Dutch Design Guide for Bicycle and Pedestrian Bridge Design

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SUMMARY

As more and more people worldwide are living in densely populated urban areas the added value of cycling and walking as means to create more liveable cities is being increasingly recognized internationally.

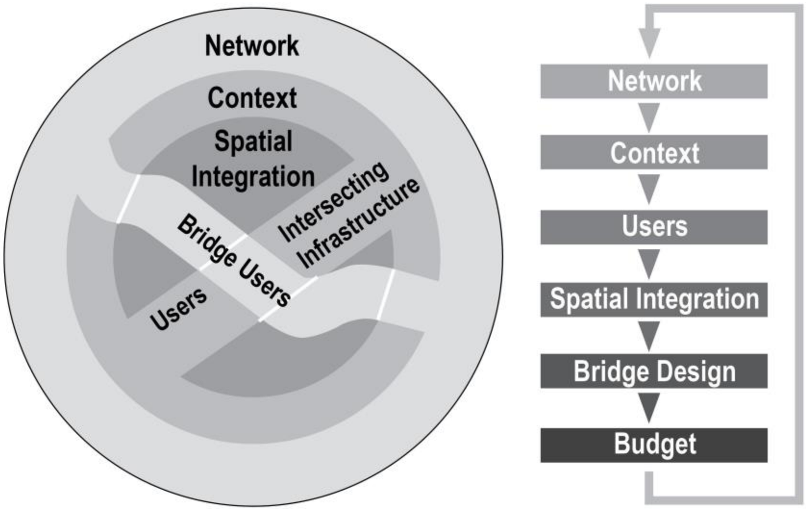
The Netherlands has decades of experience building cycling and pedestrian bridges, but there was no National Design Guide for this type of bridges. Therefore the Dutch technology platform for transport, infrastructure and public space asked ipv Delft to write the Dutch Design Guide for cycling and pedestrian bridges [1], which was published in 2014. An English Summary of the Guide [2] (Fig. 2) was written in 2015.

To develop successful cycling and walking networks we need to cross all kinds of natural and manmade barriers. Bridge design therefor often is more than only an engineering task. Bridge projects have many stakeholders whose interests need to be taken into account to develop an optimal solution for all.

To be able to take all interests into account designers and engineers need to analyse thoroughly the requirements of all involved parties and stakeholders. Therefor ipv Delft developed a method which forms the backbone of the Dutch Design Guide. The method subsequently analyses the requirements from the network, context and users which then form the starting point for the spatial integration and bridge design.

The method is meant for everybody involved in bridge development and explained in this paper.

Keywords: *method for requirements analysis, design specifications, bridge engineer / designer's role.*



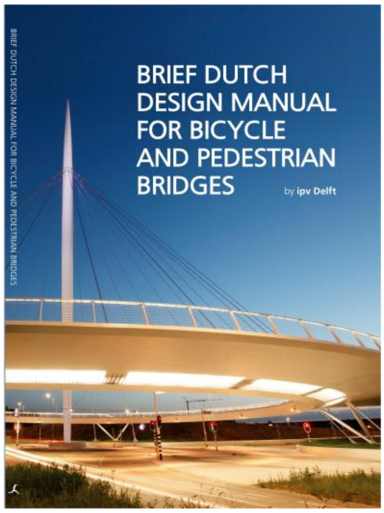


Fig. 1. Dutch Design Guide structure based on requirements analysis

Fig. 2. English Summary [2]

1. NETWORK

The need for a new footbridge arises from the existing cycling and pedestrian network and urban developments. A good network is coherent, direct and safe. Knowing the basics of a good network enables bridge engineers to discuss alternative solutions for a new connection or even a better connection. Traffic engineers tend to take the most urgently needed route as a starting point (A to B). Informed bridge engineers can advise on the best location for a bridge in relation to the route, avoiding locations which have negative consequences for buildability and costs (like bends in waterways or highways). Or they can suggest to connect the new bridge to adjacent routes (A',B'). Opportunities like these can be missed with limited knowledge of each other's interests between bridge engineers, traffic engineers and contract writers.

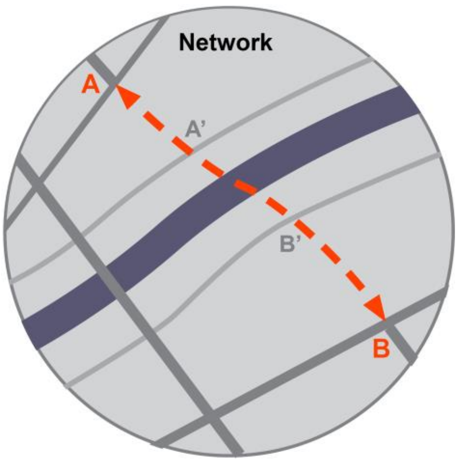


Fig. 3. Network

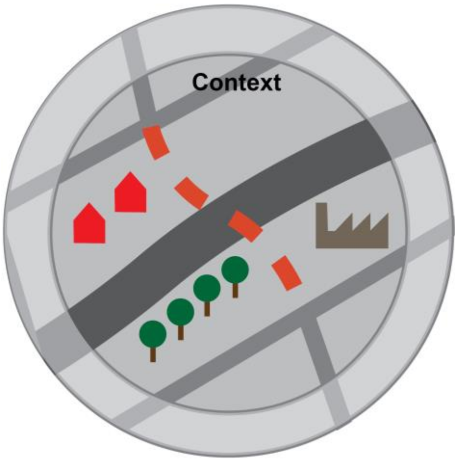


Fig. 4. Context

2. CONTEXT

The Network analysis provides the best location (the context) for a new bridge. Analysis of the context provides requirements like subsurface condition, underground infrastructure and existing and future development plans. But in our densely populated areas other requirements are also increasingly important. Urban planning requirements lik e zoning, fitting in with the environment, historical context, sightlines, social safety and ecology. Or requirements of local entrepreneurs, and citizens. Wishes from city marketeers, in fact, can lead to a landmark bridge to advertise the character of a city or region. These requirements can be threats for the feasibility of a project, or opportunities. But knowing them enables the bridge engineer or designer to come up with win-win solutions that suit all stakeholders. Early involvement of all stakeholders in the context is crucial for a successful project. And even the context itself can be an opportunity (Fig. 4).

Fig. 3. Footbridge referring to local railway history

Fig. 4. On site poured on later excavated existing dam

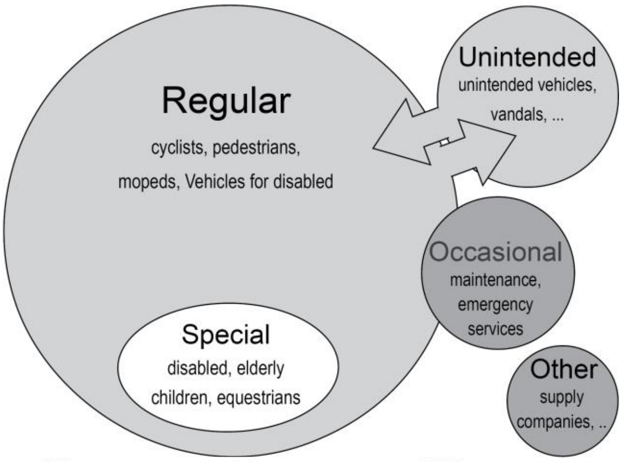


Fig. 5. Bridge users and intersecting users

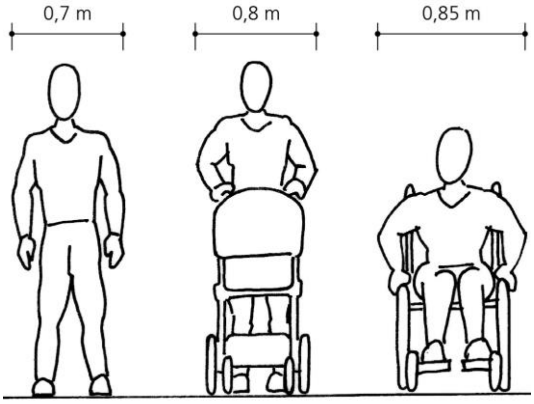


Fig. 6. Dimensions pedestrians

3. USERS

A new footbridge is designed for a particular user group like pedestrians or cyclists. But often the zone that is crossed also has users. Both the bridge users and these ‘intersecting users’ have their own requirements and need to be offered safety and comfort while passing or otherwise using the bridge. Both user groups consist of main, special, incidental and unintended users. Like for example for a bicycle bridge cyclists, disabled people, maintenance people and vandals or trucks. Even owners of pipes and cables on, through or under the bridge can be users. A good analysis of all expected bridge users and intersecting users in the present and future is essential for a comfortable and efficient usable bridge during its complete lifespan. An expected increase of the amount of intersecting car traffic can justify building a footbridge with a larger span than needed today to make future widening of the intersecting road possible.

3.1 Cyclists

Before 2014 there were no clear regulations in the Netherlands for the required deck width for bicycle bridges. Mostly a margin was added to the width of the connecting path. For the Design Guide these requirements were extensively discussed and researched by ipv Delft and a group of experts, including cycling advocates. This led to basic requirements for deck width as shown in Fig. 7.

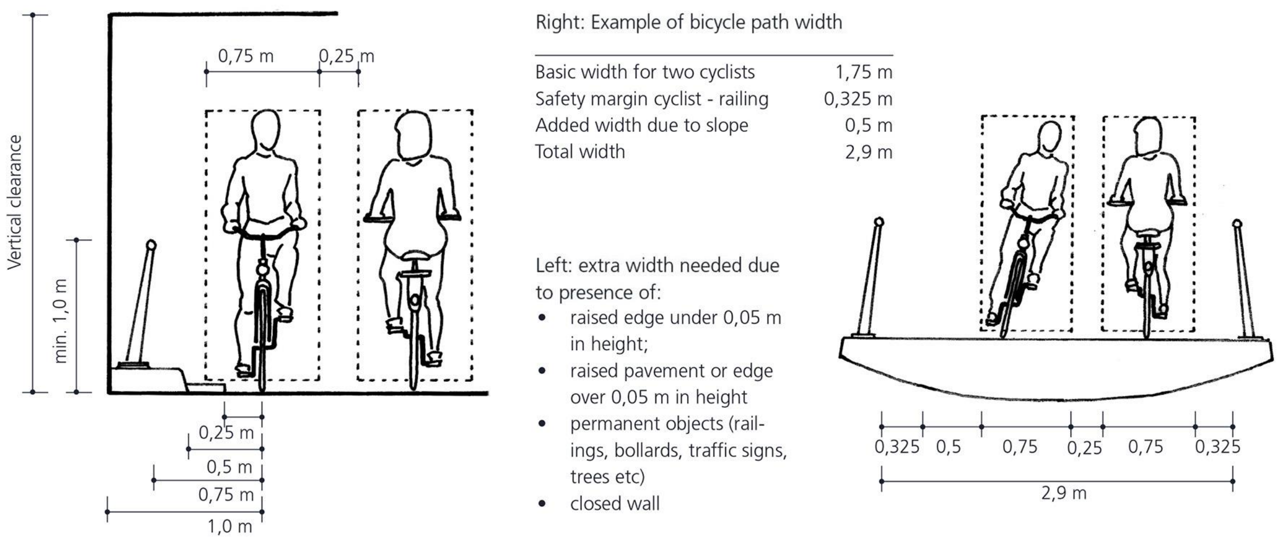


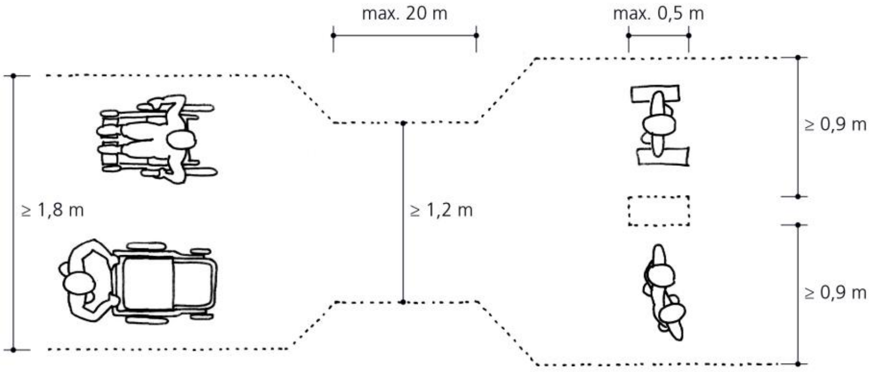
Fig. 7. Deck width needed for cyclists

The required deck width includes distances needed between cyclists, curbs, railings and walls. A distance from 0,25 m up to 0,8 m when going uphill at low speed is necessary to prevent collision between swerving cyclists. On downhill lanes it is advised to provide an extra width of 0,5 m.

It can be necessary for the new bridge and ramps to have one or more curves. The curve radius should ideally be somewhere in between 10 m and 20 m. A curve radius of 5 m should be considered the absolute minimum. Below that, cyclists have trouble staying on their bicycles as their speed is too low.

3.2 Pedestrians

The Dutch regulations for pedestrians were already pretty well defined in 2014. The basic dimensions and the required deck width are shown in figures 6 and 8.



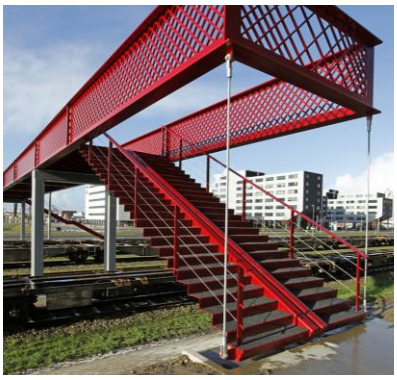


Fig. 8. Deck width required for pedestrians *Fig. 9. Hanging staircase*

3.3 Other Users

Next to cyclists and pedestrians footbridges also have other users as shown in figure 5. These other users can be crucial to the success of a bridge in terms of usability and costs. For example when a lot of children are expected to use the bridge, railings need to be safer. And in case of disabled and elderly people ramps should be shorter or less steep. The need for occasional accessibility for maintenance and emergency vehicles can lead to a larger needed deck width and exerted loads. Regarding maintenance as an important user of every bridge and being prepared for hooligans will lead to lower maintenance costs and maintenance time and thereby to less obstructions for the bridge users or intersecting users.

3.4 Intersecting Users

Next to the users that use the bridge other users and traffic types that have their own regulations can intersect the bridge. Required clearances, sightlines and exerted loads by traffic types like road, rail and water traffic are important requirements that determine needed structural dimensions and positions of supports. A required clearance over a waterway can even make a movable bridge a better solution than a fixed one.

4. SPATIAL INTEGRATION

The requirements found in the analysis of the network, context and the users define the possibilities for the spatial integration of the bridge and the potentially needed ramps. In this phase possible bridge alignments that offer a comfortable and safe solution for all users are researched, while taking into account the requirements from stakeholders in the context. Often a height difference needs to be crossed with ramps or steps. Especially for bicycle bridges ramps are a major influence on how the bridge can be integrated in the context.

4.1 Basic Guidelines Bicycle Slopes

The slope is an important part of bicycle ramp design. In the Design Guide several previously published studies regarding slopes for cyclists have been combined into one clear overview (Fig. 9) which shows a bandwidth (the blue area) of acceptable grades.

The bandwidth for the slope is based upon a formula that defines the difficulty of a ramp (Z). Z can be calculated as the square of the average grade multiplied by the length of the ramp. Or as the square of the height difference divided by its length: $Z = (H/L)^2 \times L = H^2/L$ [3]

For an average middle-aged cyclist under normal circumstances and average wind conditions the difficulty of a ramp (Z) ideally should be 0,075 with a maximum grade of 7,5% and a minimum grade of 1,75% (the blue line in Fig. 9).

The lower limit of the bandwidth is based on Z=0,0333 with a maximum grades of 6,67% and a minimum grade of 1,25%. Grades below 1,25% are considered false flats and therefor ignored. The lower limit can be seen as acceptable for less fit people.

The upper limit is based on Z=0,200 with a maximum grade of 10%. These grades are acceptable for fit people.

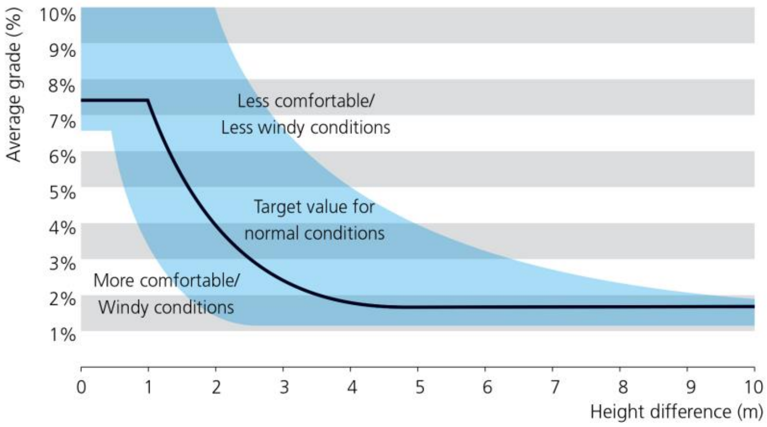


Fig. 10. Slope bandwidth for cyclists

Fig.11. Ramp in complex context

4.2 Bridge and Ramp Alignment

Together the requirements from the network, context, users and an acceptable slope (Fig. 10) form the starting point for the optimal bridge and ramp alignment. For the bridge users grade, route directness, availability of alternative routes and flat stretches determine the comfort and therefor the success of the new connection. Because of constraints in the context the perfect ramp is almost never an option and concessions must be made. But an acceptable compromise between all requirements is often possible.

An acceptable ramp needs:

- a grade within the bandwidth (Fig. 10).
- to provide the feeling that the route is not a detour and can be optimized taking into account the cyclist’s condition. When an alternative with a lower grade is available within close range a steeper slope is acceptable. And integrating steep and gentle slopes on one location is perfect. All users can take the steep one going down and the gentle one going up. With such a solution sporty cyclists can take the shortest route both ways.
- a flat stretch with a length of 25 m for a height difference over 3 m. Over 5 m this a bare necessity. The flat stretch must be situated in a bend when these occur in the ramp.
- to be clearly visible from afar and have a flat stretch at the end of a ramp. This makes it possible to anticipate the ramp by increasing speed going up or to reduce speed on time going down.

- bends that have a radius that allow enough speed and safe passage.

Open-mindedness to the interests of all stakeholders in phase ‘Spatial Integration’ often can deliver win-win solutions like ramps that are also sound barriers.

5. BRIDGE DESIGN

The approved horizontal and vertical alignment found in the phase ‘Spatial Integration’ form the basis for the structural and architectural design of the bridge. Loads, allowed vibrations and railing requirements determine the structural dimensions. The desired character of the bridge inspires the architecture. And the structural efficiency, buildability, durability and maintainability of the design determine the lifecycle costs.

5.1 Loads

The typical loads used to determine the dimensions of a Dutch footbridge are those of the Eurocodes [4] and the Dutch national Annexes of these codes. Most of these loads have fixed values determined by the bridge users and the intersecting users and are not mentioned in this paper. The size of some loads are influenced by decisions made in the phase ‘Spatial Integration’ and ‘Bridge Design’ by designers, engineers, authorities and clients and can have a positive effect on the building costs.

5.1.1 Uniformly distributed load

For footbridges with a span larger than 10 m the uniformly distributed load can be decreased from 5 kN/m² to 2,5 kN/m² with a span of 210 m when large crowds are not expected to use the bridge.

5.1.2 Impact loads for lightweight structures

The Eurocodes do not dictate any impact loads for lightweight structures such as footbridges. It is therefore unclear what impact loads should be used when designing a steel, fibre-reinforced polymer or wooden footbridge. If the impact loads for road traffic bridges are applied to a footbridge, 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 lower impact loading specifications.

Another option is to use dynamic calculations. Rather than the simplified static method provided by the Eurocodes. This way, the actual forces and their effects are calculated. The Eurocodes specify what weight and speed the test vehicles should have.

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. In that case the impact loads can be lower. Sometimes elements that prevent too high vehicles getting to the bridge can be introduced, for example by letting signage portals double as anti-collision portals.

Fig. 12. Design for 250 kN collision force

Fig. 13. Signage portals as anti-collision portals

5.2 Vibrations

During the design process, basic calculations can be used to predict the natural frequency of the bridge. 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 of Steel Structures) [5].

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 stay cables. These vibrations can be especially difficult to predict. 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.

Several measures can be taken to prevent bridge vibrations. The most commonly used ones are: increasing rigidity, increasing dead weight and applying dampers like tuned mass dampers or viscous dampers.

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. But researching possible damping solutions in the design phase is advised.

5.3 Railings

The Dutch building codes [6] dictate that any bridge with a drop of 1 m or more requires a railing. The required height of the railing depends on the height of the deck above the intersecting zone and the users. Because of their higher centre of gravity (1,2 m) cyclists prefer a higher railing of 1,2 or 1,3 m.

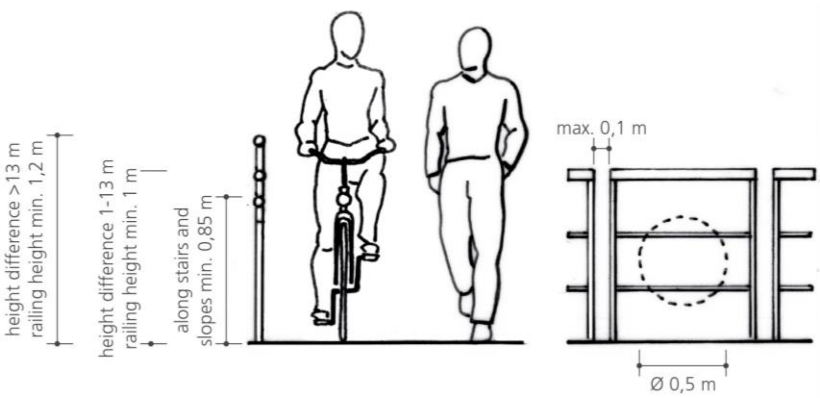


Fig. 14. Railing details *Fig. 15. Integrated lighting*

In general gaps between elements of a railing must be small enough that a 0,5 m sphere cannot pass through them. But when a bridge is situated in a child friendly area applying stricter regulations can be wise. The Dutch Building codes dictate openings to be smaller than 0,2 m for railings and fencing inside residential and school buildings and smaller than 0,1 m for childcare facilities for children under the age of 4. 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. Nevertheless a railing can still be a challenge for children and you might see them climbing a not climbable railing.

5.4 Costs

Striving for a structural efficient, buildable, durable and maintainable bridge does not necessarily reduce the architectural quality, but taking these aspects into account often does reduce the lifecycle costs.

Structural efficiency depends on the span(s), alignments and possibilities to place supports. These aspects are determined by choices made in the phases ‘Network’, ‘Context’ and ‘Spatial Integration’.

Introducing modularity in all elements of a bridge design often has a positive effect on the buildability. Even custom bridge parts are cost efficient when they can be used in large enough quantities. An extruded aluminium handrail with integrated fixtures, lighting and wiring (Fig. 15) or aluminium casted posts are worth considering when enough railing length is required. And prefabricated reusable steel molds, used to make custom shaped concrete decks and supports, can be an effective way to a build a good looking winding alignment.

Taking maintenance into account in the design process can seriously reduce the costs and the experienced quality of the bridge during the lifecycle.

And although choosing a more durable material can be expensive it also can lead to lower lifecycle costs when maintenance is difficult or causes unwanted obstruction of the intersecting infrastructure.

6. BUDGET

Now knowing the bridge design and having gathered the requirements the most appropriate tender and contract format can be chosen and the needed budget for the total lifespan can be estimated.

The tender and contract format can have a big influence on the lifecycle costs. Modern tender and contract formats tend to leave a lot of design decisions to the contractors. But in general it seems wise as a client to dictate solutions for problems that you know best. Through years of experience clients are often more familiar with the requirements from the local network, context and users then a contractor.

Bonuses offered in contracts can be a means to stimulate the quality of bids or make competitive bids with higher quality materials possible.

When the expected life cycle costs of a design exceed the budget the gathered requirements can form the basis for a cost optimized alternative design. Designing is and will always be an iterative process.

7. GUIDE FOR A PROCESS

The Design Guide is meant to be useful for all disciplines involved in the development of networks for cyclists and pedestrians. In the Design Guide it is emphasized that a good bridge design often is not only the result of an engineering effort. It is the result of all involved disciplines and stakeholders being open to each other’s interests and requirements. Such a process often needs a mediator between the soft (social, economic, architectural) and hard (technical) requirements. Designers and engineers can fulfil this role in their projects. Creating bridges that meet all their present and future expectations.

The Design Guide gives insight in important aspects of bridge design to all involved disciplines and stakeholders. Hopefully it also helps changing bridges from being the gap closer to being the advertiser of the network. Designers of networks often see bridges as complex expensive objects. So mostly a network is started with a path. But bridges are the hardest parts of a network to integrate in the context. Planning bridges in the early stages of network development can result in large cost reductions. Money that can be used to make more and better paths and footbridges.

An English summary of the Dutch Design Guide [2] is available for free download at ipvdelft.com/publications.

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