced speed limits can be established. Advisory signs should be used in advance of the reduced speed limit zone to warn motorists of the upcoming change in speed limit. Speed limit and advisory signs should be reinforced with physical measures such as traffic barriers where appropriate.

Traffic barriers protect workers and reduce the need for many other traffic control devices and police presence. The cost of furnishing and removing temporary traffic barriers on long-duration projects can often be less than the cost of periodically relocating other traffic control devices and providing a higher level of police presence. Traffic barriers may also provide greater nighttime visibility of work areas or traffic shifts.

17.5.2 Road User Safety

Road users assume that they have full use of the facility, unless directed otherwise. The message conveyed to the user through signing, markings, and other traffic control devices must be consistent and credible. Considerations for the various roadway user groups are provided in the following sections.

17.5.2.1 Pedestrians

Pedestrian safety and accessibility are important issues in and around work zones. Pedestrians are susceptible to the impacts of changes in access, dirt, noise, and fumes in construction areas. Pedestrian routes through construction areas should be maintained. When a pedestrian route is affected by construction, temporary access and detours should be provided to ensure safe, unimpeded travel in and around work zones. Access to bus stops, crosswalks, sidewalks, and other origins and destinations should be maintained. Pedestrians should feel safe and secure when traveling near work zones.

Pedestrian Routes through Construction Zones

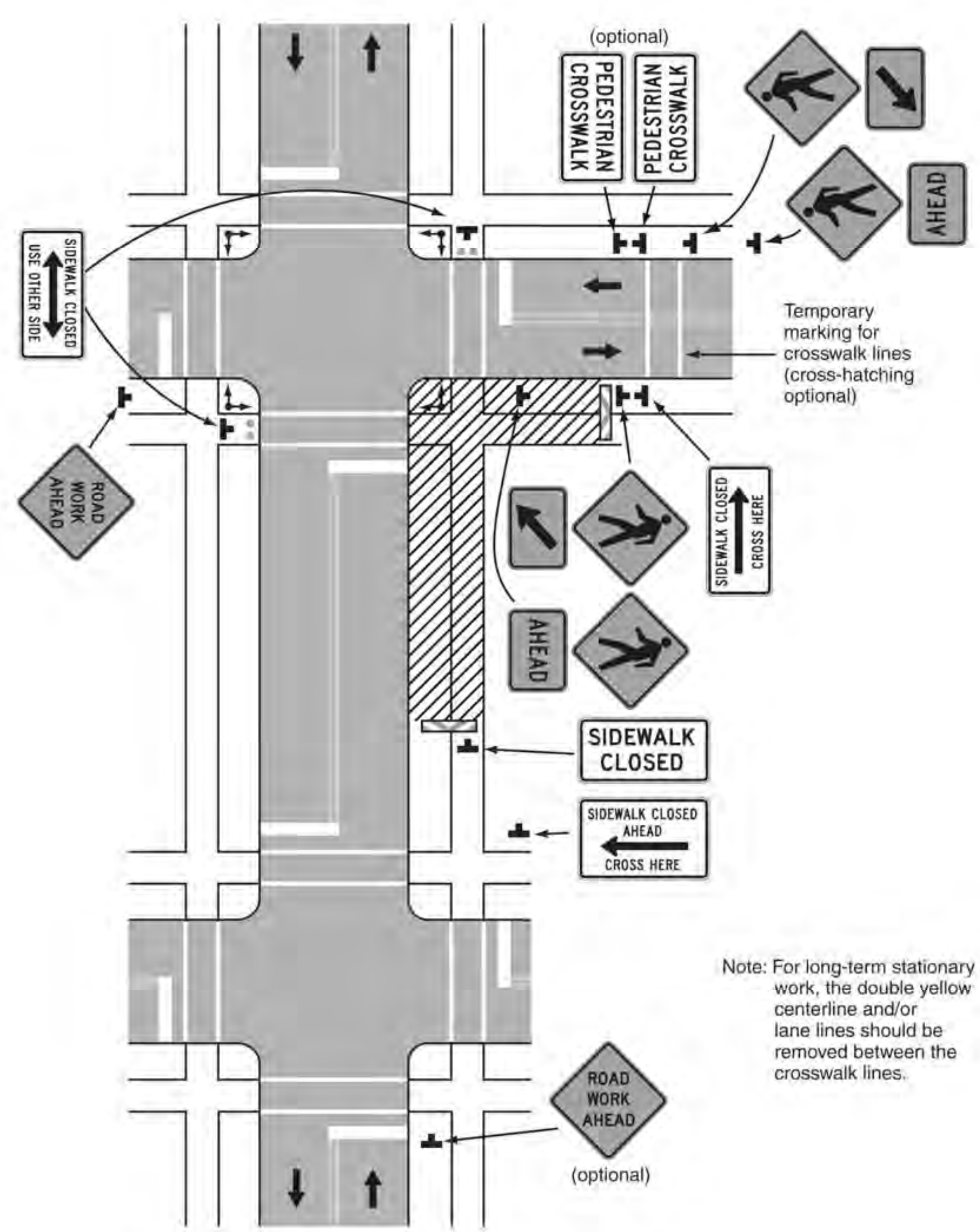
Proper planning for pedestrians through and along construction areas is as important as planning for vehicle traffic, especially in urban and suburban areas which have the highest volume of pedestrian traffic. Three key considerations for pedestrian safety in work zones are:

- Separate pedestrians from conflicts with construction vehicles, equipment, and operations.
- Separate pedestrians from conflicts with traffic moving through or around the worksite.
- Maintain pedestrian routes with a safe, accessible, and convenient path of travel that duplicates, as nearly as possible, the most desirable characteristics of sidewalks.

When construction requires closing sidewalks, crosswalks, paths and other walkways, a safe, accessible, and convenient alternative route must be maintained. The alternative route preferably should be provided adjacent or close to the existing route. Completely closing a sidewalk for construction and rerouting pedestrians to the other side of the street is another, less desirable option. In the event pedestrians are rerouted to the other side of the street, the street crossing should be located at an intersection, existing crosswalk, or other suitable and safe location, as shown in Exhibit 17-5.

Exhibit 17-5

Crosswalk Closures and Pedestrian Detours



Source: Manual on Uniform Traffic Control Devices, 2003. Part 6 Temporary Traffic Control.

If a temporary route is created in the roadway, shoulders, parking lanes, or travel lanes can be converted to temporary walkways using appropriate barricades, reflectorized drums, and signage. Walkways must be clearly identified and fully accessible for people with disabilities, protected from motor vehicle traffic, and free from hazards such as holes, debris, abrupt grade changes, mud, and standing water.

A width of at least 5 feet should be provided. Wider walkways may be necessary where there are high pedestrian volumes. Construction traffic control signs and other equipment should not be placed within the walkway and sidewalks open to pedestrians should not be used as storage areas for construction equipment, workers' vehicles, signs, barricades, or drums. Additionally, signs should not be placed where they block pedestrians using wheelchairs or protrude at head height (between 27" and 80").

At intersections, avoid closing crosswalks but mark temporary crosswalks if necessary. Access to pedestrian push buttons should be maintained, where applicable. Advance signage should be provided at intersections to alert pedestrians of mid-block worksites.

Protective Barriers

Barriers to prevent pedestrians from entering construction zones should be continuous and constructed of rigid materials in order to be discerned by pedestrians with vision impairments. The use of "caution" tape or other measures is not acceptable for defining a pedestrian route since these materials are easily broken and do not adequately direct pedestrians into the temporary pathway. Scaffolding and other construction fencing should not have objects that protrude into the clear head space for pedestrians. Temporary work on sidewalks also needs to be barricaded.

At fixed work sites of significant duration, especially in urban areas with high pedestrian volumes, fences may be needed to prevent pedestrian access into the construction site. Where used, fences should be 8 feet high. If chain link fencing is used around an existing sidewalk, signs indicating "Sidewalk Closed/Detour" should be placed at eye height to increase visibility of the fence. Covered walkways and other barriers must be designed to provide ample sight distance at intersections and crosswalks for pedestrians, cyclists, and motorists.

It may be necessary to use a longitudinal traffic barrier to separate the pedestrian from vehicular traffic. The barrier must be of sufficient strength to avoid intrusion by an impacting vehicle. See the AASHTO *Roadside Design Guide* and *NCHRP Report 350* for information on barrier system performance. For work adjacent to high speed traffic, continuous temporary, pre-cast concrete barriers are recommended. Wooden railings, chain link fences, and other similar systems are not suitable for use in this situation.

17.5.2.2 Bicyclists

Like pedestrians, bicyclists should be accommodated through work zones. If bike accommodation is normally provided on the roadway, the designer should strive to maintain this accommodation through the work zone. In many cases, however, it is not practical to maintain this additional cross-section. When it is not possible to maintain bicycle accommodation, the following should be considered:

- In work areas where the motor vehicle speeds are in the range of 25 to 30 miles per hour, the bicycle can use the same route as the motor vehicles. “Share the Road” signs should be used to alert motorists to the presence of bicycles.
- On higher speed facilities, the designer should attempt to reduce motor vehicle speeds so that they are compatible with shared-lane operations. Reducing the vehicle speeds also improves the safety for pedestrians and crews within the work zone.
- Where appropriate shared use speeds can not be achieved, a different route or detour is desirable. Bicyclists may also be instructed to dismount and walk their bikes through the work zone, following the route provided for pedestrians.
- Loose gravel, abrupt grade changes, milled pavement, standing water, mud, and other hazards create difficulty for bicyclists and should be avoided within the traveled way.
- Raised utility covers and other objects along the edge of the traveled way also pose hazards for cyclists and should be avoided when possible. When these objects are present, they should be marked with reflective paint or other means to improve their visibility.
- Objects protruding from barriers or signs into the bicyclist’s head zone pose serious hazards and must be avoided. If construction

requires taking space where bicyclists travel, “Share the Road” signs or alternative routing signs need to be used.

17.5.2.3 Motorists

If motorists can easily understand the traffic control and have adequate time to make decisions, they will generally operate their vehicles in a safer manner. As speeds increase, the motorist requires more time to respond to conditions. The details of this relationship are covered in MassHighway’s *Standard Details and Drawings for the Development of Traffic Management Plans.*

Insufficient, conflicting, or too much information conveyed by signage will confuse the motorist and contribute to erratic driving behavior. For example, credibility might be damaged if signing and other devices warn motorists of conditions that do not exist at the time, or provide incorrect directional guidance. Key elements of work zone management plans for motorists include:

- **Speed reduction**. Motorists tend to drive at a speed that seems appropriate for the setting. Imposing an artificially low speed limit is rarely effective, even for work zones. The designer must provide appropriate guidance and transitions from the normal speed condition outside the work zone to a lower-speed environment within the work zone.

In general, speed reduction should not be greater than 10 mph below the posted speed limit. If a greater than 10 mph reduction is required, the speed should be reduced in 5 mph increments. An R2-1 sign should be used to post the reduced speed limit and a W3-5 or W3-5a advisory sign should be used to provide advance warning of the upcoming speed limit change.

- **Enhanced enforcement**. Police details are sometimes present in work zones and reinforce physical measures intended to reduce speeds and moderate driver behavior. In addition to construction zone details, aggressive enforcement of traffic regulations along approaches to and within construction zones can be an effective strategy for reducing motor vehicle speeds and moderating aggressive driving behavior.
- **Temporary Traffic Control (TTC) Plans**. A full complement of barriers, warning signs, pavement markings, and impact attenuators are available for use in different work zone management situations. The following section describes TTC plans in more detail, including the use of various traffic control devices and their placement.

17.6 Temporary Traffic Control (TTC) Plans

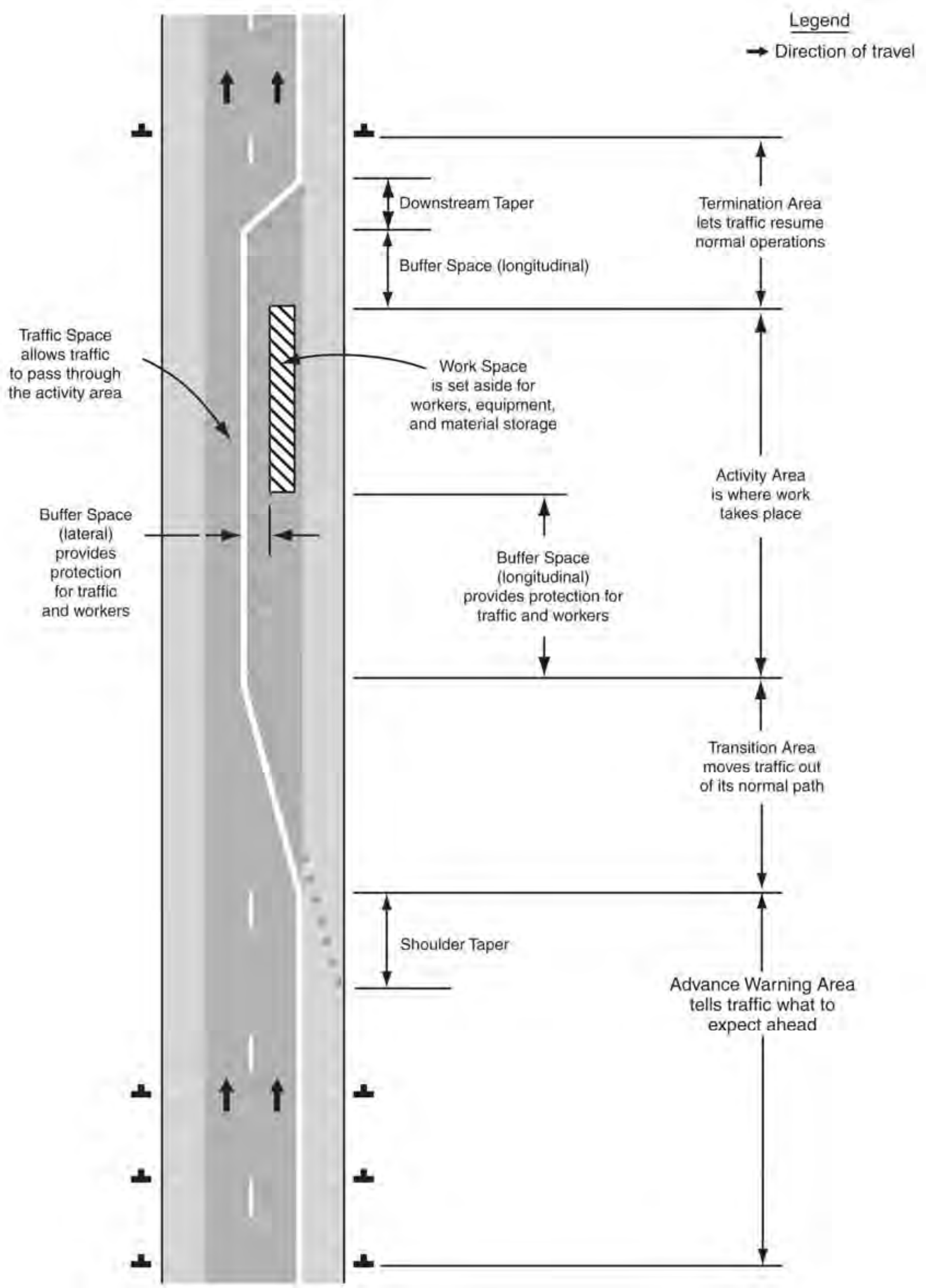
TTC Plans depict the basic layout of the worksite, the resulting configuration of lanes, and the placement of signage, barriers, and other traffic control devices. Exhibit 17-6 shows the component parts of a TTC Plan. Basic work zone traffic management configurations include:

- Lane narrowing, where the basic number of lanes is maintained;
- Lane closure of one or more lanes;
- Alternating one-way operations for a segment of a two-way roadway with temporary traffic control;
- Use of a temporary bypass constructed within the roadway's right of way;
- Intermittent closure of the roadway for short periods of time;
- Crossover of traffic onto one side of a median, often separated by a temporary barrier;
- Shoulder use for traffic diversion;
- Paved median use for traffic diversion;
- Detour of traffic to alternate routes; and
- Construction between lanes on multilane segment (lane separation).

Procedures, standard drawings and details for these work zone types are included in MassHighway's *Standard Details and Drawings for the Development of Traffic Management Plans*. Additional information on Work Zone Management can be found in the *Manual on Uniform Traffic Control Devices*.

Exhibit 17-6

Component Parts of A Temporary Traffic Control Zone



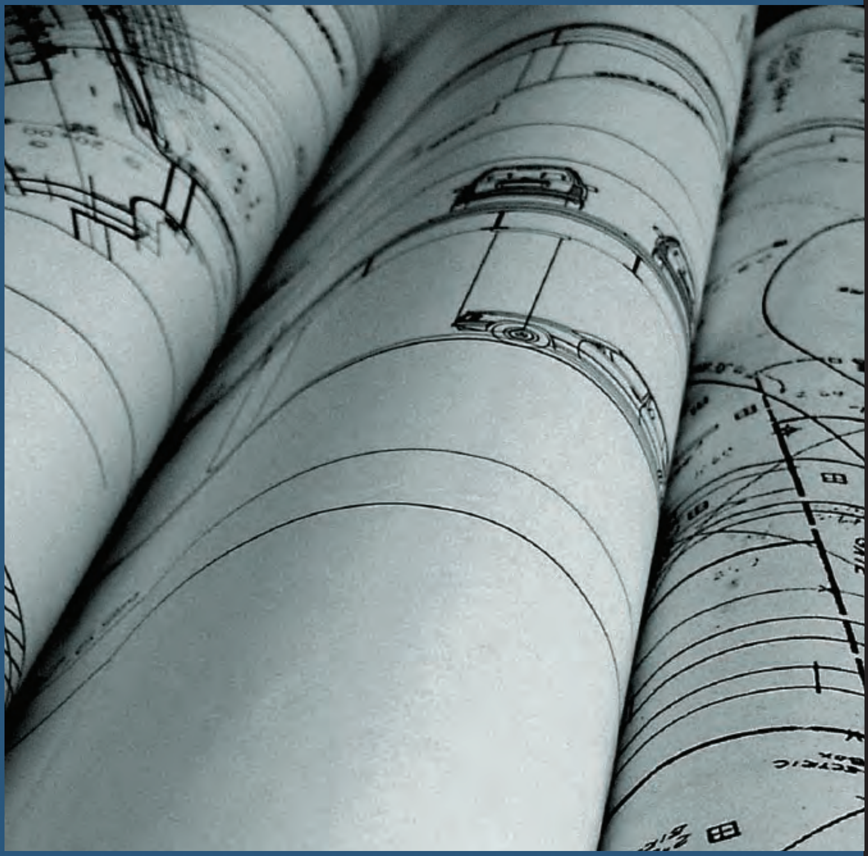
Source: Manual on Uniform Traffic Control Devices, 2003. Part 6 Temporary Traffic Control.

17.7 For Further Information

- *Standard Details and Drawings for the Development of Traffic Management Plans*, MassHighway, 2005.
- *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004.
- *Guide for the Planning and Design of Pedestrian Facilities*, AASHTO, 2004.
- *Manual on Uniform Traffic Control Devices*, Federal Highway Administration, 2003.
- *Pedestrian Facilities Guidebook: Incorporating Pedestrians into Washington's Transportation System*, Washington State Department of Transportation, Puget Sound Regional Council, County Road Administration Board, Washington Association of Cities, 1997.
- *Design Manual*, Washington State Department of Transportation, 2004.
- *Accessible Rights of Way: A Design Guide*, Architectural and Transportation Barriers Compliance Board, 1999.
- DRAFT *ADA Accessibility Guidelines for Public Rights of Way*, Architectural and Transportation Barriers Compliance Board, Washington, D.C., 2002.
- 521 CMR: The Rules and Regulations of the Massachusetts Architectural Access Board, Boston, MA., 2002.
- ADA Accessibility Guidelines for Buildings and Facilities (ADAAG), U.S. Department of Justice, Washington, D.C., 1992.
- National Cooperative Highway Research Program Report 350, Recommended Procedures for the Safety Performance Evaluation of Highway Features, Part A and Part B, NCHRP Project 22-07.
- *Notes on Work Zone Capacity and Level of Service*, Texas Transportation Institute, Texas A&M University, 1984
- 23 CFR Part 630, subpart J: Work Zone Safety and Mobility, Washington DC, 2004.

Chapter 18

Plans, Specs and Estimates



Plans, Specifications, and Cost Estimates

18.1 Introduction

Plans are the documentation prepared to convey physical information so that designers, reviewers, and the public can understand both the existing conditions and the project. Plans also allow a contractor to construct the project and define the right-of-way available or to be acquired. This chapter describes the procedures for different types of plans associated with MassHighway projects.

Specifications define the materials and methods to be used by the contractor when constructing a project and are discussed. Standard specifications are used for most MassHighway projects; however, supplemental specifications are often prepared to alter the basic requirements for specific projects. This chapter describes the procedure for developing supplemental specifications, describes their format and content, and provides guidance on specific language to be used or avoided.

Estimates are prepared for project budgeting and to evaluate responses to project advertisements. Estimating procedures for MassHighway projects are also discussed.

18.2 Construction Plans

18.2.1 Base Plans

Base plans show all man-made and natural features located within the proposed project limits. Examples of such details as they would be shown on a plan are indicated in Exhibit 18-1. Base plans also show state, county, city, and town layouts, city/town lines, property lines, owners' names, deed references, land court case numbers and land court certificate number.

In addition to the plan symbols in Exhibit 18-1, base plans also use numerous abbreviations to convey information. Exhibit 18-2 lists some of the most commonly used abbreviations. Exhibit 18-3 shows an example base plan with symbols and abbreviations.

18.2.1.1 Survey Data

The MassHighway Survey Manual provides the Department's criteria and procedures for highway location and survey work, including the requirements for aerial photography, photogrammetry, and geodetic surveys. Surveys are collected with computerized "Total Station and Data Collector" survey equipment. The designer will be furnished digital base plan information for use in CADD systems. The designer should consult with the MassHighway Survey Section for more information.

Field Notes (Survey Books)

After the field survey is completed, the surveyor will compute and plot the alignment data, details, bench level notes, and cross-section notes. The surveyor will adjust all baseline data, traverses, and levels by the Department method and to the allowable limits of closure. The surveyor can use the method of weighted least squares, the compass rule, or the transit rule. However, the method of weighted least squares is the preferred method. All field notes should be checked. Any discrepancies which cannot be readily adjusted should be checked in the field. All survey books must have a plan number, date plotted, and the initials of the plotter. The initials are noted on a stamp on each page in the survey book.

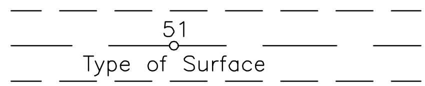
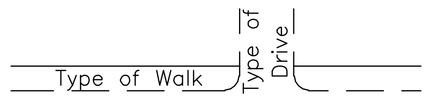
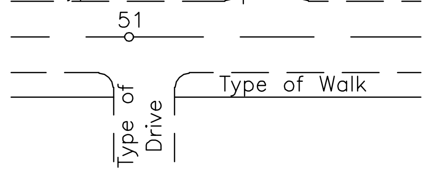
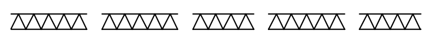
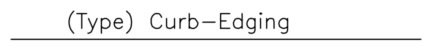
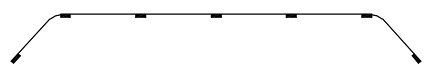
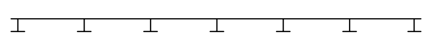
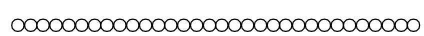
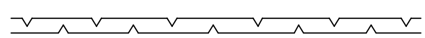
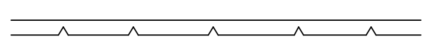
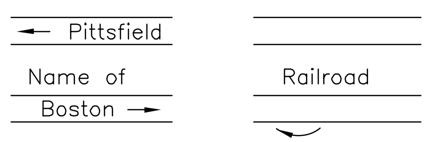
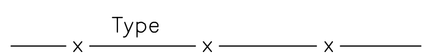
Aerial Surveys

The photogrammetric aerial surveys are required to be supplemented by field surveys. Field surveys supply critical elevations, utility details, surface types, property lines, etc., which are plotted on the photogrammetrics.

Cross-section Field Data

The surveyor should check the bench mark datum and transcription used in running a circuit of levels against the originally established references. Exhibit 18-4 illustrates a datum table. A field bench mark should be checked arithmetically. If it is correct, a red ink check mark should be made in the field book. All corrections should be noted with red ink directly above the original.

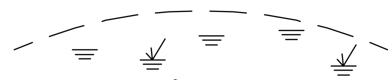
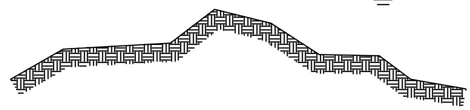
Exhibit 18-1
Plan Symbols

Roadway edges dash ¼" long	
Cement concrete walks and drives, solid line	
Walks and drives (bituminous concrete, gravel, dirt, etc.) Dash line ⅛" long	
Paved gutter	
Curbing, edging double solid line	
Wood guard rail steel beam guard, wood or steel posts	
Guard rail, steel posts	
Balanced stone wall	
Retaining wall	
Double faced wall	
Pointed wall	
Railroad or s-ree- railway -racks	
- nce	

Note: All symbols noted apply to existing details. They are similarly shown on base plans and construction tracings in black ink, unless otherwise noted.

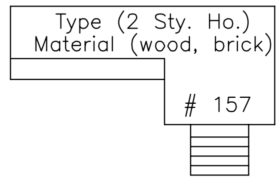
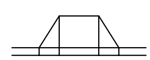
Source: MassHighway

Exhibit 18-1
Plan Symbols (continued)

Woods or Brush	Woods
Hedge	
Wetland	
Rock/ Ledge	
Utility pole: telephone, power	. o- pole & Type o -ili- (2' diame- r)
Guy pole	Guy (2' diame- r)
Light pole	(2' diame- r)
Trolley pole	(2' diame- r)
Trees	Diame- r & Type (- ale)
Proper- line, pencil i- approx.	Mark Approx: I- -pproxima-
S-a- boundary line	ame o -a ame o -a-
Coun- mmissioner's line (layou- i- r - n layou- line railroad sideline	. Comm., Ci- Town, or R.R. Layou- a-
City, town, or county boundary line	Name o- Town, Ci- r Coun- a- Name o- Town, Ci- r Coun- a-
State hwy. layout line: on mylar roll on construction plan	a- -l- ra-ion e- (Da -a- Highway Layou-
Stone bound	□ (2' Square) Type o- a- rial
Mass. highway bound	HB ■ quare) Type o- a- rial
County bound	Co. Bd □ (2' Square) Type o- a- rial
Town or ci- bound	Town or City Bd. ■ quare) Type of Material
Mass. -riangula-ion s-a-ion	Number △ (Each Leg 2')

Source: MassHighway

Exhibit 18-1
Plan Symbols (continued)

Buildings, houses, etc.	
Drainage pipe	Size & Type of Material
Concrete box culvert	Width, Height Conc. Box Culvert
Underground Utilities	Name of Utility (Tel. & Tel. etc.)
Catch basin & curb inlet	CBCI (2' Each Side)
Manhole — Label type, i.e. sewer, drainage, etc.	MH (2' Diameter)
Water gate	WG (1' Diameter)
Hydrant	Hyd. (2' Diameter)
Gas gate	GG (1' Diameter)
Catch basin	CB (2' Each Side)
Deep Sump Catch basin	DSCB (2' Each Side)
Leaching Basin	LB (2' Each Side)
Drop inlet	DI (Rectangle 4' x 2')
Concrete headwall (end) for culverts	Conc. Hdr 1' x Actual Length
Stone headwall (end) for culverts	Stone Hdr.
Wheelchair ramp	

Source: MassHighway

Exhibit 18-2
Abbreviations

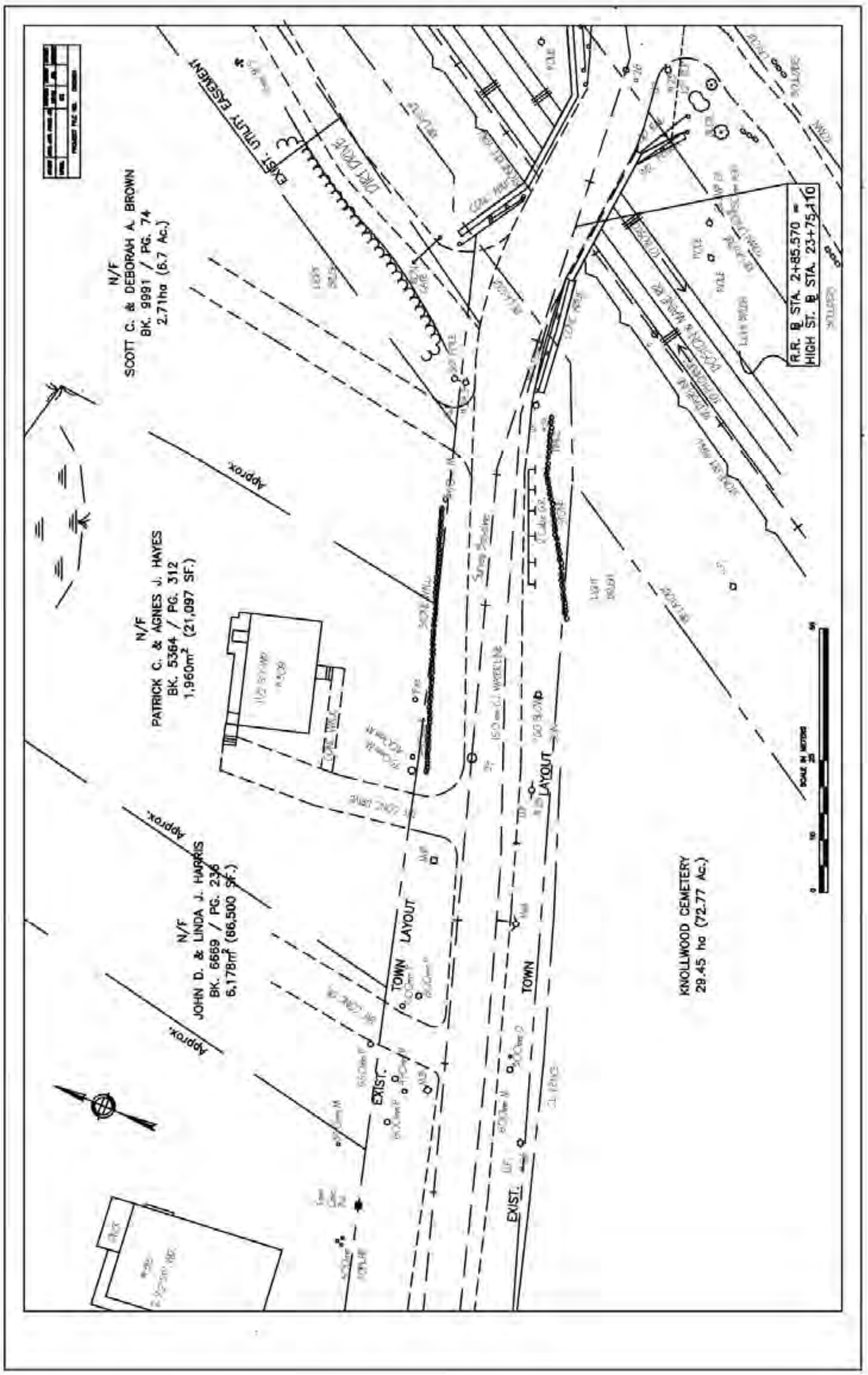
AADT	Annual Average Daily Traffic
ABAN	Abandon
A.C.	Asphaltic Concrete
ACCM PIPE	Asphalt Coated Corrugated Metal Pipe
APPR	Approach
BD.	Bound
BIT CONC	Bituminous Concrete
BL	Baseline
BLDG	Building
BMA	Bituminous Macadam
BM	Bench Mark
BO	By Others
BR.	Bridge
CB	Catch Basin
CBCI	Catch Basin With Curb Inlet
CC	Cement Concrete
CCM	Cement Concrete Masonry
CEM	Cement
CI	Curb Inlet
CIP	Cast Iron Pipe
CI.	Class (Concrete, Excavation, etc.)
℄	Center Line
℄ CONST.	Ceneterline of Construction
CMP	Corrugated Metal Pipe
CSP	Corrugated Steel Pipe
CO.	County
CO. BD.	County Bound
CONC	Concrete
CONST	Construct(ion)
CR GR	Crown Grade
CULV	Culvert
CM	Cubic Meter
D	Delta Angle (Central Angle of Horiz. Curve)
Δ	Directional Percentage of DHV (Title Sheet)
DA	Drainage Area
DHV	Design Hourly Volume
DI	Drop Inlet
DIP	Ductile Iron Pipe
DR	Drive
E	External
EB	East Bound
ELEV (OR EL)	Elevation
EMB	Embankment
ENT	Entrance
EXC	Excavation

EXIST (OR EX.)	Existing
FAS	Federal–Aid Secondary
FL (OR FL)	Flow Line
FLDSTN	Fieldstone
GAR	Garage
GD	Ground
GG	Gas Gate
CI	Gutter Inlet
GIP	Galvanized Iron Pipe
GRAV	Gravel
GRAN	Granite
GRD	Guard
HDW	Headwall
HI	Height of Instrument
HMA	Hot Mix Asphalt
HO	House
HOR	Horizontal
HYD	Hydrant
IT	Intersection of Slopes or Profile Grade Lines
JCT	Junction
L	Length of Curve
LB	Leaching Basin
LP	Light Pole
LT	Left
MB	Mail Box
MED	Median
MH	Manhole
MHB	Massachusetts Highway Bound
NB	North Bound
NIC	Not In Contract
PVM'T	Pavement
PC	Point of Curvature
PCC	Point of Compound Curvature
PI	Point of Intersection
PL (OR PROP. LINE)	Property Line
POC	Point On Curve
POT	Point On Tangent
PRC	Point of Reverse Curvature
PROJ	Project
PROP	Proposed
PT	Point of Tangency
PVI	Point of Vertifcal Intersection
PVC	Point of Vertical Curvature
PVT	Point of Vertical Tangency
PWW	Paved Waterway
R	Radius of Curvature

PC	Reinforced Concrete
RD	Road
RDWY	Roadway
REM	Remove
RET	Retain
RET WALL	Retaining Wall
ROW	Right–of–Way
RR	Railroad
RT	Right
R/W	Right–of–Way
SB	Stone Bound
S.BD.	South Bound
SD	Subdrain
SEC	Section
SECTS	Sections (End sections for pipes)
SH	Sheet
SHLD	Shoulder
SK	Skew
SMH	Sewer Manhole
SM	Square Meter
ST	Street
STA	Station
SSD	Stopping Sight Distance
SURF	Surfacing or Surface
SW	Sidewalk
T	Tangent Distance of Curve/ Truck Percentage
TAN	Tangent
TEMP	Temporary
TP	Turning Point
TR	Top of Rail
TR SIG	Traffic Signal
TSC	Traffic Signal Conduit
V	Speed (usually Design Speed)
VAR	Variable
VC	Vertical Curve
VCP	Vitrified Clay Pipe
VERT	Vertical
[illegible]	Wheelchair Ramp
WB	West Bound
WD	Wood
WG	Water Gate
WIP	Wrought Iron Pipe
WM	Water Meter/Water Main
X–SECT	Cross Section

Source: MassHighway

Exhibit 18-3
Base Plan



Source: MassHighway

Exhibit 18-4
Relation of Datum Planes

TOWN OF ORANGE...+434.91
TOWN OF NORTH ATTLEBOROUGH.............................+170.48
NEW ENGLAND POWER CO. (WESTBOROUGH)...........+105.15
WESTERN MASS ELECTRIC CO. (GREENFIELD).........+68.71
CITY OF LOWELL...+54.39
LOCKS AND CANALS CORP. (LOWELL).................+4.39
CITY OF LAWRENCE..+4.28
MEAN HIGH WATER*.......................+4.23
TOWN OF FRAMINGHAM...................................+3.30
CITY OF FALL RIVER.....................................+1.87
CITY OF TAUNTON...+1.77
CITY OF NEW BEDFORD............................+1.73
CITY OF ATTLEBORO.................................+1.48
CITY OF LEOMINSTER.............................+0.86
CITY OF WORCESTER..............................+0.15
NGVD 88 DATUM =0.000 FEET
MEAN TIDE LEVEL* -0.54
TOWN OF NATICK.......................................-0.81
CITY OF CHICOPEE....................................-1.08
CITY OF SPRINGFIELD..................................-1.18
TOWN OF GREENFIELD...................................-1.38
CITY OF HAVERHILL..-2.23
CITY OF BROCKTON...-2.37
HOLYOKE WATER POWER CO.............................-3.23
CITY OF HOLYOKE..-3.30
CITY OF SALEM..-5.17
SOUTH ESSEX SEWAGE DISTRICT (SALEM).............-5.27
TOWN OF MANCHESTER...-5.27
MEAN LOW WATER*...............................-5.32
CITY OF PEABODY...-5.63
BOSTON LOW WATER ....-5.70
LOGAN AIRPORT (WATERWAYS).......................................-6.08
CITY OF LYNN...-6.09
LOGAN AIRPORT (HIGHWAYS)...-6.15
CITY OF SOMERVILLE...-6.20
TOWN OF WELLESLEY...-6.29
CITY OF BEVERLY...-6.34
TOWN OF DEDHAM...-6.43
BOSTON CITY BASE & WALTHAM CITY BASE............................-6.46
CITY OF NEWTON..-6.53
TOWN OF STOUGHTON..-6.55
TOWN OF BROOKLINE..-6.60
CITY OF QUINCY...-6.63
CITY OF REVERE..-6.64
CITY OF EVERETT...-6.69
CITY OF CHELSEA..-6.80
TOWN OF NORWOOD...-6.82
CITY OF CAMBRIDGE...-11.66
TOWN OF WALPOLE...-24.06
THIRD HARBOR TUNNEL...-100.81
U.S. ARMY ENGINEERS (BOSTON)..-101.16
BOSTON NAVY YARD (BASIC BENCH)...-105.89
TOWN OF NEEDHAM..-106.41
MASS. WATER RESOURCES AUTHORITY & BOSTON TRANSIT COMMISSION......-106.43
MASS. BAY TRANSPORTATION AUTHORITY...-106.46
MASS. BAY TRANSPORTATION AUTHORITY REDLINE (BOSTON).........................-106.68

* Tidal Bench Marks located at Appraiser's Stores Building, U.S. Custom House, Purchase and High Streets, Boston.

NOTE: Elevations shown are derived from NGS VERTCON PROGRAM, VERSION 2.0, for NGVD 29 to NAVD 88 conversions. Tests of the predictive capability of the physical model show a 2.0 cm RMS agreement. The VERTCON model can be considered accurate at the 2 cm level nationwide, with better accuracy in the eastern United States.

4.23
0.54
5.32
AS OF 1978

Source: MassHighway

These instructions also apply to the survey cross-section data:

- The number of significant figures in the final computation will be determined by the degree of precision used in taking the rod readings.
- Check and underline the height of instrument (H.I.) in green ink. When an H.I. is adjusted, show the correction in green ink.
- Computed elevations should be shown directly under the rod readings with red ink.
- Green ink is used for checking and correcting office computations. A green check mark should be placed at the extreme right end of each line of elevations to indicate that they have been checked and corrected, if needed.
- The engineer's name and the date of calculations should be recorded at the end of each set of notes.

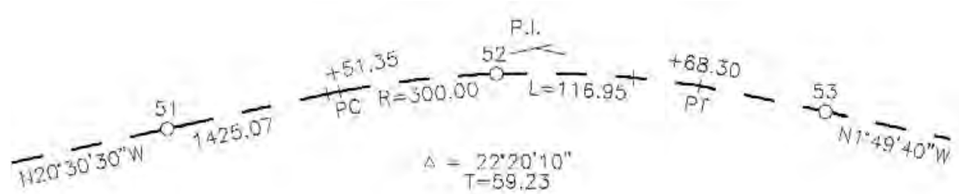
18.2.1.2 Plotting Base Plan

Base plans will be plotted on paper for review purposes. The following criteria will apply in plotting the base plan:

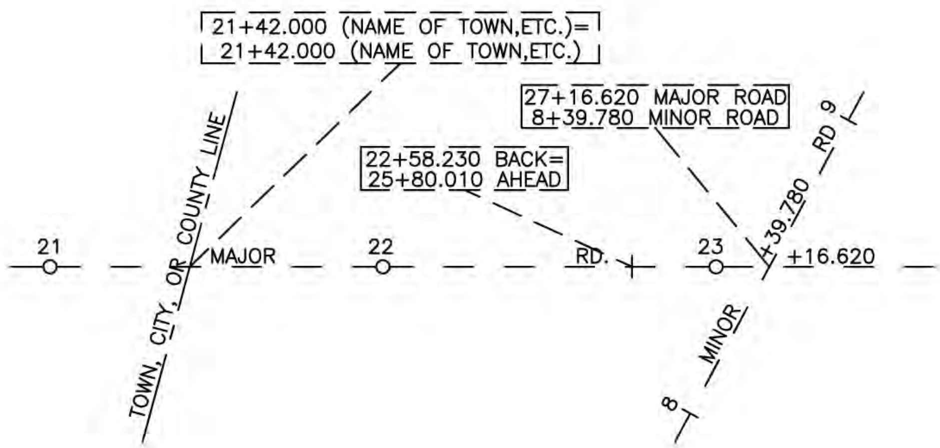
- Plans require a title.
- The baseline shall be stationed at 100 foot intervals (100 feet = 1 station) and can break where necessary, but there should be an overlap of 100 feet.
- Match lines should be plotted to indicate overlap sections.
- Plans should extend at least 100 feet beyond the anticipated beginning and end of the project, unless there is an intersection, major structure, or railroad crossing within 300 feet.
- All baselines and center lines are plotted by coordinates on the North American Datum 83 System as follows:

Scale	Size of Coordinate Squares
1” = 20’	250’
1” = 40’	500’
1” = 100’	1250’

- Indicate coordinate points by intersecting 1-1/2 inch lines. Describe these by noting the coordinate values at each point.
- The baseline or center line is drawn as a dashed line, with the dashes about 1/2-inch long (see below). The 100-foot stations are indicated by small circles of 5/40-inch diameter, and the stations are noted above each circle with numerals 5/40-inch (L120) high with 4/40-inch ticks at 50-foot intervals. Points of curvature and tangency and angle points are marked with a short line intersecting the baseline at a right angle. The stations above the baseline or center line and the description of points (P.C., P.T.) below the baseline are 5/40-inch high. Bearings, length of tangents, curve number, and length and radii of curve are shown below the line. The remaining curve data (i.e., delta angle, length of curve tangent) are shown in a curve table or on the concave side of the curve if the curve data will not interfere with other plan details.



- An equation may occur where baselines intersect or at a change in station (see diagram below). This is usually offset from the point to which it refers and is enclosed by a rectangle to the point. If the plan detail requires the equation to be removed from the point, the equation may be placed on the intersection lines.



- Arrange the lettering so it can be read without turning the plan from its normal position (i.e., from bottom to top and from left to right).

18.2.1.3 Plotting Base Profiles

Basic profiles may be plotted on paper for review purposes. The following criteria apply:

- Scales of 1” = 20’ horizontally and 1” = 4’ vertically may be used.
- Scales of 1” = 40’ horizontally and 1” = 8’ vertically are usually used.
- The stations at the beginning and end of each profile will coincide with those of the corresponding plan. Stations to be at 100-foot intervals.
- The plan and profile may be shown on the same sheet.
- The horizontal profile scale shall be the same as the horizontal base plan scale when shown on the same sheet.
- The base elevation should be in multiples of 5 feet.
- A minus base value is indicated as "Base = Minus 10" and a zero base is shown "Base Zero."
- Bench marks with datum noted are described on the profile approximately above the corresponding station on the profile.
- Equations are noted below the datum line.
- Broken profiles are permissible, when the ground rises or falls rapidly, to keep the profile within the limits of the sheet. They should be overlapped 100 feet horizontally.

- Punchings in wetland areas are shown as a dashed line at the proper elevations and are designated "Approx. Hard Bottom."
- Culverts which cross the baseline are shown in section on the profile. The field book usually provides the elevation of the flow line (invert), elevation of the end (header), width and height of a square or rectangular box culvert, and diameter of a pipe. The dimensions describing the square and rectangular structures are the width of opening first and height of opening second.
- The clearance to the lowest wire of a high tension line will be shown on the profile. Plot the elevation of the lowest wire at the proper station location, and show this point as a heavy black ink dot. The number of wires, voltage, and clearance from the ground to the lowest wire will be indicated. The location of these wires is highlighted by a finger indicator next to it.
- Water levels are shown as a thin dashed line, and the elevation and date of measurement are noted.
- Sills of major structures are plotted at their respective elevations. A dimension facing the baselines is determined by projecting the extremities of the structure at right angles or radial to the baseline stations.
- Side streets should be shown on base profiles.

18.2.1.4 Cross-sections

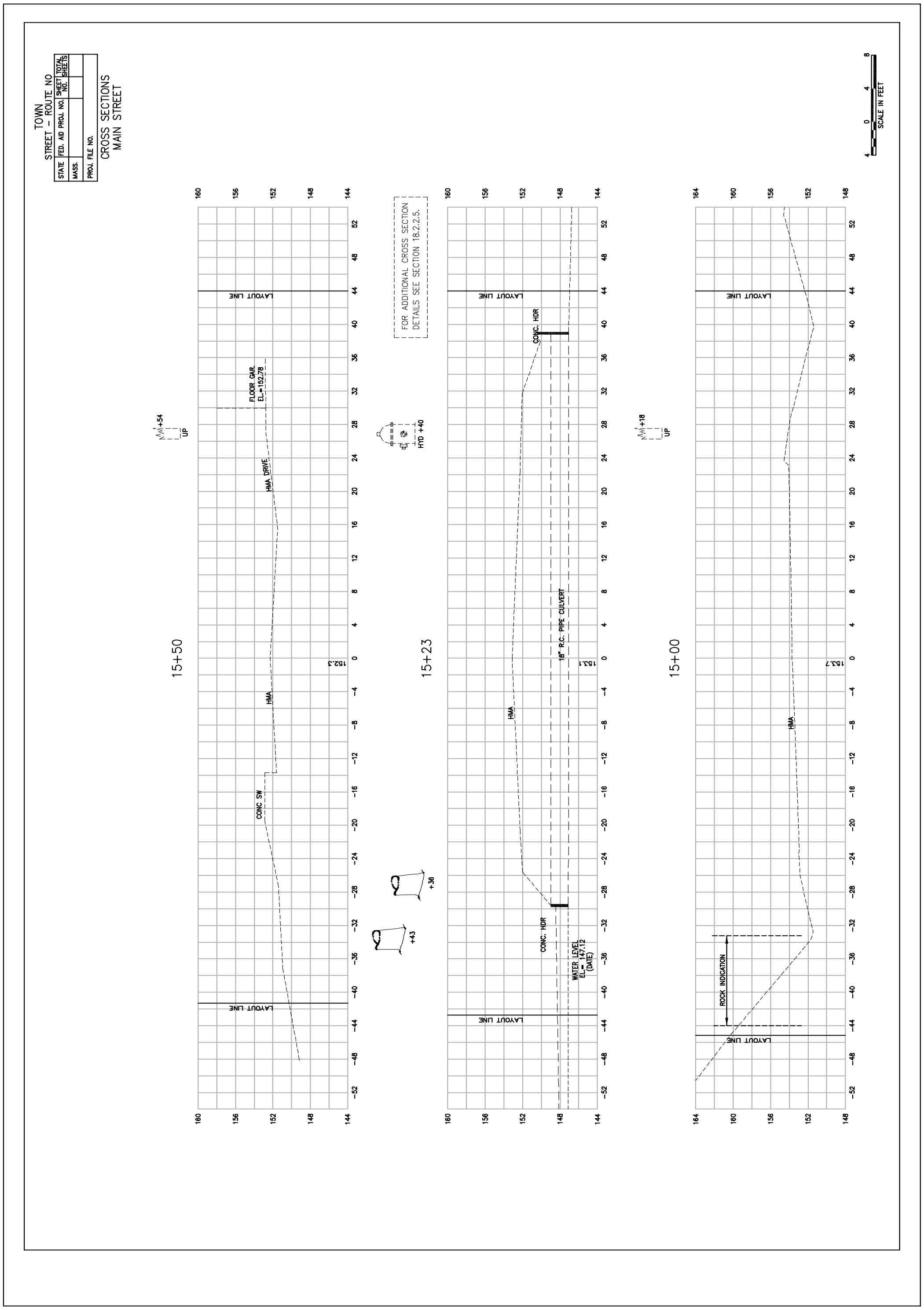
The sample sheet in Exhibit 18-5 shows the method of plotting existing ground sections and title block. Symbols for cross-sections are illustrated in Exhibit 18-6. The data for plotting sections is either obtained from field books, survey data collectors (digital terrain modules) or by interpolating from photogrammetric maps and contour plans. These last two methods are described in Section 18.2.1.1.

The following criteria apply for plotting cross-sections:

- The usual scale for cross-sections is 1” = 4’ horizontally and vertically. However, on multilane divided highways, a scale of 1” = 8’ is more practical. The selection of the proper scale depends on the width of the cross-section.
- Cross-sections shall be plotted at 50-foot intervals and at critical points, such as superelevation transition points, intersecting streets, driveways, etc..

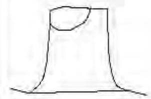
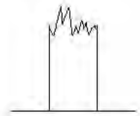
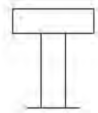
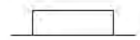
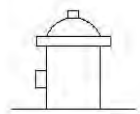
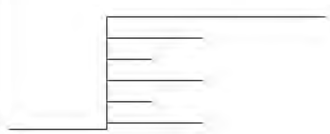
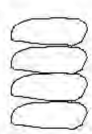
- Cross-sections are normally plotted along the length of the cross-section sheet. The stations of cross-sections increase from the bottom to the top of the sheet. The cross-sections of very narrow roads may be plotted across the width of the sheet.
- Existing ground line should be plotted as a thin dashed line.
- Sufficient space between cross-sections should be provided so that the proposed highway template can be drawn without overlapping the adjoining section. To determine spacing, refer to the tentative grade line furnished by the designer. Additional space allowances may be needed if punchings or soundings are shown.

Exhibit 18-5
Sample Existing Ground Cross-sections



Source: MassHighway

Exhibit 18-6
Symbols for Detailing Sections

Tree (8" and over)		Diameter & Type Station Offset
Pole		Type of Utility Pole, Number Station
Mail box		Mail Box Station
Well – cesspool		
Hydrant		Hydrant Station
Sill of structure (when plotted)	Sill of (Type of Structure) EL. = _______ HO#	
Sill of structure (when beyond limits of sheet)	Offset = _______ Sill of (Type of Structure) EL. = _______ HO#	
Retaining wall		
Balanced wall		
Punching	Approx. Hard Bottom	

Source: MassHighway

- A complete cross-section must be shown on one sheet for estimating and continuity. This practice should be followed even if space is wasted.
- Equations of stations are shown whether or not a cross-section is drawn at that point.
- Profiles of intersecting streets, drives, roads, etc., are plotted in the sequence of the base or center line stationing. The reference baseline for intersecting streets, drives, walks, and steps may be offset from the regular cross-section to allow more room for plotting the profiles. When streets, drives, and roads are indicated by stations along their profile, only the main baseline station is shown rather than an equation.
- Often, the width of the cross-section extends beyond the limits of the sheet. Extensions may be indicated by noting the next offset and elevation near the margin slightly above the cross-section.
- Plus and minus cross-sections are plotted as one section. The plus and minus are indicated on the cross-section lines. "Minus" always indicates the section back and "Plus" the section ahead.
- The cross-section limit should not be extended beyond the border of the sheet, and the data in the title box must be provided.

The following features should be shown on the preliminary cross-sections:

- Edges of roads, drives, walks, steps, wetlands, lawns, etc., should be plotted.
- Walls should be plotted.
- Hydrants, poles, and mailboxes are plotted by station and offset.
- All trees 8 inches and over should be plotted. The diameter and type of tree, station and offset should be noted on the side of the tree away from the baseline or center line.
- Punchings are shown as a dashed line and labeled "Approx. Hard Bottom."
- Indicate elevation, station, and description of wells, cesspools and septic systems, and provide a description and elevation for sills of buildings. Plot sill elevation and offset to proper dimension, scaling offset from the plan when not shown in notes. Sills which fall between cross-sections are shown by a vertical line at the correct distance from the baseline. The elevations are printed away from the baseline.

- Culverts are shown as long dashed lines. (Dimensions in a field survey book indicate width first and height second.)
- Water elevations are shown as a dashed line. The elevation and date recorded are noted.
- The limit of rock excavation are indicated as shown in Exhibit 18-5 and labeled "Rock Indication". To avoid interference with the proposed roadway cross-section, the notation will appear either above or below the section, depending upon the type of earthwork involved.
- Lines of bridge seats or tops of openings are shown as long dashed lines.
- Rails are shown as a "T" with the horizontal line representing the elevation of top of rail. Indicate the elevation of the top of rail nearest the baseline for rails which run parallel to the main baseline. The elevation is printed vertically.
- Descriptions (type of surface, etc.) are shown on the bottom and top cross-sections only if the description applies to all cross-sections on the sheet (see Exhibit 18-5).
- A Federal-aid block including a project file number must be shown.

18.2.2 Final Plans

18.2.2.1 Drafting Standards for Construction Plans and Cross-sections

The plans shall include all drawings and data necessary for proper construction of the proposed project. The plans will be plotted on the standard size translucent mylar (4 mil) matted on at least one side. Minimum height of all lettering is 1/8 inch. The density of screened mylars may be approved on a project-by-project basis. Exhibit 18-7 provides an example of the Standard Drawing Sheet.

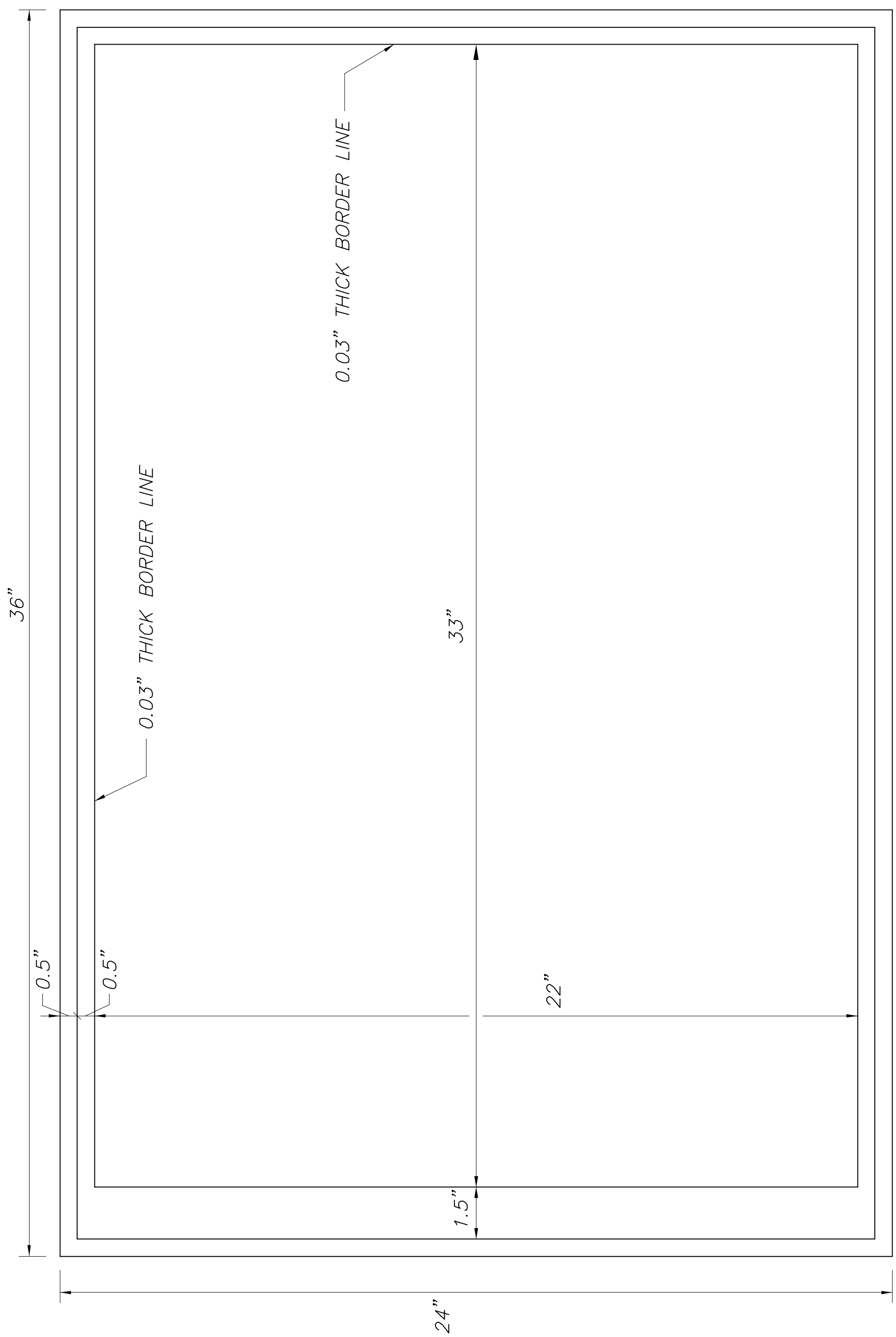
These drafting procedures will ensure archival original quality drawings. It is absolutely necessary to produce drawings with uniform density of line work.

The lettering line thickness shall not be less than .017 inch.

18.2.2.2 Construction Plans

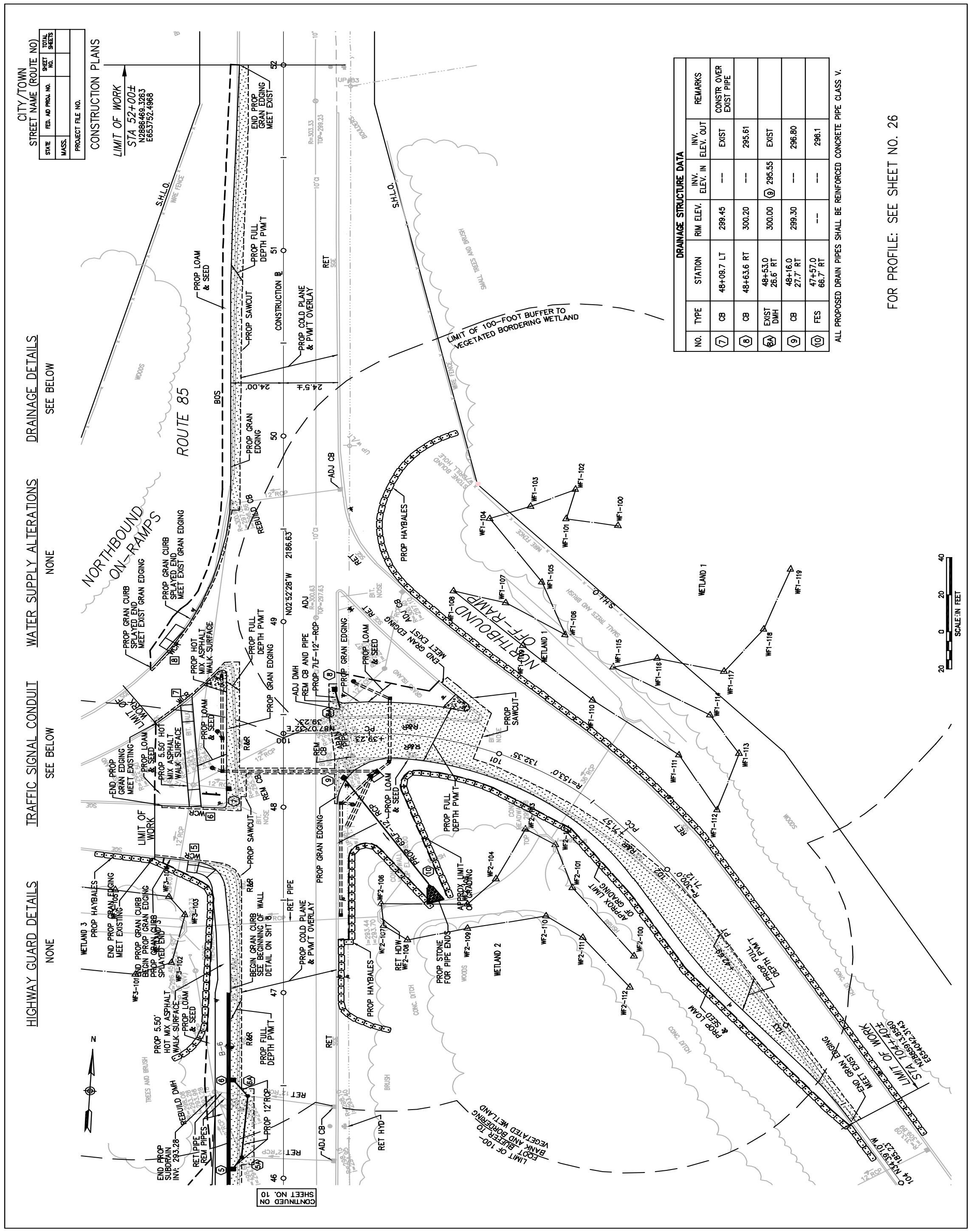
Exhibit 18-8 provides an example of a plan view. Exhibit 18-9 illustrates the necessary data for construction plans. Design symbols are illustrated in Exhibit 18-10.

Exhibit 18-7
Sample of Standard Drawing Sheet



Source: MassHighway

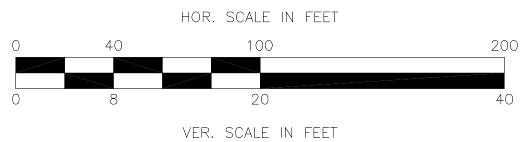
Exhibit 18-8
Sample Construction Plan



Source: MassHighway

Exhibit 18-9
Data for Construction Plans

STANDARD BARSCALE

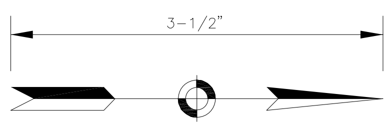


FEDERAL AID BLOCK

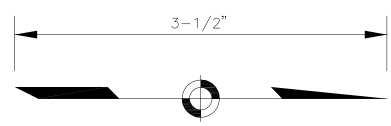
STATE	FED.PROJ. AID NO.	SHEET NO.	TOTAL SHEETS
MASS.			
PROJ. FILE NO.			

(ACTUAL SIZE)

STANDARD NORTH ARROWS



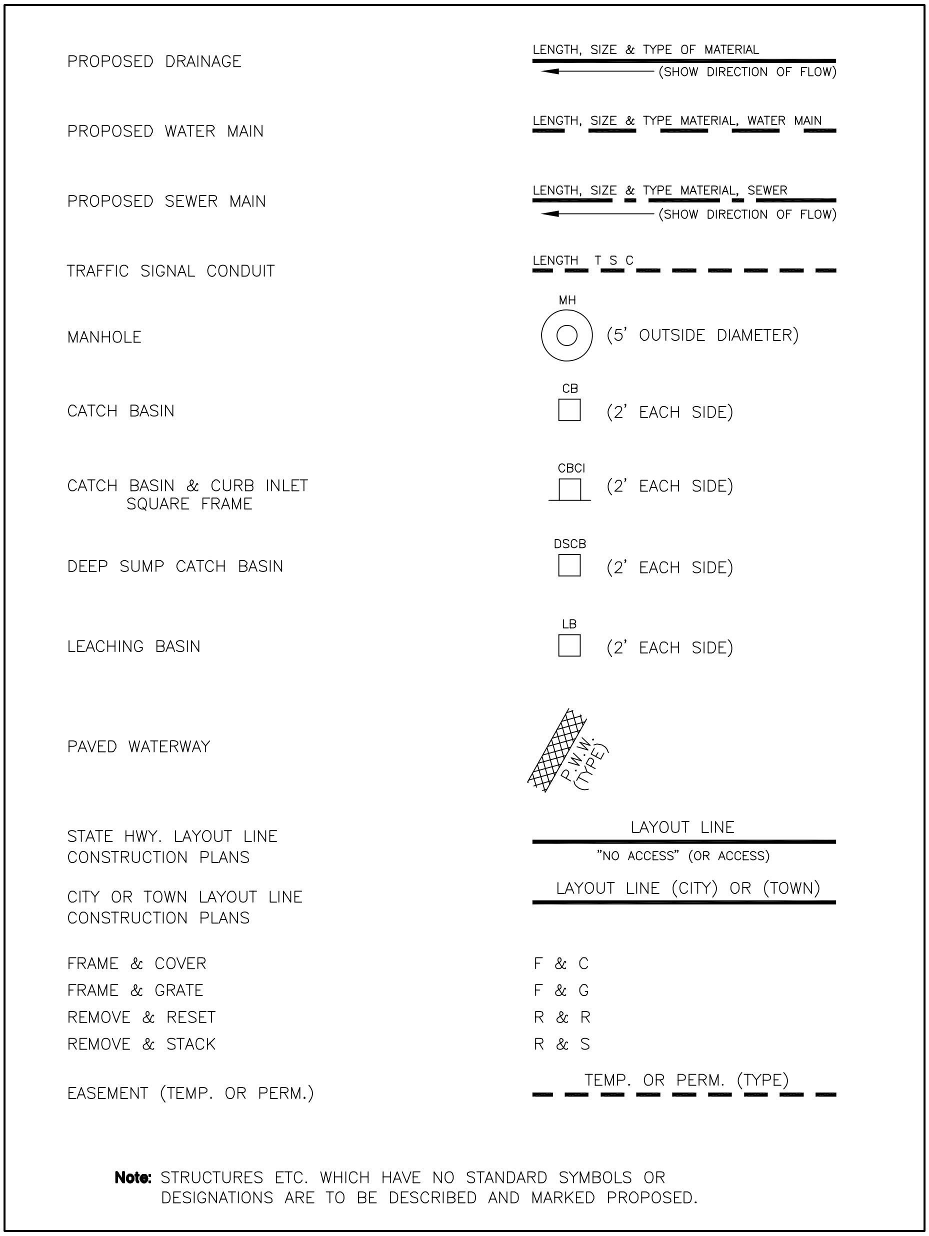
TRUE NORTH OR MASS. CO-ORD SYSTEM



MAGNETIC NORTH OR ASSUMED

Source: MassHighway

Exhibit 18-10
Symbol for Proposed Design



Source: MassHighway

When preparing construction plans, the following apply:

- Existing detail information should be screened for clarity.
- Construction plans are normally drawn at a scale of 1” = 20’. Plans at a scale of 1” = 40’ may be approved on a project to project basis.

- The corresponding profile is placed below the plan. If there is too much detail, the profile should be placed on a separate sheet.
- For 40-scale plans, each succeeding plan is overlapped 100 feet and the plan information will extend a minimum of 150 feet beyond the beginning and end of the project. When 20 scale plans are used, the overlap may be reduced to 50 feet. Match lines should be plotted to indicate overlap sections.
- P.I.s of curve tangents are not shown on final plans.
- The proposed center line and record baseline are shown, stationed at 100-foot intervals.
- If there is a portion of a curve or tangent at either end of a plan more than 100 feet in length, indicate the curve data or bearing and distance.
- Show the State Highway, City, Town, or County layout as shown in Exhibit 18-1. Do not show the radii, ties, etc., of layout lines. Show the beginning and end of the state highway layout, alterations of the layout, and the year recorded.
- When the plan and profile are on the same sheet, the town, city, county, and state names are shown only on the plan portion. If on separate sheets, this data must be shown on each sheet.
- Show a north arrow on all plan sheets. The direction of the north arrow can be determined from the coordinates.
- The stations and coordinates for the beginning and end of project are shown where appropriate.
- Plans showing at-grade intersections should be drawn in a manner that provides the greatest amount of continuity and the least amount of repetition.
- Bar scales will be shown on all construction plans.
- Construction plans which show only the roadway drawings must have profile sheet number references in the lower right edge of the sheet (inside the border). When the continuity of streets or ramps is broken, a sheet number reference should be noted at the breaks.
- Denote the beginning and end of the project and the limit of work. Indicate the project number, associated stations, and coordinates. The beginning of a project is the southerly or westerly end; the end of a project is the northerly or easterly extremity, regardless of the direction of the line stationing and center line.

- Proposed state highway location lines are drawn as solid lines labeled "Proposed State Highway Location Line." Town, city, or county locations are drawn as solid lines labeled " Proposed Location Line (town, city, or county)."
- Easement lines are drawn as long dash lines and labeled drainage, slope, or construction easement, as appropriate. Designate whether the easement line is temporary or permanent.
- Names of property owners are noted in the proper locations.

The following criteria apply to the presentation of the technical content in construction plans:

- **Sight Distance –** Horizontal sight distances shall be noted on the plans in the vicinity of the horizontal curve or in the curve table.
- **Roadway Widths –** All proposed roadway edges will be heavy solid lines. The widths are indicated at the beginning and end of each sheet and at all other points where a change in width occurs. The offset from the center line at all of these points should be shown. All curved edges that are not concentric with the center line of construction should have the radius and any other data noted. All points of curvature and the tangency at the edge should be noted with ties to the center line.
- **Center Line –** A construction center line will be used as the baseline for proposed projects. The proposed center line shall be stationed and labeled with appropriate geometric data. Coordinates in NAD 83 shall be shown at the project limits along with ties to known reference points as appropriate to establish this new line in the field. It is critical that the Record Baseline is also shown within the plan set. The Record Baseline is a historical reference and is necessary to establish reference in the field. It is also the reference used for all Right of Way work.
- **Drives, Sidewalks, Walks –** Proposed edges of drives, sidewalks and walks to houses are drawn as heavy solid lines. The radii of drive curb returns are noted; other curve data is not necessary unless there is a wheelchair ramp (see below). The type of structure should be noted with the abbreviation "PROP" (proposed) before the description. The minimum width of sidewalks and walkways is necessary. Slopes and cross slopes of sidewalks and pedestrian paths should be detailed.

- **Wheel Chair Ramps –** Wheel chair ramps must be drawn as heavy solid lines. A separate sheet listing critical dimensions including ramp length, design slope, curb transition lengths, gutter slopes and level landings must be shown.
- **Edging, Curbing, Berms –** The types of edging, curbing, and berms are shown without indicating lengths. Extremities of each type will be defined by arrows or similar notations. The abbreviation "PROP" (proposed) will appear before the description.
- **Drainage –** The words "DRAINAGE DETAILS" with location reference such as "SEE BELOW" or "SEE PAGE NO. ___" will be placed on the upper part of the sheet near the border. The above is noted whether or not drainage is required in the area shown on the sheet. Where there is no proposed drainage required, the word "NONE" is substituted for the location reference. The proposed drainage details, such as pipe, catch basins, manholes, detention basins, drainage swales, etc., are shown directly on the roadway plan with heavy solid lines so the proposed detail will be easily distinguished from the existing. Where there is a considerable amount of detail on the plan that may obscure the proposed drainage, a separate plan showing the proposed drainage details is recommended. Any water supply alterations and other underground utility data should also be shown on the separate plan.

The length, size, direction of flow, and type of material will be noted at each pipe. Special drainage structures must be noted; the abbreviation "PROP" is not necessary before the description. The stations of the drainage structures are also noted. Details of all special drainage structures will be shown on a separate sheet. The type of material used for culvert ends will be noted at each end. To indicate which pipes or structures of the existing drainage system will be incorporated in the new system, the proper notations will be made, such as "RET” (retain),"ADJ “ (adjust),"R&R” (remove & reset), "ABAN” (abandon), "REM” (remove), etc.

- **Ditches –** Ditches that are not part of the normal section are shown by two heavy broken lines. Note the appropriate payment item. The distance between the lines represents the width of the bottom of the ditch to scale. The abbreviation "PROP" is part of the description.

- **Paved Waterways –** The type is identified and the abbreviation "PROP PWW." is required. Paved waterways are drawn as heavy lines and cross-hatched with its description shown.
- **Sub-Drains** – These are shown as heavy solid lines with their length and diameter of pipe; for example: " 300' – 8" SUBDRAIN." The abbreviation "PROP" is required. When a grade line is broken, the designer should indicate the direction of flow.
- **Relocation of Streams** – The relocation of brooks, rivers, or other waterways is shown as a solid line. The lines defining the new location will be designated by crosshatching. Plans should indicate whether this change is temporary or permanent.
- **Water Supply** – The words "WATER SUPPLY ALTERATIONS," with a location reference such as "SEE BELOW" will be placed on the upper part of the sheet near the border. This is only noted when water supply changes are required in the area shown on the sheet. Plans should also note what type of water supply is within the area, including boundaries of Zone A, Zone 1, and Zone 2. Where the proposed water supply system may be obscured by existing detail, a separate plan is recommended. This should be combined with the proposed drainage details as discussed previously under the "Drainage" bullet. Heavy, solid lines designate any proposed water pipe. The length, size, type of material, direction of flow, and bends must be noted. Other details include hydrants, gates, etc. The abbreviation "PROP" is required before the description. The description will include any special materials such as insulation, etc.
- **Traffic Signal Conduit** – The words "TRAFFIC SIGNAL CONDUIT," with a location reference such as "SEE BELOW," will be placed on the upper part of the sheet near the border. This is only noted when a traffic signal conduit is required in the area shown on the sheet. The conduit is indicated with a short, heavy, dashed line (about 1/4 -inch long). Complex traffic signal installations should be shown on a separate plan.
- **Utility Relocation** - The proposed relocation of utilities such as utility poles, underground utility conduit, gas lines, etc., are shown directly on the roadway plan with heavy solid lines so the proposed detail will be easily distinguished from the existing facilities. Where there is a considerable amount of information on the plan that may obscure the proposed utility, a separate plan showing the proposed utility information is recommended. The symbols for the utilities

are shown in Exhibit 18-1. The overhead wire is indicated with a long dashed line with “OHW” noted on each length. Underground conduit is shown as two parallel short dashed lines with the type of conduit marked on each span. All utility structures (both existing and proposed) must be noted. The abbreviation “PROP” is necessary before the description. Proposed work that is not performed by the MHD Contractor, but which is performed within the project limits either by or for a utility company, shall be clearly labeled “(type of work) BY OTHERS.” To indicate the utilities in the existing utility system that will be incorporated into the new system, but not relocated, the proper notations must be made, such as “RET” (retain), “ADJ” (adjust), “ABAN” (abandon), “REM” (remove), etc.,

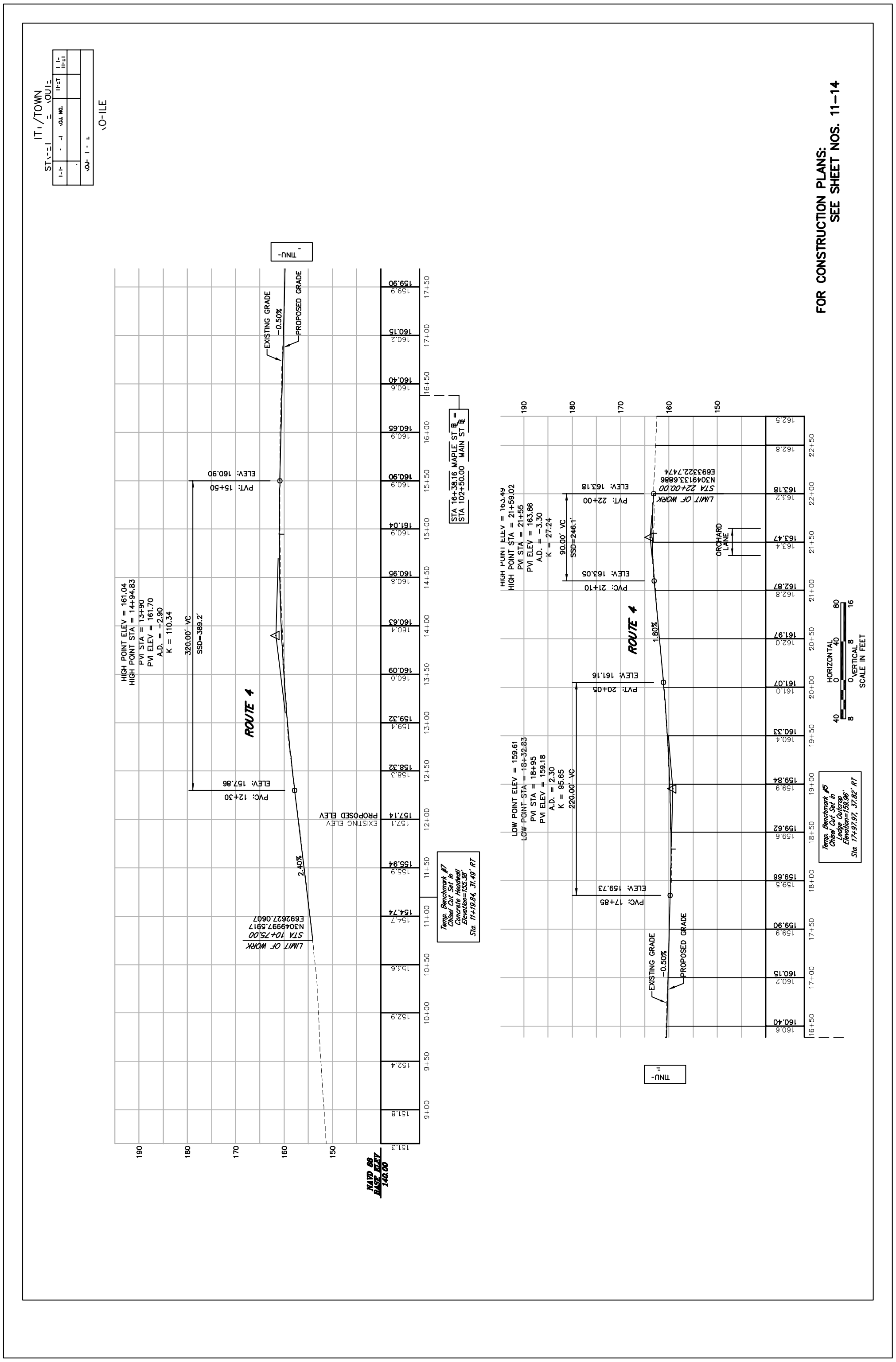
- **Demolition –** Buildings that will be demolished are designated with cross-hatching and marked "STRUCTURE NO. ___." (Insert number shown on the demolition report or detail sheet).
- **Bridges –** The outlines of all bridges will be shown on the construction plans. The bridge number will be placed as close to the bridge as possible.
- **Special Sloped Paving –** The area where special sloped paving is placed, such as on the slopes at open-end span bridges, should be indicated as "SPECIAL SLOPED PAVING."
- **Highway Guard –** The words “HIGHWAY GUARD DETAILS” with locations references such as “SEE BELOW” or the type and station of guardrail will be tabulated in the upper part of the sheet near the border. The above is noted whether or not highway guard is required in the area shown on the sheet. Where there is no proposed highway guard required, the word “NONE” is substituted for the location referenced. If the proposed highway guard does not obscure the detail than it can be drawn on the plan.
- **Slopes –** Tops and bottoms of slopes are shown as dashed lines and marked "TOS (Prop. Top of Slope)” or "BOS (Prop. Bottom of Slope)."
- **Fences –** Proposed fences are not indicated on the construction plans. However, they must be listed on the "Detail Sheets."
- **Work by Others –** Work that is not performed by the MassHighway contractor but which is performed within the project limits either by or for a utility company or for other construction work, shall be clearly labeled " (type of work) BY OTHERS."

18.2.2.3 Construction Profiles

Exhibit 18-11 provides an example of a construction profile on the sheet. The following criteria shall apply:

- The method of presenting the data on the profile sheet is similar to that used on base plans. The base elevation (datum) need only be shown once to the left of the profile, unless the profile is broken.
- When the profile is shown on the same sheet as the plan view, the length of the profile should be the same length in stations as the baseline of the plan, to the extent possible. When the profile is on a separate sheet, the length shown must be the same as the length of the corresponding plan in stations. An overlap of 100 feet is required for each profile.
- Horizontal and vertical bar scales will be shown on construction profiles.
- The proposed profile lines are drawn as heavy solid lines.
- The proposed elevations are labeled to the right of the respective upright as shown in Exhibit 18-11. The proposed elevation labels are darker than the existing elevation labels, which are to the left of their respective uprights.

Exhibit 18-11
Sample Roadway Profile



Source: MassHighway

- The rates of grade, points of curvature and tangency, and vertical curve data (length of curve, K value, PVI station and elevation, etc.) must be labeled as shown in Exhibit 18-11.
- The proposed outline of each bridge and its bridge number is traced from the profile shown on the first sheet of the bridge plans.
- The calculated lengths of vertical curve sight distances are labeled and described as "(distance in feet) SSD."
- Sheets that show only profiles will have their corresponding plan sheet number placed on the lower right edge of the sheet inside the border.
- The beginning and end of the project will be shown and the project number, stations, and coordinates indicated.
- Profiles should extend a minimum of 50 feet beyond the beginning and end of the project.

18.2.2.4 Grading and Tie Plans

Grading plans and tie plans (Exhibit 18-12) are required for all ramp and major at-grade intersections. They are also required on projects where roadway widening and resurfacing results in horizontal realignment (crown line shift) of the roadway. Grading and tie plans may also be required to locate wheelchair ramps and drainage ditches. These criteria apply:

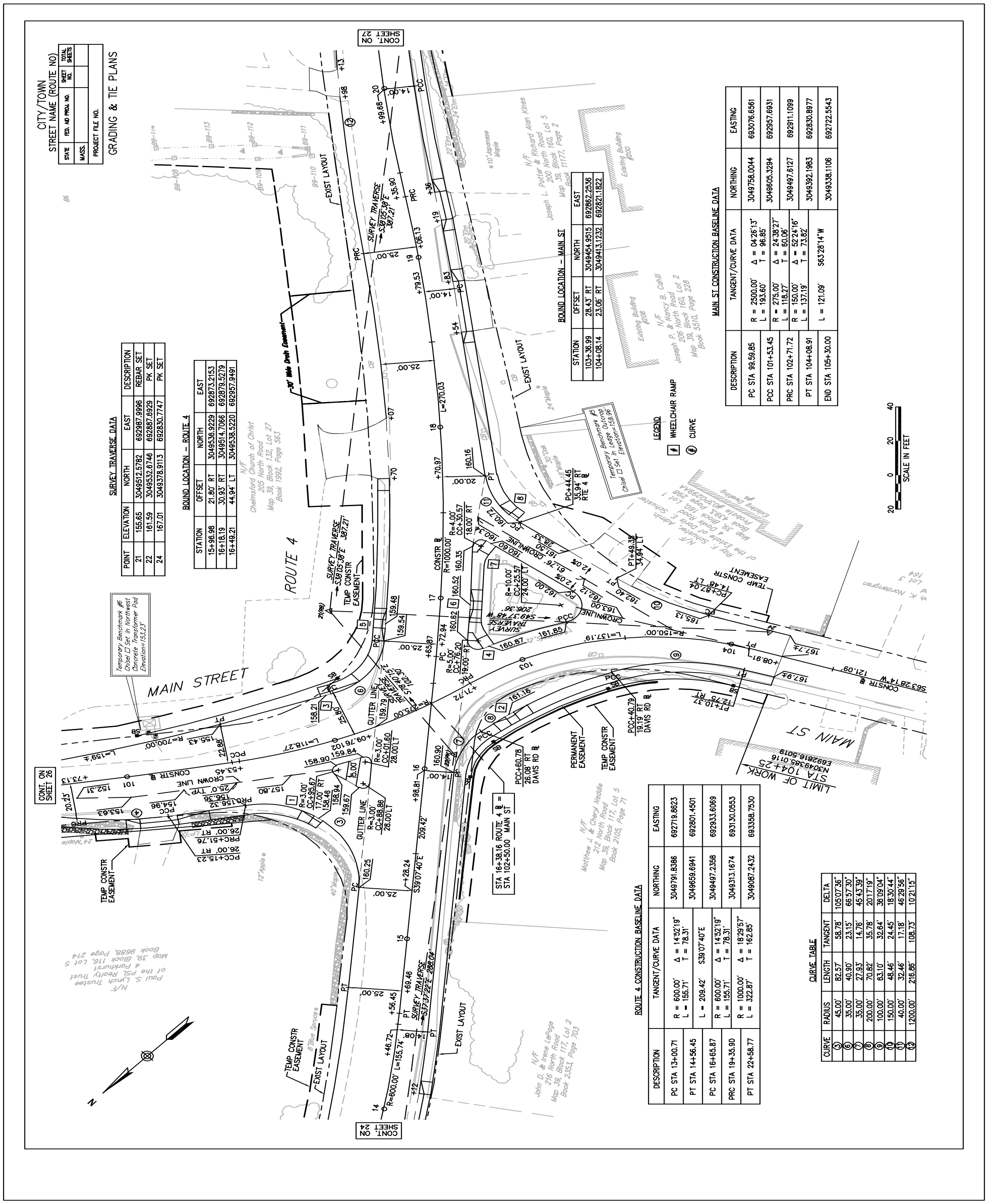
- The elevation will be computed along each roadway edge at 50-foot intervals and at other intermediate points where required. The edge profiles for the grading plan are normally plotted to a scale of 1” = 40’ horizontally and 1” = 8’ vertically.
- Ties will be computed and shown on the plans (at P.C., P.T., etc.) to properly locate the roadway edge in the field.
- Contour plans may be required for special grading areas (drainage, landscaping, aesthetics, etc.).

18.2.2.5 Construction Cross-sections

Exhibit 18-13 provides an example of the construction cross-section. The following criteria apply:

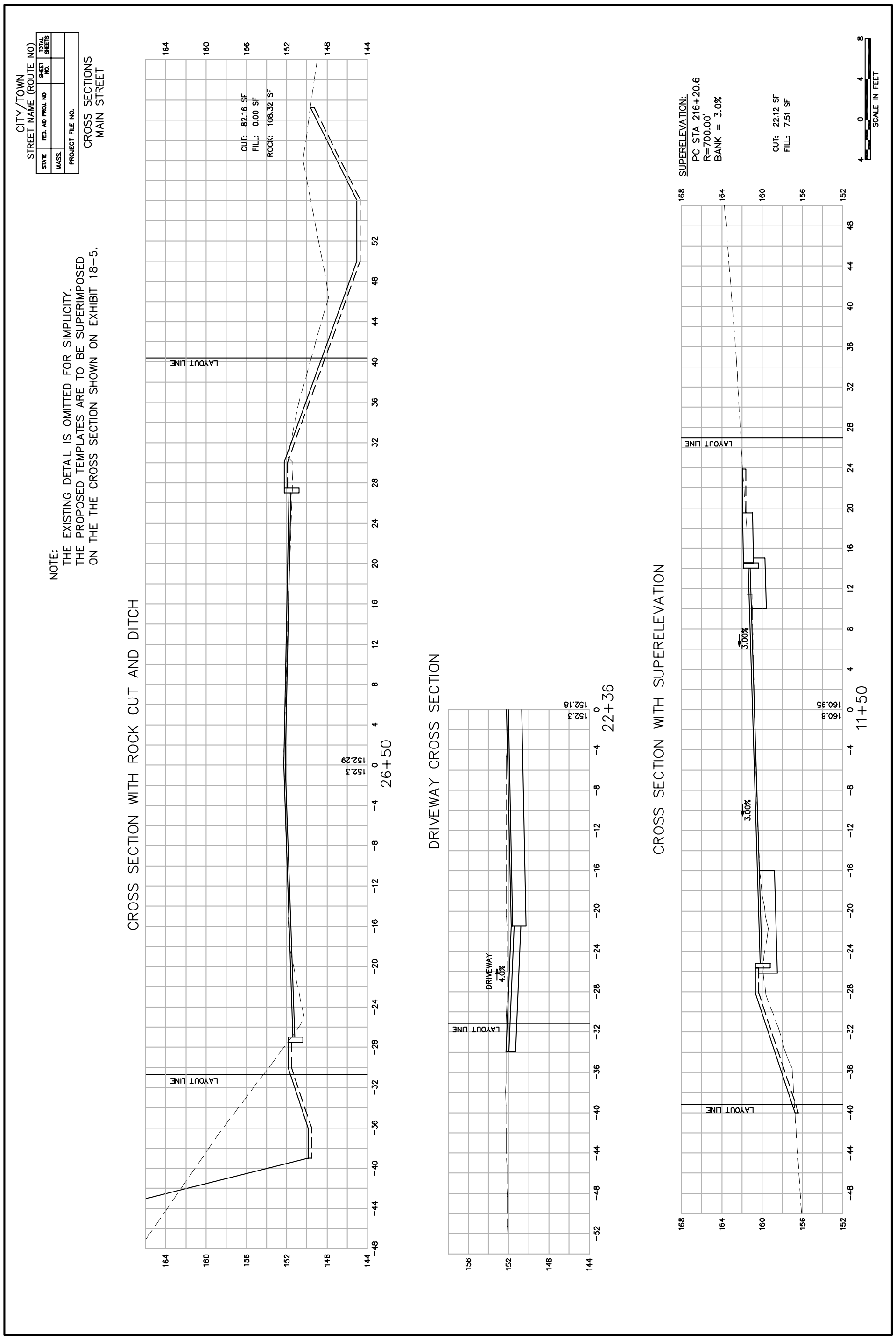
The proposed roadway cross-sections are on the cross-section sheets described in Section 18.2.1.4. The proposed roadway cross-sections are to be plotted as a thick, dark lines.

Exhibit 18-12
Sample Grading & Tie Plan



Source: MassHighway

Exhibit 18-13
Sample Finished Ground Cross-section



Source: MassHighway

- The proposed profile elevation shall be noted on each roadway cross-section. On a banked curve or a curve transition, the theoretical profile elevation is noted on the left side of the profile grade line, and the actual elevation is noted on the right side of the profile grade line (with "actual" noted in parentheses). Show actual edge elevations for banked curves and curve transitions.
- Rate of bank and the P.C. or P.S. and P.T. stations of the horizontal curve in areas where normal cross slopes do not apply must be shown on each sheet that has any portion of the curve or transition of the curve on it. The above data is placed at a convenient location near the right-hand border of the sheet.
- The cross-section must show the limits of muck excavation, if any, as determined by the standard MassHighway methods.
- The depth of existing topsoil to be excavated and stacked will be indicated with a dashed line and marked "TOPSOIL STRIPPING." This information is generally obtained from the boring logs or test pits.
- Show details of rock excavation and special borrow in embankment areas.
- The type of surface or subbase of the proposed roadway will not be indicated.
- Proposed layout lines will be shown on each cross-section where the layout falls within the sheet limits. Proposed layout lines are drawn as solid lines parallel to the proposed centerline of the cross-section and are labeled “PROP LAYOUT LINE” (Town, City, County or state).
- PTH (Planimeter to Here) lines will be indicated where required. The limits of bridge excavation and gravel backfill should always be indicated for estimating purposes.
- Show all ditches within the limits of cross-section sheets. Indicate the type of excavation for estimating purposes.
- Record cut and fill (square feet) for each section to the right of the particular proposed roadway cross-section so that the areas measured will be clearly defined.
- A legend of terms (abbreviations) should be included on the first sheet.

18.2.2.6 Assembly of Construction Plans

A complete set of construction plans shall include:

1. *Title Sheet*

A title sheet is required for all projects (See Exhibit 18-14). The title sheet will show:

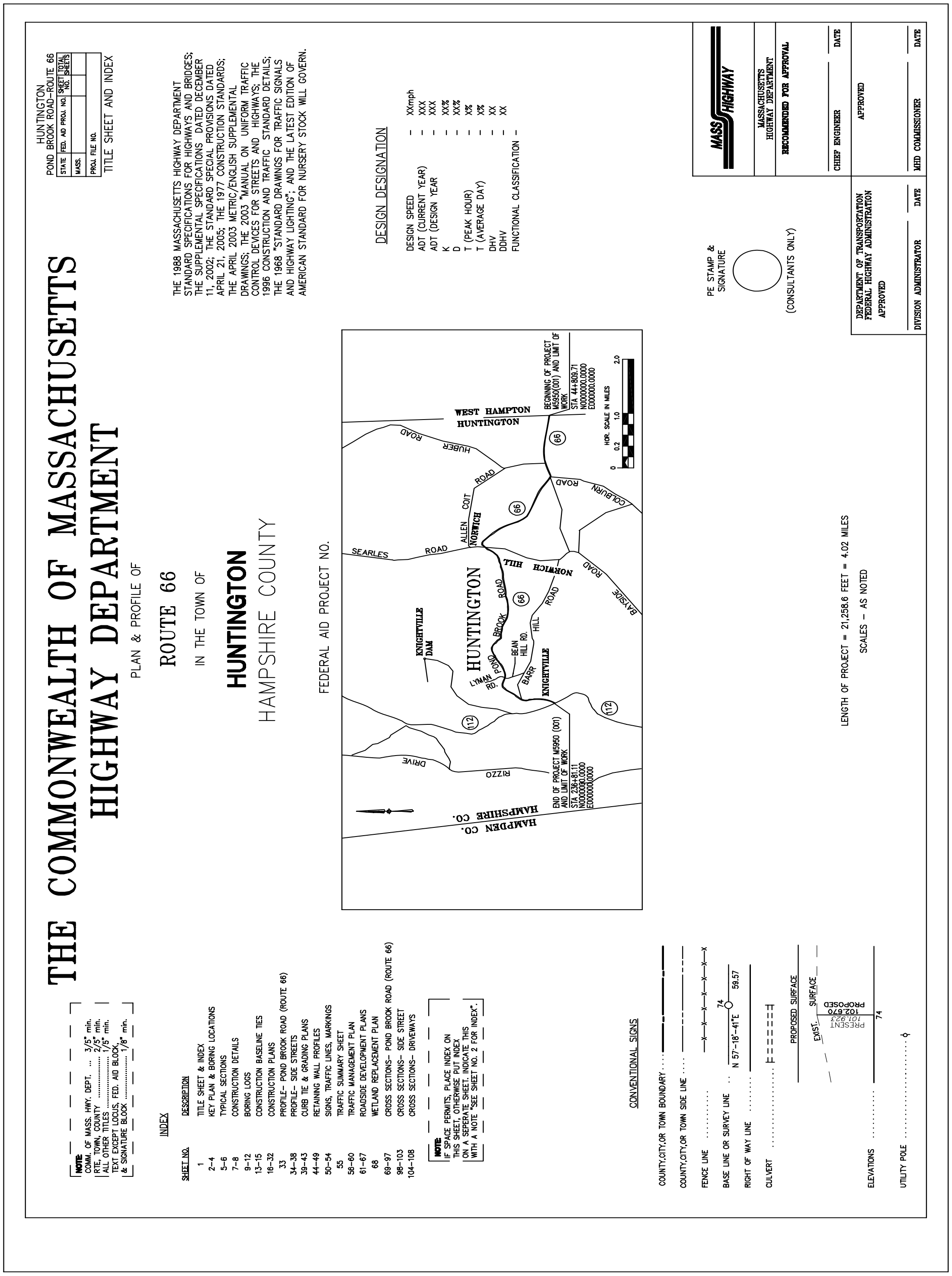
- A locus plan reproduced from a topographic map without contours, or similar map or plan. The scale must be large enough to identify project location. The locus map should not be a photograph, color map, or shaded map and should be suitable for producing a clear photocopy. The locus plan will show:
  - Stations of beginning and end of project and limits of work;
  - Coordinates of beginning and end of project expressed to the nearest 0.0001 foot;
  - Federal-aid project number and an adjacent Federal-aid project number, if any;
  - Route numbers of all roads in the vicinity of the project; and
  - Bridge numbers and stations of the bridges.
- Conventional signs on lower left corner of sheet.
- The project length of roadway, expressed to the nearest 0.01 foot and 0.001 mile. This is the length of roadway measured along the center line of construction considering all equations. The length of divided highways will be the average length of each roadway.
- In the lower right corner of the sheet, blocks for the signature of the MassHighway Chief Engineer and MassHighway Commissioner; in the extreme lower right corner, a block for the signature of the FHWA Division Administrator; above the FHWA block, the P.E. seal and signature for the design consultant as well as the name of firm if applicable.
- Federal-aid Block in the upper right corner with project file number (See Exhibit 18-14).
- Directly below the Federal-aid Block, place the following note:

  "The (latest year) Massachusetts Highway Department Specifications, as amended, the (latest year) Construction Standards, as amended, and the (latest year) "Manual on Uniform Traffic Control Devices for Streets and Highways," and the (latest year) Standard Drawings for

Signs and Supports, and the (latest year) Edition of the American Standard Nursery Stock will govern."

- Listing of the Design Designation Data including all traffic data and Functional Classification of roadway(s).
- Plan submissions should show design stage (25, 75, or 100 percent) and include the submittal date. The date is not required on the final stamped mylar.

Exhibit 18-14
Sample of Title Sheet for Construction Plans



Source: MassHighway

Exhibit 18-14 (continued)
Sample of Title Sheet for Construction Plans

	MASS HIGHWAY
	MASSACHUSETTS HIGHWAY DEPARTMENT
	RECOMMENDED FOR APPROVAL CHIEF ENGINEER Date
DEPARTMENT OF TRANSPORTATION FEDERAL HIGHWAY ADMINISTRATION APPROVED DIVISION ADMINISTRATOR Date	APPROVED MHD COMMISSIONER Date

Source: MassHighway

2. Index Sheet (optional separate sheet)

An index is required for all projects. Exhibit 18-15 provides an example.

3. Key Plan

A key plan is required for all projects, as illustrated in Exhibit 18-16.

4. Boring Logs

Boring Logs are required for all projects, as illustrated in Exhibit 18-17. Boring logs may be provided in the specifications, as necessary.

Exhibit 18-15
Sample of Index Plan

IND

SHEET NO.	DESCRIPTION
1	TITLE SHEET
2	INDEX
3	KEY PLAN AND BORING LOCATION
4	BORING LOGS
5–8	TYPICAL SECTION
9–50	PLANS ROUTE I–99
51–56	PLANS SUSAN AVE.
57–61	PLANS WILLIAMS ST.
62–103	PROFILES ROUTE I–99
104–109	PROFILES SUSAN AVE.
110–116	PROFILES WILLIAMS ST.
117–118	PROFILES S.W. RAMP AT WILLIAMS ST.
119–120	GRADING AND TIE PLAN S.W. RAMP AT WILLIAMS ST.
121–123	PROFILES N.E. RAMP AT WILLIAMS ST.
124–126	GRADING AND TIE PLAN N.E. RAMP AT WILLIAMS ST.
127	DRAINAGE DETAILS (NOT SHOWN ELSEWHERE)
128	WATER SUPPLY DETAILS
129	SIGN PLANS AND DETAILS
130	TRAFIC LINES AND MARKINGS
131	LIGHTING DETAILS
132–136	BRIDGE NO. D–5–43, ROUTE I–99 OVER SUSAN AVE.
137–140	BRIDGE NO. D–5–43, ROUTE I–99 UNDER WILLIAMS ST.
141–201	CROSS SECTIONS ROUTE I–99
202–220	CROSS SECTIONS SUSAN AVE.
221–239	CROSS SECTIONS WILLIAMS ST.
240–249	CROSS SECTIONS S.W. RAMP AT WILLIAMS ST.
250–261	CROSS SECTIONS N.E. RAMP AT WILLIAMS ST.

MINOR ROADS

SUSAN AVE.
- PLANS — SHEET NO. 51–56, 72
- PROFILES — SHEET NO. 104–109

WILLIAMS ST
- PLANS — SHEET NO. 57–61, 83
- PROFILES — SHEET NO. 110–116

RAMPS

S.W. RAMPS AT WILLIAMS ST.
- PLANS — SHEET NO. 16–18, 58
- PROFILES — SHEET NO. 117–118

N.E. RAMPS AT WILLIAMS ST.
- PLANS — SHEET NO. 16–19, 60
- PROFILES — SHEET NO. 110–116

TEMPORARY ROADS AND DETOURS

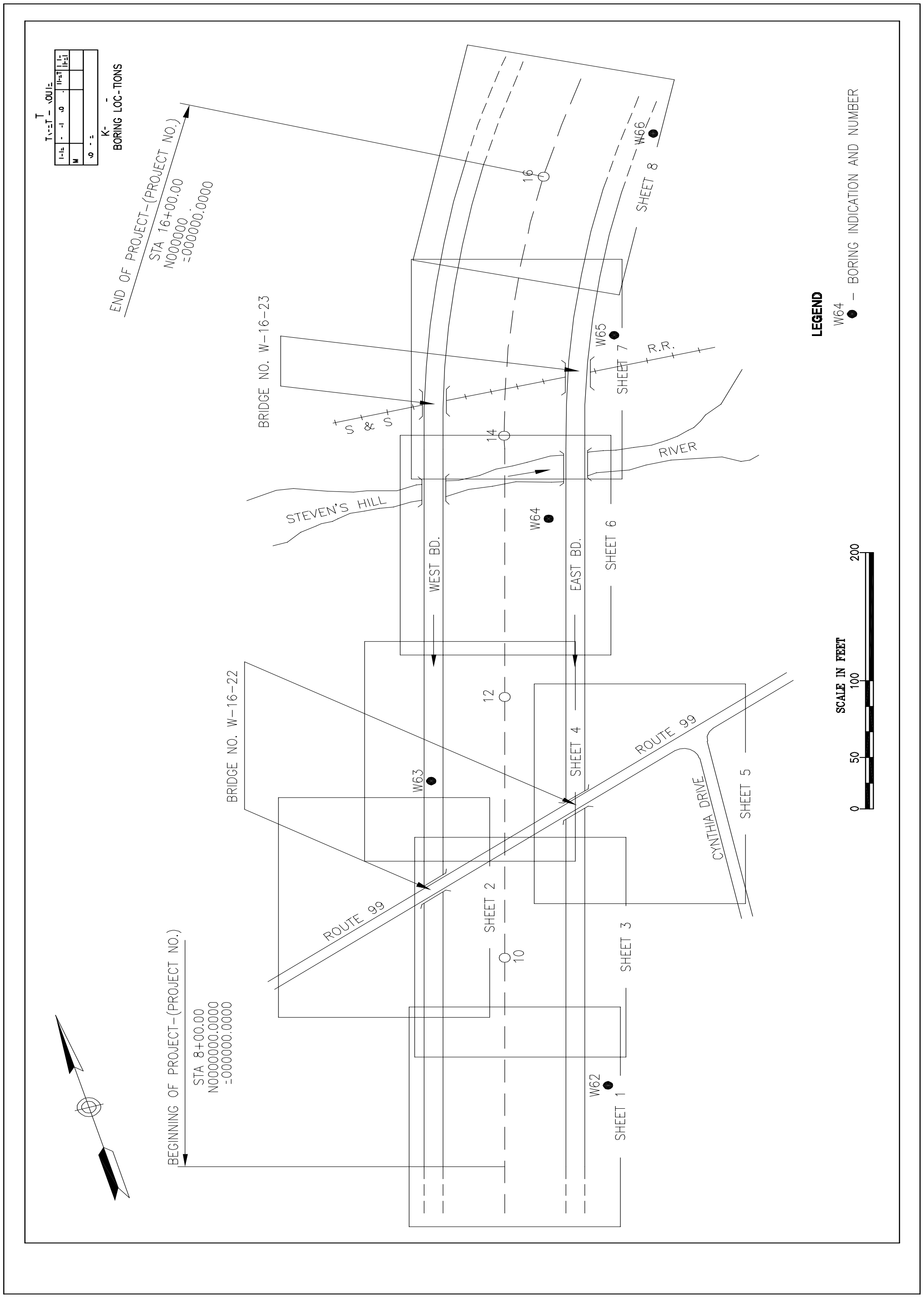
SUSAN AVE.
- PLANS — SHEET NO. 22–23, 53
- PROFILES — SHEET NO. 71

WILLIAMS ST
- PLANS — SHEET NO. 48, 60
- PROFILES — SHEET NO. 97

IND=X

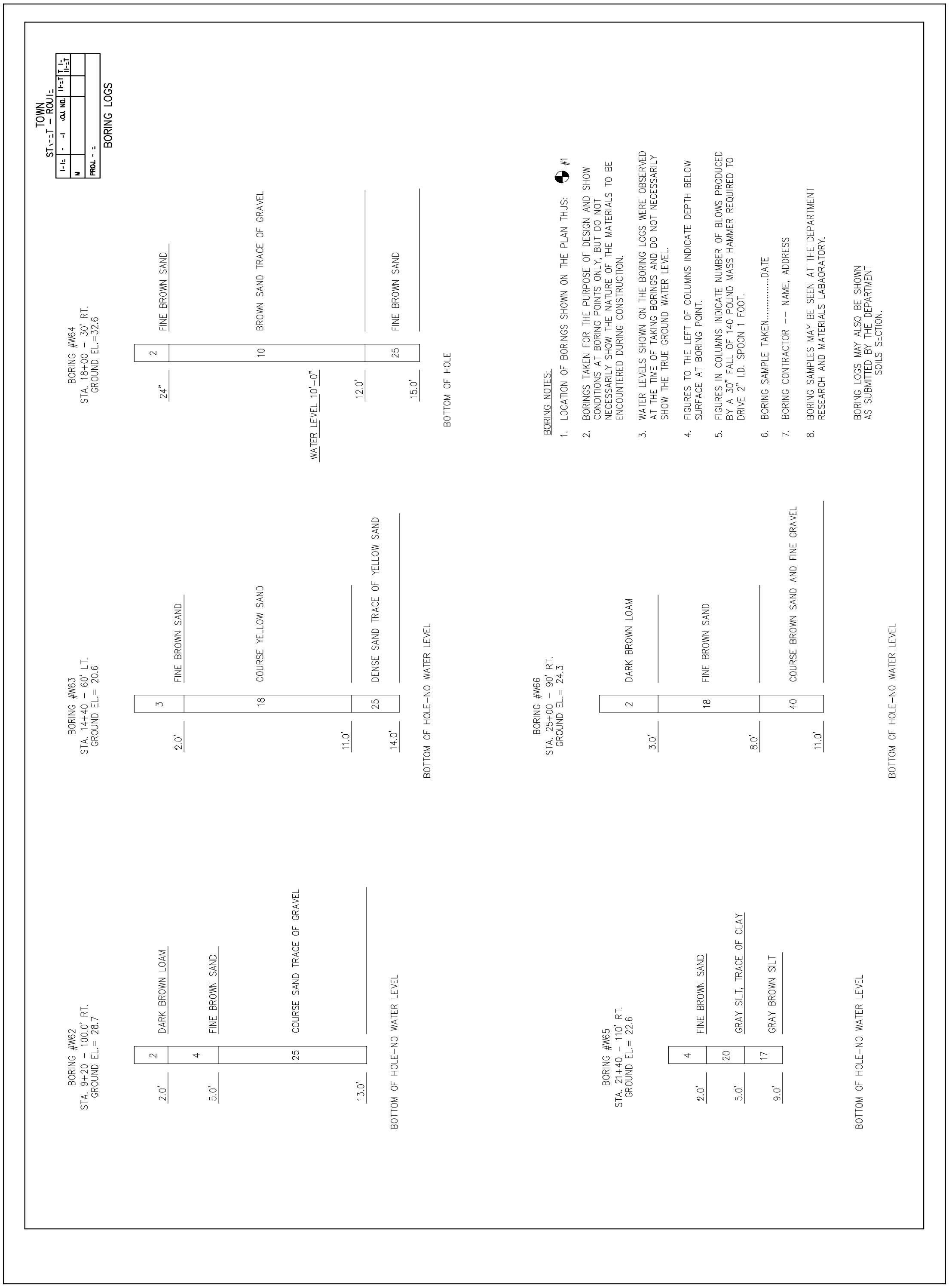
Source: MassHighway

Exhibit 18-16
Sample Key Plan and Boring Location Plan



Source: MassHighway

Exhibit 18-17
Sample Boring Logs Plan



Source: MassHighway

Exhibit 18-18
NOTES - PAVEMENT FOR (Name or Rte. No.)

Traveled Way and Shoulders	
Surface Course	2” HMA Surface Course -Type B
Intermediate Course	2” HMA Intermediate Course – Type A
Base Course	4” HMA Base Course -Type A.
Subbase	4” Dense Graded Crushed Stone over 8” Gravel.

All roads, ramps, etc., are similarly described on the typical section sheets. The thickness of the layers are only for illustration; they vary for each project, and must be approved by the Pavement Design Engineer. In addition, note other pertinent data such as the application of special borrow.
Source: MassHighway

5. Typical Sections

Show typical sections as illustrated in Exhibit 18-19, for all roads and ramps, indicating the following on the typical section sheets:

- Descriptions of pavement and shoulder structures (see Exhibit 18-19);
- Method of banking; and
- Special types of curbing, edging, berms, structures and details which have not been approved as standards.

Plans and profiles may appear on the same sheet when marked with a star below.

6. Construction Plans (Exhibit 18-8)

- Plans of Main Road*
- Plans of Side Roads*

7. Profiles (Exhibit 18-11)

- Profiles of Main Road*
- Profiles of Side Roads*
- Ramp Profiles*

8. *Grading and Tie Plans (Exhibit 18-12)*

9. *Drainage Details and/or Water Supply Details*

10. *Sign Plans and Details*

11. *Traffic Signal Plans*

- Pavement Markings

12. *Traffic Management Plans*

13. *Utility Plans and Details*

14. *Landscaping Plans and Details*

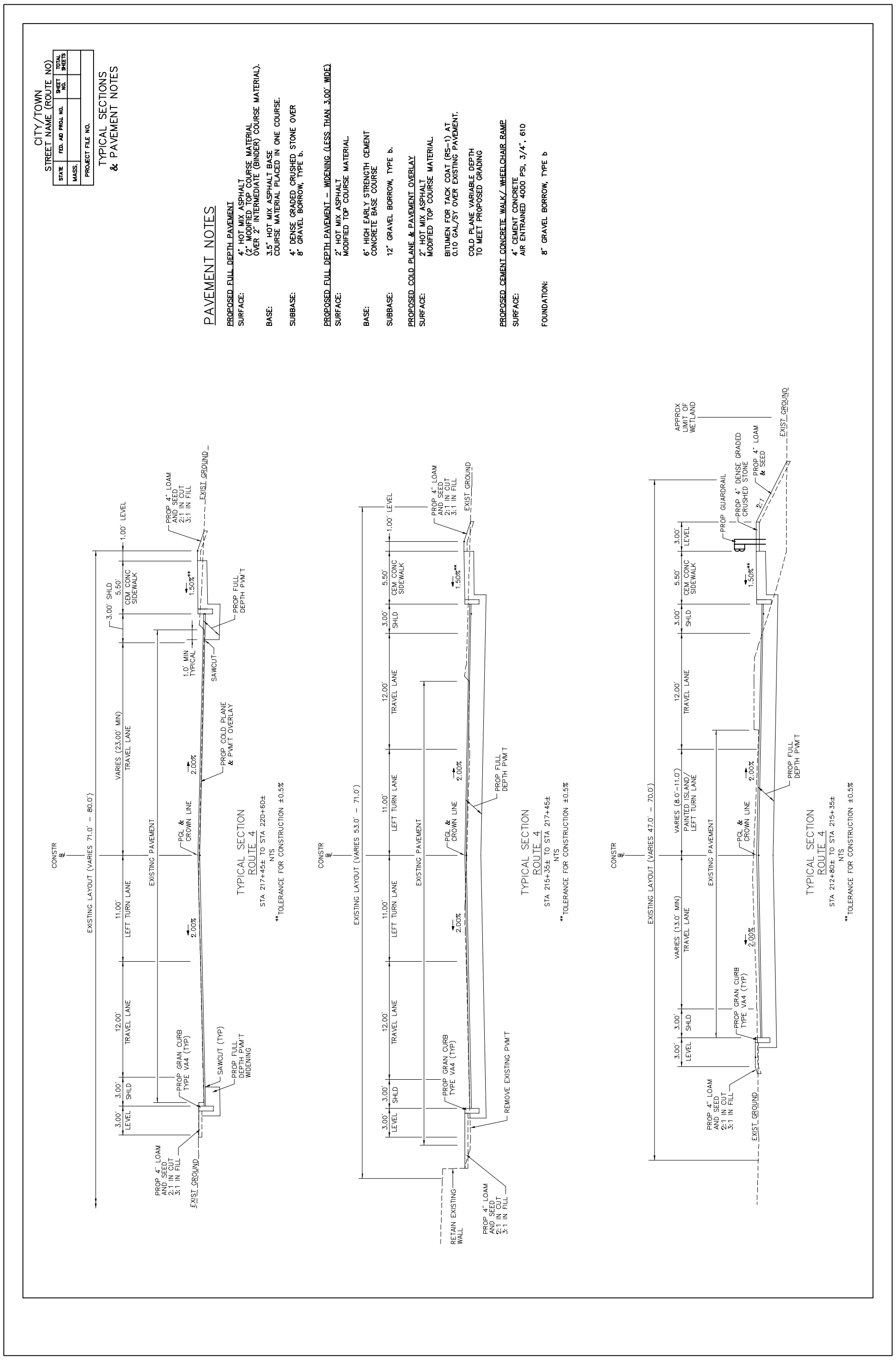
15. *Special Details*

- Construction Details
- Pedestrian Amenities (Wheelchair Ramp) Details (Exhibit 18-20)

16. *Bridge Plans*

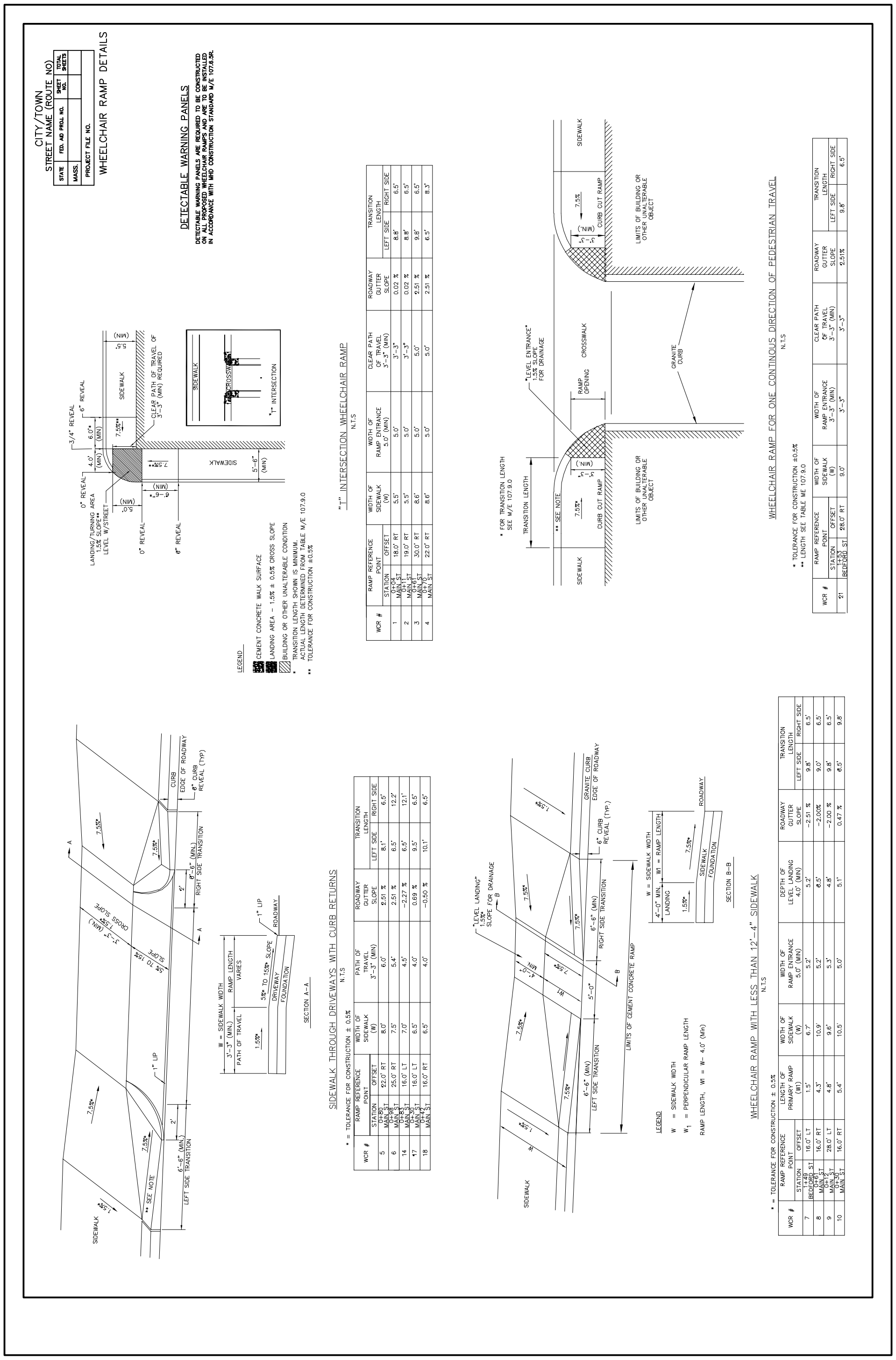
17. *Cross-sections (Exhibit 18-5 & Exhibit 18-13)*

Exhibit 18-19
Sample Typical Sections



Source: MassHighway

Exhibit 18-20
Sample Wheelchair Ramp Details



Source: MassHighway

18.3 Decree Plans

MassHighway is required to make decree plans when existing railroad crossings are abolished or altered in conjunction with highway work. MassHighway has jurisdiction for abolitions on all public highways within the state for any alterations on state highways or direct continuations of state highways.

When a new state highway layout crosses a railroad where no crossing previously existed, a decree plan is not required - the layout plans will be sufficient.

A crossing is considered to be altered when:

- an existing bridge has major structural changes to strengthen or improve it;
- an existing highway layout at a grade crossing is widened; or
- the grade crossing is resurfaced or repaired outside the state highway layout (changes to grade crossings within the existing state highway layout are not considered alterations).

Decree plans for alterations must show layouts, takings, major construction and design detail, bridge plans and plans of existing conditions. The plan should extend about 600 feet on either side of the crossing. Decree plans are not a part of the construction plans but a separate set of plans.

The following data must be shown on decree plans:

- **Existing Conditions** — All existing detail and proposed edges.
- **Proposed Surface** — The type of surface on pavements, walks, drives, etc. should be identified as "Proposed (kind) Pavement."

18.4 Layout Plans

Layout plans, descriptions, and orders of taking are required to establish highway right of way for all projects which involve land takings. The proposed layouts may result in changes to existing state highway layouts or to existing county, city, or town layouts, or may revise existing limited access provisions.

All proposed layouts must be accurately computed. A complete set of original calculations and a check set of calculations must be submitted. Where a project is in more than one municipality, separate layouts are required. Railroad baselines should be tied to the state highway layout.

The procedure and methods outlined below provide a guide for the preparation of layout plans:

- On the Right-of-Way Plans, the designer will furnish the tentative location of the layout line.
- The tentative location is then definitely set and the computations of curves, lengths, bearings, etc., are made. The computed layout data is then shown on the Layout Plans along with the Massachusetts State Plane Coordinates to all angle points, points of curvature, and points of beginning and ending. Deeds, existing state, county, city, and town layouts, survey ties into the Massachusetts State Plane Coordinate system, and other sources of information may be needed to complete the above. If the Massachusetts State Plane Coordinate system is not readily available, MassHighway should be contacted for further instructions.
- Layout plans will show proposed layout (location) lines, approximate property lines, corner markers, names of property owners, access and non-access (if limited access highway) points, and the locations of bounds. The plans will indicate existing surface details, such as trees, poles, structures, manholes, curbing, walls, fences, streams, existing streets, etc. All of the above details are shown in black. The proposed details are not shown.
- The bearings and distances, or radii and lengths of all proposed layout lines are shown in English units, including Massachusetts State Plane Coordinates to all angle points, points of curvature, and the points of beginning and ending. When a record baseline exists in the area of proposed layout or alteration, it shall be shown on the plan to facilitate in determining locus. (Ties to this baseline are not to be used.)

Data on the layout plans are to be drawn as described below:

- Layout plans are normally drawn to a scale of either 1” = 20’ or 1” = 40’.
- Where a record baseline exists and is shown, points of curvature, points of tangency and the applicable description "Main Baseline"

or "Auxiliary Baseline" will be shown along each baseline. The 100-foot stations are indicated by small circles with a 5/40-inch diameter. The stations are noted above each circle. Tick marks are shown at 50-foot intervals between the circles. All bearings, distances, and radii are marked below the line.

- The proposed state highway layout line is a heavy, solid line, with bearing, radius, and length indicated along the outside of the line. Access provisions are shown inside the layout line.
- The old state highway layout line, where superseded by a revised state highway layout line, is a broken line.
- The state highway layout line is a thin solid line.
- The proposed town or city layout line is a solid line. The bearings, radii, and lengths, are indicated along the outside of the line.
- The old town or city layout line is a broken line. The date that the existing layout line was made is noted along the line.
- Property lines are shown as broken lines.
- Each parcel of land to be taken must have its parcel number, owner's name, area and length of each course ± distances noted. Registered land must show the parcel number, exact name of owner, the words "Registered Land," Land Court case number, Land Court certificate number, book and page number, the area, and the length of each course. Supplementary plans and traverses must be submitted to the Land Court to conform to Land Court Regulations for the land taken and land remaining. Easement locations taken in connection with the layout will be outlined in black, dashed ink lines marked "Line of Easement."
- Existing state highway layout lines shall be identified with the proper notation, as follows: Layout Lines of December 20, 1995 State Highway Layout/Alteration (L.O. No. 5678).

In accordance with MassHighway practice, parcels are numbered in a manner that will indicate permanent or temporary takings and the nature of the rights taken. Locations where rights of access to or egress from existing ways are taken, but no land taking is involved, will be designated by parcel numbers AT-1, AT-2, etc.

The written instrument for the Layout and Order of Taking will be prepared according to MassHighway practice. Four typewritten copies, double-spaced and carefully checked against the layout tracings, must be submitted. Separate plans and written instruments for advance taking and/or additional easements may be required.

All submissions of tracings to the Department shall be comprised of the original tracings and full-size wash mylar reproductions. Electrostatic mylar plots are unacceptable. The reproductions, to be acceptable to the registers of deeds, must meet the most recent Plan Regulations approved by the State Attorney General.

Among the requirements for recording are the following:

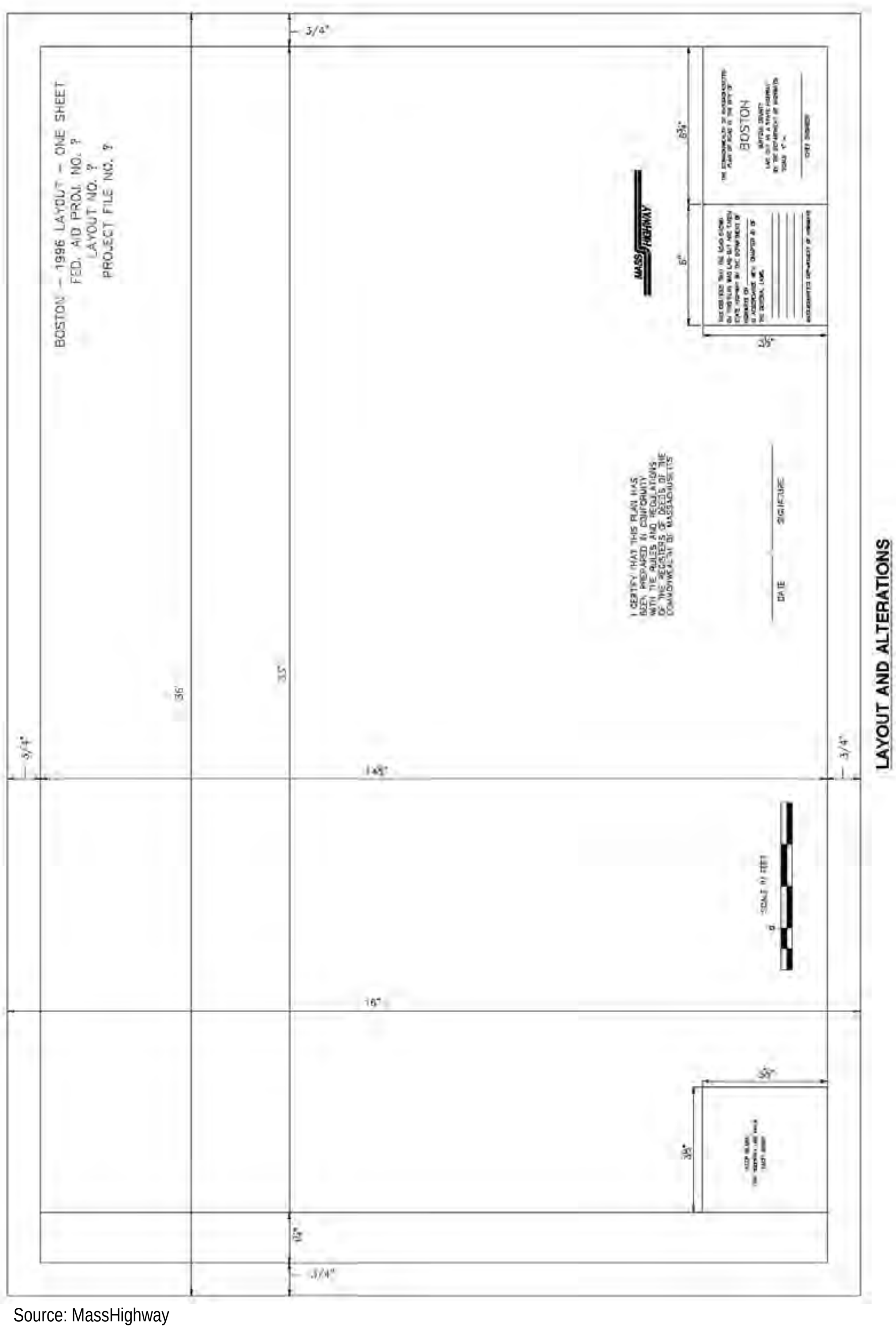
- Plans must be on mylar wash-off matted on at least one side, having a thickness of .4 mil. The matte surface and ink must be on the front of the mylar sheet.
- Ink must be opaque and of archive quality. It is imperative that the ink used on mylar plans be specifically designed for mylar applications to prevent its chipping off.
- The minimum letter height permitted on plans is 1/8-inch for hand-lettering and 1/10-inch when a machine or template is used.

In addition, the Federal Aid Project No. shall be shown on the upper right-hand corner of the first sheet; the Layout No. shall be shown in the upper right-hand corner of each sheet; and on Limited Access projects the notation “Limited data, parcel nomenclature and existing detail” shall be on one side only on both the original and the reproduction. Also, a key plan is needed for all layouts and alterations where sheets do not follow each other in successive numerical order. No reproductions are needed for key plans.

All layout tracings, supplementary plans and traverse computations for the Land Court will be stamped with the seal of a Massachusetts Registered Land Surveyor. All layout plans will show on the title sheets the words "Plans Prepared By," followed by the name and address of the person or organization responsible. Samples of the supplementary plans and traverses for registered land, general type of layout descriptions, and order of taking may be obtained from the Layout Engineer.

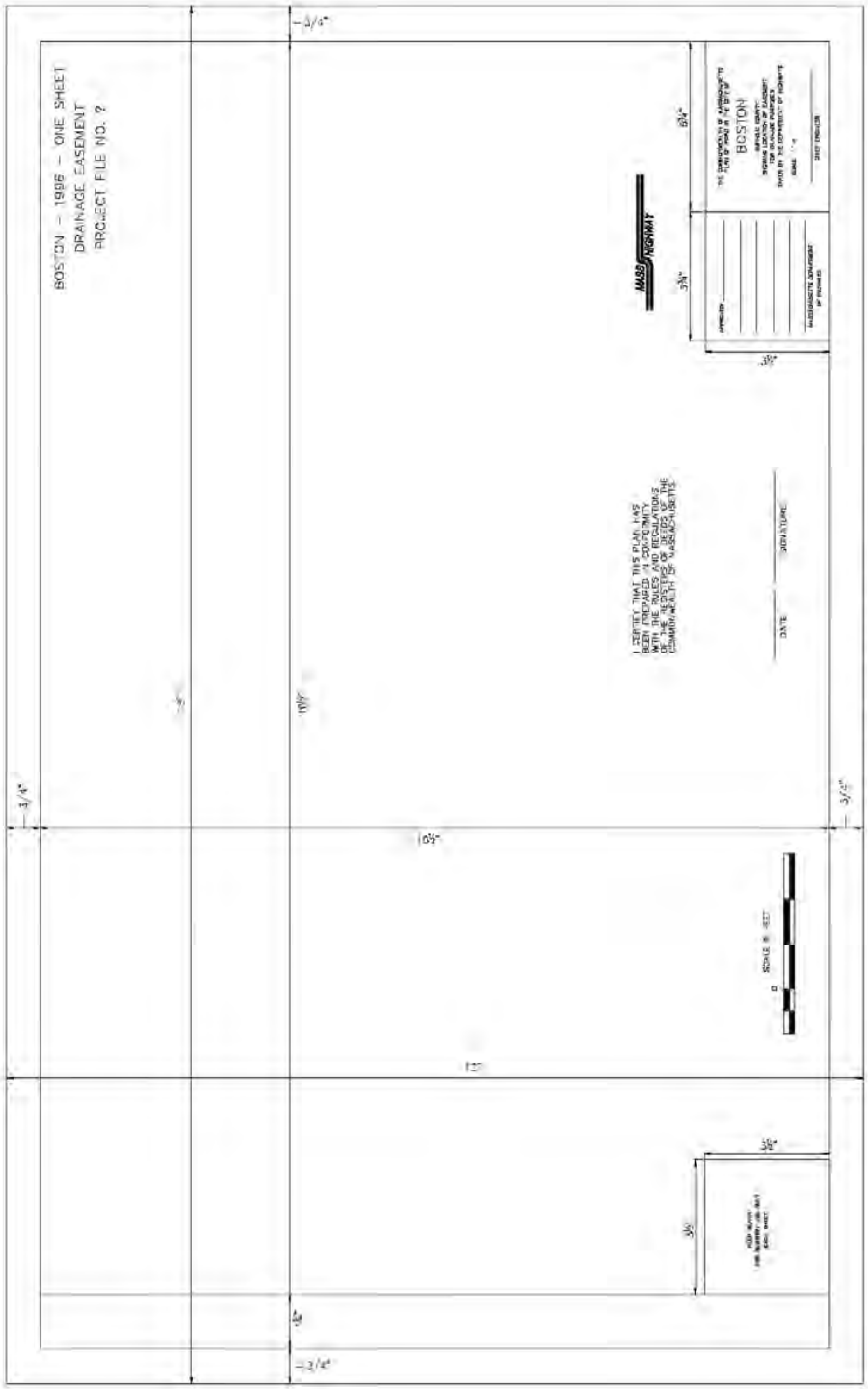
Titles of plans and necessary notes for signature by the MassHighway Commissioners are shown in Exhibit 18-22. Exhibit 18-21 provide sizes of standard tracings. Exhibit 18-23 provides symbols for layout tracings. Exhibit 18-24 provides abbreviations for Layout Plans. Both of these tables also apply to right-of-way plans.

Exhibit 18-21
Sizes of Standard Tracings



Source: MassHighway

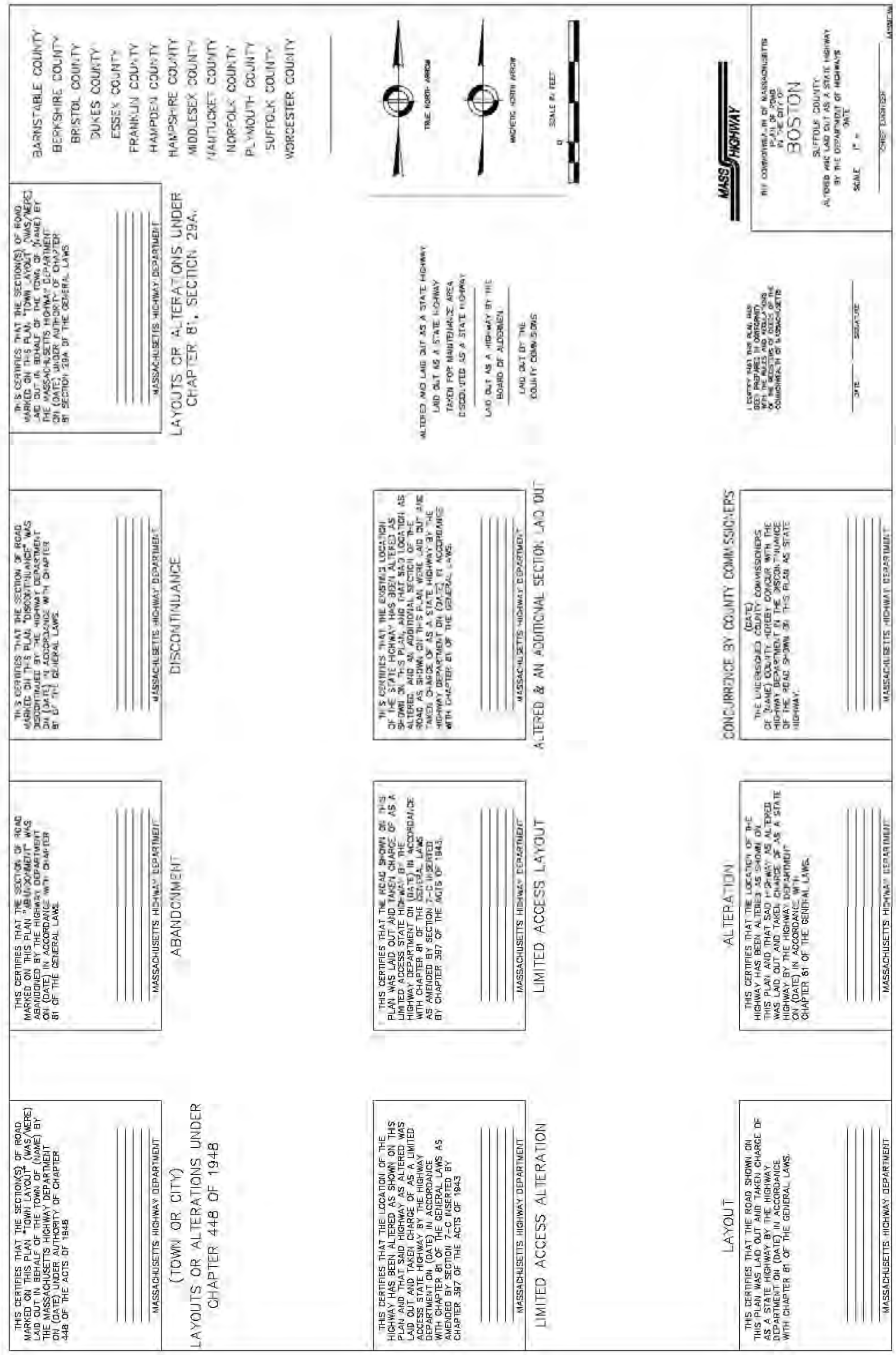
Exhibit 18-21 (continued)
Sizes of Standard Tracings



SPOT TAKINGS AND EASEMENTS (LARGE SHEET)

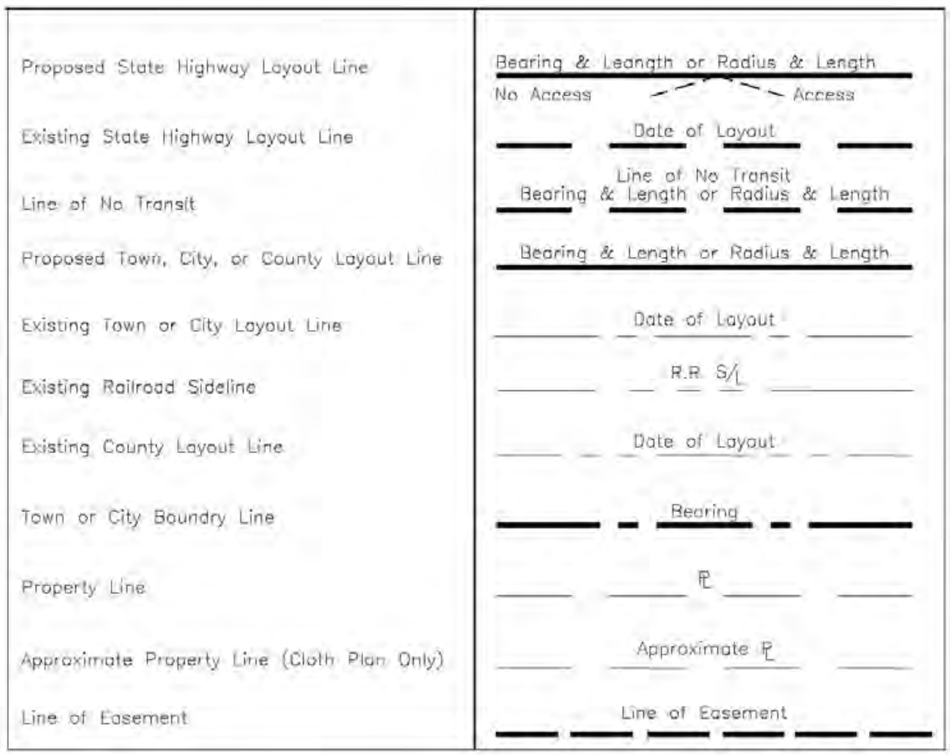
Source: MassHighway

Exhibit 18-22
Data for Layout Plan and Title Sheet



Source: MassHighway

Exhibit 18-23
Symbols for Layout Tracings



Source: MassHighway

18.5 Right of Way Plans

These procedures for the preparation of "Right of Way" (ROW) plans are consistent with the Federal Aid Policy Guide (FAPG). Since these instructions are general, the designer must discuss the content requirements for each project with the MassHighway Right of Way Bureau.

The "Right of Way" plans are not a substitute or replacement for the Department layout plans described in this manual; both are required.

Preliminary ROW plans shall be prepared and submitted along with the 25 Percent Construction Design submittal. Preliminary ROW plans shall be available for the Public Hearing.

If the Designer determines that no ROW acquisitions, and no new layouts or alterations are required to advertise and construct their project, a letter stating so must accompany the 25 Percent design submittal. If MassHighway concurs, the designer will show and identify all ROW and property lines on the construction plans, identify the abutting owners, and a set of ROW plans will not be required. If, as the design progresses, ROW acquisition does become necessary, the designer will prepare and submit a set of Preliminary ROW plans in accordance with the following guidelines.

18.5.1 General

Preliminary and Final ROW plans will be prepared by the designer as specified and as noted in the Federal Aid Policy Guide (FAPG).

Preliminary and Final ROW plans will include all pertinent data affecting the cost of ROW such as structures, land service or access roads, improvements, landscaping, drainage, and fences.

The linestyles used shall conform to the requirements given for Layout plans. Abbreviations used in Layout and ROW plans are shown in Exhibit 18-23.

The electronic drafting standards, and object naming requirements, used on the "Right of Way" plans shall conform to the requirements for Constructions drawings and Layout plans.

The Preliminary Right-of-Way plans are used by MassHighway Right-of-Way agents to communicate with property owners, title examiners, and appraisers. The Preliminary Right-of-Way plans must be prepared to be clearly understood by non-engineers.

The size, form and arrangement of Preliminary and Final ROW plans will conform to the general requirements of highway plans. They will contain sufficient dimensional and angular data to permit easy identification of all fee parcels and easement areas that are required by the highway project. The following symbols and/or identification information shown on the construction plans will also be shown on ROW plans:

- Right of Way Federal-aid project number.
- Scales to be used.
- A north arrow for each Property and Location plan sheet, and for each insert plan included on any sheet.
- Access symbols or any other symbols which may be used.
- A revision block on the Title Sheet which will show identify any changes, and the date of revision.

Exhibit 18-24
Abbreviations for Layout and Right-of-Way Plans

Abbreviations for Fee Takings

1	Taken in fee in behalf of the Commonwealth	D-1-F	Drainage Taking in Fee
1-C	Taken in fee in behalf of the City	C-1-F	Channel Taking in Fee
1-T	Taken in fee in behalf of the Town	UR-1	Uneconomic Remainder
1-U	Taken in fee (ordinarily conveyed to utility)	VP-1	Vehicular Parking
1-RR	Taken in fee in behalf of the Railroad	CVP-1	Commuter Vehicular Parking
1-X	Excess Land	FRL-1	Functional Replacement Land
M-1	Maintenance Area	RL-1	Replacement Land

Abbreviations for Easement Takings

AT-1	Access Taking	R-B-S-1	Road, Bridge and Slope
B-1	Bridge	RD-1	Temporary easement for removal or demolition of certain structures
BA-1	Bridge Abutment	RR-1	Railroad Bypass
C-1	Channel	R-RR-1	Road and Railroad Bypass
CD-1	Channel Drainage	RS-1	Slope in connection with Right-of-Way
CL	Construction Limitation	RT-1	Temporary easement for removal or demolition of certain structures
D-1	Drainage	S-1	Slope
DS-1	Drainage and Slope	SRE-1	Temporary Sign Removal
E-1	Highway Easement (Portion of Right-of-Way)	SS-1	Sanitary Sewer
E-RR-1	Easement on behalf of Railroad	SW-1	Sidewalk
FB-1	Footbridge	SW-S-1	Sidewalk and Slope
FS-1	Flight of Steps	TB-1	Tie Back
GD-1	Gravel Dike	TE-1	Temporary Easement for various purposes
GR-1	Guard Rail	TR-1	Temporary Road
GU-1	General Utility	U-1	Utility Easement (ordinarily conveyed to a utility company)
HS-1	Highway Sign	W-1	Wall
HL-1	Highway Light	WM-1	Watermain
PL-1	Power Line	WMD-1	Watermain and Drainage
R-1	Right-of -way taken in behalf of owner of land whose rights of access thereto and egress therefrom would otherwise be inoperative due to limited access provisions	WQM-1	Water Quality Monitoring Station
R-B-1	Road and Bridge	WS-1	Wall and Slope

Abbreviations for Disposition of State Property

LL	Land Lease (Portion of State Highway)	LS	Land Sale (Portion of State Highway)
LR	Land Lease (Not part of State Highway)	SR	Land Sale (Not part of State Highway)
LU	Land Use (Portion of State Highway)	LA	Land Acquired by Department (usually be deed)

* Notes for Easement Takings:
1 Temporary easements are preceded by letter "T". (For example, TD-1, TWM-1, etc.)
2. Easement in behalf of Town, City, Railroad or the M.D.C. are followed by letters: "T", "C", "RR", "MDC" (For example, D-1-T, D-1-C, D-1-RR, D-1-MDC, etc.)
3. EG-1. This symbol is used to delineate an area comprising a portion of State Property in which an easement is to be granted.
4. The symbols listed and described above may be preceded by a number prefix. (For example, 1-1, 1-D-1, 2-1, 2-D-1, etc.)
5. The symbols A, B, C, etc. designate "Spot Takings in Fee." The symbols B-11-1, B-11-2, etc. designate "Block Takings in Fee."

Source: MassHighway

18.5.2 Preliminary Right-of-Way Plans

A set of Preliminary ROW plans will be prepared to produce legible reproductions. Each sheet will be labeled in the upper right hand corner as "Preliminary Right of Way," with sheet type identified (for example “Location Plan,” “Typical Section,” etc,) and if more than one of a sheet type, sequential and total of sheets (for example, “Sheet 1 of 2”).

ROW plans will remain “Preliminary” until a submission of “Final” ROW plans is requested by the Right of Way Bureau, or project close out, which ever is sooner.

ROW acquisition information will be posted on the Preliminary ROW Parcel Summary by the designer when the designer obtains the information.

18.5.3 Final Right-of-Way Plans

After the ROW Bureau requests submission of the Final ROW plans, the designer will change “Preliminary” to “Final” on all sheets, update the revision box, and produce and submit a set of Mylars.

18.5.4 Format of Right-of-Way Plans

The set of ROW plans shall include the following:

Title Sheet and Index — The Title Sheet will include the same information as the title sheet prepared for highway construction drawings. Information noted on the construction plan title sheet which is not germane to the ROW plan should be removed.

The following information will be noted on the Title Sheet of the ROW plan:

- The ROW Federal-aid project number;
- Project file number;
- An index;
- The termini baseline stations of the project on the Locus plan, and the length of project below the Locus plan;
- An indication of a Preliminary or Final ROW plan; and
- A revision block.

Typical Cross-sections — Typical cross-sections shall be provided to facilitate the understanding of the impacts to properties affected by the proposed work. Detail sections shall be provided as determined to be needed by the designer, or requested by the ROW Bureau.

Critical Profiles — Profiles shall be provided to illustrate the difference between existing and proposed conditions, where necessary.

Parcel Summary Sheet — A parcel summary, in MassHighway format, will show the following information:

- All parcel numbers (the format of parcel numbers is as follows: a Department supplied prefix number which is project specific, followed by the easement abbreviation from Exhibit 18-24 if not a fee parcel, then the sequential numerical designation);
- Sheet numbers of where the parcel is shown on the Location plan and the Property Plan sheets;
- The name of the owner of record as it appears on the deed;
- A reference to the book and page where the title is recorded in the appropriate registry of deeds and/or probate court;
- The area of the parcel, noting whether the parcel is in fee, or as a permanent or temporary easement;
- The areas of all portions of an affected property which remain after the takings;
- The area of each property before the taking (this is preferably the Deed area, less desirable is the Assessors area, last resort is a calculated area); and
- A remarks column giving the purpose of TE's, acquisition information when available, or other pertinent information regarding the property or acquisition.

On some projects it may be possible to place the parcel summary box on the Property or Location plan.

Location Plan — All properties impacted by a fee taking or permanent easement shall have their entire perimeter shown and dimensioned. If this cannot be done on the Property Plan, a location plan will be prepared. The location plan map will be to a scale practical to show the property in its entirety without match lines, and that will produce legible reproductions.

Location Plans will show the dimensioned outline of all properties affected by fee or permanent takings, the owner's name, total property area, the parcel linework, the parcel identification number with a leader to the parcel, and enough auxiliary information to orientate the user (such as street name, baselines, identified L.O. lines, etc.) Parcel dimensions, parcel areas, base mapping and or proposed design features are not shown on Location Plans. On some projects it may be possible to place the location plan of a property(s) as a detail on the Property Plan.

Property Plan Sheets — Property Plan(s) will be prepared at an appropriate scale to clearly illustrate the takings, and impacts to, affected properties. This is typically 20 scale in highly developed areas, and 40 scale in rural areas. The hierarchy of linework and text is as follows: ROW information (property lines, L.O. lines, street lines, parcel dimensions and identification text, etc.) is darkest, the proposed work is lighter, and the existing conditions base mapping is lightest. All layers must be legible and reproducible.

The following information will be shown on the Property Plan sheets:

- Existing ROW limits identified as State, County, City or Town, with year if known. Existing S.H.L.O.s shall also be identified by number. Both the existing and proposed baselines, with stations. Do not show distances, bearings, radii or curve length. All property lines, identified with a "PL" symbol, or "Z" symbol if common ownership.
- All parcels. All sides of the parcel will be dimensioned +/-, with tic marks at all changes in direction of the parcel boundary. The parcel will be identified by the parcel identification text in this format: parcel identification number, owner's name, then approximate area. If the parcel identification text cannot be practically fit within the boundaries of the parcel, a leader ending with a dot inside the parcel will be used to locate the parcel.
- Proposed L.O. lines, identified as such, and with the MassHighway supplied L.O. number, when applicable. Do not identify proposed layouts by year.

- All existing improvements included within any taking, such as structures, driveways, landscaping, and fences, etc. The disposition of all improvements within temporary easements will be identified.
- The proposed tops and bottoms of slopes will be shown, and identified.
- All new construction features, such as pavements, sidewalks, signals and foundations, erosion control measures, structures, and drainage. It must be clearly shown and identified what proposed work necessitates the acquisitions.
- All work to be performed to mitigate land damage.
- All dimensions are to be shown in the English system. Bar scales shall be provided.
- Names of the property owners of all properties affected by takings. Known abutter names of properties not affected by takings shall be identified as “N/F.”
- All streets shown will be identified by name and Route number, and as public or private. Waterways, and other named features will be identified.
- Project limits.

18.6 Specifications

Construction specifications for highway improvement projects are prepared by utilizing the current edition of the Massachusetts Highway Department Standard Specifications for Highways and Bridges as the base specification for the project, and the Department’s supplements to the standard.

The goal of the designer is to use the standard items specified in the Standard Specification to the greatest extent practicable, therefore avoiding the need to supplement the construction documents with unique items that are currently not standard. In certain instances, however, projects contain proposed features that are not specified in the Standard Specifications, thereby requiring the use of the supplemental specifications or development of Special Provisions.

Supplemental specifications are prepared to alter or supplement the base specification requirements provided in the Standard Specifications for Highways and Bridges (hereinafter called the

Standard Specifications). As stated above, new specifications are prepared for special work involving materials or construction requirements not covered by the Department standard or supplementary specifications.

18.6.1 Procedure

The Standard Specifications for Highways and Bridges (hereinafter called the Standard Specifications) are usually based on a unit price format. Each major item of work is defined and paid for separately at the unit price bid for the work. Payment for most items of work is based on the measured quantity of work actually constructed, while some are paid on a lump sum price basis.

The first task in preparing project specifications is to determine the unit price items needed to totally pay for all the project construction. The MassHighway Standard Item List is used for this purpose. New items are established for special work not included on the list.

The next step is to determine if the proposed work requires a supplemental or new specification by:

- Carefully review the work as defined on the drawings and read the Standard Specifications for the work included in the particular unit price item under consideration. If some part of the required work, such as a material or performance requirement, construction method or payment provision is not adequately covered, then additional supplemental specifications, called Special Provisions, must be written for this part of the work.
- If a Special Provision for the item does not exist, then a new complete Special Provision must be written.
- When a Special Provision covers the same work under several unit price items, it is not repeated but made applicable to all by including all the item titles in the title of the Special Provision.

18.6.2 Format and Content

Special Provisions are written to contain the following information in the following order:

Reference. The first sentence references the Special Provision to the applicable section of the Standard Specification and thereby ties both standard and Special Provisions together into a single complete specification. The first sentence should read:

> "The work under this (these) items shall conform to the relevant provisions of Section (no. or nos.) of the Standard Specifications and the following:"

This sentence is omitted only in the new specifications that are not supplemental to any section of the Standard Specifications.

Content. The body of the specification contains the material, quality, performance and method instructions. It should not duplicate any requirements already adequately covered in the Standard Specifications.

The first sentence should read "The work shall include ..." followed by a brief overview of the particular construction to be specified.

Material and material quality specifications are described next by generic name or manufacturer title. Generic material quality is defined by standard ASTM, AASHTO, or other specifications references. When specifying materials by manufacturer, include three choices whenever possible, and end with "or approved equivalent."

Material and material quality requirements are followed by requirements for construction performance, equipment and methods, such as:

> "place, grade and compact the gravel base..."
> "the concrete base shall be thoroughly cleaned..."
> "... shall be conducted by workmen thoroughly experienced..."

This part of the specification should be written in concise language in start-to-finish order. For example, requirements for preparatory work are written first, followed by principal construction, followed by finishing requirements.

Measurement and Payment. These clauses are the last part of the specification and should not be inserted fully or partially within the body of the Special Provision. If desired to call attention to separate or no separate payment for a particular task within the body of Special Provision, say so, but put detailed description in measurement and payment clause.

The Standard Specifications describe separately how a particular item of work will be measured for payment and how the measured quantity will be paid for. Special Provisions must use this same format.

Measurement clauses are written:

> "(Item title words in lower case) will be measured for payment by the (measurement unit) (follow with the definition of where the measurement will be taken, e.g., from end post to ..., on the pavement surface..., etc., when applicable), complete in place. Measurements are assumed to be taken in a horizontal plane or vertical plane unless otherwise noted in the measurement clause. The difference can be significant when the work is on a slope and the measurement is linear or an area, such as for pipe, seeding, etc."

Lump sum items do not require a measurement clause.

Payment clauses are written:

> "(Item title words in lower case) will be paid for at the Contract unit price per (measurement unit), which price shall include all labor, materials, equipment and incidental costs required to complete the work."

The payment clause can be written to cover more than one unit price item with the same measurement unit with the words "at the respective Contract unit prices per (measurement unit)."

Do not expand the "all labor, materials,..." clause with additional words such as "transporting," cutting," "storage," "cleaning," etc. since these can all be considered covered by the words labor, materials, equipment or incidental costs, or clarified by inclusion in the "no separate payment" sentence.

When payment for a particular part of the work is to be paid for under another item, add the standard sentence: "(work description)... will be paid for separately under (Item title), (Item number)."

When the cost of a particular part of the work is to be included in the unit price bid and therefore no separate payment is to be made, but there could be some question of payment since the same or similar work is included in the other items, then include the standard sentence:

"No separate payment will be made for (work or material description), but all costs in connection therewith shall be included in the Contract unit price bid. (If the Special Provision is for more than one item, include item title and number reference here.)"

This sentence can also be used to call attention to some special or unusual part of the work whose cost is to be included in the unit price.

18.6.3 Coordination With the Drawings

Terminology – The labels used on the drawings must be consistent with the payment item titles, material names and specification titles used in the technical applications.

For example:

- The plans should not label fill or backfill as structural fill, or gravel, while the specification and payment item is for gravel borrow or processed gravel.

Reference to information on the drawings – The term, "as shown on the drawings," is frequently found in specifications. The term appears to be most often included out of force of habit, usually in the sentence, "as shown on the drawings and as directed by the Engineer."

This term is needed since the drawings are as much a part of the contract documents as the specifications and the contractor is responsible for finding the information and does not have to be repeatedly told to do so. The term should be reserved for some unusual type of work where:

- The specifications and the drawings need to be studied together to achieve a full understanding of what is required.
- The contractor is given a choice of options in the specifications and the drawings illustrate only one of the choices.

Also, when the term is used, there must be something shown on the drawings. Too often the term is included, but there's actually nothing on the drawings and the term therefore is not only unnecessary, but erroneous.

***Duplication of notes* –** Notes shown on the drawings should not replace or duplicate information that is already in, or should be in, the specifications.

Notes should not include:

- Material requirements, such as concrete strength, reinforcing steel strength,
- AASHTO references.
- Performance requirements.
- Measurement and payment statements.

18.6.4 Language

Specifications are precise legal requirements which effect how a Contractor will perform the work and how he will determine his costs and bid prices. The language, therefore, must be clear and specific to avoid questions on the intent, requirements and basis of payment. Specification language must be clearly worded, consistent, specific, and complete. The key to good specification language is to use:

- Only those words that are necessary.
- Words whose meaning can be determined by a quality or quantity criteria.
- Words that are technically correct and not jargon.

<u>Unnecessary words are empty words</u> – words with no meaning that only make the specification harder to read and understand. Empty words to be avoided include:

- in order to
- So as to
- To the fact that
- In such a manner as to

Words and phrases must also be technically and legally correct and with only one meaning:

NO	YES
are to be, may, must, should	shall
his, hers, him, he, she	contractor, agency (not a person)
directed by the Engineer	required by the Engineer
insure (means insurance)	ensure
manner that will not cause	prevent
necessary (subject to dispute)	required
borne, absorbed, covered	paid

Words and phrases that have no criteria to define or enforce their meaning should not be used. These include:

- satisfactory, adequate, neatly, suitably, properly
- workmanlike, workmanship
- highest quality, best practices
- to the satisfaction of
- excessive stress
- a manner acceptable to
- pleasing, well tailored, etc., appearance
- firmly, securely, necessary

Strive to use those words which are most specific, yet are general enough to cover all conditions.

USED	BETTER
"Excavate and dispose of"	"Remove and dispose of," or "Excavate, remove and dispose of"
"... fire alarm apparatus"	"... fire alarm system equipment"
"... operations on the water mains ..."	"... alterations of the existing water system ..."
"damaged by the Contractor due to neglect ..."	"... damaged by the Contractor's operations ..."
"... of the applicable item aforementioned in these Special Provisions"	"of Item (No.) ..."

Words used to describe materials and technical terms must not be jargon and must agree with the words and terms used on the plans and in the payment items. These include:

YES	NO
Excavate, trench	Dig, bulldoze
Pipe	Main, line
Bituminous concrete, hot mix asphalt	Blacktop
Open graded friction course	Popcorn mix
Grading	Blading, dozing
Gate Valve	Gate
Conduit (single electrical pipe)	Duct
Duct (many electrical pipes in the group)	Conduit
Cold plane	Mill
Course (bituminous concrete)	Layer
Reinforcing bars (steel)	Rebar
Masonry work, brick work, etc.	Masonry, brick
Through bolts	Thrubolts

In addition to the use of correct words, phrases and sentences must be worded clearly and correctly. Some frequently used phrases to be avoided include:

- "as directed by the Engineer" – The engineer does not "direct" the contractor's work, but provides the contractor with requirements. The contractor has the legal responsibility to determine the means and methods needed to accomplish the requirements and to "direct" the workmen implementing the means and methods.
- "The Contractor shall be responsible for" – The contractor is responsible for all the contract requirements, thus it is not necessary to state it. This statement is only needed when the task may normally be accomplished by others, but paid for elsewhere, and similar circumstances. Permits are an example.
- "to the satisfaction of the Engineer" – An undeterminable requirement.
- "or equal" use "or equivalent" instead since no product can truly be equal to another.

- Quotation marks for dimension units should not be used since they can be easily incorrectly typed or lost in printing. The words foot, inch, etc. should always be used and fully spelled out.

18.7 Estimates

All projects require a final estimate of the quantity and unit bid price for each construction item. The following apply:

- The method of payment and units of measurement must conform to the latest editions of the *Standard Specifications for Highways and Bridges* and the *Standard Nomenclature and Designation of Items*.
- Any item of work not covered in the Standard Specifications must be submitted to the Specifications Engineer as a special provision.
- Earth quantities are calculated by computer or by planimetering the cross sections.
- At the 25% and 75% stages, project cost estimates are prepared using up-to-date information.

18.7.1 Types of Project Estimates

Federal-Aid Projects
Separate estimates are required for Federal-Aid projects.

- **Non-Participating Estimate** - This is required for items which will be paid for with other than state and federal funds:
  - Non-Participating State only; i.e., cleaning pipes and drainage structures.
  - Non-Participating Municipal; i.e., "gas lanterns," "ashfield stone" paved sidewalks.
- **Federal-Aid Roadway Estimate** - This is required for roadway construction items, exclusive of bridge items.
- **Federal-Aid Bridge Estimate** - This is required for each bridge and for walls which are assigned a structure number by the Bridge Section.
- **Contract Estimate** - This is an estimate for the project showing the total project cost, including total contract items, construction

engineering, contingencies, force accounts, non-participating costs, and a summary of project costs which include the requested federal funds.

Exhibit 18-25 provides the shrinkage and swell percentages for excavation and embankment quantities. Exhibit 18-26 provides the weights and measures used for estimating.

Exhibit 18-25
Shrinkage and Swell Criteria

Item	Factor in Percent to Be Applied
Estimate of earth excavation available for embankment: Earth excavation quantity (excluding rock and unsuitable materials) measured and/or computed	-5% (Shrinkage)
Estimate of embankment required: Embankment quantity measured and/or computed	+15% (Swell)
Estimate of rock excavation available for embankment: Rock excavating quantity measured and/or computed	+37.5% (Swell)
Estimate of muck excavation: Muck excavating quantity measured and/or computed	0%
Estimate of gravel borrow required: Borrow quantity measured and/or computed	+25% (Swell)
Estimate of Loam Required: Loam quantity measured and/or computed	+25% (Swell)
Estimate of topsoil required: Topsoil quantity measured and/or computed	+25% (Swell)

Note: These percentages are for estimating purposes only.
Source: MassHighway

The Shrinkage factor accounts for loss of material during handling and stockpiling. The Swell factor accounts for the increased volume of earth due to through excavation. Stockpiled or hauled materials assume a larger volume area than in their natural state. After swelled (loose) material has been placed as fill, it is compacted to a 95% density. Therefore when calculating the quantities required for special borrow, gravel borrow and loam borrow material, the volumes are increased per the above percentages.

Exhibit 18-26
Weights and Measurements for Estimating Purposes

Material	Use	Weight – Ton Per Square Yard	Remarks
Bituminous Concrete	For surface, binder or base	0.056	Per 1 inch of depth
Bitumen	Dust layer	—	Estimate 0.2 gallons per square yard of surface area
	Prime coat	—	Estimate 0.05 gallon per square yard of surface area
Crushed Stone	For top course or base course	0.05	Per 1 inch of depth
	Dense packed mass	0.062	Per 1 inch of depth
Pea Stone	For driveways	0.05	Per 1 inch of depth, to be included in the item: "Crushed stone for wearing surface," use when a small quantity is required.
	For driveways	—	3,300 pounds per cubic yard, use when a large quantity is required. Item designation is "peastone for driveways"
Stone Dust	Walks, drives, etc.	—	Estimate 2,700 pounds per cubic yard
Water	Dust layer	—	Estimate 1.0 gallon per square yard of surface area

Source: MassHighway

Quantity Detail Sheets are part of the contract documents and are required to advertise a project. The amounts match those in the Contract Estimate, but without the estimated costs. Exhibit 18-27 provides examples of Quantity Detail Sheets.

Non Federal-Aid Projects

Only one contract estimate is required for non Federal-Aid projects. This estimate is similar to the final Contract Estimate for Federal-Aid projects.

Utility Force Accounts

On many highway projects, utility adjustments or relocations will be necessary. The costs of labor and materials may be reimbursable by the State on a force account basis. A separate estimate should be prepared for any force account work for a highway project. The utility company usually prepares this estimate.

Exhibit 18-27
Sample Quantity Detail Sheet

ORDER NO. ____________

THE COMMONWEALTH OF MASSACHUSETTS
MASSACHUSETTS HIGHWAY DEPARTMENT
TEN PARK PLAZA - BOSTON, MA

—PRELIMINARY ESTIMATE OF QUANTITIES — DETAIL SHEET—

CITY/TOWN: (CITY / TOWN)
STA: 10+75 to 22+00
Type of Project: Transportation Improvement Project

YEAR: 2006
ROAD: MAIN STREET
CLASS: ____________
DATE: JAN 12, 2006

Unclassified Excavation	3,700	Cu. Yards	Gravel for Sidewalks	289	Cu. Yards
Class "B" Trench Excavation	20	Cu. Yards	Gravel for Driveways	185	Cu. Yards
Subbase Borrow	383	Cu. Yards	Embankment +15%	374	Cu. Yards

PROPOSED FULL-DEPTH PAVEMENT (WIDENING) — **AREA = 1,211 SY**

SURFACE: 4 INCHES HOT MIX ASPHALT
[2 INCHES MODIFIED TOP COURSE MATERIAL OVER 2 INCHES INTERMEDIATE (BINDER) COURSE MATERIAL].

BASE: 3.5 INCHES HOT MIX ASPHALT BASE COURSE

SUBBASE: 4 INCHES DENSE GRADED CRUSHED STONE OVER
8 INCHES GRAVEL BORROW

PROPOSED COLD PLANE & PAVEMENT OVERLAY — **AREA = 3,749 SY**

SURFACE: 2 INCHES HOT MIX ASPHALT
MODIFIED TOP COURSE MATERIAL.

LEVELING COURSE: VARIABLE DEPTH HOT MIX ASPHALT TOP COURSE MATERIAL

TACK COAT: BITUMEN FOR TACK COAT (RS-1) AT 0.10 GALLONS/SQUARE YARD OVER EXISTING OR COLD-PLANED SURFACE.

COLD PLANE: COLD PLANE VARIABLE DEPTH TO MEET PROPOSED GRADING

Plan No.'s ____________ Estimated by ____________
Profile No.'s ____________ Reviewed by ____________
Calculation Book No.'s ____________ Submitted by ____________

Source: MassHighway

Exhibit 18-27 (Continued)
Sample Quantity Detail Sheet

PROJECT FILE NO. 000000

—PRELIMINARY ESTIMATE OF QUANTITIES — DETAIL SHEET—

TOWN-CITY NAME MAIN STREET YEAR 2006

DATE- JAN 12, 2006

ALL ITEMS NOT COMPLETELY DESCRIBED AND LOCATED ON THE PLANS ARE TO BE DETAILED AS SHOWN BELOW:

ITEM 102. **SELECTIVE CLEARING AND THINNING**

MAIN STREET
Sta. 10+40 to Sta. 14+00 LT
Sta. 14+70 to Sta. 16+70 RT
Sta. 19+00 to Sta. 19+80 LT

MAPLE STREET
Sta. 213+00 to Sta. 215+70 RT

ITEM 103. **TREE REMOVED – DIAMETER UNDER 24 INCHES**

MAIN STREET
Sta. 19+02 – 25' RT Sta. 19+56 – 28' RT
Sta. 19+77 – 29' RT Sta. 19+96 – 28' RT

MAPLE STREET
Sta. 215+85 – 31' RT Sta. 216+78 – 20' RT
Sta. 216+85 – 21' RT Sta. 216+88 – 33' RT
And as directed

ITEM 104. **TREE REMOVED – DIAMETER 24 INCHES AND OVER**

At various locations as directed.

ITEM 123. **MUCK EXCAVATION**

MAPLE STREET
Sta. 213+56 to Sta. 214+34

For removal of the top 12 inches of topsoil in wetland impact areas as shown on the plans and as directed.

ITEM 141. **CLASS A TRENCH EXCAVATION**

For excavation at the proposed stone masonry walls, cement concrete headwall and as directed.

Source: MassHighway

Municipal utilities are those operated by a municipality such as fire alarm systems, water, sewer, or electric power and light systems. Private utilities refer to utilities such as Telephone, Cable and Electric.

The following criteria apply in determining the eligibility for State reimbursement for utility force account work:

- MassHighway will replace in-kind or adjust all municipally owned utilities on state highways which are disturbed by construction. If any ‘betterments’ are to be made to a utility, the municipality must pay for the additional cost. MassHighway will also reimburse the municipality for the required relocation of municipally owned monuments, flagpoles, etc.
- Private companies may be reimbursed for adjustments made to facilities only when they occupy the way by legal title or easement. A company incurs the cost of making the adjustments at its own expense when the facilities are within a public way by permit, license, or sufferance. The only exception is on the Interstate Highway System where the Department will reimburse for all adjustments.
- MassHighway will pay a railroad under a force account agreement for any work done by the railroad as a result of highway construction. Special provisions submitted by the Railroad will become part of the proposal to bidders.

The designer is responsible for the preparation of utility plans for the Utilities Section which in turn will distribute them to each municipality or utility company. The plan must show all utility changes required by the highway construction. The MassHighway Utility and Railroad Engineer will request the municipality or utility company to submit its force account plans, estimates, and special provisions for reimbursable items. The utility owner must also include special insurance requirements in the special provisions. The MassHighway Utility and Railroad Engineer will prepare all agreements with the utility owner covering costs, scope of work, etc. The MassHighway utility policy is fully discussed in the "*Utility Accommodation Policy*." Note: Special reimbursement to utilities for bridge reconstruction work may apply.

18.7.2 Procedures for Submitting Estimates

The cost estimate cover sheets are prepared on standard MassHighway forms. See the MassHighway Web site at www.mass.gov\mhd for these forms. The Engineer shall submit an electronic version of the

Construction Cost Estimate Spreadsheet to the MassHighway Project Manager in a format acceptable to the Department. Estimates for bridges, non-participating items, or work paid by a municipality directly to the contractor appear on the cover sheets and all contract items appear on the electronic estimate sheets.

18.7.3 Office Calculation Book

The Office Calculation Book (OCB) is to contain all calculations together with locations of the contract quantities as listed in the Proposal. Prior to binding, the OCB pages are to be numbered and two additional sets copied for submission with the PS&E (Copies are to be used in construction). The OCB (original) is to be assembled with a cardboard cover and back, and labeled with an assigned OCB number for the specified project issued by the Plans and Records Section.

The format of the office calculation book should meet these criteria:

- Place index in the beginning.
- Illustrate by stations calculated surface areas, including sketches of street approaches and driveways.
- Quantities should be entered in the calculation book in the order in which they are estimated; i.e., chronologically. (See Exhibit 18-28)
- Quantities must be initialed and dated by the estimator and checked, initialed and dated by the checker.
- Include an earthwork summary with the earthwork calculations. (See Exhibits 18-29 and 18-30.)
- All work is to be neat, legible, and suitable for reproduction.
- Do not make erasures; strike out with a single line.
- Provide a one inch border around each page.
- Handwritten entries are acceptable.
- Enter all project calculations in the office calculation book.

See the MassHighway Web site at www.mass.gov\mhd for samples and excerpts illustrating the recommended format for the preparation of the office calculation book.

Exhibit 18-28

Sample Item Quantity Sheet

151 **GRAVEL BORROW** CY

Drainage Trenches in Full Depth Pavement:

Drainage Trenches: (3+D)ft width x 18" high x length of pipe(ft)

Str		Str	Pipe Dia. (ft)	Pipe Length	Area (sf)	Volume (cf)	Volume (cy)
3A	to	1A	1.00	38.00	6.00	228.00	8.44
3	to	3A	1.00	208.00	6.00	1248.00	46.22
5	to	6	1.00	34.00	6.00	204.00	7.56
7	to	8	1.00	13.00	6.00	78.00	2.89
11	to	10	1.00	14.00	6.00	84.00	3.11
12	to	13	1.00	61.00	6.00	366.00	13.56
13	to	13A	1.00	44.00	6.00	264.00	9.78
19	to	16	1.00	229.00	6.00	1374.00	50.89
19A	to	19	1.00	13.00	6.00	78.00	2.89
23	to	19	1.00	69.00	6.00	414.00	15.33
17	to	18	1.00	32.00	6.00	192.00	7.11
25	to	26	1.00	4.00	6.00	24.00	0.89
							168.67

Stone Wall Sta 103+65.64 Maple St to Sta. 15+25.00 Main St

Panel	Average Height (ft)	Area (sf)	Length (ft)	Volume (cf)	Volume (cy)
1	5.65	16.30	24.00	391.20	14.49
2	6.28	17.56	24.00	421.44	15.61
3	6.00	17.00	24.00	408.00	15.11
4	5.88	16.76	24.00	402.24	14.90
5	6.00	17.00	24.00	408.00	15.11
6	6.00	17.00	24.00	408.00	15.11
7	6.00	17.00	24.00	408.00	15.11
8	6.00	17.00	13.50	229.50	8.50
					113.94

Gravel bedding under Stone Masonry Wall - Dry

3ft (wide) x 1ft (deep) x 180ft (length) x 1cy/27cf = **20.00**

SUBTOTAL:	302.61
PLUS 25% SWELL:	75.65
	378.26

ITEM 151.01 SAY 400 CY

Estimated by: Intials and date
Checked by: Intials and date

Source: MassHighway

Exhibit 18-28 (Continued)
Sample Item Quantity Sheet

ITEM 220.5 — DRAINAGE STRUCTURE REMODELED — EACH

MAIN STREET

	Structure No.	Station	Offset		Type	Quantity
*	--	11+21.2	17.2'	RT	CB	1
*	1	11+66.0	15.4'	LT	GI	1
*	3A	11+55.0	7.5'	RT	DMH	1
*	3	13+65.0	15.3'	RT	CB	1
*	7	17+26.4	31.1'	RT	CB	1
*	8	17+42.1	39.4'	RT	CB	1
*	10	18+32.4	25.0'	LT	CB	1
*	11	18+50.0	25.0'	LT	CB	1
*	12	18+92.5	14.0'	RT	CB	1
*	13	19+60.9	5.5'	RT	DMH	1
*	--	21+22.2	15.2'	RT	CB	1
*	--	21+64.4	32.8'	RT	CB	1

MAPLE STREET

	Structure No.	Station	Offset		Type	Quantity
	24	218+56.2	25.0'	LT	CB	1
	15	214+01.6	11.4'	LT	CB	1
*	16	214+00.0	8.7'	LT	DMH	1
*	19	216+30.0	16.6'	LT	DMH	1
						16

ITEM 220.5 SAY 16 EACH

* To raise structures (lowered for reclamation) to binder course

Estimated by: Intials and date
Checked by: Intials and date

Source: MassHighway

Exhibit 18-28 (Continued)
Sample Item Quantity Sheet

ITEM 460	HOT MIX ASPHALT	TON
FROM SURFACE AREA CALCULATIONS:		Quantity
	FULL DEPTH PAVEMENT: 1211 SY 1211 SY x 4" x 0.056 TON/ SY*IN =	271.3 TON
	FULL DEPTH LESS THAN 3.0 ft: 340 SY 340 SY x 2" x 0.056 TON/ SY*IN =	38.1 TON
	FULL DEPTH RECLAMATION: 6453 SY 6453 SY x 4" x 0.056 TON/ SY*IN =	1445.5 TON
	COLD PLANE & PVM'T OVERLAY: 3750 SY 3750 SY x 2" x 0.056 TON/ SY*IN =	420.0 TON
	From Cross Sections Leveling Volume: 114 CY 114 CY x 2.02 TON/CY =	230.3 TON
		2405.1 TON

ITEM 460 SAY 2,500 TON

Estimated by: Intials and date
Checked by: Initials and date

Source: MassHighway

Exhibit 18-29
Sample Earthworks Quantity Sheet

EARTHWORK QUANTITY SHEET

MAIN STREET

Station	Length (ft)		Cut Area (sf)	Avg Cut Area (sf)	Cut Vol (cy)		Fill Area (sf)	Avg Fill Area (sf)	Fill Vol (cy)
10+50			0.00				0.00		
11+00	50		2.90	1.45	2.69		2.02	1.01	1.87
11+50	50		3.70	3.30	6.11		2.31	2.17	4.01
12+00	50		2.71	3.21	5.94		1.15	1.73	3.20
12+50	50		15.47	9.09	16.83		0.00	0.58	1.06
13+00	50		24.98	20.23	37.45		2.61	1.31	2.42
13+50	50		16.03	20.51	37.97		8.86	5.74	10.62
14+00	50		16.14	16.09	29.79		10.42	9.64	17.85
14+50	50		25.06	20.60	38.15		14.19	12.31	22.79
15+00	50		28.68	26.87	49.76		1.05	7.62	14.11
15+50	50		27.84	28.26	52.33		3.25	2.15	3.98
16+00	50		38.83	33.34	61.73		0.00	1.63	3.01
16+50	50		16.61	27.72	51.33		15.86	7.93	14.69
17+00	50		10.68	13.65	25.27		3.43	9.65	17.86
17+50	50		4.32	7.50	13.89		1.46	2.45	4.53
18+00	50		7.52	5.92	10.96		2.11	1.79	3.31
18+50	50		24.35	15.94	29.51		1.78	1.95	3.60
19+00	50		24.95	24.65	45.65		1.29	1.54	2.84
19+50	50		20.95	22.95	42.50		3.08	2.19	4.05
20+00	50		19.24	20.10	37.21		0.00	1.54	2.85
20+50	50		13.36	16.30	30.19		0.22	0.11	0.20
21+00	50		9.14	11.25	20.83		1.35	0.79	1.45
21+50	50		0.00	4.57	8.46		0.00	0.68	1.25
22+00	50		0.00	0.00	0.00		0.00	0.00	0.00
				TOTAL:	**654.56**			TOTAL:	**141.56**

Estimated by: Initials & date
Checked by: Initials & date

Source: MassHighway

Exhibit 18-30
Sample Earthworks Summary Quantity Sheet

SUMMARY QUANTITY SHEET

FROM EARTHWORKS SHEETS:

EXCAVATION			EMBANKMENT		
Main Street:	655.00	CY	Main Street:	142.00	CY
Boston Road	482.00		Boston Road	49.00	
	1137.00	CY		191.00	CY

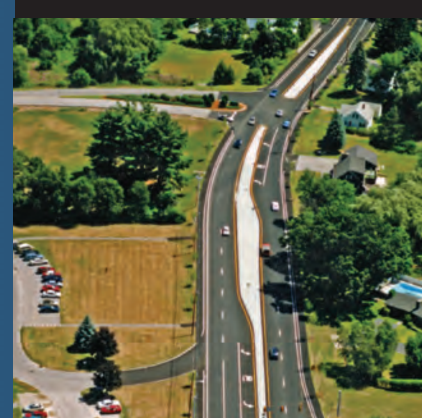
EXCAVATION			EMBANKMENT		
Earthworks:	1137.00	CY	Earthworks:	191.00	CY
HMA Driveways:	208.91				
Cement Driveways:	27.77				
Class A Trench:	71.15				
Estimated Excavation:	1444.83	CY	Estimated Embankment:	191.00	CY
DEDUCT 2.5% (Boulders):	- 36.12				
DEDUCT 5% (Unsuitable):	- 72.24				
DEDUCT 5% (Shrinkage):	- 72.24		PLUS 15% (Swell):	28.65	
Available for Embankment:	1264.23	CY	TOTAL Embankment Required:	219.65	CY
			Available from Embankment:	-1264.23	
			WASTE:	**-1044.59**	**CY**

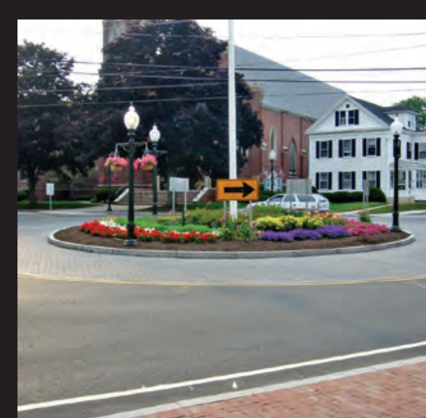
Estimated by: Initials & date
Checked by: Initials & date

Source: MassHighway

Chapter G

Glossary





A

Abutter - Owner of a contiguous property

Access Aisle - Aisle which runs the full length of a handicap parking space and is marked with a series of diagonal lines

Access Control - Tool used to maintain safe and efficient roadway operations; exercised by statute, zoning, right-of-way purchases, driveway controls, turning and parking regulations, and geometric design

Access Control - Full Control - Priority given to through traffic by providing access only at grade-separated interchanges with selected public roads; no at-grade crossings or private driveway connections are allowed; freeway is the common term used for this type of highway

Access Control - Partial Control - An intermediate level between full control of access and regulatory restriction; priority given to through traffic, but a few at-grade intersections and private driveway connections may be allowed; may be provided for certain rural arterials

Access Control - Statute, Zoning, Regulation - Zoning may be used to effectively control the adjacent property development so that major generators of traffic will not develop; driveway regulations and permits are used to control the geometric design of an entrance, driveway spacing, and driveway proximity to public road intersections

Access Management - Broad set of techniques that balance the need to provide efficient, safe and timely travel with the ability to allow access to an individual destination

Access, Controlled - Access control applied to freeways or other major arterials where access to the roadway is limited to interchange points or major intersections

Access, Full - Access control applied to arterials or collectors where access is provided to adjoining properties without restrictions on turning movements

Access, Limited - Access control applied to arterials where intersections are widely spaced and driveway connections are limited

Access, Uncontrolled - Refers to collectors and local roads where access controls are not employed

Accommodation - Provision of safe, convenient, and comfortable travel roadway users

Aesthetic Pavement Surface - Decorative pavements used to reflect architectural materials and details in historically significant areas, to beautify otherwise significant downtown locations, or to highlight pedestrian zones

Alignment, Horizontal - Horizontal location of a road

Alignment, Vertical - Vertical location of a road

Allowable Headwater (AHW) - Maximum allowable ponding elevation at the culvert entrance, as a measured from the culvert invert

All-Way Stop Control - Traffic calming measure providing stop control to all legs of an intersection

Alteration - Modification made to an existing facility that goes beyond normal maintenance activities and affects or could affect usability

Alternatives Analysis - Analysis of project alternatives, selected from those advocated by interested groups or recommended by local or State government; could include various transportation facility types for all modes of transportation (pedestrian, bicycle, motorist, or transit) and range of management strategies

Americans With Disabilities Act Architectural Design Standards (ADAAG) - Requirements for accessibility to buildings and facilities by individuals with disabilities under the Americans with Disabilities Act (ADA) of 1990

Angle of Intersection - Angle formed by the centerlines of intersecting streets, at the center of their jointly used pavement

Approach Leg - Side of an intersection leg used by traffic approaching an intersection

Architectural Access Board (AAB) - Regulatory agency within the Massachusetts Executive Office of Public Safety with a legislative mandate to develop and enforce regulations designed to make public buildings accessible to, functional for, and safe for use by persons with disabilities

Area-Sensitive Species - Species which will not use a habitat patch (such as forest, grassland or marsh) unless it is above a particular size threshold

At-Grade Intersection - Intersection at which two or more roadways meet or cross at the same elevation

Automatic Traffic Recorder (ATR) - Recorder which provides continuous traffic monitoring and collects traffic data for analysis, including volume, speed, classification, and gaps

Auxiliary Lane - Portion of the roadway adjoining the traveled way for speed change, turning, storage for turning, weaving, truck climbing, and other purposes supplementary to through-traffic movement

Average Annual Daily Traffic (AADT) - Total yearly volume of automobiles and trucks divided by the number of days in the year

Average Daily Traffic (ADT) - Daily traffic volumes in a time period greater than one day and less than one year, divided by the number of days counted

Axis Of Rotation – Line about which the pavement cross-section is rotatated to

B

Bankfull Width - Elevation on a stream bank where flooding begins; in many stream systems, the stage associated with the flow that just fills the channel to the top of its banks and at a point where the water begins to overflow onto a floodplain

Base Mapping – Plan or geographic information

Basic Design Controls - Foundation for establishing the physical form, safety and functionality of a roadway

Basic Number of Lanes - Minimum number of lanes needed over a significant length of a highway based on the overall capacity needs of that section

Bearing Ratio - Load required to produce a certain penetration using a standard piston in a soil, expressed as a percentage of the load required to force the piston the same depth in a selected crushed stone

Bedload Material - Material transported by a stream

Berm (1) - Raised mound of earth used in different ways; as a site barrier, to separate roadway embankment from a drainage way, as a sound barrier, or for architectural reasons; **or**
(2) - A shoulder curb on rural and urban highways which do not have continuous curb and require control of drainage; directs water to closed drainage systems, prevents sloughing of the pavement edge, and provides additional lateral support

Bicycle Count/Demand – Data collection to determine bicycle flow and patterns usually conducted during peak hours when vehicle turning movement counts are being conducted

Bicycle Lane - Delineated road space for preferential use by bicyclists traveling in same direction as the adjacent motor vehicle traffic

Biotechnical Stabilization - Method of stabilization which integrates plant material with layered geogrid reinforced systems, riprap, and/or gabion systems; provides the benefits of vegetative systems with the more predictable benefits of non-living structures and measures

Bituminous Concrete - Paving material composed of a petroleum derivative and crushed stone or crushed gravel

Blockloading - Completely closing a street

Boat Section – A subgrade structure with an open top used to convey a roadway or other facility

Bollard - Most common type of barrier used to control motor vehicle access to a path; a pole

Boring - An earth-drilling process used for installing conduits or pipelines

Borrow Pit - Excavation site outside the limits of construction that provides necessary material, such as fill material for embankments

Box Culvert - Culvert with a square or rectangular cross-sectional profile having four sides, including a bottom

Bridge - Structure which carries pedestrians, bicycles, and/or vehicles over various types of transportation facilities or natural features

Bridge, Historic - A bridge that is of a rare type, is unusual from an engineering perspective, has historic significance because of location or association with an important event or person, or is 50 years of age or older is a candidate for classification as a historic bridge

Broken Back Curve - Awkward combination of curves and tangents in both the horizontal and vertical planes

Buffer - Area which provides separation between higher speed vehicular traffic and lower speed users such as pedestrians and bicylcists

Bulk Stone Deposit - Energy dissipators installed at culvert outlets for erosion control purposes

Bus Bay - Bus stop that requires buses to exit from and re-enter an adjacent lane of traffic, a pull-off

Bus Stop, Far-Side - Bus stop located immediately after passing through an intersection

Bus Stop, Midblock - Bus stop located within the block, not necessarily associated with an intersection, and generally adjacent to major generator of transit ridership

Bus Stop, Near-Side -Bus stop located immediately prior to an intersection

C

Call Button - Button used to initiate a pedestrian crossing phase at traffic- actuated signals

Canopy -Branches and foliage formed collectively by the crowns of adjacent trees

Capacity - Transportation facility's ability to accommodate a moving stream of people or vehicles in a given time period

Catch Basin - Inlet structure in which a grate is used to intercept storm runoff which is delivered to an underground structure (usually an inside diameter of 4 feet) with a 2-3 foot sump

Causeway - Bridge or roadway constructed over marshy land or water which may be either an earth fill or bridge type structure

Centrifugal Force - Outward pull, here referring to the outward pull of a vehicle traversing a horizontal curve

Channel - A waterway with bed and banks, either naturally or artificially created, which periodically or continuously contains moving water, or which forms a connecting link between two bodies of water; also called a watercourse

Channel Capacity – Limit capacity of an open channels ability to accommodate the peak flows

Channel Cross Section - Physical measurements (width and depth) across the channel and floodplain

Channel Lining – Material linings which protects the channel section from erosion and reduces maintenance

Channel, Bottom of Slope - Channel provided at the bottom of a slope to convey the storm runoff from roadway channels to a discharge point

Channel, Intercepting - Channel provided longitudinally at the top of a cut to intercept runoff from a hillside before it reaches the roadway

Channel, Roadway - Channel provided in cut sections to remove storm runoff

Channelizing Island –Short median added to an intersection to help delineate the area in which vehicles can operate; can also provide for pedestrian refuge

Check Dam -Small dam constructed in a gully to decrease the flow velocity, minimize channel scour, and promote deposition of sediment

Chicane - A series of deflections involving the narrowing of one side of the street by an amount that requires the through traffic to deflect from its previously straight path

Clear Recovery Zone - Area provided along highways to allow vehicles veering off the travel lane opportunity for safe recovery or stopping

Clear Zone - Traversable, unobstructed roadside area beyond the edge of the traveled way, available for safe use by errant vehicles; also called a recovery area

Clear Zone - Recovery area adjacent to the roadway

Community - Group of people with common interests living in a particular area

Composite Pavement - Combination of bituminous concrete over portland cement concrete

Compound Curve - A series of two or more simple curves with deflections in the same direction immediately adjacent to each other, used to transition into and from a simple curve and to avoid some control or obstacle which cannot be relocated

Concept – See alternative

Concurrent Pedestrian Phasing – Traffic signal operation that allows pedestrians to cross at the same time as parallel traffic movements

Constituent - Group or individual that is involved in, has an interest in, or is affected by a proposed project

Construction - The building or assembly of infrastructure

Context Sensitive Design - Collaborative, interdisciplinary approach to develop a transportation facility that fits its physical setting and preserves scenic, aesthetic, historic, and environmental resources, while maintaining safety and mobility for all users

Contextual Classification - System of identifying and classifying land uses and other characteristics adjacent to a roadway

Control Delay - Delay which is the result of traffic control devices needed to allocate potentially conflicting flows at an intersection; reflects the difference between travel time through the intersection at free flow versus travel time under the encountered conditions of traffic control

Corner Clearance - Distance from roadway intersections to the nearest driveway entrance

Corner Marker - Permanent marking of the corner of a roadway, typically a durable stone, concrete, or metal marker

Corridor - A transportation pathway, often including surrounding areas

Corridor Study - Study of a corridor including, social, economic, and environmental considerations, and project alternatives

Course, Base - Layer of asphalt below the surface course

Course, Friction - Asphalt mixture applied to exhisting pavement with low measured skid resistance; may eliminate the need for corrective work; in some instances a friction course may be placed or new or reconstructed pavements

Course, Surface - Top layer of asphalt used on a roadway

Crash Cushion - Crash impact protection system which can be designed to redirect a vehicle impacting the side of the cushion (redirective) or to decelerate the vehicle to a stop when impacted on the side (non-directive)

Critical Cross Section - Points where structures and resources are avoided or impacted by the typical section

Critical Depth - Depth of flow at which the discharge is maximum for a given specific energy, or the depth at which a given discharge occurs with minimum specific energy

Critical Flow - When the discharge is maximum for a given specific energy head or, conversely, when the specific energy head is minimum for a given discharge

Critical Slope - Slope which will sustain a given discharge at uniform, critical depth in a given channel

Critical Velocity - Mean velocity when the discharge is critical.

Cross Section - View of a vertical plane cutting through the roadway, laterally perpendicular to the center line, showing the relationship of various roadway components

Cross Slope - Slope measured perpendicular to the direction of travel

Cross Street - The minor street in an intersection

Crossing Island - Short divisional islands located at crosswalks

Crossover - At-grade connection between opposing lanes of traffic on a median-divided highway

Crosswalk, Textured - Crosswalk which uses non-slip bricks or pavers to raise a driver's awareness through increased noise and vibrations; colored pavers, which increase the visibility of the intersection, may also be used

Crown - Convex road surface that allows runoff to drain to either side of the road prism

Crown Integrity - Assessment of crown's healthy foliage, which typically signifies a healthy tree

Cultural Resources - Sites, structures, landscapes, and objects of importance to a culture or community for social scientific, traditional, religious, or other reasons

Culvert - A metal, wooden, plastic, or concrete conduit through which surface water can flow under or across roads

Curb – A raised device used extensively on urban streets and highways, controls drainage, restricts vehicles to the pavement area and defines points of access to abutting properties

Curb Extension - Extenstion of curb which shortens the crossing distance, provides additional space at the corner (simplifying the placement of elements like curb ramps), and allow pedestrians to see and be seen before entering the crosswalk; sometimes called curb bulbs or bulb-outs

Curb Radius - Measurement of the sharpness of a corner at an intersection

Curb Ramp - Short ramp cutting through or built up to a curb

Curb Ramp Flare - Graded transition from a curb ramp to the surrounding sidewalk

Curb Ramp, Diagonal - Single perpendicular curb ramp that is located at the apex of the corner

Curb Ramp, Parallel - Curb ramp used where the available space between the curb and the property line is too tight to permit the installation of both a ramp and a landing

Curb Ramp, Perpendicular - Curb ramp oriented so that the fall line of the ramp is both parallel to the crosswalk and perpendicular to the curb

Curvature - Sharpness of a curve

Curve Number - Method of expressing the retention characteristic of soil

Curve Radius – Distance from a point on a highway curve to the center of a circle formed by that curve

Cut-To-Fill Transition - Earth-moving process that entails excavating part of an area and using the excavated material for adjacent embankments or fill areas

D

Decree Plan - Documentation required when existing railroad crossings are abolished or altered in conjunction with highway work

Deflecting - Introducing curvature to the vehicle path

Density - Amount of development per acre on a parcel either existing or permitted under the zoning law

Departure Leg - Side of an intersection leg used by traffic leaving an intersection

Design Bearing Ratio (DBR) – A strength measure used to design the pavement

Design Discharge - Design flow of a storm drain system for the same frequency as the pavement drainage

Design Flood - The flood, observed or synthetic, that is chosen as the basis for the design of a hydraulic structure

Design Hourly Volume (DHV) - One-hour volume in the design year selected for determining the highway design

Design Speed - Selected speed used to determine the various design features of the roadway

Design Vehicle - Type and size of vehicle expected to be regularly accommodated on a roadway

Design Volume - A volume determined for use in design, representing traffic expected to use the highway 20 years in the future; unless otherwise stated, it is an hourly volume

Designer – Engineer responsible for developing a project and preparing project plans including specificiations, and estimates

Detention Basin -Basin that can provide additional storage in order to mitigate increases in peak stormwater discharge

Direct Ramp Connection – Interchange ramp that does not deviate greatly from the intended direction of travel (as does a loop, for example)

Discharge - Flow from a culvert, sewer, channel, or other watercourse

Diversion Channel - Temporary channel to divert water around an ongoing construction site for a permanent drainage structure; keep the worksite dry and minimize the chance for erosion

Divided Highway - Highway with separated roadways for traffic in opposite directions

Drainage -Removal of water from the highway right-of-way

Drainage Area - Total surface area that drains to a point of interest, typically reported in acres (small watersheds) or square miles

Drainage Blanket (permeable base) - An open-graded aggregate subbase used to intercept and/or transfer the water to subsurface drain pipes

Drainage Design - Comprehensive plan to adequately drain the roadway and also protect adjacent landowners, wetlands, and public water supplies from drainage related problems

Drainage Structure -Any device or land form constructed to intercept and/or aid surface water drainage

Driveway -Point of access from a public street to private property

Driveway Closure - Method of eliminating conflicts with an arterial, elimination of a driveway

Drop Inlet -Inlet structure in which a grate and side-opening "throat" are used with a 2-3 foot sump; typically used in ditches

Drop Structure - Type of energy dissipator which involves a series of gentle slopes with intermittent vertical drops into a stilling basin

E

Ecopipe -Small, dry tunnel (1 foot to 1.3 foot diameter) used to facilitate movements of small and medium sized animals

Edging - Pavement edge treatment

Embankment - Mound of stone or earth, often built to support a road

Endangered Species - Species which is threatened with extinction by man-made or natural changes in their environment; identified in accordance with the Endangered Species Act of 1973

Energy Dissipator - Device used to reduce the energy of flowing water

Energy Grade Line - Line defined by a distance of one velocity head above the hydraulic grade line; slope of the line is the energy gradient

Energy Grade Line (EGL) - A line representing the total energy (potential plus kinetic) of the water flow

Energy Gradient - Slope of the energy grade line, usually parallel to the hydraulic gradient

English Units - System of measurement widely used in the United States; the primary alternative to the metric system

Environmental Justice - Fair treatment and meaningful involvement of all people—regardless of race, ethnicity, income or education level—in environmental decision making, including protection of human health and the environment, empowerment via public participation, and the dissemination of relevant information to inform and educate affected communities

Erosion - The process of wearing away of the land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep; the detachment and movement of soil or rock fragments by water, wind, ice, or gravity

Erosion Control - Protection of soil from dislocation

Estimate - Documentation prepared for project budgeting and to evaluate responses to project advertisements

Estimate, Contract - Estimate for the project showing the total project cost, including total contract items, construction engineering, contingencies, force counts, non-participating costs, and a summary of project costs which include the requested federal funds

Estimate, Federal Aid Bridge - Estimate required for each bridge and for walls which are assigned a structure number by the Bridge Section

Estimate, Federal Aid Roadway - Estimate required for roadway construction items, exclusive of bridge items

Estimate, Non-Participating - Estimate required for items which will be paid for with other than state and federal funds

Exclusive Pedestrian Interval - Stops traffic in all directions, eliminating pedestrian conflicts with turning vehicles; most applicable to downtown areas with high pedestrian volumes (e.g., more than 1,200 pedestrian crossings per day); also called scramble timing

F

Fatality Sign - Roadway sign updated on a regular basis to reflect the current number of motorist fatalities from moose and deer collisions

Fencing - Common practice used to keep wildlife off highways

Flow (1) - Measurement of the number of pedestrians, bicycles, and/or motor vehicles moving through a transportation network; quality of flow stated as "level of service" and maximum flow stated as "capacity"
(2) – Also a measure of conveyance for a watercourse

Flow, Non-Uniform - When the depth of flow changes along the length of the open channel

Flow, Steady - When the quantity of water passing any section is constant with time; at any point, the rates of inflow and outflow must be constant and equal

Flow, Uniform - Flow which results from a constant channel cross section, grade, and roughness; depth, slope, and velocity will remain constant over a given length of channel;the slopes of the channel bottom, hydraulic gradient, and energy gradient are equal

Flow, Unsteady - When there are variations in the discharge with time

Footprint Bridge Program - Program to replace bridges roughly within their existing location to expedite replacement of deficient structures

Freeboard - Distance between the allowable headwater and some reference point (e.g., the edge of the pavement surface)

Freeway - Roadway primarily for interstate travel (very high mobility, limited access)

Freeway Lane Drops - Where the basic number of lanes is decreased

Frontage Road - Local street or road along an arterial highway allowing control of access and service to adjacent areas and property; also called a service road

Frost Heave - Raising of a pavement surface due to the accumulation of ice in the underlying soil or rock

Functional Boundary - Referring to intersections, the lengths of auxiliary lanes, the storage needs for queuing vehicles, and acceleration and deceleration distances

Functional Classification - Classification of roadway types based on the degree of access and mobility provided

Functionally Obsolete - Refers to a bridge which has no structural deficiencies but does not meet standards to adequately serve current user demands

G

Gabion - Galvanized wire box filled with stones used to form retaining walls

Gateway - Street-side feature, located close to the pavement edge, which appears to narrow the road and therefore reduce the operating speed of approaching motorists

Geographic Information System (GIS) - Computer system capable of assembling, storing, manipulating, and displaying geographically referenced information

Geometric Improvements - Improvements which focus on increasing intersection capacity and enhancing safety; often involve widening to provide auxiliary turn lanes and the installation or modification of traffic signals

Glare Screen - Device which may be used as part of a median barrier to eliminate headlight projection from oncoming vehicles; plantings often considered as an alternative

Gore - Area where a ramp diverges from the mainline; normally considered to be both the paved triangular area between the through lane and the exit lane and the unpaved graded area which extends downstream beyond the gore nose

Grade - Slope of roadway surface

Grade Separation - A crossing of two roadways, a roadway and railroad, or a roadway and a pedestrian/bicycle facility at different levels

Gradient - Percent of vertical or longitudinal slope

Greenway - Generally an unpaved trail that serves hikers, mountain bikers, equestrians, or other off-road users

Groundwater - Water beneath the earth's surface that is stored naturally in aquifers, or that flows through and saturated soil and rock, supplying springs and wells

Growth Center - Area designated by the Federal Highway Administration for the purpose of studying economic growth performance

Guard Rail - Steel rail at the shoulder edge of a highway, usually in front of roadsize hazards

Gunite - Mixture of cement, sand, and water that is sprayed on a surface under pneumatic pressure

H

Habitat Fragmentation The subdivision of once large and continuous tracts of habitat into smaller patches

Habitat Loss - Loss of habitat which occurs when an area previously providing food, cover, shelter, or breeding habitat is developed

Haul Road - Temporary or permanent road over which freight or construction materials are transported from a loading site to a public road; also know as an access road

Hay Bale – A conglomeration of cut grasses bound together installed as method of erosion control during construction

Hazardous Material - Substance or material that poses a risk to the safety and health of the community and the environment and has been identified and listed by the USDOT or other agency

Hazing - Non-lethal approach for reducing roadway conflicts between traffic and wildlife, i.e. annoyance

Headwall - The supporting structure at the end of a drainage structure

Headwater (HW) - Vertical distance between the invert at the culvert inlet and hydraulic gradeline (water surface)

Herbicide – Chemical used to kill unwanted plants

High Occupancy Vehicle (HOV) Lane - Lane designated for the exclusive use of high-occupancy vehicles, such as carpools, vanpools, other ridesharing modes, and buses

High-Speed Roadway - Roadway with a design speed of 45 mph or greater

Highway Corridor Overlay District (HCOD) - Set of zoning regulations for parcels within a certain distance from a roadway, usually an arterial highway, which govern access, visibility, and corridor aesthetics

Historic District - An area, usually classified through zoning, with an identifiable geographic boundary that contains a significant concentration or continuity of sites, buildings, structures or objects united by past events or aesthetically by plan or physical development

Horizontal Curve - Bend from a straight line along a roadway

Hydraulic Analysis - Analysis to determine hydraulic adequacy of the structure or the effect on the floodplain where bridges or structures are involved

Hydraulic Design - A branch of engineering dealing with liquids in motion

Hydraulic Grade Line (HGL 1) - Line defined by the water surface in an open channel

(2) - A line representing the potential energy of the water flow; in closed pipes, also called the pressure line

Hydraulic Gradient - Slope of the hydraulic grade line

Hydraulic Jump - Abrubt, turbulent, transition from super-critical flow to sub-critical flow

Hydraulics - Study of the properties, movement, and behavior of water flowing in open channels or pipes

Hydrograph - Graph showing flow, stage, velocity or discharge with respect to time, for a given point in the stream

Hydrologic Analysis - Analysis performed to determine the peak discharge of a water way for the selected design year

Hydrologic Method - Method used to provide the estimated discharge expected at a specific location for a given design year, frequency, drainage area, and set of hydrologic conditions

Hydrology - Study of the properties, movement, and behavior of water on the land surface and underground

I

Impact - Effect of any direct man-made actions or indirect repercussions of man-made actions on existing physical, environmental, social, or economic conditions

Impact Energy Attenuator - Protective system that prevents an errant vehicle from impacting a hazard by either gradually decelerating the vehicle to a stop when hit head-on or by redirecting it away from the hazard

Infrastructure - Basic facilities, services, and installations needed for the functioning of a community or society, including water and sewage systems, lighting, drainage, parks, public buildings, roads and transportation facilities, and utilities

Inlet - Structure with an opening allowing for water to enter

Inlet Control - Discharge capacity which is controlled by the conditions at the culvert entrance, including the depth of headwater and entrance geometry (barrel shape, cross-sectional area, and type of inlet edge)

Interchange - Provides access between roadways by incorporating a network of ramps

Interchange Spacing - Distance measured along the main roadway between the centerlines of the intersecting roadways

Interchange, Cloverleaf - Interchange used at four-leg intersections which combines the use of one-way diagonal ramps in each quadrant for right turns with loop ramps in each quadrant to accommodate left turn movements; an interchange with loops in all four quadrants is called full cloverleaf

Interchange, Compressed Diamond - Diamond interchange where the nearest ramp terminal is less than 200 feet from the bridge; often used where right of way is restricted

Interchange, Diamond - Interchange which uses one-way diagonal ramps in each quadrant with two at-grade intersections provided on the minor road

Interchange, Directional - Interchange where one or more left-turning movements are provided by direct connection, even if the minor left-turn movements are accommodated on loops

Interchange, Fully Directional - Interchange where all left-turning movements are provided by direct connections

Interchange, Semi-Directional - Interchange where one or more left-turning movements are provided by semi-direct connections, even if the minor left-turn movements are accommodated on loops

Interchange, Service - Interchange which connects a freeway to a lesser facility; typically diamond, cloverleaf, or partial cloverleaf interchanges

Interchange, Single Point Urban (SPUI) - Interchange which consolidates left-turn movements to and from entrance and exit ramps at a single intersection

Interchange, Systems - Interchange which connects freeway to freeway; typically three-leg, full cloverleaf, or directional interchanges

Interchange, Three-Leg - Interchange provided where major highways begin or end; also known as T- or Y-interchanges

Inter-Parcel Connections - Driveway and sidewalk connections between commercial sites, so that traffic moving from one to the other need not access the public street

Intersection - Area where two or more streets cross at grade, including areas needed for all modes of travel (pedestrian, bicycle, motor vehicle, transit)

Intersection Alignment - Alignment which controls the centerlines of both the main and cross streets, in turn establishing the location of all other intersection elements (for example, edge of pavement, pavement elevation, and curb elevation)

Intersection Leg - Segment of roadway adjacent to an intersection

Intersection Sight Triangle -Triangular-shaped zone, sufficiently clear of visual obstructions to permit drivers entering the intersection to approach and negotiate it safely

Intersection Spacing - Spacing of intersections, particularly for urban streets, to minimize the possibility of conflicts in traffic operations between adjacent intersections
Intersection, Channelized - Intersection which uses raised islands to designate the intended vehicle path

Intersection, Flared - Intersection in which the typical cross section of the street (main, cross or both) is expanded, often to accommodate a left-turn lane

Intersection, Multi-Leg - Intersection with five or six legs

Intersection, Simple - Intersection which maintains the street's typical cross section and number of lanes throughout the intersection, on both the main and cross streets.

Intersection, Skewed -Intersection in which the angle of intersection departs significantly (more than approximately 20 degrees) from right angles

Invasive Species - A species that is non-native (or alien) to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health

Island, Central - Island which consist of a core area not intended to be traversed by vehicles, bordered by an apron of a slightly raised pavement not intended to be used by the design vehicle, but readily useable by the inner rear wheel track of larger vehicles

Island, Divisional - Island useful in dividing opposing directions of traffic flow at intersections on curves, or with skewed angles of approach

Island, Refuge - Pedestrian refuge within the right-of-way and traffic lanes of a highway or street; also used as loading stops for light rail or buses

Island, Splitter - Island which guides traffic into a roundabout, separates the entering and exiting traffic streams, assures a merge between entering and circulating traffic at an angle of less than 90 degrees, and assists in controlling speeds; may also provide a refuge for pedestrians and bicyclists, and can be used as a place for mounting signs or landscaping

K

K-Factor - Percent of daily traffic that occurs during the peak hour; PH = (ADT)(K)

L

Land Use - Occupation or utilization of land or water area for any human activity purpose, typically classified under a system which designates the appropriate uses of particular properties

Lateral Clearance - An area relatively flat and free of obstacles beyond the edge of the travel way for the recovery of out-of-control vehicles

Layer Coefficient - Relative structural value of each pavement layer per inch of thickness; multiplied by the layer thickness to provide the contributing structural number for each pavement layer

Leading Pedestrian Interval - Advance walk signal for pedestrians before motorists get a green signal, giving the pedestrian several seconds to start in the crosswalk where there are vehicular turning movements across the crosswalk

Left-Turn Lane - Lane which removes stopped or slow-moving left-turning vehicle from the stream of through traffic

Level of Service - Measure of user satisfaction with degrees of movement through a transportation network

Live Crown Ratio - Ratio of length of live crown to the height of the tree

Living Fence - A barrier of native plantings created to minimize or mitigate potential wildlife or visual impacts as part of the retrofitting of roadways

Loam - Soil composed of sand, silt, clay, and organic matter, with particles of various sizes, evenly mixed; generally contain more nutrients than sandy soils and retain water easily

Local Road / Street - Roadway that permits access to abutting land (high access, limited mobility)

Longitudinal Drain - Perforated pipe running beneath the roadway to collect the subsurface water

Longitudinal Slope - Either a foreslope, which occurs when the roadway is located on a fill and the clear zone slopes down from the roadway, or a backslope, which occurs when the roadway is located on a cut and the clear zone slopes up from the roadway

Low-Speed Roadway - Roadway with a design speed of less than 45 mph

M

Macadam - Roadway surface pioneered in the early 1800s comprised of small pieces of stone compacted with a heavy roller; tarmacadam, or tarmac, is macadam combined with tar to bind the stones; often erroneously used in reference to bituminous concrete

Macrotexture - A function of aggregate gradation; provides passages for water to escape from the tire-pavement interface, thereby reducing hydroplaning; becomes more important as speed increases

Main Street - Intersecting street with greater traffic volume, larger cross section, higher functional class, and greater continuity

Major Arterial - Roadway that services statewide travel as well as major traffic movements within urbanized areas or between suburban centers (high mobility, limited access)

Major Collector - Roadway that links arterial roadways and provides connections between cities and towns (moderate mobility, moderate access)

Major Fork - Area where a freeway separates into two freeways

Manhole - Underground structure with an opening for manual access

Match Line – A plan element which designates where the information tires to another sh

Median - Portion of a roadway separating opposing directions of the traveled way, with purpose and design varying depending on roadway type may be traversable or nontraversable

Median Barrier - Double faced longitudinal barrier system normally used in narrow medians for separating opposing traffic or for separating traffic flowing in the same direction, i.e. collector-distributor roadways and High-Occupancy Vehicle lanes

Median Barrier, Blocked-Out Thrie Beam - System which may be used on highway facilities with design speeds over 40 mph

Median Barrier, Blocked-Out W-Beam - System which may be used as median barrier on roadways with design speeds of 40 mph or less

Median Barrier, Concrete Double-Faced - Reinforced concrete barrier in which the sloped shape of the face is designed to minimize occupant injury, redirection into traffic, and the possibility of rollover; the F-shape and Jersey shape are used for this barrier systems, though the F-shape is preferred because it better redirects passenger vehicles

Median Swale - Shallow, depressed area in a median which drains the median area of a divided highway

Median, Depressed - Unpaved median which is lower in elevation than the traveled way and provides for a drainage ditch below the roadway gravel subbase

Median, Flush - Painted or deliniated through a contrasting surface material such as scored white concrete; generally paved and may or may not have a barrier depending on traffic conditions; normally crowned to provide positive drainage and discourage parking.

Median, Raised - Median which is higher in eleveation than the traveled way and usually outlined with a berm or curb

Metropolitan Planning Organization (MPO) - Federally mandated transportation decision-making organization charged with allocating federal funding to transportation projects

Microclimate - A local zone in which the climate differs from the surrounding area

Microhabitat - Immediate surroundings and other physical factors of an individual plant or animal within its habitat

Microtexture - Determined by the surface roughness of aggregate particles; roughness penetrates the water film on the road surface to provide direct contact with the tire, ensuring skid resistance at low speeds

Minor Arterial - Roadway that links cities and towns in rural areas and interconnects major arterials within urban areas (moderate mobility, limited access)

Minor Collector - Roadway that connects local roads to major collectors and arterials (moderate mobility, high access)

Mobile Work Zone - Activities that progress along the road either intermittently or continuously, often involve frequent stops for litter cleanup, pothole patching, or utility operations

Mobility - Ability to move or be moved from place to place

Mode - Particular means of transportation (e.g., transit, automobile, bicycle, walking)

Multi-modal - Serving multiple user groups, including motor vehicles, pedestrians, bicyclists, and transit vehicles

N

Native Species - Species that occur in a region as result of natural forces rather than as having been brought in by humans, either intentionally or accidentally

Natural Site - Location (urban or rural) where the principal objectives concern natural systems

Neighborhood - Group consisting of all persons who live in local proximity; neighborhoods form the more or less cohesive cells of a larger community

Newsletter - Forum for public meeting notification and periodic updates of project status and decisions, either traditionally mailed or electronically distributed

Noise Wall - Wall installed where traffic noise exceeds or is expected to exceed established threshold levels

Non-Traversable Median - Median which separates opposing traffic

O

Off-Road Path - Dedicated pedestrian facility, often in rural and suburban low density areas, which follows but is set back from the roadway and can deviate around sensitive environmental areas

Office Calculation Book (OCB) - Documentation which contains all calculations together with locations of the contract quantities as listed in the proposal

Open Channel - Roadside drainage channel which removes and diverts surface runoff from the highway right-of-way

Open House - Informal conversation about a project, the design elements, and its potential impacts which often involves discussion of details of interest to particular individuals

Operating Speed - A speed measurement that reflects the majority of motorists

Outfall – Location where a river, drain, or sewer discharges into the sea, lake, etc.

Outlet Control - Discharge capacity which, in addition to the entrance conditions, is controlled by the culvert characteristics and outlet conditions, including culvert length and slope and depth of tailwater

Overbank - Water flow over the top of a bank

Overdesign – Selection of design values for infrastructure to meet conditions that will rarely occur, if ever

Overpass - Grade separation where a roadway passes over an intersecting roadway or railroad; also called over-crossing

Overpass, Railroad - Structure that carres a roadway over railroad traffic

Overtopping - Flow of water over the top of a dam or embankment

P

Paratransit - Alternative mode of high occupancy passenger transportation that does not follow fixed routes or schedules

Park and Ride Facility - Lot which provides a collection point for travelers to transfer between the automobile mode and transit, or between the single occupant vehicle (SOV) and high occupancy vehicle modes; other modes potentially supported include pedestrian, bicycle, paratransit, intercity bus transit, airport service, and intercity and commuter rail

Parking, Back-In Diagonal - Method of parking whereby cars are parked at an angle with the front bumper of each car facing the roadway and the rear bumper facing the curb

Parking, Diagonal - Method of parking whereby cars are parked at an angle with the front bumper of each car facing the curb and the rear bumper facing the roadway

Parking, Parallel - Method of parking a vehicle in parallel to other parked cars; cars parked in parallel are in one line, parallel to the curb, with the front bumper of each car facing the back bumper of an adjacent one

Patch – A small, isolated section of habitat

Path Crossing, Mid-Block - Path which crosses a street at a location other than an intersection

Paved Waterway – An open channel which conveys water using a durable lining such as concrete

Pavement – The constructed surface for the facilitation of vehicular movement

Pavement Corner Radius - Curve connecting the edges of pavement of intersecting streets

Pavement Design - Design of the foundation and surface of pavement

Pavement Drainage - Storm discharge from pavements

Pavement Marking - The lane lines or symbols affixed to pavement surfaces

Pavement Overlay - Needed thickness of hot mix ashpalt is placed on an existing pavement

Pavement Structure - Combination of sub-base, base course, and surface course placed on a subgrade to support the traffic load and to distribute it to the roadbed

Pavement, Flexible – Hot mix asphalt; consists of three layers - subbase (foundation), base, and surface

Pavement, New - Pavement structure placed on a previously undisturbed subgrade

Pavement, Reconstructed - Existing pavement structure is completely removed to the subgrade and replaced with a new pavement structure

Pavement, Recycled - Existing pavement structure (from which all or part of the pavement is removed on or off site), is combined with new materials and replaced; recycling is performed in conjunction with a pavement overlay or reconstructed pavement

Pavement, Rigid - Portland cement concrete placed on a granular subbase; portland cement pavements are either plain and jointed or reinforced

PDE - MassHighway Pavement Design Engineer

Peak-Hour Factor (PHF) - Ratio of the volume occurring during the peak hour to the maximum rate of flow during a given time period within the peak hour; typically five minutes for freeways and 15 minutes for intersections

Peak-Hour Traffic (PH) - Highest number of vehicles passing over a section of highway during 60 consecutive minutes; T(PH) is the PH for truck traffic only

Pedestrian Count/Demand – Data collection to determine sidewalk demands, crossing demands, and corner reservoir demands (total number of pedestrians waiting to cross the street); usually conducted when vehicle turning movement counts are completed

Permanent Sedimentation Basin - Basin designed for use during construction, but intended to remain as a permanent facility; may be used for stormwater once it is cleaned out after construction

Permeability (1) – The degree to which a material allows the passage of another material
(2) – The degree to which a road presents a barrier to wildlife or other activity

Plan - Documentation prepared to convey physical information so that designers, reviewers, and the public can understand both the existing conditions and the project; plan also allow a contractor to construct the project and define the right-of-way available or to be acquired

Planning - Phase of the project in which the proponent identifies issues, impacts, and potential approvals so that subsequent design and permitting processes are understood

Plan, Base - Plan which shows all man-made and natural features located within the proposed project limits

Planimeter - Technical drawing instrument used to measure the surface area of an arbitrary two dimensional shape by tracing the perimeter

Planting Pit - Pit for planing of a tree which extends beneath and provides structural support to sidewalks, allowing sufficient room for root growth

PONTIS - System used by most state transportation departments to record, organize, and analyze bridge inventories and inspections

Population Fragmentation - Fragmentation of plant and animal species into smaller isolated populations

Profile - Side view of roadway or ditch grade; line showing ground elevations or a vertical section along a horizontal survey line

Project Area - Area to which proposed activities are limited

Project Development - The process that takes a transportation improvement from concept through construction

Project Information Board - Board posted at project site which illustrates project details and provides contact information to facilitate community involvement

Project Need - Condition, deficiency, situation or opportunity, that indicates the need for action

Project Review - Formal review which gives full consideration to the project's viability and design details

Proponent - Individual or organization that proposes, prepares, manages, and implements a project

Public Hearing - Legally recognized formal meeting held at particular time(s) during the project development and design phases

Public Meeting - Informal gathering of designers, officials, and local citizens to share and discuss proposed actions; a forum for public participation in a project

R

Rail Trail - A former railway line converted to a path designed for pedestrian, bicycle, skating, equestrian, and/or light motorized traffic (snowmobiles, etc.)

Raised Crosswalk -Speed hump frequently used to complement pedestrian crossings, particularly where curb extensions are in place, also called flat-top speed hump

Raised Intersection - Flat-top hump extended to an entire intersection, raising the entire intersection to sidewalk height or nearly so

Ramp -All types, arrangements, and sizes of turning roadways that connect two or more legs at an interchange

Ramp, Entrance - One-way roadways which allow traffic to enter a freeway

Ramp, Exit - One-way roadway which allows traffic to exit from the freeway and provide access to other crossing highways

Recharge - Addition of water to the aquifer by natural or artificial means

Recovery Area - Traversable, unobstructed roadside area beyond the edge of the traveled way, available for safe use by errant vehicles; also called a clear zone

Reclamation - Reusing existing paving materials for the rehabilitation and maintenance of pavements, conserving energy, aggregates, and asphalt

Reflectorized Drum -Plastic drum, sometimes with a steady-burn light or flashing, used in roadway work zones

Regional Transportation Plan - Plan which summarizes regional transportation goals and objectives, describes the regional transportation system and existing conditions, evaluates alternative courses of action, and recommends short- and long-term strategies and actions; prepared by MPOs every three years

Rest Area - Area that provides a location for travelers to relax and take a break from highway travel; often serves multiple purposes, providing comfort stations, and in some cases, food and beverage services

Restoration - The repair and/or replacement of specific lost functions within a natural system, such as habitat, water buffers, and soil function

Resurfacing - Application of an additional surface to an existing base pavement or wearing surface to improve the ride, strength, or safety of the pavement

Reverse Curve - Two simple curves joined together, but curving in opposite directions

Rhizomes - A usually-underground, horizontal stem of a plant that often sends out roots and shoots from its nodes

Right-of-Way - The land (usually a strip) acquired for or devoted to highway transportation purposes

Right-Turn Lane - Lane which removes decelerating right-turning vehicles from the traffic stream

Riparian Zone -Interface between land and water; area adjacent to water courses that are prone to flooding

Riprap -Rock or other large aggregate that is placed to protect streambanks, bridge abutments, or other erodible sites from runoff or wave action

Riprap Basin - Large angular and rounded stones are used at the culvert outlet to dissipate the kinetic energy

Road Closure - Closing of a roadway during construction; often the most efficient arrangement from a construction perspective as it isolates construction from the public

Road Diet - Allocation of the pavement width of the street in a manner that gives more space to pedestrians, bicycles, and parking, reducing the width of the motor vehicle traveled way

Road Ecology - The study of the interaction of organisms and their environment linked to roads and vehicles

Roadside Barrier - Longitudinal barrier used to shield motorists from natural or manmade obstacles located along either side of a roadway; occasionally used to protect pedestrians and bicyclists from vehicular traffic

Roadside Barrier, Blocked-Out Thrie Beam - Barrier system which is similar to the normal steel beam guardrail, except a deeper corrugated metal face is used to minimize the possibility of underride or vaulting by impacting vehicles
Roadside Barrier, Blocked-Out W-Beam - Barrier system which uses a heavy post (steel or wood) with a block out and corrugated steel face (W-beam)

Roadside Barrier, Concrete Safety Shape - Most commonly the F-shape concrete barrier which is preferred because of its better performance with small vehicle impact with respect to vertical roll and redirection

Roadside Barrier, Steel-Backed Timber Rail - Barrier system which consists of heavy wood rail backed with a steel plate installed on heavy wood posts; rustic appearance is sometimes compatible with the surrounding area, but it may be used only on low volume facilities with design speeds under 55 miles per hour

Roadway Alignment - The vertical and horizontal location of a road

Roadway Landscape - Interface between the functional area of a road and the community or environment through which it passes

Roughness Coefficient - A factor in the Kutter, Manning, and other flow formulas representing the effect of channel (or conduit) roughness upon energy losses in the flowing water; abbreviated "n"

Roundabout - Channelized intersection that creates a one-way traffic stream circulating around a central island

Routine Maintenance - Preserving a roadway, roadside, structure, and facility as close as possible to its original condition as constructed

Rub-rail - Part of a physical barrier adjacent to a shared use path often installed to prevent snagging of handlebars

Rumble Strip - Strip of painted, ridged, or grooved road surface to warn drivers when they stray from their lanes onto the shoulder

Runoff - Portion of precipitation that makes its way toward waterways, lakes, or oceans as surface or subsurface flow

Runoff Coefficient - Fraction of total rainfall that will appear as runoff

Runout Length - Distance of barrier needed to adequately shield a roadside hazard

Rural - Refers to areas with large expanses of undeveloped or agricultural land, dotted by small towns, villages, or any other small activity clusters

S

Sag Vertical Curve - Curve that connects descending grades, forming a bowl or a sag

Sand Asphalt - Asphalt consisting of bitumen and sand

Scenic Road - Designation of roadway to ensure that any alterations maintain its historic and natural features and character

Scour - Soil erosion when it occurs underwater, as in the case of a streambed

Sediment - Solid soil material, both mineral and organic, that is being moved or has been moved from its original site by wind, gravity, flowing water or ice

Sediment Basin - Detention areas used to intercept runoff and allow its sediment to settle out; installed to protect streams, rivers, ponds and lakes from the excess sediment produced during construction.

Sediment Control - Control measures designed to collect displaced soil during construction

Sedimentation - The action or process of depositing particles of waterborne or wind-borne soil, rock, or other materials

Semi-Direct Ramp Connection - Ramp that is indirect in alignment yet more direct than loops

Serviceability Index - Measure of a pavement's ability to serve automobile and truck traffic on a scale of 0 to 5; reflects the extent of pavement distress

Shared Lane - Vehicular travel lane shared by pedestrians, particularly on low-traffic and low-speed roadways

Shared Street - Street designed to be fully part of the public realm and integrated into the surrounding context; examples include plazas in a town center, market places with street vending, streets regularly used for festivals, and places of unusual civic interest

Shared Use Path - Facility for non-motorized users that is independently aligned and not necessarily associated with parallel roadways; designed to accommodate a variety of users, including walkers, bicyclists, joggers, people with disabilities, skaters, pets and sometimes equestrians.

Shoulder - Portion of a roadway adjacent to a traveled way for accommodation of stopped vehicles, for emergency use, and for lateral support of the base and surface courses

Sidewalk – Path for pedestrian travel which follows a street and occupies the border between the vehicular travel ways and private property

Sight Distance - Line of sight available to the driver to see another roadway user or a fixed object

Sight Distance, Decision - Distance required for a driver to detect an unexpected or otherwise difficult-to-perceive information source or hazard in a roadway environment that may be visually cluttered, recognize the hazard or its threat potential, select an appropriate speed and path, and initiate and complete the required safety maneuver safely and efficiently

Sight Distance, Intersection - For a two-lane highway, the operator of a vehicle approaching an intersection should have an unobstructed view of the entire intersection, including any traffic control devices, and an adequate view of the intersecting highway to anticipate and avoid potential collisions

Sight Distance, Passing - For a two-lane highway, the distance needed to enable a driver to pass a vehicle without interfering with an oncoming vehicle which appears when the passing vehicle begins its maneuver

Sight Distance, Stopping - Absolute minimum sight distance that should be provided at any point on the highway; the sum of two distances: (1) the distance traveled during driver perception/reaction time and (2) the distance traveled during brake application

Signal Timing – The operational program for a traffic signal and resulting assignment of right-of-way to different users

Silt Fence - Temporary barrier made with a geotextile filter fabric which traps sediment before it leaves a construction area

Simple Curve - The most frequently used curve because of its simplicity for design, layout, and construction; has a constant circular radius which achieves the desired deflection without using an entering or exiting transition

Siphon - Continuous tube that allows liquid to drain from a reservoir through an intermediate point that is higher than the reservoir, the up-slope flow being driven only by barometric pressure without any need for pumping

Skid Number - Measure of skid resistance

Skid Resistance - A function of the pavement surface texture, which is a combination of fine (or micro-) texture and coarse (or macro-) texture

Soil Quality - Evaluation of soil for texture, pH, moisture and biology

Soil Support Value (SSR) - Index of the relative ability of a soil or stone to support the applied traffic loads

Sound Attenuation - Reduction in the intensity or in the sound pressure level of sound

Special Provisions - Developed by the project designer to explain conditions or special construction practices not covered in the current edition of the Massachusetts Standard Specifications for Highways and Bridges or Supplemental Specifications to the Standard Specifications for Highways and Bridges.

Specific Energy - Total energy head at a cross section measured from the bottom of a channel; the sum of the potential head (depth) and the velocity head (kinetic energy)

Specifications - Define the materials and methods to be used by the contractor when constructing a project

Speed Cushion - Variety of flat-top hump that does not extend fully across the street, but rather affects only one side of the vehicle

Speed Hump - A measure which controls vehicle speed by allowing vehicles operating at intended speeds (typically 15-20 miles per hour) pass with little discomfort to the driver

Speed Hump, Flat-Top - Speed hump frequently used to complement pedestrian crossings, particularly where curb extensions are in place; also called raised crosswalk

Speed Hump, Round-Top - Speed hump that are 12-14 feet in length and rise to a height of 3-4 inches with a parabolic crown profile

Splash Pad - Energy dissipator installed at culvert outlets for erosion control purposes

Spot Narrowing - Narrowing of a street at a mid-block location to reduce the speed of vehicles

Spot Traffic Calming - Measures applicable to only a small segment of street

Stakeholder - Individual having an interest or share in a project, or who may be impacted by the outcome of a project, either directly or indirectly

Station - Unit of measurement consisting of 100 feet in horizontal distance

Stationary Work Zone – A location where construction activity proceeds in-place for a certain duration

Stilling Well - Device which dissipates the kinetic energy by forcing the flow to travel upward to reach the downstream channel

Stop Control, All-Way - Traffic on all approaches controlled by “STOP” signs

Stop Control, Two-Way - Traffic controlled by "STOP" sign on the cross street approaches; main street traffic is not controlled; typically applied to "T" intersections, even though there may be only one approach under stop control

Storage Area - Auxiliary lane approaching an intersection which stores turning vehicles expected to accumulate during an average peak period

Storage Area - Water storage within the banks of the channel (channel storage)

Storm Drain System -Closed system which conveys storm runoff

Street Furniture - Elements such as trees, signs, signals, street lights, walls, fencing, and pedestrian furnishings such as benches, shelters and trash receptacles

Streetscape - The road and its surrounding built environment as a whole

Structural Capacity - Capacity of a facility to support the traffic load

Structural Number (SN) - Measure of the structural strength of the pavement section based on the type and thickness of each layer within the pavement structure

Structurally Deficient - Refers to a bridge structure that has a defect requiring corrective action

Subcritical Flow - Flow which occurs when the depth is greater than critical and the velocity is less than critical

Substructure - Part of a bridge structure that includes the cap and foundations of the abutments and the cap, columns, and foundations for bridge piers or support columns

Subsurface Drainage - Drainage system below the roadway surface provided to maintain the integrity of the roadway structure

Suburban - Refers to fringes of metropolitan areas that are typically lower density than cities and where land uses are widely variant

Supercritical Flow - Flow which occurs when the depth is less than critical and the velocity is greater than critical

Superelevation - Geometric design element employed to counterbalance the centrifugal force, or outward pull, of a vehicle traversing a horizontal curve; refers to the method of banking the roadway by attaining a vertical difference between the inner and outer edges of pavement

Superelevation Runoff - Length of highway needed to accomplish the change in cross slope from a section with adverse crown removed to a fully superelevated section, or vice versa

Superstructure - Part of a bridge structure that includes bridge deck and beams
Survey - Process by which boundaries are measured and land areas are determined; drawing showing the legal boundaries of a property

Sustainable Development - Development that meets the needs of the people today without compromising the ability of future generations to meet their own needs

T

Tailwater (TW) - Vertical distance between the invert at the culvert outlet and depth of water; often be determined by conditions downstream from the culvert

Tangent Runout -Length of highway needed to accomplish the change in cross slope from a normal section to a section with the adverse crown removed, or vice versa

Temporary Berm - Ridge of compacted soil which intercepts and diverts runoff from small construction areas

Temporary Sediment Trap - Small sediment basin intended for short-term use, often at a construction site

Temporary Sedimentation Basin - Sedimentation basin intended to remain operational during the entire construction period

Temporary Slope Drain - System which carres water from a work area to a lower elevation, typically down an embankment; helps prevent erosion of the slope until permanent protection is established

Terminal Serviceability Index - Pavement design factor which indicates the acceptable pavement serviceability index at the end of the selected design period (usually 20 years)

Terracing - Grading technique that reduces erosion and enhances soil stability; in general, terraces should be provided at approximately 20 foot intervals

Terrain - Physical features of a tract of land

Textured Pavement - Pavement which encourages motorists to be aware of an area of special concern due to the appearance of the texture, vibration, more noticeable motion of the vehicle, and tire noise

Thickly Settled District - Area in which houses or buildings are, on average, fewer than 200 feet apart for a length of ¼ mile

Time Restriction - Restriction of construction activities to off-peak travel periods

Traffic Calming - Physical road design elements intended to reduce vehicle speeds and improve driver attentiveness

Traffic Control Device - Any sign, signal, or marking installed for the purpose of regulating, warning, informing, or guiding traffic

Traffic Forecast - Technical analysis and policy consensus on future traffic volumes resulting from the type and intensity of land use, future regional economic activity, presence of transit service, the needs of pedestrian and cyclists, and many other factors

Traffic Impact and Access Study (TIAS) - Assessment of the impacts on nearby roadways of new development proposals, often resulting in commitments for access design and offsite roadway improvements

Temporary Traffic Control Plan - Plan which depicts the basic layout of the worksite, the resulting configuration of lanes, and the placement of signage, barriers, and other traffic control devices

Traffic Signal – Electronic device which assigns right-of-way to both motorized and non-motorized traffic through the use of alternating visual indicators

Transit - Public transportation, especially rail and bus services

Transit Center - A multi-modal facility, often located within major activity center, connecting various regional, express, circulator and local bus services with each other and providing vehicular, bicycle and pedestrian access to these services

Transportation Demand - Demand by motorists, pedestrians, and bicyclists for a facility, assessed in terms of volume, composition, and patterns

Transportation Demand Management (TDM) - Programs designed to reduce demand for transportation through various means, such as the use of transit and alternative work hours

Transportation Improvement Program (TIP) - Five year funding program that allocates state and federal transportation funds, both highway and transit, for the region; prepared by MPOs every year

Transverse Drain - Lateral pipes used to carry subsurface water away from the pavement structure or side slope

Transverse Slope - Slope of a line parallel to the roadway, offset into the clear zone, created by median crossovers, berms, driveways, or intersecting side roads

Travel Lane - Portion of a roadway for the movement of vehicles, exclusive of shoulders and auxiliary lanes

Traversable Median - Median typically built of textured or contrasting materials such as stamped concrete, bricks, pavers, or cobblestones; flush with the travel lanes but notably different in appearance and in feel to the driver; can be an effective traffic calming device

Treadway - Portion of a pathway designated for a particular user or set of users

Tree Grate - Decorative element installed around the base of a street tree, typically where pedestrian traffic is expected to occur over the tree pit

Turning Movement Count (TMC) - Level of service analysis at an intersection to determine how the intersection operates under different traffic conditions

Turning Roadway - Short segment of roadway accommodating a right turn, delineated by channelizing islands; used where right-turn volumes are very high, and where skewed intersections would otherwise create a very large pavement area

Typical Section - Section which shows usual roadway (or bridge) cross sectional features including lane and shoulder widths; limits of surfacing; pavement structure data including subgrade treatment type and depth, base course(s) thickness(es) and type of surfacing material; travel lane and shoulder cross slopes; side slope rates for cut and fill sections; ditch or storm sewer location and depth; typical right-of-way limits; profile grade line location; typical traffic barrier location median width and slopes; and curb location and geometry

U

Underdesign – A facility that does not adequately serve its user demands

Underpass - Grade separation where a roadway passes under an intersecting roadway or railroad; also called under-crossing

Underpass, Railroad - Structure that passes a roadway under a railroad

Urban - Refers to central business districts, residential districts and open space parks typical of larger cities.

USGS Wandle Method - A hydrologic method used in Massachusetts to estimate peak discharge

Utilities - Facilities, such as sewer/water pumping, storage, substations, switching stations, generation, transformer, relay and electric devices, and transmission or distribution facilities, for telephone, gas, electric, sewer and water

V

Vertical Clearance - Minimum unobstructed vertical passage space required along a roadway, sidewalk, or trail

Vertical Curve - Parabolic curve used to provide a gradual change in grade between roadway segments with differing grades

Viaduct - Elevated roadway span over a valley, floodplain, wetland, or gorge which provides unrestricted wildlife movements or passage of other activity

Volume - Number of vehicles or persons that pass over a given section of a lane, roadway, or other traffic way during a time period of one hour or more; can be expressed in terms of daily traffic or annual traffic, as well as on an hourly basis

W

Walking Speed - Speed at which a pedestrian passes through an intersection or along a facility

Walkway - Interior or exterior pathway with a prepared surface intended for pedestrian use, including but not limited to general pedestrian areas such as plazas, courts and crosswalks

Wasted Pavement - At an intersection, area of pavement unusable by either vehicles or pedestrians

Water Resource Protection - Protection of water quality for public water supply and marine aquatic life

Watercourse - A waterway with bed and banks, either naturally or artificially created, which periodically or continuously contains moving water, or which forms a connecting link between two bodies of water; also called a channel

Watercourse - Any flowing body of water, including rivers, lakes, streams etc.

Watershed – An area of land which contributes flows to a particular watercourse

Weaving Section - Highway segments where the pattern of traffic entering and leaving at contiguous points of access results in vehicle paths crossing each other

Wetland - Land that is transitional between aquatic and terrestrial ecosystems and is covered with water for at least part of the year

Wildlife Crossing Structure - Structure designed to safely move wildlife either over or under a roadway

Wildlife Overpass - Buried highway section that functions by providing a wildlife “bridge” over a highway

Wingwall - Wing portion of a culvert headwall or the wall adjacent to a bridge abutment

Workshop - Informal gathering of designers, officials, and local citizens, usually in smaller groups, to facilitate problem solving around design issues for which several options are available and the best solution is unclear

Work Zone Traffic Control - The planning, design, and preparation of contract documents for modification of the normal traffic and pedestrian patterns during construction

Y

Yield Control - Traffic controlled by “YIELD” signs on the cross street approaches; main street traffic is not controlled