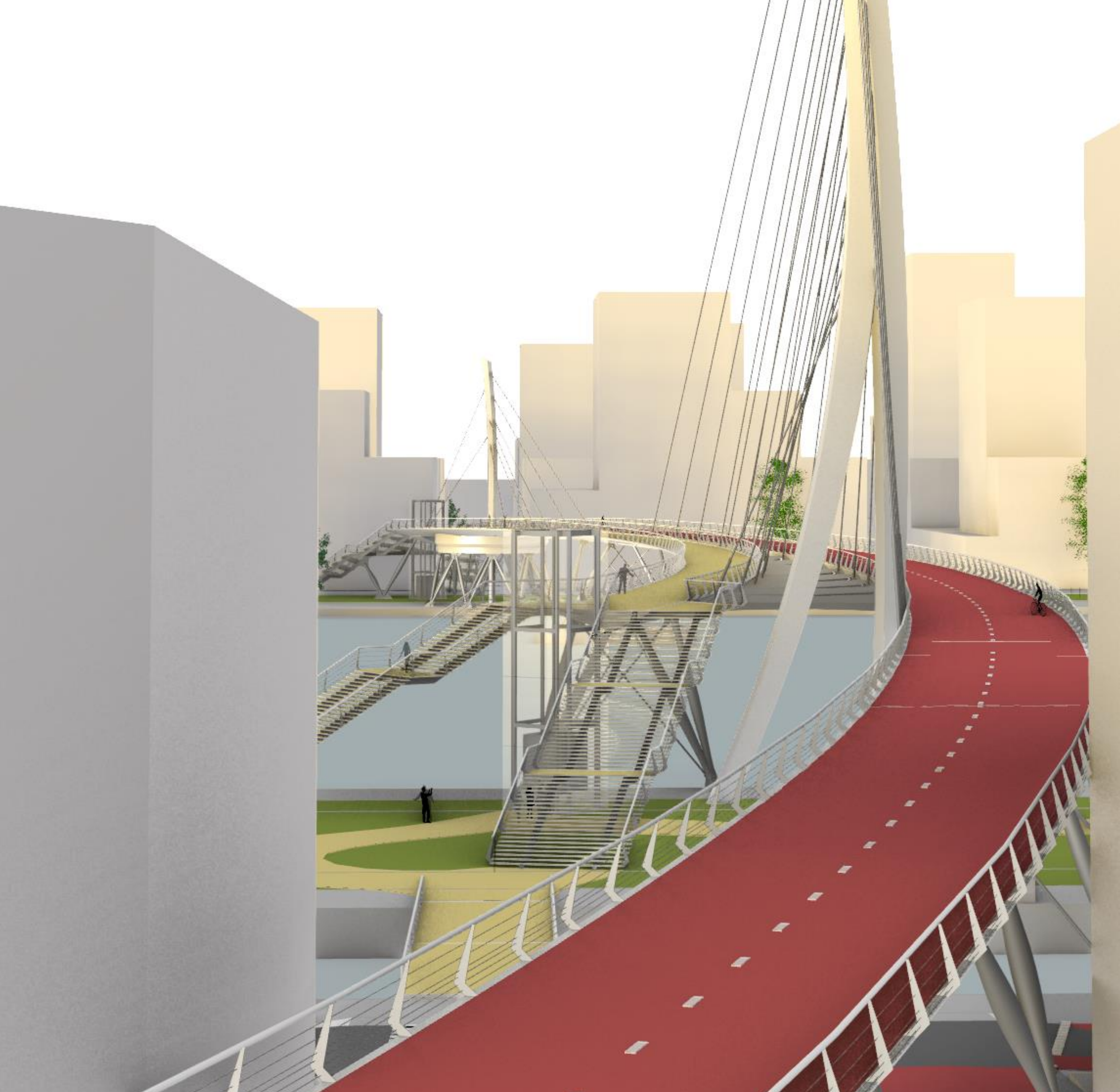
P5 report Noud Gorter

One Small Span

Leaping the IJ



One giant Leap over the IJ for Amsterdam

P5 report Noud Gorter

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1. Introduction

Problem statement

The North of Amsterdam is rapidly growing, but is separated from the rest of the city by the IJ River. Now as the north bank continues growing and the pressure to reduce our CO_2 emission increases, better cycling, walking and public transport connections across the IJ are needed. However, in a dense cityscape and across one of the busiest waterways in the Netherlands, this is simpler said than done.

For most of its history Amsterdam has only developed on the south bank of the IJ. This changes at the start of the 20th century, and for the past 100 years Amsterdam North has been one of the fastest growing areas of the city. This growth is expected to continue, as redevelopment of the north banks old industrial areas are some of the largest construction projects that are currently planned. Despite this growth, and even though cycling is the most popular mode of transport in Amsterdam (Fietsberaad, 2010), there is no fixed connection across the IJ. While cars and busses can use the IJtunnel, cyclists and pedestrians are forced to cross the IJ on a number of ferries.

Figure 1.1: Rush hour on the IJ ferries (Gemeente Amsterdam)

As activity on the banks of the IJ increases, so will the number of people that commute across the water every day. Currently about 45.000 people use the ferries every day, but this number is expected to double by 2030. (Gemeente Amsterdam, 2015a) This prompted the mayor and city council in 2015 to start a study into the possibilities of adding and/or improving connections across the IJ. Initially an open invitation to send in ideas and concepts for river crossings, this study developed into a large project named “Leap over the IJ” (Dutch: Sprong over het IJ)

"Sprong over het IJ"

The Leap over the IJ project is an urban development project guided by the municipality of Amsterdam. After an extensive research into different possible crossing locations and variant, 5 variants were chosen to be realized. Together these measures should complete the slow traffic and public transport network to connect the north and south bank of the IJ.
A bill was passed in 2017 confirming these 5 measures and clearing three of these to be carried out before 2025. The 4th and 5th measures are set to be revaluated, and a decision on these will be made in 2020.

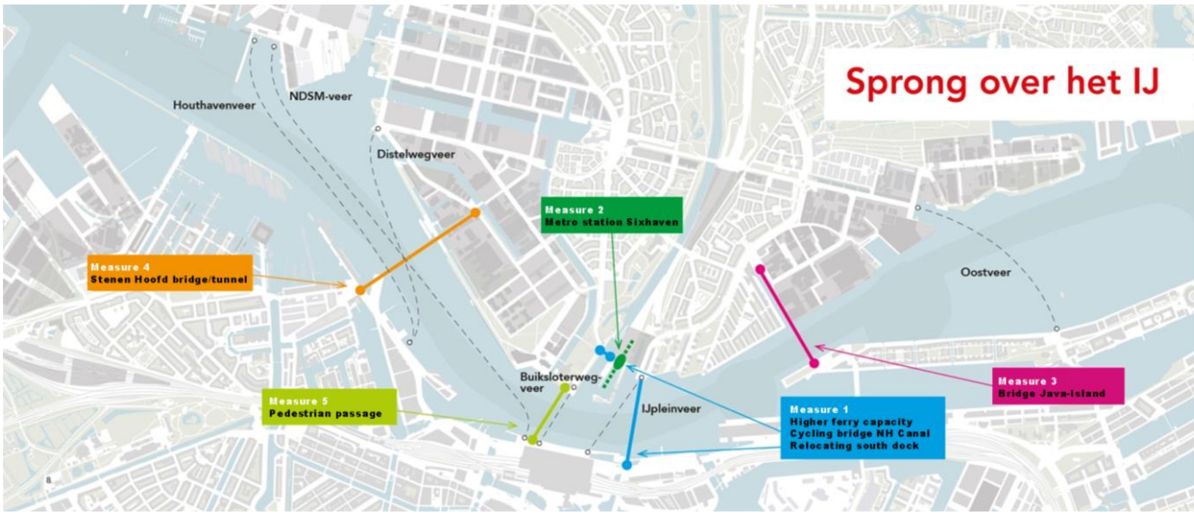

Figure 1.2: The 5 proposed measures that form the 'Leap over the IJ' Project.

The 5 measures

1. Improving the capacity and accessibility of the ferry services

To increase mobility across the IJ on very short term, the frequency of the ferry services will be increased, and larger boats will be introduced. Meanwhile the south dock will be relocated for a better connection to the cycling network. A new bridge will be constructed across the Willem I Locks to increase accessibility from the North.

2. Extra station "Sixhaven" on the North-South metro line

The North South line is an important step in connecting the North of Amsterdam to the city. First proposed in 1975, after many delays and cancellations, it is set to open in 2018. To increase the connectivity of the North Bank directly opposite the station and the fast developing Overhoeks, an extra station will be inserted.

3. Java Bridge

The first bridge to be constructed across the IJ will be a cyclist an pedestrian bridge between Java Island and the Hamerstraat industrial area. It crosses the IJ at its narrowest point with a span of little over 200m.

4. Stenen Hoofd Bridge/tunnel

Another fixed connection is proposed between the Western Docks and Overhoeks, named after the old pier called the Stone Head (Dutch: Stenen Hoofd).

5. Pedestrian passage IJplein

This passage, most likely a tunnel, will cross the IJ directly from the Central Station. This would connect the same places as the Buiksloterweg Ferry, currently the busiest ferry service.

The Java Bridge

Probably the most high-impact measure is the Java Bridge crossing as it will not only be the first fixed connection for cyclists and pedestrians across the IJ, but it will also become an important part of the city image for many years. It is one of the three measures that have already been approved by the municipality, so it is set to be completed by 2025. The bridge crosses the IJ at its narrowest point at only 205 meters wide but demands and restrictions for passing ships make it a complex case.

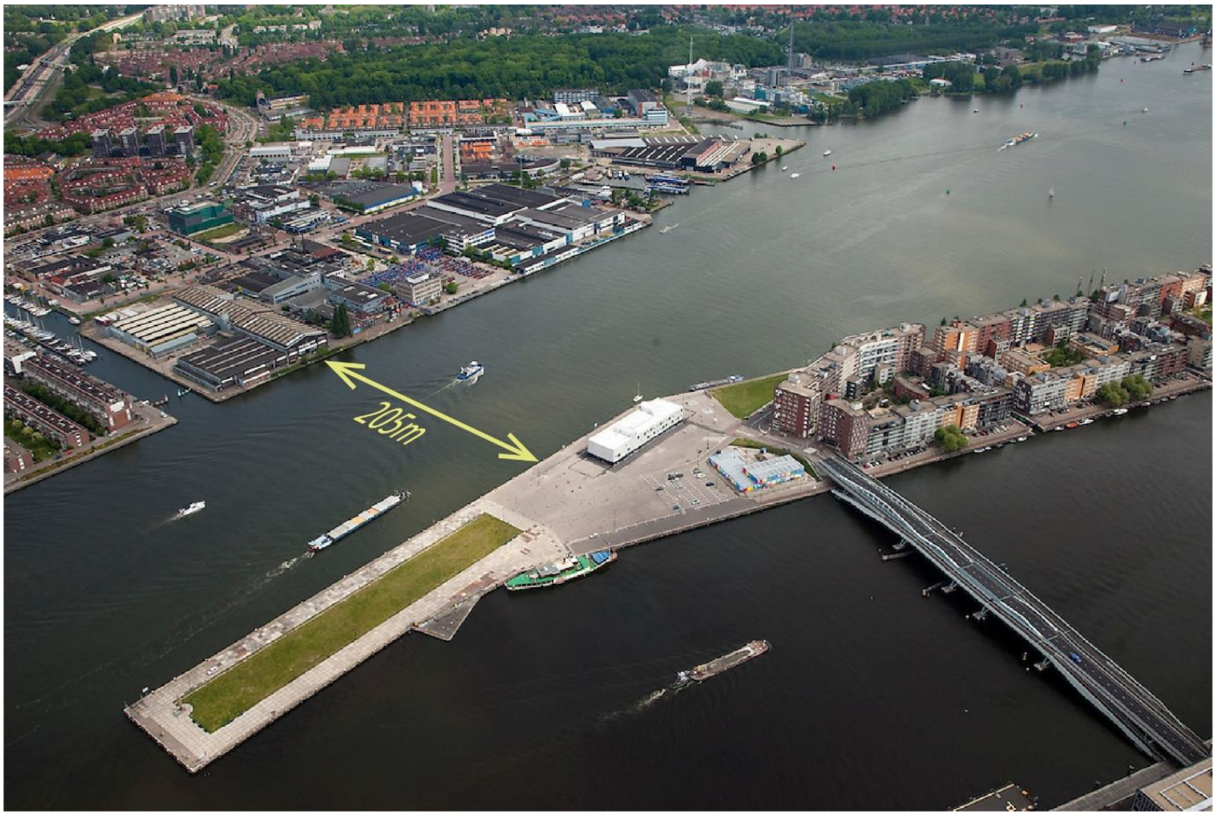

Figure 1.3: Aerial view of the proposed location for the Java Bridge

Considering its prominent location, complexity and significance to the city the Java Bridge will be a fitting case as the main scope of this thesis.

2. Methodology

Study scope

The main scope of this research will be creating a complete visual and structural design for the Java Bridge in Amsterdam. The end result should be a bridge where architectural design and engineering work as a unity. As this is a thesis for the master Building Technology, the structural design should be fully engineered including models, calculations, detailing and construction methods.

However, in order to create a successful design, a deep insight is required into the social and spatial context of the location, as well as an understanding of the infrastructure and functionality of the bridge. The main scope of the initial literature study will therefore be on the city of Amsterdam and the Java Bridge location in specific. The bridge is surrounded by social and political controversy, and although these issues will be mentioned, this discussion will not be part of the scope of this study. Instead the design will be based on the current assignment as set by the municipality of Amsterdam.

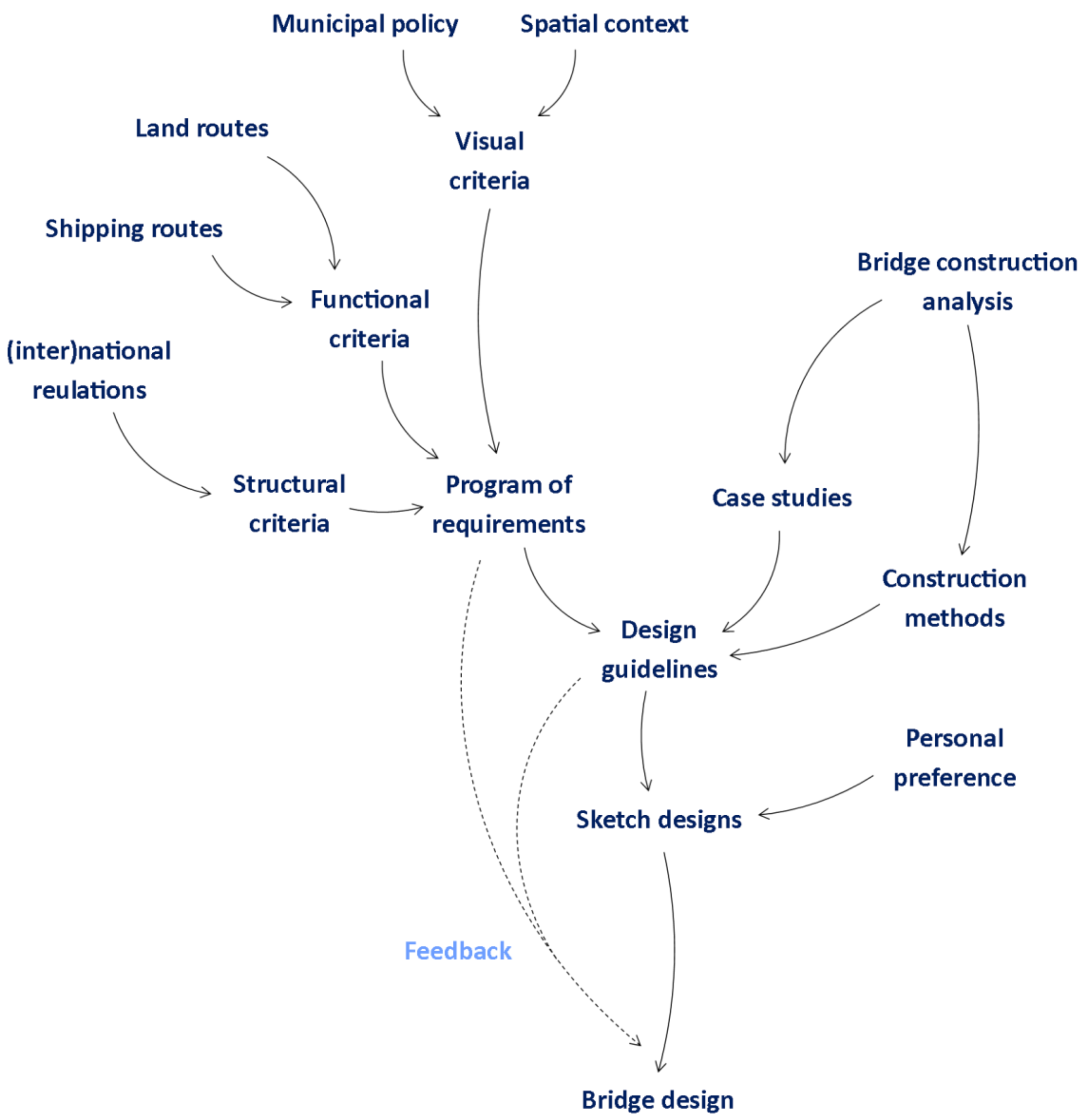

Figure 2.1: Visualisation of steps and sources that lead to a successful design

Objectives

The main objective for this research will be to provide an insight into how a bridge at the proposed location can best be designed to solve the infrastructural problems that currently exist around the IJ. These solutions should work on a functional, structural and visual level. Sub objectives can be defined as:

- Determining the challenges of designing a visual landmark that complements all facets of this varied area
- Determining the infrastructural challenges on the east part of the IJ
- Determining the structural challenges of a river crossing in this complex area
- Designing, engineering and detailing a bridge that rises to all these challenges

Research Question

How can the Java Bridge be designed and engineered to form a fitting functional and visual connection across the IJ?

Research framework

This research will be divided into four phases: Analysis, Sketch Design, Definitive Design & Engineering and Detailing. However, these phases are named as such just to give an indication towards the main objective of that part. All these phases will require different tasks, such as analysing, sketching and engineering, on a visual, structural, mechanical and functional level.

Phases 2 – 4 together form the entire design process and will therefore know some overlap. They can however be characterised as a progression through design scales: The sketch design will deal with typologies, overall layout and general shapes in an urban scale. The definitive design phase will deal with specific shapes and elements on bridge scale. The detailing phase will deal with, logically, details and building parts on element level.

1. Analysis

The analysis phase will mainly consist of a literary study that charts the challenges and possibilities of the design case. It will include a historic and social background, a site analysis and an analysis of bridge design & construction. This will result in a program of requirements that in turn produce a set of design guidelines that can be used to start the actual design process. Sources should include scientific papers & books, municipal publications & policies, (inter)national regulations and a personal investigation of the location.

Tools: Sources (scientific sources & government documents), location visit, reference projects
Products: Site analysis, social background, analysis of bridge design, program of requirements, design guidelines.

2. Sketch Design

The sketch design phase will be an exploration into different visual & structural solutions for the requirements as set in phase 1. As the name suggests, this should start as a series of sketches and ideas that tries to find many different shapes, configurations and solutions. These should be tested on how well they match the design criteria for both functionality and visual impact. Although no real in-depth calculations should be made, it is important to also analyse these designs from an engineering point of view. Structural elements should be dimensioned by rule-of-thumb to give an indication of realistic proportions, as these can strongly impact the look of a design.

As the sketch design phase progresses, a selection of designs should be made and developed further by altering them and trying to find the optimal form for each. At this point simple computer models can be made that can help to quickly try many small alterations, as well as create a better perspective with the bridge's environment. At the end of the sketch design phase a preferred variant should be chosen.

Tools: Guidelines form analysis phase, hand drawings, rule-of-thumb calculations, Google SketchUp and/or Rhino 5 with Grasshopper.
Products: Drawing & impressions, very basic 3D models, maps and elevations up to scale ± 1:2000

3. Definitive design & engineering

The preferred variant can now be processed into a complete design. Based on more detailed drawing and structural calculations, a final form will be defined. This design should now include a final shape, material and colour. All structural elements should be dimensioned, and connections engineered that allow for all loads, including wind loads and thermal expansion. A type of bridge deck and supporting structure for the slopes should be selected and designed including strength calculations. The movable bridge parts should be designed and space for their mechanical parts incorporated.

As stated before, this phase should not be limited to designing and engineering. Additional analysis will likely prove necessary as the project progresses and new fields of design come into play. Decisions on detailing will have to be made as well in this phase, as a good design should incorporate all its aspects, including fencing, signage and illumination, into one single unity.

Tools: Hand drawings, AutoCAD, Rhino with Grasshopper, iDiana
Products: Maps and elevations up to scale 1:500, sections of parts up to scale 1:50, artist impressions incl. materials and colours, structural analysis.

4. Detailing

The final phase should finalise all aspects of the design process. Details include fencing, curbs, signage and lighting. Detailed structural drawings, for example sections of the bridge deck, should also be completed. The mechanical parts of the movable bridge parts should be designed and incorporated in the complete design. Finally, a planning should be made for the construction process of the bridge, including fabrication methods and order of construction.

Tools: AutoCAD, Rhino with Grasshopper, iDiana
Products: Sections & details up to scale 1:10. Finals maps, elevations & artist impressions.

3. Historic and social background

History of Amsterdam and the IJ

Amsterdam is a lot younger than most other prominent Dutch cities such as Nijmegen, Rotterdam and Utrecht. It was only a small settlement when a dam in the river Amstel and numerous dikes where constructed in the 12th century as a response to several floods. The part of the River outside the dam was the first harbour. The town gained city rights around 1300, from which point it flourished as a trading port.

During the Dutch Golden Age, the city of Amsterdam experienced an explosive growth, becoming the largest city in the Netherlands and one of the wealthiest cities in the World. This was accompanied by a large, planned expansion with the canal district. During this time many of the grand and beautiful buildings that are now part of the UNESCO listed city centre were built.

After the end of the Golden Age the growth of Amsterdam stagnated, and the city remained roughly the same size until the start of the industrial revolution during the 19th century. New industries and commerce initiated another rapid expansion. Part of this expansion was the construction of the newly invented railway and the central station on several artificial islands in the IJ. This did break up the connection between the IJ and the city docks, which were rapidly becoming unsuitable for the increasingly large steamships brought forth by the industrial revolution. For this reason, the Eastern Docklands were created along the new railway. This also included a large breakwater that would later be expanded into the current Java Island. The new and larger harbour flourished mainly from shipping goods and people to the East Indies.

It was also during the 19th century that the Zuiderzee lost its economic purpose. Until this point all shipping from Amsterdam had to pass through the increasingly shallow bay, but in 1824 the North Holland Canal was opened, offering a connection from Amsterdam to Den Helder. In 1875 this was followed by the North Sea Canal which is still used today, rendering the Zuiderzee obsolete. It would later be dammed from all sides to protect the inland from tidal flooding, creating the Ijsselmeer and Markermeer.

The city growth continued during the start of the 20th century, which prompted the creation of the General Expansion Plan (Dutch: Algemeen Uitbreidingsplan) in 1934. This included large expansions in the west and south but put developments in the north on hold. Due to the Great Depression and the second World War the realisation of these plans was put on hold, but they were eventually completed during the post-war boom.

The General Expansion Plan also dictated a large expansion of the harbours west of Amsterdam. The Eastern Docklands had already suffered greatly from the Great Depression, blockades during the Second World War and the decolonization of the East Indies, and by 1979 the last shipping company had gone. By this time the largely abandoned area had gained the attention from artists and squatters. Partly by their efforts some of industrial heritage would be saved from demolition. It was determined that the Eastern Docklands would be redeveloped into high density housing. Being prime location waterside property, it grew into a modern neighbourhood featuring contemporary architecture and a high quality of living.

Figure 3.1: Remnants of a history of shipping and trading can be found throughout the city, especially in the former docklands (Pakhuis Oostenburg)

History of Amsterdam north of the IJ

Throughout history, the north bank of the IJ River was only home to a few small parishes. Opposite the city centre was only a small strip of land, which from 1824 onwards housed the entrance to the North Holland Canal. This changed during the 19th century when polders were created to either side of it. (Schoewert, 1997) After the opening of the North Sea Canal the demand for large docks for steam ships grew, and the first companies settled themselves on the north bank. However, workers for these industries had to cross the river on ferries every day, prompting the need for housing on the north bank.

In 1900 a design for the development of Amsterdam North was put forward by Johan van Hasselt. This included ample space for housing and (heavy) industry. It also included plans for a new Main Canal, which would split the North Bank from the mainland. The creation of the canal would allow the construction of a bridge over the IJ, connecting the North Bank to the City Centre. Construction of the canal was started from both sides, but never finished.

Proposals for a permanent connection across the IJ were put on hold by the General Expansion Plan in 1934. This plan considered further expansion of the North bank to be undesirable and therefore stated a fixed connection would not be needed. However, when the municipal government accepted the GEP in 1935, it did add motions that would later be the base for the construction of the IJ-tunnel.

During the next years multiple reports and proposals for a bridge or tunnel would be published, but the final decision would not be made until 1953. However, a further delay over financial issues pushed the opening of the tunnel back to 1968. The final design only featured a motorized traffic tunnel. Although earlier proposals had included a tunnel for pedestrians and cyclists, these plans were put on hold and never completed.

As the demand for housing continued to grow in the post-war economic boom, combined with the 1953 resolution to construct a tunnel, the GEP was altered in 1958 to include plans for a rapid expansion of Amsterdam North. As the industry declined and moved to the harbours in the west, many large new neighbourhoods were constructed. Again, the need for better connectivity to the rest of the city grew, as Amsterdam North developed into a large residential borough with little to no other functions.

Motorized connectivity was increased with the 1966 opening of the Coentunnel, which connected Amsterdam North to the new Motorway system. The ring of Amsterdam would be completed in 1990 with the opening of the Zeeburgertunnel. However, transport within the city was still limited to the IJ-tunnel for motorized traffic and a number of small ferries for slow traffic.

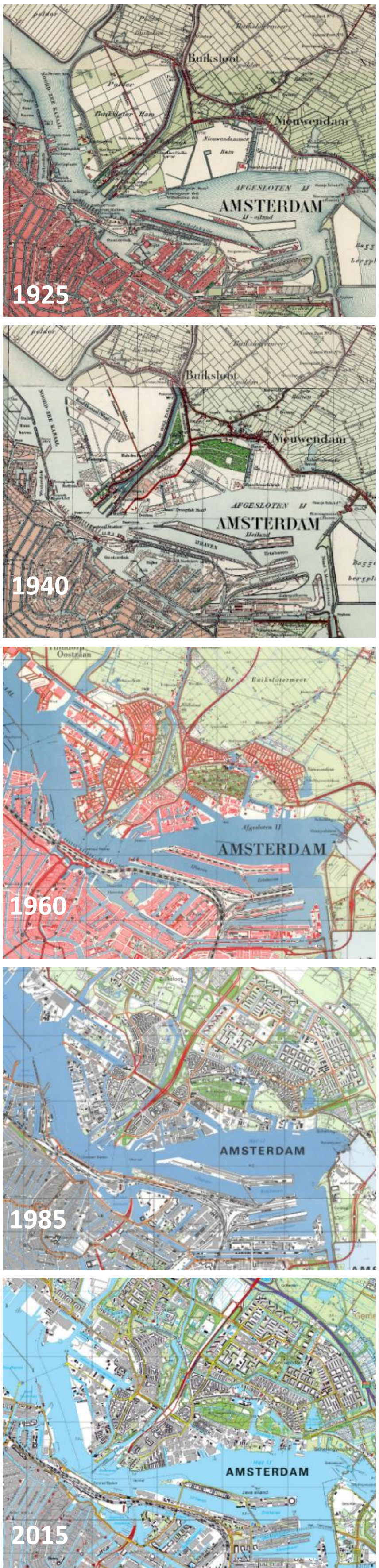

Figure 3.2: Historic maps showing the growth of northern Amsterdam (Topotijdreis.nl)

Cycling in Amsterdam

A product of the 19th century, the use of bikes increased all over the world during the industrial revolution. The Netherlands and Amsterdam have always been favourable places to cycle as the land is flat and the weather mostly moderate. This, accompanied with the construction of dedicated cycling infrastructure, caused the Netherlands to have one of the highest bicycle usages in the world.

However, as the economy grew during the Post-WWII reconstruction, so did prominence of the personal car. It was widely recognised as the most modern form of transport, and large-scale plans were made to adapt the historic cities to accommodate it. An iconic example of this is the post-war reconstruction of Rotterdam, with wide avenues instead of small streets. Similar plans were drawn up for Amsterdam, including proposals to fill in all canals to accommodate wider roads. All across the country existing bicycle infrastructure was erased to clear up more space for cars.

However, as the prominence of the car rose, so did traffic casualties, especially amongst cyclists and pedestrians. During the 1970's, around 3000 cyclists were killed, including 500 children. A large-scale protest was called to life under the slogan of "Stop the Child Murder". Together with other factors, such as global oil shortages, this prompted the Dutch government to change its policies concerning road design. City planners started incorporating separated cycle lanes and designated cycle paths again. This not only increased cycling safety, but also started a trend of people favouring the bicycle and other modes of transport over the car. This trend later continued with most cities closing off (parts of) their city centres for cars.

The city of Amsterdam has now developed a large network of cycling lanes and paths, totalling around 767km. Bicycles outnumber people in Amsterdam, and 58% of residents cycle at least once a day. (Gemeente Amsterdam, Verkeer en Openbare Ruimte, 2017) Amsterdam is regarded as one of the world's leading cities in cycling infrastructure. In 2006 the Nesciobridge was opened. It is one of the longest cyclist bridges in the world and connects the IJburg islands to the rest of the city. However, as stated before, there is still no fixed connection to the North Bank. Cyclists between Amsterdam North and the city can use a number of ferries for free.

In the 21st century, the growing popularity of e-bikes is changing the way people cycle, which will require changes in the way bike infrastructure is designed. As e-bikes increase the cycling speed, and more importantly speed difference with other cyclists, wider cycling paths and longer turns are required to ensure safe passing spaces.

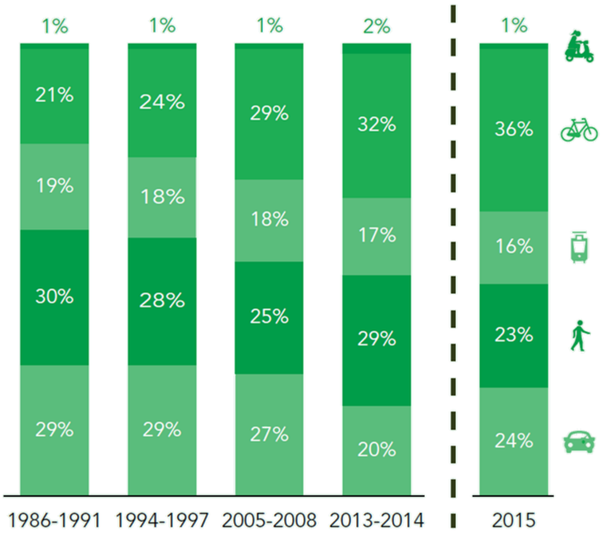

Figure 3.3: Percentage of all trips in Amsterdam by mode of transport (Gemeente Amsterdam)

Social context "Leap over the IJ"

The main motivation for the 'Leap over the IJ' project is the expected increase in passengers across the IJ in the coming years. Currently around 46.000 people cross the IJ every day, which is expected to increase to between 80.000 and 110.000 people by the year 2030 (Sprong over het IJ). The increased connectivity across the IJ will be a solution to the existing mobility problem, as well as a driving factor behind new developments planned all along the banks of the IJ.

This expected increase in passengers is largely due to population increase in Amsterdam North. The North bank has been growing steadily over the last decades and is expected to continue doing so. Current projections show an increase of between 100.000 and 160.000 inhabitants by 2030 (Gemeente Amsterdam, Onderzoek, Informatie en Statistiek, 2018). Figure 3.4 shows the intensity of residential building projects in comparison with the rest of the city. This indicates that the increased population in North is not only a local development but one of great importance to the development of the city as a whole.

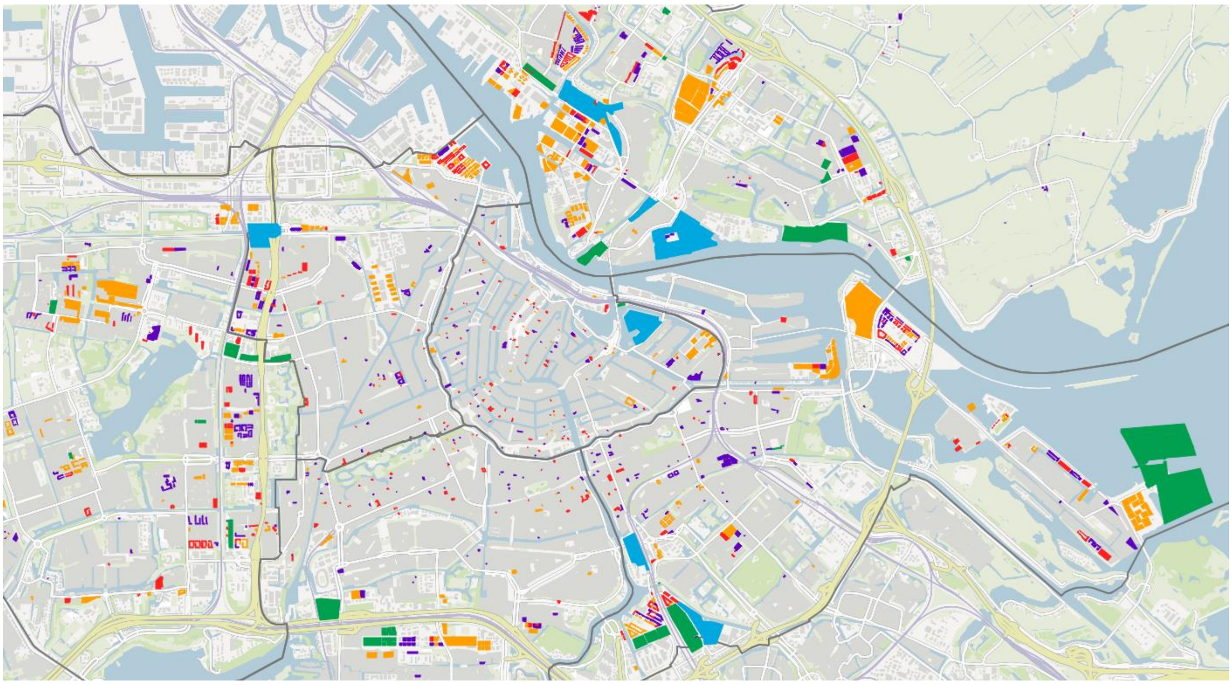

Figure 3.4: Residential real estate projects currently planned or in development (Maps.amsterdam.nl)

Some of these projects are set to be mixed function areas. This is a much-needed development, as Amsterdam North is characterised by a very high percentage of residential space but very little other functions, including workplaces, education and facilities. Figure 3.5 illustrates the difference in density of non-residential functions of Amsterdam North when compared to the rest of the city. This contrast is increased when taking into account that the current areas of North with most non-residential functions are the old industrial estates along the IJ banks, which are set to be redeveloped into (mostly) housing.

The separation of functions across the city is not necessarily a bad thing, as it allows for peaceful, safe neighbourhoods to exist outside the bustle of the city. However, it does require many people to commute across the IJ, increasing the need for better connectivity.

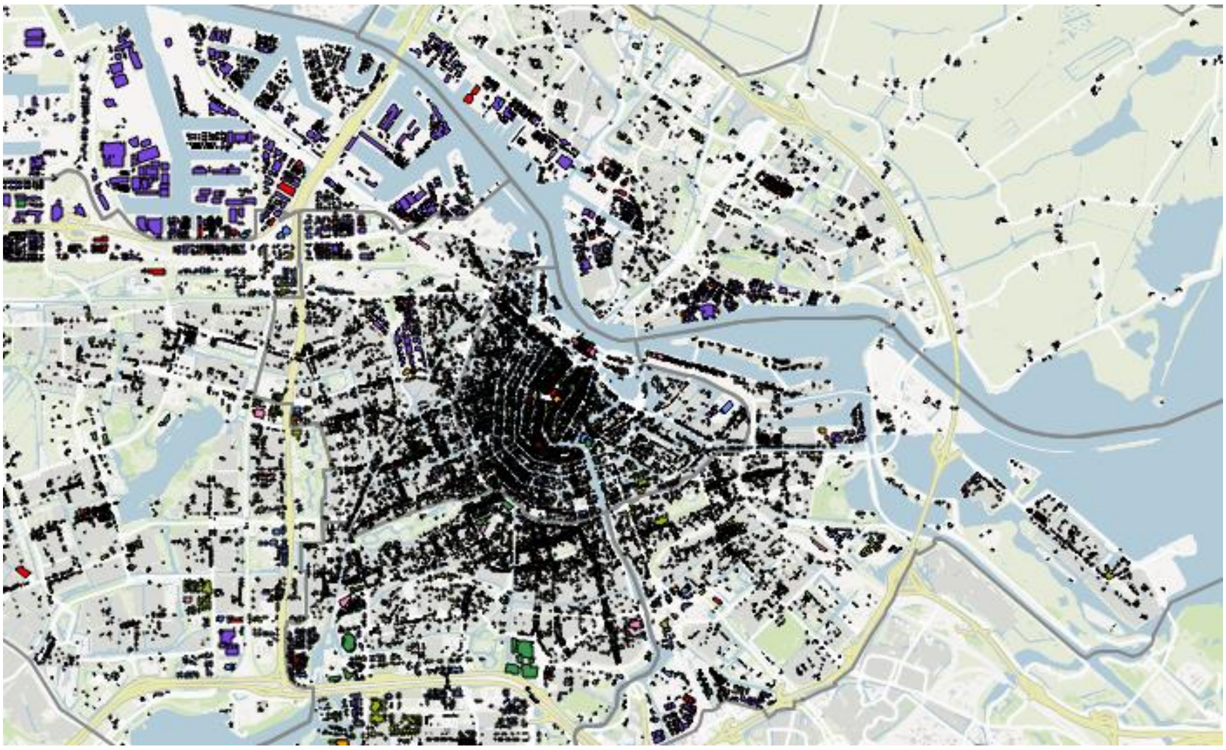

Figure 3.5: Map of all non-residential functions in Amsterdam (Maps.amsterdam.nl)

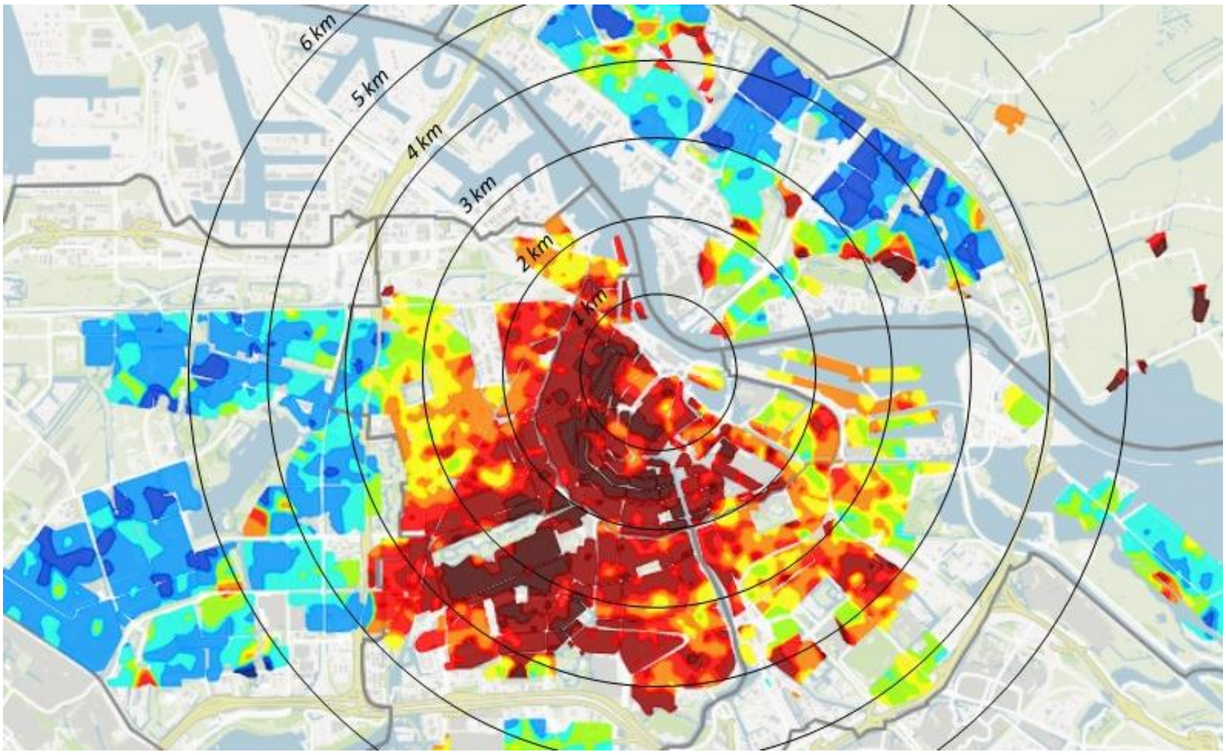

Figure 3.6: Map of average house prizes per m² with an overlay of distances to the city centre (Maps.amsterdam.nl)

The newly developed housing on the North bank will likely be high priced, prime real estate. This is due to the proximity to the city centre, which has a significant influence on house prices, as can be seen in figure 3.6. While Amsterdam already has the highest house prices in the Netherlands, this development of prime housing does conform to the expected continued growth of high-level jobs in the city. (Hekwolter of Hekhuis, Nijskens &

Heeringa) In addition, the development of expensive housing near the city centre could reduce property prices in neighbourhoods further out.

A key aspect in many of these observations is the proximity of the North Bank of the IJ to the city centre. For decades the expansion of Amsterdam North has been an expansion of the city limits comparable to that in the West and in the Southeast. Most of these areas were planned and constructed for cars as the main mode of transport, and proximity to the city centre or cycling networks was less important than creating large living spaces. However, when these suburbs are compared, Amsterdam North is much closer to the actual centre, albeit being separated from it by the IJ.

At the present, the pressure to create a more sustainable society has caused us to rethink this ideal of living outside the city and commuting in every day. Redevelopment and densification projects have become more common than expansion, and bicycle usage is on the rise (Gemeente Amsterdam, Verkeer en Openbare Ruimte, 2017). This means the centrally located North Bank has a key place in the development of a sustainable Amsterdam, hence all the planned construction projects, but only if there is an adequate cycling network to support it.

Political context

While the city council has already given permission for the construction of the Java Bridge, there has been continuous critique from Rijkswaterstaat and both the current and former ministers for infrastructure. (Van Weezel, 2017) Their main cause for concern is obstructions for river traffic, as the IJ is one of the busiest waterways in the Netherlands.
Rijkswaterstaat takes objection to the choice for a bridge rather than a tunnel, as it contradicts large investments that have been made in recent years to construct deep level tunnels and a new large lock at IJmuiden. For this same reason they also object to the relocation or removal of the cruise terminal. If the Bridge is to be constructed, they demand a free height of 11,35 meters to allow passage of container ships stacked 4 containers high, which is the norm for Rhine traffic. This demand is opposed by the city council green party, as most bridges on the Amsterdam-Rhine Canal, which is the direction for all cargo barges from the IJ, have a height of 9,10m. A final decision on the bridge height will be made later in 2018.

The projected height of the bridge has also led to some protest from locals, who argue that the bridge will be too high and/or steep to be a comfortable alternative to the ferries. There are also still some sentimental feelings that the IJ should remain open and a bridge would spoil the view.

4. Site analysis

The Java Bridge will cross the IJ between Java Island and the Hamerkwartier. Routes across the bridge will cross both these areas and connect to the existing cycling network. This location is surrounded by many different building typologies and interacts with multiple different land and water routes. A successful bridge design will have to fit in with, and even complement, all surroundings that it interacts with.

Local context

One initial observation is that despite the IJ has been at the centre of the development of Amsterdam throughout its history, it is not actually part of the city centre. This differentiates Amsterdam from cities like London, Paris and Rotterdam, where the river is very much the heart of the city. This is largely due to the construction of the Central station between the IJ and the historic city.

The IJ and its surroundings do however form the main skyline of the city, as the historic centre has little to no high-rise buildings. The large mixed-function developments planned on the banks of the IJ will likely add to this visual attractiveness. It is likely that the IJ area will in the future draw more and more visitors, which could create a modern extension of the historic city centre.

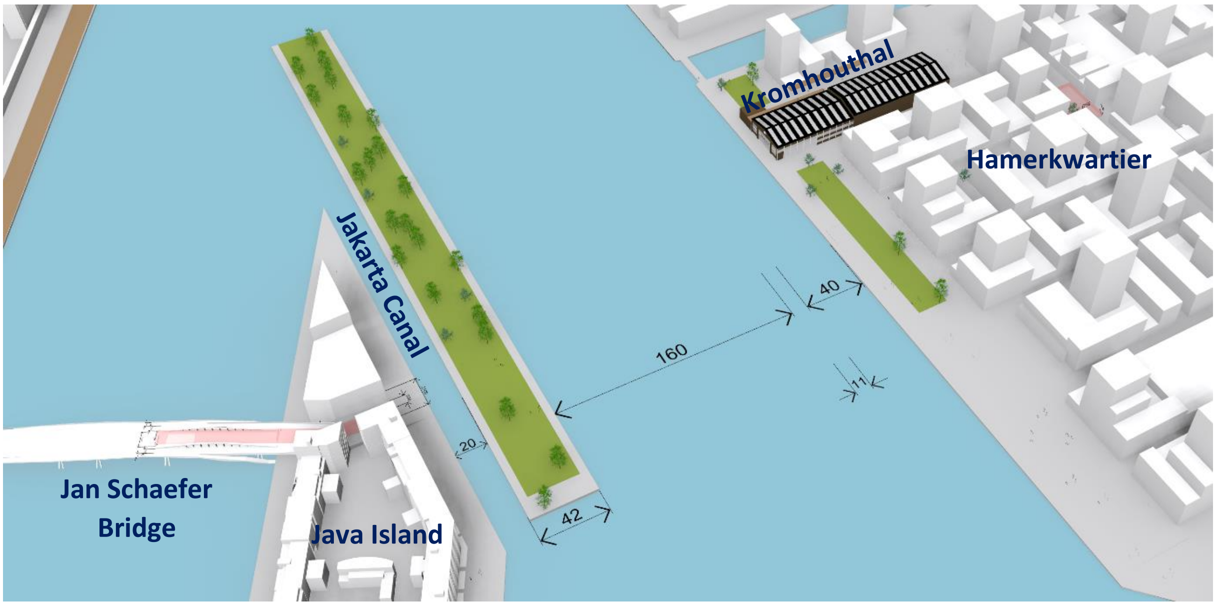

Figure 4.1: Local situation for the Java Bridge as of the most recent municipality plans at the time of writing.

Hamerkwartier

The Hamerkwartier, formerly Hamerstraat, is an industrial area that originated as an expansion of the docklands during the end of the industrial revolution. As the docklands were moves to the west of Amsterdam it lost all its harbour-based functionality and at present very few industrial users remain.

However, in recent years new users have started to take over the old warehouses, as is the case with many abandoned industrial estates in the Netherlands. Current users include an indoor skate park, a small brewery and an escape room, as well a number of bars and restaurants. This is slowly transforming the Hamerkwartier into a lively neighbourhood.

Figure 4.2: Former industrial buildings in the Hamerkwartier (Google Maps)

Redevelopment

There are large-scale plans by the municipality to redevelop the Hamerkwartier into a modern, high density mixed function neighbourhood (Gemeente Amsterdam, Projectteam Hamerkwartier, 2017). These plans include high-rise up to 140 meters and mixed blocks including housing, workplaces, education and health related functions. Construction is set to start in 2020.

Due to the newly found livelihood of the area, it is highly likely that some of the old industrial buildings will be preserved. In a fashion strongly resembling the Eastern Docks redevelopment, when artists and squatters found new uses for derelict industrial buildings, this could lead to a modern and vibrant area that still has solid connections to its historic background.

Figure 4.3: Artist impression of the redeveloped Hamerkwartier (Gemeente Amsterdam)

As this redevelopment is an active project, alterations will be made during the course of my graduation project. For sake of efficiency I have based my project on the most recent plans as of September 2018. This mean there may be some discrepancy between my design and the final development plans.

Figure 4.4: Municipality plans for the redevelopment of the Hamerkwartier

The September 2018 municipality plans show a dense collection of buildings, including both preserved industrial real estate and newly built mid- to high-rise blocks. At the waterside there is a large recreational area that is partly park and partly city square. The most eye-catching construction is the renovated 'Kromhouthal'. This is an old industrial warehouse that is currently in use as a food market and event location. In the municipality plans this hall is transformed into an open community centre and cultural hub. It's prominent location on the waterfront makes it a focus point of the waterside park and the neighbourhood.

Figure 4.5: The redeveloped Kromhouthal as a central part of the new waterfront

Java Island and Eastern Docklands

In the south the Java Bridge connects to Java Island, which is part of the Eastern Docklands. These former docks were redeveloped to housing during the 1990's. The docklands are now a modern, high density living area, especially along the waterside. Most of these buildings contain large, high-priced apartments. There are however still traces of its maritime and industrial heritage visible, as several old warehouses have been preserved and repurposed. This preservation is largely due to the presence of an artist and squatter community that inhabited the derelict area before its redevelopment. This creative community is also the root of the number of clubs and bars still present, making it a lively area.

Figure 4.6: Residential blocks on Java Island

The proposed landing spot for the Java bridge it at the western end, where the Jan Schaefer Bridge connects the island to the mainland. The steep slope of the Jan Schaefer Bridge cuts a narrow passage between a residential block and the newly constructed hotel Jakarta. The far end of the island is a currently undeveloped piece of land populated only by a temporary school building. According to the latest municipality plans this area will be developed into a city park and recreational area. Part of these plans is the construction of a new 'Jakarta Canal' which splits the park from the mainland in order to create more navigable space on the busy waterway.

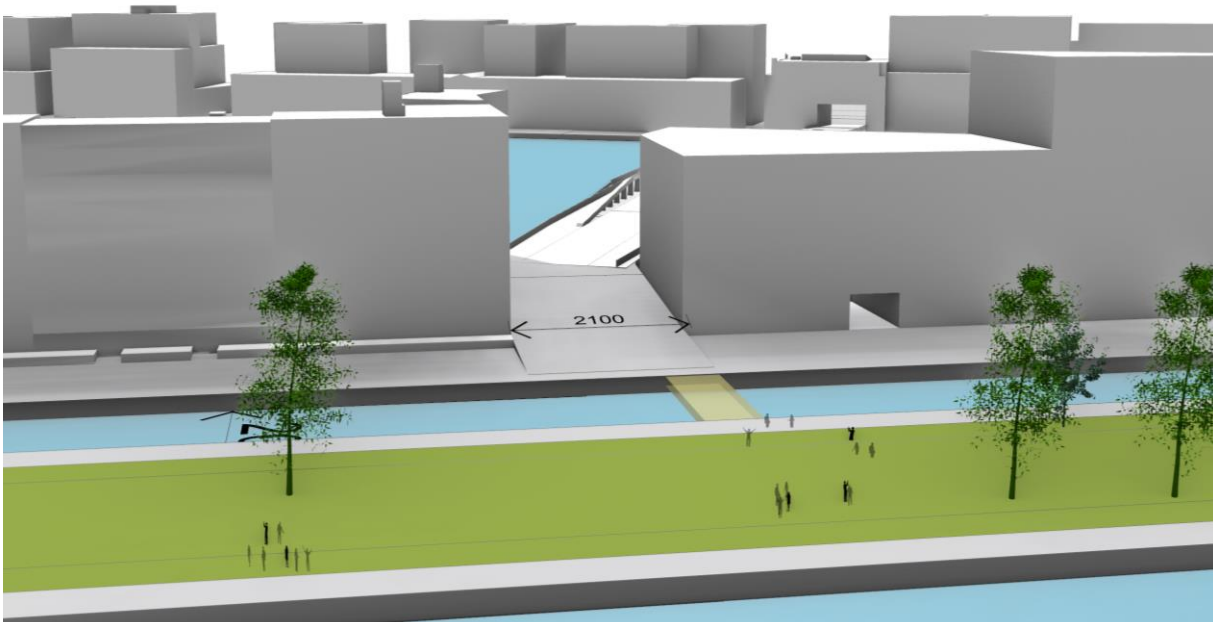

Figure 4.7: The narrow passage at the landing of the Jan Schaefer Bridge

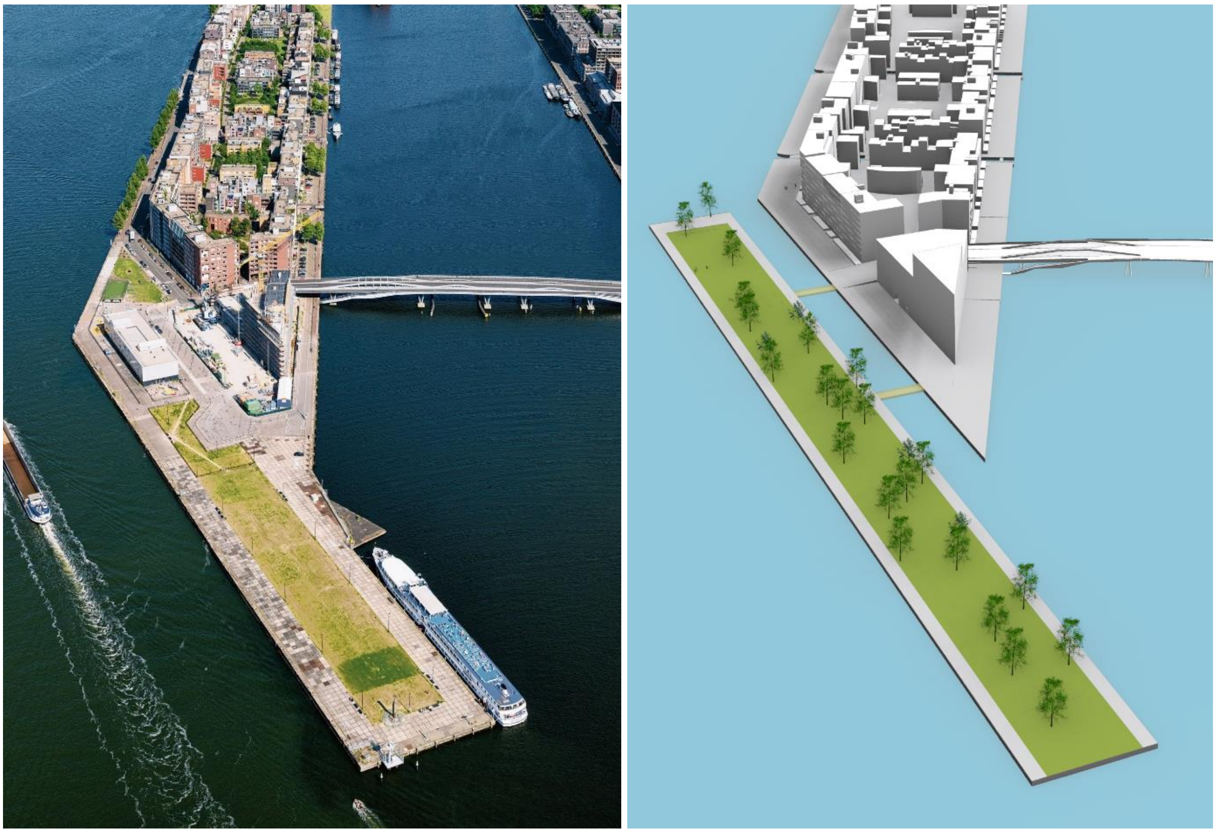

Figure 4.8: (left) Current situation on the western end of Java Island (Marco van Middelkoop) (right) Proposed situation in the most recent municipality plans including Jakarta Canal

Shipping routes

The IJ around Java Island is very busy with many different types of traffic. The bridge will have to meet requirements regarding height, width and layout of shipping lanes for all of these. However, it shouldn't just be seen as an obstacle, as the bridge will form an important part of the journeys across these routes. It will act as a sort of city gate for all ships passing through Amsterdam, both commercial and private, and should aim to enhance their journeys.

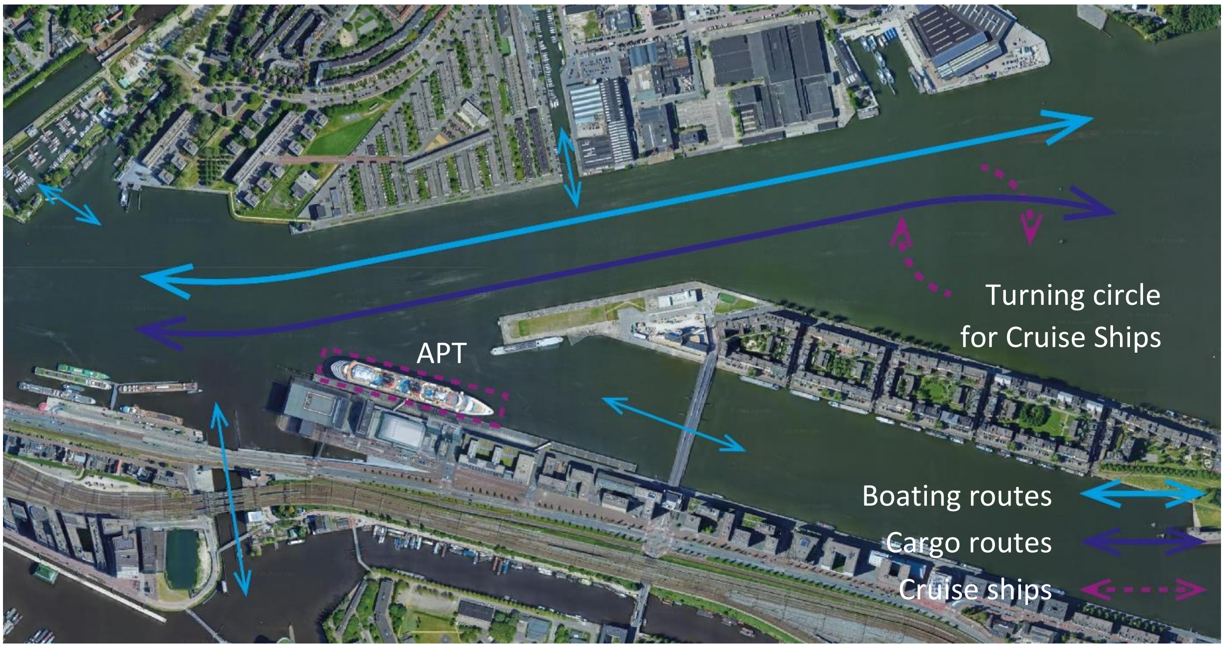

Figure 4.9: Current shipping routes past Java Island (edited from Google Maps)

Amsterdam Rhine Canal

The Amsterdam Rhine Canal is a large shipping corridor between the Harbour of Amsterdam and the Waal (the main distributary of the Rhine) at Tiel, and via the Rhine to the Ruhr area in Western Germany. As the Canal connects to the IJ east of the city and the harbour is in the west, all ships on this route must pass through the city centre and therefore past the site of the Java Bridge.

It is one of the busiest canals in the world, with around 100.000 ships using it every year (Amsterdam-Rijnkanaal, 2018). Most of these ships are barges; low, long ships build for inland traffic. The canal is unsuitable for many other types of ship, as it is crossed by many bridges that cannot be opened. The maximum free shipping height on the canal, based on the lowest of these bridges, is around 9 meters (Rijkswaterstaat, Centrale informatievoorziening, 2017).

Figure 4.9: Typical layout of the Amsterdam Rhine Canal (Bezoekerscentrum Rijkswaterstaat)

Pleasure craft

The IJ is a very popular spot for boating. Not only because it offers beautiful views of the city itself, but also because it is part of some of the most popular boating routes in the Netherlands. It connects to the Zaan, the North Holland Canal, the Markermeer and to all different access point of the Mast-up route, the most popular boating route in the Netherlands.

Most of these pleasure craft have a mast of up to 30m high, and therefore require most bridges to open. Most bridges along popular sailing routes have set times during the day or during the hour at which they open to all boats that are waiting before it at that time. The Schellingwouderbrug on the Buiten IJ opens for 10minutes 3 times an hour, so it is opened about half the time. For sailing ships that want to navigate through the canals of Amsterdam there is a nightly convoy: Once per night a group of ships is navigated through all the bridges of Amsterdam in both directions.

Figure 4.10: A typical standing mast ship on the IJ

Cruise terminal

The Amsterdam Passenger Terminal is currently located on the Veemkade, just southwest of the top of Java Island. It is the mooring place for vast, seagoing cruise ships, which bring thousands of tourists to the city. Although these large ships can dock here, the IJ is too narrow on this stretch to turn the cruise ships around. Therefore, they currently sail past Java Island to a wider stretch, where they turn around and return to the west, passing the bridge site again.

However, to reduce the effects of mass tourism and to allow the construction of the Java Bridge, plans have been made to relocate the terminal to the Western Docks. In May 2018 the new municipal government published plans that included the removal of the passenger terminal altogether. (van Weezel, 2018) For the design process of the Java Bridge, the APT will be assumed to have been removed.

Figure 4.11: Large cruise ships moored at the APT

Amsterdam Skyline

Figure 4.12: View of the projected bridge location from the east

The skyline of Amsterdam is unique in its almost complete lack of high-rise. The layout of the city is dominated by its historic centre and its waterways, as most of the financial and business districts are located well outside the city centre. The current Skyline is defined by 4 main features:

1. The Central Station
2. The A'DAM Tower and Amsterdam Eye
3. The APT and 'Muziekgebouw' (concert hall)
4. The IJDok

This is set to change as the Overhoeks and Hamerkwartier areas on the north bank will be redeveloped to include high-rise buildings. Although this will add several prominent buildings on the riverside, these areas will still be islands of high-rise amongst the predominant low-level areas.

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Figure 4.13: Birdseye view of the Amsterdam Skyline, including proposed new high-rise around the A'DAM Tower (Team V Architecture)

The overall low 'cut' of the skyline means that any addition of some height, especially on the IJ, will have a significant impact on the skyline of the city. This creates both an opportunity to improve, as well as a responsibility to create a design that befits the city as a whole.

5. Program of requirements

Functional

Road Traffic

The bridge will accommodate a separate cycling and footpath, with traffic crossing in both directions.

- A 2-way cycling path of at least 6m wide;
- A separate footpath of at least 4m wide;
- Minimum possible height difference from ground level;
- A gradual slope leading up to the bridge for cyclists with an average slope of at most 3%. Locally steeper grades can be used if compensated for by flat plateaus;
- Quick access to bridge deck from ground level for pedestrians by stairs and/or escalators;
- Step free access for physically impaired users. This should be a separate route from the cyclist's slope, either by an isolated slope for wheelchair users or, preferably, lifts.

River Traffic

The bridge will allow passage of cargo barges, pleasure craft with masts and incidental exceptional traffic.

- A single span that allows three CEMT-class VIb cargo barges to pass each other unobstructed at all times without waiting. This requires a clear span of 145m (Gemeente Amsterdam, 2017a) and a height of 9,7m (Rijkswaterstaat, Water, Verkeer en Leefomgeving, 2017). The height is however still subject of political debate. Awaiting a final decision, the bridge height will be designed according to the highest possible standard: a clear height of 11,35m;
- Movable bridge part(s) to allow clear passage for pleasure craft with masts at set times. A single bridge part of 40m wide or two parts of 20m wide are required to open to unlimited height (Gemeente Amsterdam, 2017b);
- Waiting space in front of the movable bridge(s) for pleasure craft;
- Movable bridge part that can accommodate exceptionally large transport up to 35m wide. Including buffers this requires a passage of 40m wide and unlimited height.

Structural

- The structural design should be strong enough to withstand all load combinations as described in NEN-EN 1991. This includes permanent loads, road traffic, rain & snow, wind and thermal expansion;
- The bridge should be designed to a variable load on the bridge deck of 5kN/m²;
- The bridge should be designed to wind speeds up to 27m/s;
- Flexibility and movement of the bridge deck should be limited to increase comfort;
- Depending on the construction method, special attention should be paid to reduce the chance of resonance and positive feedback occurring;
- The bridge should be constructed for a lifespan of at least 100 years;
- Considerations for service and inspection of all sides and parts of the bridge should be made;
- The movable parts should allow quick and reliable operation.

Visual

The Java Bridge will be a historic structure for the city of Amsterdam and the IJ and should be designed as such. Although it could contain symbolism that reminds of the historic background of the city, it should be a modern design rather than a classical revisit. Lightness and transparency are desired to make it fit in, rather than block out, the view over the IJ. This does not however mean that it should aim to be inconspicuous, as it will form an important part of the city's skyline and should aim to enhance it.

It should however also work on smaller scale levels: For the residents of the neighbouring houses it should not be dominating or overshadowing and for cyclists and pedestrians it should be an inviting route. It should aim to be a fitting visual connection between the neighbouring areas.

Personal ambitions

In addition to these requirements that follow from aspirations and limitations set by the municipality's assignment, I added some extra ambitions to pursue in this thesis.

The Java Bridge is primarily intended as a larger scale connection between north and south. This may be one of the causes of the controversy that surrounds the project among local residents. Their reservations include that the bridge will cut through the area as an unassailable obstacle due to its large height and that it will damage the view over the IJ.

As a reaction to this my ambition will be to enhance the impact the bridge will have on its close surroundings. As it will be built between two recreational area's and in the middle of a redevelopment, there is a great potential to incorporate the bridge into this new livelihood. As there is still the requirement for an efficient connection for commuters on a larger scale, this implies a split in functionality. One part will act as a connection between north and south, mainly for cyclists, and should be designed as an efficient expressway. Another part, mainly for pedestrians, will act as a direct connection between the two recreational areas in the newly developed Hamerkwartier and at the end of Java Island. The design should aspire to optimise both parts for their separate function.

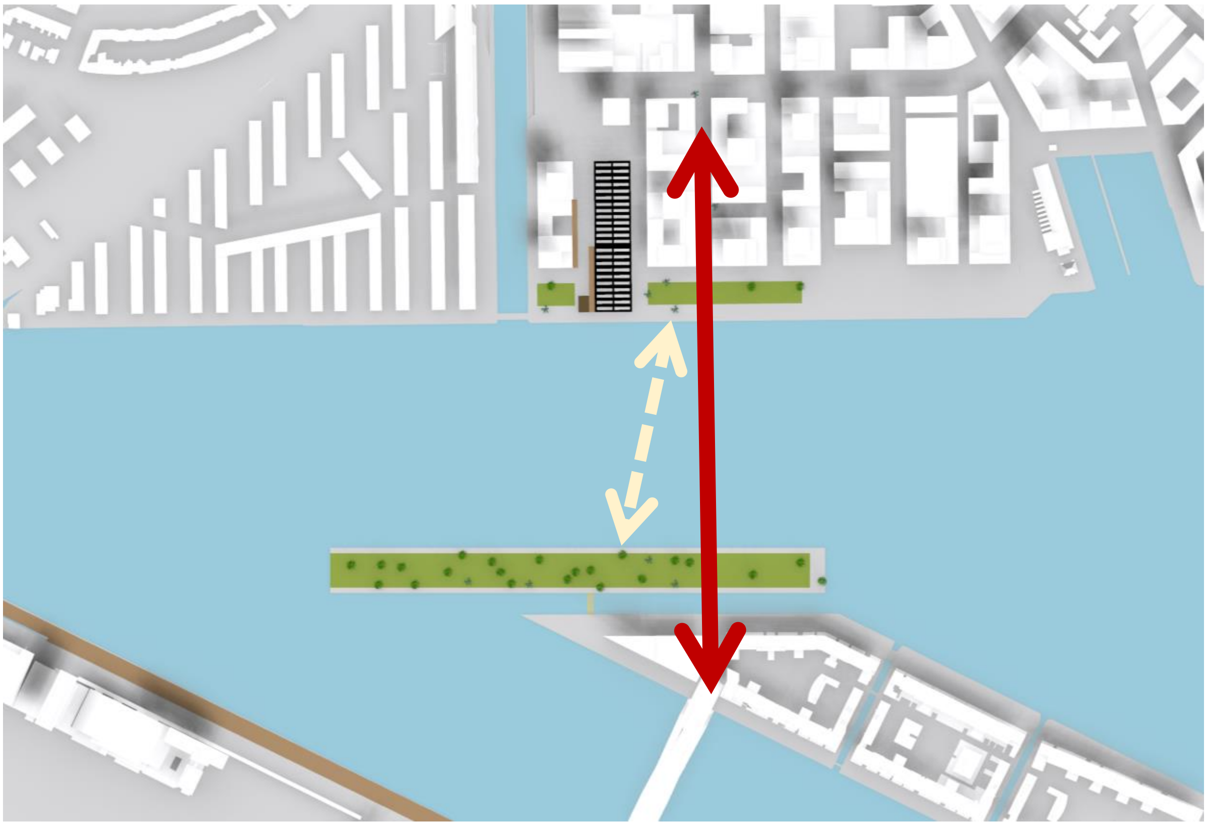


Figure 5.1: Separate connections for local and through traffic

6. General layout Java Bridge

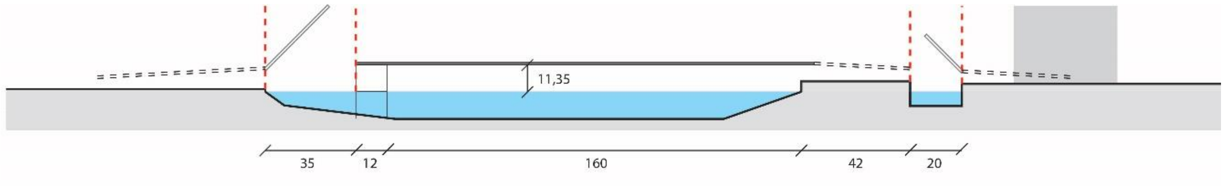


Figure 6.1: Proposed section of the IJ, including the new Jakarta Canal on the right

Based on the design criteria the city of Amsterdam has published six possible locations for the bridge, including courses for the slopes leading up to it. Four of these proposals include a new, 20m wide canal through the end of Java Island to accommodate pleasure craft heading east. There is another movable part on the north side measuring 40m wide and a main span of 160m.
There options are based on a clearing below the bridge of 11,35m high and the assumption of a bridge deck of 1m high, leading to a total height of 12,35m. In order to keep the average gradient below 3%, the slope on Java Island needs to be at least 311m long, while the slope on the north bank, where the ground level is lower, needs to be at least 378m.

Variant west 1

Variant middle 1

Variant east 1

Variant west 2

Variant middle 2

Variant east 2

Figure 6.2: The six proposed location variants (Gemeente Amsterdam)

Recent developments

In November 2018 Rijkswaterstaat rejected all six variants due to nautical safety concerns. The division between a north and south movable part meant that all pleasure craft heading east would have to cross all traffic from the Amsterdam Rhine Canal while on their way to the Oranje Locks. Additionally, there were not enough waiting spaces in front of the movable bridges to accommodate all traffic. This is still an ongoing development.

As the division of west- and eastbound traffic across two movable bridge part is an integral part of the design, it was not possible to incorporate these concerns into my graduation project anymore. I will therefore assume the situation hasn't changed since the publication of the six variants.

Proposed connections

Jakarta Canal

The west and middle variants include the new canal in the top of Java Island called the Jakarta Canal. The final options move the bridge further east where the IJ is wider. This removes the need for the canal but does add a sharp corner and detour to the bridge slopes.

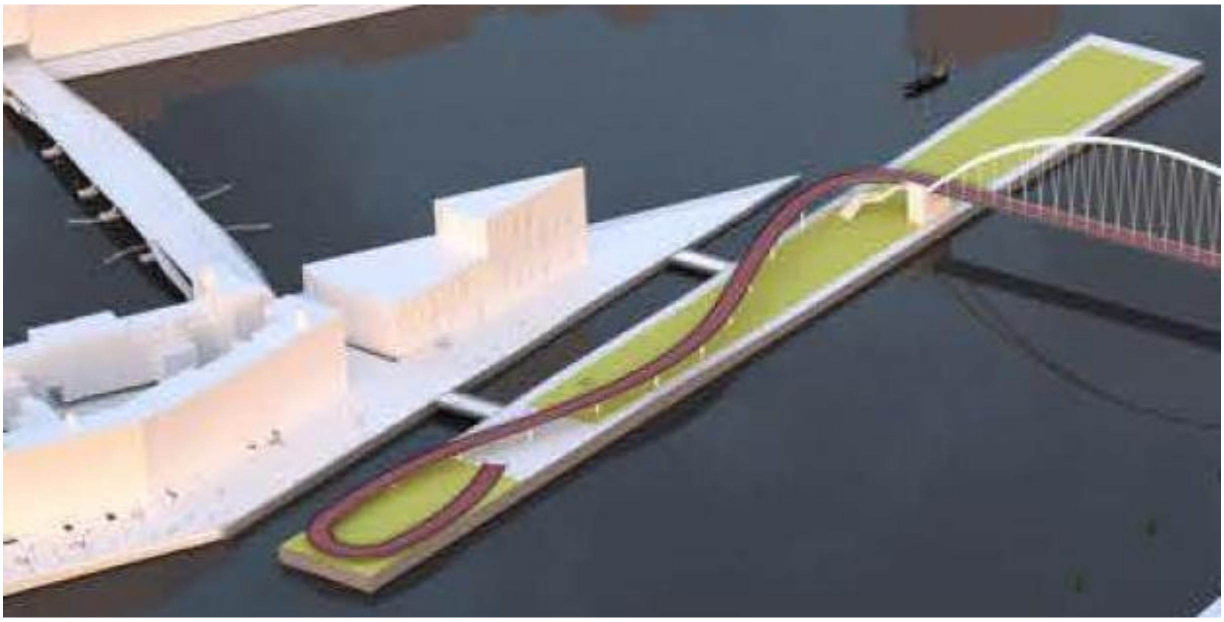


Figure 6.3: Proposed layout of the top of Java Island including the Jakarta Canal (Gemeente Amsterdam)

South Landing

There are two main variants for the slope at the south end of the bridge. One involves a long, winding slope on the top part of Java Island; the other extends the Java Bridge from the highest point of the existing Jan Schaefer Bridge.

The variants that use Java Island for a long slope will likely require a path that doubles back on itself to create the required length. The means it will always present a small detour for cyclists from all directions. In addition, the curves could be experienced as dangerous or uncomfortable, as descending cyclists with high speeds and slower climbing cyclists pass each other.

The variant that continues from the Jan Schaefer Bridge offers a more direct route for cyclists from the south. It reduces both the total distance as well as the total height that must be climbed, as the path never declines from the top of the Jan Schaefer Bridge. However, for cyclists from Java Island the slope leading up to the bridge is inaccessible. They would either have to cycle all the way back and forth across the Jan Schaefer Bridge or, more likely, use stairs and lifts to get them and their bikes to the top of the bridge.

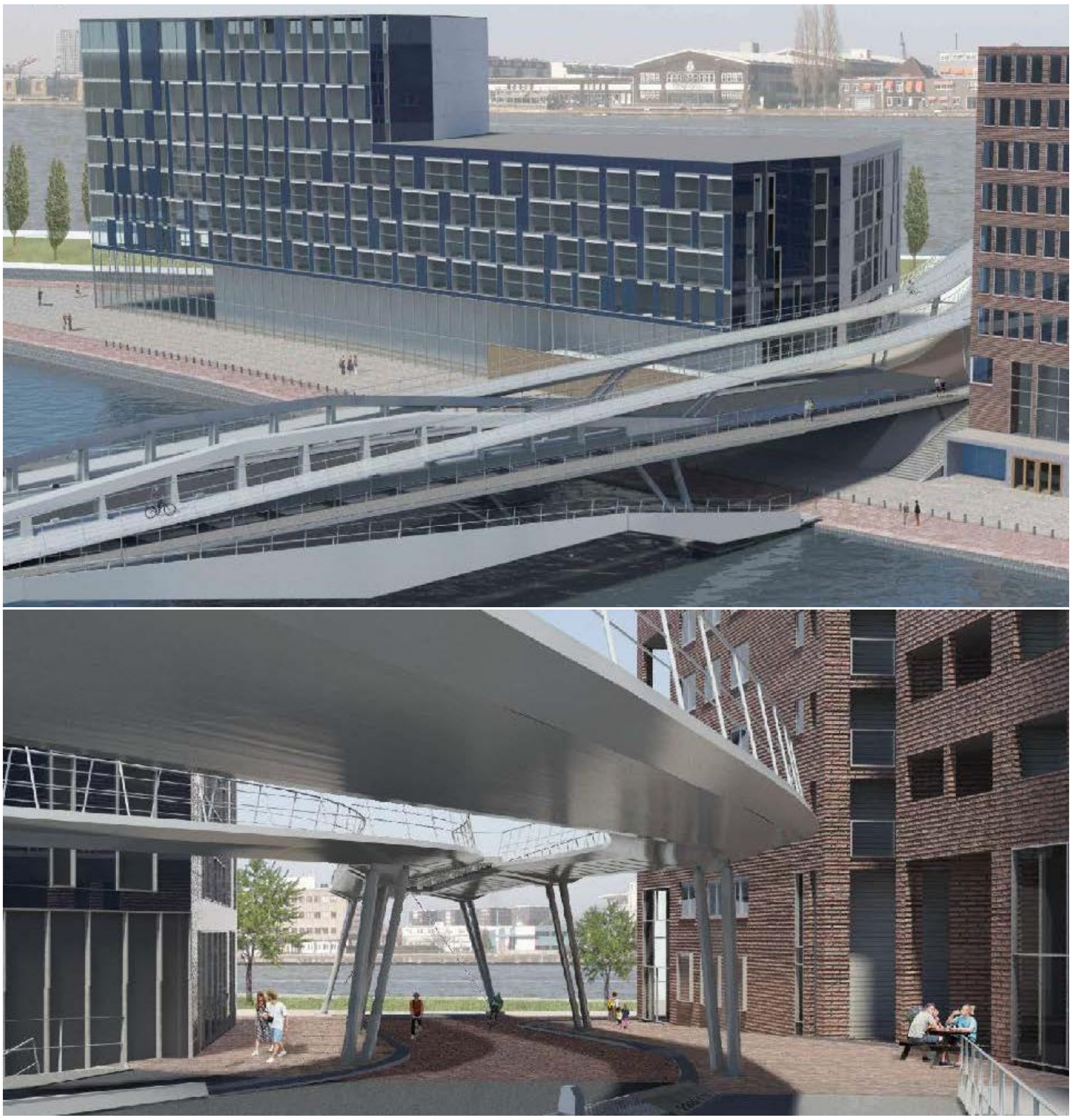


Figure 6.4: Artist impressions of the proposed connection to the Jan Schaefer Bridge (Gemeente Amsterdam)

The direct approach does mean that the bridge cuts across the entire Java Island at an elevation. Cyclists from Java Island itself cannot cycle directly up the bridge's slopes. Instead they have to take a detour back and forth across the Jan Schaefer Bridge or, more efficiently, use stairs or elevators on the waterside.

Another important observation of the Jan Schaefer Bridge variant is that is has a much larger impact on the surrounding buildings and infrastructure than the longer slope variant. To accommodate the slopes above the Jan Schaefer Bridge deck, the cycling lanes for traffic to Java Island itself must be moved to the current car lanes, either as cycling lanes on the side of the road or by creating a dedicated cycling road. The road and intersection under the slope on the Island itself would also have to shrink. The slopes themselves cross very close to the existing buildings: 2 apartment blocks and the newly constructed Jakarta Hotel. This has raised questions about privacy and living comfort.

North Landing

All variants for the slope on the North Bank include a long gradual slope to ground level, but the main differences are where the slope connects to the existing cycling network. These variants can be simplified to 3 options:

- The passage under the shopping centre north-west of the Hamerkwartier
- The Meeuwenlaan between the Hamerkwartier and the Vogelbuurt
- In the centre of the Hamerkwartier

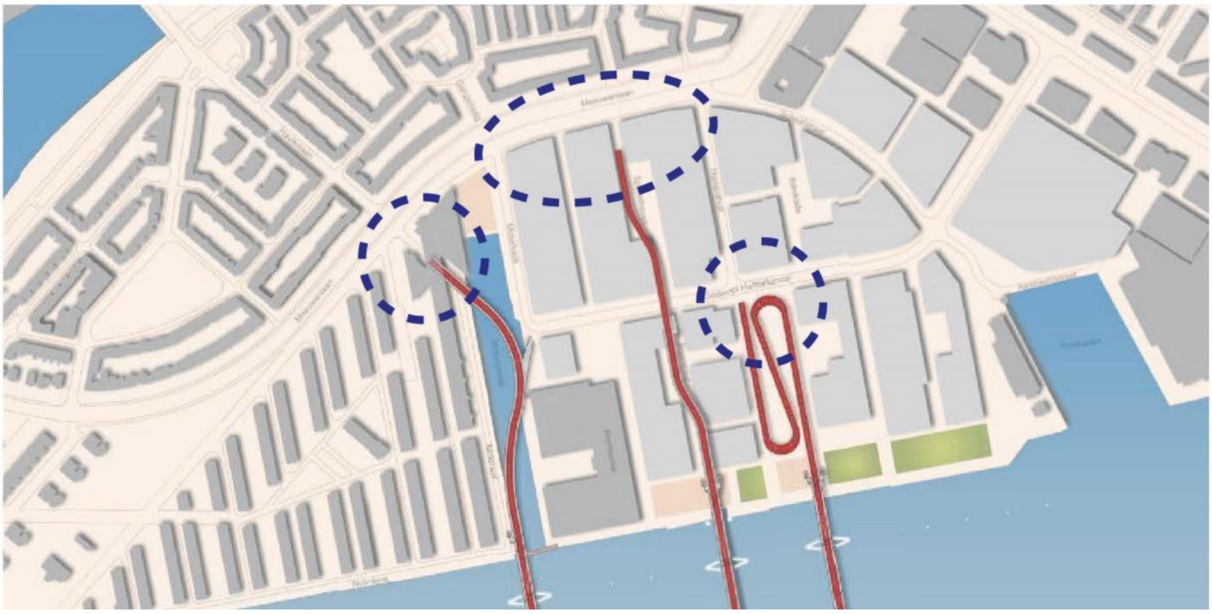


Figure 6.5: The three proposed landing sites on the north bank

These options should be assessed both on their location within their direct surroundings, as well as how well they connect to the existing cycling network and traffic demands.

The option to the west of the Hamerkwartier has the most free space away from buildings as it can use the Motorkanaal, which is currently a small harbour. As it must cross the water to reach its final landing point, this variant will require (partial) relocation or removal of the harbour. There is very little space for stairs or lifts on the Hamerkwartier side of the Canal, although it is unclear what will happen to the current buildings when the area is redeveloped. There is slightly more space on the opposite bank of the Canal, although this also moves the bridge closer to the existing houses.

The other 2 options construct the slope within the Hamerkwartier. This involves the demolition of several buildings, although this is planned in the pending redevelopment anyway. The fact that the slopes would be built in a still to be designed area makes it possible to ensure very good integration within the neighbourhood without creating issues of privacy or discomfort. However, is could also work as a limiting factor in the development of the area as it presents another factor to consider.

The western option mainly grants easy access to traffic from the west of the Hamerkwartier. All traffic from the east or from the Hamerkwartier itself must take a detour to reach the slope or use the stair and lifts. The northern and central option offer a wider accessibility, although the northern option still bypasses most of the Hamerkwartier, even though it cuts directly through it. The central option however presents a detour for everyone as the slope itself has to curve around multiple times. This could be experienced as dangerous or uncomfortable, just as the winding curves on the south bank.

Traffic flow

When assessing where the bridge should connect to the cycling network, it is important to know where its users come from and what routes they take. Considering the other measures that are part of the ‘Leap over the IJ’ (Metrostation Sixhaven, Stenen Hoofd Bridge etc.) it can be assumed that the Java bridge will mostly be used by traffic to and from the east side of the city south of the IJ. These destinations are currently mainly serviced by the IJplein and Oostveer ferry services (Gemeente Amsterdam, 2015b). Figures 6.6 and 6.7 give an indication for the passenger streams that would likely use the bridge.

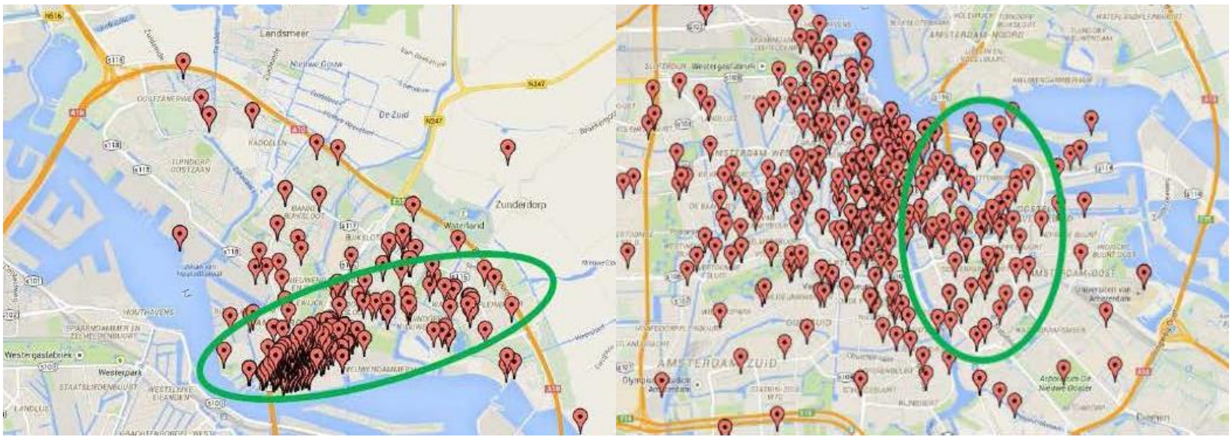


Figure 6.6: Origins and destinations of current users of the IJPlein ferry service (Gemeente Amsterdam)

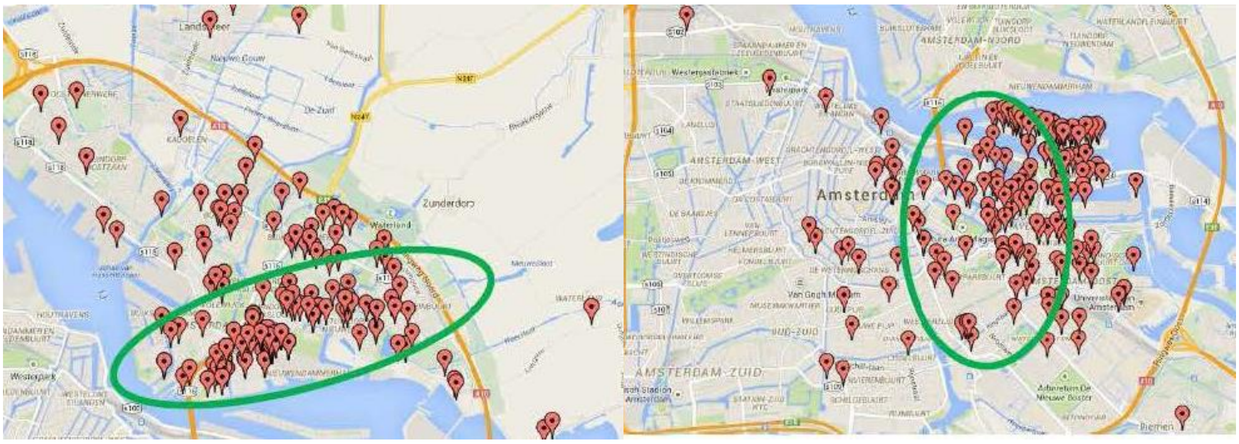


Figure 6.7: Origins and destinations of current users of the Oostveer ferry service (Gemeente Amsterdam)

A few observations can be made from this:

- There is a high concentration of traffic originating from Java Island itself, mainly to easterly destinations on the north bank
- On the north bank there is little to no traffic west of the North Holland Canal
- Most traffic from the north bank originates from the areas directly surrounding the bridge location: the Vogelbuurt and IJplein neighbourhoods
- It can be assumed that the redeveloped Hamerkwartier would generate at least as much traffic as its direct surroundings.

Preference

Based on these observations we can select a preferred variant.

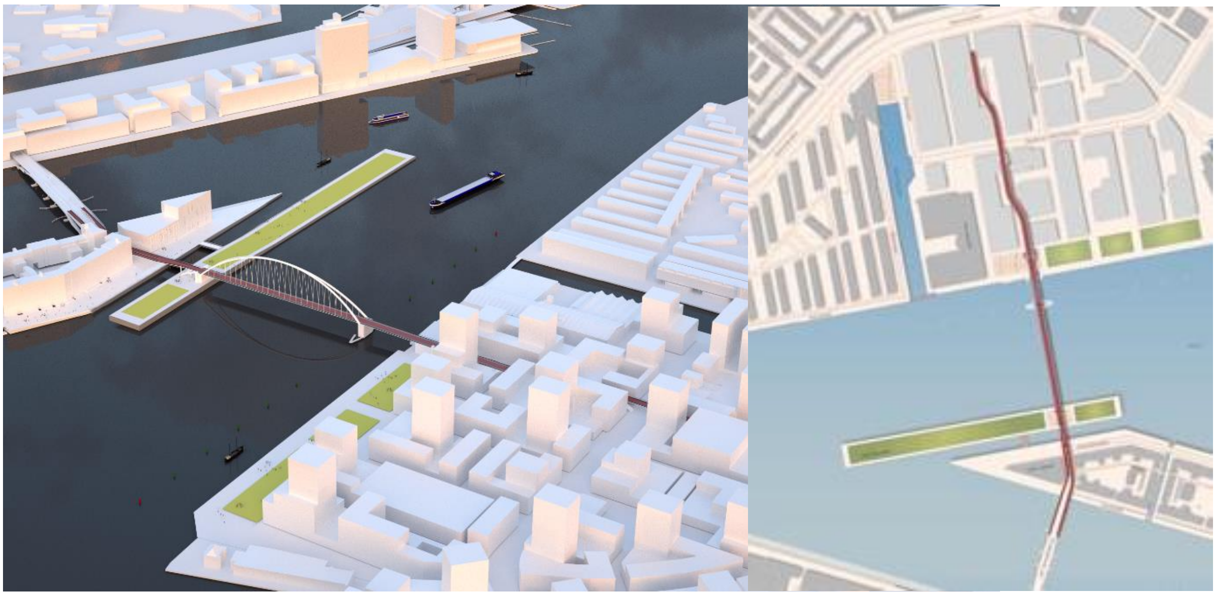


Figure 6.8: Chosen preferred variant (Gemeente Amsterdam)

Although the large amount of traffic from Java Island would speak for a slope on Java Island itself. However, considering the ambition to design the cycling route as an expressway the Jan Schaefer variant is more direct. This increases the value of the bridge on a larger scale and as part of the entire city's network. In addition, it provides an interesting design challenge.

Considering on traffic demands and the ambition for and efficient cycling path the middle option is by far the most direct route. This leaves me to select variant middle 2 as the basis for the design.

Alterations

This variant describes the cycling route, but local traffic and pedestrians require different connections. To optimize the connection between bridge and surroundings the north landing should have the Kromhouthal as a focus point, just as it is a focus point for the recreational area on the waterside. On the south landing the access point should focus on the park, as well as provide a direct connection to the nearby bridge across the Jakarta Canal.

By splitting the pedestrian and cycling parts of the bridge, the pedestrian route can be curved towards these focus points. (Figure 4.9, middle) This split also frees up space around the pedestrian bridge landings to accommodate large, marquee access points.

In this configuration the cycling path does take a few turns mid-course, which make it appear a bit thrown together. This line can be smoothed into a more flowing curve by following the tangent of the Jan Schaefer Bridge. (Figure 4.9, bottom) This enhances the cycling path as a fast through route while at the same time clearing more space for the pedestrian path, which moves its landing closer to the bridge across the Jakarta Canal.

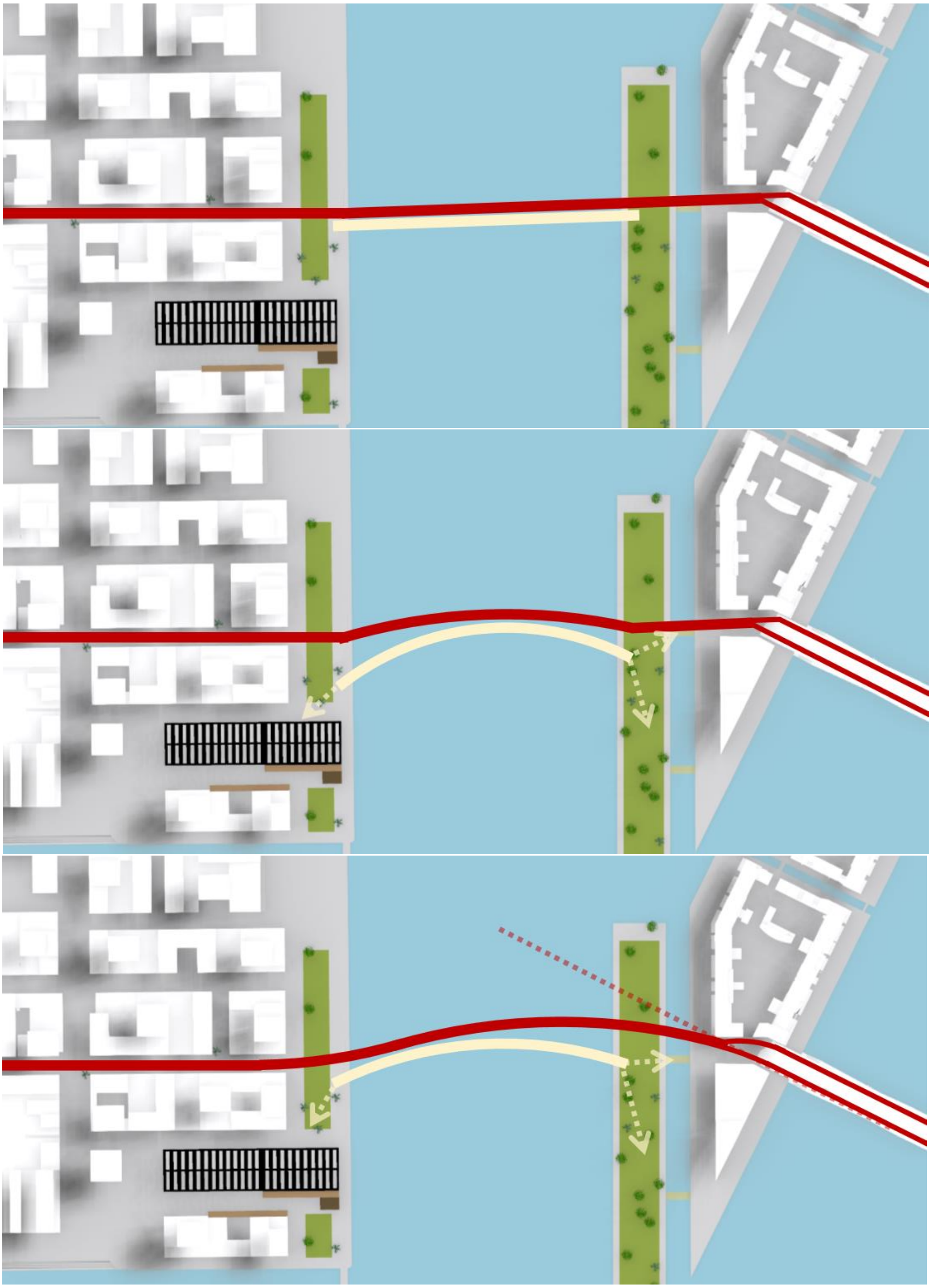


Figure 4.9: Development of bridge layout. (top) Straight connection. (middle) Freed access points. (bottom) Definitive layout with flowing lines from the Jan Schaefer Bridge.

However, this new configuration does require some awkward turns in the java island passage to split/merge the cycling paths from the Jan Schaefer bridge. These turns are necessary to clear enough space above the road that runs between it. (Figure 4.10 left)

Even though the cycling paths will fit above it, the limited space around road and bridge decks will complicate the placing of columns and lower cycling/footpaths. Another issue with this configuration is that the Jan Schaefer bridge simply doesn't have enough space to accommodate large enough cycling paths, and possibilities of altering the construction are very limited. It should be noted that this is a problem for all configurations that lead all traffic from the java bridge to the existing cycling paths of the Jan Schaefer bridge.

Rather than continuing a design that from the start lacks capacity, another option is to divert all road traffic and connect the cycling bridge to the main deck of the Jan Schaefer bridge. (Figure 4.10 right) In this case all road traffic would have to be diverted to the eastern connection between Java Island and the mainland. The cycling path however runs a much smoother course and leaves more space for construction and local routes. Cycling- and pedestrian paths to and from Java Island will stay in their current place.

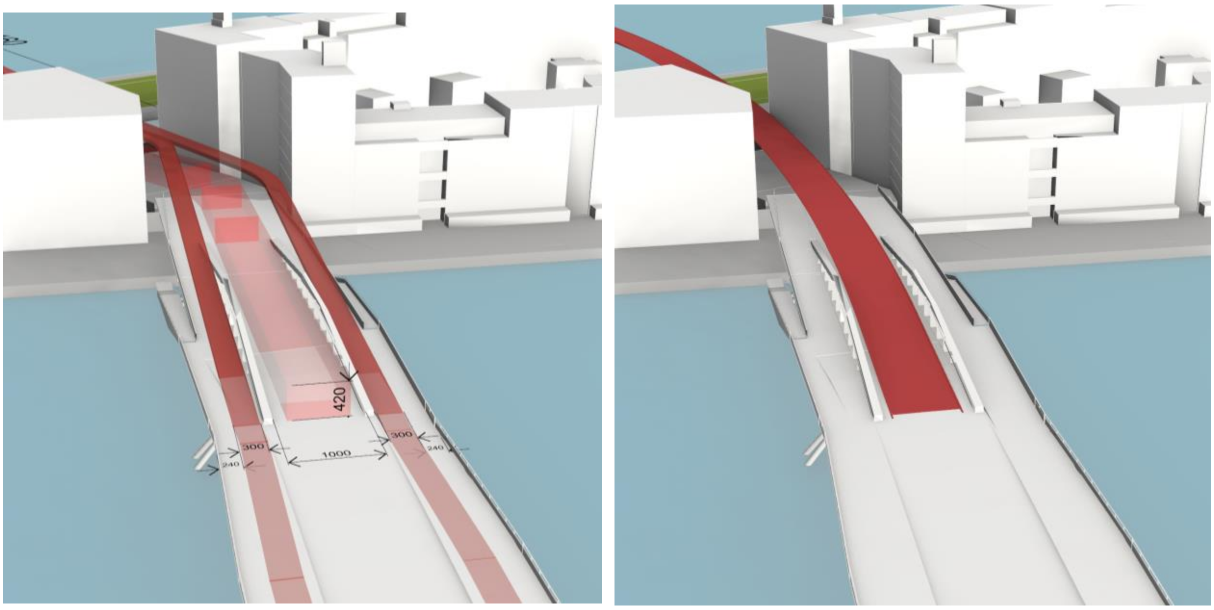


Figure 4.10: (left) original configuration showing the clearance required by the road (right) New configuration without road

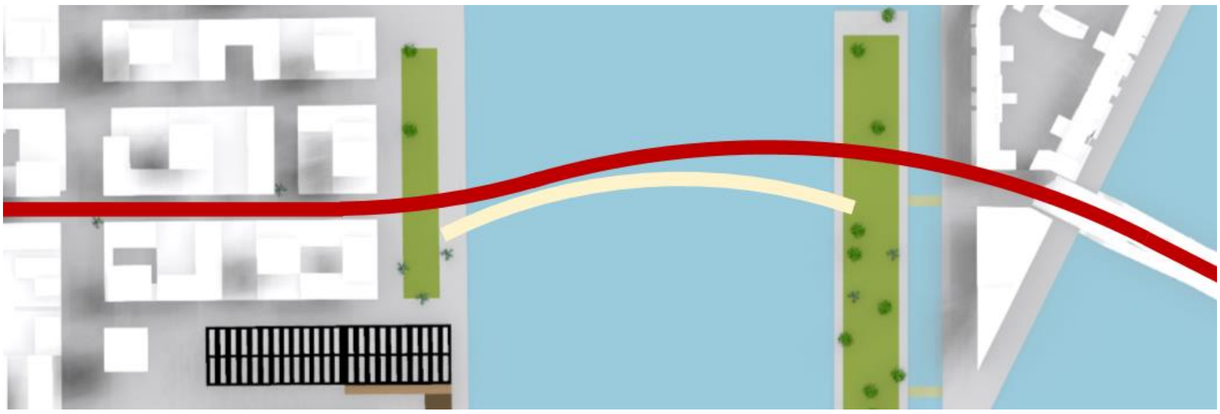


Figure 4.11: Final layout as used in this project

7. Analysis of bridge design

To be able to design a functional and visually pleasing bridge, a thorough knowledge of bridge design is required. By performing an analysis of structural, mechanical and visual bridge design, insight can be created that will help make the right decisions for the Java Bridge case

Structural design

The main structural challenge for the Java Bridge will be the main span. There are many ways of constructing a bridge across this distance, although each method will have its own strengths and limitations. These characteristics will affect the bridge height, functionality, material efficiency and visual impact. In this analysis 6 common types of construction will be researched.

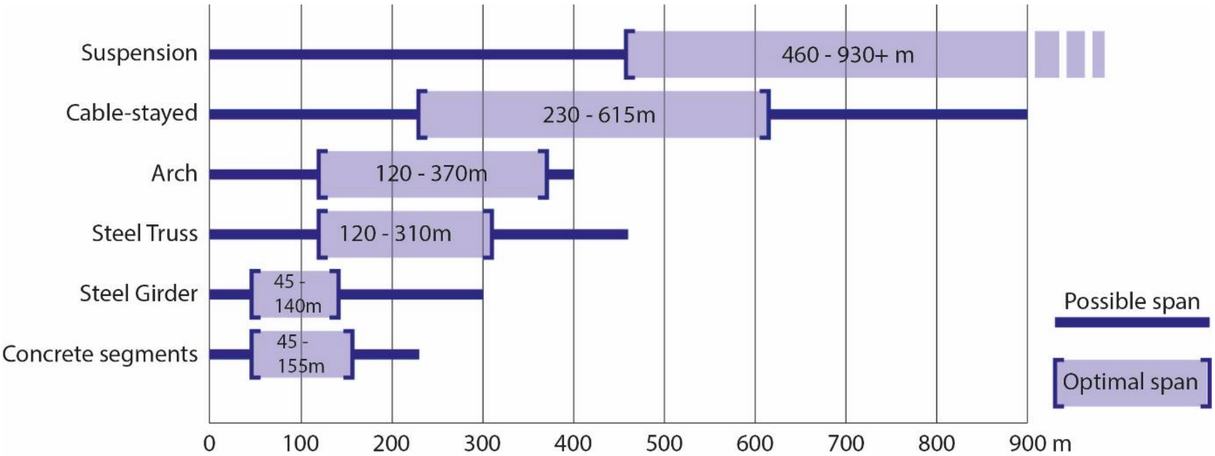
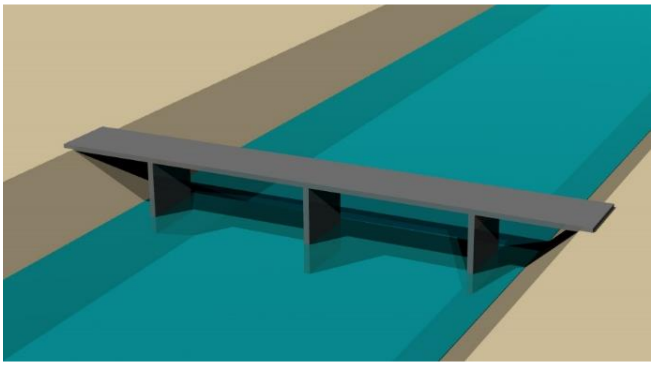


Figure 7.1: An indication to the limits and optimal span lengths of different bridge types (Pipinato, 2015)

Beam bridge

The oldest and most basic form of bridge construction is a simple beam bridge. This comprises of a series of horizontal beams or slabs across vertical supports. Beam bridges are usually constructed out of concrete and/or steel, though wood or stone could also be used. As the bridge deck supports itself, the maximal span between two columns depends on the thickness of the bridge deck and the materials used.



Beam bridges are cheap and simple to construct and are therefore one of the most common types of bridges in infrastructure projects. They are especially useful in applications where there is no restriction on the number of columns, such as motorway interchanges. However, in applications where larger clear spans are required, such as large river crossings, extra measures are needed.

The bridge deck in a beam bridge acts as a beam supported on both ends. Vertical loads will cause the deck to bend, and the moment created this way is usually the most defining factor of the loads in the bridge deck. The moment will be countered by tension in the bottom of the beam and compression in the top. The simplest way of strengthening a beam bridge is therefore increasing the heights of its girders, as this increases its moment of inertia. However, this is not a very efficient use of material when compared to for example a truss construction.

Apart from being the simplest of all construction types, the beam bridge is also the most inconspicuous. This makes it unsuitable for a landmark bridge like the Java Bridge. However, it is still often used as part of a monumental bridge, as part of the slopes leading up to the main span for example. Not only is this often the cheapest way of constructing these slopes, their simplicity helps to isolate and highlight the often visually more interesting main span.

Figure 7.2: Zeeburger Bridge in eastern Amsterdam, opened 1990 (Beeldbank Rijkswaterstaat

Cantilever bridge

A more efficient way of increasing the span of a beam bridge is by only increasing its thickness above the columns, rather than over its whole length. This creates what is known as a cantilever bridge. The spans of the bridge cantilever out to the centre from the stronger sections above the columns. This means that the highest moments are found on the sides of the span, rather than in the centre. The moments are also inverted: the bottom of the bridge deck is now in compression and the top under tension.

Figure 7.3: The Betlembridge across the Amsterdam Rhine Canal, opened 2017 (Beeldbank Rijkswaterstaat)

Rather than a solid concrete bridge deck, a cantilever bridge can also be constructed in other ways, for example a steel truss. As this can be a hollow construction, it can be constructed either above or below the bridge deck, or both. Constructing the cantilever above the bridge deck has the advantage of increasing the clearance below or decreasing the height of the bridge deck.

On top of increasing the flexibility of the bridge, using a superstructure like a truss will increase the visual impact. Although a solid concrete cantilever can certainly look elegant, its simplicity can cause it to look underwhelming.

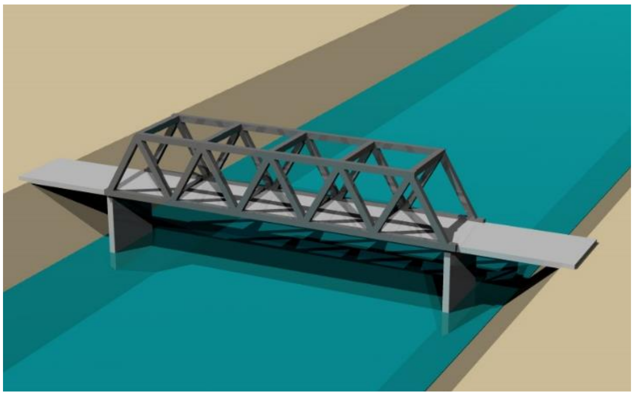
Figure 7.4: The Sacramento River Bridge, opened 1923 (Bridgehunter.com)

Truss bridge

A truss is a rigid structure made from beams and or cables. The elements of a truss are only subject to tension or compression, no moments or shear forces, but by ordering these elements into triangles the whole construction starts acting as a single beam. Truss bridges are comparable to beam bridges in overall composition, as truss elements span vertical columns in the same way as a girder bridge deck.

As is the case with solid beams, the top of the truss structure will be experiencing compressive stress and the bottom will see tensile stress (illustration 4). The connecting beams will deal with either compressive or tensile strength, alternating and depending on the exact configuration of the truss. Many different configurations have been used (illustration 7.6).

Trusses are a more efficient way of increasing the moment of inertia of a bridge than using large girders, as more of the material is located at the top and the bottom of the truss beam. Therefore, larger spans can be achieved using the same amount of material. The structure will effectively act like a very thick beam, but because it is an open structure, it



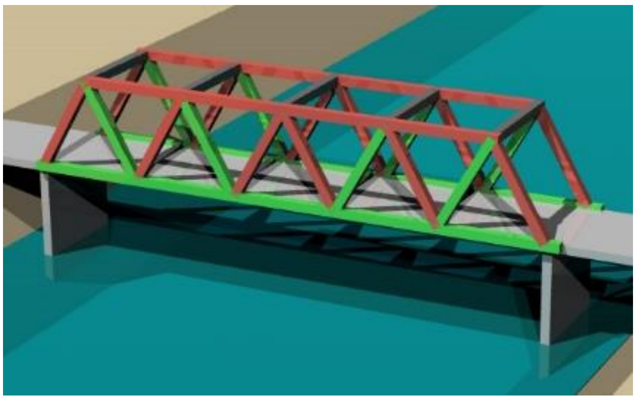


Figure 7.5: Tensile (green) and compressive (red) forces in a basic truss bridge

can be constructed above the bridge deck as well as under it. Placing the truss above the bridge deck decreases its thickness, meaning the bridge can be constructed lower without losing clearance under the bridge.

The truss structure also gives the bridge a very distinct look. It is an open structure, so you can see through it from both inside and outside, but because it has larger proportions than a girder bridge, it can still be quite imposing. It has a strong association to (old) railway bridges, as it was a very common construction method during and after the industrial revolution, before large scale infrastructure projects for cars were undertaken.

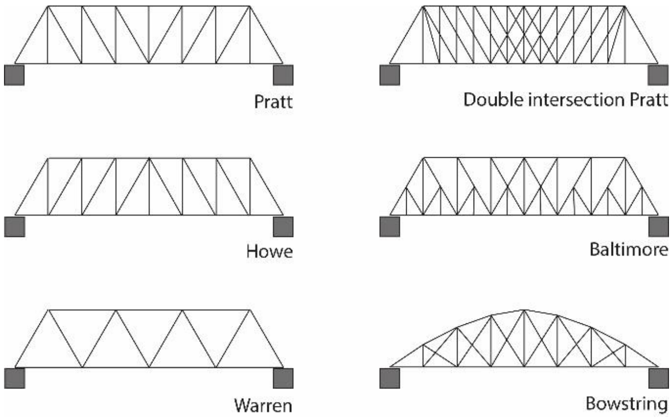
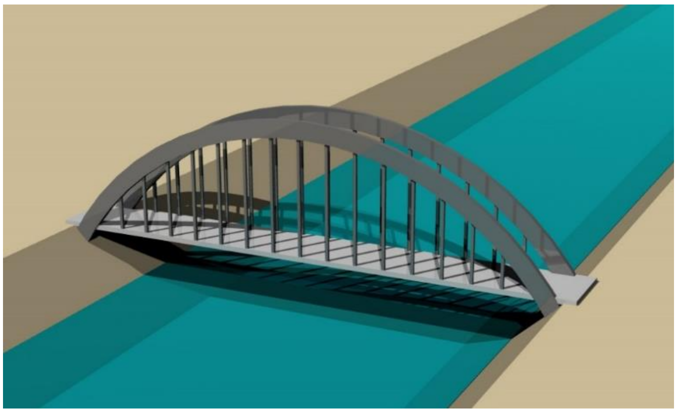


Figure 7.6: A small selection of common truss configurations

Figure 7.7: Moerdijk rail bridge, opened 1955 (Beeldbank Rijkswaterstaat)

Arch bridge

An arched bridge is a construction in which an arch shape dissipates all forces to the foundation through compressive force. This is a very old construction method which was very popular during Roman times, as it allowed them to create spans using only masonry, which could not be submitted to tensile forces. Arched bridges were continued to be build using stone and concrete, but it was also the construction method used for the first iron bridge, using many of the same principles.



An arch shape transfers vertical loads into compressive force along the curve of the arch, eventually grounding them into the foundation. Old designs would use a half circle, which required no horizontal support to keep the arch from deforming. However, it is not the most efficient approach. Modern arch bridges are designed with a much sleeker arch. This requires strong foundations able to counter the outwards forces going through the arch's 'feet', but it is a much more efficient use of material.

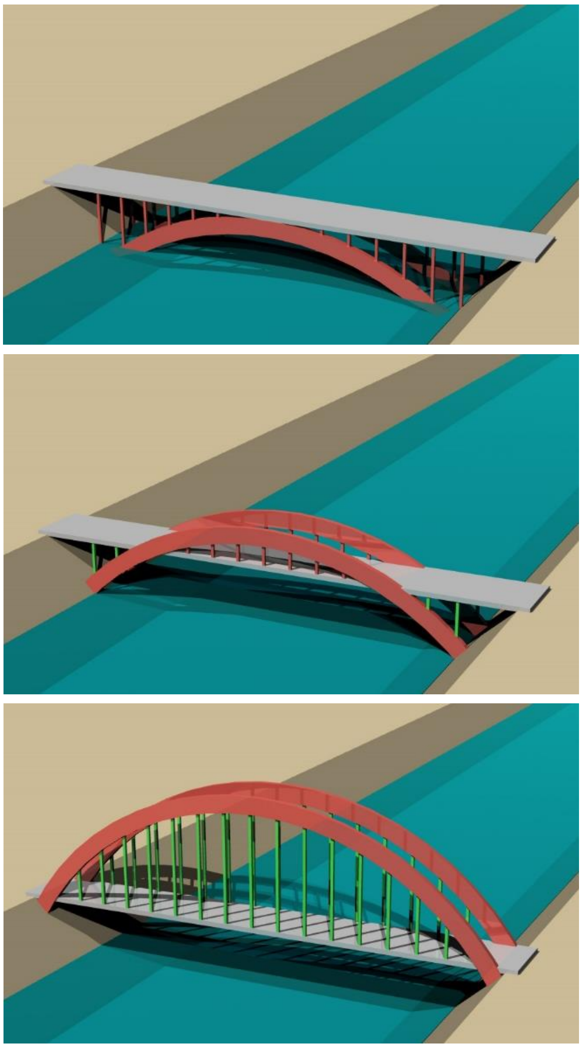


Figure 7.8: Tensile (green) and compressive (red) forces in arches placed below, alongside and above a bridge deck

The arch of the bridge can be placed either below the bridge deck, above it, or as a combination of both. The construction principle remains the same as the arch dissipates vertical forces from the bridge deck through compressive stress. However, when the arch is located below the deck, the loads have to be transferred to the arch through compressive forces, whereas when the arch is located above the deck, they are transferred through tensile forces (illustration 7.8). This means that in the case of an arched superstructure cables will suffice in connecting the bridge deck to the arch. An arched substructure will require heavier connection elements as compressive forces can lead to buckling.

Modern arch bridges are a very commonly used construction method when a large clear span is required, for example in a large river crossing. A steel or concrete substructure arch is most commonly used when the bridge very high above the ground, i.e. in a mountainous area. In the Netherlands steel superstructures are most commonly used.

As an arched superstructure adds a lot of material and height to a bridge, is also has a large visual impact. Arch bridges can be iconic and imposing, although they also inherently look stable and safe. As they have been extensively used for a long time, most arch bridges tend to have a very classical look.

Figure 7.9: Werkspoorbrug over the Amsterdam Rhine Canal, opened 2002 (Movares)

Suspension bridge

A suspension bridge is a bridge where the bridge deck is suspended from cables, that transfer the loads to large pylons. As almost all load transfer is done through cables, this construction is extremely light. Combined with the high tensile strength of steel cables, this allows for the construction of very long spans. Almost all the world's longest bridge spans are suspension bridges. The bridge deck of a suspension bridge can be relatively slender, as all the vertical forces are transferred to the vertical suspension cables. However, the bridge deck should be stiff enough to guarantee an equal distribution of forces through the cables.

Figure 7.10: Tensile (green) and compressive (red) forces in a typical suspension bridge construction

Loads from the bridge deck are transferred through vertical suspension cables to larger cables connecting to the pylons and from the pylons to the foundation. Vertical forces from the cables are transferred through the vertical pylons to the ground. Due to the angle of the cables they also carry large horizontal forces. To prevent the transfer of these horizontal forces to the pylons, which are slender and would buckle and collapse, the cables are connected to large foundation blocks at both ends of the bridge. The cables are connected to the pylons on rollers, and the cables depart from the pylons at equal angles. This results in an equilibrium, meaning no horizontal forces can be transferred through the pylons.

Although modern suspension bridges are most commonly utilized for extremely long spans, its simple construction also makes it a viable solution for smaller applications. One relevant example is the Nescio slow traffic bridge over the Amsterdam Rhine Canal in Eastern Amsterdam (figure 7.11). Due to the low loads of the cycling and pedestrian lanes a single suspension cable and two single columns are enough. In order to transfer horizontal forces through the pylons, they are connected to the foundation on hinges and supported by two cables each.

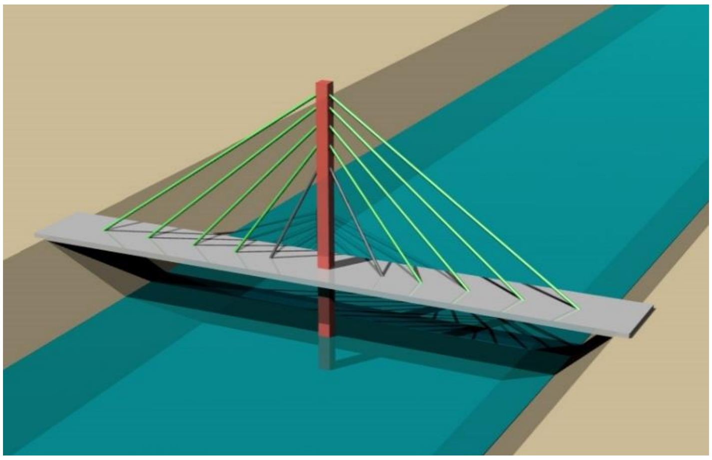
Figure 7.11: Nesciobridge in Eastern Amsterdam, opened 2006 (Architectuur Centrum Amsterdam

One engineering challenge that is specific to suspension bridges is preventing the bridge from swinging on its cables. Even though a little swinging motion is not necessarily a problem, though it can be discomforting for its users, uncontrolled swinging can cause to structural damage. One specific type of swinging is known as harmonic resonance. This is an effect where a slight swinging motion becomes subject of positive feedback, i.e. reaction to the swinging motions cause the swinging to increase.

One of the most recent examples of this was the Millennium Footbridge in London. This bridge is a slender variant of the traditional suspension bridge. As the suspension cables are lower than the bridge deck for part of the span, the bridge deck is suspended from them using steel girders, rather than vertical cables. When the bridge opened in 2000, it would experience tremors due to wind and people's footsteps. The swaying of people on the bridge as a reaction to these tremors would cause the bridge to swing even more, as the frequency of the swaying people matched the bridge's own resonant frequency. The bridge had to be fitted with specially tuned buffers to eliminate this effect.

Figure 7.12: Millenium Footbridge over the Thames in London, opened 2000 (Walklondon.co.uk)

Cable-stayed bridge



Cable-stayed bridges are in principle similar to suspension bridges: Loads from the bridge deck are transferred as tensile forces through cables that connect to a vertical pylon, which transfers the forces to the foundation. However, instead of using vertical cables that connect to a more horizontally strung larger cable, the cables connect directly from the bridge deck to the Column. This results in an even more efficient design, although it can't match the maximum spans of a suspension bridge.

Bridge decks for cable-stayed bridges are often designed as stiff box sections, which are more rigid than their suspension bridge equivalent. This increased rigidity allows for designs with less cables or different configurations. This makes the cable-stayed bridge a more versatile design principle than a suspension bridge, whose form is always determined by the same structural composition. (Figure 7.14)

As is the case with suspension bridges, horizontal forces cannot be transferred through vertical columns. Most commonly the columns are stabilised by cables connection on 2 sides. This can be a symmetrical design, where both sets of cables carry a span of the bridge, or an asymmetrical design where one of the sets of cables supports a span while the other set simply connects to a foundation to stabilize the column. Part of this horizontal force can be dealt with by angling the column away from the bridge span. Now the horizontal forces can transfer through the columns as compression.

As with suspension bridges, the tall superstructure of a cable-stayed bridge quickly creates an iconic or monumental design. However, cable-stayed bridges are a more recent development, with broad implementation of cable-stayed designs only taking of in the past few decades. This inherently gives them a more modern look than other types of bridge construction.

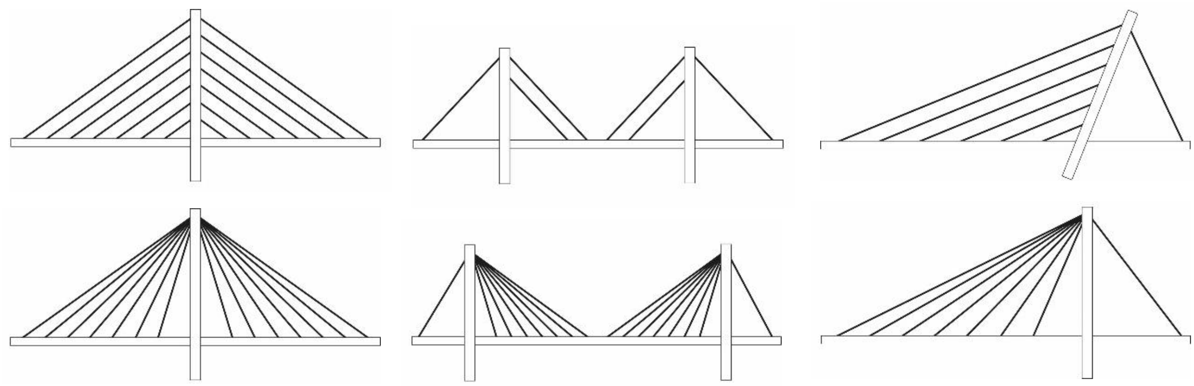


Figure 7.14: Examples of possible configurations of cable-stayed bridges

Figure 7.15: Prins Claus Bridge over the Amsterdam Rhine Canal, opened 2003 (Royal Haskoning)

Movable bridge parts

The Java Bridge will require a number of moving bridge parts. There are many different types of movable bridge, but the most commonly used types can be simplified to three principles of removing the bridge deck: Hinging, lifting or rotating (illustration 8)

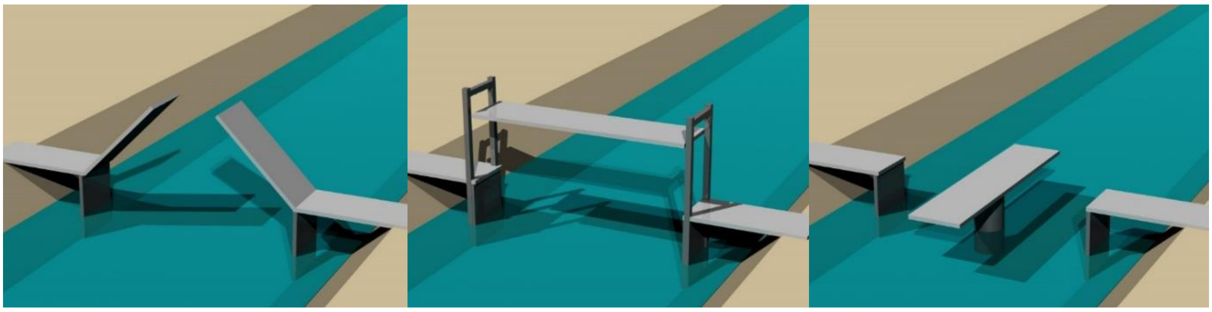


Figure 7.16: The most common types of opening bridge design

Hinging bridges

The most common type of hinging bridge is the bascule bridge. A bascule bridge is a cantilevered bridge deck that is connected on one side with a hinge. On the other side of the hinge is a counterweight that balances the bridge above its turning point, though its centre of mass is slightly tipped to the side of the bridge deck so the bridge can't accidentally open without being operated. This counterweight is commonly sunk in a cavity under the road surface but can also be suspended above or alongside the surface. Bascule bridges can either be designed as a single bascule, or a double bascule, with two cantilevers that meet in the middle. Double bascules can be used to create larger spans with shorter bridge parts, but one of the advantages of a single bascule bridge is that the bridge can rest on the abutment when closed. This means that while subject to traffic loads, it does not have to support itself as a cantilever. A double bascule needs a more complex locking mechanism that allows some small residual moments to be transferred between the bascules. Due to these disadvantages the double bascule bridge has become very uncommon.

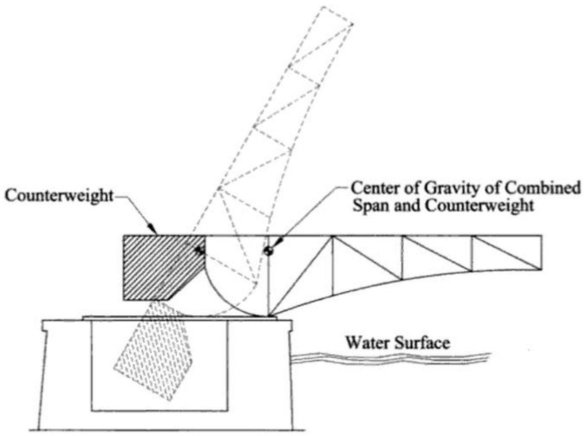


Figure 7.17: Typical layout of a bascule bridge (Koglin, 2003)

Bascule bridges are the most commonly used type of movable bridge in the world, as its balance allows it to be opened relatively quickly and with relatively little energy. It vertical opened position allows passage ships of unlimited height. Modern bascule bridges are most commonly operated by an electric engine that is connected to the axle by gears.

One disadvantage of a bascule bridge is that it is susceptible to high wind loads in open position, as the bridge deck forms a large vertical surface. As this wind force is perpendicular to the axis of the hinge, these forces not only have to be withstood by the bridge deck, but also by the machinery. As opening the bridge requires relatively little energy due to its counterweight, it is common that wind loads are the actual dimensions of the machinery are determined by the wind loads (Koglin, 2003). Fortunately, as the bridge is opened at this point, it does not have to deal with road traffic loads at the same time.

A drawbridge is a variation off the bascule bridge, but rather than being driven from its axle, it is operated by pulling on the bridge deck in some way. A type of drawbridge that is very common in the Netherlands consists of two hinges and 2 arms. The extra arm is suspended above the bridge deck and holds the counterweight. It is connected to the bridge deck by a rod or cable. This has been a popular design for centuries, as it did not require sinking the counterweight below the road, and small bridges could be operated by hand, by pulling on a rope connected to the counterweight. Modern drawbridges are operated by an electric engine that drives an operating strut.

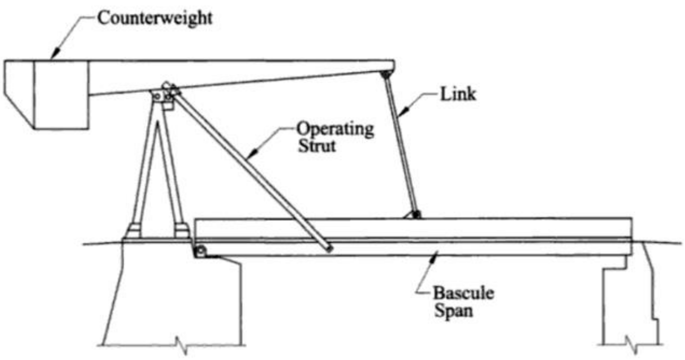


Figure 7.18: Typical layout of a drawbridge (Koglin, 2003)

There are many other variations on bascule bridges and drawbridges, including folding superstructures, winching cables or rolling hinges, but they all mostly depend on the same principles.

Figure 7.19: Interesting variants of bascule- or drawbridges (Wikimedia Commons)

Vertical lift bridges

A vertical lift bridge is any type of bridge that is opened by raising the bridge deck straight up, without rotating it. This usually includes tall vertical structures from which the bridge deck is hoisted up on cables. These cables are connected to large counterweights that lift or descend in opposition to the bridge deck. This reduces the time and energy required for opening the bridge deck, similar to the counterweight in a bascule bridge. Also similarly to a bascule bridge, the bridge deck is still slightly heavier than the counterweights, preventing the bridge from accidentally opening without being operated.

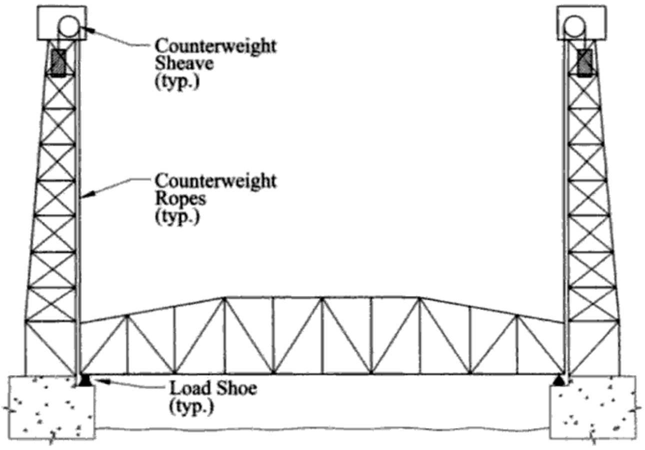


Figure 7.20: Typical vertical lift bridge layout (Koglin, 2003)

One of the main advantages of a vertical lift bridge is that it can be used to create very large movable spans. As the span is always supported on either end at all times, even when opened, it does not have to be cantilevered. The most common type of span used in vertical lift bridges is a truss bridge, as it can be used to create these large spans without requiring large superstructures. However other types of construction are usable as well.

The main restriction of vertical lift bridges is that they can’t offer unrestricted height for passing ships. To create large movable spans with large clear height as well, the height of the towers can be increased, but there is always a limit. In addition, increasing the height of the bridge increases the material and investment cost, as well as the operation time to fully open the bridge.

Figure 7.21: Salford Quays Lift Bridge in Manchester, opened 2000 (Pinterest)

Swing bridges

A swing bridge is a type of movable bridge that opens by pivoting the bridge horizontally on a bearing. As swing bridges have no vertical movement, they can be designed low to the ground with minimal impact on its scenery, if desired.

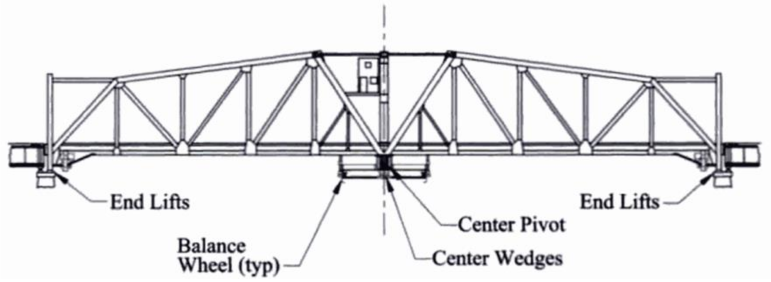


Figure 7. 22: Typical layout of a centre-balanced swing bridge (Koglin, 2003)

Most commonly the bearing is located on a central pier in the middle of a symmetrical bridge part. The entire bridge part rotates around the centre, creating two clear lanes for passing ships. If no two lanes are required, or the central pier is undesirable, an unsymmetrical design can also be applied, which is also known as bobtailed. As this unsymmetrical layout would create large stresses in the pivot axle, these types of bridges are often built with a counterweight on the other side of the pivot to balance it out. A bobtailed design does require enough space alongside the shipping lane to accommodate the bridge when opened. This means a swing bridge, logically, requires a larger floor area than a bridge that moves its deck vertically.

As this type of bridge requires no lifting, it should inherently be an efficient way of moving a bridge part. There are however several complications. As the bridge deck should hang free before it can be moved, it requires lifts on the abutments that latch and unlatch it from its locked position. It also requires a centring device to help it find its locked position when closing. These extra operations cause it to have a longer operation time than other bridge types, as well as increase the mechanical complexity and inherently its chance of technical failure.

Figure 7.23: Samuel Becket Bridge in Dublin, opened 2009. A hobsided cable-stayed swingbridge. (Ilovedublin)

Alternatives

There are many more types of movable bridges. Some of these were commonplace for a time but fell out of use when more efficient or reliable methods became available. Others are unique and constructed as an experiment or design statement. For most of these uncommon types there are clear reasons why they are not applied more often, as they are prone to problems with reliability, operation speed and/or limited functionality.

It is therefore not impossible to apply a new or uncommon type of movable bridge, but in a complex case with many requirements and limiting factors, it is extremely important to ensure that the chosen bridge type is well engineered and operates at least as well as more common bridge types.

One definite advantage of applying a unique or new type of movable bridge is that it grants the bridge a unique visual appeal. An 'interesting' way of opening a bride can be just as effective in creating a landmark bridge as a very elaborate superstructure, as people will want to see the bridge operate.

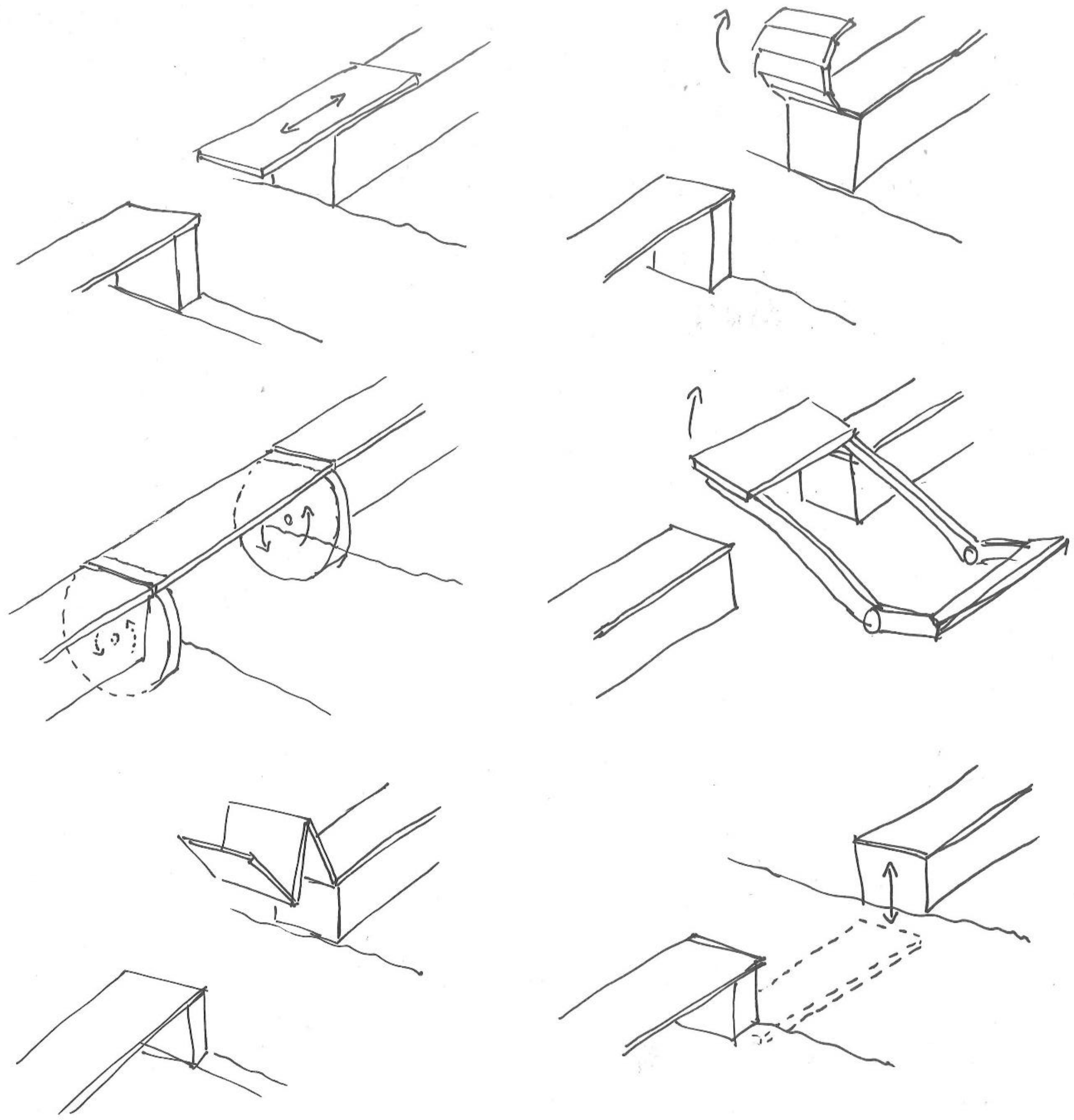


Figure 7.24: Several different ways of opening a bridge, some existing, some personal designs

Bridge aesthetics

Although the motivation for construction a bridge is always functional, its aesthetics are often considered to be one of its most important features. Many bridges, large and small, have become landmarks of their respective city or country. The drive to build bridges as more than a functional object has existed for centuries. (Ryall, Parke, Hewson & Harding, 2000) Part of this drive originated from the fact that the ability to build bridges was in itself an achievement. Bridges became a showcase of technological and scientific prowess, as well as economic power. Even though in the modern-day bridges have become commonplace, constructing a bridge that is particularly beautiful can be seen as a sign of advancement and prosperity.

What makes bridges especially suitable as landmarks is the fact that they are almost always prominently visible. As they are typically constructed over large bodies of water or above roads or valleys, they are always a prominent feature with a clear line of sight.

Aesthetic qualities

The visual design of bridges differs from other constructions as it is mostly based on its structural design. In most buildings the structural design can be hidden by a shell, but most bridges showcase its constructive parts. This means that the visual design of most bridges can be described as a composition of lines and basic shapes. The way these elements interact with each other can be separated into 8 main qualities that make up the composition of the bridge. (Minnesota Department of Transportation, Office of Bridges and Structures, 1995) A good design should ensure that all these qualities are carefully attended to and work together as a whole.

1. Proportion: The relative sizes of elements define the relationship between structural parts, as well as implying the order of significance. Large parts are expected to carry large loads while smaller parts are expected to carry smaller loads.

2. Scale: Scale deals with the proportion between the total structure and its surroundings as well as its users. Larger objects can be experienced as monumental, but they may lose their connection to surrounding buildings. For a pedestrian and cycling bridge it is especially important to keep a connection with the human scale.

3. Order: A design is orderly when the arrangement of all elements works as a single unit. Order can be achieved by limiting the number of lines, directions and variations in proportions in the design. The orderly application of multiple similar elements can create rhythm.

4. Rhythm: The frequency and relation between repeating elements in a design. A good coordination of major rhythms (structural columns) and minor rhythms (cables, details) can create movement and direction. A rhythm is not necessarily linear. An example of this is a steadily increasing span size of bridge parts towards a main span.

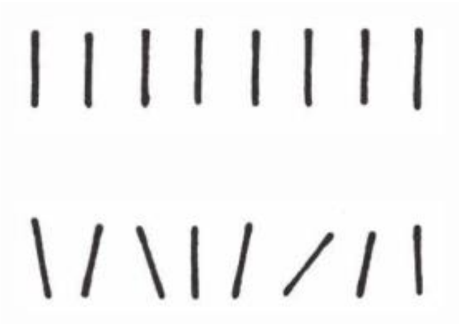


Figure 7.25: Order and disorder

5. Balance: A perceived equilibrium in visual elements. This does not have to coincide with symmetry or even a structural equilibrium. Visual balance can be influenced by volume, visual mass, texture and the visual focal point of the design.

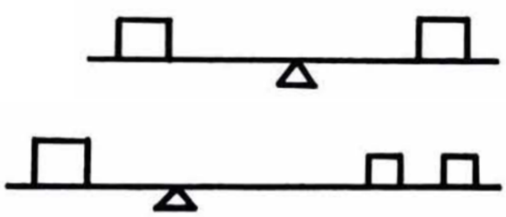


Figure 7.26: Examples of symmetrical and asymmetrical visually balanced compositions

6. Harmony: The relation between similar elements within a structure. Elements are most likely to be perceived as harmonious when they have more similar than dissimilar characteristics. These characteristics can include shape, size, direction or colour, amongst others.

7. Contrast: Superficially, contrast is the opposite of harmony. However, contrast is not the absence of harmonious similarities, but the presence of complementary characteristics. In practise contrast and harmony can strengthen each other.

8. Unity: Unity represents a perfect integration of the other 7 qualities, creating a single, complete design.

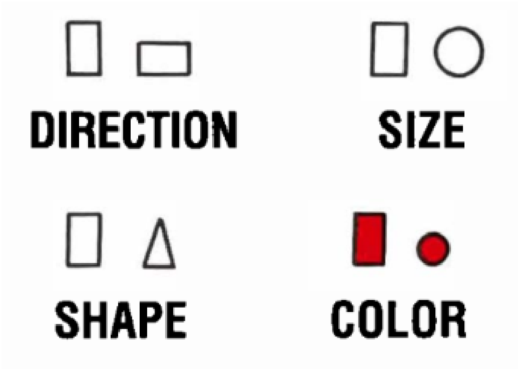


Figure 7.27: Characteristics that can cause harmony or contrast (Minnesota Dept. of Transportation)

Analysing beauty

One step further from good design is beauty. The perception of beauty and is highly subjective and dependent on personal preference. However there do seem to be certain rules and guidelines that lead to compositions that are pleasurable to the human senses. Interestingly, these rules apply across multiple human senses and disciplines, including art, music, graphic design and architecture, and they can be recognized in nature too. Many of these relations can be explained through mathematical analysis.

Although they have been used as such in history, these mathematical theories should not be as strict laws that form the base of a design process. However, when during the design process a proportion or ratio needs to be defined, these theories form a good base to start looking for what results in the most beautiful design.

One recognizable effect that can be noted is the perceived beauty of rational proportions. This has been known at least since ancient Greek times, when philosophers and mathematicians tried to describe beauty as a function of mathematics and geometry. (Williams & Ostwald, 2015) They noted that shapes with ratios of whole numbers had a pleasing look, so buildings would be designed such that the height to width ratio of elevations and floor plans were all rational fractions. Greek philosophers were also the first to notice that these fractions were the basis of appealing musical notes (Chen & Duan, 2014), as can be seen in figure 7.28. These diatonic scales are still the most commonly used in music today. It appears that the perceived beauty of these small fractions is built into the human brain and can be the base of harmony in both music and design.

String Length	*Frequency*	*Note*
1:2	2:1	Octave
2:3	3:2	Perfect Fifth
3:4	4:3	Perfect Fourth
4:5	5:4	Major Third
5:6	6:5	Minor Third

Figure 7.28: The relation between small rational fractions and notes in diatonic scales

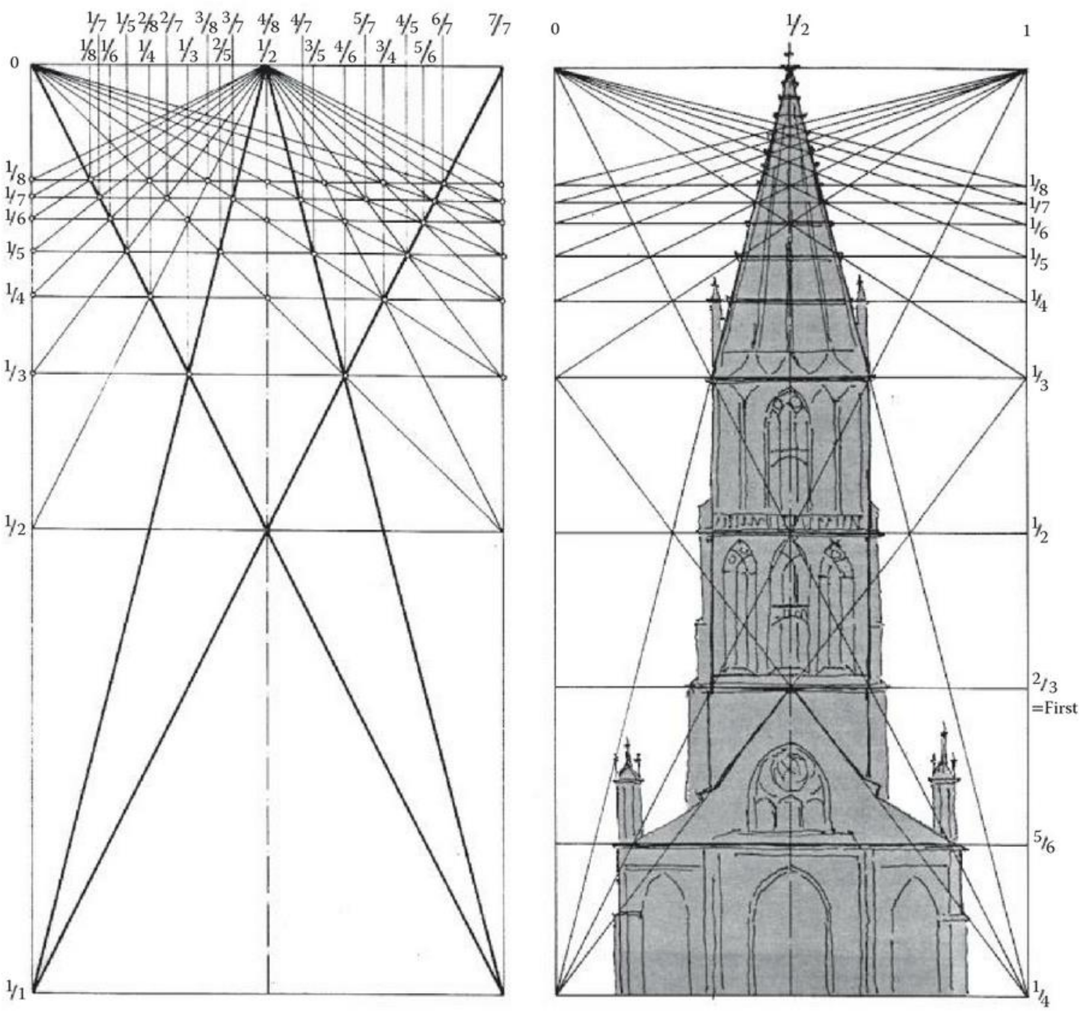


Figure 7.29: A Villard diagram showing architectural design based on rational fractions (Chen & Duan, 2014)

Another well-known mathematical concept that for centuries has been considered a base for beauty is the golden ratio. This is an irrational number that is defined as the number where $\frac{1}{\varphi} = \varphi - 1$, which results in it being around 1,618. This number has some unique properties, which has caused it to be considered important in mathematics, geometry and architecture. There are also many examples of the golden ratio being used in nature, which underlines its status as an important geometrical constant rather than a curiosity. The number can be used to define width to height ratios of shapes, create curves (figure 7.30) or built up compositions. Compositions based on this ratio are considered to be natural and well-balanced. Part of this balance is caused by the fact that if two shapes are proportioned according to the golden ratio, the ratio between the larger and smaller shape is the same as that of the larger shape and the whole composition.

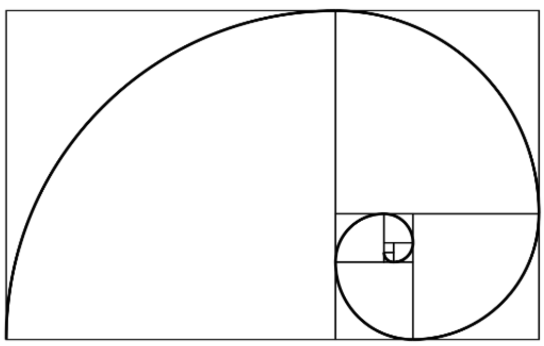


Figure 7.30: A shape made up of squares whose proportions increase by the golden ratio

Classical and modern

Although beauty can be analysed and described in general principles, it cannot be viewed as a constant. The appreciation of designs will also be influenced by cultural history and background. Certain bridge types have been used in a given form for centuries. The shape and composition as remained very constant as they were developed to be the most efficient structure for the materials and construction types used. As these bridges have existed in the same form for a long time, these bridges have become embedded in their cultures view of bridge design. This created a form of archetypes of that type of bridge in the perception of the public.

Modern technology allows us to deviate from these generic structural principles and create more varied shapes. This variation from the classical shapes can now be used as the definition of modern design: The more closely a design resembles its historic archetype, the more classical it looks. The more it deviates from its archetype the more modern it looks.

Figure 7.31 shows two steel truss pedestrian bridges that both started construction in 2010. They both have about the same dimensions and they both use the same structural principles. However, as the bridge on the left resembles a traditional steel truss bridge much more closely, it appears more classical while the bridge on the right appears more modern.

Figure 7.31: Wolf river pedestrian bridge, Memphis, USA, 2010 (left); Peace Bridge, Calgary, Canada, 2012 (right) (Pinterest)

Another example of an archetype is the steel arch bridge. After becoming a popular construction method during the industrial revolution, these bridges have been constructed for decades in roughly the same manner: A thick steel truss arch that is connected to the bridge deck using steel rods. When comparing a classic steel arch bridge to two contemporary equivalents, the effect of the archetype becomes noticeable (figure 7.32). Both contemporary bridges use much sleeker, angled arches without truss constructions and diagonal cables instead of rods. However, 'de Oversteek' will still be considered more modern by most people as it deviates more strongly from its archetype.

Figure 7.32: Waalbrug, Nijmegen, 1936 (top); Lake Champlain bridge, Crown Point, USA, 1994 (bottom left); 'De Oversteek', Nijmegen, 2013 (bottom right) (Wikipedia)

Viewing angles

An important aspect of this skyline image is the direction from which the bridge will be seen (figure 7.33). Whereas some bridges will almost always be viewed from a single angle, the Java Bridge will be surrounded by buildings and quays from all sides. These different sides do however have a differing correlation to be bridge.

The municipality refers to these different viewpoints as 'scales' of the bridge design, which refers to the distance from which the bridge will be view from different angles. From close-up to a progressively larger scale the different viewpoints can be placed in three different categories: Users of the bridge, neighbouring buildings and a far-off view perpendicular to the bridge.

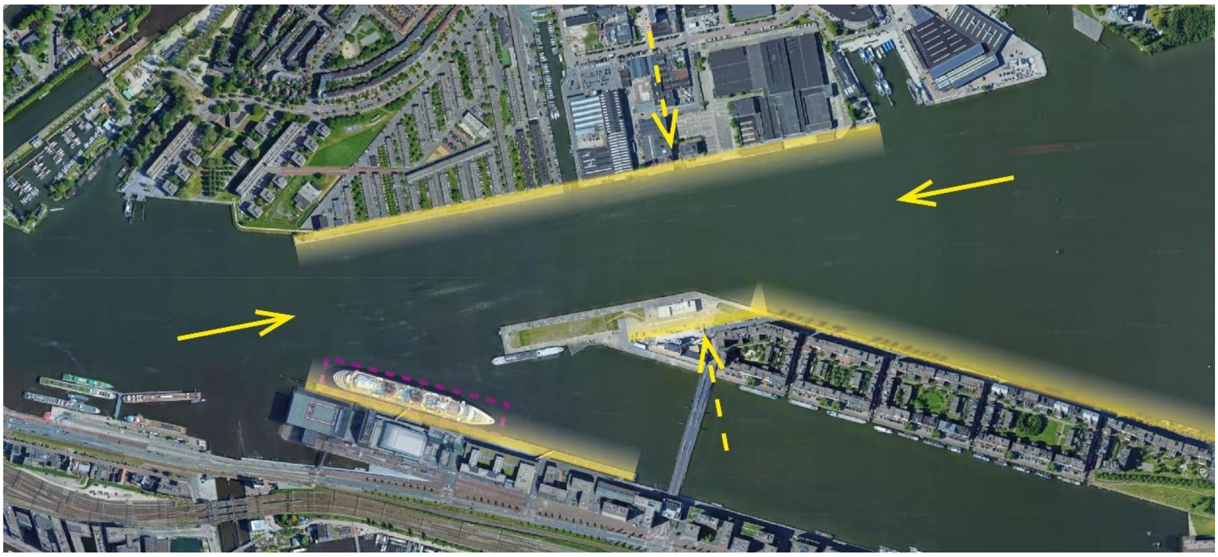


Figure 7.33: Viewing points of the Java Bridge (edited from Google Maps)

For the users of the bridge deck, who will look directly along the direction of the bridge deck, the bridge should be an inviting and pleasant image. It should not feel closed or confined, as this can quickly become an unsafe feeling. Openness of the sides of the bridge deck is desired, as the bridge will not only be seen from the city, but the city should also be seen from the bridge.

For the (mostly) residential areas directly surrounding the location, the bridge will be a permanent feature from their windows and balconies. Most of these houses will look up to the bridge, which can quickly lead to the structure being imposing. The bridge should not be designed to be too imposing or dominant from these angles as it could impact the living comfort of residents.

As part of the city skyline, for tourists for example, it will be best visible from the Central Station quay, which looks directly perpendicular on the bridge. Ships entering Amsterdam from the east, for which the bridge will act as a gate to the city, will also see it from a perpendicular angle. Therefore, bridge design should aim to look most imposing or monumental from these angles.

City footbridges

There has been an increase in the construction of cycling- or footbridges in cities over the past decades. This can be attributed to the increasing resistance to cars in city centre and increased focus on safe and pleasant pedestrian zones. This influx in city centre pedestrian bridges has lifted this type of bridge into its own category, and certain design conventions can now be recognised.

Most of these footbridges are designed as sleek and slender as possible. This is possible due to the relatively small loads of footpaths. The use of thin superstructures that suspend the bridge from cables rather than rods supports this slenderness until the bridges almost seem transparent. It is also no coincidence that many of these bridges are coloured white, which accentuates the sleek, clean design.

Figure 7.34: Infinity Bridge, Stockton-On-Tees, UK (A as architecture)

While this transparency often helps to preserve the local view across the river, it must not be mistaken as an attempt to reduce the visual impact of the bridge. Many of these bridges feature a prominent superstructure that makes it stand out in its surroundings. Instead the sleek design is applied to showcase the composition and design of the bridge, rather than its components. Lines and shapes appear sharper and cleaner than those of bridges with large, solid components.

Figure 7.35: Limerick City Footbridge (proposed), Limerick, Ireland (Brownlie Ernst and Marks)

Figure 7.36: MediaCity Footbridge, Manchester, UK (ArchDaily)

Most of these designs are clearly based on a classic structural bridge type: Arches, Suspensions, cable-stayed bridges etc. These constructions are used to efficiently create suitably large spans with minimal required material or construction. However, they do all deviate quite strongly from the classic forms of these construction types, which is what gives them their modern image. However varied though, these designs all retain visual simplicity. Regardless of the engineering solutions required to construct them, all these bridges could be recognisably drawn with a few lines. This recognisability enhances their value as city icons and postcard pictures.

As these a lot of these footbridges are cable suspended designs, order and rhythm play an important part in the appearance of the bridge. The layout of the cables is an important part of the overall composition. Proportion and scale are often determined based on structural demands. However, harmony, balance and contrast appear to be the main play tools of the designers, and these are the qualities that are used to deviate from classic designs.

One more important observation is the fact that the most dominant part of the structure is never located on the river banks but always on a pier in the water. This means that the bridge construction is often lower at the banks. This can be attributed to the fact that these bridges are generally constructed in high-density built-up areas. Large features close to existing buildings could conflict with their surroundings, disturbing the harmony between the bridge and its environment.

Figure 7.37: Peace Bridge, Londonderry, UK (WilkinsonEyre)

Conclusions regarding the Java Bridge

Main span construction

The location and layout of the Java Bridge presents some requirements for the construction methods. The main span is 160m wide and requires a clearance under it of 10,35m. One of the requirements is that this is a clean span with no columns in the shipping route, and is should measure the required 10,35m height for its entire length.

Directly north of the main span is one of the movable parts, measuring 40m. This requires a clearance of unlimited height. Between the movable part and the main span is an area of 12m wide that can be used for constructions. South of the main span is a strip of land 42m wide, that separates the main shipping channel from the new Jakarta Canal, which is 20m wide.

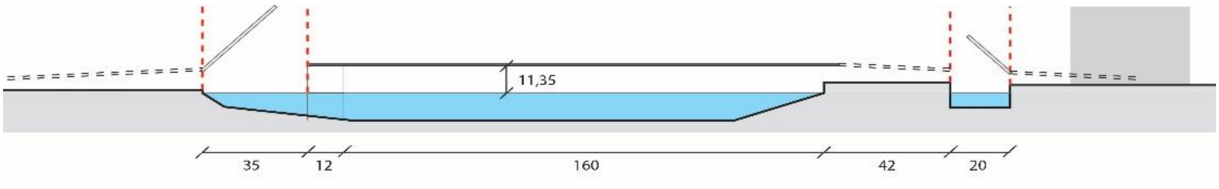


Figure 7.38: Profile of the proposed Java Bridge layout

Based on these requirements we can state that a successful design should clear the areas shown in figure 7.39. There is ample room for structural elements in the areas shown in figure 7.40.

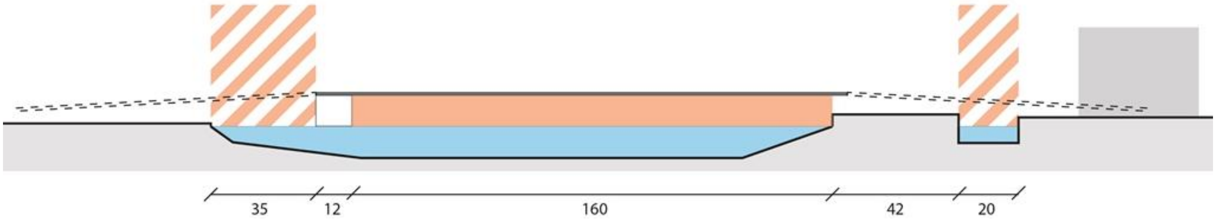


Figure 7.39: Areas that should remain clear of constructive elements

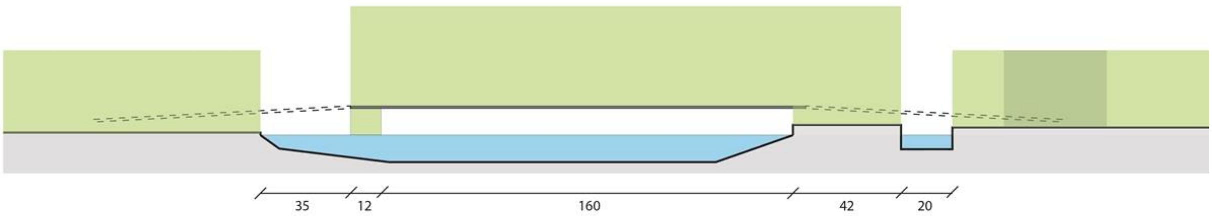


Figure 7.40: Areas that can be used for constructive elements

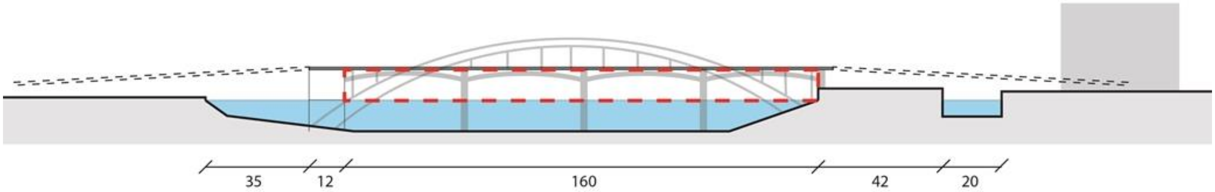


Figure 7.41: Construction methods with substructures conflict with the clear area under the main span

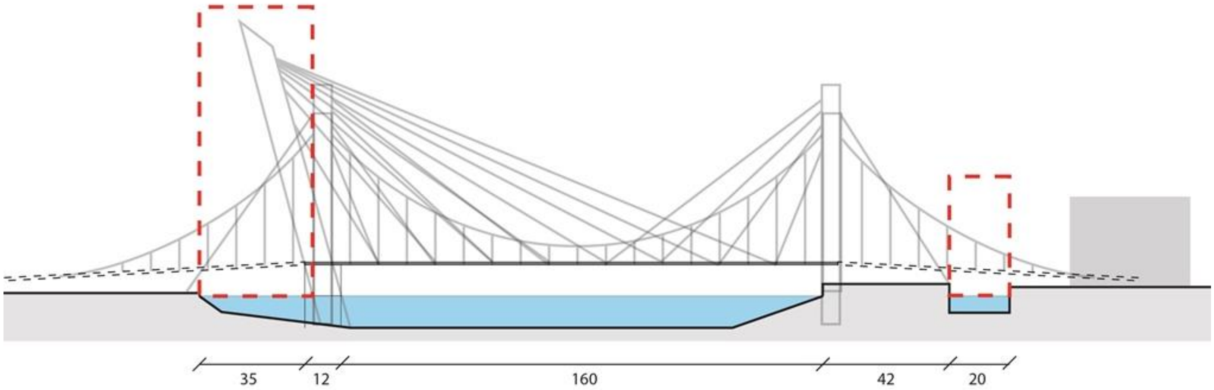


Figure 7.42: Construction methods with horizontally supported superstructures conflict with the unlimited height of the movable parts.

If we try to match these criteria to the analysis of bridge types, we can draw a few conclusions. Any bridge type that requires any form of substructure, such as small span beam bridges or archways below the bridge deck, fails to clear the required shipping lanes below the main span (Figure 7.41). Room for this substructure can be made by raising the top of the bridge deck, but this would conflict with the functional requirements for cyclists and pedestrians.

A more likely solution is to create a superstructure above the bridge deck. This is also a likely solution for the requirement of the bridge being an eye catcher. However certain types of superstructures, such as suspensions and cable-stayed pylons, require elements to either side of the span to transfer horizontal forces. In the case of the Java Bridge, this would conflict with the unlimited height required above the movable parts (Figure 7.42). Not all configurations of cable-stayed bridges are incompatible, as the strip of land in front of the Jakarta Canal could be utilized, most likely for an asymmetrical design.

In conclusion, the design for the Java Bridge should look to utilize a superstructure that does not require any horizontal elements past the movable parts of the bridge. Likely solutions include a standing arch, truss or asymmetrical cable-stayed bridge, amongst others. (Figure 7.43)

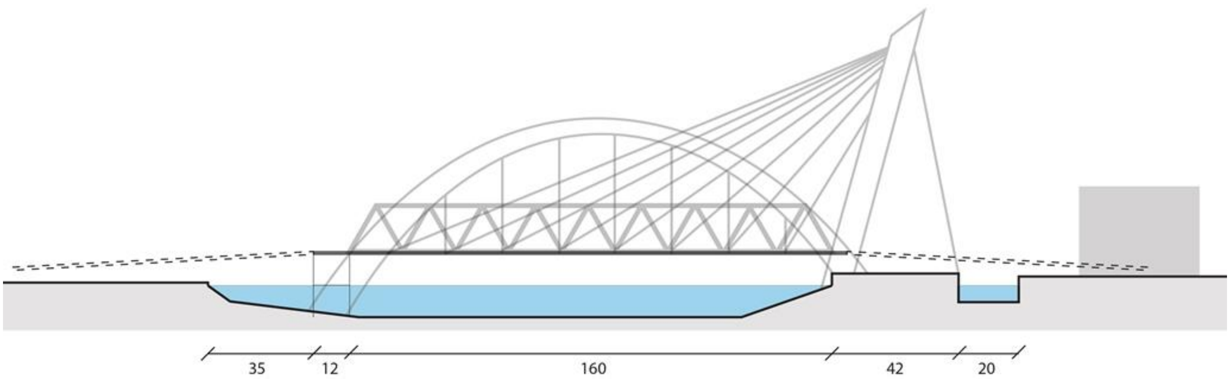


Figure 7.43: A selection of suitable construction types

Movable bridge parts

Of the two movable spans, the north span appears to be more restricted, as it has a larger, 40m span and less space around it, especially on the side of the main span. There is a space of 12m reserved for bridge construction between the main span and the movable part but depending on the construction type for the main span this may or may not be enough room for all movable bridge types. On the banks there is an unknown amount of space available as this area is still to be developed. The bridges on Java Island have a shorter span and more available space, especially on the north side.

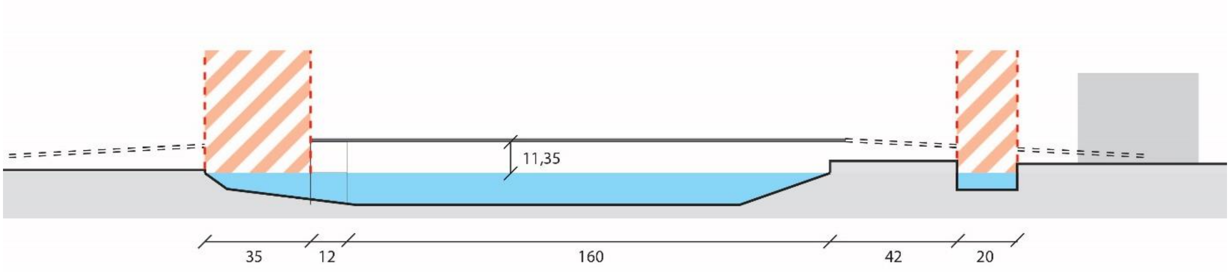


Figure 7.44: Profile of the proposed Java Bridge layout with movable parts highlighted

Both bridges have a requirement of unlimited height for ships when opened. Based on this we can eliminate a vertical lift bridge. A centre-balanced swing bridge with a pier in the middle of the shipping lane is also unsuitable as this space is not available. (Figure 7.45) A bobtailed swing bridge on the north side of each span would be possible. However, the longer operation time of a swing bridge when compared to a bascule bridge makes it unsuitable for this location with high intensity traffic on both the road and the water.
An additional disadvantage to a bobtailed swing bridge is the space it would take up on the north bank. Although this space is technically available, claiming of this soon-to-be high density prime real estate space should be avoided.

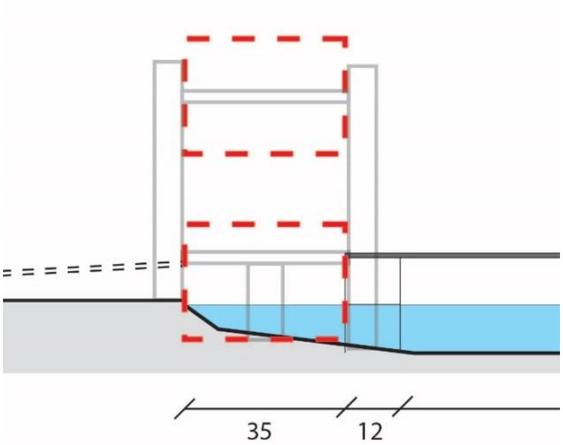


Figure 7.45: Conflicting movable bridge types

In conclusion, of the three commonly used bridge types only the bascule bridge appears to be suitable for the north span. The bridges across the Jakarta Canal however are lower above the water and have more empty space available. Combined with the fact that the two-bridge layout reduces the necessity of a speedy operation, this makes bob-tailed swing bridges a viable alternative, although bascule bridges are still preferred.

One of the disadvantages to a bascule bridge however is its great height when opened. As the spans are 20m and 40m respectively, this would result in a rather imposing image when raised to a vertical position, blocking out the view over the water and likely overshadowing nearby buildings. This vertical size could be reduced by using a double bascule, but that has several technical disadvantages.

As all the common bridge types have disadvantages, it is possible that the best solution is a more uncommon way of opening the bridge. This will have to be explored as part of the design process. However, in this complex case it is important that a quick and reliable operation is ensured. Further criteria on which possible opening mechanisms should be evaluated are minimal required space, efficient opening and forming a fitting part of the whole design.

One opportunity for innovation is that although the north span is 40m wide, for most of the time it is only used by pleasure craft with a required width of 20m. A type of bridge opening that could open partly for most traffic, with an optional further opening for exceptional traffic, would be beneficent if that could reduce the operation time.

9. Design guidelines

1. Modern
- Light construction
- Transparent design

2. Eye-catching
- Design based on prominent superstructure
- Recognizable

3. Work on all scales
- Iconic from far off
- Elegant from close by
- Inviting for users

4. Movable part integrated in design
- There should be coherence between the main structure and the movable parts
- The type of movable bridge should be selected in unison with the overall design

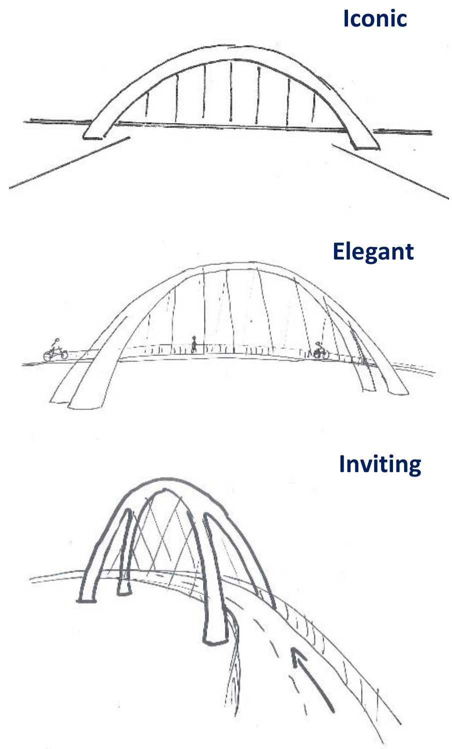


Figure 9.1: Qualities on different scales

5. Separated through- and local traffic
- Split functions between cycling and pedestrian bridge parts
- Each part should be optimized for its specific function:
    - Pedestrian bridge should offer good connections to areas directly adjacent to bridge
    - Cycling bridge should act as a highway on a larger scale, cutting through the area

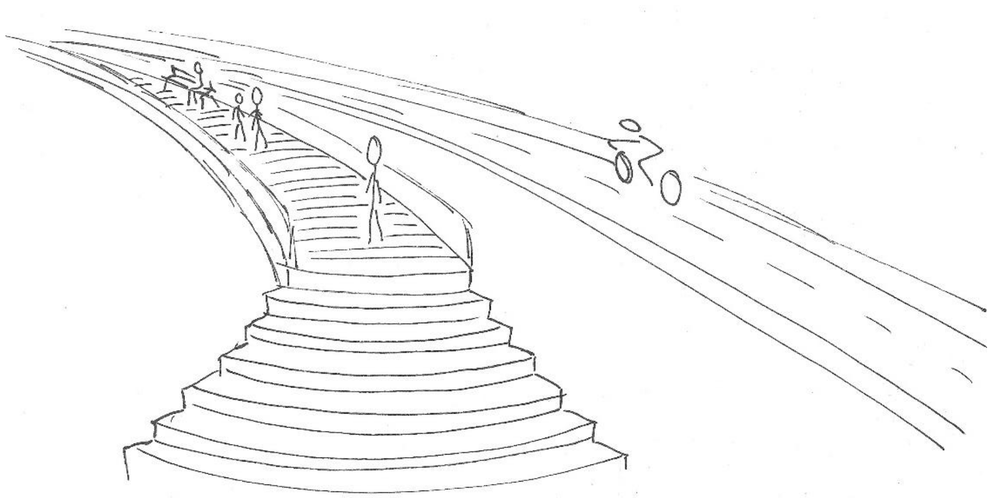


Figure 9.2: Separated bridge decks optimized for separate functions

10. Sketch designs

Workflow

Based on the design guidelines, a large number of sketch designs were made and tested for suitability. 3D modelling software proved useful from a rather earlier stage than envisioned in the methodology, as it gave more accurate insight into dimensions and special properties of each design.

These sketch models combined with hand drawn sketches formed a pool from which options could be selected. Eventually four candidates were selected and developed into more detail. This included rough dimensioning, combining the superstructures with the envisioned curved deck layout and optimizing the structures with techniques like form-finding.

From these four designs a single variant would be chosen as basis of the definitive design.

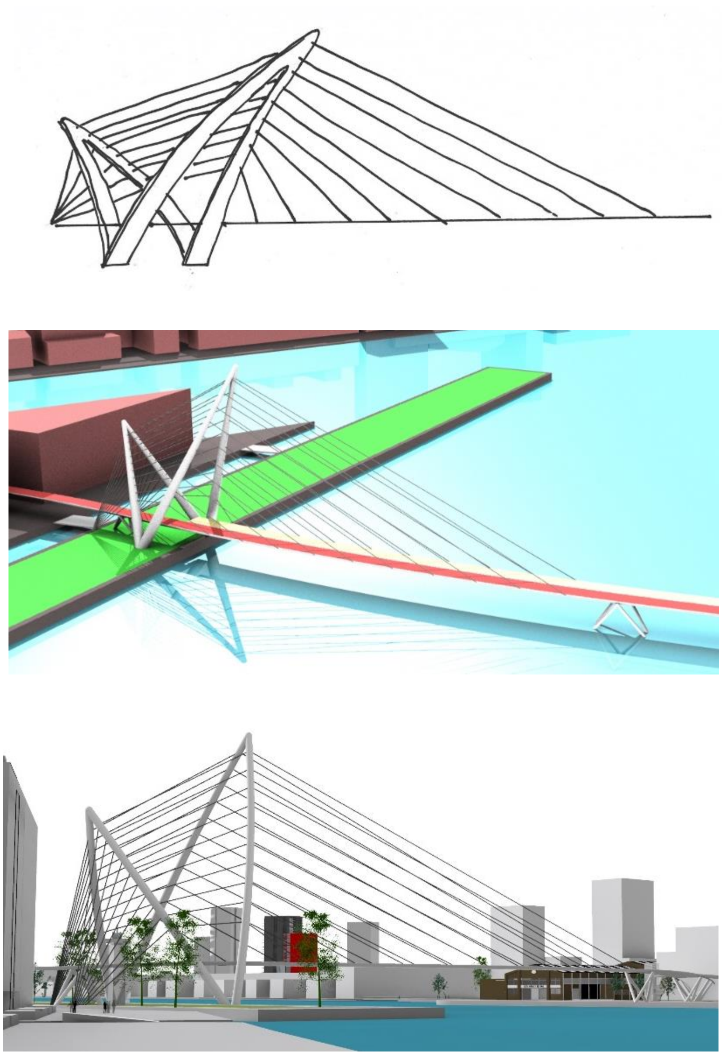


Figure 10.1: Example of development from sketch to sketch model to developed model

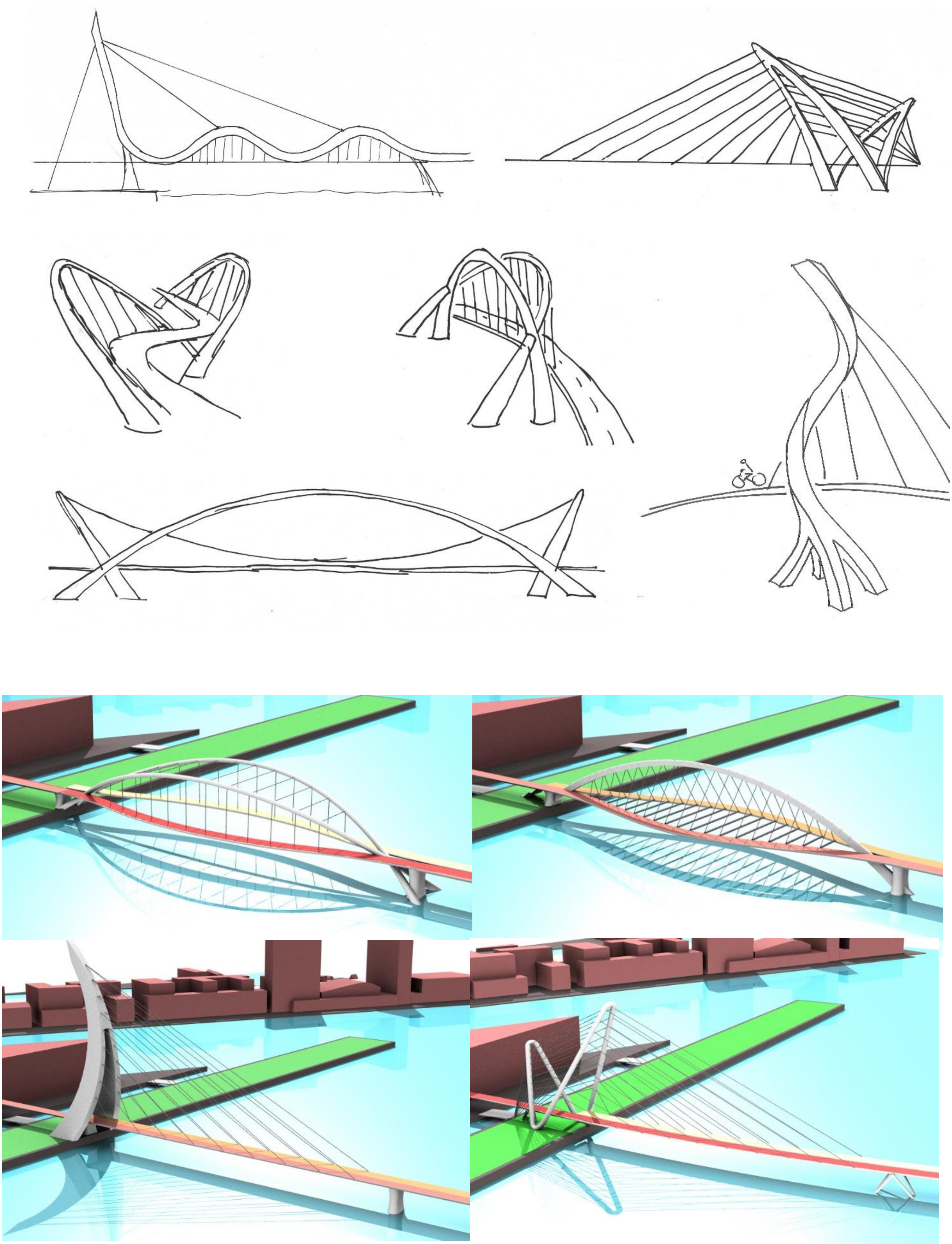


Figure 10.2: Selection of sketches (top) and sketch models (bottom)

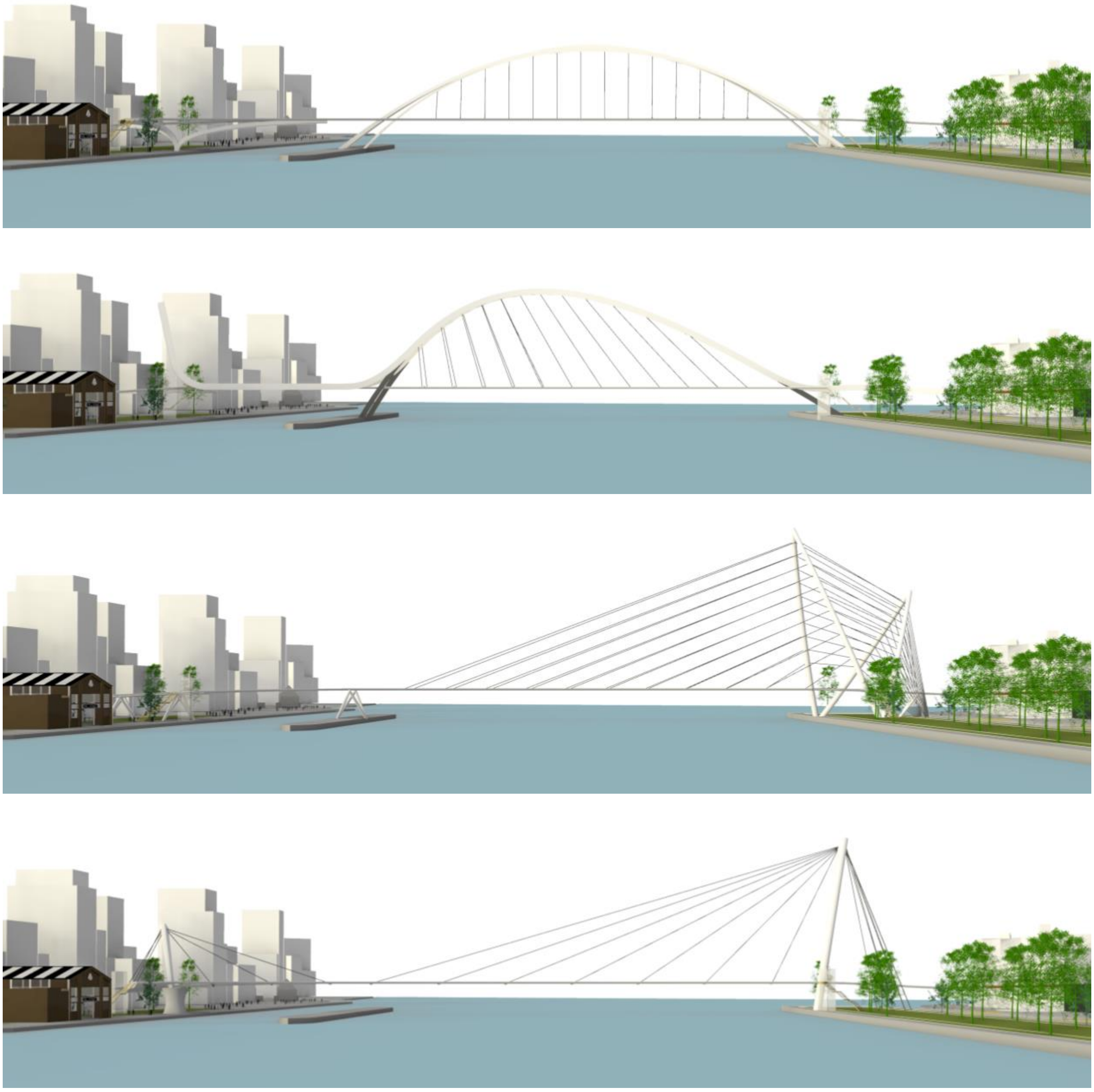


Figure 10.3: The four designs that were developed from the sketch phase

11. Design study

Of the four developed designs, the cable stayed design with a single pylon seemed to have the most potential. The arch bridges appeared a bit static and had to terminate in the middle of the river to accommodate the movable part, which made them look slightly off-balance. The chosen variant had a slightly more elegant simplicity and the cable stayed movable bridge on the opposite bank gave the bridge a nice balance of the IJ.

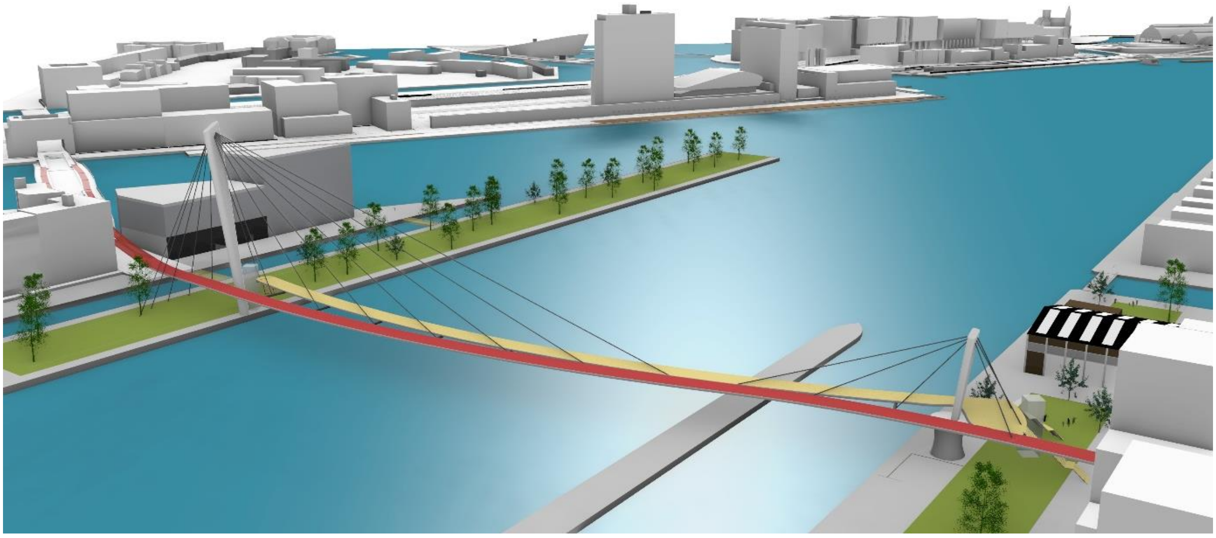


Figure 11.1: Birds-eye view of the preferred variant

The base design includes a single pylon, slightly slanted backwards, from which the main span is supported by cables. The movable bridge parts are designed as swing bridges. The largest of which, on the Hamerkwartier bank, is also designed as a cable stayed bridge, which mirrors the large pylon on the opposite bank.

This is still a very basic design, but it will serve as a basis for further design study. The next step is to redesign the basic model in more detail. This is a complex process where many different aspects must work together om many different levels. However, for sake of clarity these next steps are structured here as if the bridge is designed element by element from the ground up.

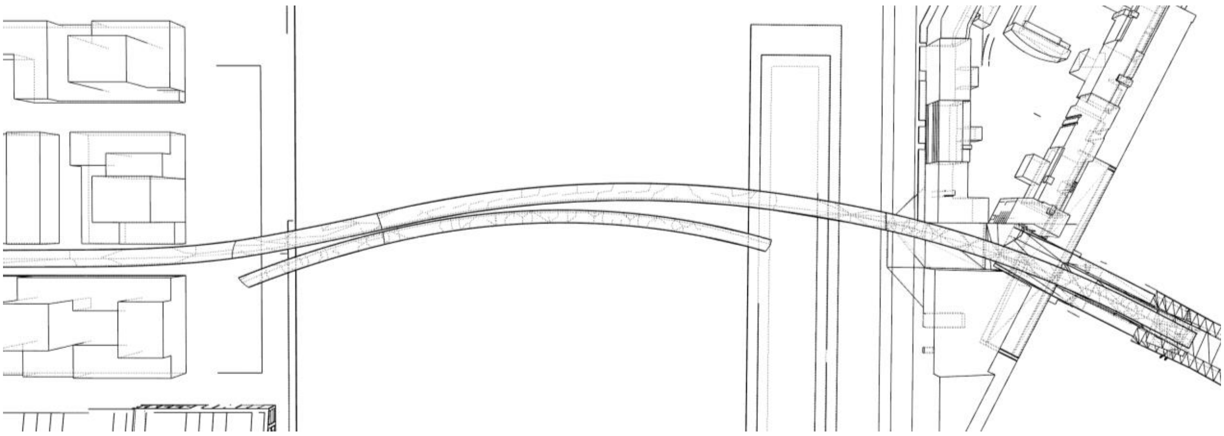


Figure 11.2: Ground plan showing overall bridge deck layout

Bridge deck

Designing the bridge deck will play an important part in the overall design, as it directly resembles the connections the bridge creates between the banks.

The separated optimization of local and through traffic is an important part of the design requirements, and this literal split is already created in the general layout. However, it is important that these parts are still working together to create one bridge, rather than two separate structures. To illustrate this, the bridge decks are designs asymmetrically, angled towards each other. (Figure 11.3) This shape also gives the bridge a sleek appearance by reducing the area of the bridge deck as seen from the side.

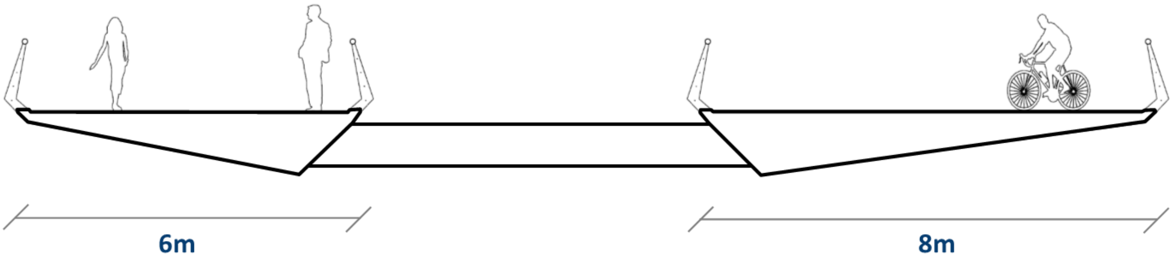


Figure 11.3: Basic shape of bridge deck cross sections.

As the bridge decks will be supported by cables that connect to beams between the decks, this deck shape also has some mechanical advantages. As the beams are supported in the middle, the bridge decks will act as cantilevers that introduce a moment in the beam. This moment will be strongest in the centre, where deck is thicker, and weakest on the bridge's outside edges where the deck is sleekest. (Figure 11.4)

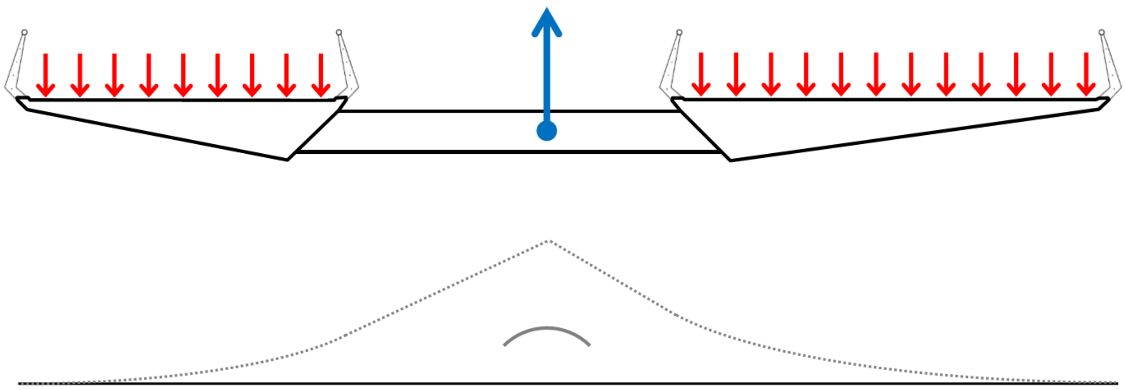


Figure 11.4: Moment line as a result of bridge deck loading

When moving away from the main span of the bridge, the pedestrian bridge stops, and the angled shape has no further advantage or significance for the cycling bridge. The shape of the bridge deck will therefore morph along the flowing lines of the deck, into a more symmetrical section.

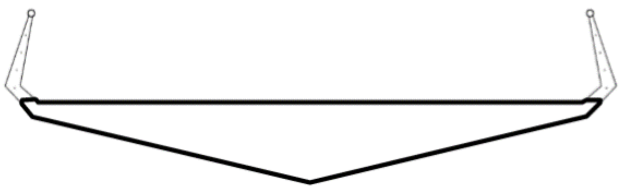


Figure 11.5: Deck section at either end of the cycling bridge

This flowing change along the bridge's length will play an intricate part in the bridge's design. It resembles the two different functions of the bridge that were split apart, but still brings them together over the water. Preserving these lines will be an important theme in all further design stages.

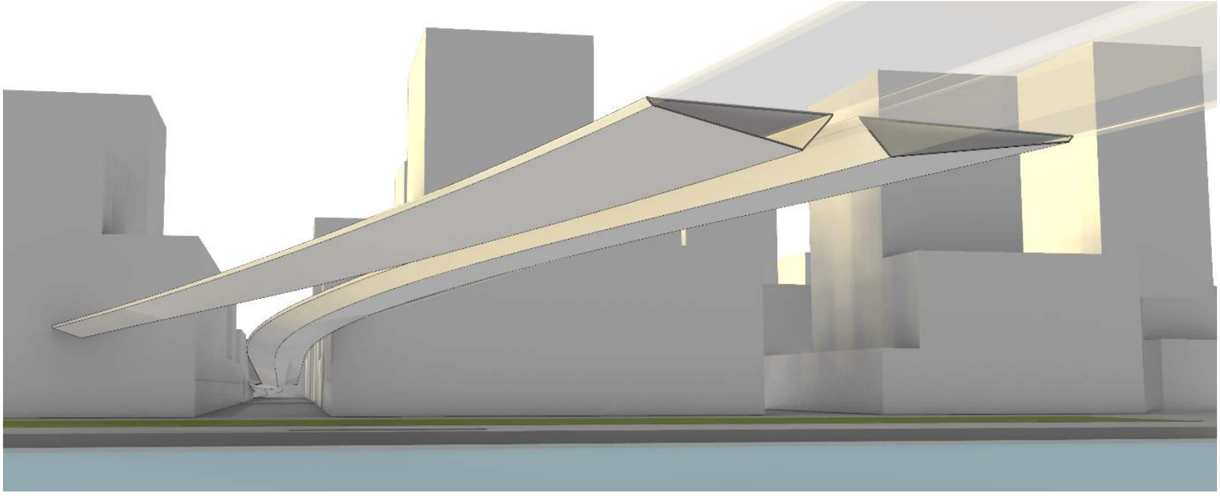


Figure 11.6: Showing the change between the angled section over the water and the symmetrical section at the ends of the cycling bridge

In order to create these shapes, the deck will be constructed as a steel box section. This will consist of a closed outer shell with several vertical flanges. The steel shell will supply the majority of stiffness over long spans and for torsion, but for local loading it is supported by steel ribs on the inside.

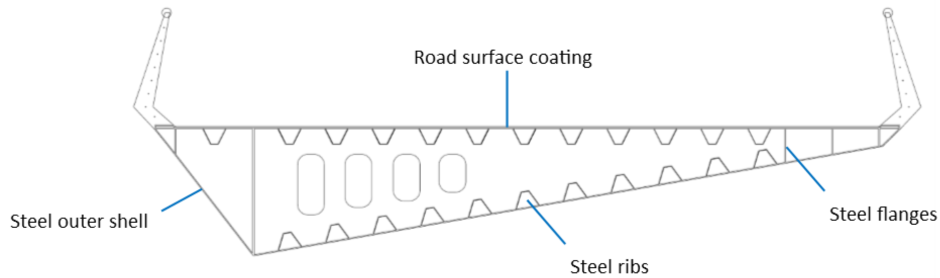


Figure 11.7: Bridge section showing steel construction.

This method creates a very stiff section which allows it to be as sleek as possible. The closed shell means the bottom of the deck will have a pleasing and finished look from the underside without requiring any additional panels. The top also requires no further layers or construction as it is supported by ribs. The only finishing the road deck needs is a coating to provide grip and protect the steel from wear.

Pylon & cable construction

Cable connections

The main span will be supported by a single pylon on Java Island. The original design used only a single set of cables, that attached to the centre of gravity between both bridge decks. This will however cause some problems with balance and torsion. In general, closed box sections as used in this design have a high torsional strength. Therefore, at the points where the two bridge decks are close together, and the centre of rotation is close to the deck sections, they should be able to withstand any rotation due to imbalance.

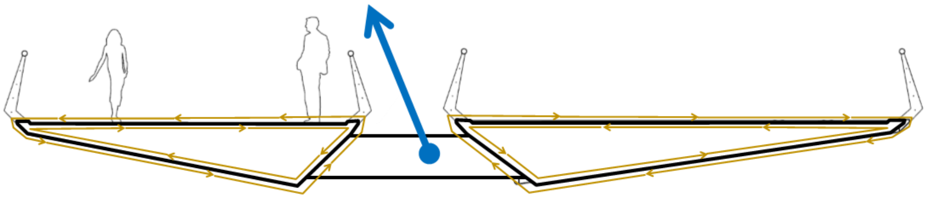


Figure 11.8: Imbalance when the decks are close together introduces torsion in the bridge decks

However, as the decks move further apart near Java Island, imbalances will introduce more vertical bending moments rather than rotation. The decks are designed to withstand the bending moments in the distance between two support cables. However, imbalance could cause the bridge to swivel over a much longer distance, which would require an inconceivably stiff bridge deck to prevent deformation.

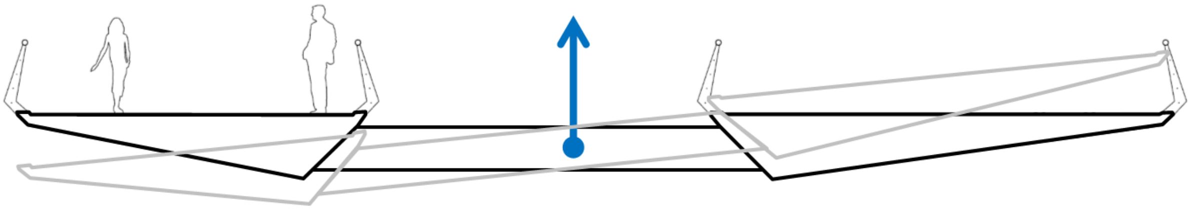


Figure 11.9: Imbalance when the decks are far apart creates large bending moments.

Therefore, each of the two bridge decks will be supported by its own set of cables. For the four points furthest away from Java Islands, these cables would be so close together that it would not provide any benefits, and there is to little space to accommodate them. As these are not required these points will be supported by a single cable.

In a cable-stayed bridge, vertical loads in the bridge deck will be diverted to the foundation through tension in the cables and pressure in the pylon. One important property of this system however is that large horizontal forces will be introduced in the bridge deck due to the angle of the cables. These horizontal forces will also have to be taken care of in some way.

Normally it would be sufficient to simply connect both the bridge deck and the rear cables to the foundation. However, as the main span ends at a movable bridge part at both sides, it stands isolated at an elevation, and the bridge deck isn’t automatically connected to the foundation. This would require a construction connecting the bridge deck to the Java Island foundation that could divert large shear forces across a 10m elevation. This construction would likely have to be more substantial than desirable according to the design guideline of making a transparent design. (figure 11.10)

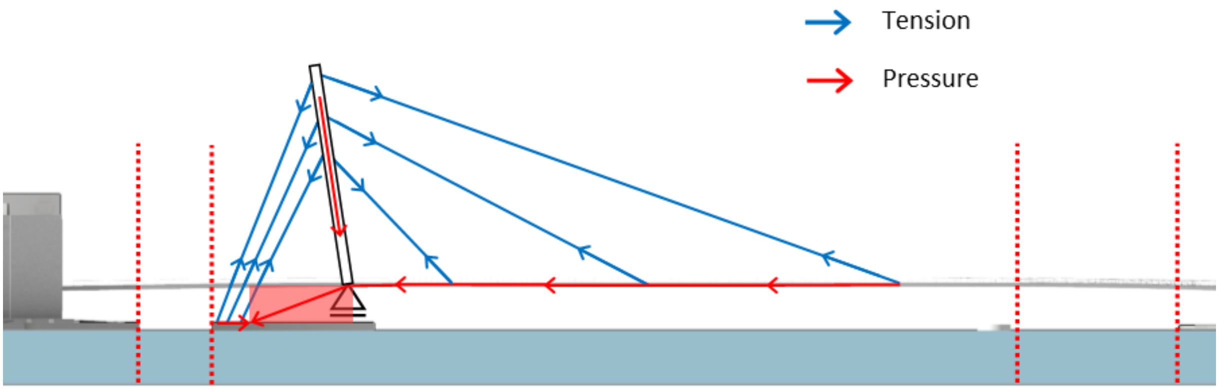


Figure 11.10: Diagram showing the flow of forces through the bridge. The red rectangle resembles the construction required to divert horizontal forces from the deck to the foundation

This can be solved by attaching the rear cables to the bridge deck, rather than the foundation. This means the forces from the main cables and the rear cables cancel each other out. However, as the pylon is also slanted backwards in this case, this will also carry some horizontal forces as introduced by the cables. Therefore, the pylon should also be connected to the bridge deck. (Figure 11.11) As all the loads on the decks are vertical, and all the horizontal forces are merely the result of the angles of the cables and pylons, all horizontal forces connected in this way will, by definition, cancel each other out.

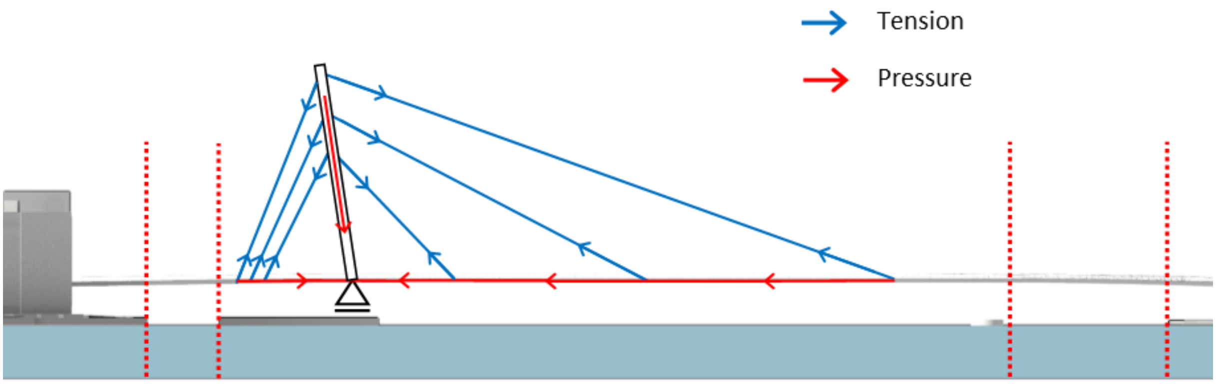


Figure 11.11: Diagram showing the flow of forces through the bridge. As all horizontal forces cancel each other out, no large stability elements are required beneath the bridge.

As this design has two separate bridge decks, horizontal forces from both decks must be combined in order to cancel out. This will be done by introducing diagonal cables or beams between the two decks, allowing shear forces to be exchanged between them. As the footbridge stops relatively close to the waterside, this is unsuitable to connect the rear cables to. The pylon and the rear cables will therefore have to be connected to the cycling path.

Pylon design

This system is complicated by the fact that the design has a curved bridge deck. When both the pylon and all cables are connected to the deck, the cables will turn a corner in the horizontal place when they connect to the pylon. (Figure 11.12) This will create undesirably large bending moments in the pylon.

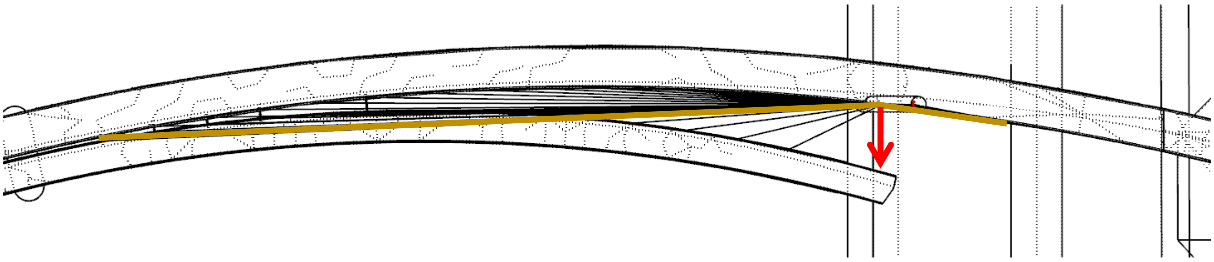


Figure 11.12: Diagram showing the angle the cables make with a straight-up pylon and its resulting force

If the bridge was a single curve, this could be amended by placing the pylon at an angle. However, as the footbridge curves away from the cycling bridge, the centre of gravity is located somewhere between the two bridge decks. As lines connecting from the bridge deck to the pylon will now always have to cross over each other, it is demonstrably impossible to create a straight pylon that will carry these forces without significant bending moments. (Figure 11.13)

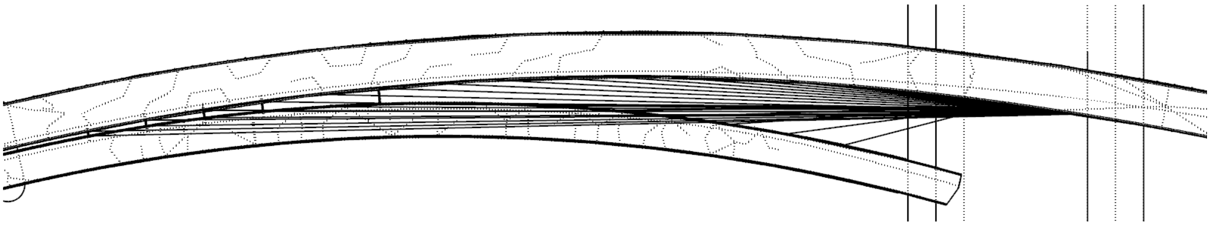


Figure 11.13: Diagram showing straight lines between the connection points on the decks and the connection points behind the pylons. The multitude of crossing lines indicate the induction of bending moments in a straight pylon

While it is inevitable that the pylon will have to deal with some bending moments, they should be kept to a minimum. To achieve this, straight lines can be drawn between the cable connection points on the bridge deck and the connection points at the rear of the pylon. These lines can be mapped in increasing height onto a plane representing the backward slant of the pylon. (Figure 11.14) The pattern that is created in this way represents a configuration in which none of the cables form an angle at the pylon, meaning they only induce vertical forces in the pylon. As these vertices are slightly offset from each other, there will still be some inevitable bending moments, but these are much smaller than those introduced by angled cables.

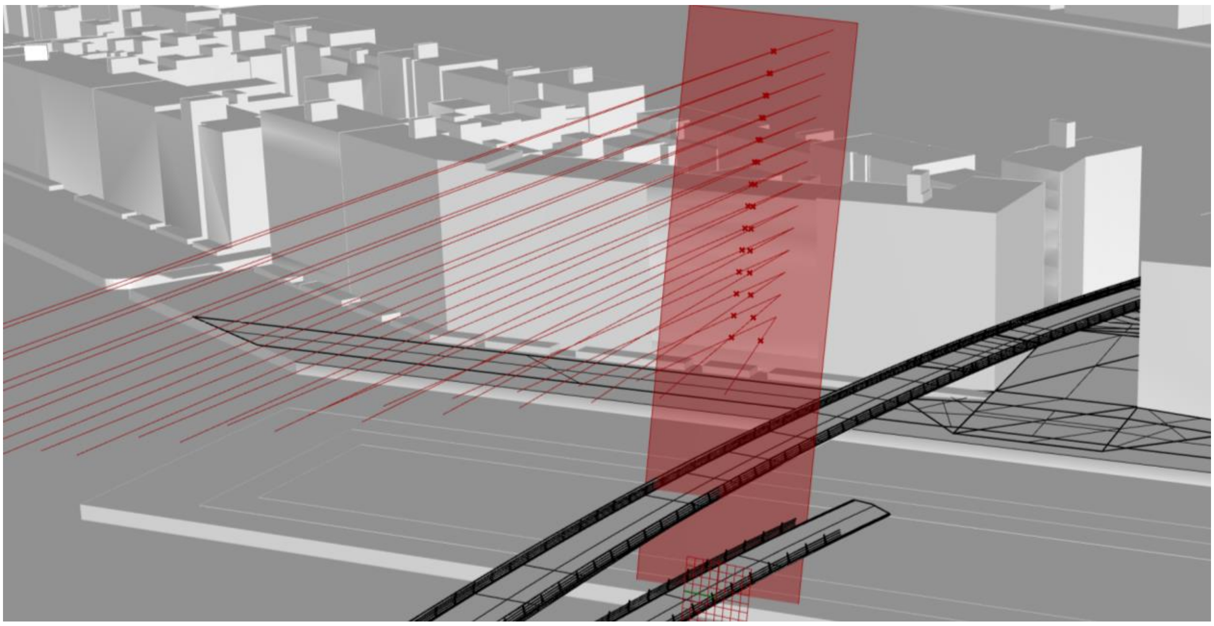


Figure 11.14: Mapping of the ideal cable lines onto a plane, illustrating an efficient shape of the pylon.

The original pattern runs quite wide near the bottom and requires the pylon to cross through the cycling deck. Therefore, the two sets of points have been scales closer to each other. This creates some angles in the cables, but these are always mirrored on the opposite side, which cancels out any lateral forces.

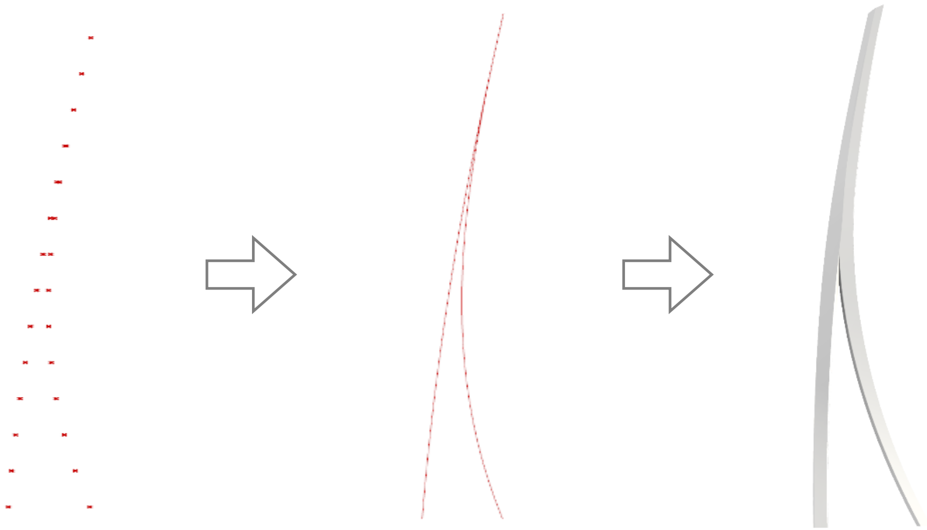


Figure 11.15: Designing a pylon from a set of intersection points

As the points describe two curved lines, the pylon has been designed as two sections merging together. These are kite-shaped steel box sections that merge together to a diamond shaped section. This means the pylon is wider than it is deep, which gives is the rigidity that is required by the offset cable configuration. Its wide base is also useful for this aspect.

The shape of the sections mirrors the shape of the bridge decks, just as the overall curvature of the pylon is a projection of the curvature of the decks. This creates a nice harmony across the design.

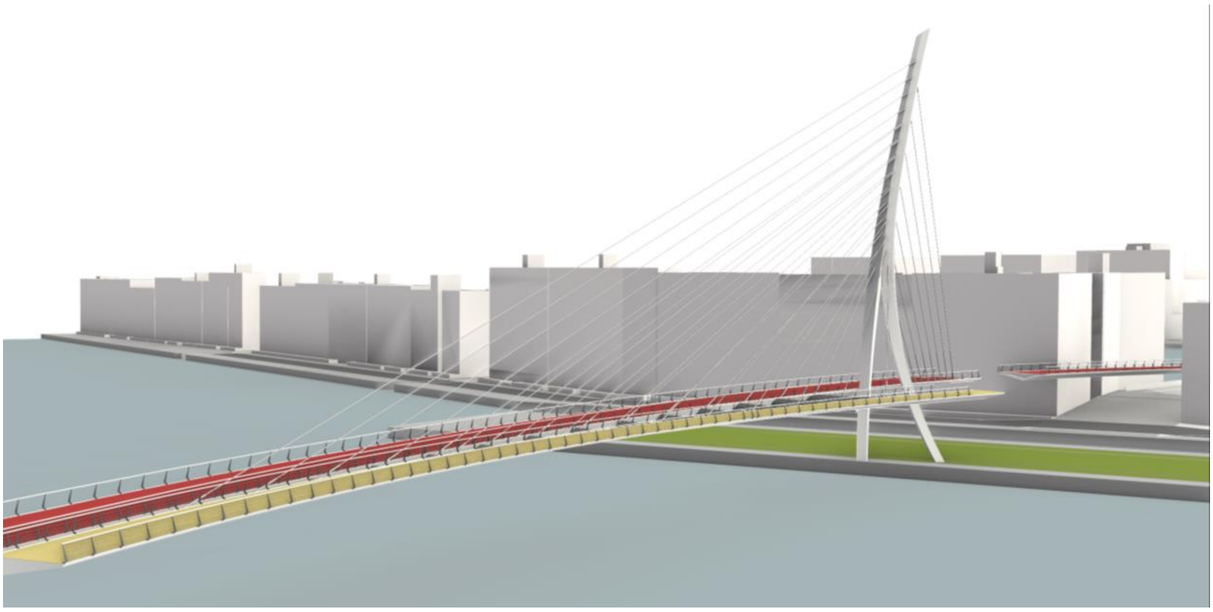


Figure 11.16: Showing the pylon and cable configuration

Beams & cross cables

Both decks are now supported by a set of cables, but they will still need to be connected in order to keep them in position. Beams will be placed between the points at which the main cables connect. They will have to be designed for two main loads: Firstly, they will carry the moment created by the offset between the cable connection points and the centre of gravity of each deck. Secondly, they will experience axial stresses due to the decks trying to warp from their initial curvature as they are being pulled horizontally by the main cables.

The design of the beams mirrors the design of the main pylon. The sections are diamond shaped and bulge out slightly near the ends, where the main cables connect. This helps transferring the large loads directly to the deck sections.

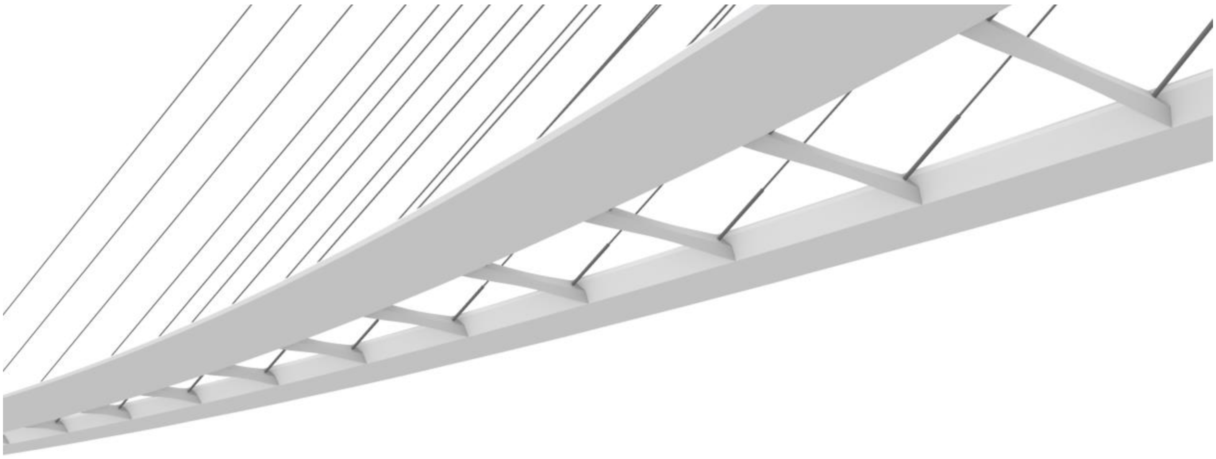


Figure 11.17: Shape and configuration of beams connecting the decks together

As the cables at the rear of the pylon only connect to the cycling bridge deck, all horizontal forces introduced by the cables in the footbridge must be diverted to the opposite deck. As the beams are unsuitable for transferring large shear forces, the decks will have to be connected by diagonal elements.
From each cable that connects to the footbridge deck, a cable will be drawn to the next beam on the cycling deck. (Figure 11.18) These cables should be pretensioned so that all horizontal forces from the main cables are diverted to the opposite deck. The resulting forces in the footbridge should be vertical forces equal to the vertical loading on the deck and axial loads in the beams.

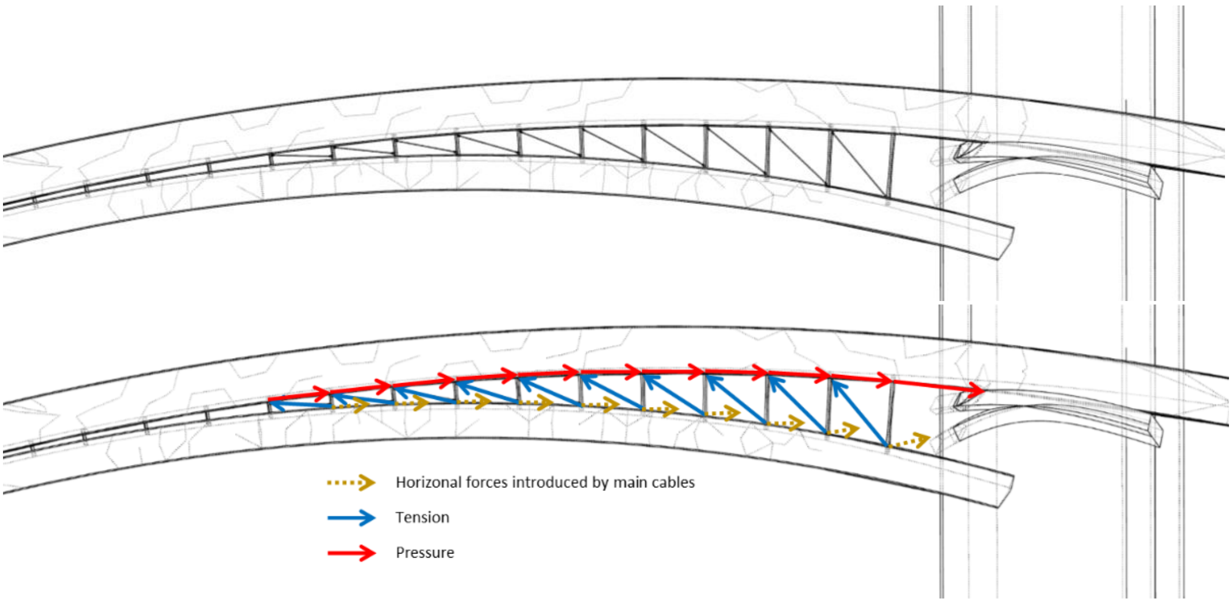


Figure 11.18: Configuration of beams and cross cables between the bridge decks (top) and a diagram showing how forces are diverted from the pedestrian deck to the cycling deck (bottom)

Local supports

While the main span is supported by cables, the rest of the bridge will require ground supports. The slopes leading up to the bridge are designed as simple beam bridge, so they require a regular array of support along their length.
The main span itself is isolated from the slopes by the movable bridge parts. The span will therefore require a support structure on either end to keep it in place. Although all lateral forces that are introduced by the cable configuration should cancel out, the supports at either end should still be able to cope with horizontal forces, such as wind loads and warping in the decks. The movable bridge parts connecting to these points will likely have a very limited margin of allowable displacement, so the supports need to be rigid in all directions.

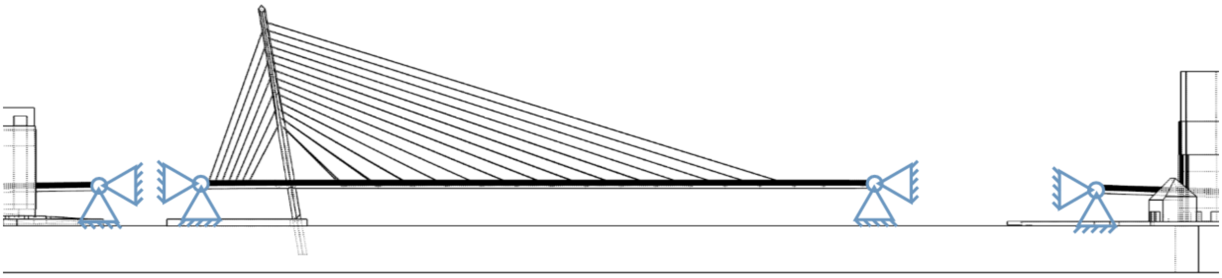


Figure 11.19: Elevation showing required supports on and around the main span

The actual design of the supports is rather important for the overall look of the bridge. Most of the areas from which people will see the bridge, the recreational areas on either bank, will have people looking up at the bridge deck above them. The flowing lines as described in the section 'bridge deck' are a vital part of the bridge's aesthetics.

Applying large, closed support columns would interrupt or block out these lines from most viewing angles. (Figure 11.20) A set of sleeker supports preserves the viewing lines better. To minimize the connection between column and bridge deck, the columns can be connected by swivels to steel plates protruding from the deck.

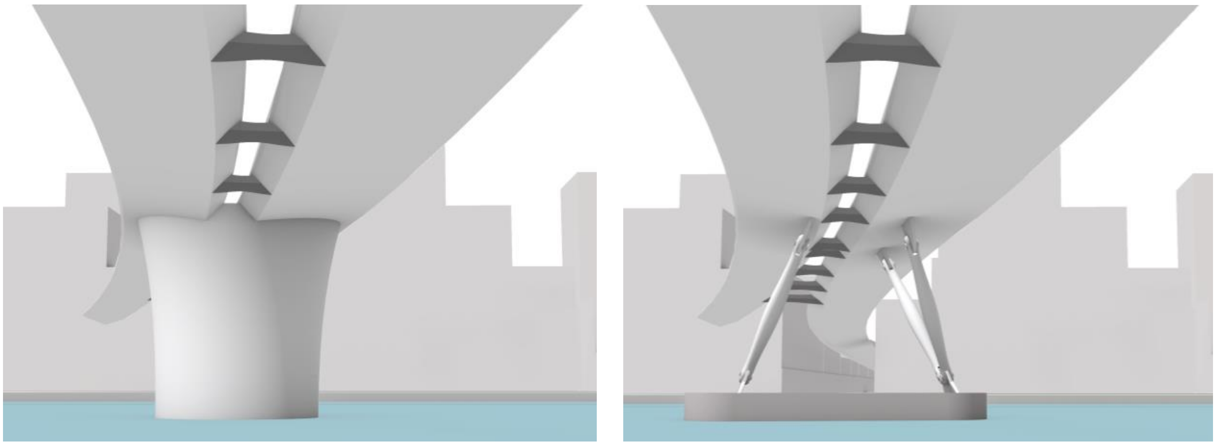
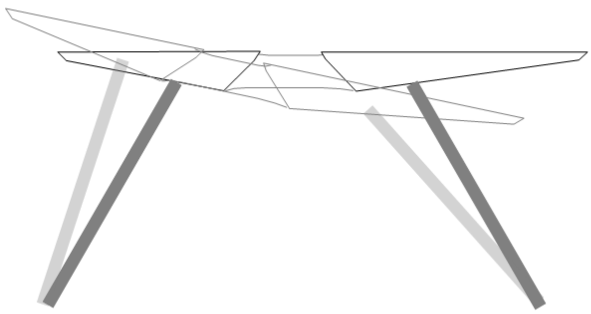


Figure 11.20: Solid supports will interrupt the flowing lines as created by the bridge decks (left)
Sleeker support structures leave the flowing lines intact (right)

These sleek columns are too slender to withstand any bending moment, so they will have to act as rods in a diagonal configuration. By creating triangles in this way, the support structure becomes stiff enough to handle the required lateral forces. As the largest columns will be more than 10 meters high, the buckling factor will likely be the critical number for these columns. To prevent buckling without enlarging the connection to the deck too much, the centre of the column, where buckling would take place, can be enlarged.

To improve resistance against torsion, the supports are placed away from the middle, rather than in a true tetrahedron. However, as the connection points are very slim, this decreases the actual stability of the support configuration. To fix this, a cross of cables is drawn between each set of columns.



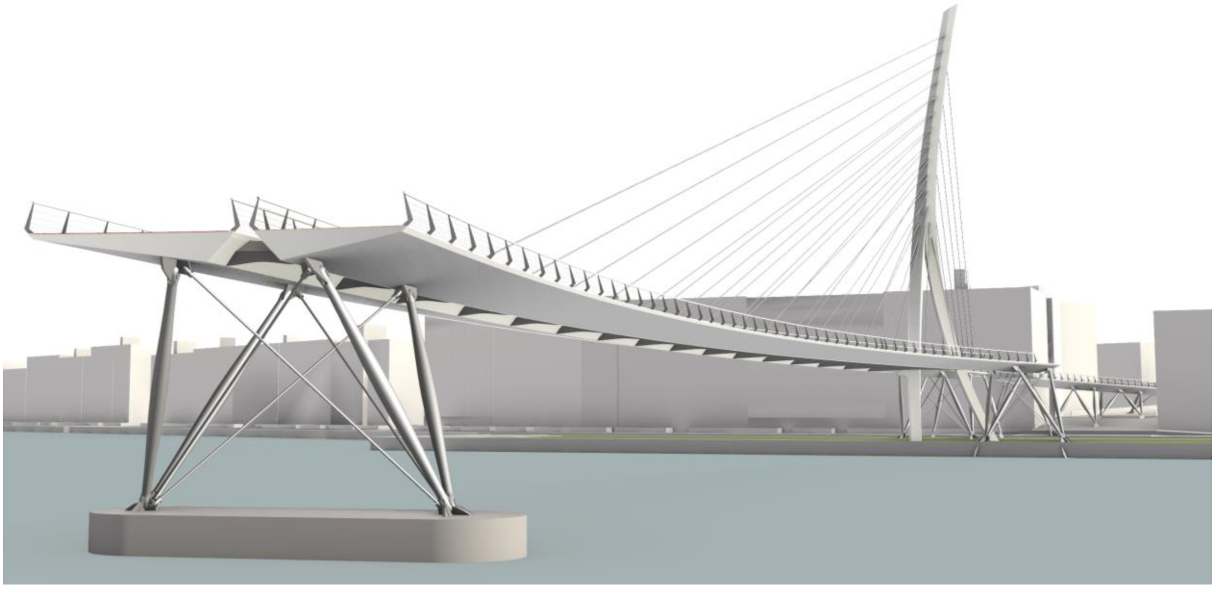


Figure 11.21: Configuration of columns on the end of the main span

Movable bridge parts

In the base design, both movable bridge parts are designed as swing bridges. The main reason for this is that due to the size and elevation of the movable parts, an open bascule bridge would have an overshadowing effect on its surroundings. Also, the choice for a swing bridge on the North Bank allows it to have a cable-stayed construction, which mirrors the main pylon and gives the bridge's profile balance.

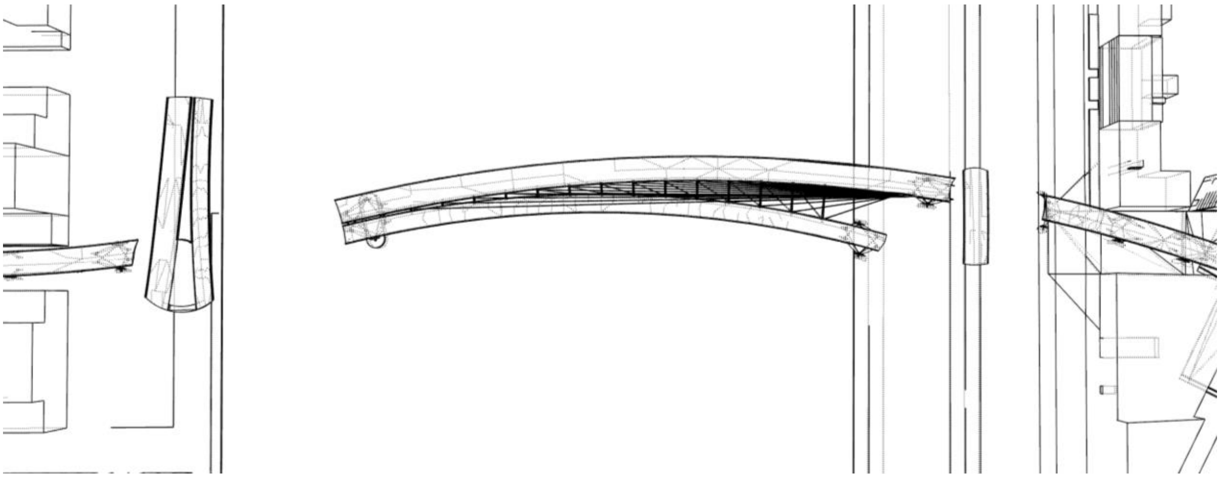


Figure 11.22: Top view with both swing bridges in open position.

North bank

The movable bridge on the north bank is the largest of the two. The required span to be opened is 40m, but as the bridge widens on this stretch, the actual arm of the swing bridge needs to be around 54m to be able to move the entire bridge deck out of the way. This large span requires a superstructure to support it, for which a cable stayed design is used to mirror the main pylon.

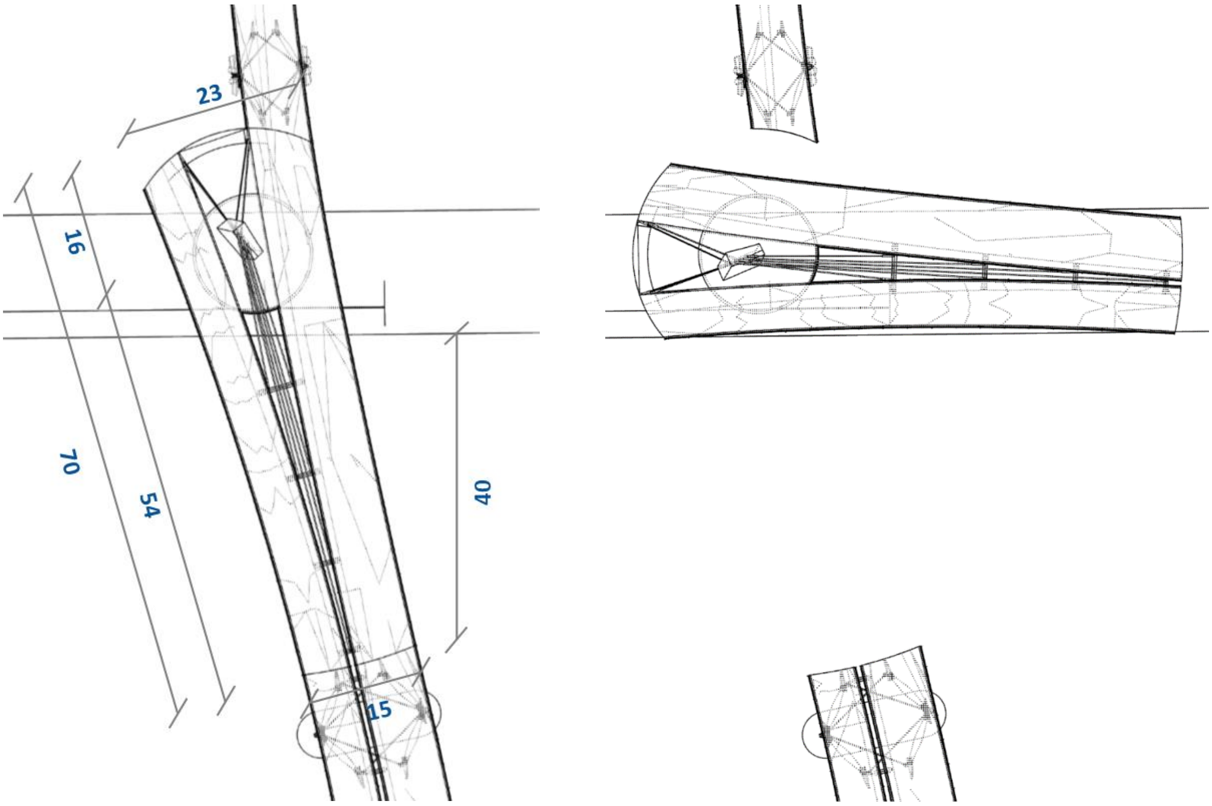


Figure 11.23: Plan of large movable bridge in closed and open position

Along the course of the movable bridge, the course of the cycling deck starts curving the other way. This means that there is much less cause to create a curved pylon, such as the main pylon. Also, the fact that this is a swing bridge makes a split pylon much less desirable, as a singe pylon connecting directly to the axle is structurally much simpler.

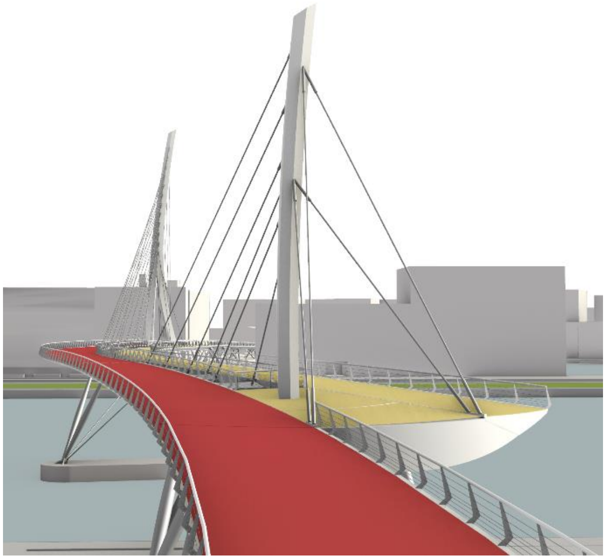


Figure 11.24: Design of the pylon of the swing bridge

To still invoke some aesthetic harmony with the main pylon, the smaller pylon has been given a slight curvature and a similar cross section.

The cable configuration along the deck is very similar to that of the main span. Cables connect to both decks, except the furthers two points where there is neither space nor structural benefit for two cables.

At the rear of the movable bridge is a counterweight designed to balance the weight of the span. The rear cables from the pylon connect to this at two points along its width to improve balance. Also, as both bridge decks are now connected to the rear cables, this removes the necessity of the cross cables between the bridge decks.

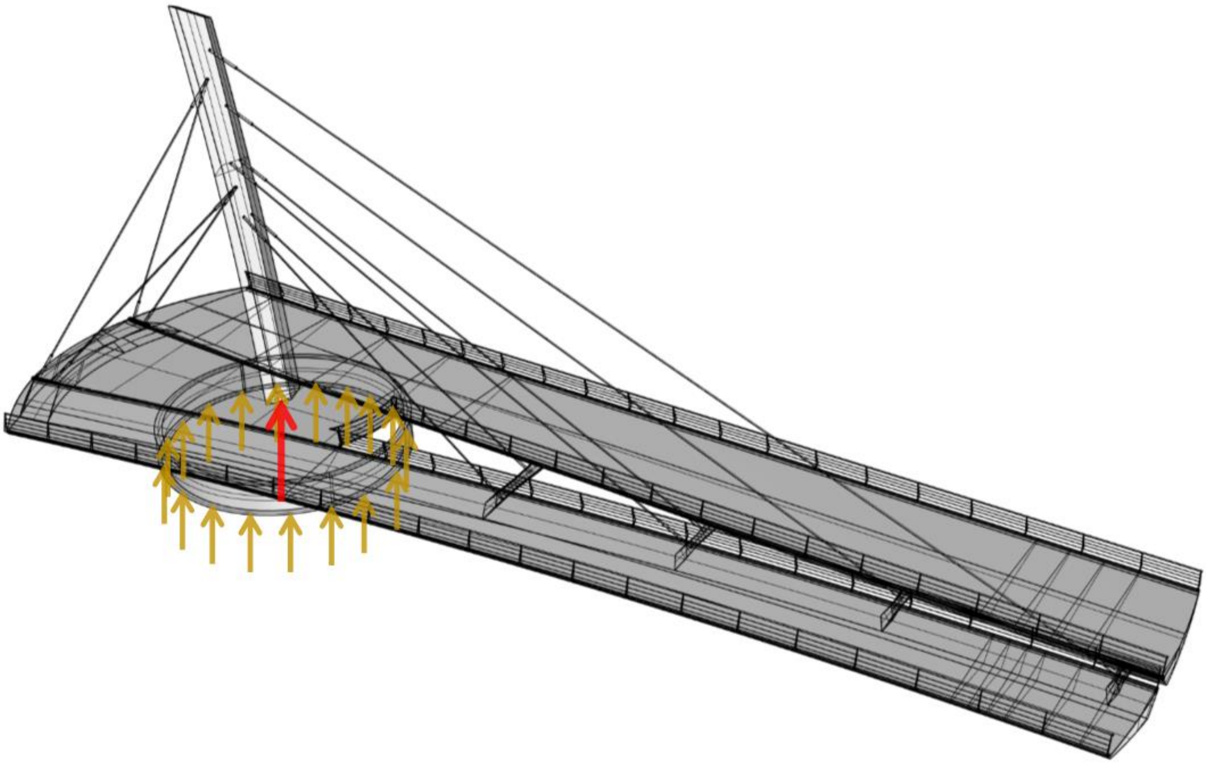


Figure 11.25: Required supports for swing bridge

The pylon will have to be supported from the bottom of the swing bridge. In addition, supports will be required around the pylon to keep the bridge deck balanced, both when its closed and in any open position. To keep the weight of the movable part at a minimum, only the very top part of the construction will turn in relation to the bottom part. For this reason, a circular support is the most obvious choice.
When relating back to the section about supports, creating a large circular support will inevitably disrupt the flowing nature of the bridge decks from some angles. Any attempts to morph the lines of the bridge deck to try

to incorporate the support into the flowing lines only showed that these extra lines only distracted from the original flow. A simple round disc inserted into the decks proved to be more pleasing, as it allowed the mind's eye to follow the lines through the support much more easily. (Figure 11.26)

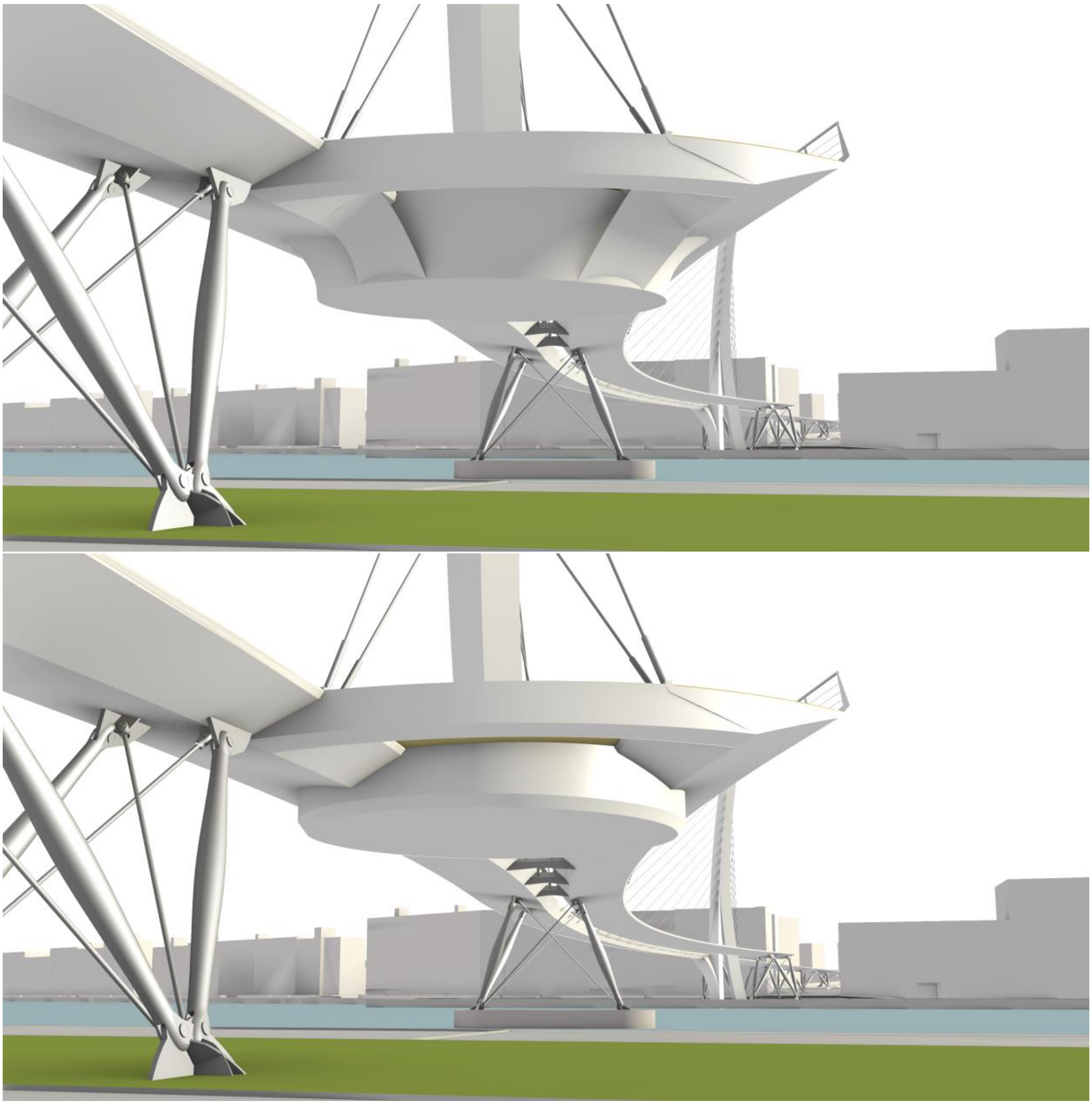


Figure 11.26: Any support that tried to incorporate the flowing lines of the deck only complicated the connection. (top) A simple disk proved the more elegant solution (bottom)

If this top ring is dimensioned large enough to transfer the loads from the bridge decks equally across its perimeter, there is no actual solid construction beneath this required. A set of columns would be enough, improving the transparency of the design. However, these columns must still be able to transfer torsional loads around the axle, as the accelerating and decelerating of the bridge deck will cause significant torque. For this reason they are positioned diagonally to form a drum-like structure.

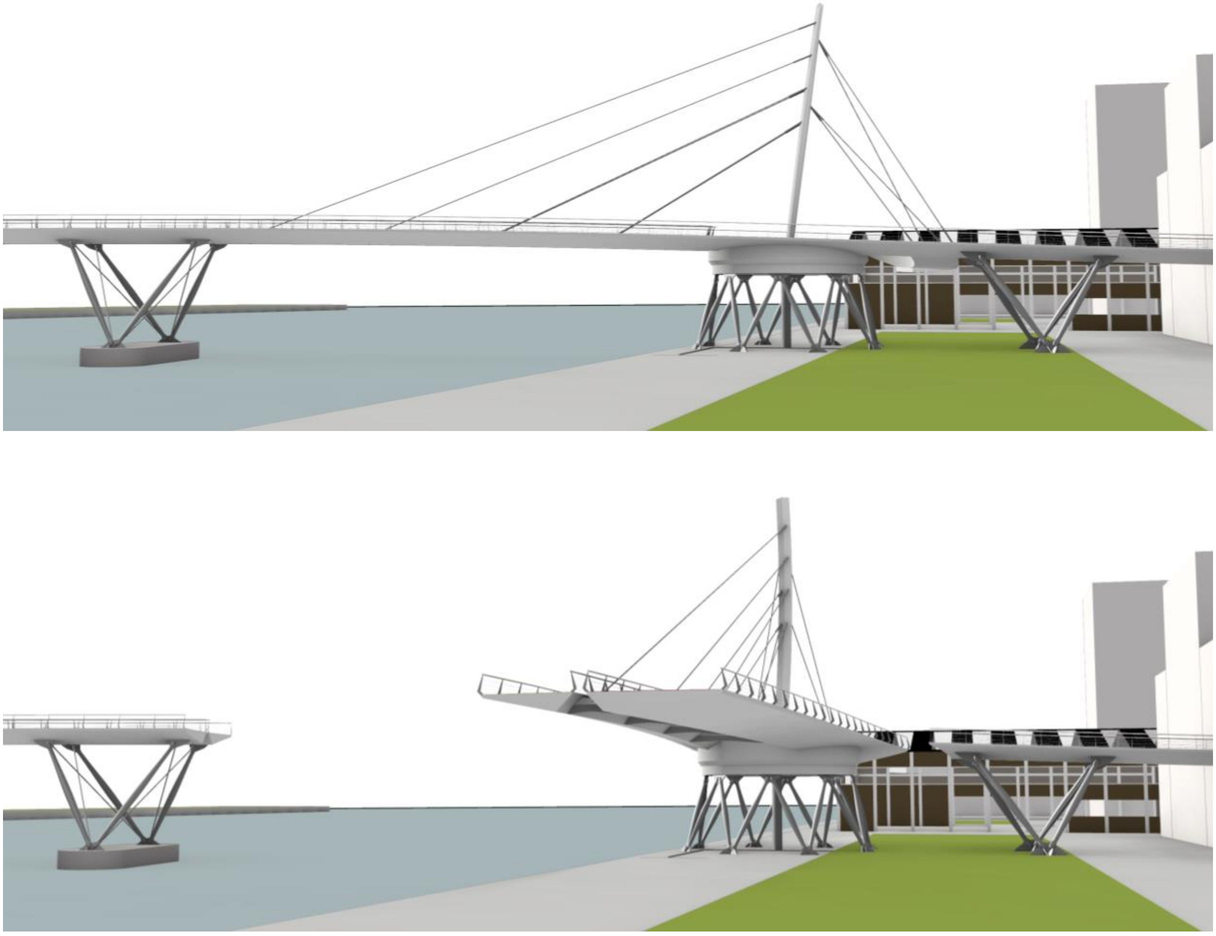


Figure 11.27: Complete design of large swing bridge closed and open

South bank

The southern movable bridge part has a smaller span and incorporates just a single bridge deck. The deck should be strong enough to span the gap as a cantilevering bridge, without the need for a further superstructure. However it is still located at an elevation of almost 10m which means its smaller base isn't necessarily desirable.

When applying a similar design to the larger movable bridge part, it becomes apparent that the narrower base gives the bridge a rather awkward, unbalanced look. Also, the bridge is placed in a much more cramped position, as that space is also required for the rear cables and support of the main span. The end result is rather chaotic. (Figure 11.29)

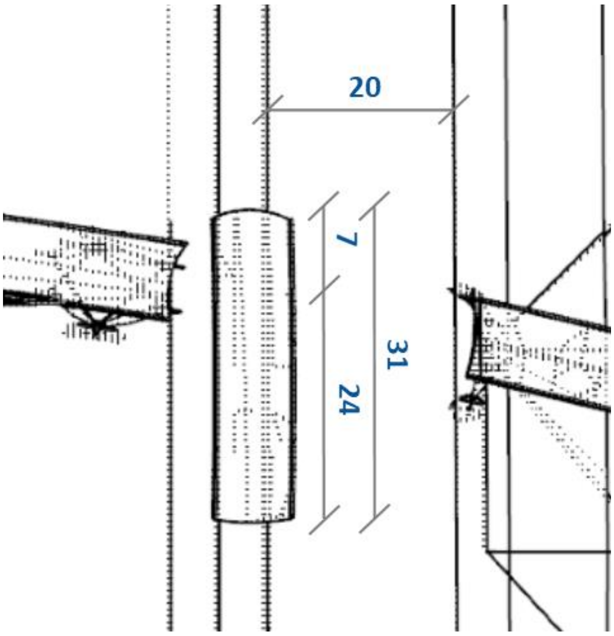


Figure 11.28: Plan of south bank swing bridge

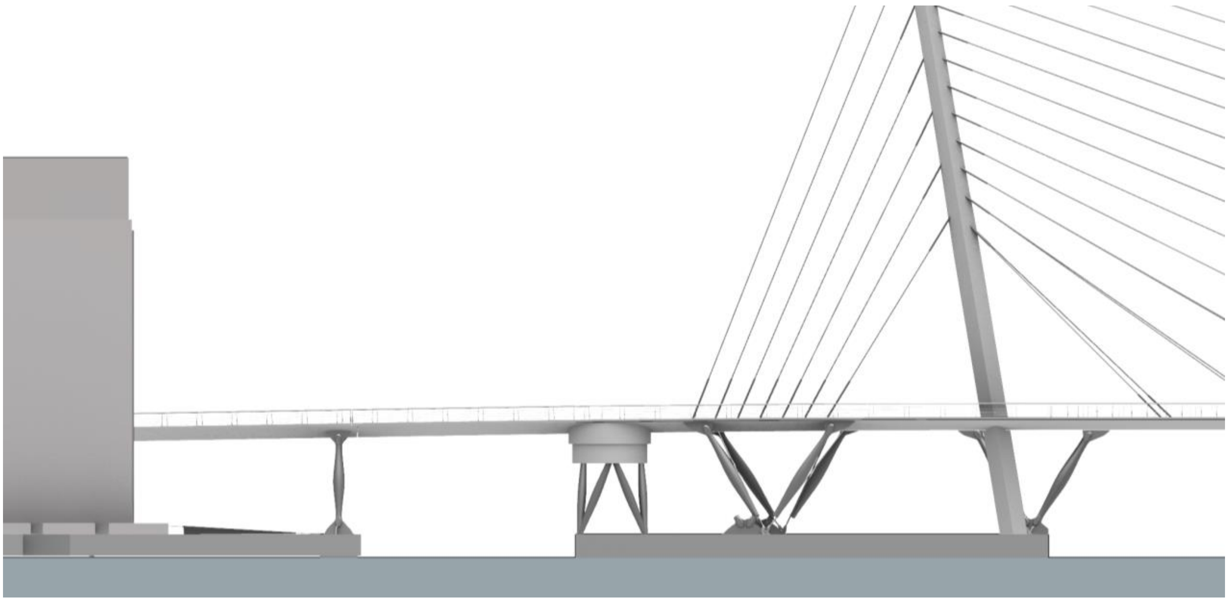


Figure 11.29: Side view of java island with simplified swing bridge construction

In the end it proved more pleasing to replace the swing bridge with a bascule bridge. As long as the swivel is connected to the main bridge deck, this has lower requirements for the supporting construction, as it is not required to balance completely free-standing. This creates a much cleaner situation on java island. Another advantage is that the turning point of a bascule bridge can stand closer to water. This reduces the size of the movable bridge and creates more space for the rear cables from the main pylon.

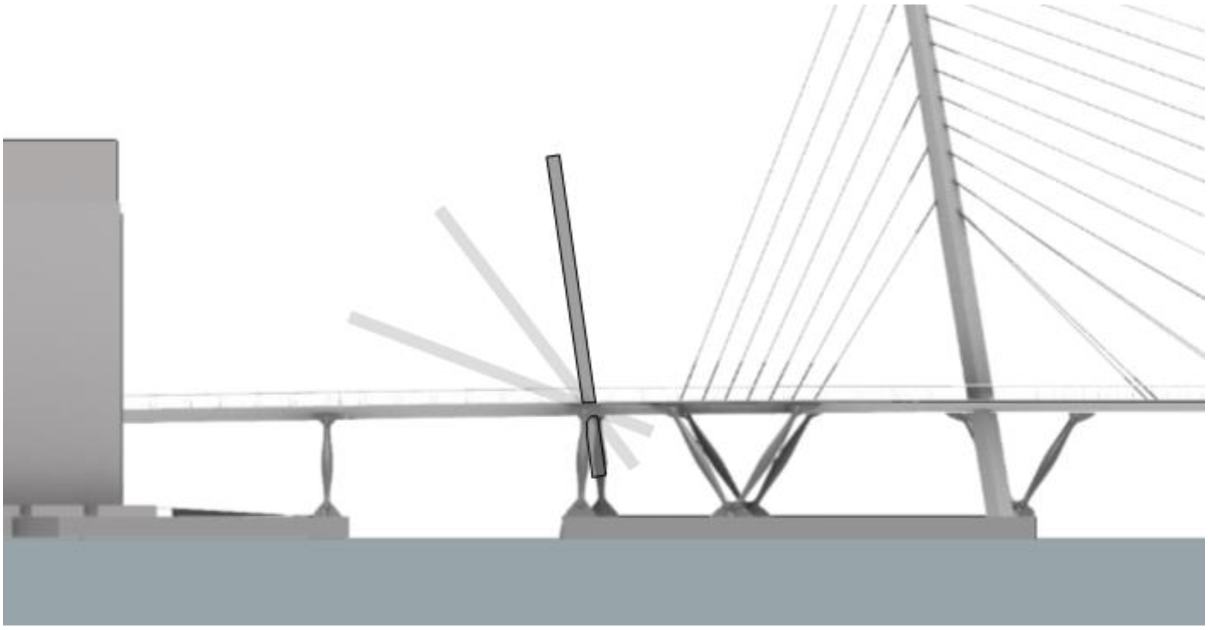


Figure 11.30: Side view of Java Island with bascule bridge

Originally, the counterweight of the swing bridge was intended to be placed within the bridge deck by filling the space between the steel flanges with concrete. However, as the bascule bridge still needs a part of the bridge deck to be connected to the main deck, there is too little space to fit a sufficiently large counterweight. This means some addition to the volume of the bridge deck is required.

In this case it did seem the most suitable option to do this by morphing the existing lines of the bridge deck into a flowing shape. This does interupt the main line through the deck but appears to be the least intrusive way to at volume.

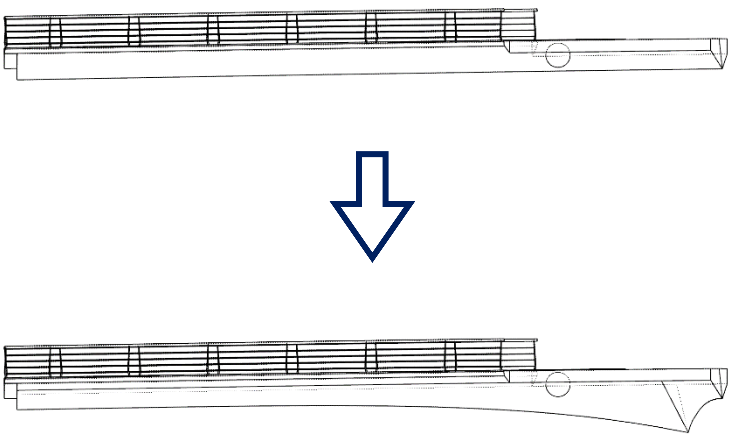


Figure 11.31: New deck shape to accommodate counterweight

As the sleek and transparent supports allow very little space for mechanical installations at bridge level, the bridge will be opened by a hydraulic ram. This is placed at the waterside and connected to the bottom of the movable bridge deck. As this system requires moving parts at ground level, this does mean that the area around the base of the bascule bridge has to be fenced of.

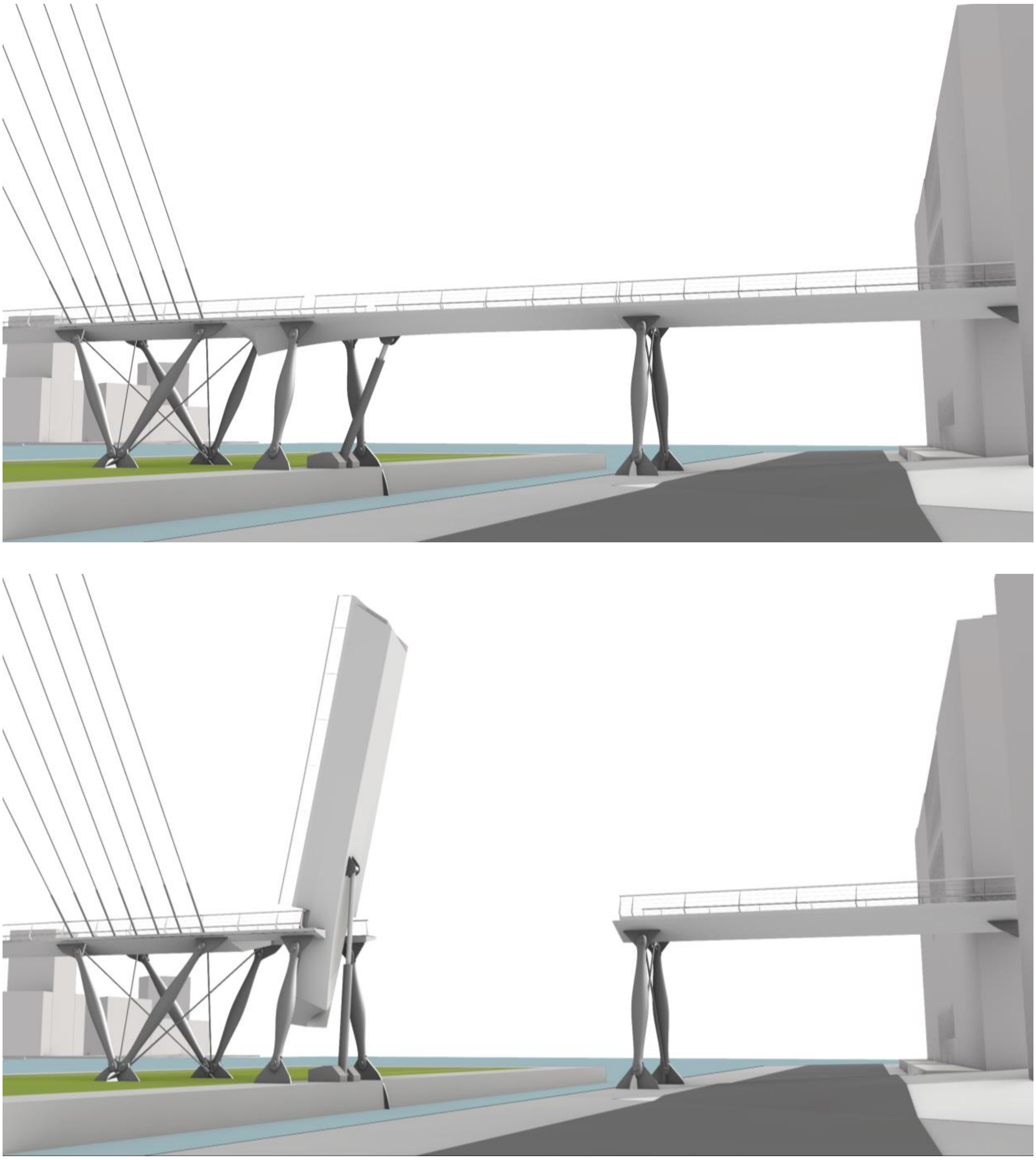


Figure 11.32: Bascule bridge in closed and opened position

Stairs & lifts

The stairs and lifts at either end of the bridge are the most important way in which the bridge interacts with its direct surroundings. In this design they have a special significance as the entire layout of the bridge can be related back to the planned connections to direct surroundings. (figure 11.33).

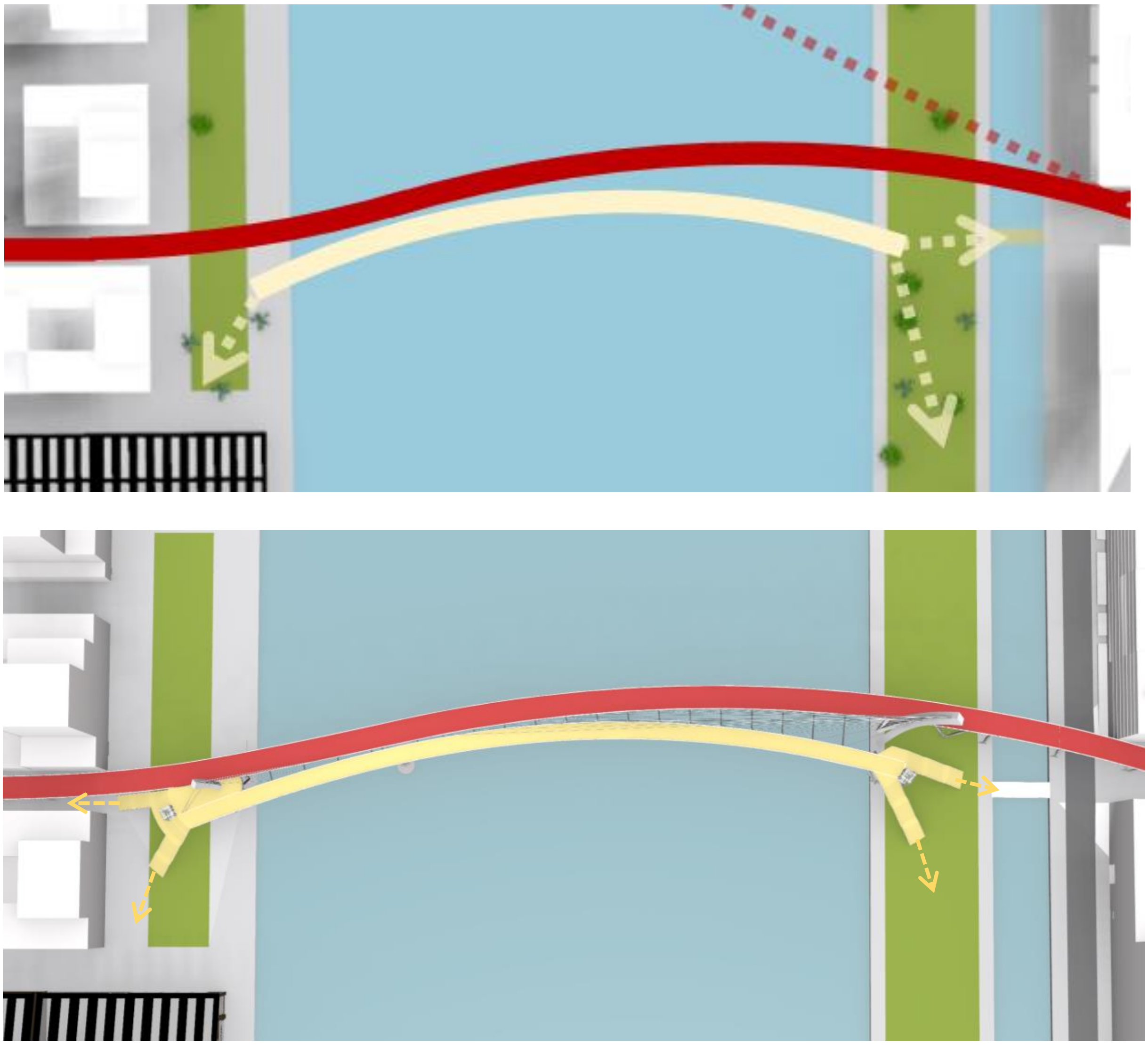


Figure 11.33: Envisioned connections while determining the general layout of the bridge decks (top) and designed connections (bottom)

At both end the connection has been designed as a duel set of stairs. Not only does this improve connectivity, it also adds some visual significance to the bridge as an object within the public space. The stairs on the north bank are curved around the centre point of the swing bridge. This creates a clear visual connection between the stairs and the bridge structure itself. The south bank connection lacks a point like this to be based on. It has nevertheless be angled in roughly the same shape. Not only does this point the stairs in the desirable connections, it creates a nice harmony with the opposite bank.

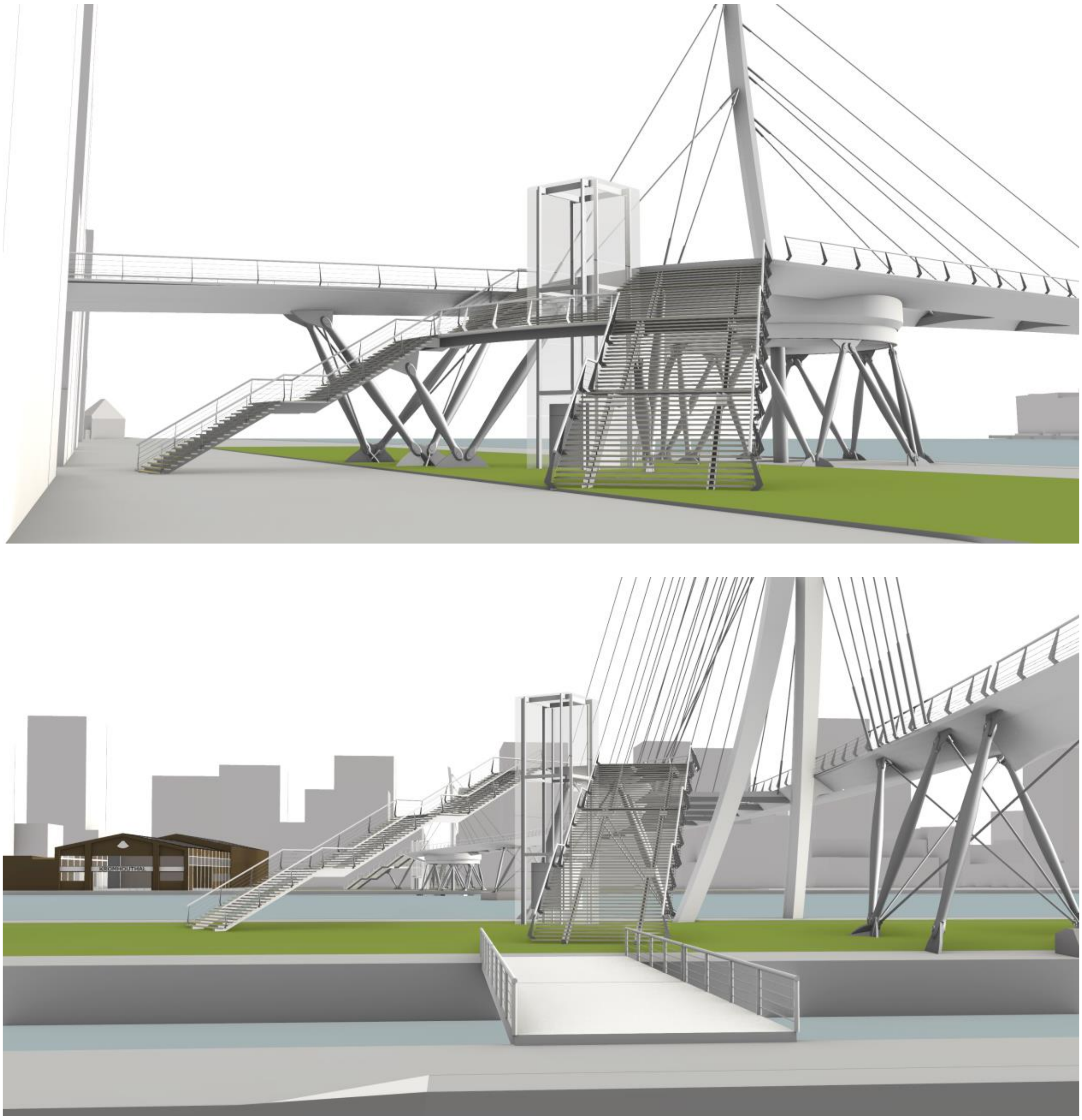


Figure 11.34: Stairs and lifts at the north (top) and south

12. Structural design

Main span

The main span can be simplified as a simple beam structure. The connecting beams cantilever outwards from the cable connection points to carry the decks, which can be seen as a single continuous beam across these connecting beams.

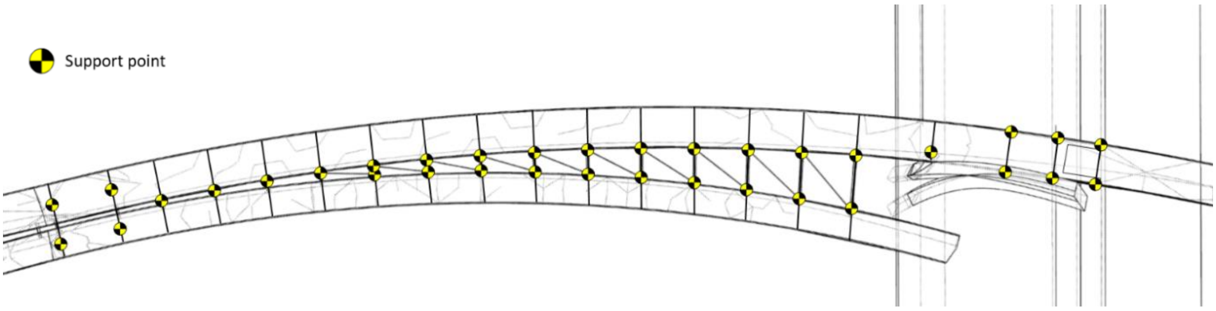


Figure 12.1: Top view of main span showing support points and internal structure

All structural elements are created out of high-grade structural steel S460. The cables are made from high tensile steel with a maximal allowable stress of around 1900 MPa.

Vertical loads

Dead load cycling bridge:	15,1 kN/m
Dead load footbridge:	12,0 kN/m
Permanent loading factor:	1,3
Distributed variable load*:	5,0 kN/m^2
Effective width cycling bridge:	7,6 m
Effective width footbridge:	5,6 m
Concentrated variable load (service vehicle):	10,0 kN
Wind load (horizontal):	2,0 kN/m^2
Traffic load factor:	1,5
Variable load factor (wind, temperature):	1,65

*This is the nominal value for footbridges. For long span footbridges this can be reduced according to the formula: $q_{fk} = 2{,}0 + \frac{120}{l+30}$ (Calgaro, 2008), which represents the statistical unlikelihood of the entire bridge deck being fully loaded simultaneously. In this case this would reduce the variable load to about 2,6 kN/m^2. However, the bridge's prominent location over the IJ increases the likelihood of maximal loading during events such as Sail. A detailed analysis would be required to determine a more suitable reduction factor, in lack of which I have simple adapted the maximum value.

Wind loads

The nominal wind load of 2,0 kN/m^2 is derived from the standard norms and based on the bridge's location and surrounding structures. (TGB Basiseisen en belastingen, 2011) However, this is a force placed horizontally on the diagonal side of the bridge decks. Due to the aerodynamic nature of the bridge decks, effects like lift and suction will likely have a larger effect than the horizontal force. The exact effect of the wind loading can only be properly quantified in a fluid dynamic analysis, but study of reference material can help predict the types of forces that will act on the bridge deck. (Lee, Kwon & Yoon, 2014)

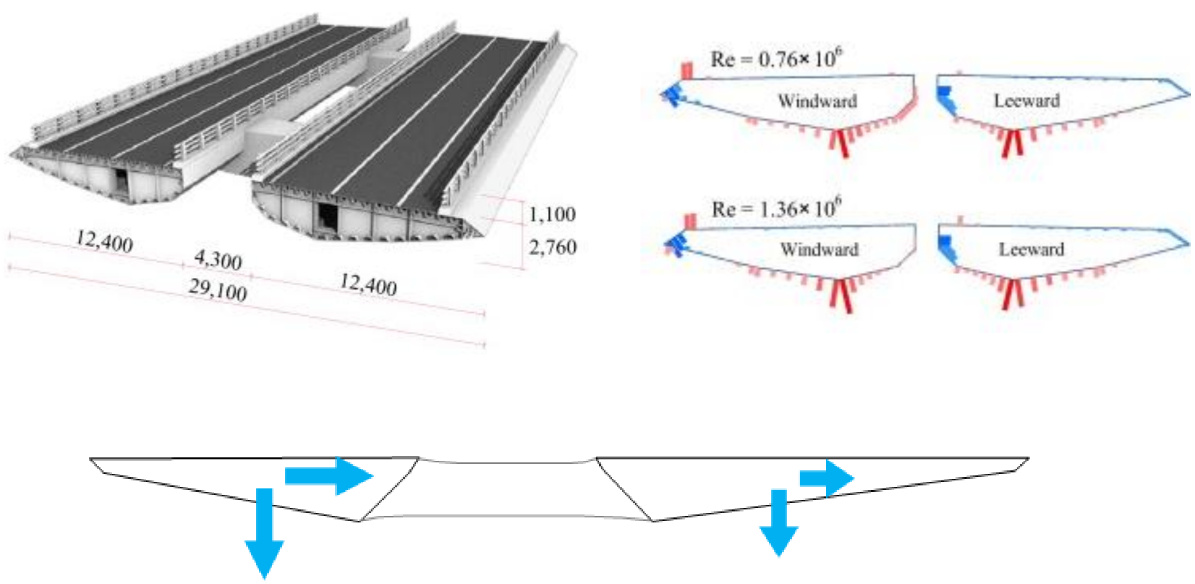


Figure 12.2: Images from Lee, Kwon & Yoon's research, showing a similar construction to the Java bridge design (top) (Lee, Kwon & Yoon, 2014) and expected resulting forces in current design (bottom)

It is expected that all faces in the windward direction will experience pressure while all faces in the leeward direction experience suction. The numerical value of these forces and the ratio between them is hard to predict but based on the convex shape of the bottom of the decks, it can be assumed that the total sum of the forces is some value of downward lift. For the calculations a vertical force with the same strength as the horizonal drag force was used, based on the reference project by Lee, Kwon & Yoon (2014).

Initial dimensioning

For most parts of the bridge simplified line diagrams can be made and stresses can be calculated by hand. (Figure 12.3) In this way initial dimensioning was done for the pylon, cables, cross beams and supports. For information on the more complex sections, such as the bridge deck, a grasshopper tool could be used to analyse shapes from the 3D model.

These rough calculations provided unrealistically thin heights for the bridge deck box sections (<10cm), which indicates that in a bridge design on this scale, uniform vertical loads aren't the most significant factor in determining the size of construction parts.

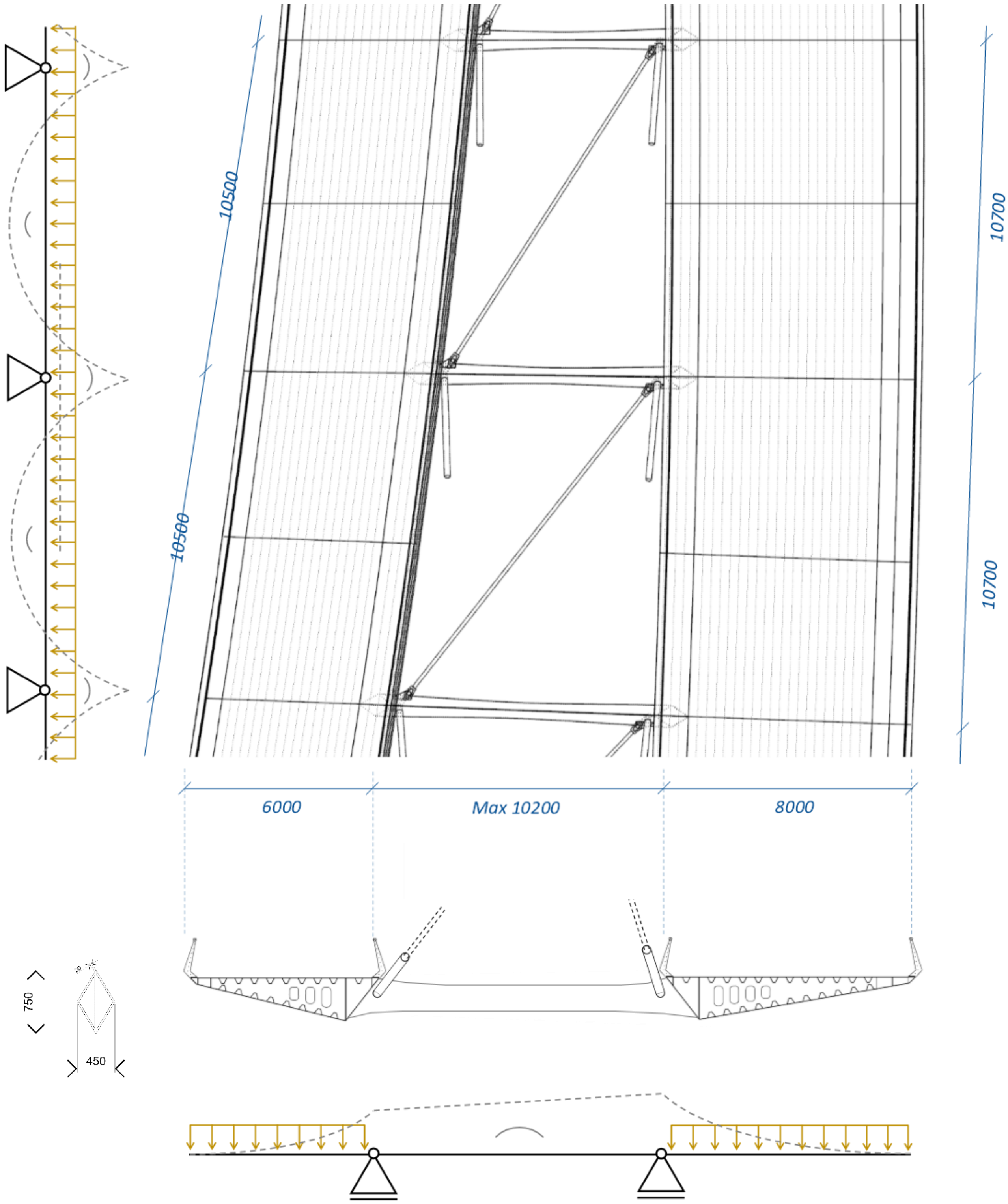


Figure 12.3: Internal structure of the bridge deck, accompanied by diagrams showing loading patterns and moment lines.

To gain more accurate insight into the workings of the structure, a finite element analysis was required. This was carried out in Karamba, which is a plugin for Grasshopper, the program that was mainly used for the bridge's design.

The most accurate way to model complex shapes like the bridge decks is by modelling them as shell structures. However, this is a process with a very small margin of error. When these shells are not perfectly generated, they can produce peak values at critical points. As the program is designed to scale all results according to the maximum and minimum values, a peak in a shell, no matter how local, can reduce all other results to insignificantly small numbers, rendering them unusable.

For this reason, the bridge deck had to be modelled as a continuous line element. This does limit the amount of accurate data that can be retrieved from the model.

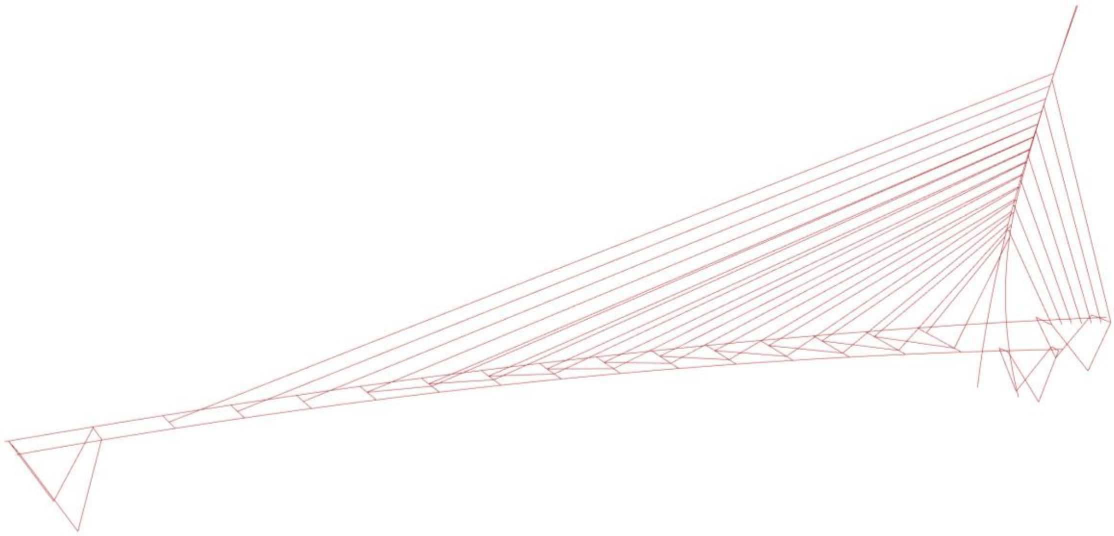


Figure 12.4: Diagram of model layout

Firstly, the cross section of the bridge deck will not exactly match the properties of the actual shell structure. Karamba has only a limited selection of sections available, closest of which is a trapezoid beam. These cross sections can be modified to closer match the actual design. Values like moment of inertia, area, elastic modulus etc have therefore been extracted from the shell structure and appended to the trapezoid beam, but there were no tools to determine more complex properties like the torsion constant. This means the simplified bridge deck will react in a realistic way when bending and stretching but will still have the properties of a trapezoid beam under torsion and warping.

Secondly, the change from a shell to a line element requires some virtual connections to be made to simulate forces being transferred within the shell structure. For example, in the design the main cables connect to the side of the bridge decks. These forces will distribute themselfves through the shell, although the main part wil remain on the inner half. In the line model, the decks are modeled around their centre line. Therefore additional elements are added as diagonals through the virtual bridge deck. (Figure 12.4)

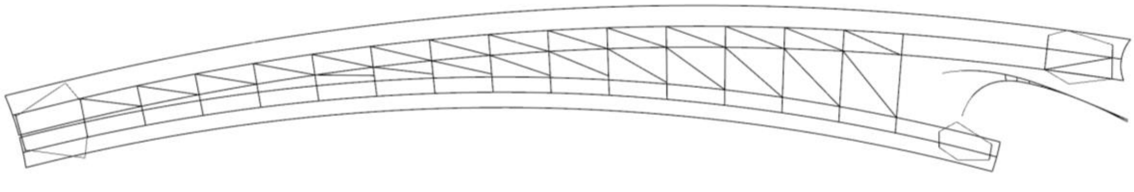


Figure 12.5: Top view of line model with additional diagonals

These additional elements will be given infinite strength and stiffnes as to not effect the results of other construction parts, but this will nevertheless have some unknown effect on the accuracy of the model.

Karamba handles pretensioning of elements as a load entered into the model before calculations take place. However in reality most of the tension in the cables is a reaction to loads applied to it, so there is no simple way to accurately predict the required tensioning without running the model first. To achieve a high level of accuracy in the required pretension, the model was run in two iterations. The first analysis is done without any pretentioning to determin the deformation of elements. The strain in the cables is then transferred to an initial strain load for the second iteration. To achieve a truly accurate result, many more iterations have to be calculated, but there is no way of doing this in Karamba without using an excessive amount of computing power. Two iterations will be sufficienct for this project.

Load cases

The model was analysed in 6 different load cases:

Load case 0: Only permanent loads
Load case 1: Permanent loads, distributed variable loads on both decks
Load case 2: Permanent loads, concentrated variable load on cycling bridge
Load case 3: Permanent loads, distributed variable loads only on cycling bridge
Load case 4: Permanent loads, distributed variable loads only on footbridge
Load case 5: Permanent loads, distributed variable loads on both decks, wind load

The first state was just used as a baseline to calibrate model. Load cases 1, 2 and 4 are designed to test the construction at its maximum stress. Load cases 3 and 4 are used to see how the bridge reacts under torsion, as the bridge will be unequally loaded.

Results

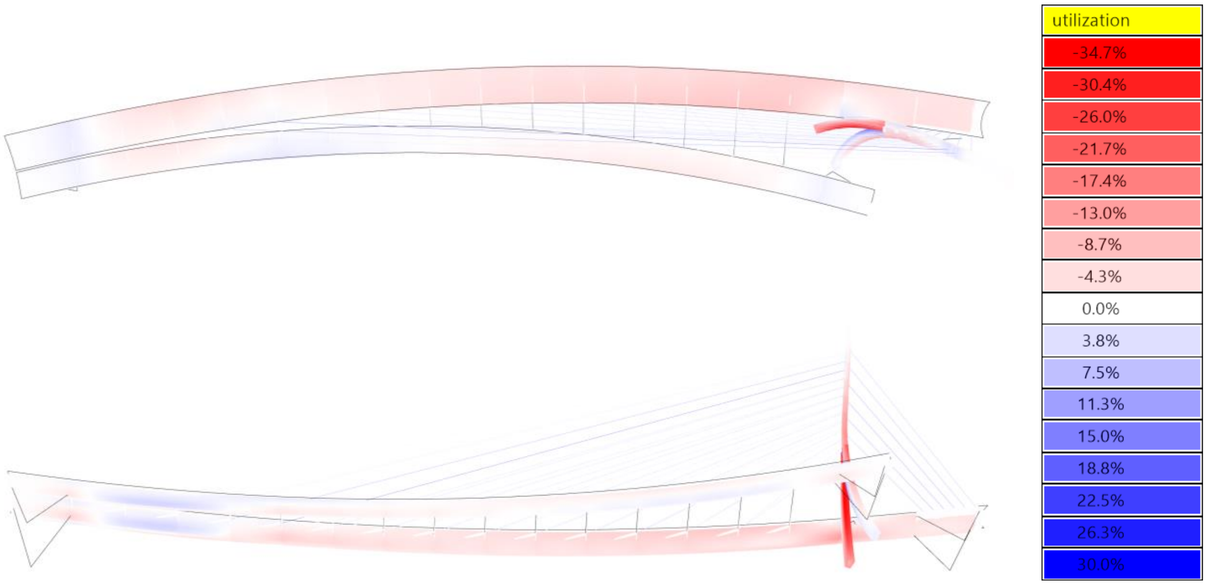


Figure 12.6: Load case 1, utilization of elements

The results of the first load case in the finite elements analysis seem to display the expected behaviour. (Figure 12.6) The cycling bridge deck shows a large area of compressive stress, increasing in intensity towards the pylon. The footbridge shows no large area of compression, which indicates that the diagonal cables are effective in transferring most horizontal forces from the footbridge to the cycling bridge. The smaller zones of compression or tension in the footbridge indicate different bending moments, which are the result of the horizontal cable forces trying to warp the bridge deck, as well as imperfections in the two-iteration method of determining prestresses.

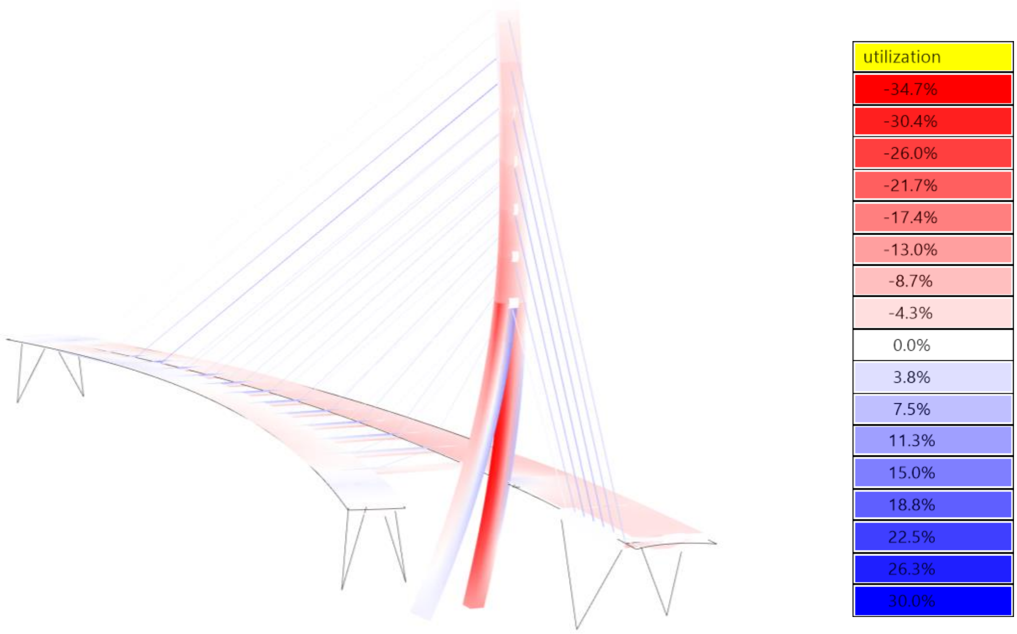


Figure 12.7: Load case 1, utilization of elements

Along the upper part of the pylon, where the cables connect, there is an increasing amount of compressive stress with a very limited bending moment, which is what the pylon was designed to achieve. At the bottom though there are some significant bending moments after the pylon splits, which is to be expected when introducing an axial stress into a curved collumn.

These diagrams also illustrate the function of slightly moving one of the 'feet' of the pylon backwards, away from the waterside. Most of the force is now going into the foot that is connected to the bridge deck. This is required in order to balance the system of forces around the pylon, as the horizontal forces in the pylon are used to establish an equilibrium. The backwards stance of the other foot also make it more vertical, further ensuring that most horizontal forces will meet at the bridge deck.

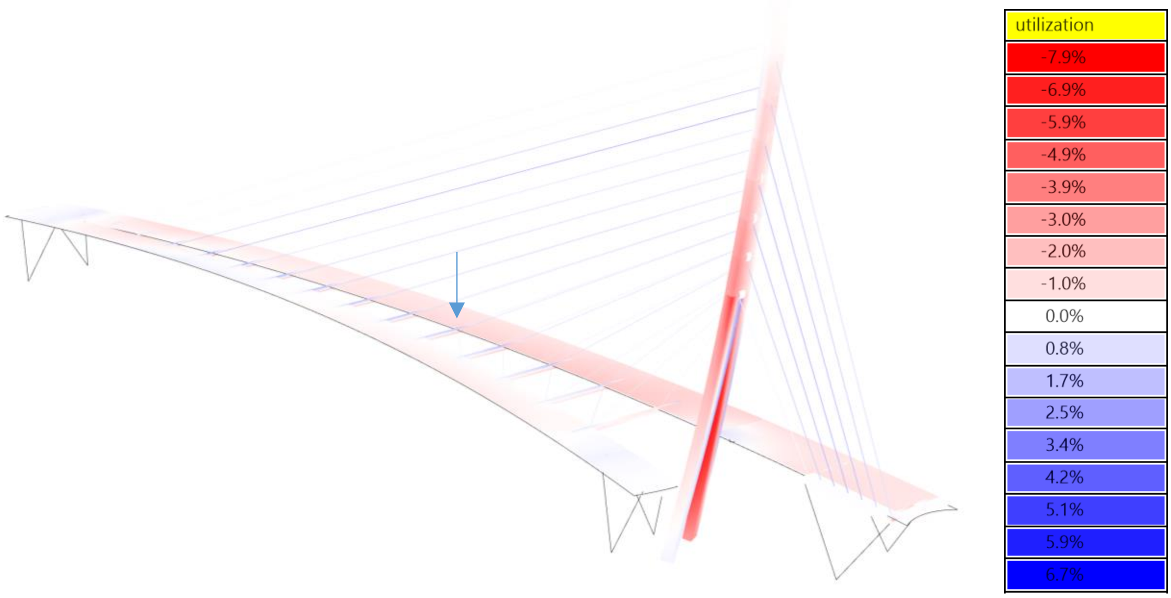


Figure 12.8: Load case 2, utilization of elements

Unsurprisingly, load case 2 which only includes a single point load yields lower stresses. The parts that are most effected by a point load are the bridge decks on a single span, and these are the elements that in this design are most overdimensioned.

All the stresses for the first two load cases are very low, because for almost all construction elements displacement was the critical measurement, rather than stress. For the first two load cases these displacements are still low, but more serious displacements are found in the asymetric load cases and under wind pressure.

Based on earlier results from the finite element analysis, most parts of the bridge have been dimensioned such that the displacements in the bridge stay within allowable limits. The official limit for displacement in a bridge deck is about 1/300th of the total span. For this bridge of 160m that would mean a displacement of about 55cm. However this is meant as a height different accros the length of the bridge deck. Under asymetrical loading however, the main concern is torsion around the centre of the bridge, lifting one bridge deck above the other. Over a bridge width of about 15m, 55 cm height difference is unacceptable. Lacking an official target, a nominal target of half the official allowable displacement was chosen to dimension the bridge compenents. (Figures 12.9 & 12.10)

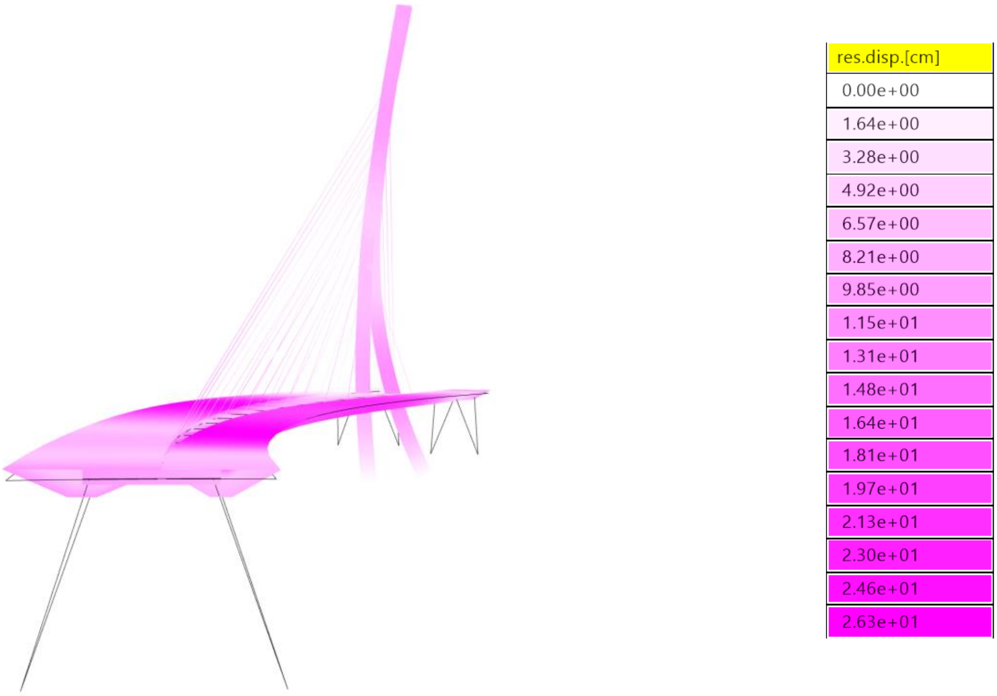


Figure 12.9: Load case 3, displacement of elements

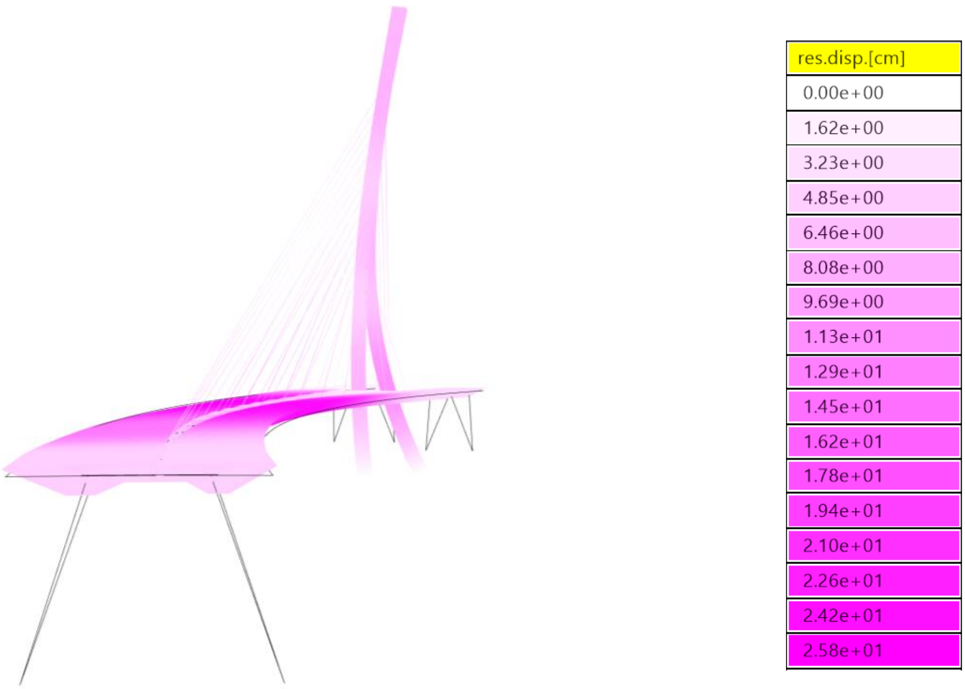


Figure 12.10: Load case 4, displacement of elements

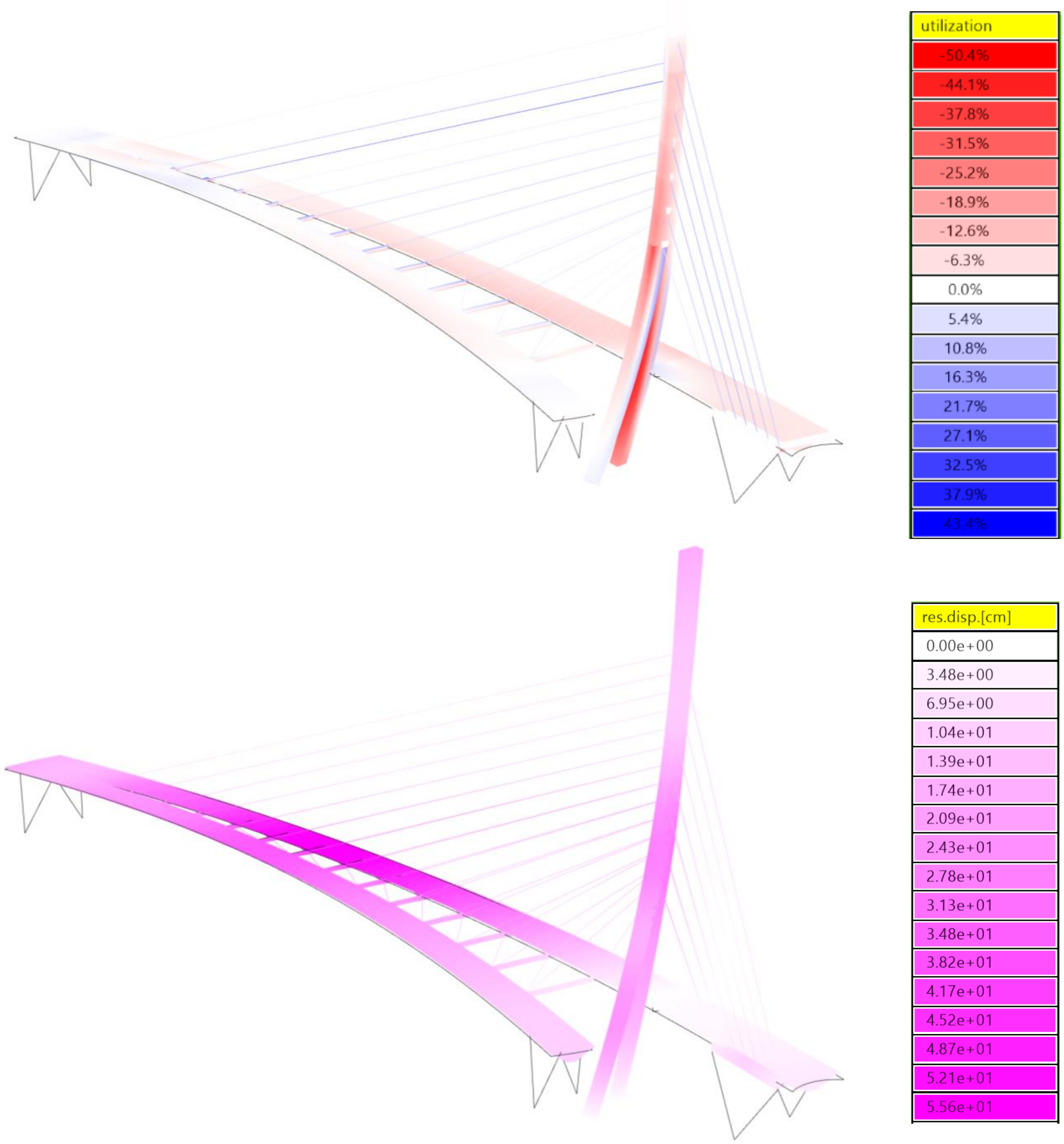


Figure 12.11: Load case 5: Utilization of elements (top) and displacement (bottom)

The addition of wind pressure raises the measured stresses, but these are still not the determining values. Under the vertical component of the wind pressure, the bridgedeck experiences larger displacements than under asymetric loading. However now these displacements are height differences over the entire length of the structure and fall within the allowable values.

Conclusions

Although the model was a siplified version of the bridge's structure, it appeared to behave according to expectations. Based on these findings, the bridge construction parts have been dimensioned such that all stresses and displacements are within alowable limits. It should still be noted however that this model is a severe simplification, and numerical values should be assessed with serious scrutiny. It does however function as an indication that the overall construction layout is sound.

Large movable bridge

For the most part the structual design of the large swing bridge resembles that of the main span: The two decks are supported by cross beams. Four of those are supported by cables, two are supported by the cylindrical base around the axle

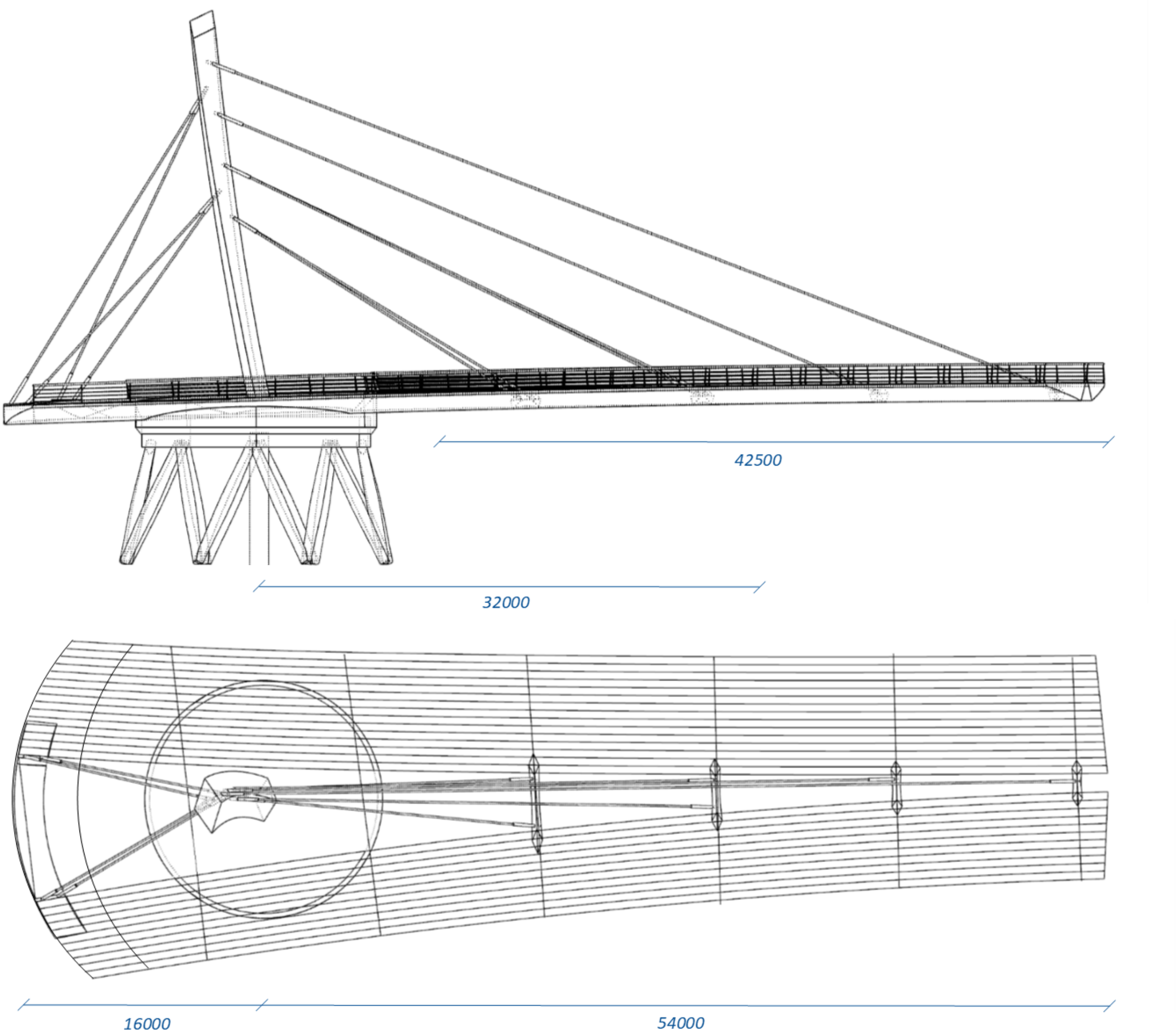


Figure 12.14: Schematic structural design of large movable bridge

The counterweight is designed to balance the cables stayed beams when the bridge is in open position, without any significan variable loading.

$$F_{deck,total} = 42m \cdot (19{,}6kN/m + 14{,}9kN/m) = 1449kN$$

$$M_{deck} = 1449kN \cdot 32m = 4{,}6 \cdot 10^4 kNm$$

$$F_{counter} = \frac{4{,}6 \cdot 10^4 kNm}{16m} = 2898kN$$

$$V_{concrete} = 96{,}5\% \cdot \frac{\frac{2{,}9 \cdot 10^6 N}{9{,}81}}{2400kg/m^3} = 119m^3$$

The counterweight designed earlier is too small, so a bigger counterweight is added.

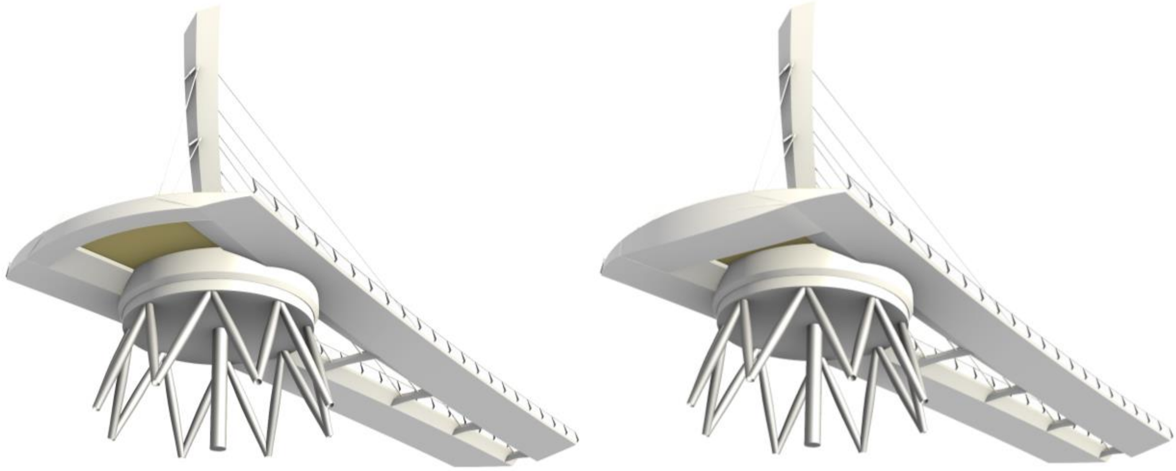


Figure 12.15: Old counterweight (left) and newly designed counterweight (right)

Mechanical design

The bridge is operated by an old fashioned mechanical motor. This is as opposed as a hydraulic system that is more commonly applied in modern swing bridges. This choice was made as the hydraulic system requires a larger solid base to house the axle. The mechanical system is can be designed flatter, which helps create a transparent design with columns rather than a large solid base.

The turning mechanism exists of two discs that rotate on a ring of wheels. All are kept in place by the central axle. On the outside of the lower cylinder a rack gear is mounted. The motor and gearbox are placed in the upper cylincer, and connect to the rack gear via a pinion.

Most swing bridges built in this fashion are either axle bearing or rim bearing (Koglin, 2003) meaning almost all load is transferred to either the axle *or* the cylindrical support. In this case, a hybrid solution is more suitable. The pylon is placed on top of the axle, so the loads from this divert straight down. The beams directly around the axle however do not connect to the pylon, so they can better be supported by the rims.

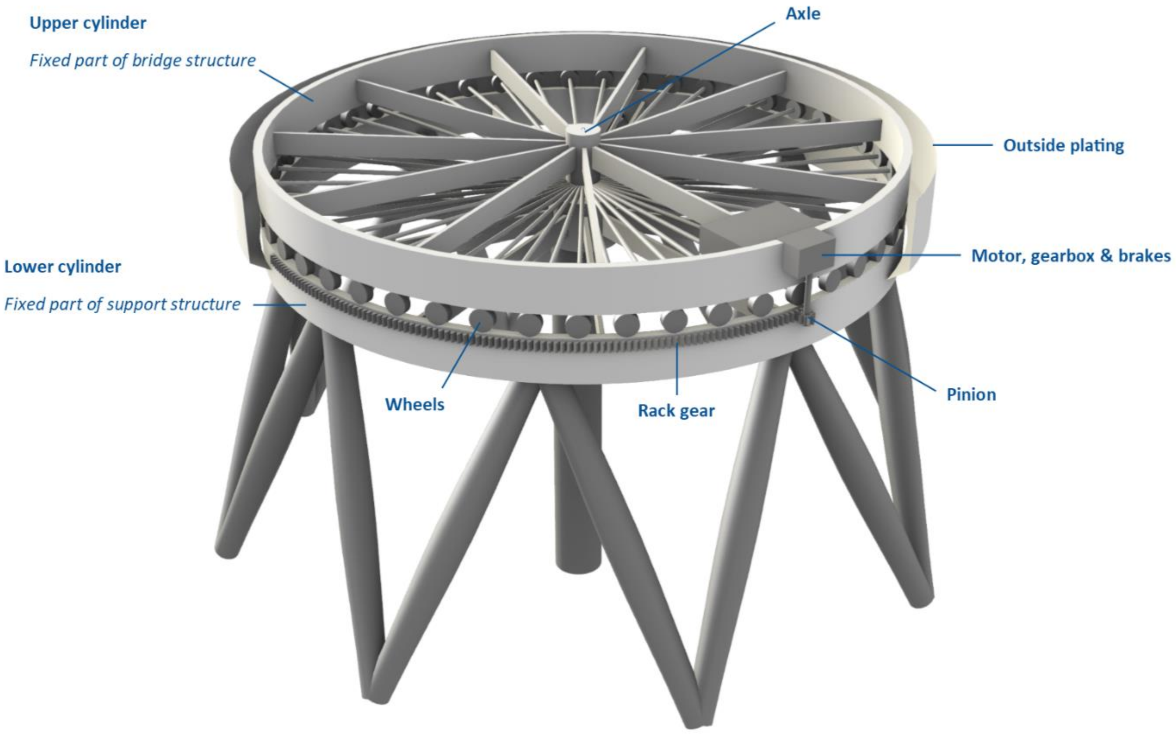


Figure 12.16: Diagram showing important mechanical components

Small movable bridge

The small movable bridge is simpler in construction, as it is smaller and only compasses a single bridge deck. The size of the counterweight can be determined in the same manner as for the larger movable bridge. In this case about 40m^3 of concrete is required, meaning the conterweight has to be slightly enlarged.

The hydraulic ram operates at an arm of about 4,6m. As the counterweight accounts for most of the bridge's weight, the ram mostly has to overcome the bridge's moment of inertia. As the bridge nears it's maximum angle, the arm of the ram's moment decreases. For this reason it is imporant that the ram is placed at an offset from the bridge's axle. Also, the bridge is located slightly off the water's edge, and the bridge only has to open to about 80°.

When the bascule bridge is opened, the wind load becomes a more significant factor, as the bridge decks forms a large flat surface area. The wind load can again be calculated by the formula:

$$F = \frac{C_d \cdot \rho \cdot v^2 \cdot A}{2}$$

In this case the drag coëfficient is that of a flat plan which is around 1,2. At maximum wind speed and the most disadvantageous wind direction this results in a total force of 106kN and a moment around the axle of about 1200kNm. Even though it is unlikely that the bridge is operated at all during gale force winds, the structure should be designed to withstand these loads. Most of these loads will be handles through the beams that connect the axle to the main bridge deck.

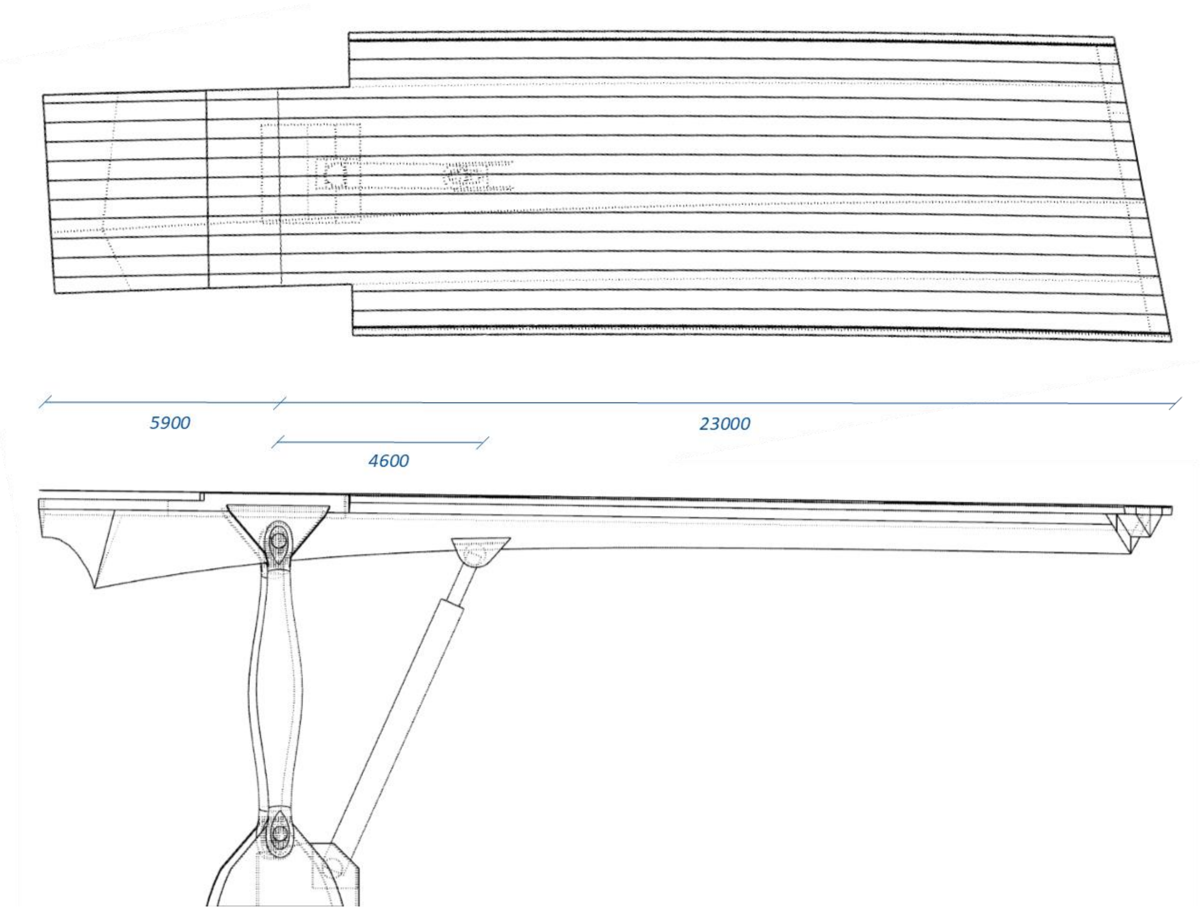


Figure 12.17: Schematic structural design of small movable bridge

13. Definitive design

Plans

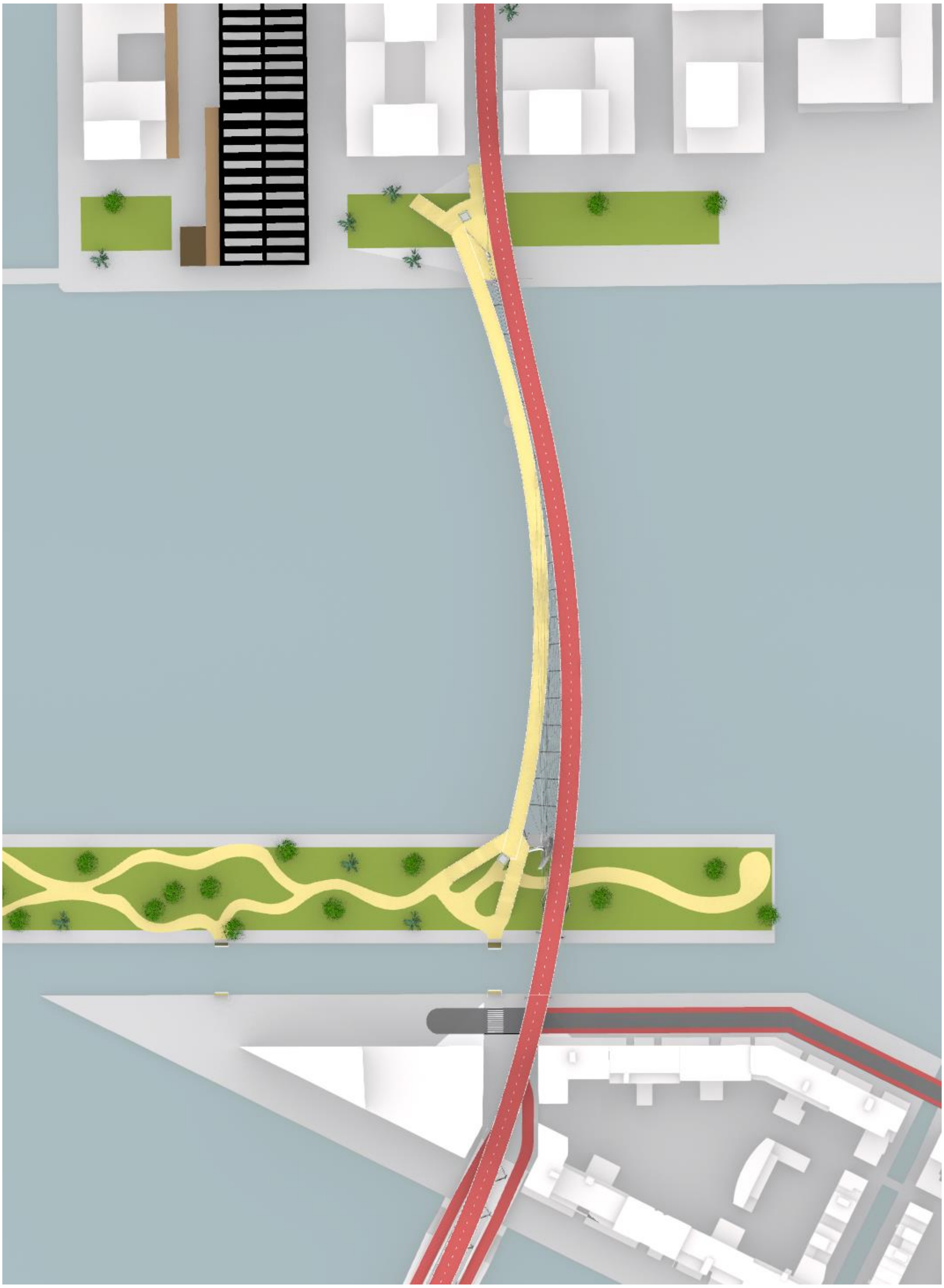


Figure 13.1: Ground plan of the bridge and context

Elevations

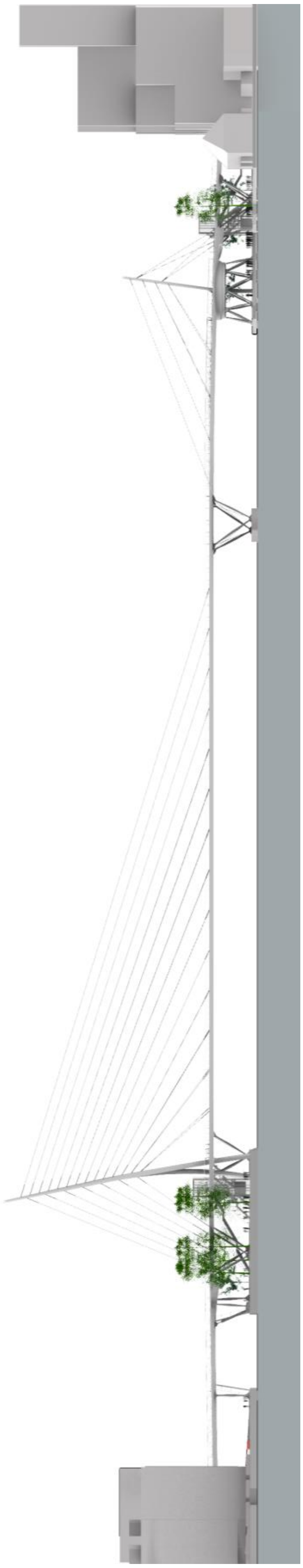


Figure 13.2: East elevation

Figure 13.3: South elevation. Buildings on Java Island are hidden. The Jan Schaeferbridge can be seen on the foreground

Sections & details

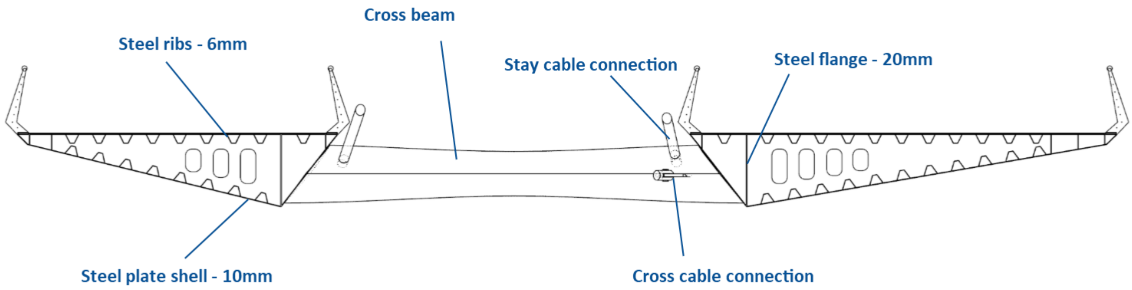


Figure 13.4: Section showing bridge deck construction

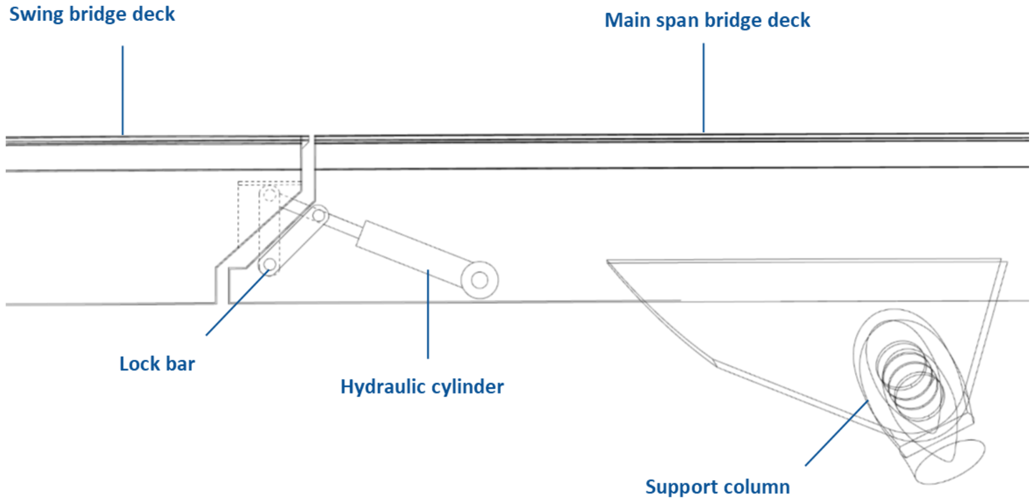


Figure 13.5: Detail of locking mechanism on swing bridge

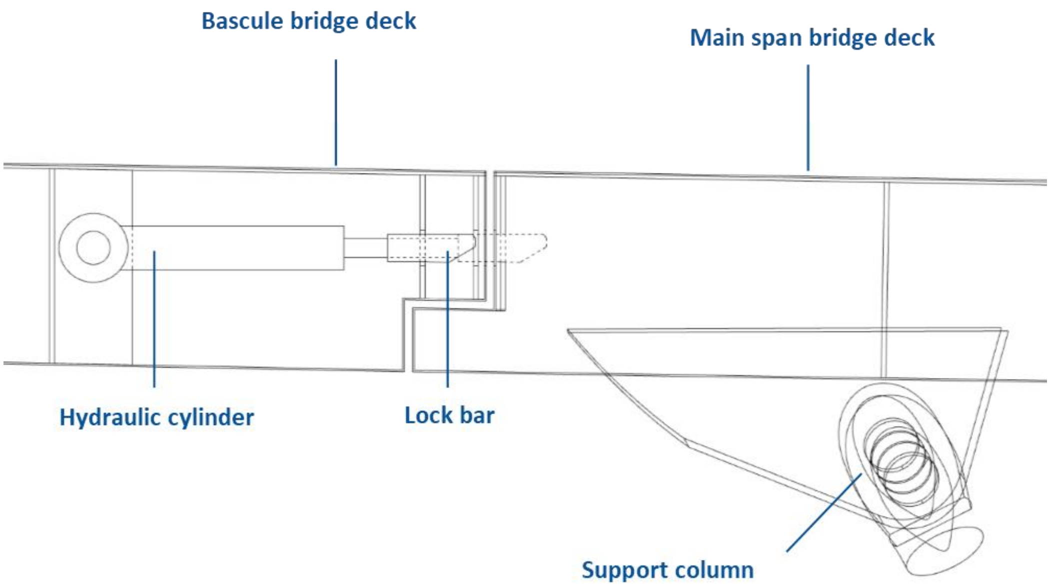


Figure 13.6: Detail of locking mechanism on bascule bridge

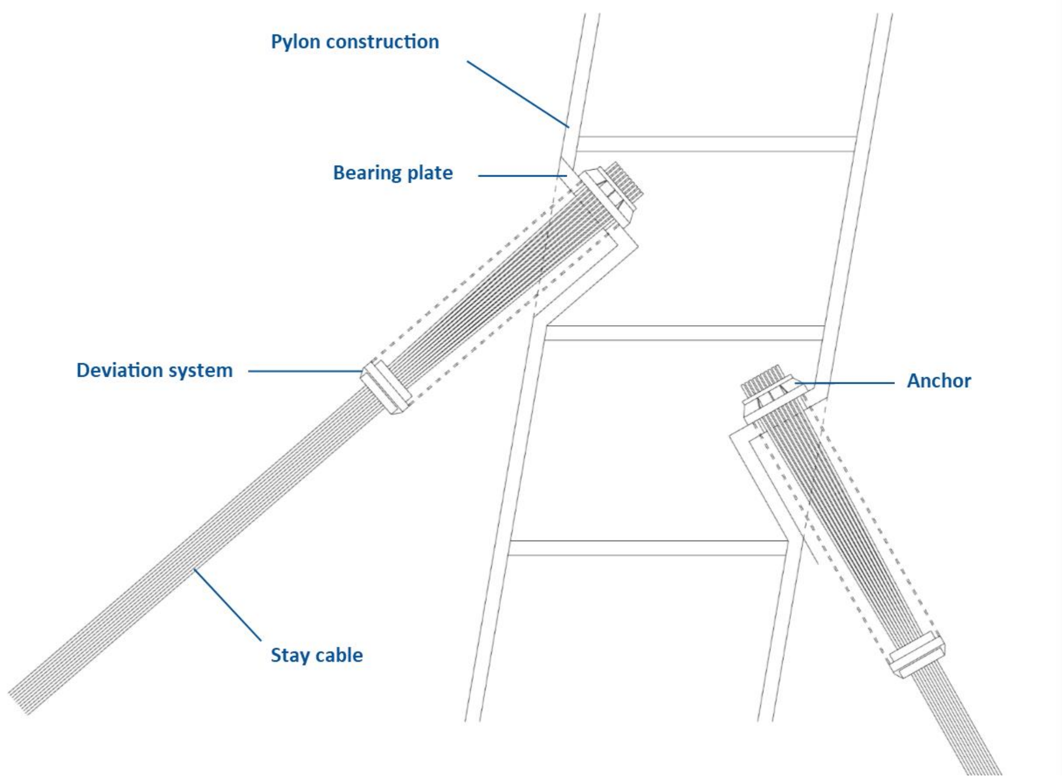


Figure 13.7: Detail of connection between stay cable and pylon

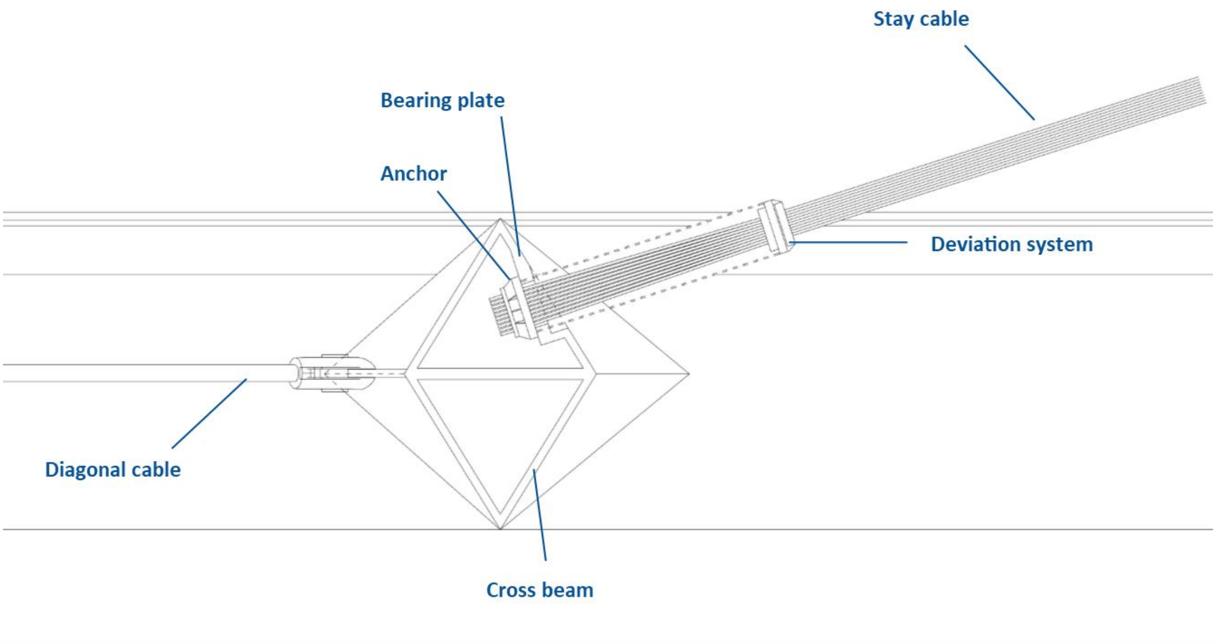
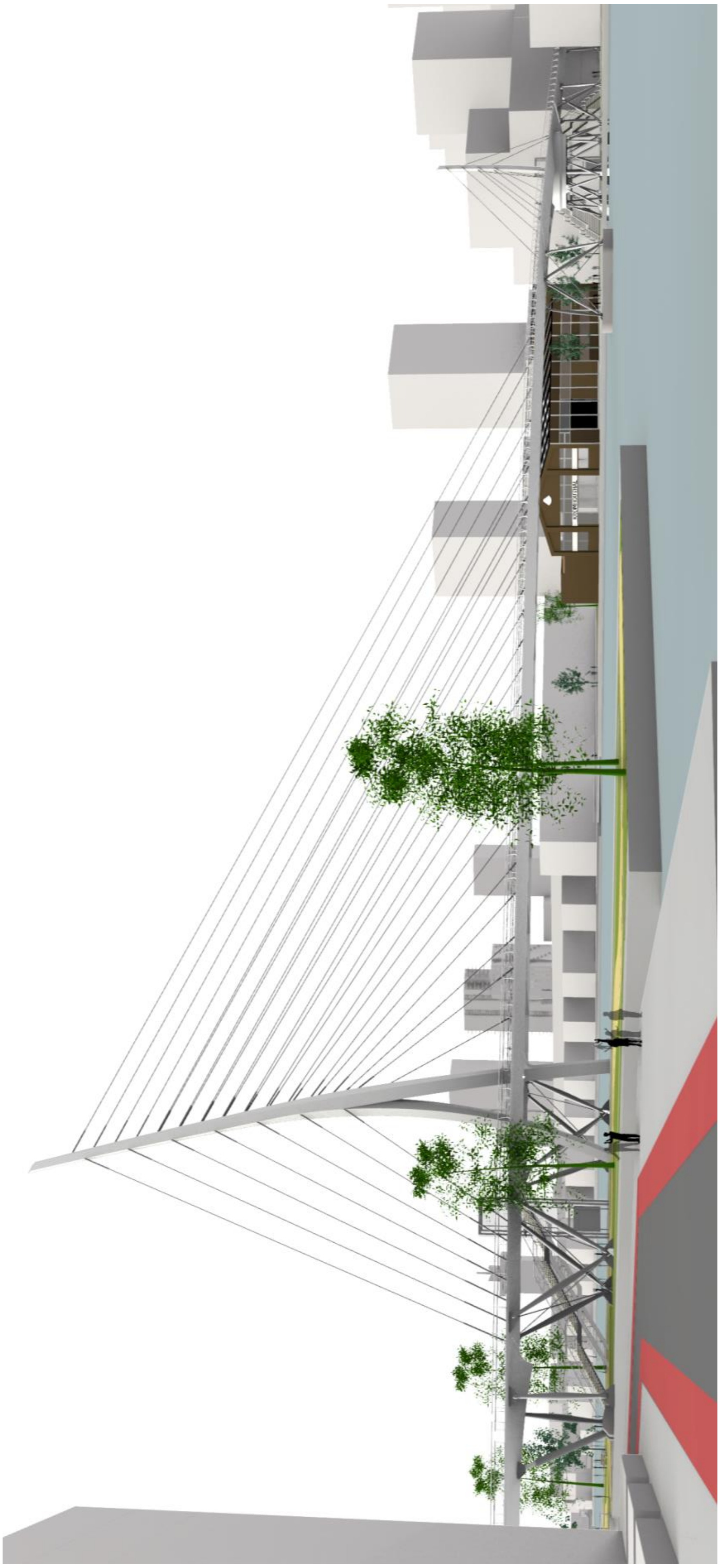
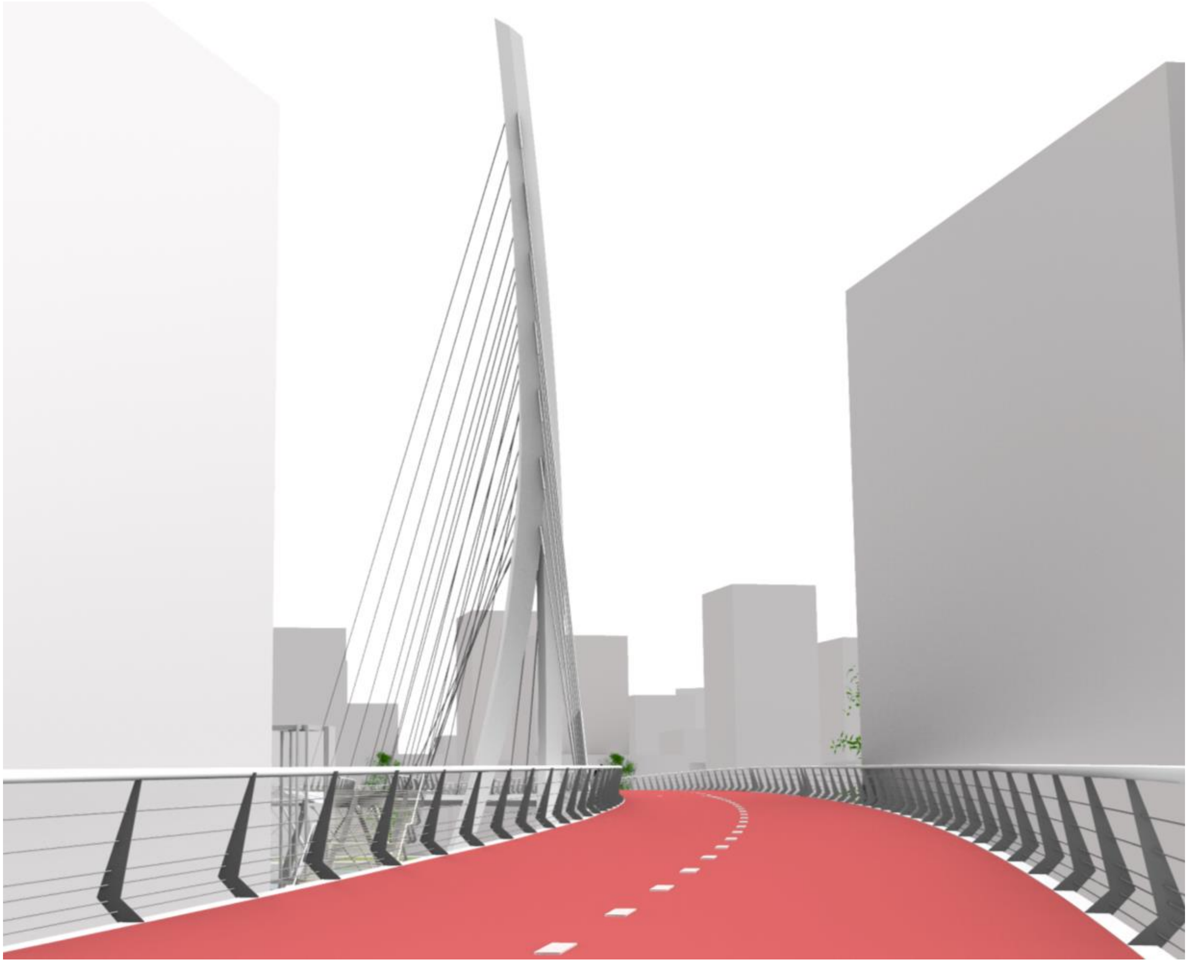
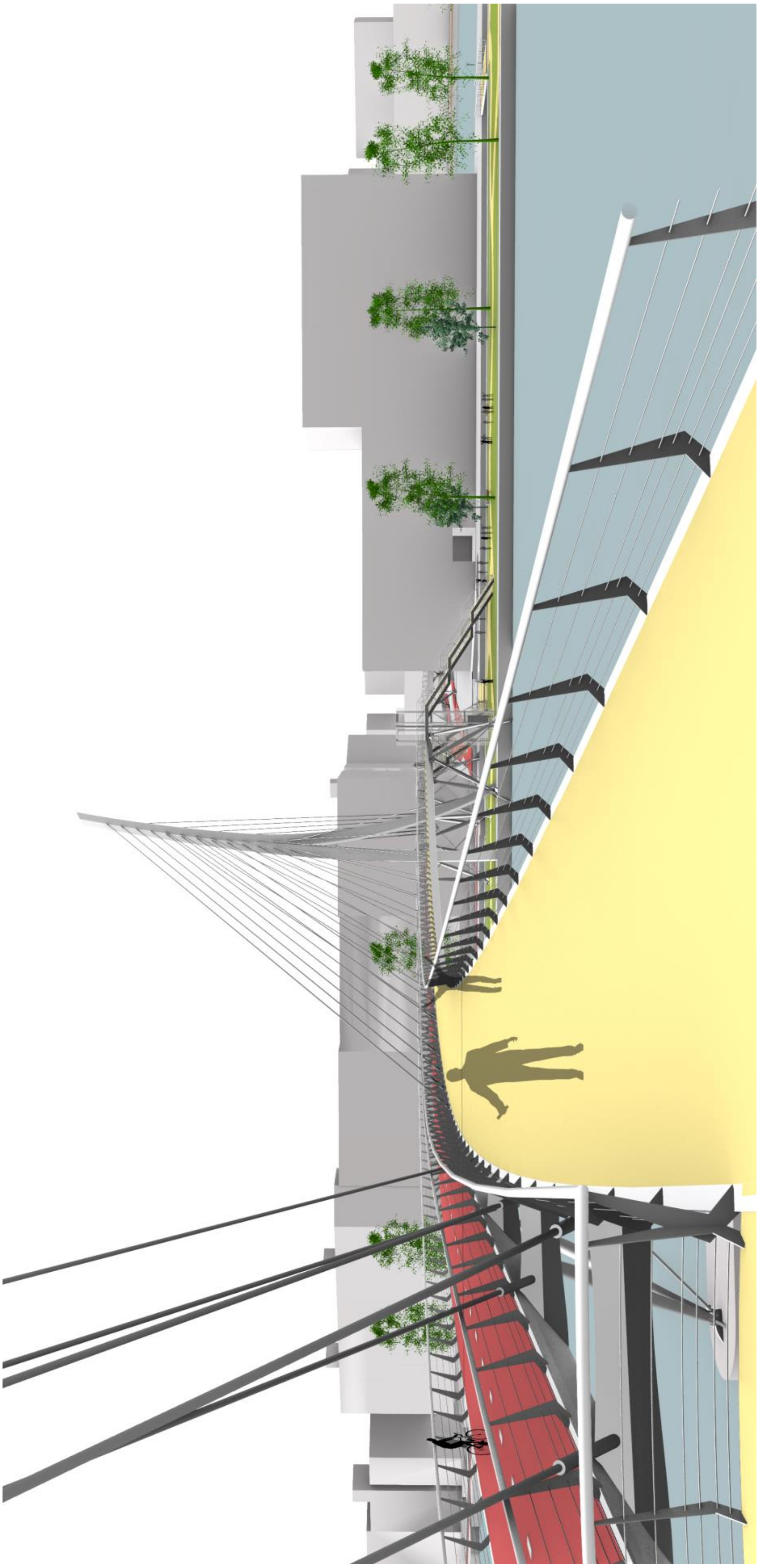


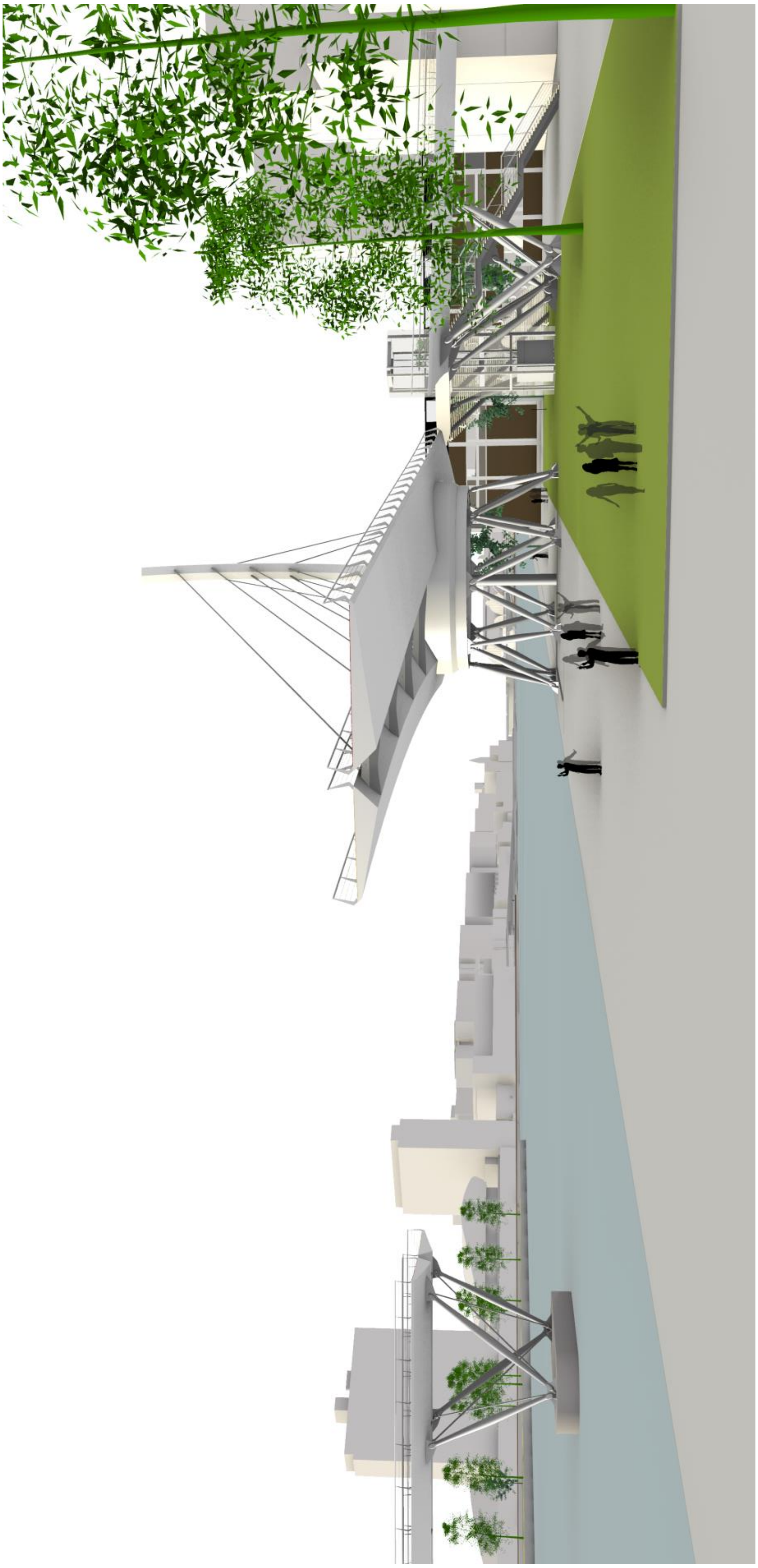
Figure 13.8: Detail of connection between stay cable and cross beam

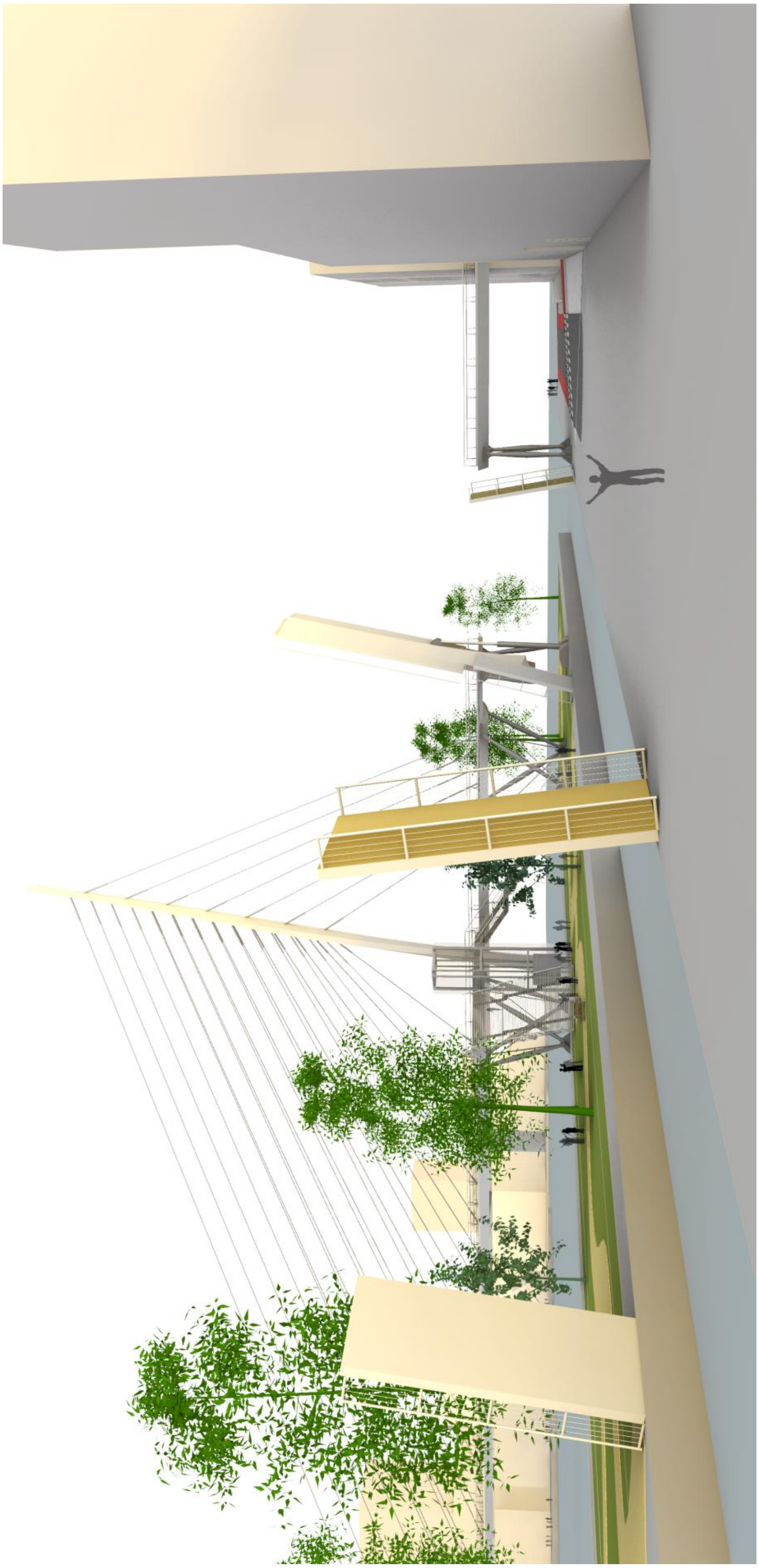
Impressions











14. Conclusions

The Java bridge turned out to be a complex and challenging case. While the location and prominence of the project are inspiring and push for creative design, the spatial and functional limitations are so strict that no design question ever has a simple answer.

Choosing the two different functions of the bridge as a main guideline for the design made for an interesting process. It did however magnify the challenges as described above. When early in the design I made the choice to split the deck in two parts and have the flowing lines of these parts play the most important part in the design, I created another significant limitation to the design of support construction or dimensioning of the decks. The end result is a design that sort of achieved the intended goals, but not entirely satisfying, while at the same time clearly showing compromises being made in terms of support structure.

For example, the desire to create a transparent construction and minimal connection size between support and deck meant that extra supports were required in a configuration that took up a lot of space. As the decks were split two of these constructions were required on Java Island, which is still excluding the pylon, stairs, lifts and movable bridge design. Clean as though the design of the deck itself is, the public space is cluttered with columns.

An important recommendation is therefore: In a case that is already defined by limitations to start with, do not add extra limitations from initial ambitions. A better workflow would perhaps be to start out with the limitations and work backwards from here. In this case this could be: In the very limited space on Java Island, supports for the main span, the movable bridge and the connections to ground level must be placed, with minimal impact on the usable public space.

In light of all the controversy that surrounds this case, whether the bridge should be built at all, I can conclude that, from a designer's point of view, the site offers many opportunities to create beautiful structures and interactions between the bridge and its surroundings. The complicated requirements and limited space do mean that the bridge will benefit from a simple, uniform design. Whereas I maintain that a proper connection to and between the banks itself are equally important as the larger scale connection between north and south, creating these landings should not clutter or otherwise damage these public areas by placing too many/too large structures.

15. Reflection

This section will serve as a reflection on the research and design process, the success and relevance of the final result and my personal experiences of this project.

Process

During the P2 I drew up a research framework to structure the project along its course. It consisted of four phases:

1. Analysis: A study of bridge design in general
2. Sketch design
3. Definitive design
4. Detailing

This mainly described the design process as it narrowed itself from large to small scale. Also, part of this framework was a list of tools and methods that would be best suited for each phase. Specifically software: Grasshopper (parametric design) for the sketch phase and Rhino (nonparametric design) for the definitive design phase.

In practice this was much more complicated. As so much of the requirements of this design case are based on the urban context, the larger scale design was much more important, and stayed important throughout the process. Even as the design progressed, each decision would put into question the bridges position and interaction with its complex surroundings. For this reason, most of it was done in grasshopper in the end, because grasshoppers parametric design allowed me to continue making changes to the larger scale layout while the smaller details were filled in. By switching from Diana to Karamba, it also allowed me to perform the finite element analysis within the adaptable model.

The main drawback of using parametric design is that creating detailed models is very time inefficient. At a certain point you have to step back to nonparametric design to work on a smaller scale. By diverting from the initial framework, it was very hard to find the right time to make this switch. Therefore, the balance between large scale design and small-scale engineering is rather lopsided to the first in comparison to the intended framework. This underlines the importance of selecting the correct tool for the correct job.

Results

Despite the complexity of the case, the final design does seem to adhere to all the requirements. However, I am not sure if it is a completely pleasing design.

As this is a research project, I set some specific ambitions and made some decisions to ensure the project would provide some interesting challenges. Coupled with my already very analytic style of designing, this put the project very much at the far end of the 'Design by research' spectrum, rather than at the 'research by Design' end. This meant most of the complex problems in the design were approached by first determining all the possible limitations, some of them self-inflicted, and only then trying to find the shape of the blanks that were left. By limiting the possibilities like this, eventually some decisions must be made that are never fully satisfactory.

An example: By setting the split deck shapes as the leading design guideline for the columns underneath, the Java Island side became very crowded with constructions in a very small space. The desire for a clean, neat look of the bridge decks was fulfilled, but the overall design became more chaotic.

The main conclusion from this regarding the existing Java bridge project is that the last thing this already over-complicated case needs is more restrictions from the designer's own ambitions. Also, starting from ideas and concepts and whittling these down to a feasible design may have more satisfactory results than starting from the limitations and trying to locate solutions.

Relevance

This project was purely a design case study, without any explicit initial focus such as a specific design method, building material or construction technique. This greatly limits its value as a contribution to general knowledge on bridge design.

It will be of some relevance to the design case that it addresses: the current development of the Java bridge. However, during my graduation project changes have been made to the existing case, and I have also made several decisions mainly based on creating and interesting and challenging graduation project. This widens the gap between graduation project and reality, again limiting its relevance.

There is however one area where I think this project shines an interesting light and poses some important questions, even though this was not initially intended to be its purpose. As the case study is set in a politically and socially controversial atmosphere, and a very complex urban setting, the effect that different priorities have on the development of urban areas becomes clear.
There is a consensus that we need to improve the sustainability of our society, including its transport networks, both for environmental purposes and allow further growth without catastrophic congestion. Large infrastructure projects like the Java bridge are required, even though they may conflict with other interests such as marine infrastructure and local residents trying to protect their current surroundings. In the present time it is very hard for government officials to find the middle ground between all these interested parties without encountering controversy and resistance at every step, as is being experienced in the current Java bridge project.
Independent studies like this graduation project have the freedom to explore solutions that would not be feasible within official projects, but that nevertheless might be off help in determining where the correct middle ground should be. It can help pose and answer general questions such as 'What is the value of efficient infrastructure design as opposed to maximum protection of existing surroundings?' or 'Does the benefit of better aesthetic design justify reducing consideration of other priorities?'

As part of the master track building technology these results may seem rather far from home. However, I think that this is very much an integral part of the building technology track, as even though these relevant questions are not technical in itself, in order to answer them the case needs to be explored from the perspective of an engineer, amongst others. This illustrates the connection between building technology, architecture and urban design.

Personal reflection

This project has been mostly enjoyable for me, and though I don't feel that the resulting design is a perfectly pleasing design for this case, it does represent the best I could achieve in the time I had and along the path I had chosen. However, there are some very important lessons I have to reflect on for myself.

The most important one is the importance of producing materials and moving the design process forward, even though I'm not sure about the solutions. When in doubt of a certain problem, I would find myself in a form of analysis paralysis where I would discard almost all possibilities before putting anything down on paper or in the computer. Then, without any physical products to show, I would hesitate to ask for help as I'd have nothing to ask help about. Before each meeting or deadline, when I could force myself to start producing materials, the speed of progress would multiply tenfold, for the simple reason of creating physical products. Also, then I would be able to receive feedback, which always proved useful to find new angles into problems that first seemed unsolvable.

This whole experience wasn't helped by my limited drawing skills: as I was not able to draw sketches good enough to give me some helpful insight, most of the work had to be done by computer. This takes more time and always feels more permanent, making it harder to simply try out different things.

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