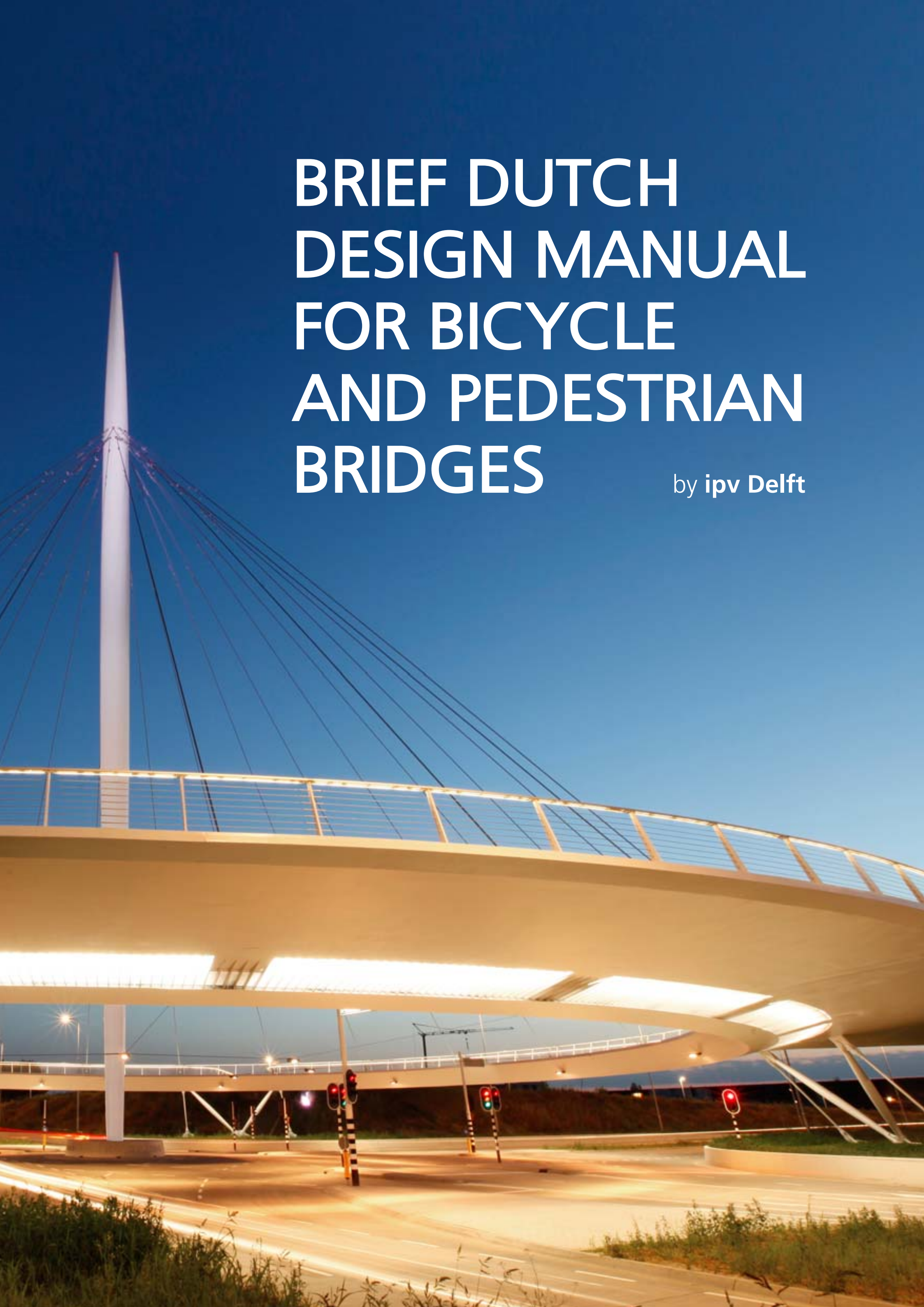
BRIEF DUTCH DESIGN MANUAL FOR BICYCLE AND PEDESTRIAN BRIDGES

by **ipv Delft**



Brief Dutch Design Manual for Bicycle and Pedestrian Bridges

English summary of the CROW design guide

July 2017

by **ipv Delft**

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INTRODUCTION

As more and more people worldwide are living in densely populated urban areas, the added value of cycling as a means to create safer and healthier cities is being increasingly recognized internationally. Countries such as the Netherlands, where cycling has been part of everyday life for decades and cycling infrastructure is fully embedded in town planning, have now become the ultimate example of how to go about creating attractive and well functioning cycling infrastructure.

As one of the main Dutch bridge design offices, ipv Delft has focused on designing bicycle and pedestrian bridges for two decades. Their extensive experience in designing bicycle bridges prompted the Dutch technology platform for transport, infrastructure and public space, CROW, to ask ipv Delft to write the Dutch Design Guide for Bicycle and Pedestrian Bridges, which was published in 2014.

In recent years, ipv Delft received growing international atttention after completion of the renowned Hovenring, a circular cable-stayed bicycle bridge in the city of Eindhoven. When talking to professionals from the field of bridge design and engineering in various countries, the Dutch designers found their knowledge and experience was something that could benefit city councils, engineers and designers worldwide. This realisation led the firm to write an English summary of the Dutch Design Guide for Bicycle and Pedestrian bridges.

This publication focuses on the fundamentals of bridge design, answering practical questions on bridge width and slope design. It also lists all things that should be taken into account before starting on the actual design, and it offers insight in the Dutch regulations regarding regular loads and collision loads. To illustrate the theoretical fundamentals, several of ipv Delft's projects are shown and discussed. General advice on cost reduction is also included, making this publication a vital source of practical information and bridge design inspiration.

< Tanerij Bridge, Zwolle

1 CONTEXT

Once the decision to build a new bicycle or pedestrian bridge has been made, it is key to assess all preferences, requirements, and regulations. Each location also has its own qualities, parties involved, and (im)possibilities. Listing all things that could be relevant to the bridge design is the first step towards building the best possible bridge. It may also reveal contradictions or possible conflicts of interest.

Among the things to assess are subsurface conditions, underground infrastructure, and existing development plans. Future developments need to be taken into account as well, for instance when the new bridge crosses a two lane road that in future will be expanded into a four lane road.

The location itself can also have a large impact on the bridge design. Spatial integration could be challenging, especially when building a bridge in a busy and complex built environment such as inner cities. This chapter will therefore also take a closer look at the main site-specific characteristics that could influence the design, namely existing infrastructure and site adjustment.

In order for the project to succeed, it is vital to have the support of all stakeholders involved. Ask for their opinions right from the start and keep them involved in the project as it unfolds.

As this chapter only briefly points out all aspects that can be relevant (illustrated with pictures and real-life examples), it can best be used as a checklist.

< Bicycle underpass, Haarlem

Figure 1.1 **Pedestrian bridge Waalwijk**
Participation of locals led to a design that refers to the site's railway history

Figure 1.2 **Bicycle bridge Heerhugowaard**
Businesses remain clearly visible due to slender bridge design and transparant railing

Figure 1.3 **Hilversums Kanaal bicycle bridge**
Newly built bicycle bridge respects existing historically significant road bridge

1.1 LOCAL RESIDENTS

- Is participation desirable? (Fig. 1.1)
- Is there a risk of noise nuisance?
  If so: can this be prevented?
- Is there a risk that the bridge will have a negative influence on residents' views from their homes?
  If so: can this be prevented?
- Is there a risk that the bridge invades residents' privacy?
  If so: can this be prevented?

1.2 COMMERCIAL PARTIES

- Could the bridge have a negative influence on the visibility of a nearby company?
  If so: can this be prevented? (Fig. 1.2)
- Does the situation offer any co-financing opportunities?

1.3 OWNERSHIP

- Is there an inventory of the ownership of nearby parcels?
  If so: does it offer potential conflict or possibilities?

1.4 PLANNING

- Does the location have significant historical meaning? (Fig. 1.3)
- What function(s) should the bridge fulfil?
- Does social safety require extra attention?
- Are there sightlines that need to be preserved?
- What new opportunities does the site offer? (Fig. 1.5.)
- Does lighting require extra attention?
- Is there a zoning map?
  If so: does it contradict building a bridge?
  If so: can the zoning map be altered?
  If so: look into what needs to be done.
- Is there a site plan or development plan for the site?
- Are there any plans to possibly expand or adjust existing infra-structure on site in the (near) future?
- Which regulations apply?

1.5 ROAD OR WATERWAY PASSING

- Is there a nearby turn or corner in the road or navigable waterway? (Fig. 1.4.)
  If so: try to refrain from intermediate supports.
- Should that be impossible, make sure the supports do not obstruct views and place them as far apart as possible.
- Are there nearby traffic lights?
  If so: make sure the bridge does not obstruct motorists' views of the traffic lights. (Fig. 1.6)
- Also: ensure motorists notice traffic lights in time to safely reduce speed and stop.

1.6 ECOLOGY

- Is the site part of an ecological zone?
  If so: consult an ecologist.
- Does any type of vegetation at the site require extra care or attention (such as preservation)?
- Does any type of animal at the site require extra care or attention (such as preservation)? Do any trees need to be preserved or replanted?

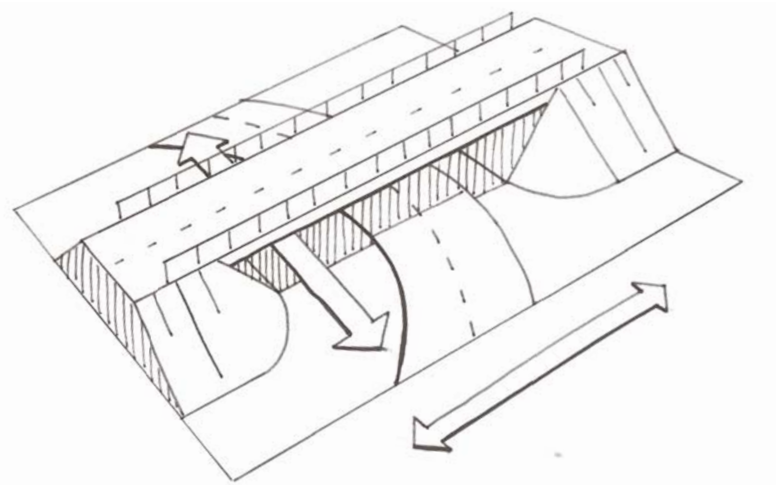


Figure 1.4 Motorists sightlines
Clear sightlines require extended span over curved road

Figure 1.5 Ulft bicycle and pedestrian bridge
Curved layout offers room for benches, adding a function to the bridge

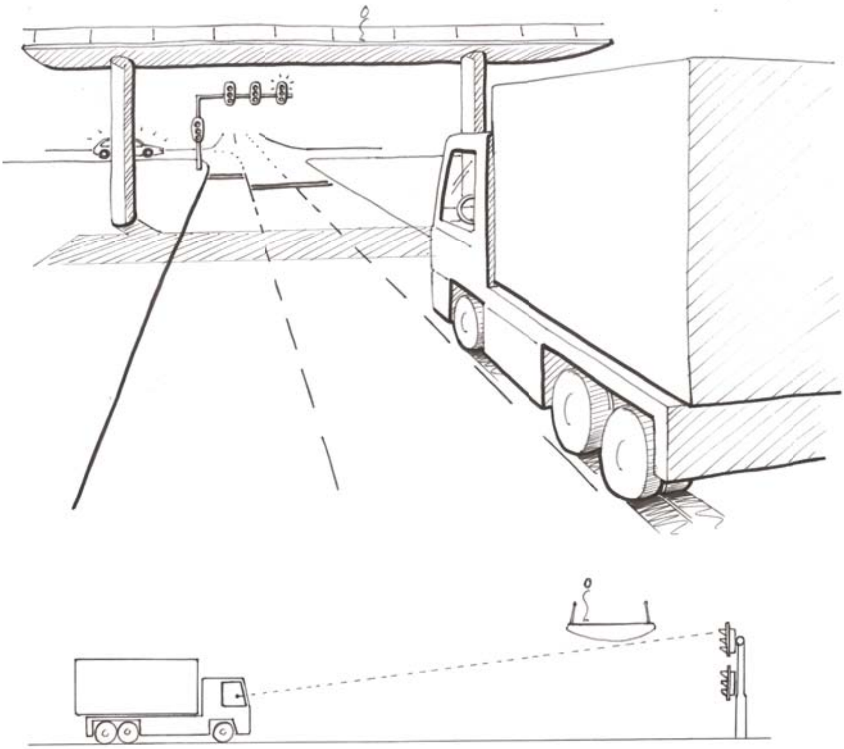


Figure 1.6 Unobstructed view of traffic lights

Positioning
It will sometimes be necessary to opt for another location or a slightly different positioning of the bridge. When the proposed location is right next to a busy intersection, it can be a better option to place the bridge away from the intersection by several meters. On other occasions, a relatively simple adjustment to the site such as lowering the road underneath (Fig. 1.7) or moving the connecting bicycle path might make a big difference to the viability of the project.

1.7 SUBSURFACE

- Has a land survey been done?
- Are there any vibration vulnerable buildings nearby?
- Has a soil survey been done?
- Is calculation of load factors for embankments necessary?
- Are there any factors that might influence planning?
- Is the soil possibly polluted?
- Is soil excavation necessary?
  If so: start necessary procedures, apply for clean up order et cetera.

1.8 INFRASTRUCTURE

- Is there an underground utility map?
  If so: is it recent and likely to be accurate?
- Should the utility company be contacted?
- Are there any underground cables or pipelines that (might) prevent the bridge from being built on this particular location?
  If so: make an inventory of the possibilities.
- Are there any overhead power lines nearby?
  If so: be aware to earth steel structures and check if inspection is required (Fig. 1.9).
- Does the proposed bridge cross any type of railway?
  If so: look into the specific requirements of building across a railway.

1.9 MAINTENANCE

- What is the bridge's required structural lifetime?
- Has a maintenance budget been set for the bridge?
- Does the city council have a maintenance management plan?
- Are there any special desires regarding the bridge's maintenance, such as low or no maintenance?

Figure 1.7 Hovenring
Lowering the intersection underneath allowed for comfortable slopes

Figure 1.8 Nesselande Bridges
Overhead power lines meant the steel bridges had to be earthed

Figure 1.9 Nesselande Bridges
Close-up of earthing system applied

2 USERS

Knowing who will be using the bridge is key to a good design, as is the predicted traffic flow. Types of users, and traffic numbers help define bridge width, railing design, surface layout, and ramp gradient.

The two main groups of users are cyclists and pedestrians. Both have subgroups that may require special facilities. It is essential to also look at these subgroups, as their influence on the design can be rather large. When building a pedestrian bridge near a home for the elderly, a steep incline or steps are out of the question, whereas in a different situation both could most likely be an option.

Sometimes other parties may want to use the bridge structure as well. A pipeline might need to be integrated in the bridge deck or emergency services might have to use the bridge. This chapter will not go into these special types of users extensively, but will name them so their special requirements can be taken into account.

Please note: all measurements are in meters. A conversion table can be found in the Appendix.

< Werkdonken Bridge, BredaW

2.1 PEDESTRIANS

For this publication, anyone traveling by foot qualifies as a pedestrian. This includes people with walking aids or a pushchair, but also people on in-line-skates.

BASIC NEEDS

Key to designing for pedestrians is accessibility. The bridge therefore should ideally:

- Be free of obstacles;
- Have a gentle grade ramp, if any at all;
- Have a smooth connection to the adjoining sidewalk or footpath;
- Not have a very large height difference to cross;
- Have a direct route towards the bridge without the impression of a detour.

Overall, the best way to avoid accessibility issues is to think from the pedestrian's point of view.

SPATIAL NEEDS

In order for all pedestrians to be able to safely use the bridge, the following minimum width (in between railings) should be applied:
1,5 m (preferably 1,8 m). [1][2]

HEIGHT DIFFERENCE

Any height difference larger than 0,21 m should be overcome either by a ramp or one or several steps. When doing so, the following rules apply:

Ramp

The minimum width of a ramp is 1,1 m. The maximum height difference covered by a single ramp is 1 m.
A larger height difference should be overcome by using several ramps, connected by a flat landing. [3][2]

Step

The maximum height difference covered by a single flight of steps is 4 m. A larger height difference requires several flights of steps, connected by a landing of at least 0,8 m x 0,8 m, but preferably 1,2 x 1,2 m. [3][2]

In-line-skaters
When designing several bicycle and pedestrian bridges for a large new recreational park in Rotterdam, special attention was given to creating comfortable routes for in-line-skaters as it was expected that the new park would attract many in-line-skaters. Therefore, the designers did not use wooden bridge decks, as they would be quite uncomfortable for this particular group of users, and went for steel decks instead.

2.2 CYCLISTS

Cyclists come in different shapes, and sizes, as do bicycles (city bikes, mountain bikes, tricycles, electric bicycles et cetera). This publication regards all people on all types of bicycles as cyclists.

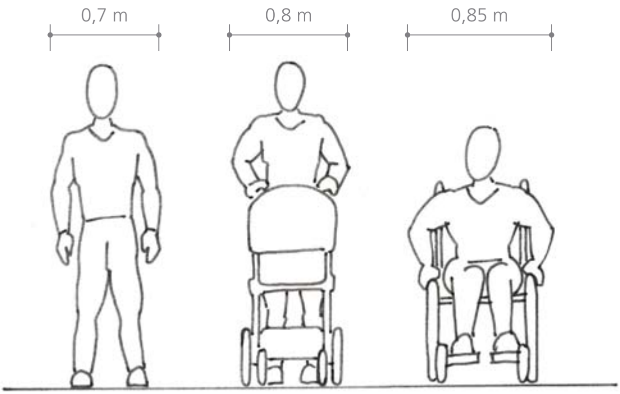


Figure 2.1 **Basic spatial needs**

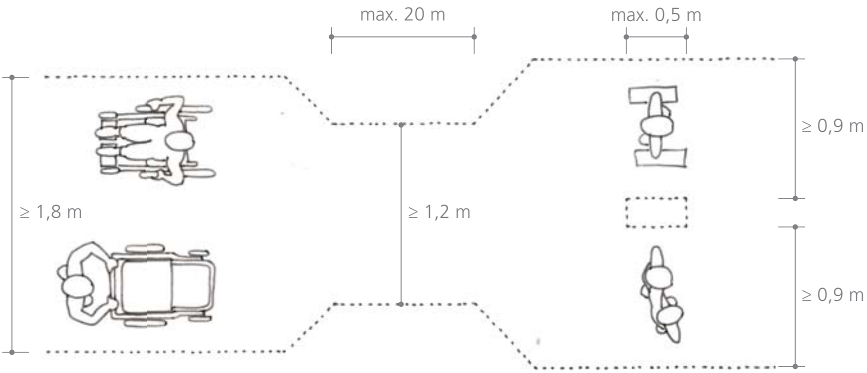


Figure 2.2 **Minimal width for pedestrians**
A 1,2 m width allows for two pedestrians to pass eachother

Figure 2.3 **Bijlmerweide Bridge Amsterdam**

BASIC NEEDS

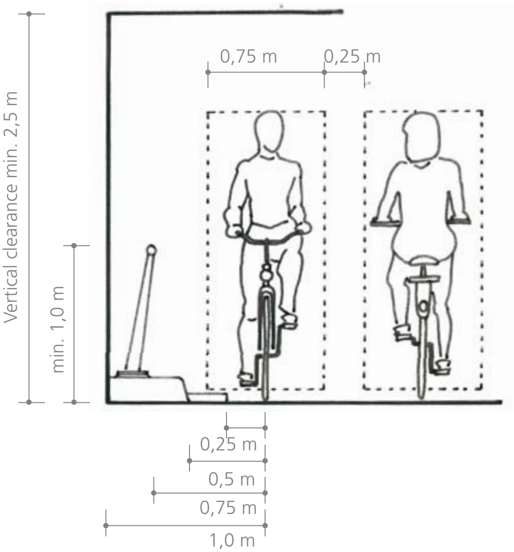
All basic needs described for pedestrians, apply for cyclists too. The main additional aspect to be aware of is that cyclists travel at a much larger speed. Therefore, a bridge should additionally:

- Offer cyclists a clear view of the road;
- Take into account that when traveling uphill, cyclists tend to swerve, and thus need more width/space (from an extra 0,25 m at regular speed to as much as 0,8 m at low speed);
- Take into account that when taking a curve at high speed, cyclists lean towards one side and therefore need more width/space (add an extra 0,5 m to the total width);
- Have at least reasonably comfortable ramps (if any at all) (see chapter 3);
- Have a smooth transition between flat and sloping sections.

SPATIAL NEEDS

In order for all cyclists to be able to safely use the bridge, the following minimum width for a two-way cycling path (in between railings) should be applied:
2,4 m [4][5]

The actual width depends on whether the bridge offers one-way or two-way access, and if it is accessible for scooters and mopeds as well (if so: add 0,5 m to the total width). Finally, the expected number of cyclists using the bridge also influences the deck width. The examples on the right page illustrate how the width can be calculated. (Fig. 2.5 -2.7)



Extra width needed due to presence of:

- raised edge under 0,05 m in height;
- raised pavement or edge over 0,05 m in height
- permanent objects (railings, bollards, traffic signs, trees etc)
- closed wall

Figure 2.4 **Minimal width for cyclists**

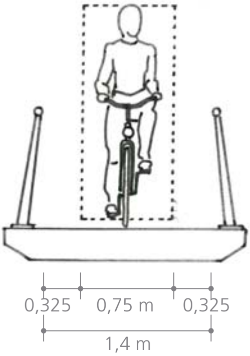


Figure 2.5 **One-way bicycle path**

Bicycle path width

Basic width of cyclist	0,75 m	
Safety margin cyclist - railing	0,325 m	(2 x)
Total width	1,4 m	

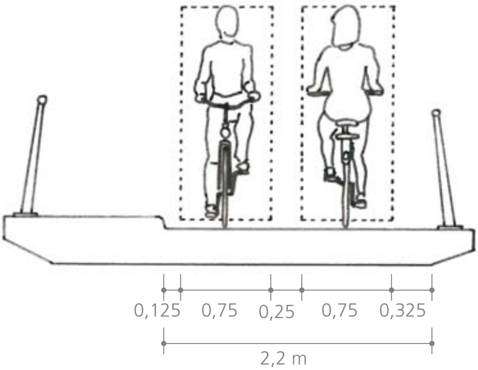


Figure 2.6 **Two way bicycle and pedestrain bridge**

Bicycle path width

Basic width for two cyclists	1,75 m
Safety margin cyclist - railing	0,325 m
Safety margin cyclist - raised pavement > 0,050m	0,125 m
Total width	2,2 m

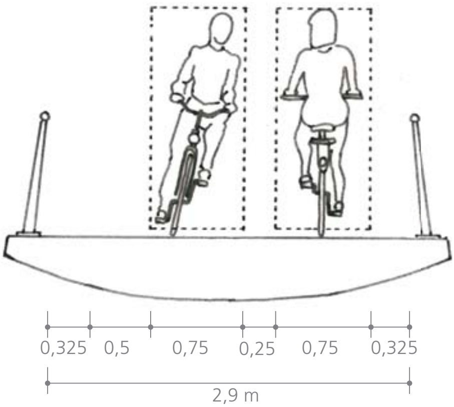


Figure 2.7 **Two-way bicycle path on slope**

Bicycle path width

Basic width for two cyclists	1,75 m	
Safety margin cyclist - railing	0,325 m	(2 x)
Added width due to slope	0,5 m	
Total width	2,9 m	

Figure 2.8 **Pedestrian bridge Midden-Delfland**
Old situation: pipeline along side of the bridge

Figure 2.9 **Pedestrian bridge Midden-Delfland**
New situation: the pipeline is now placed underneath the wooden decking

Figure 2.10 **Weideveld Bridge**
Integrated stainless steel cable mesh to avoid objects being thrown of the bridge

CURVES

It can be necessary for the new bridge to have one or more curves. In that case, the curve radius should ideally be somewhere in between 10 m and 20 m. If space is limited, a curve radius of 5 m should be considered the absolute minimum; anywhere below that, cyclists will have trouble staying on their bicycles as their speed will be compromised too much.

RAMPS

The preceived comfort of a bicycle ramps is influenced by the grade, route directness, availabillity of alternative routes and the availabillity of flat stretches. Aspects which in turn are influenced by the available space and budget. There is no ideal grade. The preferred grade depends on the situation and expected users.
Extensive and detailed information on ramps and grades can be found in chapter 3: Slopes.

2.3 DISABLED, ELDERLY, AND CHILDREN

The basic needs for these types of individuals do not differ much from those of regular pedestrians or cyclists. However, certain things may require extra attention [2]:

- Disabled people require shorter ramps, with a level landing after every 0,5 m of height difference;
- Obstacles such as a step or threshold can make it difficult to cross the bridge comfortably;
- Children tend to swerve more when cycling upgrade, so add another 0,5 m to the bridge width when it is likely that many children will be using the bridge (for instance when it is located near a school);
- In areas with many children, a child safe railing may be required (not easy to climb upon, with small openings only, see chapter 5: Railings for additional information).

2.4 OTHER USERS

MAINTENANCE VEHICLES

Some bridges have to be accessible to maintenance vehicles such as winter service vehicles (for gritting and ice clearance), road cleaners or park maintenance vehicles. When designing the bridge, it is crucial to know whether or not this is the case, and to obtain the vehicle specifications. Vehicle weight, measurements, and turning circle may mean the bridge has to be wider or be able to carry more weight than initially expected. Early on communication with the city maintenance department therefore is essential.

EMERGENCY SERVICES

Another possibility is for the bridge to be on an emergency access route. Emergency vehicles will then incidentally have to cross the bridge. If this is the case, the bridge also needs to be of a certain minimum width and the bridge structure needs to be able to carry the extra load of a relatively heavy fire engine. Again, early on communication (with local emergency services in this case) is crucial.

UTILITY COMPANIES

Gas, water or electricity companies may want to use the bridge for crossing their infrastructure. (Fig. 2.8 and 2.9) Sometimes underground infrastructure may already be present or when replacing an existing bridge, there may already be some utility company infrastructure present above ground.
Once the utility company's desire to use the bridge structure has been expressed, it is important to collect information in:

- The amount and type of pipes and cables to be carried across;
- The measurements of the space required;
- Rules and regulations regarding accessing the pipes and cables.

OOLIGANS

Just as any other object in public space, a bridge can be subjected to vandalism, such as graffiti or intentional damage. When a bridge crosses a motorway, there is the added possibility of people throwing rocks or other heavy objects from the bridge onto the road underneath. A bridge across water can be used as a springboard. Although it is impossible to prevent all types of vandalism, certain (simple) measures can make a bridge less appealing to vandals.

Avoiding large, smooth surfaces or applying anti-graffiti paint can discourage graffiti.

A 2,5 m high fence or railing will discourage anyone from throwing objects from the bridge onto a road underneath. Such a railing does however have a significantly larger load, meaning the bridge structure has to allow for this, which will most likely mean additional costs. Adding a high fence of course also strongly influences the bridge's appearance.

It is therefore best to decide in advance whether or not a safeguard against objects being thrown from the bridge is desirable or necessary. If the answer is yes (when the bridge crosses a motorway for instance), then the high railing can be integrated into the design, which will lead to a much better and visually pleasing end result. (Fig. 2.10)

Weideveld Bridge (Fig. 2.10)
This recently built bicycle and pedestrian bridge crosses a busy main road. A high fence has been integrated gracefully into the bridge design, adding to the bridge's unique character. At night, the integrated lighting only further emphasizes this.

2.5 MIXED USE

Usually, the cross section and layout in plan of a new bridge coincides with the layout of the adjoining footpath and/or cycleway. Various scenarios are possible:
Two separate bridges (one for cyclists, one for pedestrians) (Fig. 2.11);
One bridge with separate cycleway and footpath;
One bridge with a single path, to be used by both groups of users (Fig. 2.12).

Which scenario is most suitable depends on several things, mainly:

- The adjoining bicycle and footpath layout/ road design;
- The expected traffic flow;
- The available budget.

TRAFFIC FLOW

If a high-density traffic flow is to be expected, a non-separate road layout can cause a safety hazard, as pedestrians and cyclists traveling at different speeds will be using the same path. Therefore, it is advisable to separate footpath and cycleway in such cases by creating a physical or visual separation. Another option can be to widen the path as a whole.

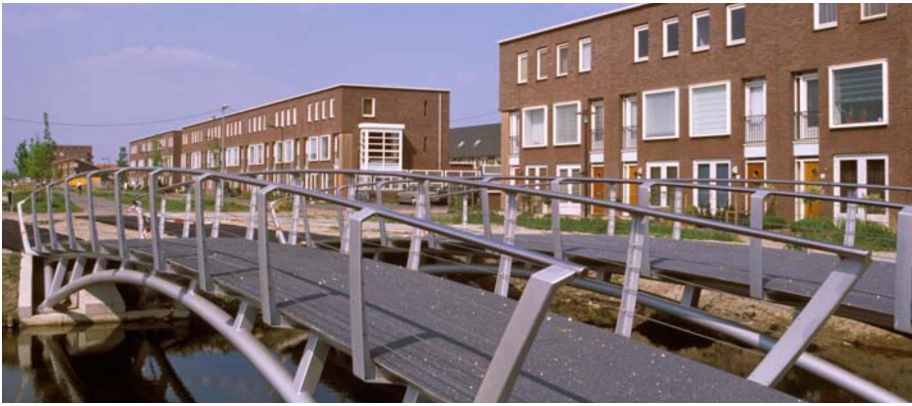


Figure 2.11 Nesselande Bridges
Two seperate bridges: one for cyclists, one for pedestrians

Figure 2.12 Weerdsprong Bridge Venlo
Single path bridge with visual separation between cyclists and pedestrians

3 SLOPES

If there is a height difference to be crossed by the new bridge, that means either ramps or steps are necessary. As steps are not accessible to cyclists or disabled people, they are usually used in combination with ramps, offering pedestrians a shortcut via the steps, and cyclists (and/or disabled) a comfortable path. The basic specifications for steps and wheelchair ramps can be found in the previous chapter.

This chapter [9] will focus solely on ramps. It is divided into the following sections:

- Basic guidelines;
- Grade;
- Design;
- Construction;
- Costs;
- Alternatives.

3.1 THE BASIC GUIDELINES

The longer and steeper the ramp, the more difficult cyclists will find it to traverse. In this, the average grade (G) of a slope plays a much larger role than its length. The difficulty of a ramp (Z) can be calculated as the square of the average grade multiplied by its length, or as the square of the height difference divided by its length:

$Z = (H/L)^2 \times L = H^2/L$ [6]

$G = H/L = Z/H$

Table 3.1 Examples of slope height, length and difficulty

H[m]	L[m]	G[%]	Z[m]
2,50	31	8,0%	0,2
5,00	250	2,0%	0,1
5,00	125	4,0%	0,2

H = height difference
L = length
G = average grade
Z = difficulty

The table shows that:

- If you double the grade while the height difference bisects, the difficulty will remain the same;
- If you double the grade and don't change the height difference, the difficulty will double as well.

TARGET VALUES

Suitable for most (Dutch) cyclists under normal circumstances and with average wind conditions, the difficulty of a ramp should ideally be 0,075, with a maximum grade of 7,5 % and a minimum grade of 1,75 %. Z=0,075 means $L=H^2/Z = H^2/0{,}075$

Figure 3.1 shows not only the target values for an ideal situation, but also the upper and lower limits, creating a possible bandwidth. In situations with less wind than average or where user

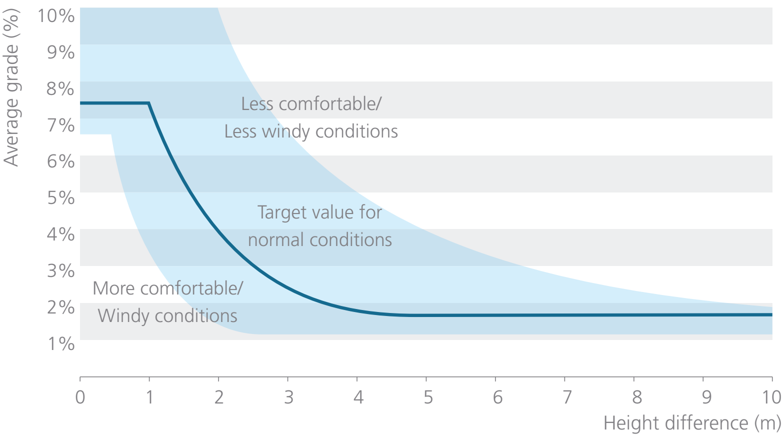


Figure 3.1 Slope bandwidth [4][6][7][8]

comfort is less important, one can apply grades up to the upper level. In windy conditions or situations where comfort is highly important, grades up to the lower limit are recommended.

LOWER LIMIT

The lower limit is based on Z=0,0333, with a maximum grade of 6,67 % and a minimum grade of 1,25 %. Grades below 1,25 % are considered false flats, and therefore ignored here.

UPPER LIMIT

The upper limit is based on Z=0,200, with a maximum grade of 10 %.

Figure 3.1 is based on several previously published Dutch studies on bicycle grades. These have been combined into one figure to get a clear overview.

3.2 SETTING THE GRADE

Just like there is no such thing as the standard cyclist – physical build and capabilities vary greatly and there are many different types of bicycles, there is no perfect ramp grade either. Each situation is different and requires its own analysis. Which grade is acceptable depends on many things, among which are available space, nearby alternatives, logic and budget. By looking at all the options, a suitable solution can usually be found.

Available space

If space is limited, it might be impossible to create a comfortable ramp. Is a slightly uncomfortable ramp an option? What grade is acceptable if the ramp offers cyclists a substantially faster route?

Type(s) of users

A bridge that is on a high speed cycling route will have a different type of user than one located on the main route between schools and retirement homes and the inner city, therefore the acceptable grade will differ as well.

Height difference

A short steep ramp will be less of an obstacle for cyclists than a longer steep ramp. A larger height difference means a longer ramp and therefore more need for comfort.

Nearby alternatives

Is there another bridge or cycling route within the vicinity that offers easy access to those requiring a less steep ramp and also gets them from A to B? Or is the new bridge the only one in the wide vicinity?

Surroundings

A bridge in a rural area prone to heavy winds will be harder for cyclists to tackle, therefore needs a more comfortable ramp.

Sight lines

If cyclists have a clear view of the ramp and can see from afar that there is a steep slope ahead, they can anticipate on it by increasing speed.

Detour

Cyclists don't want to feel like they have to take an unnecessary detour. If they do get that feeling, chances are many of them will not use the bridge and choose another route, especially if the ramp is steep.
When the bicycle route allows for a shortcut that was not part of the design, cyclists will most likely go and create their own unintended shortcut.

Budget

Is a less comfortable ramp that can be built within budget a good alternative to a comfortable slope that exceeds the available budget?

Road safety

If there is an intersection, corner or connecting road at the bottom of the ramp, the ramp may have to be less steep to prevent high-speed collision and a possible safety hazard.

Appearance

A narrow concrete cycling path surrounded by tall office buildings looks much less appealing than a spacious slightly curvy path that offers nice views of the surrounding area.

3.3 DESIGN

Besides the average grade, the layout in plan of the ramp also has a large influence on how comfortable a ramp is regarded by cyclists. For example, a ramp that has the same grade from bottom to top will be less comfortable than one that has a gradually reducing grade from the bottom towards the top. Cyclists automatically lose speed as they go uphill, making it more difficult to negotiate the ramp as they go further up. Gradually reducing the grade of a ramp from bottom to top allows for an overall constant speed and effort.

Cyclists usually have a relatively high speed when they start their ascend, which means they are more able to cope with a short steep ramp right at the beginning. A steeper ramp at the bottom however does require extra attention to safety for cyclists going downhill. Intersections, corners or any type of obstacle should be placed well away from the bottom of the ramp, allowing for plenty of room and time for downhill cyclists to reduce their speed. Of course, the same amount of space is also needed for those going uphill to gather speed in order to negotiate the climb.

A height difference of 3 m or more generally requires a level landing somewhere along the route, allowing for cyclists to catch their breath and maintain or build up speed. When the height difference is more than 5 m, such a landing is a bare necessity. A level landing should generally be around 25 m in length.[4]

If mid ramp intersections or corners are unavoidable, it is strongly recommended to make that specific section of the ramp flat. This will make it easier and more comfortable for cyclists to negotiate the ramp.

Figure 3.2 **Hofstraat Bridge Landgraaf**

Figure 3.3 **Nescio Bridge Amsterdam**

Figure 3.4 **Tanerij Bridge Zwolle**

Offering choice

Space and budget allowing, there is always an option to offer users more than one route. For instance, a bridge could have two separate ramps: a shorter route for the more energetic cyclists and a longer one that is more comfortable.

3.4 TYPOLOGY

A ramp can either be constructed on an earthen embankment or as a bridge-like structure on intermediate supports. Combinations are also possible. These construction methods differ greatly as far as costs, amount of space needed, cross-section, maintenance and appearance are concerned and therefore the choice of construction has a large influence on the ramp design.

SLOPE ON EMBANKMENT

The costs of a ramp on an earthen embankment can be up to ten times less than those of a ramp on intermediate supports. However, this only applies when there is enough space available to build the embankment. If the ground needs to be bought first, or if there are trees or buildings at the site that need to be removed or demolished before the embankment can be built, this will of course imply additional costs.

Specifications

- For safety reasons, there usually is a 1 to 1,5 m shoulder between the bicycle path and the incline on either side. If this is unwanted or impossible, a railing could protect cyclists from going down the incline;
- Sometimes, it can be desirable to have a footpath on top of the embankment as well. In that case, be sure to discuss the additional requirements so they can be incorporated;
- The grade of the incline dictates the amount of space needed to build the embankment;
- The grade of the incline itself is usually dictated by its planned vegetation and means of maintenance. Generally speaking the following rules apply:

Table 3.2 Slope steepness

Type of maintenance	Grade
Mowing machine	Up to 1:2
Side arm mower	Up to 1:1,5
Grazing sheep	Up to 1:1

- Make sure to discuss the issue of drainage, as rain falling on the bicycle path will find its way down the incline and could cause flooding if no appropriate measures have been taken;
- A retaining wall can substantially decrease the amount of space needed by an embankment and its inclines. Especially when space is limited, building a retaining wall can offer an alternative to a more expensive ramp on intermediate supports.

SLOPE ON SUPPORTS

The main advantage of a ramp built on intermediate supports, is that this allows for a smaller footprint as less space is needed, especially when there is a large height difference. It does, however, involve higher costs as foundations, supports, bridge deck and rail-

Figure 3.5 Appearance

ings need to be built. The actual costs depend on things such as span, design and whether or not the ramp is made up of identical sections. A ramp comprising several identical standard concrete elements will be much cheaper than one comprising corners of varying radii and elements of different lengths.

Specifications

A ramp on intermediate supports is usually considered a bridge. Therefore, specifications of a bridge apply.

APPEARANCE

The desired appearance of a bridge and its slopes may also affect the choice of construction. Ramps on intermediate supports may be the more logical choice in an area of high-rise buildings, whereas in a rural area or a park ramps on an earthen embankment may be preferred. (Fig. 3.5)

3.5 SOLUTIONS

What can be done when it is not possible to design ramps that both fit the location and comply with the guidelines? Several possible solutions could be looked at:

- Reducing the height difference;
- Choosing a more compact ramp design;
- Accepting a steeper slope;
- Alternatives to a slope.

REDUCING THE HEIGHT DIFFERENCE

Reducing bridge deck height

This can be done in various ways, for example by choosing a different construction material or shortening the span(s). A shorter span means a more slender deck, which results in a reduction of the overall height of the bridge (clearance envelopes plus deck height). The dimensions of a steel bridge are generally smaller than those of a similar bridge in concrete, therefore choosing steel rather than concrete reduces the overall bridge height as well.
Opting for another bridge type is another possible way. An arch bridge for example could mean a long span with a relatively slender deck.

Lower clearance

A new bridge comes with a set of requirements, among which is the clearance envelope. The clearance will usually be based on an ideal situation. However, there are cases where the new bridge crosses a road that already has several other bridges crossing it

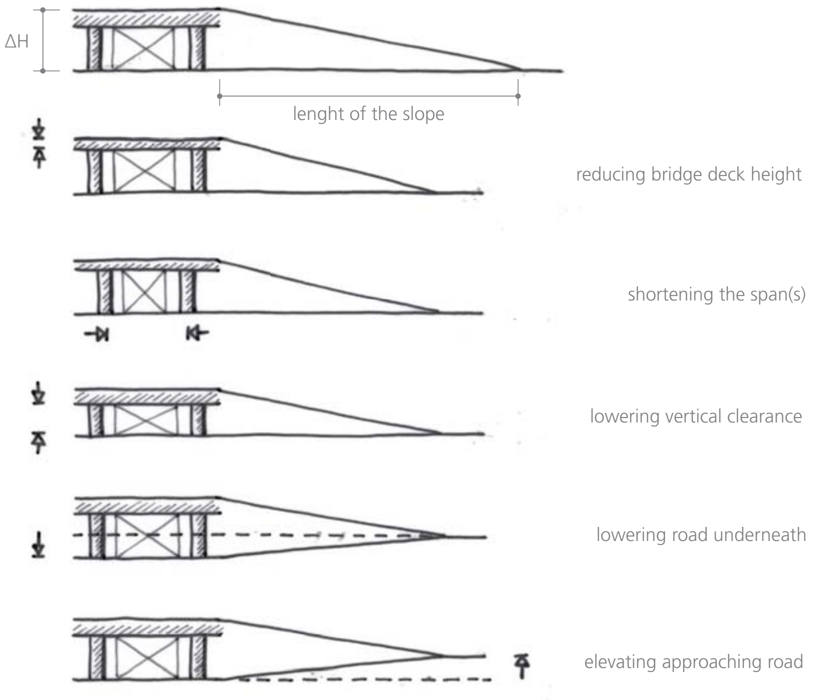


Figure 3.6 Height difference reducing solutions

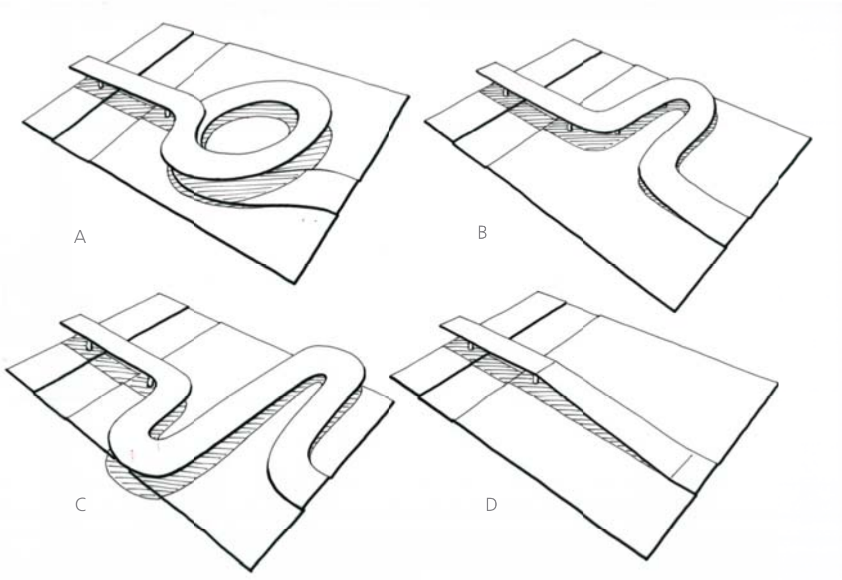


Figure 3.7 Compact ramp design and steeper slope
Various options for a less space consuming ramp design

that have lower clearance than what is required for the new bridge. It can then be useful to discuss this and see whether a lower clearance can be acceptable for the new bridge. A lower clearance means a reduction of the height difference that has to be overcome and therefore a shortening of the required slope.

Elevating the approaching road

By elevating the road from which the slope sets off, the height difference can be reduced as well. Perhaps the connecting bicycle path can be elevated, or the embankment near the bridge abutments.

Lowering the road underneath

If the proposed bridge crosses a road or intersection, it might be an option to lower this existing infrastructure, especially when it was in need of refurbishment anyway.

CHOOSING A MORE COMPACT RAMP DESIGN

A different, more compact layout in plan requires less space. Possibilities include:

- U-shape (Fig. 3.7 b);
- Z-shape (Fig. 3.7 c);
- Spiral (Fig. 3.7 a).

Please note! These solutions are not preferred as cyclists may find them rather uncomfortable (the spiral mainly) or inefficient (Z-shape), feeling they have to take a detour. However, when all else fails and if executed carefully, a compact ramp design could well be an option.

ACCEPTING A STEEPER SLOPE

Unusual situations sometimes call for unconventional solutions. In cooperation with interest groups representing cyclists, elderly or other stakeholders, the decision can be made to accept a slope that is steeper than the guidelines propose (Fig. 3.7 d). For instance when there is an alternative cycling route nearby that those unwilling or unable to use the steep slope can choose to use. Seriously weighing all the options is essential though, as there is no point in erecting a bridge that hardly anyone will be using.

3.6 ALTERNATIVES

When all solutions mentioned above are out of the question and there is definitely no way of constructing the required slopes, perhaps less user-friendly alternatives do offer a solution:

- A flight of steps with an adjacent bicycle wheeling ramp;
- A bicycle escalator;
- A movable bridge.

Please note! As interesting as these alternatives may seem, they do not offer a complete alternative to a well-designed bicycle bridge. Cyclists will have to dismount from their bikes and walk the steps or stand on the escalator holding their bicycle. This will not be suitable for all types of users. However, when there is a relatively low intensity of cyclists and no other options are available, it might be a viable solution.

MOVABLE BRIDGE

Choosing to build a movable bridge can only be an option for a bridge crossing a waterway. Whether or not it is a proper alternative depends on budget, traffic flow (both on the waterway and the bicycle and/or footpath), and existing infrastructure.

Generally speaking, a movable bridge will be more expensive than a non-movable one with ramps, although the costs of a basic movable bridge will not be too far off of those of a non-movable bridge with extensive ramps and stairs. A movable bridge will need more maintenance and has to be operated. Both mean extra costs during the lifetime of the bridge compared to a non-movable bridge.

When the bridge crosses an important navigable waterway, a movable bridge could conflict with the interest of maritime transport and therefore not be an option. Therefore, consult local water authorities when considering a movable bridge.

Table 3.3 Lifetime costs of non-movable and movable bridges

	Non-movable	Movable
Construction	Bridge slopes possibly stairs, elevator	Bridge, machinery, operating system (local, central), communication system (cameras, sound system, signals), access barriers, slopes, possibly stairs, elevator
Maintenance	Bridge	Bridge, machinery, communication system (cameras, sound system, signals), access barriers
Operation	None	Operating system (local, central)

Figure 3.8 Gorredijk movable bridge

Figure 3.9 Movable Willem III Bridge Assen

Figure 3.10 Swing bridge Rijswijk

4 LOADS

In the Netherlands, codes and regulations concerning loads are those of the EN Eurocodes [10], the European building standards. Individual countries are allowed to create their own additional parameters, which are published in a National Annex.

This design manual focuses on the Eurocodes and the Dutch National Annex [11], therefore the regulations mentioned below apply to structures built in the Netherlands. By giving an overview of these regulations, this publication aims to offer insight in the Dutch Building Code [3] and how its regulations are applied in everyday Dutch engineering practice.

Note! Always use your local codes and regulations!

Please note: this publication uses the metric system, which means loads are expressed in kN and kN/m^2. For those who prefer the usage of Kips or tonnes, the Appendix offers the converted numbers.

< Weerdsprong Bridge, Venlo

4.1 VERTICAL LOADS

The two basic live loads used to determine the dimensions and structure of the bridge are the uniform load and the concentrated load. They apply to every bridge.

UNIFORMLY DISTRIBUTED LOAD (MANDATORY)

This load usually determines the dimensions of the bridge's main structure. It is commonly set at 5kN/m2, which equals the load of a deck filled with people. When the bridge spans more than 10 m, the uniform load can be decreased using this formula:
uniform load = 2,0 + (120/(bridge length (m) + 30), with a minimum of 2,5 kN/m2.

Reduction of the uniform load is not allowed on locations where large crowds can be expected, such as near stadiums or public transport facilities.

CONCENTRATED LOAD (MANDATORY)

The concentrated load is a force acting on a single point, such as the load caused by the wheel of a vehicle. It mainly determines the detailing, such as steel thickness or wooden decking dimensions.
Any pedestrian or bicycle bridge should be designed for a concentrated load of 7 kN on a surface of 0,1 x 0,1 m.

MAINTENANCE VEHICLE

If the bridge has to be accessible to maintenance vehicles as well, and semi-permanent vehicle access restriction such as a removable bollard is in place, the load caused by a maintenance vehicle has to be taken into account as well.

Maintenance vehicle specifications:

- Two axles with a 3 m wheelbase;
- Axle load of 25 kN (2500 kg);
- Two wheels per axle, with a 1.75 m track width;
- 0,25 m x 0,25 m contact surface per wheel.

Please note that a bridge that incidentally will be used by emergency services will have to be able to carry the load of a fire engine or ambulance as well. Make sure to use the specifications of the appropriate vehicles instead of those of the standard maintenance vehicle as stated above, as the average fire truck weighs a lot more than a maintenance vehicle.

Maintenance vehicle
The standard maintenance vehicle has a total weight of 5 tons, roughly 50 kN. In most cases (bridge surfaces of 20 m2 and over), this will not be the prevailing global load case. A bridge full of people will usually lead to a larger load (the uniform load of 5kN/m2). The wheel loads will however introduce higher local loading, for example on the deck.

UNAUTHORIZED VEHICLE

Any bridge that does not obstruct vehicle access automatically will have to be able to withstand the additional load of an unauthorized vehicle, even when

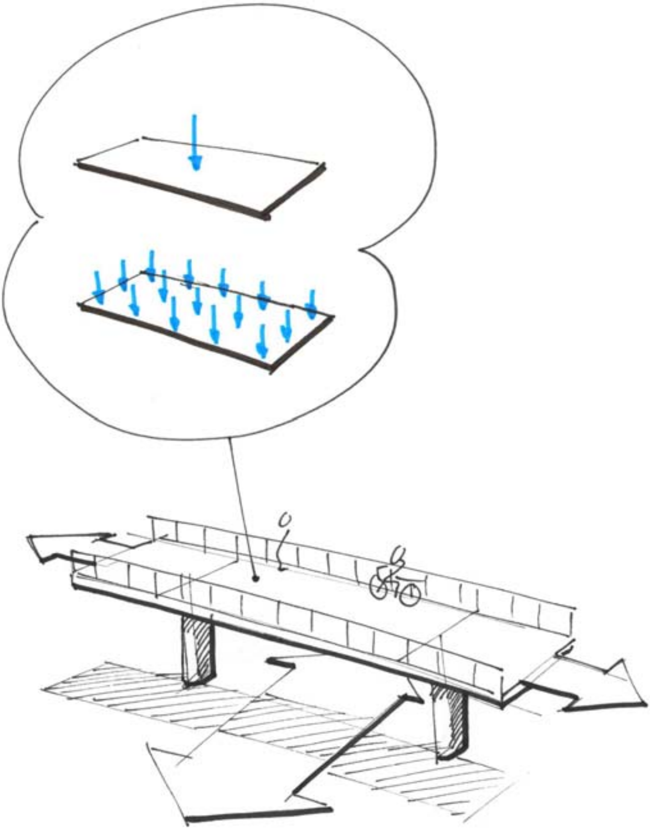


Figure 4.1 Basic loads
Uniform and concentrated loads on the bridge deck

Figure 4.2 Maintenance vehicle
Despite bollards on either side of the path, this vehicle has access

Figure 4.3 **St. Gerardusstraat Bridge Emmen**

Figure 4.4 **Vehicle obstruction**
Not so ordinary but effective solution to obstruct vehicle access

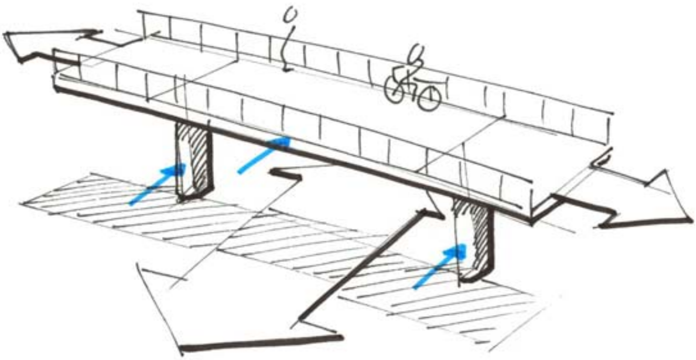


Figure 4.5 **Collision loads**

it is unlikely that any vehicle other than the maintenance vehicle will ever use the bridge. If there is no permanent obstacle keeping cars from accessing the bridge, the bridge needs to be able to withstand loads caused by any type of vehicle, ranging from a regular car to a tractor or truck. A lorry driver could be lost and see no other option than to access the bridge, or a reckless driver could intentionally try to use the bridge as a shortcut.

Unauthorized vehicle specifications:
- Two axles with a 3 m wheelbase;
- Characteristic axle load of 40 kN and 80 kN;
- Two wheels per axle, with a 1,3 m track width;
- 0,2 m x 0,2 m contact surface per wheel.

The load caused by an unauthorized vehicle is much larger than that caused by the standard maintenance vehicle. Refraining from the use of a bollard or barrier can therefore lead to a much more expensive bridge.

Placing bollards is an effective way to prevent unauthorized vehicle entry, but it does potentially offer a safety hazard as well as they are a common cause of single-bicycle accidents.

4.2 HORIZONTAL LOADS

Vehicles and people not only cause vertical loads on the bridge deck, but horizontal loads as well, braking load for instance.

To determine the horizontal load, the largest of the following two should be used:
- 10 % of the total load, in compliance with the uniformly distributed load;
- 30 % of the maintenance vehicle's total weight, if applicable.

4.3 COLLISION LOADS

VEHICLE IMPACT

When the bridge crosses a road, it should be able to withstand the collision loads caused by a potential collision. This applies to both the bridge deck, which potentially could be hit by a vehicle that is too high or a boom truck or loader crane that is not properly stowed, and to the supporting structure, which could be hit by a vehicle that has swerved out of control.

In the Netherlands, there is quite a large difference between the collision loads dictated by the Eurocodes and those dictated by the Dutch National Annex. A concrete bridge structure will usually be able to withstand the much larger Dutch collision loads without any modification to the design. For a light steel structure such as a bicycle bridge however, having to comply with the Dutch National Annex standards has a large influence on the overall building costs and can in some cases easily double the price of a bridge.

Collision loads on bridge deck

The collision loads as shown in table 4.1 (below) apply to all bridges with clearance of 4,8 m and under. For bridges with a clearance of 7 m or more the collision load is 0. For values between 4,8 m and 7 m, the collision loads can be interpolated.

Table 4.1 Collision loads on bridge deck, Eurocodes without Dutch appendix [12]

Traffic category	Fdx (kN)
Highways	500
Roads outside urban areas	375
Roads within urban areas	250
Car parks	75

Collision loads on the bridge deck as per Dutch National Annex are approximately 4 times higher than those of the Eurocodes.

The collision loads caused by a boom truck or loader crane that is not properly stowed usually only affect the structural detailing of the bridge deck. For instance, small longitudinal ribs on the bottom side of the deck are especially vulnerable and will have to be able to withstand both horizontal and vertical collision loads, whereas a smooth and closed bottom side will only have to withstand vertical collision load.

Collision prevention
At circular cable-stayed bicycle bridge the Hovenring in the Dutch city of Eindhoven, designers chose to place a tailor-made collision prevention portal carrying overhead traffic signs on the roads leading up to the intersection underneath the bridge. As this portal was designed to withstand collision loads caused by vehicles, impact loads on the bridge deck could be ignored. (Fig. 4.7)

Collision loads on supporting structure

The collision loads on the supporting structure (Table 4.2) are related to the distance between the structure and the road. When the distance between the centre of the road and the centre of the support is 20 m or more, the collision loads can be ignored, as it is deemed any vehicle will have significantly lost speed by then and will not be able to cause significant damage to the bridge.

The collision loads can also be ignored, if there is impact collision prevention such as a traffic barrier of sufficient strength in place around the bridge supports.

Collision loads on the supporting structure as per Dutch National Annex are approximately two times those of the Eurocodes.

VESSEL COLLISION

A bridge over a navigable waterway could potentially be hit by a vessel and therefore has to be able to withstand collision loads caused by ships colliding with it.

Collision loads on bridge deck

If relevant, the bridge deck should be able to carry the equivalent static impact load perpendicular to the length of the bridge. The value for this equiva-

Table 4.2 Collision loads on supports, Eurocodes without Dutch appendix [12]

Traffic category		Fdx (kN)	Fdy (kN)
Highways		1000	500
Roads outside urban areas		750	375
Roads inside urban areas		500	250
Car parks accesible to:	Cars	50	25
	Trucks (>3,5 ton)	150	75

Figure 4.6 Hofstraat Bridge Landgraaf
This bicycle bridge was designed for a 250 kN collision load

Figure 4.7 Hovenring
Portal for overhead road signs designed to withstand collision loads

lent static load is 1000 kN. The area of application should be 0,25 x 3.0 m.[12]

Collision loads on supports

The relevant collision loads depend on the waterway's CEMT class (Classification of European inland waterways) and the value for this equivalent static load ranges from 2000 kN to 20.000 kN.

The collision load should be projected onto the bridge structure at 1,5 m above the designated water level. [12]

4.4 LIGHT STRUCTURES

The Eurocodes are unclear regarding what impact loads should be taken into account when designing lightwheight bridges such as a steel, fibre-reinforced polymer or wooden bicycle bridge. If the usual impact loads for bridges are applied to a lightwheight bridge, the impact on structural dimensions and costs will be significant. To reach a more balanced solution the increased flexibility and crumple zone of a light steel bridge can be taken into account by the authorities, which could result in a slightly lower impact loading specifications.

This can be accomplished by using dynamic calculations rather than the simplified static method. This way, the actual loads and their effects are calculated. The Eurocodes specify what weight and speed the test vehicles should have. Be aware that this method requires enough plastic deformation capacity of sections and joints, and an agreement on the parameters of the calculation.The results of a dynamic calculation are different from that of a static calculation, depending on the stiffness and plastic deformation capacity of the structure. In some cases (stiff structures) a static calculation can also be more economic in its results.

The most cost effective method of reducing impact loads is by increasing the clearance under the bridge, or by filtering over-height traffic using nearby structures with lower clearance.
When the new bridge is located in between other bridges that cross the same road, it could mean that those other bridges will prevent vehicles that are too high from even getting to the bicycle or pedestrian bridge. If that is the case, then the impact loads can be lower.

These smaller loads mean the dimensions of the bridge's structure can be reduced, which has a positive effect on the overall building costs.

4.5 VIBRATIONS

The dynamic loads caused by wind or people, especially a larger group walking the same rhythm, can cause a bridge structure to vibrate. Vibration caused by people is usually easier to predict than wind-induced vibration. Lightweight and slender structures such as cable-stayed and suspension bridges are especially vulnerable to wind-induced vibration. Therefore, when designing a cable-stayed or suspension bridge, special attention must be paid to vibration. Unfortunately, vibration is rather difficult to predict. The probability of occurring vibration can be predicted using complex calculations, however, bridges often act differently once they have been erected. Keeping in mind possible design adjustments and allowing room for additional costs will help prevent conflicts later on.

Every structure has its own resonance frequency, governed by geometry, structural mass and rigidity. Wind or bridge users can cause the bridge or a part of it (such as a suspension cable) to vibrate. If the frequency of excitation by external loads approximates the bridge's own natural frequency, the bridge will start to resonate. If the source of vibration introduces more energy than the bridge can absorb, the amplitude of vibrations will increase, leading to discomfort and ultimately structural damage.
Long and slender structural elements are more susceptible to vibration, due to their lower resonance frequency.

USER-INDUCED VIBRATIONS

During the design process, basic calculations can be used to predict the bridge's natural frequency. It is advised to do so for every bridge, in order to determine whether or not additional calculations are advisable.

For user-induced vertical vibration modes, natural frequencies under 5 Hertz (Hz) are critical, whereas for horizontal and torsional vibration modes any frequency under 2,5 Hz is critical. When one or more of the bridge's natural frequencies are within a critical area, the bridge is likely to be susceptible to vibrations. Further calculations are then needed to estimate whether or not vibrations will cause discomfort. Detailed information on these calculations and bridge vibrations can be found in the European guidelines called Hivoss (Human induced vibrations in steel structures).[13]

WIND-INDUCED VIBRATIONS

Wind-induced vibration of an entire structure mainly occurs in extremely slender or long usually cable-stayed or suspension bridges. In order to predict the bridge's susceptibility, wind tunnel tests or computer simulations could be necessary.

Wind can also induce vibration of slender elements of bridges such as cables. These vibrations can be especially difficult to predict, even using the most sophisticated methods. For this type of vibration, high natural frequencies for structural elements unfortunately do not guarantee that wind-induced vibrations will not occur.

High-frequency vibrations of cables usually cause more damage than low-frequency vibrations because they can quickly introduce fatigue. Strategies to stop vibrations if they occur therefore must be considered during the design phase of any cable-stayed or suspension bridge.

PREVENTION

Several measures can be taken to prevent bridge vibrations. The most commonly used ones are:

- Increasing rigidity;
- Increasing dead weight;
- Applying dampers;

Increasing rigidity

By increasing the bridge's rigidity, its natural frequency will become higher. This way, it might leave the critical area. This can usually only be achieved by significantly increasing the structural height.

Increasing dead weight

Increasing the structure's dead weight, for instance by adding a concrete deck or dead load (such as a counterweight), has a positive effect on the ratio between variable load and dead weight, making it more difficult for the structure to be set in motion. Adding concrete can also increase the internal damping properties of the structure.

Applying dampers

Dampers suppress wind-induced vibrations, dissipating the energy of oscillations to an acceptable level. The most commonly used types of dampers are the tuned mass damper and the viscous damper.

Increasing rigidity and increasing dead weight are measures that can be taken prior to the building process. They will influence the bridge's appearance and design, as well as its costs.
Applying dampers can only be done once the bridge has been built, as the exact frequency of the vibrations cannot be predicted in advance.

Figure 4.8 Milennium Bridge London

Figure 4.9 Zouthaven Bridge Amsterdam

Figure 4.10 Tuned masss damper

5 RAILINGS

Except for the occasional exception (a small bridge with a less than 1 m drop), bicycle and pedestrian bridges need to have railings for safety reasons. Apart from their function, railings play an important role in the bridge's appearance and can make a real difference. Especially when the bridge structure itself is not too fancy, a well-designed railing can turn it into a proper eye catcher, or can make people smile as they cross the bridge.

This chapter briefly discusses all regulations that apply to bridge railings.

< Amerikalaan Bridge, Alphen aan den Rijn

5.1 HEIGHT

Although mentally it might make a big difference whether a bridge has a 1 m drop or a 5 m drop, building regulations are independent of the height between bridge deck and the ground or water underneath. The Dutch building codes [3] dictate that any bridge with a drop of 1 m or more requires a railing of at least 1,0 m tall, measured from the bridge deck surface. Please note that these regulations have been made for buildings and their (pedestrian) users. When mainly cyclists use a bridge, consider choosing a higher railing. For instance when the bridge has a large drop or if it crosses a busy motorway. A higher railing will then have a positive effect on the bridge users feeling of safety. In general, the centre of gravity for a cyclist lies at around 1,2 m, which is higher than that of a pedestrian. This alone can justify a higher railing, for example one that's 1,2 m or 1,3 m.

CHILD SAFETY

Sometimes it may be wise to apply additional, stricter rules. For instance when the bridge is situated in a child friendly area.
The Dutch Building codes dictate openings to be no larger than 0,2 m for railings and fencing inside residential and school buildings and no larger than 0,1 m for childcare facilities for children under 4 years of age. In addition, the openings must be 0,1 m or less in the lower 0,7 m of the railing if it is accessible to any children of ages 12 and under.

In a child friendly area, it is also advisable to prevent children from climbing the railing. Choosing vertical spindles rather than horizontal ones for instance can achieve this.

5.2 LOADS

The railing needs to be able to withstand a line load of 3,0 kN/m (horizontally and vertically) on the top of the railing, which is 300 kg per meter. (Fig. 5.2)

5.3 SPACING

Openings between elements of a railing must be small enough that a 0,5 m sphere cannot pass through them.
The horizontal opening between deck and railing must be less than 0,05 m and the handrail must not have any gaps larger than 0,1 m. [3]

Figure 5.1 Weerdsprong Bridge Venlo
The glass panels of the railing are illuminated at night

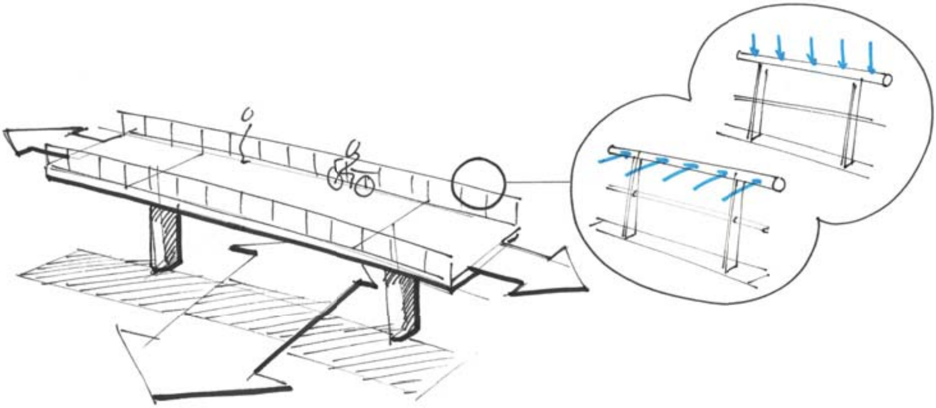


Figure 5.2 Loads on bridge railing

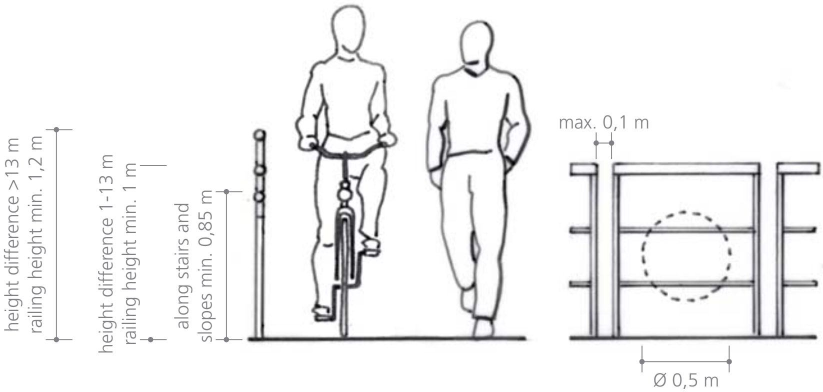


Figure 5.3 Spacing

6 COSTS

The total costs of a bridge are defined by building costs as well as lifetime costs such as maintenance costs. The design of a bridge plays a major role in both. Although a low maintenance bridge could cost more to build compared to a regular bridge, the overall costs will be lower in comparison as maintenance costs during the bridge's lifetime will be (much) lower.

The total costs depend on a variety of parameters, such as dimensions, span, number of supports, materials and contextual issues such as on-site underground infrastructure.

This chapter's focus is on cost reduction. It shows what can generally be done to reduce both building costs and total lifetime costs.

< Literatuurwijk Bridge, Almere

6.1 REDUCING BUILDING COSTS

If a budget is tight, or a design is expected to be over budget, there are usually several options to reduce the total costs of a bridge. Below are some basic cost reduction measures.

STRUCTURE

The cheapest and easiest way to construct a bridge is by using standard beams. By adding custom designed railings, custom made edge beams or a one-of-a-kind intermediate support, the end result will still be a tailor made design, but one that fits a limited budget.

SUPPORTS

Sometimes increasing or reducing the number of intermediate supports can lead to cost reduction. For instance when expensive pile foundations are necessary, it is most cost effective to minimise the number of intermediate supports. When soil conditions allow for spread footings, it is more economical to go for shorter spans and increase the number of intermediate supports. The cost reduction caused by a lighter bridge structure will then outweigh the costs of the extra footings.

BRIDGE TYPE

For bridges with spans of around 15 m and longer, choosing another, more structurally efficient bridge type such as a truss, arch or cable-stayed bridge can also create significant cost reduction.

MODULAR DESIGN

Production of a bridge comprising a number of identical modular sections is usually more cost effective than that of a bridge comprising unique custom made elements only. Repetition, the use of as many of the same elements as possible, can up to a certain level lead to cost reduction.

SCALE

Building several identical bridges at once can lead to lower costs per bridge. Three or more identical bridges will lead to an approximate 10 % cost reduction. However, the cost reduction effect should not be overestimated, as the ratio between repetition and project scale has a major impact. A small project with a lot of repetition will still have a higher price per square meter than a large project, simply because of the large share of fixed costs per square meter.

UNFORESEEN COSTS

When erecting a bridge, there are plenty of scenarios that could cause the bridge to become more expensive than anticipated. Especially when those possible scenarios have not been taken into account. Most common unpleasant surprises can be avoided by making sure the following cost increasing scenarios have been properly looked at upon project initiation:

- Presence of soil pollution (costs of clean-up order, consultations, excavation);

- Presence of underground cables in the wrong place (costs of having them moved or replaced);
- Required emergency vehicle access (costs of increasing the bridge's load capacity);
- Need for additional land in order to build necessary ramps (costs of buying extra land, possibly expropriation);
- Need to increase deck width due to the type and number of bridge users (costs of redesigning, increase of material).

6.2 REDUCING LIFETIME COSTS

The costs do not automatically stop once a bridge has been erected. After completion, maintenance is generally needed. The costs involved can add up quickly. The best way to reduce maintenance costs is to be aware of what maintenance a bridge will need during its lifetime and to take the costs and impact of maintenance into account right from the start of the design process. Conciously choosing building material, structural detailling, making design choices, and thinking in advance can seriously reduce maintenance costs, and will also ensure the bridge still looks appealing years after completion.

Unfortunately, maintenance is often considered something to think of after the bridge has been completed and by then the only cost reductive measure is to not maintain the bridge, which will definitely shorten its lifetime and decrease its appealing value.

A few examples of how certain design choices can influence maintenance costs:

AESTHETICS

Coated steel offers many opportunities to influence the appearance of a bridge. A coating's lifespan however is much shorter than the bridge's lifespan. Maintenance is needed every 3-5 years and the coating needs to be removed and replaced every 15 to 20 years. Alternatives such as stainless steel or aluminum might be more expensive at first but hardly need any maintenance during their lifetime, possibly making them an economical option nonetheless.

WATER ABSORPTION

Any flat surfaces, holes or corners in the bridge structure can cause water and dirt to gather, which will inevitably lead to an increase in the amount of maintenance needed. Joints and fixtures as well as places where there is a change in material or shape are especially vulnerable and therefore need proper detailing.

EXPANSION JOINTS

An in situ concrete bridge is more expensive to build, but if the bridge does not have any maintenance prone and vulnerable expansion joints, maintenance costs will be lower.

6.3 EXAMPLES

The relation between building costs, a bridge's appearance, and its size can best be illustrated with a range of ipv Delft projects. Please note all bridges mentioned below have been built in the Netherlands, under Dutch regulations and by Dutch manufacturers.

1. WEERDSPRONG BRIDGE, VENLO

bicycle and pedestrian bridge
size: 80 x 5 m | 400m²
price per m²: € 4.975 | price level 2013
building costs: € 2.000.000

2. ST. GERARDUSSTRAAT BRIDGE, EMMEN

bicycle bridge
size: 54 x 3 m | 162 m²
price per m²: € 3.575 | price level 2014
building costs: € 577.000

3. HOFSTRAAT BRIDGE, LANDGRAAF

bicycle and pedestrian bridge
size: 33 x 4,5 m | 149m²
price per m²: € 2.775 | price level 2013
building costs: € 410.000

4. KLOOSTERVEEN BRIDGES, ASSEN

two identical bicycle and pedestrian bridges
size: 32 x 4,5 m | 144m²
price per m²: € 2.650 | price level 2010
building costs: € 382.000

5. UHPC BRIDGE, PIJNACKER

fiber reinforced ultra-high performance concrete bicycle and pedestrian bridge
size: 10,5 x 4,8 m | 50,4 m²
price per m²: € 1,675 | price level 2014
building costs: € 85.000

6. PARK RANDENBROEK BRIDGES, AMERSFOORT

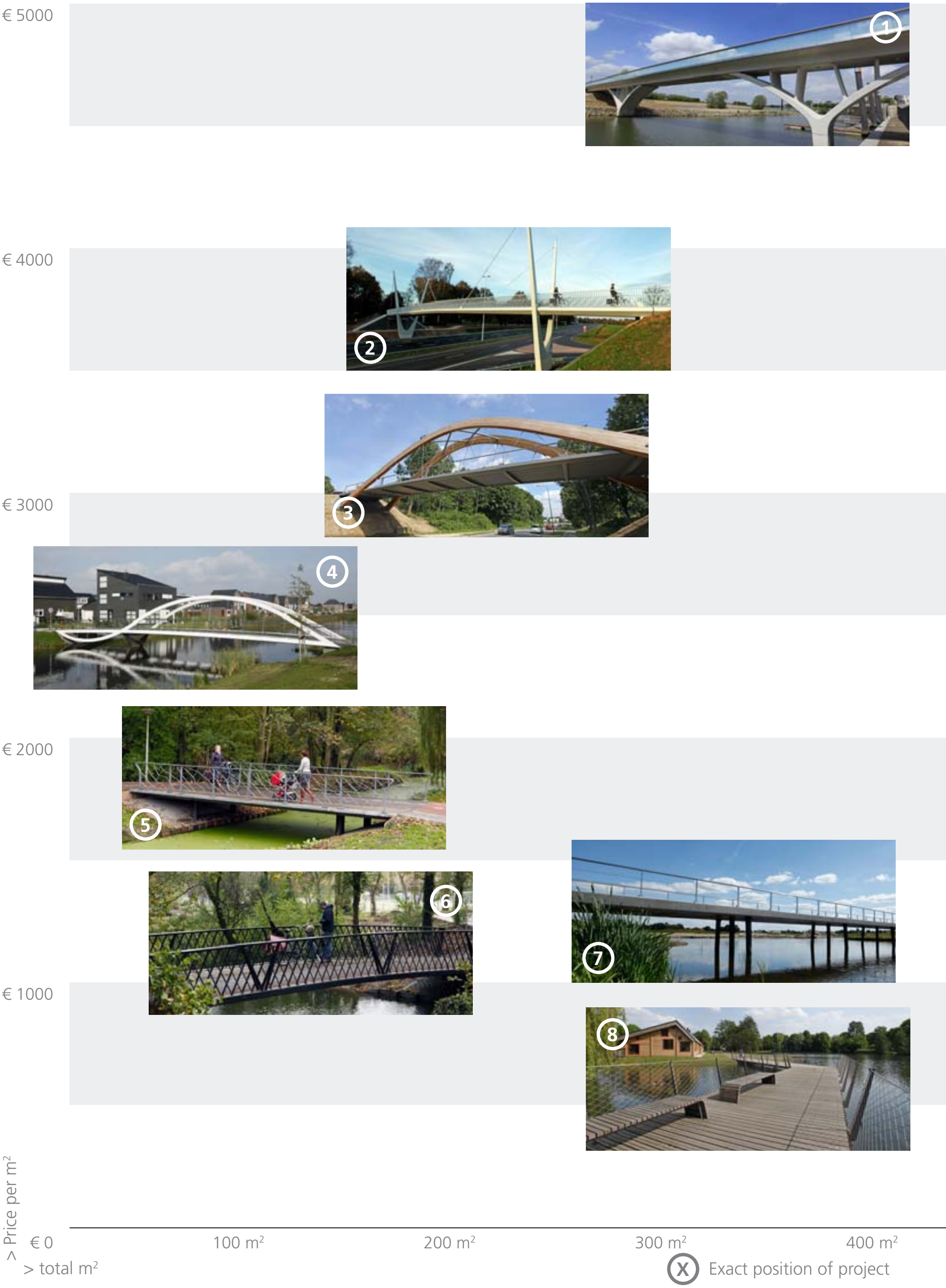
three bicycle and pedestrian bridges
size: 14-17 x 4 m | 192 m²
price per m²: € 1.345 | price level 2013
building costs: € 258.000

7. WERKDONKEN BRIDGE, BREDA

bicycle bridge
size: 72 x 3,9 m | 281 m²
price per m²: € 1.175 | price level 2012
building costs: € 330.000

8. ELZENHOEKPARK BRIDGE, OSS

pedestrian bridge
size: 287 m²
price per m²: € 875 | price level 2012
building costs: € 254.000


€ 5000
1
€ 4000
2
3
€ 3000
4
€ 2000
5
6
7
€ 1000
8
> Price per m²
€ 0
100 m²
200 m²
300 m²
400 m²
> total m²
X Exact position of project

7 PROJECTS

Now that the fundamentals of bridge design have been discussed, it is time to illustrate them. This chapter focuses on four projects by Dutch bridge design office ipv Delft. All four offer real-life examples of the choices, difficulties, and solutions that designing and building a bridge can entail.

The carefully chosen projects represent just a few of the bridges that ipv Delft has completed over the past twenty years.

Please feel free to contact ipv Delft for any additional information or advice on bridges or cycling infrastructure. The company's contact information can be found at the back of this publication.

< St. Gerardusstraat Bridge, Emmen

7.1 HOVENRING, EINDHOVEN

Vertical clearance: 4,65 m
Height difference: 4,7 – 5,2 m
Diameter: 72 m (outer diameter)
Deck width: 4,5 m
Slope gradient: 3 slopes are 2-2.3 % (=1:50-1:43), one is 3.1 % (=1:32)
Building costs: 6.300.000 euro (bridge only)
Completed: 2012

CONTEXT - SPECIAL CONCERNS

- Nearby gas station, and hotel;
- Nearby development of new residential and business areas;
- Fitting in with exisiting landmarks;
- Supporting the hightech image of Eindhoven.

The main objective was to improve the car traffic flow. An exisiting grade level roundabout used by all traffic modes would not suffice in the near future because of planned new developments.

It was decided to seperate cyclists and pedestrians from a new intersection with traffic lights for the car traffic. A bicycle underpass conflicted with the council's cyclist safety policy and was to expensive because of a high ground water level. Ipv Delft therefore designed a bicycle roundabout that hovers above the intersection to create a comfortable level-separated crossing for all users.

STRUCTURE

The steel bridge comprises a 70-metre high pylon, 24 steel cables, and a circular bridge deck. The cables are attached to the inner side of the bridge deck, right where the bridge deck connects to the circular counter weight. This way, torsion within the bridge deck is prevented. The M-shaped supports near the approach spans also ensure stability.

LIMITED SPACE

One of the challenges of the design process was the spatial integration. The existing infrastructure and buildings set the boundaries for the grades of the slopes leading up to the roundabout. As space was limited, it was decided to lower the ground level of the intersection underneath by a metre and a half, allowing for a comfortable slope for pedestrians and cyclists.

LAYOUT

Research of possible alignments showed that a two way roundabout bridge with four connector bridges offers direct routes for cyclists in all directions. Also the circular form proved to be a good fit with the architectural and urban design.
The 4.5 m wide bridge deck offers enough space for a safe two lane two way use of the bridge by cyclists.
The circular part of the bridge is level and the connector bridges have a 2% slope.

COMMUNITY INVOLVEMENT

Right from the start all stakeholders were involved, including local commercial parties, representatives of cyclists groups, elderly, and the nearby airport.

COLLISION PROTECTION

In order for the bridge structure, especially its deck, to be as slender as possible, a freestanding structure to support overhead road signs was designed that also functions as a collision prevention portal as its vertical clearance lies below that of the Hovenring itself. The portals are designed to withstand collision loads, which in this case means the bridge deck does not have to be. Furthermore, in case they are damaged by an accidental collision, the portals will be much easier to replace or repair than the bridge, and at a much lower cost.

TAILOR-MADE

The design and building process offered many technical challenges as well. Ipv Delft had a very clear view of what the bridge should look like: little more than a thin circular bridge deck, and a powerfully shaped pylon. Amongst other things, this meant the standard way of attaching cables to the pylon wouldn't suffice, as it would result in a bulk of steel near the pylon top. Therefore, a tailor-made solution was designed. The same applies to the M-shaped supports near the span bridges.

LIGHTING DESIGN

Befitting Eindhoven's identity as the 'City of Light' (Eindhoven is home to the Philips company), ipv Delft also made a lighting design for the Hovenring. One of its main elements is integrated into the circular deck.

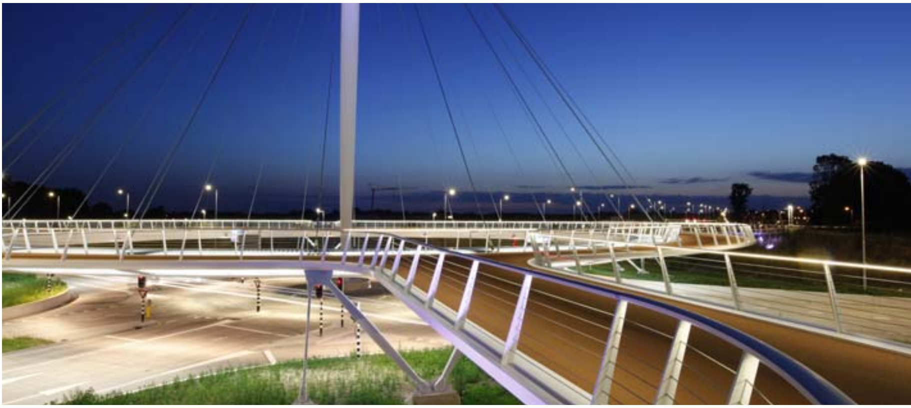
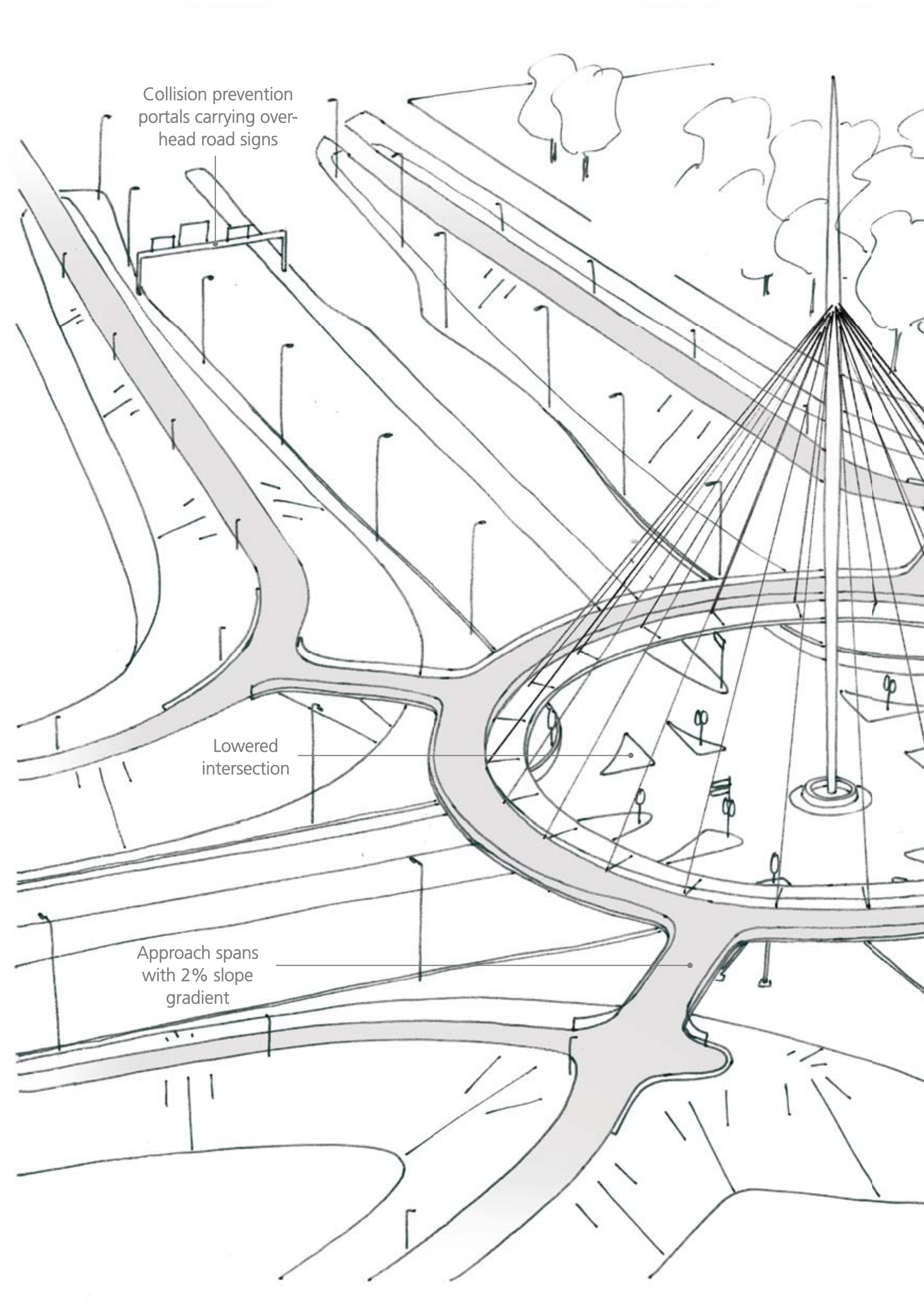
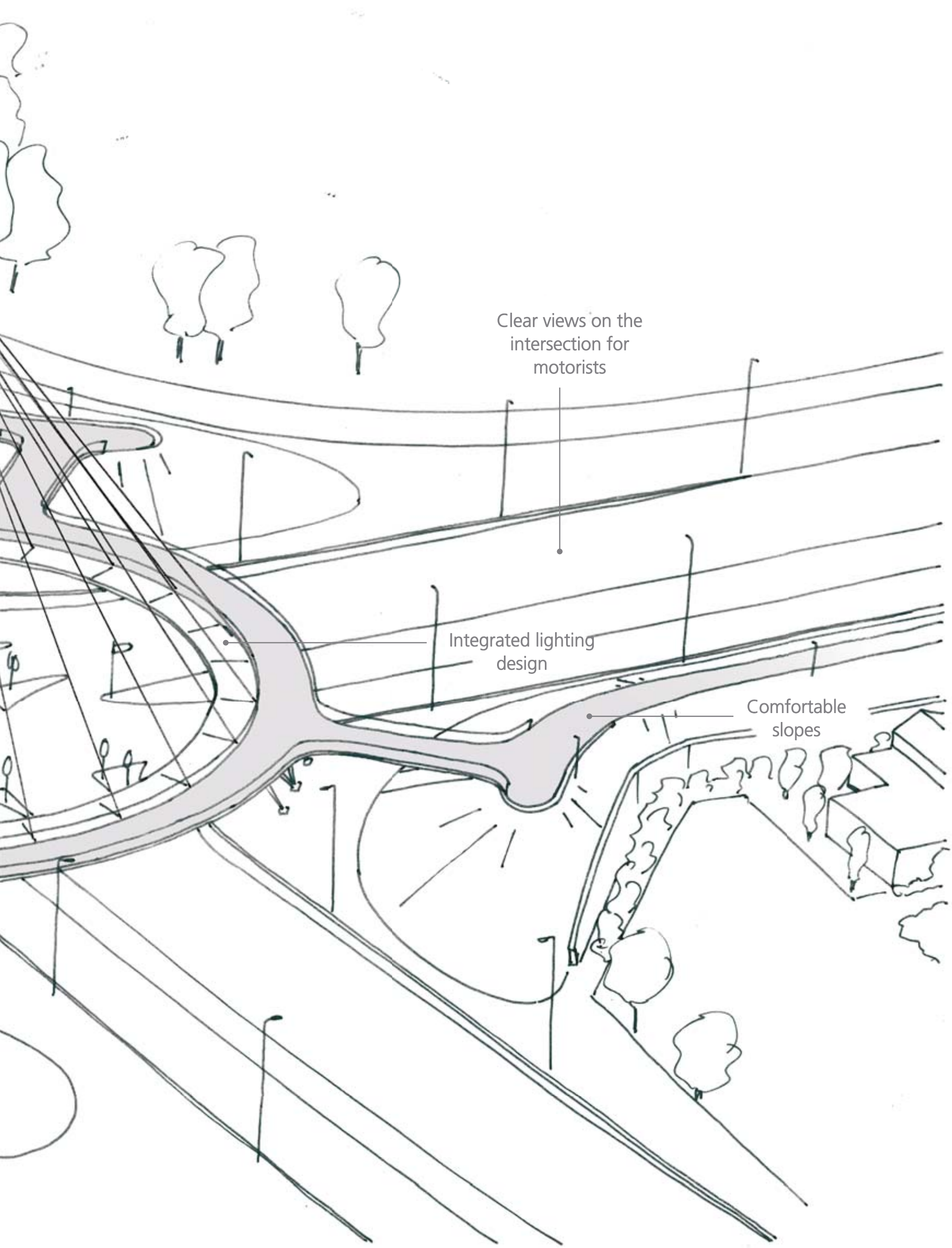


Figure 7.1 **Hovenring**
As seen by cyclists approaching the bridge

Figure 7.2 **Hovenring**
Cable anchorage

Figure 7.3 **Hovenring**
Ring of light as seen by motorists


Collision prevention portals carrying over-head road signs
Lowered intersection
Approach spans with 2% slope gradient


Clear views on the intersection for motorists
Integrated lighting design
Comfortable slopes

7.2 AUKE VLEERSTRAAT BRIDGE, ENSCHEDE

Vertical clearance: 5 m
Height difference: 5,87 m
Total length: 430 m (of which 150 m (65+45+40) on embankment)
Main span: all spans are 20 m
Deck width: 4,1 m
Slope gradient: 3,5 % and 2,6 % (= 1:28 and 1:38)
Building costs: 1.400.000 euro
Completed: 2011

CONTEXT - SPECIAL CONCERNS

- Nearby intersection and traffic lights;
- Businesses right next to bridge location;
- Several trees at the site that should be spared if possible;
- Visibility of the rural surroundings needs to remain.

The prescribed clearance of 5 m meant a 5,87 m height difference had to be overcome. To do this in a cyclist friendly way, the length of the overall slope would be at least 460 m. A bridge of that length was only possible if it had several turns/corners. By meandering the bridge across the site, most of the existing trees on the eastern side of the intersection could be spared. Placing the main span away from the intersection itself allowed for enough distance in between bridge and traffic lights for motorists to notice them in time and well ahead of the intersection.

SLOPES

The newly built bicycle path has a total length of 427 m and a 280 m total span. On either side of the span, the slope leading up to the bridge is built on an earthen embankment. As the bridge is located right in between rural and urban environment, this was not only cost effective, but also befitting. The embankments are set back from the actual road intersection and therefore do not obstruct motorist's views of the rural surroundings.

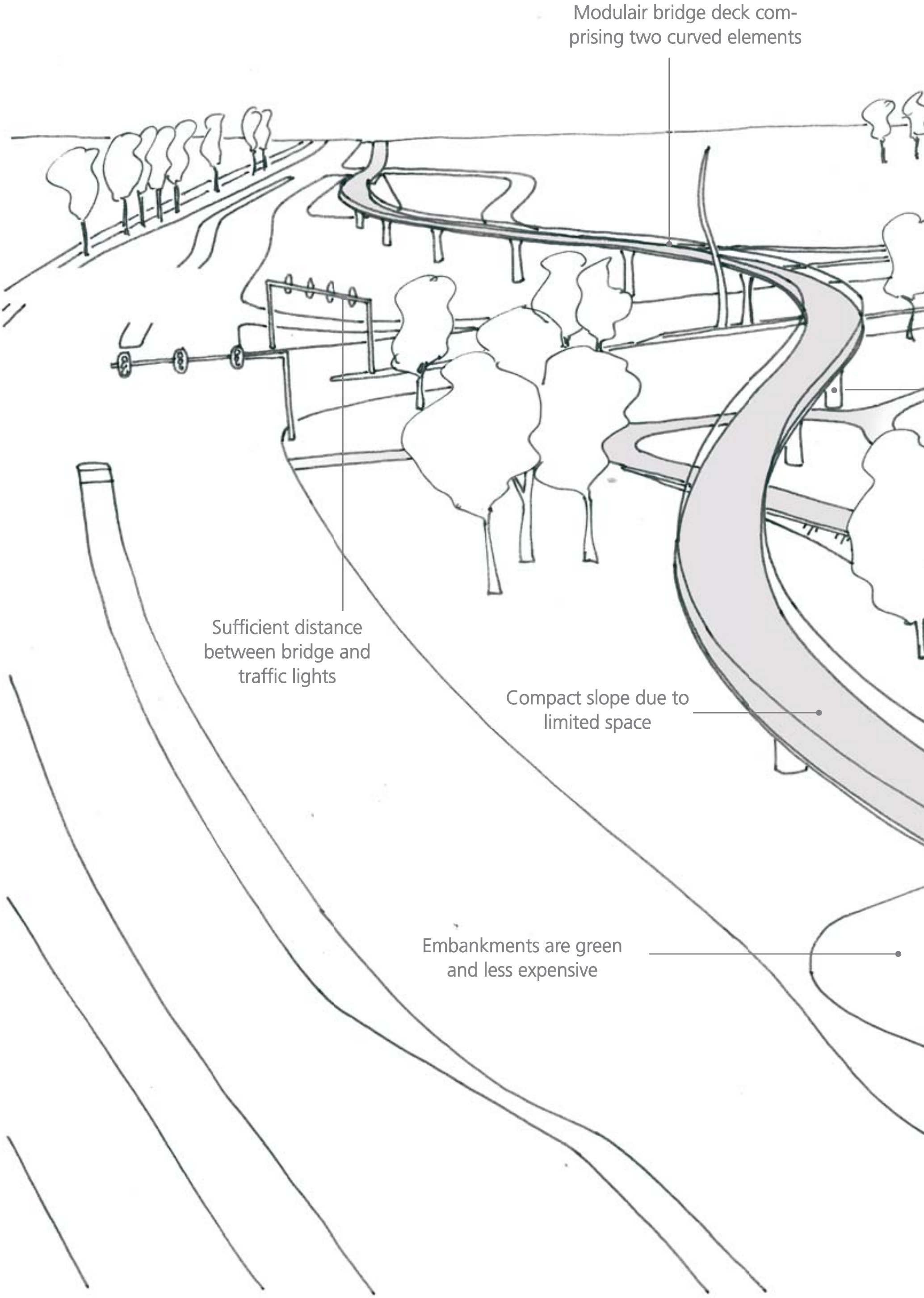
MODULAR STRUCTURE

In order to reduce costs, the bridge deck is made with only two different types of prefabricated pre-stressed concrete sections (radii of 75 and 180 m) placed in a carefully designed order. Consequently, only 2 expensive molds were needed. The 20-metre long sections are very slim, with a maximum height of only 0,8 m. Due to the chosen bearing type, supports and deck come together in one fluent and appealing shape. To give the bridge an extra nice touch, a curvy pattern was added to the bottom side of the concrete sections.

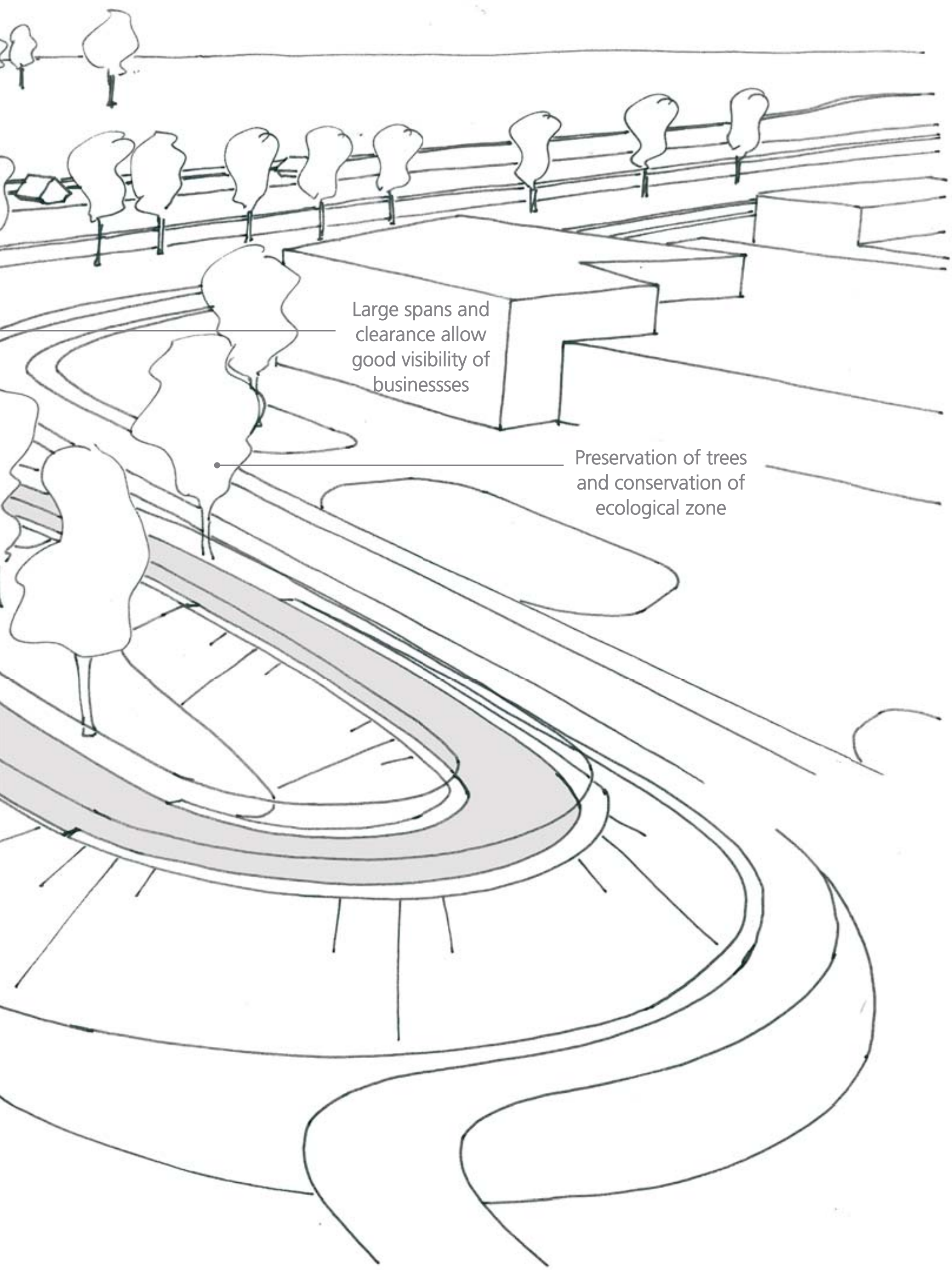
Figure 7.4 **Auke Vleerstraat Bridge**

Figure 7.5 **Auke Vleerstraat Bridge**
Due to its length, the bridge has a gentle slope

Figure 7.6 **Auke Vleerstraat Brigde**
Some of the trees that the bridge was designed around



Modulair bridge deck comprising two curved elements
Sufficient distance between bridge and traffic lights
Compact slope due to limited space
Embankments are green and less expensive


Large spans and clearance allow good visibility of businessses
Preservation of trees and conservation of ecological zone

7.3 SWING BRIDGE, RIJSWIJK

Clearance: 21 x 3 m
Height difference: 2.75 m
Total length: ca. 140 m
Main span: ca. 27 m
Deck width: 3 m (approach), 3.5-5.3 m (main span)
Slope gradient: 5 % and 5.9 % (=1:20 and 1:17)
Building costs: 2.374.000 euro
Completed: 2014

CONTEXT - SPECIAL CONCERNS

- Regional and water authorities preferred a non-movable bridge;
- Movable bridge preferable due to user comfort;
- Limited space for integrating slopes;
- A relatively large clearance envelope was required.

MOVABLE OR NOT?

The City Council wanted a new bridge across the canal in order for cyclists and pedestrians to easily cross the canal, which forms a substantial barrier in the local transportation network. As the canal is part of the region's main waterway network, it has a relatively large traffic flow. An extensive study by ipv Delft soon showed a non-movable bridge, preferred by regional authorities, was not possible as slopes would be too long to comfortably fit in this location. The study resulted in a proposal for a movable bridge. Although the movable bridge does mean some disruption to traffic (both vessels, and cyclists and pedestrians), it was chosen as the better option overall.

CLEARANCE

Ipv Delft designed a swing bridge with an 18-metre high pylon placed to the side of the canal. The steel bridge's 35 meter long asymmetrical deck is attached to the pylon with 12 stay cables. By using the principle of a stay cable bridge, the relatively long deck is subdivided into smaller spans, allowing for a very slender deck. This structural concept made it possible to have a slender, asymmetrical deck that is extremely slim at the far end. The bridge's slender structure minimalizes visual restrictions to vessels, and as the pylon is placed to the side of the canal, clearance width is not compromised either. To achieve this, the canal has been locally widened by several meters, allowing enough room for the pylon and the swaying deck.

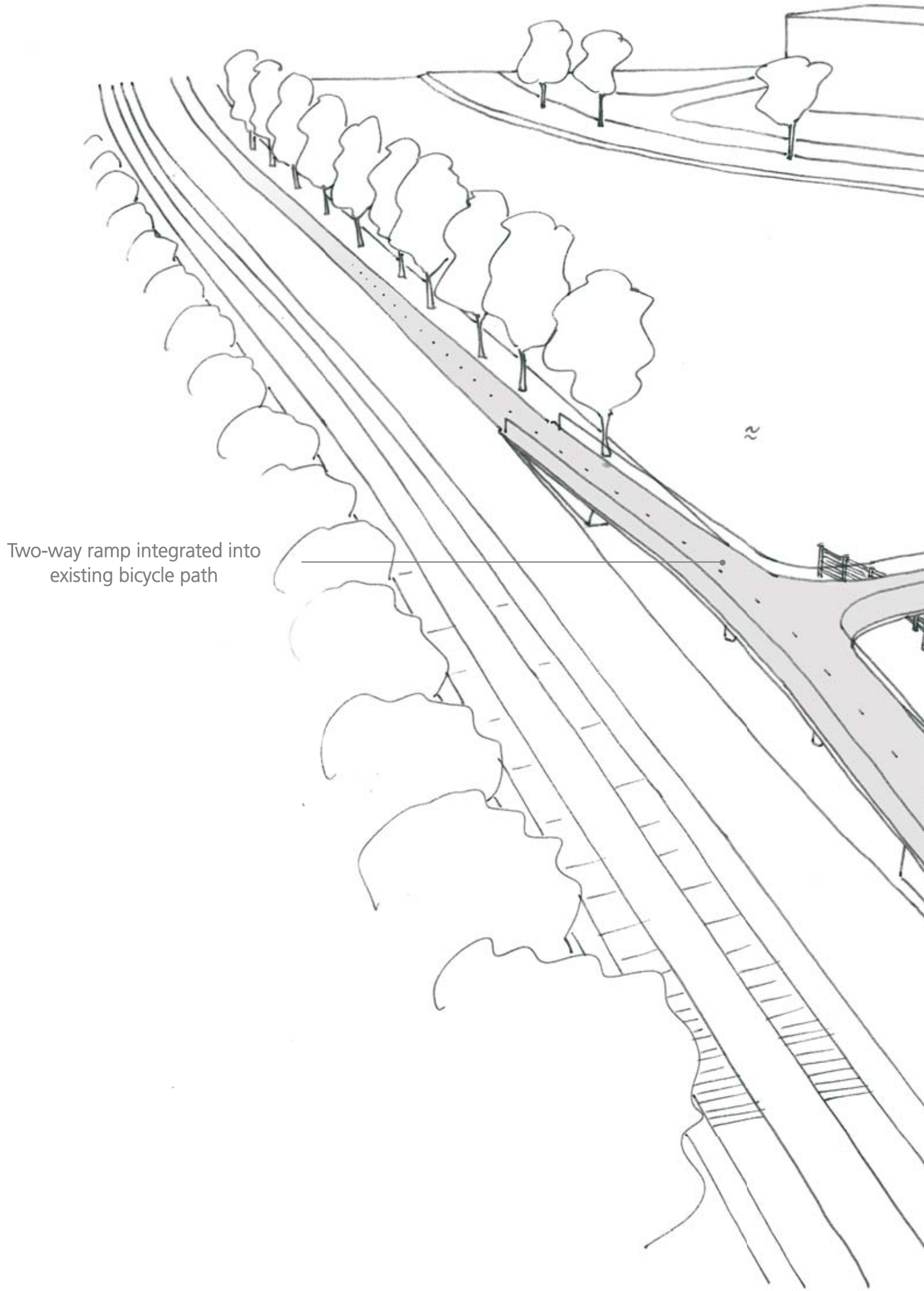
RAMPS

To overcome the 2.75 m height difference, a ramp was needed on both sides of the bridge. The west bank offered enough room for a slightly curvy ramp, but the east bank offered little possibilities given the presence of a road alongside the canal. It was decided to integrate a two-way ramp in the existing bicycle path perpendicular to the new bridge. This allows for a smooth connection between bicycle path and bridge.

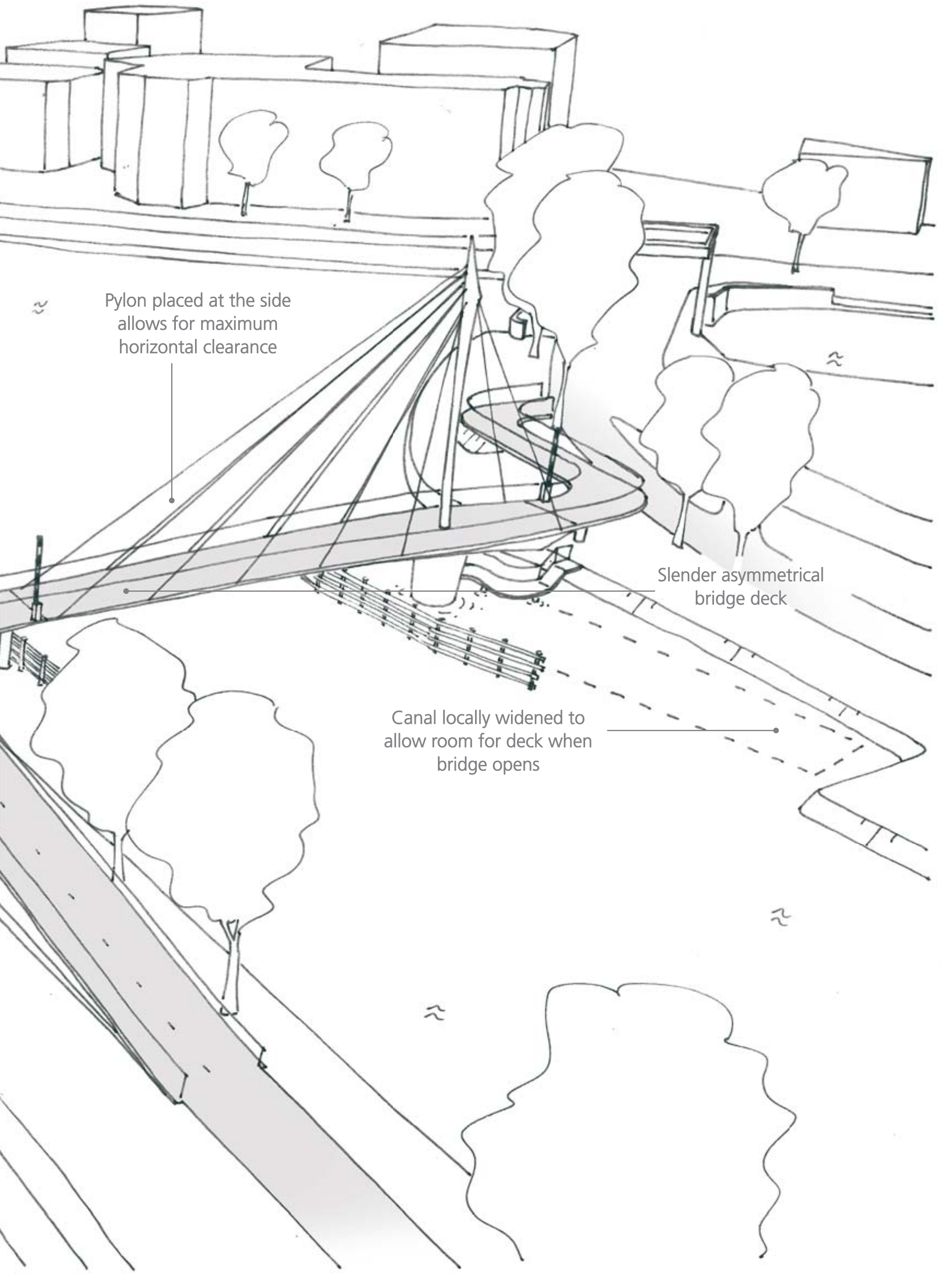
Figure 7.7 Swing bridge Rijswijk
The bridge's horizontal clearance equals the width of the canal

Figure 7.8 Swing bridge Rijswijk
The pylon footing houses the necessary machinery

Figure 7.9 Swing bridge Rijswijk



Two-way ramp integrated into existing bicycle path


Pylon placed at the side allows for maximum horizontal clearance
Slender asymmetrical bridge deck
Canal locally widened to allow room for deck when bridge opens

7.4 STATIONSWEG BRIDGE, HEERHUGOWAARD

Clearance: 17.5 x 4.7 m
Height difference: 6 m
Total length: 274 m (of which 120 m on embankment)
Main span: 24 m
Deck width: 3.5 m (main span), 4 m (straight slopes), 6 m (corners)
Slope gradient: 5 % (=1:20)
Building costs: 1.700.000 euro
Completed: 2014

CONTEXT - SPECIAL CONCERNS

- Visibility of nearby businesses;
- Presence of a peat embankment;
- Space limited by water, embankment, businesses, and existing roads;
- Many parties involved.

LIMITED SPACE

Plans to build a new housing development on the outskirts of Heerhugowaard asked for a bicycle bridge across one of the city's main entrance roads in order to connect the new housing development with the city. As space was very limited, it was at first uncertain if building a bridge on the chosen location was even possible. After a thorough study, ipv Delft found it was possible. The new bridge did however need to have several sharp tuns.

SLOPE DESIGN

The final design shows a double hairpin bridge, with the eastern one on supports. This allows for the businesses on the eastern side of the bridge to maintain their visibility. The western hairpin lies on top of the peat embankment. In order for the bridge to be comfortable for cyclists, the bridge deck widens at the curves, and the curves itself are flat. Pedestrians can take a shortcut by using the flight of steps on either side of the bridge's main span.

IN SITU CONCRETE

Except for the 24 m main span that crosses the existing road, the concrete bridge was cast in situ, allowing for a structurally efficient design and a slender deck. In situ construction also means the 154 m bridge only has two expansion joints (on either side of the prefabricated main span), seriously reducing the amount of maintenance needed.

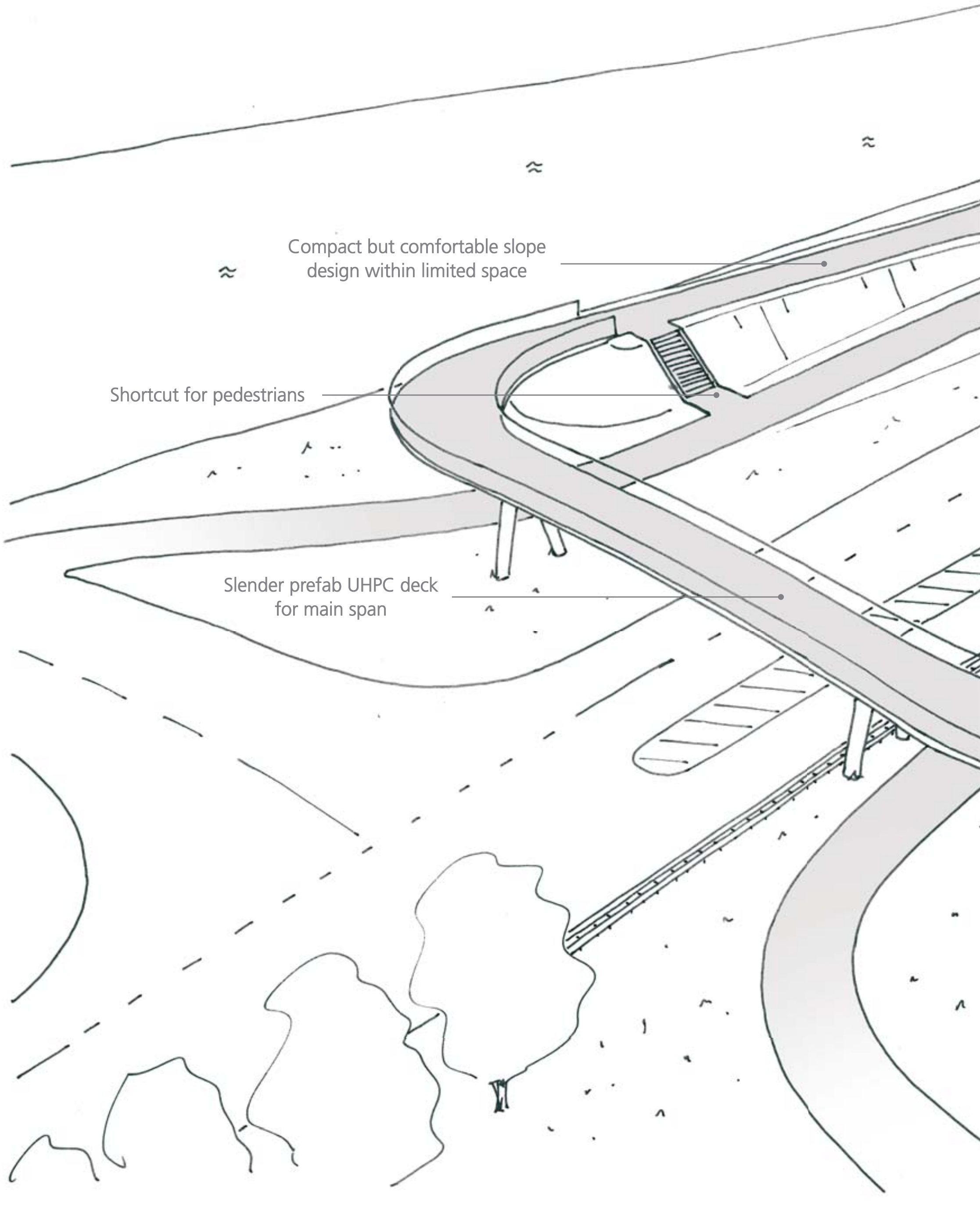
RAILING

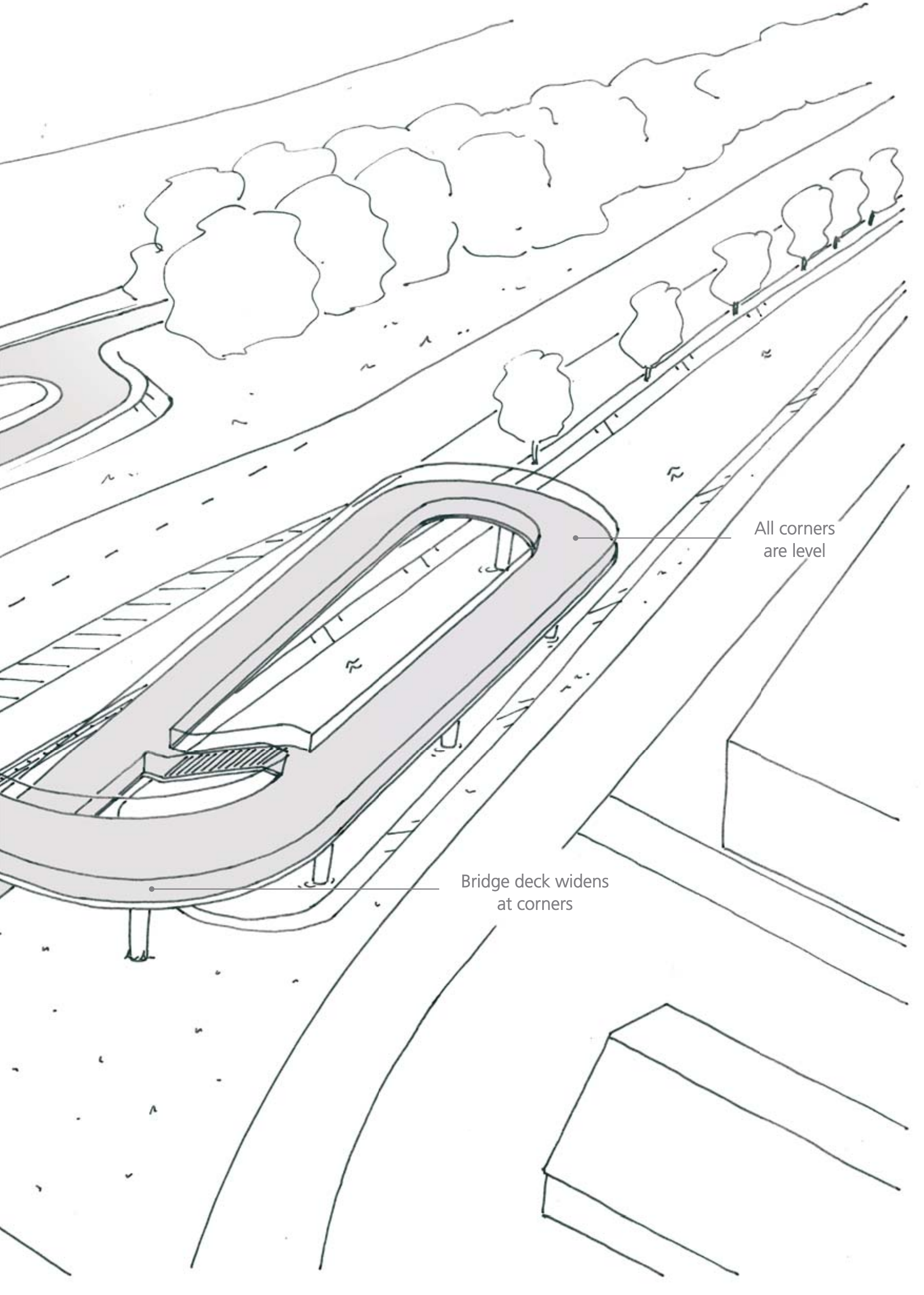
The custom designed railing has relatively small openings to ensure that cyclists feel safe when using the bridge as they cross the busy road underneath. The meticulous design comprises two rows of near vertical stainless steel rods that join at the top. This slightly tilted placement creates a railing that changes its appearance as you pass it, enhancing the feeling of safety, as it appears closed from several angles. For drivers passing the bridge, the railing appears very transparent, allowing them to notice the nearby businesses.

Figure 7.10 **Stationsweg Bridge**
The flight of steps offers pedestrians a significantly shorter route

Figure 7.11 **Stationsweg Bridge**
Cyclists have a clear view of the path and height difference ahead

Figure 7.12 **Stationsweg Bridge**
The in situ concrete deck makes for an impressive appearance


Compact but comfortable slope
design within limited space
Shortcut for pedestrians
Slender prefab UHPC deck
for main span


All corners
are level
Bridge deck widens
at corners

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APPENDIX

CONVERSION TABLES

General

	Metric	US
	0,5 m	1’-8”
	1 m	3’-3”
	5 m	16’-5”
	10 m	32’-10”
	1 kN	0,225 kip
	1 kN/m^2	0,145 psi
	1000 kN	224,8 kip

Bridge width

	Metric	US
Pedestrians, min. width in between railings	1,5 m	4’-11”
Pedestrians, preferred width in between railings	1,8 m	5’-11”
Cyclists, min. width in between railings one way traffic	1,4 m	4’-7”
Cyclists, min. width in between railings two way traffic	2,2 m	7’-2”

Loads

	Metric	US
Uniform load	5 kN/m^2	0,73 psi
Concentrated load	7 kN	1,57 kip
Maintenance vehicle axle load	25 kN	5,62 kip
Unauthorized vehicle axle load	40 kN	8,99 kip
Railing load	3 kN/m	0,206 kip/ft

< Bicycle bridge, Ulft

COLOPHON

Brief Dutch Design Manual for Bicycle and Pedestrian Bridges
English summary of the CROW design guide

version 1.5 - 27.07.2017

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BRIEF DUTCH DESIGN MANUAL FOR BICYCLE AND PEDESTRIAN BRIDGES

As one of the main bridge design offices in the Netherlands, ipv Delft has focused on designing bicycle and pedestrian bridges for two decades. The company has used their extensive experience in bridge design to write this publication. This design manual focuses on the fundamentals of bridge design, answering practical questions regarding issues such as bridge width and slopes. It also lists the things that should be taken into account before starting on the actual design and it offers insight in the Dutch regulations regarding loads and collision forces. General advice on cost reduction is also included and several of the company's projects are shown to illustrate the theoretical contents. The Brief Dutch Design Manual for Bicycle and Pedestrian Bridges therefore is a vital source of both practical information and bridge design inspiration.

This publication is an English summary of the Dutch Design Manual for Bicycle and Pedestrian Bridges, which was published by CROW in 2014 and written by ipv Delft.

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