Design of Movable Bridges - selected examples

Adriaan Kok

Designer, Project Manager
ipv Delft
Delft, The Netherlands

adriaankok@ipvdelft.nl

Niels Degenkamp

Designer, Project Manager
ipv Delft
Delft, The Netherlands

nielsdegenkamp@ipvdelft.nl

Summary

To develop successful cycling and walking networks in the Netherlands often navigable waterways need to crossed. In theory this can be done with a fixed bridge if it has a large enough vertical clearance. However, to access high bridges like these often long winding ramps are required. In practice such ramps prove to be difficult to integrate in an urban context.

Therefore a movable bridge can be the preferred solution despite the higher lifecycle costs. In a study for a possible new footbridge crossing a canal in Rijswijk this was the case.

In this paper important aspects of the design of a movable bridge are described, from the why of a movable bridge to aspects like possible mechanisms, types of machinery and the required safety measures and how to integrate all these aspects successfully.

This is done by first describing the design process of the movable bridge in Rijswijk in detail and then striking elements of others designs for movable bridges.

Keywords: *movable bridge, mechanisms, machinery, safety measures, integrated design.*

Fig. 1. Overview swing bridge Rijswijk

1. Swing Bridge Rijswijk: an Efficient Eye-catcher

The cities of Rijswijk and The Hague slowly become one city and old infrastructure like waterways that used to connect the cities become obstacles in the traffic network. The Schie canal is such an obstacle: it causes long detours for cyclists and pedestrians. Therefore ipv Delft was asked to research possible locations for bridges and bridge designs to cross the canal with a footbridge. The available budget for the new footbridge was 7 million euros.

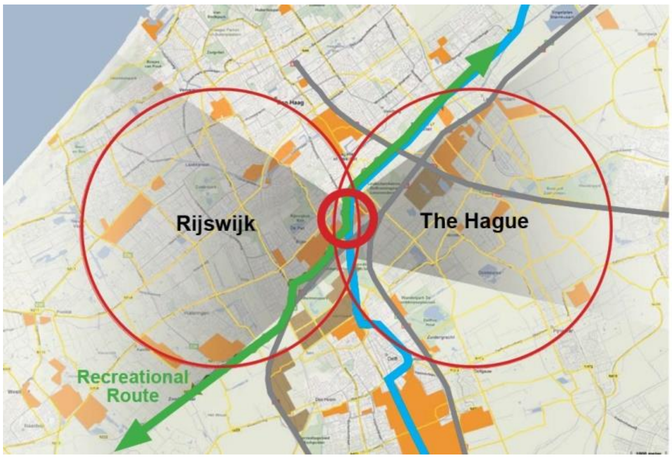

Fig. 2. Most logical search area (context) in the network

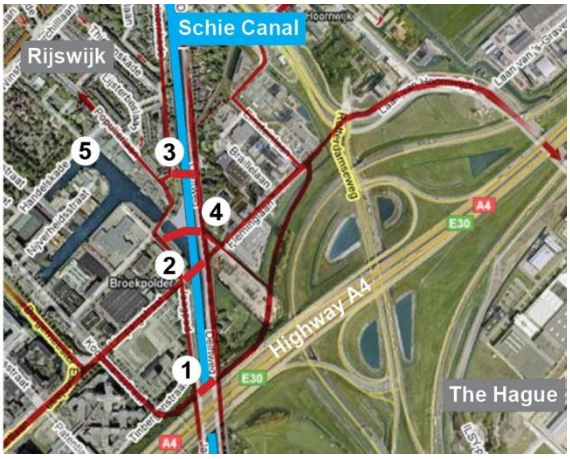

Fig. 3. Possible bridge locations in the context

1.1 Network

The most logical location in the network for the new connection was found by analysis of the expected traffic between residential and business areas on both sides of the canal. On the map in figure 2 two circles show a travel range of 7.5 kilometre from the centre of the residential and business areas adjacent to the canal. In an urban context in the Netherlands a distance of 7.5 kilometre can be travelled in the same time by bike, car or public transport. The area where the travel range circles overlap and meet an important recreational route proved to be the most logical search area (context) for a new footbridge.

1.2 Context

In the context 4 locations (Fig. 3) were found that offer a fairly direct connection between the existing bicycle and pedestrian routes. For all locations a solution had to be found to overcome the height difference between the existing routes parallel to the embankments of the canal and a bridge without disturbing these routes. A high fixed bridge also needed to cross the roads parallel to the canal and a tram track on the eastside of the canal.

To minimize hindrance of cargo ships using the canal during construction works the amount of supports in the waterway had to be minimized at every location. Also bridge designs close to the entrance of the harbour (Fig. 3, nr. 5) had to take into account space required by turning cargo ships.

1.3 Users

The bridge is intended to be used by cyclists, pedestrians and a standard maintenance vehicle. This results in a minimum required deck width of 3.5 m. For the ramps a maximum grade of 2.5% was allowed and flat stretches with a length of 25 m were required for a height difference above 5 m.

The waterway is mainly used by cargo ships with a maximum length of 70 m and width of 7.5 m (European CEMT III class). The waterway is also used by recreational vessels. The required vertical clearance for a fixed bridge is 7 m and for a movable bridge 3 m when closed. The minimum required horizontal clearance for a movable bridge is 13.4 m, but a larger horizontal clearance is preferred. A larger clearance results in less supports in the waterway and a larger turning space when the bridge is situated near the entrance of the harbour. Fenders were required to protect supports from a collision by the large cargo ships.

1.4 Spatial Integration

Next to bridges a tunnel was also considered but rejected. With a tunnel cyclists and pedestrians need to descend 10 m with at least 400 m long ramps. The expected high costs, perceived unsafety and difficult spatial integration of a tunnel make a bridge the preferred solution.

For every potential bridge location found in the context a location specific bridge concept was developed.

1.4.1 Location 1: Fixed arch bridge

For location 1 a fixed arch bridge was designed located directly next to the bridge in highway A4. The department of waterways preferred a fixed bridge. Because a fixed bridge requires a vertical clearance of 7 m ramps with a length of at least 300 m at 3.5 % are needed. The bridge also has to cross the roads and the tram track parallel to the canal. It proved impossible to connect the ramps with a direct route to the network so the ramps would feel like a detour. The ramps would also be located out of sight of the road, houses and offices and therefore be perceived as unsafe. The building costs were estimated at 4 million euros.

1.4.2 Location 2: Double drawbridge

For location 2 a double drawbridge was designed. This bridge lands directly on the existing bicycle routes parallel to the embankment of the canal. No supports and fenders in the waterway are required. Steep ramps to overcome a height difference of 2,5 m needed to be integrated in the existing cycle lanes on both sides of the canal. This would cause discomfort for both the users of the bridge and the cycle lanes parallel to the canal. The building costs were estimated at 6 million euros.

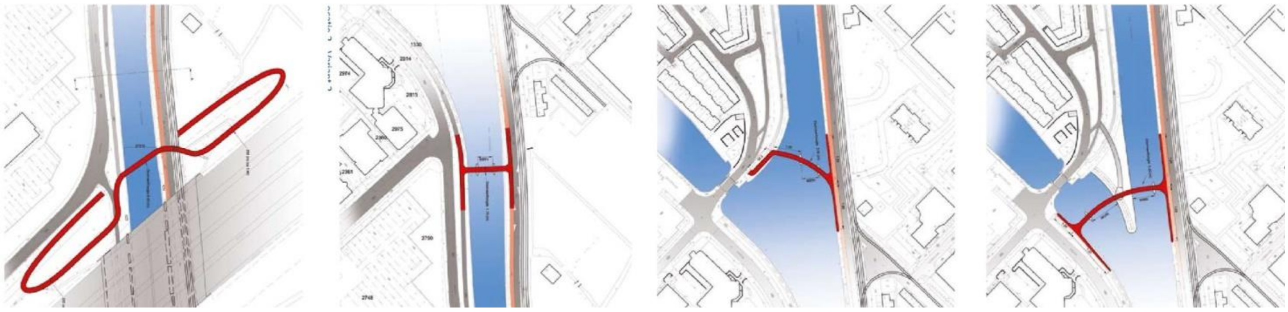

Fig. 4. Bridge and ramp alignments for location 1 to 4

Fig. 5. Bridge designs for location 1 to 4

1.4.3 Location 3: Asymmetric cable-stayed swing bridge

For location 3 an asymmetric cable-stayed swing bridge was designed. A swing bridge is less susceptible to wind forces than a drawbridge. Therefore it is easier to build a swing bridge with a large horizontal clearance. On the west side it is possible to integrate a ramp in the embankment. On the east side however the bridge lands just before the embankment to make a ramp in the waterway parallel to the existing cycling lane possible. Supports and fenders in the waterway are needed for this concept. They are located near to the embankment so the hindrance for ships during construction works is expected to be minimal. This concept needed optimisation but the possibilities for alignments and a large horizontal clearance were promising. The building costs were estimated at 4 million euros.

1.4.4 Location 4: Symmetric cable stayed swing bridge

For location 4 a large symmetric cable-stayed swing bridge was designed that bridges as well the canal as the entrance of the harbour making the existing bridge over the harbour entrance obsolete. On the east side a ramp similar to the one of concept 3 is needed. On the west side it is possible to integrate ramps in the embankment and in the bridge itself. When the bridge opens the canal as well as the harbour entrance are passable for ships. However, both the western cycle lane and the route over the canal are simultaneously closed. This concept required a lot of fender constructions in the waterway. The building costs were estimated at 5.5 million euros.

1.4.5 Concept evaluation

Because of the direct connection between existing routes, minimal expected hindrance to ships, acceptable expected costs and possibilities the decision was made to further develop the swing bridge concept for location 3.

1.5 Bridge design

Specifications size: l=110 m, w=4 m clearance width: 21 m building costs: € 2.400.000 completion: 2014

During the phase ‘Bridge Design’ the asymmetric swing bridge for location 3 was further developed. Widening the waterway locally on the west side created a space where the bridge deck can turn into when opening. In this space the opened bridge deck is protected from collision from the north by the embankment. In open position the bridge has a horizontal clearance of 21 m and leaves the waterway and the entrance of the harbour completely unobstructed. Minimizing the structural height of the bridge deck and optimizing the alignment decreased the height difference between the existing cycling lane and the bridge to 1.7 m. With the decreased height difference it was acceptable to integrate the required ramps in the existing cycling lane. Now both users of the cycling lane and the bridge need to use the ramp, but supports in the waterway are no longer required. In the waterway the bridge now only needs one support on each side of the canal: on the east side a support for the fixed bridge part and on the west side the pivot point of the bridge that supports the pylon and houses the machinery (a simple electric gear unit). To make the technical equipment in the pivot point accessible in every position of the movable deck a slender circular maintenance platform is designed that accentuates the movability of the bridge.

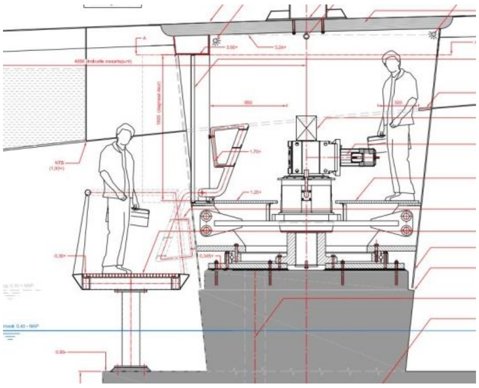

Fig. 6. Machinery, technical space

Fig. 7. Birds-eye view swing bridge Rijswijk

Fig. 8. Design details swing bridge Rijswijk

2. Kadoelen Bridge Amsterdam: Design and Operating Mechanism Become One

Specifications size: l=110 m, w=7 m clearance width: 12 m building costs: € 2.460.000 completion: 2012

Fig. 9. Overview Kadoelen bridge Amsterdam

The Kadoelen bridge in Amsterdam shows how a technical principle can be a good occasion to make an appealing design for a movable bridge. Where most bascule bridges are fitted with non-visible counterbalances in a basement underneath the bridge deck, this bridge has eye-catching counterweights at the sides of the deck. These counterweights are not only necessary to balance the bridge deck, they are also part of the operating mechanism: two curved racks seat at the ends of the counterweights. When opening or closing the bridge these racks are driven by two pinions which protrude from the hollow concrete main pilar, that contains the electromechanical gear unit and electrotechnical installations necessary to control the bridge. The visible installations required to operate the bridge – like signals, barriers and CCTV poles – are carefully integrated in the design leaving the horizontal bridge design intact.

Fig. 10. Open Kadoelen bridge *Fig. 11. Counterweight with rack* *Fig. 12. Mould edge element*

Also a lot of attention was paid to minimize building and maintenance costs. Prefabricated concrete elements are mounted to steel foundation piles to avoid relatively expensive construction works in the water and polluted subsurface. The approach spans are made of concrete and are fitted with composite edge elements to minimize maintenance. The steel movable main span has a composite deck and is fitted with 17.5 m long composite edge elements in one piece. Four steel pipe piles replace at extensive and expensive fender structures to prevent collision damage.

3. Willem III bridge Assen: simple, Affordable yet Attractive

Specifications size: l=15 m, w=4 m clearance width: 8 m building costs: € 950.000 completion: 2015

This bicycle bridge, named after dutch king William III (1650-1702), is a good example of a small, affordable, fairly simple yet attractive movable bridge. This elegant and slender steel drawbridge stands out both because of its operating mechanism and because of its integrated design. The unbalanced bridge deck is operated using hydraulic cylinders integrated in the railings of the bridge. The main advantage of this mechanism is that it does not require expensive facilities such as an underwater bascule pit or machine room and no adjustments to the embankment were needed. The use of hydraulic cylinders also allowed for a visible and visually pleasing integration of the operating mechanism into the bridge design.

Fig. 13. Overview Willem III bridge Assen

All elements of the bridge were gracefully integrated into the design: the two steel poles on either side of the span not only hide away the access barriers but also have lighting and maritime traffic signs attached to them. This enhances the bridge's clean and attractive appearance.

The necessary electrical facilities have been integrated into a wood clad bench on the waterside. This simple solution is functional and cost-efficient as well as attractive and delivers added value to the surroundings.

The bottom side of the bridge deck holds a surprise, as there is a poem written on it, which was written for this bridge especially.

4. Dolder Bridge Steenwijk: Ready for the Future

Specifications size: l=20 m, w=18 m clearance width: 8 m building costs: € 1.200.000 completion: 2010

Fig. 14. Overview Dolder bridge Steenwijk

This bridge was designed as one of the main entrances to the historical city centre of Steenwijk. Although non-moving for now, the client wanted the bridge to possibly become movable in the future without any large modifications. Two mutually rotated portals now form a symbolicate gate to the city. However, the two hollow steel portals offer enough room for the necessary mechanical works to be installed inside, if and when the bridge needs to become a movable one and can be turned into a vertical-lift bridge. The concrete deck of the main span has to be replaced with a steel or composite one, but other required adaptations are very limited.

At night, integrated lighting illuminates the outlines of the structure. Matching lamp-posts were added along the road after the completion of the bridge.

5. Gouda N207 Bridge: Low Drawbridge Fits in with Dutch Landscape

Specifications size: l=95 m, w=18 m clearance width: 22 m building costs: € 11.000.000 completion: 2012

Fig. 15. Overview Gouda N207 bridge

For this location several bridge types where considered. Given the rural location, a drawbridge was soon considered the best option. Involvement of local residents during the development of the bridge design led to some adjustments of which lowering the towers is the most striking: the towers are relatively low, in order for the bridge to optimally fit in with its horizontally orientated, typically Dutch surroundings.

The movable part of the deck is a stunning 30 meters long, which makes this bridge the largest drawbridge in the Netherlands. The bridge was part of a larger project, including a nearby underpass and a cycle bridge. All are located on Gouda's newly built southern ring road.

6. Movable Bridges Require Close Collaboration between Disciplines

The Netherlands has a lot of navigable waterways. Therefore movable bridges in almost every thinkable type are built in the Netherlands. Some types are described in this paper but even more types are known. Movable bridges are an excellent solution for footbridges over navigable waterways in dense urban areas or when a large vertical clearance is required (i.e. for sailboats). Unlike fixed bridges movable bridges do not need long ramps in these situations.

Designing movable bridges is a specialism in itself. Often a wide variety of unique solutions is possible for a specific location. This makes it necessary that a lot of attention is paid to integration of important aspects like the opening mechanism, machinery and safety measures. Therefore a close collaboration between mechanical, structural and electrical engineers and bridge designers is essential.