



ROTTERDAM ON THE RISE  
GRADUATION REPORT  
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# ROTTERDAM ON THE RISE

MASTER OF SCIENCE (MSc) THESIS  
Bridge Design

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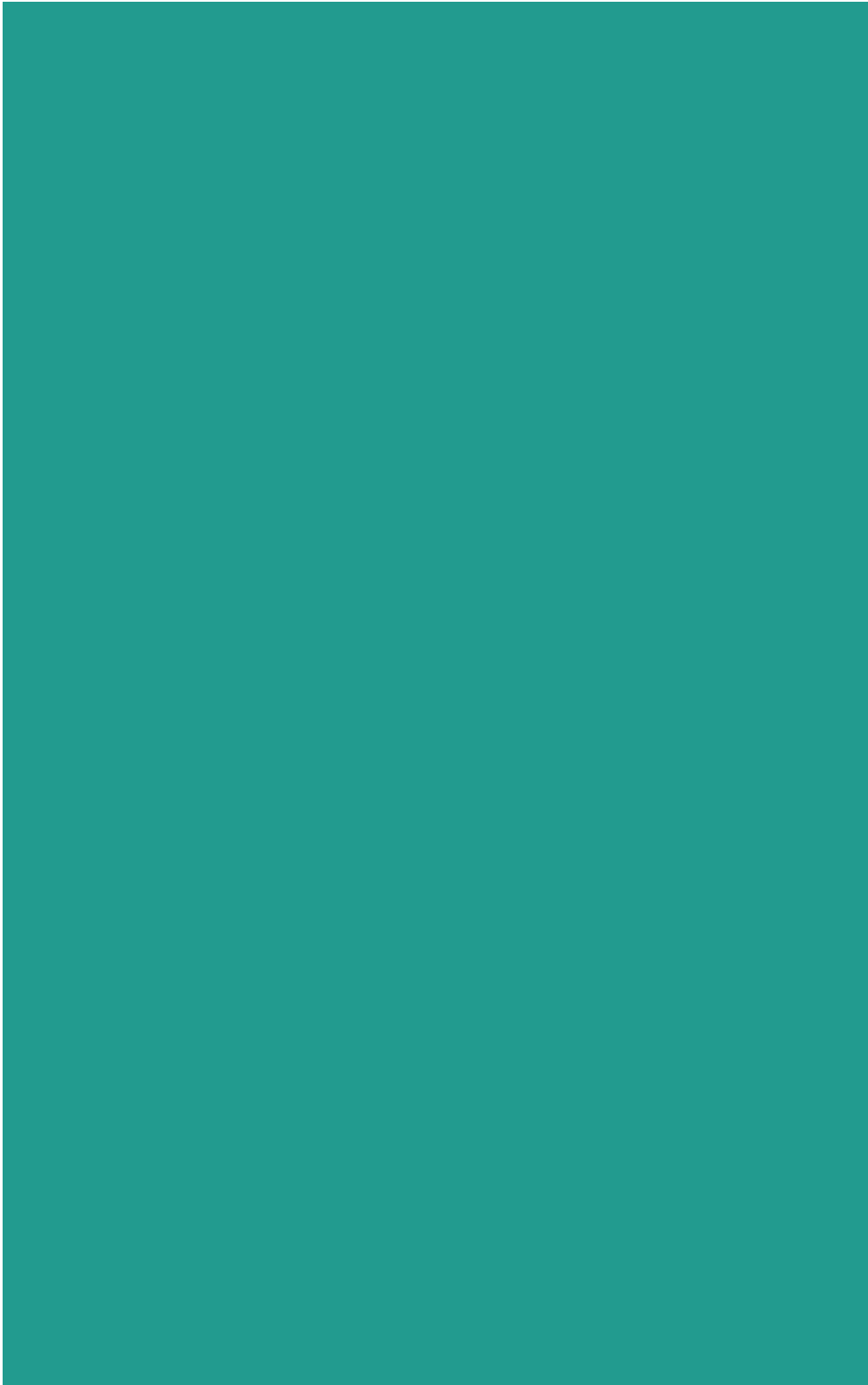
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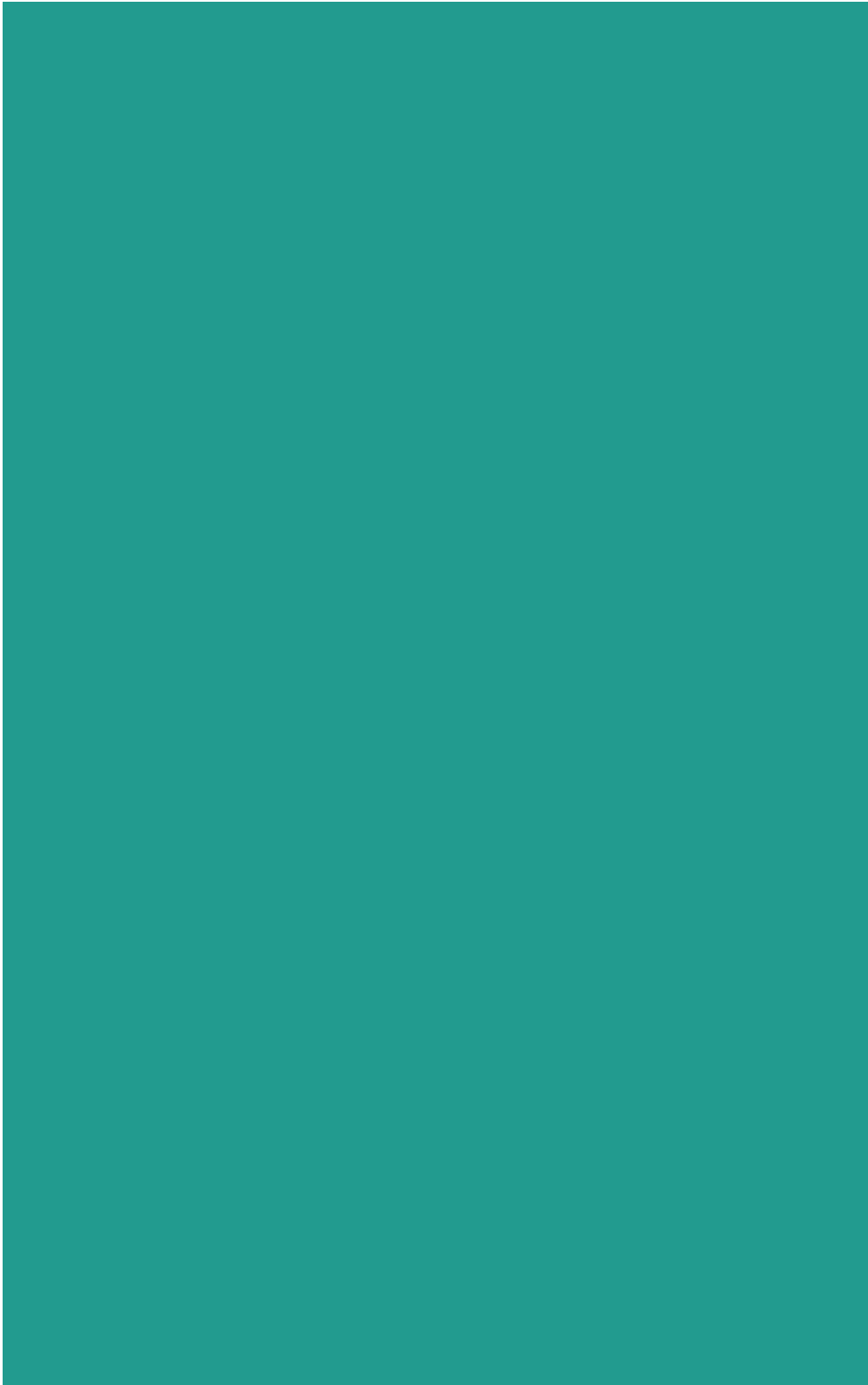
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# ABSTRACT

This research aims to find a solution for the mobility problem in the city of Rotterdam. By following the ambition and future plans of the municipality of Rotterdam a location is chosen. This location in the west of Rotterdam, between Delftshaven en Waalhaven offers various possibilities for a bridge crossing the Nieuwe Maas river. An analysis into various structural benefits of bridge design an outline for a new bridge is created. Using the strategic guidelines derived from the analysis of the location an future vision of the city of Rotterdam combined with the structural guidelines derived from the analysis in bridge design a new crossing was designed. The new bridge adds value to the direct environment by creating new public space for the residents of Rotterdam. Green quays are created at the banks of the Nieuwe Maas as well as an improved, branched public transport network. The bridge is designed as a vertical lift bridge, which allows cruise ships to pass under the bridge without effort so that they are able to dock at the Wilhelminapier in the center of Rotterdam.



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# I RESEARCH DEFINITION

# 1 INTRODUCTION

## 1.1 PROBLEM STATEMENT

The city of Rotterdam faces a mobility problem. The Nieuwe Maas is acting as a barrier between the north and the south of the city. With little possibilities to cross the river, the city center acts as the main route through which all traffic-flows lead but it is clogging with cars, cyclists and pedestrians. The problem is not only about capacity, but the lack of a high-quality alternative route across the Nieuwe Maas which can lower the strain on the city center and can provide a durable solution in terms of sustainable transport.

The municipality of Rotterdam has developed the 'Urban Traffic Plan Rotterdam 2016-2030' ('Stedelijk Verkeersplan Rotterdam 2016-2030') which provides the urban traffic vision for the city of Rotterdam till 2030. The goal is not to create mobility, but to use mobility as a tool in creating a strong economy, good health and spatial quality in the city of Rotterdam.

In the last few years there has been a shift in mobility. The people who use cars as their main use of transport has been constant for a years, but this number is now declining. In the mean time the use of bicycles and public transport is on the rise. This development however is fragile and is strongly dependent on environmental factors like demographics, developments in mobility and technological innovations (Gemeente Rotterdam, 2016).

The city center of Rotterdam is the social heart of the city, with the Coolingsingel as its main artery. The city center of Rotterdam however is also part of the main infrastructure and routes and is suffering from an overload of traffic flows. The municipality of Rotterdam is thinking about the redesign of the Coolingsingel in order to cope with this problem. Together with the redesign of the Coolingsingel there is an emphasis on the use of bicycles and public transport to discourage the use of a car for short trips inside of the city. Also, the addition of new possibilities to cross the Nieuwe Maas by bike, on foot or by means of public transport should lead to a more balanced distribution of traffic flows in the city center.

The enhancement of the national road network around the city of Rotterdam could absorb part the traffic load of the city center. The national roads around Rotterdam, also known as the 'Ruit' or Rotterdam Ringway, have the potential of redirecting a lot of the traffic around the city instead of going through.

The urban areas south of the Nieuwe Maas have always been disconnected from the city center due to poor public transport connections. This lowers the possibilities of the residents of these areas in terms of education and employment. The development of a new connection across the river can solve a lot of these problems whilst providing ample opportunities for the current residents. The construction of a new connection does however come with a lot of practical problems. The first and foremost being the issue of crossing a body of water. The Nieuwe Maas is an important waterway for the transport of cargo from the harbour of Rotterdam to the hinterland and back. Not only this high nautical activity, but also the width of the Nieuwe Maas, which is around 400 meters at most points, causes a challenge. The crossing over the river must not block these nautical traffic flows.

A second major practical problem is the implementation in the urban grid and the connection the current road network. In case of a bridge across the Nieuwe Maas, there has to be room for the bridge landings and space for the bridge deck to rise and cross the river, as well as an openable part to allow for large vessels to pass through. In case of a tunnel below the river the same applies for the connection to the current infrastructure and the space it needs in the urban grid to ascend and descent.

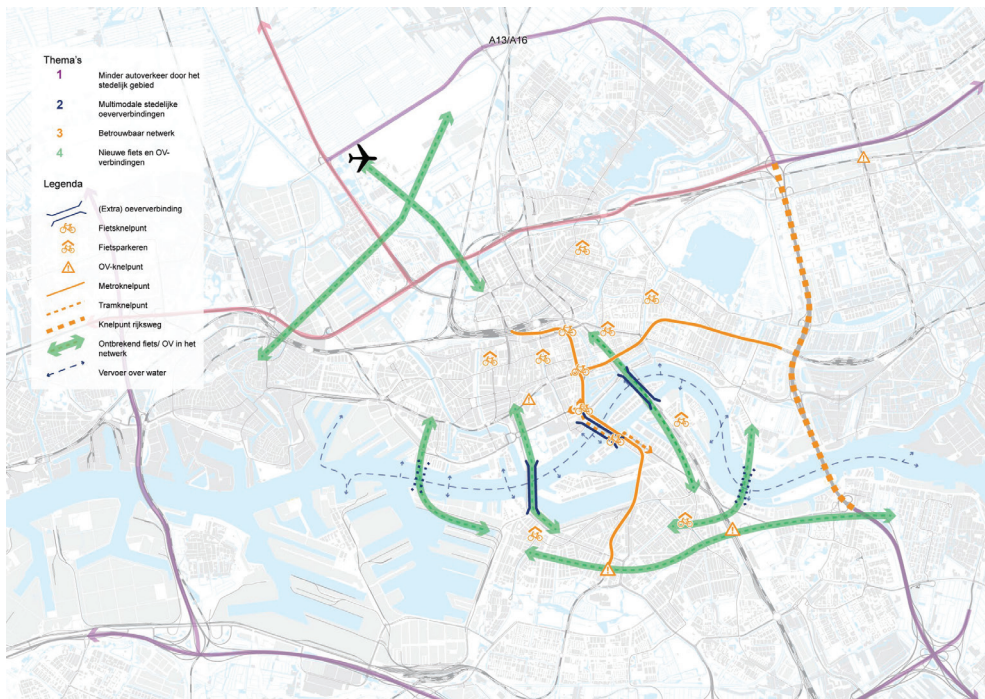


Figure 1.1: The current and envisioned traffic situation in Rotterdam (Gemeente Rotterdam, 2016)

Figure 1.1 shows an image from the Urban Traffic Plan Rotterdam 2016-2030. Highlighted in orange are the current bottlenecks in the urban grid. The most important one is the connection from the city center, across the Erasmus bridge to the south of Rotterdam. Highlighted in green are the possibilities for new connections across the Nieuwe Maas.

## 1.2 OBJECTIVES

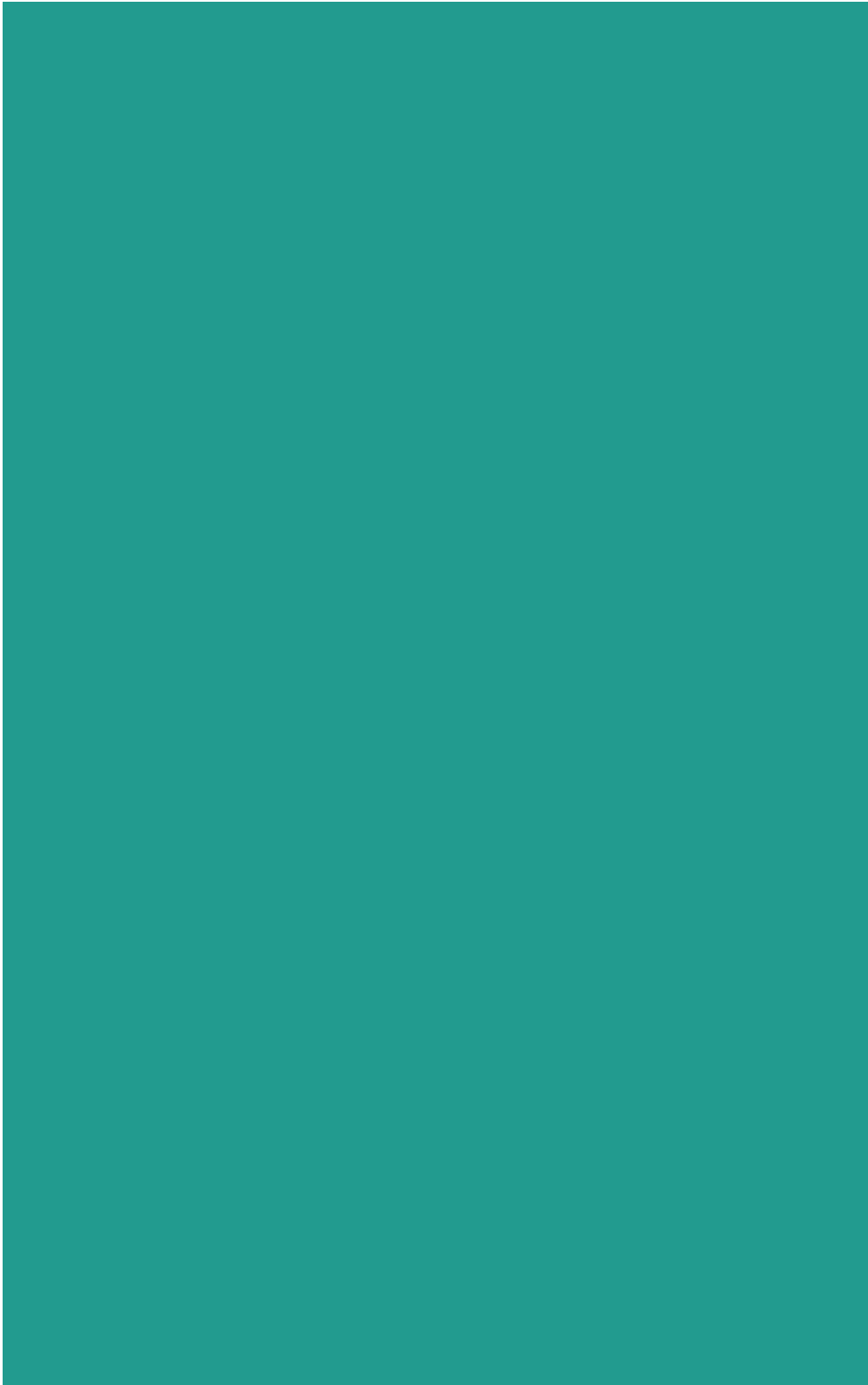
The main objective of this research is to determine the requirements for solving the infrastructural challenges in the city of Rotterdam by exploring the possibilities of a crossing over the Nieuwe Maas. This objective can be subdivided into smaller focus points:

- Provide insight in the infrastructural challenges in the city of Rotterdam
- Provide insight in the possible challenges of crossing the Nieuwe Maas
- To design, in general, a crossing of the Nieuwe Maas that complements the city of Rotterdam whilst providing improved spatial quality and accessibility.
- Solve the structural challenges of a crossing over the Nieuwe Maas

## 1.3 RESEARCH QUESTION

Can the mobility problems in the city of Rotterdam be solved with the design of a third bridge across the Nieuwe Maas, with due consideration of the preconditions and requirements on site?





## 2 METHODOLOGY

### 2.1 STUDY SCOPE

In order to conduct the research and create a design fitting for the posed problem, some choices will have to be made in order to create a fixed scope for the research. These choices are in line with the demands and future visions of the municipality of Rotterdam. Reason for this is to create a realistic assignment which fits an actual demand.

The first focus point will be the choice for the design of a bridge. A connection across the Nieuwe Maas could either be in the form of a bridge or a tunnel. The choice is made to go for the design of a bridge. A bridge is a very simple way of crossing an obstacle and in most cases cheaper than making a tunnel. For nautical activity to go undisturbed a tunnel would also have to run very deep which would make the connection and integration in the dense urban grid very difficult.

The second focus point will be on pedestrians, cyclists and means of public transport. Because of the focus of the municipality of Rotterdam to decrease the use of cars in the city center and to emphasize the use of public transport and means of slow traffic, the choice is made not to make the bridge suitable for multi-lane automotive traffic.

The third focus point will be on the location of the bridge. The Urban Traffic Plan highlight two possible places for a multi use river crossing. The choice is made to focus solely in the western option for a crossing. The western location will make a connection between Delfshaven and Waalhaven, two former harbours of the city. These locations are on the rise and a connecting bridge could not only benefit these areas, but the city of Rotterdam as a whole.

The last focus point is the choice of not allowing monster cruise ships to pass the bridge. Monster cruise ships are not able to dock at the Wilhelminapier near the center of Rotterdam. However, these cruise ships have a devastating impact on the environment. The city center has instated a low emission zone for cars to lower the amount of greenhouse gases and other harmful emissions. The city wants to make the Merwehaven in the west of the city suitable for docking of these monster cruise ships. During this research this plan will be accepted as approved.

### 2.2 METHODOLOGY

The methodology for the research consists of two major parts, a literature study and a design study. The literature study subdivides in three components, the first one being an analysis of the city of Rotterdam on an urban scale which will provide design guidelines for the bridge. The second component is an analysis of the location for the bridge between Delfshaven and Waalhaven which will provide boundaries for the design. The last component of the literature study is the research into bridging types, movable bridge types and bridge landings. This will provide structural guidelines and boundaries for the design. The second part of the research is the design study where the goal is to find the most optimal solution for the design and structure of the bridge given the guidelines and boundaries found in the literature study.

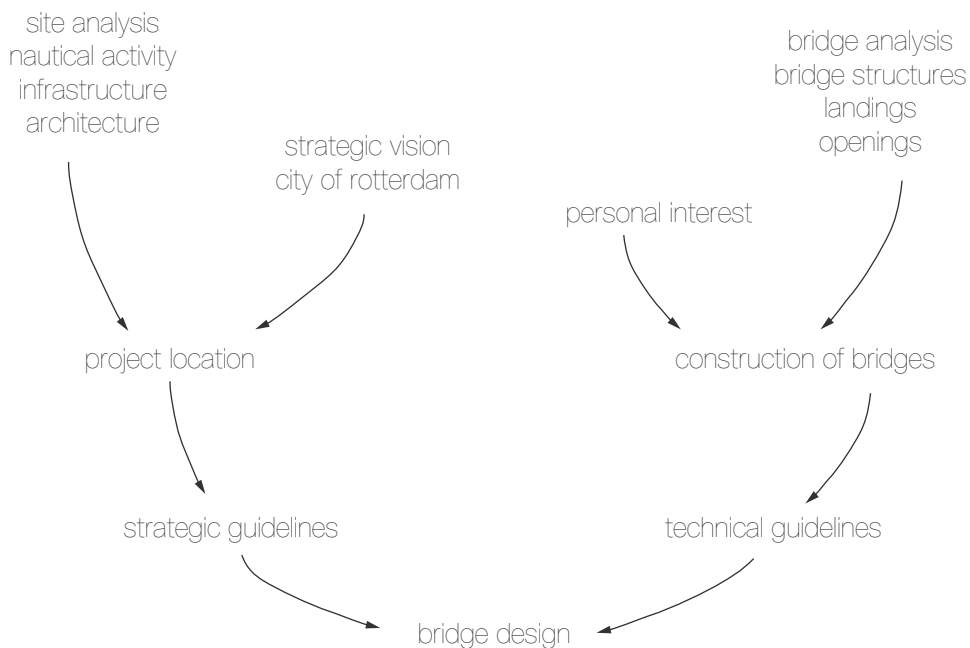


Figure 2.1: An overview of the methodology used for the research (own illustration)

## 2.3 RESEARCH FRAMEWORK

The research consists of two parts, a literature study and a design study.

### 2.3.1 ROTTERDAM

The first part of the literature study will be an in-depth investigation of the city of Rotterdam. The goal of this literature study is to provide the guidelines for the urban scale of the design.

The first important point of interest is the geographical layout of the city of Rotterdam and its history and formation. This will lead to points of reference for the design. The second point of interest is the development of the connection between the city and the Nieuwe Maas. The relationship between the city and the harbour will undoubtedly have a large impact on the design guidelines. The third point is the vision of the municipality of Rotterdam must be investigated. There are several reports written about the vision of the municipality for the future of the city of Rotterdam in terms of growth, transport and development. The fourth and final point of interest is a research into the current bridges across the Nieuwe Maas. By investigating the different styles and uses for the current bridges there can be guidelines drawn from that analysis.

### 2.3.2 SITE ANALYSIS

The site analysis will not only focus on the history of Delfshaven and Waalhaven, but will also focus



on the future plans. The history involves major changes through the years and its past as part of the harbour. The future will be the shift towards housing and business. Also the connection between the surrounding areas is of major importance. The goal is to develop a connection which will benefit the city as a whole. Source for this research are the future spatial planning plans concerning urban traffic. Not only urban traffic flows need investigating, but also the nautical activity on site. The Nieuwe Maas acts as an important waterway between the harbour of Rotterdam and the inland. Therefore an analysis of the different ships and vessels that make use of this waterway is of great importance. This will lead to guidelines and boundaries for the structural demands of the bridge crossing the Nieuwe Maas.

### 2.3.3 BRIDGE ANALYSIS

In order to design a bridge, there must first be an in-depth analysis of the different types and possibilities of a common bridge. This research will consist of an investigation towards these bridge types as well as an investigation towards the possibilities of creating an opening in a bridge and the possible methods of connecting a bridge to the existing infrastructure.

The analysis of these different bridge types, openings and landings will provide the research with benefits and disadvantages of the posed methods. When applied to the location they will act as the structural guidelines and boundaries for the design.

### 2.3.4 DESIGN STUDY

The literature study for the city of Rotterdam, the site location and into the different methods of bridge design will provide a set of boundary conditions and guidelines which can be used in the design study. The design study will search for the best possible solutions given these boundaries.



# 3 THE CITY OF ROTTERDAM

## 3.1 HISTORY AND CONTEXT

Rotterdam is one of the mainports of the Randstad area in the Netherlands. The Randstad is the conglomerate of the cities of Amsterdam, Utrecht, The Hague and Rotterdam. The future of mainport Rotterdam are of vital importance of the future of the Randstad as a whole. A second point of interest is that Rotterdam can play an important strategic role in the other economic important zone of the west part of the Netherlands; the Rijn-Schelde delta. The Rijn-Schelde delta is of vital importance in terms of logistics and industry renowned worldwide. Rotterdam connects these two areas and can is able to focus on both at the same time.

The economy of the Randstad is thriving on business services and research institutions, economic sector which are on the rise. The development of the high speed train line was of vital importance in connecting Rotterdam with Amsterdam in the north and Antwerp and Paris in the south. The shorter travel distance brought major economic opportunities.

The global position of the Randstad is strong, but it is difficult to maintain this position in the rapidly developing world economy. The cause of this is the slow growth in the economic area of knowledge and services. It is therefore of great importance that the city of Rotterdam improves the conditions on the labor market and the quality of life inside the city. These two factors are intertwined and strengthen each other, because a good living environment leads to a strong and high qualified labor force and the other way around.

In summary the goal of Rotterdam as part of the Randstad is to develop itself while focusing on improving the quality of life and living (Gemeente Rotterdam, 2007).

## 3.2 FUTURE PLANS

Through the years there have been multiple plans for the development of the city of Rotterdam. The main goal of these plans is to improve the quality of life and living. As stated earlier this has a strong connection with the urban quality. The focus of this literary study will therefore focus on the mobility aspect of the future plans for the city of Rotterdam.

### 3.2.1 ROTTERDAM MOBILITY AGENDA

In 2014 the municipality of Rotterdam published their plans for mobility in and around the city, the 'Rotterdam Mobility Agenda 2015-2018' ('Rotterdamse Mobiliteitsagenda 2015-2018'). The main focus of this publication is 'more green, less steel'. In short this means more green routes throughout the city and less focus on the car as a mean of transportation.

Cities and urban areas are growing rapidly. The four largest cities of the Netherlands; Amsterdam, Rotterdam, Utrecht and The Hague account for around 40% of the population growth. The intensification of urban areas does contribute to the sustainable use of transport. Because of the low density of facilities and services in rural areas, residents of small villages usually have to travel larger distances, which is in contrast of the high density of services in an urban area. Where people of a rural area mostly rely on cars for their transport, people in urban areas use more means public transport. With the growth of the population and the migration of people towards urban areas, the stress on public transport systems

is increasing. The cities are hereby faced with the problem of improving and enhancing their public mobility and transport. The aim for the municipality of Rotterdam is to improve these systems, while maintaining the quality of public space.

The growth of auto mobility in and around Rotterdam is decreasing and stabilizing over the last couple of years. The amount of traffic on the Rotterdam ring way, the 'Ruit' is stabilizing and the amount of traffic in the inner city is even decreasing slightly. The aim of the municipality is to lower the amount of automotive mobility even further.

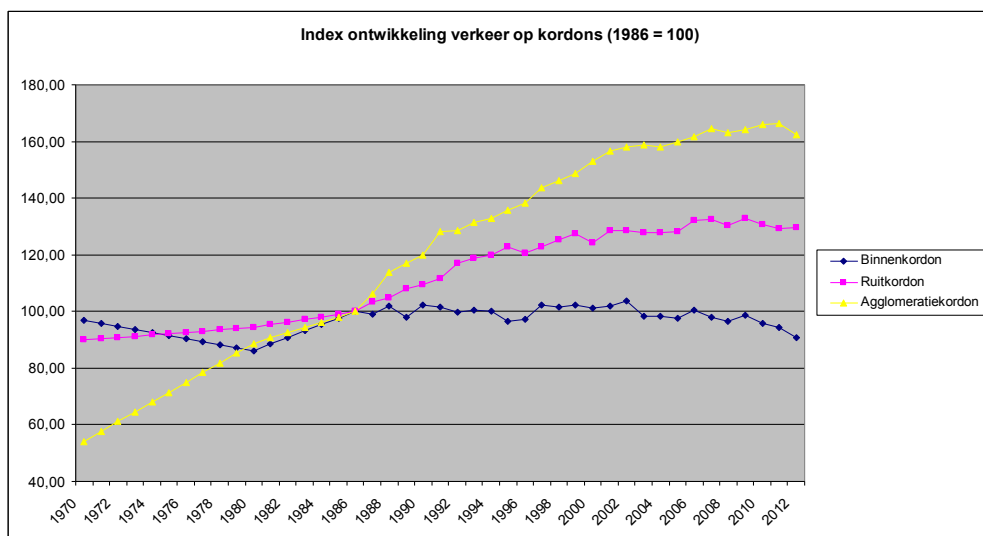


Figure 3.1: An overview of the development of automotive mobility in and around the city of Rotterdam (Gemeente Rotterdam, 2014)

The use of bicycles in and around the city of Rotterdam has increased over the years. In the period between 2002 en 2012 the use of bicycles increased over 60 percent. Also the use of electric bikes, especially for longer rides, increased. The use of public transport in the Rotterdam region has been stable for some years. There is however a slight decrease in the use of bus and tram.

The last few years there has been an increasing focus on clean mobility. The most important reason for this is the emission of CO<sub>2</sub>, NO<sub>x</sub>, fine dust and noise disturbance by traffic on the main roads. Rotterdam is encouraging the use of electric vehicles and bikes and is stimulating the use of electric vehicles for transport and distribution of goods.

### Mobility challenges

Aside from the posed development, there are mobility issues which need to be addressed in the city of Rotterdam. The first issue that needs looking after is the use of bicycles. The growing use of transportation by bike is causing the first 'bike traffic jams', for example on the Coolsingel, Erasmus bridge and Wilhelminaplein.

The second issue is the topic of spatial quality. Spatial quality has a lot to do with the attractiveness and experience of the current infrastructure. There are major opportunities in the development of spatial projects. Good examples of projects where spatial quality and mobility go hand in hand to deliver a good project are the new Central Station area, the Nieuwe Binnenweg and Parklane.



Figure 3.2: *The newly developed area in front of the Central Station in Rotterdam (Nationale Staalprijs, 2014)*

In the coherent road network of the city and region in the present situation there is a precarious balance in existence. Of one option fails, the other routes are increasingly loaded with traffic. The central routes in Rotterdam would benefit from a lower traffic load. In this perspective the river crossing is a serious point of attention. With an ongoing intensification of the traffic load in the center of Rotterdam the Erasmus bridge and Van Brieneoord bridge will be under heavy traffic load. It is for future use desirable to increase the flexibility of public transport connections. This way there can also be major steps taken in the development of the public transport in the Zuid area and the social-economic development of this area.

### 3.2.2 VISION 2030

As part of the Randstad area, Rotterdam has to develop itself. On one side the development has to focus on a knowledge and service economy, whilst on the other hand focus on creating an attractive living environment for educated, creative workers and people with a middle to high income. This strategy is of vital importance to continue to play a role in the international competition between urban regions. This is an urgent necessity, because the city of Rotterdam can only profit from the growing population for a short amount of time. The vision consists of a multitude of elements.

#### **Modern metropolis**

In 2030, Rotterdam will be a clean city at the mouth of the Maas. The city, with its recognizable skyline

will breathe the trade spirit of the old days. With more than 600,000 people living and working within the city borders, combining more than 150 nationalities. All these people are in contact with each other and with their relatives and friends around the world. Rotterdam has undergone a major transformation in the last 30 years and has now become an attractive city in Europe and sets an example as a modern inter-cultural metropolis which is finding innovative ways to further develop itself.

### **Residential city**

Within 25 years, the famous Rotterdam mentality has led to a metamorphosis of the urban areas. There is a housing option available for everyone. Living in the city center is very popular with starters in the housing market as well as older people thanks to good facilities and excellent public transport. The urban areas surrounding the city center all have their own character, history and function. They provide a peaceful and varied living environment for all layers of the population. The green urban areas at the outside of the city provide a nice living environment with good facilities. The attractive outdoor areas make this a popular neighbourhood.

### **Public transport**

Travel is made easy with plenty options to choose from. The public transport network consists of a multitude of elements including the HSL connections, subways, trams and hydrogen buses. Together with public transport is an excellent network of roads, cycle paths and sidewalks which connects the different urban areas as well as the nature and recreational areas surrounding the city. The water terminal in Leuvehaven dispenses the water taxis and a network of buses provide ample destinations in the city. Different means of clean transport complete the possibilities of transport.

### **Green areas**

Attractive pedestrian routes in the city center are used by residents and visitors alike. Opportunities for meeting and relaxing are offered everywhere on one of the many boulevards or on the quays of the Nieuwe Maas river. In addition, there are many green spaces available. Not only in the city itself, alongside the boulevards, in side streets or courtyards, but also along the quays of the river. These places provide a possibility for sports and relaxing in the heart of the city. Small restaurants, small settings and street art complete the lively cityscape.

### **Water areas**

By unveiling the historic waterways, the recreational function of the city center is improved. The connection with the water is never far away. Canals and rivers provide the center with an amazing spatial view as well as the possibility for water storage in the city.

## **3.2.3 MOBILITY PLAN**

The municipality of Rotterdam states that mobility is not the aim, but merely an essential contribution for a strong economy and improving the health and spatial quality of the city of Rotterdam. The 'Urban Traffic Plan Rotterdam 2016-2030' envisions the future traffic solutions within the city. The document creates an outline for a reliable and functioning urban network, combining different types of transport (pedestrians, cyclists, automobiles and public transport) and envisions a balance between them. By creating a longterm vision a new approach is created. This approach is to improve the quality of life in the different neighbourhoods, outside urban areas and improve the overall health of Rotterdam and its inhabitants.

In recent years the mobility transition has been on a rise. The use of a car as main mean of transport has been steady for years and is now even reclining a little. On the other hand the use of bicycles and public

transport is on a rise. The transition to more sustainable ways of transport is growing but is very hard to predict because this depends strongly on environmental factors. The environmental factors are, for example, the economic development in an area, the composition of the population, price development in mobility and technological innovations. The mobility transition is the strongest in the city center, as opposed to the outer neighbourhoods. Keeping all these scenarios in mind, the Urban Traffic Plan deals with four important outcomes.

### **Reduce traffic in city center**

Places for meeting and relaxing are signs of a healthy city. By allowing less car traffic through the city center and the surrounding city districts, the municipality wants to create more meeting places. When we better divide our traffic flows over the total network of urban streets, routes and traffic squares, this then contributes to a great livable and economic potential of which not only the city center, but also the surrounding neighbourhoods can profit.

The refurbishment of the Coolsingel is the start of this change. Also, by increasing the capacity of the national roads surrounding the city, drivers are more inclined to drive around the city center, thus creating more space on the urban roads in the city center, such as the Coolsingel. In addition, emphasizing the use of a bicycle instead of a car, will greatly reduce the number of short car trips within the city center. New possibilities for crossing the Nieuwe Maas, both fixed and by boat, for both the car as well as public transport, cyclists and pedestrians will lead to a more balanced distribution of traffic flows across the river and a rise in public transport and cyclist connections.

Emphasizing the use of a bike will be better accomplished by connecting cycling paths and cycling routes between the different city districts. This will make cycling more attractive and will reduce the number of car trips in the city center.

### **Opening up the West en South areas**

A new connection over the Nieuwe Maas in the western part of Rotterdam can play a central role in transforming the western part of the city. The Parklane is already a strong element and can, with the addition of a crossing in the West, be continued in the South of the city. A new connection between Delfshaven, through the Maashaven, to the Charlois and Carnisse will provide many social, spatial and economic opportunities. Because of the new connection, there will be a transition of traffic towards the western part of the city, moving away from the old city districts. Because of this shift in traffic, the air quality and road safety of the old districts will improve. Further improvement will be created by improving the public transport, and bicycle and pedestrian facilities, thus strengthening the movement towards clean mobility. The Maastunnel can remain an important part in the connecting network. Important locations like the Erasmus Medical Center, Hart van Zuid and the western part of the inner city can then remain accessible in an optimal way.

### **Connecting the Center en South areas**

The South of Rotterdam is missing elementary public transport connections. Apart from the metro line there need to be more connections with the regional public transport networks. This can be achieved by constructing a connection across the Willemsbrug, between Zuidplein, Stadion and Erasmus. This creates a strong route across the South area which benefits the inhabitants. The better connection improves the chances of the residents for traveling to work or school. With a new eastern connection, the City Lounge in the city center can be extended to the east. On the south bank the Kop van Feyenoord has the possibility to transform into a very interesting residential area alongside the river. An eastern connection can also help relieve pressure on the Van Brieneoord bridge.

### **An accessibility strategy that evolves with the city**

The long-term development strategy for the accessibility of the city and surrounding region provides

very promising strategies in creating an urban and regional network of infrastructure which is sufficiently flexible to the Rotterdam of tomorrow. In the area of mobility the municipality of Rotterdam is always focused on the development of the residents, partners and stakeholders of the city and the surrounding region. The current transition arises from the desired spatial and economic development of the city and the surrounding region but can be adapted to match the spirit of time.

### 3.2.4 CONCLUSIONS ON MOBILITY

When looking at the different reports and plans made by the municipality of Rotterdam, there are a few important measures. The first one is the wish of the municipality to create a city where the different traffic flows are evenly distributed and there is space for everyone. There will be a balance between all traffic flows like cars, cyclists and pedestrians. This will result in a better quality of living in the urban areas, improved opportunities in the South and West by creating a connection in the East and West as well as improving the connection with the regional network.

### 3.3 CURRENT BRIDGES

There are currently five bridges over the Nieuwe Maas in Rotterdam. Four of these bridges are right in the center of Rotterdam, whilst the fifth one is part of the A16 highway which runs to the east of Rotterdam. Of the four bridges in the city center, three are still in use as traffic bridges.



Figure 3.6: An overview of the main roads in and around the city of Rotterdam (own illustration)

When approaching Rotterdam from the west, the first major bridge you will encounter is the Erasmusbrug. After the Erasmus bridge the Nieuwe Maas will run north of the Noordereiland under the Willemsoordbrug, or south of the Noordereiland through the Koningin Wilhelminabrug. Over the Koningin Beatrixbrug there



are two bridges, the Koninginnebrug and the decommissioned Hefbrug. These four bridges are the all within the city center, whilst the Erasmusbrug and Willemsbrug are known as the main city bridges.

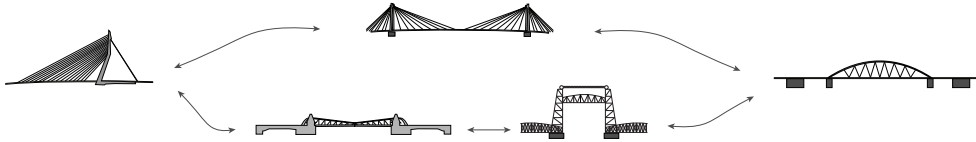
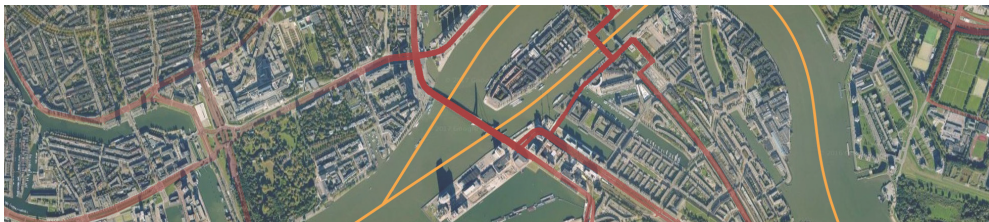
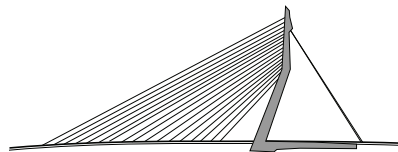


Figure 3.7: An overview of the main bridges crossing the Nieuwe Maas river in the city of Rotterdam (own illustration)

### Erasmusbrug

The first bridge is the iconic Erasmusbrug. Stretching 800 meters across the 400 meter wide Nieuwe Maas it connects the Coolsingel in the city center via the Schiedamsedijk with the urban areas in the south.

Architect:	B. van Berkel	
Year of construction:	1993 – 1996	
Construction type:	Cable-stayed bridge	
Operability:	Bascule	
Material:	Steel	
Measurements:	Total length:	802 meter
	Width:	33,8 meter
	Pylon height:	139 meter
	Vertical clearance:	12,5 meter above NAP



The Erasmusbrug was primarily built in order to allow different traffic flows to reach the south bank of the Nieuwe Maas River. There are two one-and-a-half lane roads for cars to cross, as well as two cycle paths, two sidewalks and a dual carriage tram way. Not only was it built for a physical connection between the north and the south, but for a symbolic connection as well. The Nieuwe Maas river has long been a barrier between the north and the south of Rotterdam and with the construction of the Erasmusbrug, this barrier could now be overcome. The Erasmusbrug gave a massive impulse to the southern areas both for the environment and the development.

Even more than twenty years after the Erasmusbrug was built, it still is the most iconic symbol of the city of Rotterdam. It states the symbol for Rotterdam as a modern metropolis. An ingenious part of the bridge is its traffic system. Because of the one-and-a-half lane traffic lanes, there is a natural tendency for timid driving, whilst still providing enough space in a congestion situation. Outside of the cable-stayed deck, the pedestrian and bicycle paths are given a tremendous view over the Nieuwe Maas river.

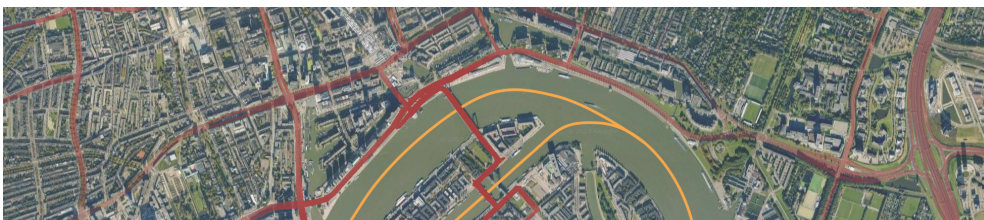
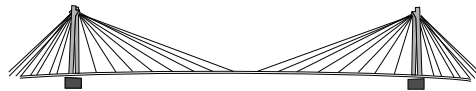


Figure 3.8: A night view of the Erasmusbrug crossing the Nieuwe Maas river in the city of Rotterdam as seen from the West (photo: Flickr)

### Willemsbrug

The Willemsbrug is the most eastern connection still within the city center. The bridge connects the city center of Rotterdam with the Noordereiland, an island which lies within the Nieuwe Maas river, just north of the Feyenoord area.

Architect:	C. Veerling	
Year of construction:	1975 – 1981	
Construction type:	Cable-stayed bridge	
Operability:	Not possible	
Material:	Steel	
Measurements:	Span:	270 meter
	Width:	34 meter
	Pylon height:	55 meter
	Vertical clearance:	11,5 meter above NAP



The northern ramp of the Willemsbrug is connected to the northern quay via a ramp which has a 90 degree angle with the main deck of the bridge. After making this 90 degree turn, the bridge crosses almost 300 meters over the Nieuwe Maas. The deck is upheld by two main towers and a cable-stayed system. The south ramp of the bridge consists of a natural ramp which follows the route over the length of the Noordereiland.

Up until the opening of the Maastunnel in 1941, the old Willemsbrug was the only fixed connection between the north and south part of the city of Rotterdam. The increase in traffic flows found a rising bottleneck in the old Willemsbrug. Plans for the replacement of the Willemsbrug with a new crossing where made shortly after the second World War. During the fifties the plan was to construct a combined rail and road tunnel underneath the Nieuwe Maas. The National railroad voted against this plan after which the municipality opted for a plan of a six lane traffic tunnel, which also this plan was soon pulled out after the municipality decided not to allow big traffic flows through the city center in favour of the Van Brienoordbrug and Beneluxtunnel.

The Willemsbrug acts as a very functional bridge with its two characteristic red pylons which hold a wide slab across the water. The wide slab allows for cars, buses, cyclists and pedestrians to cross the bridge. The downside of the Willemsbrug are the landings in the north and the south. The landing in the north makes a 90 degree turn towards the Coolingsingel. This was done to preserve the old buildings just north of the bridge, but does make for a negative feeling. Also the landing on the Noordereiland in the south feels out of place, as it does not connect to anything and feels out of place.



Figure 3.9: A view of the Willemsbrug crossing the Nieuwe Maas river in the city of Rotterdam as seen from the North (photo: Flickr)

### Koninginnebrug

The Koninginnebrug was, together with the Willemsbrug, part of the fixed connection across the Nieuwe Maas river. With an increase in traffic crossing the Nieuwe Maas, the fixed connection of the Willemsbrug and Koninginnebrug where creating a bottleneck for both car traffic as well as shipping traffic. The Koninginnebrug as it lies here today was preceded by a swing bridge up until 1923.

Architect:	A.H. van Rood	
Year of construction:	1923 – 1929	
Construction type:	Truss bridge	
Operability:	Double bascule	
Material:	Steel and brick	
Measurements:	Span:	49 meter
	Width:	30 meter
	Vertical clearance:	3,7 meter above NAP





The old Koninginnebrug was part of the fixed connection between the north and the south and consisted of a swing bridge which connected the Noordereiland with the south of Rotterdam. The location was more to the east than the current position and was in the line with the current Willemshavenbrug. The old Koninginnebrug was a small dual carriage way bridge with little space for cars and pedestrians. In the beginning of the twentieth century it was decided that the old bridge, as part of the old Maas bridges connecting the Noordereiland with the south of Rotterdam, needed to be replaced with a larger bridge with a higher capacity for traffic. Construction of the new bridge ended in 1929, with the completion of the new Koninginnebrug, featuring a double bascule system. The new double bascule system allows for larger ships to pass the bridge and, with an improved width the former bottleneck is no longer an issue. The improved width also allowed for trams to cross the bridge, thus providing an improved public transport connection between the north and south of Rotterdam. This tram line continued to exist up until 1968 with the completion of the North-South metro line. The downside of the Koninginnebrug is the limited vertical clearance when the bridge is closed. Ships which could not clear the Willemshavenbrug had to sail south of the Noordereiland and pass the Koninginnebrug.

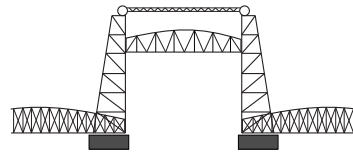


Figure 3.10: A view of the Koninginnebrug crossing the Nieuwe Maas river in the city of Rotterdam as seen from the North (photo: Flickr)

### **Koningshavenbrug or De Hef**

The Koningshavenbrug, or more commonly known, De Hef is a former railway bridge which was part of the railroad from Rotterdam to Breda. The Hef stretches from the Noordereiland to the south of Rotterdam. The Hef has been out of use since 1993, when the Willemsspoortunnel opened up for rail road traffic.

Architect:	P. Joosting	
Year of construction:	1924 – 1927	
Construction type:	Truss bridge	
Operability:	Lift	
Material:	Steel	
Measurements:	Span:	53 meter
	Width:	11 meter
	Vertical clearance:	8,2- 46,4 meter above NAP



The current Koningshavenbrug was preceded by a swing bridge up until the beginning of the twentieth century. This swing bridge, much like the former Koninginnebrug posed a bottleneck for nautical traffic crossing the narrow street between the Noordereiland and the south of Rotterdam. After many accidents and a collision with one of the pillars the municipality of Rotterdam decided to replace the old swing bridge with a vertical lift bridge, at the time the first of its kind in Western Europe. The decision to change the bridge from a swing bridge to a vertical lift bridge led to the possibility to allow much wider ships through the passage, however limiting the vertical clearance to about 46 meters. After construction of the Willemsspoortunnel at the end of the twentieth century, the Hef lost its function as a railway bridge and was set up for demolition. After heavy protests from the residents of Rotterdam however it was decided to preserve the bridge and restore it as a monument. The bridge has now been restored and stands strong as an important image of the city of Rotterdam.

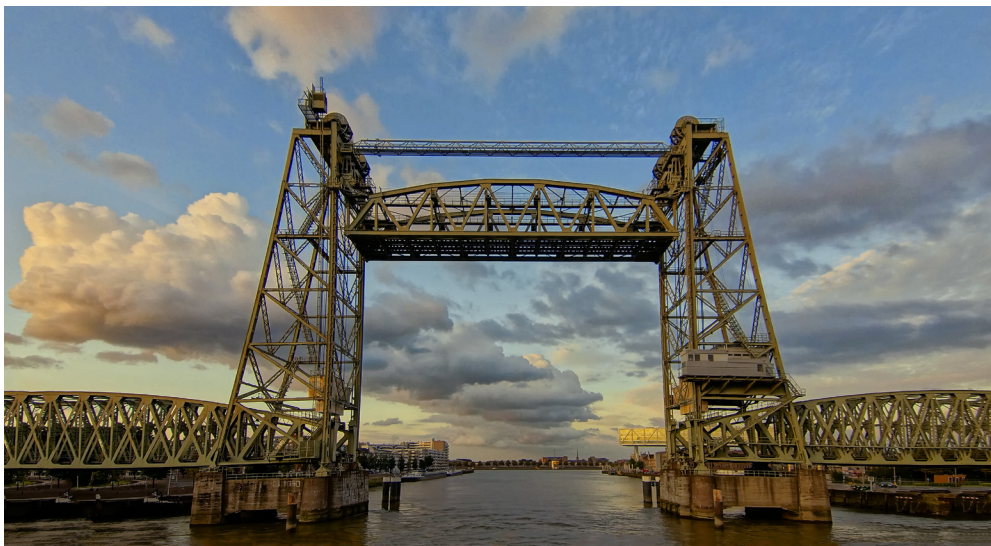
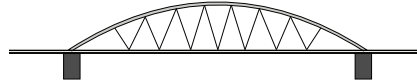


Figure 3.11: A view of the Koningshavenbrug or De Hef crossing the Nieuwe Maas river in the city of Rotterdam as seen from the Koninginnebrug (photo: Flickr)

### Van Brienoordbrug

The van Brienoordbrug is part of the regional network of roads and crosses the Nieuwe Maas just east of Rotterdam as part of the A16 ringway. The van Brienoordbrug consists of two almost identical spans which are the largest spanning traffic bridge in the Netherlands. The van Brienoordbrug is a very busy bridge with almost a quarter of a million vehicles crossing the bridge every day.

Architect:	W.J. van der Eb	
Year of construction:	1961 – 1965 1986 – 1989	
Construction type:	Arch bridge	
Operability:	Lift	
Material:	Steel	
Measurements:	Total length:	1320 meter
	Width:	2 x 28 meter
	Vertical clearance:	25 meter above NAP



The first plans for a bridge crossing the Nieuwe Maas in the east of Rotterdam originated in the thirties of the twentieth century. These plans were not executed however because the budget was used to construct Maastunnel just west of the city center. It was not until long after the second World War when the plans for a bridge crossing were brought up again. In 1961 the construction began on what was, at the time, a very slender arch bridge. The slender construction was made possible by creating



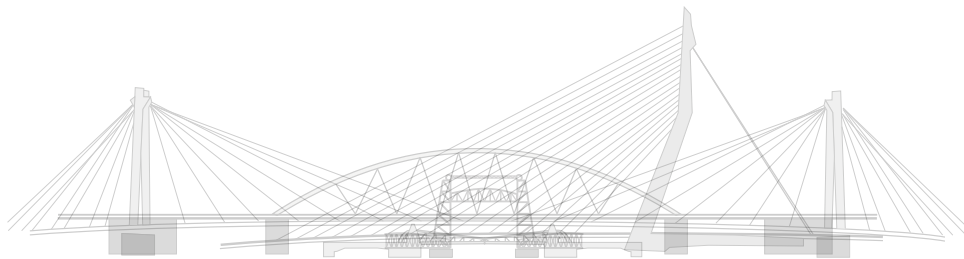
Figure 3.12: A view of the van Brienoordbrug crossing the Nieuwe Maas river east of the city of Rotterdam as seen from the North (photo: Flickr)

an arched bridge which was stiffened by diagonal tension cables which crossed and connected the two arches. The bridge was constructed on site between 1961 and 1965. Soon however the capacity of the newly revealed bridge proved to be insufficient. In the eighties a second, similar bridge was constructed. In order to not interfere with the nautical traffic on the location the entire arch construction was built elsewhere and sailed to the location after completion. The entire bridge was then hoisted into place. The current van Brienoordbrug thus consists of two similar parts, which lay side by side.

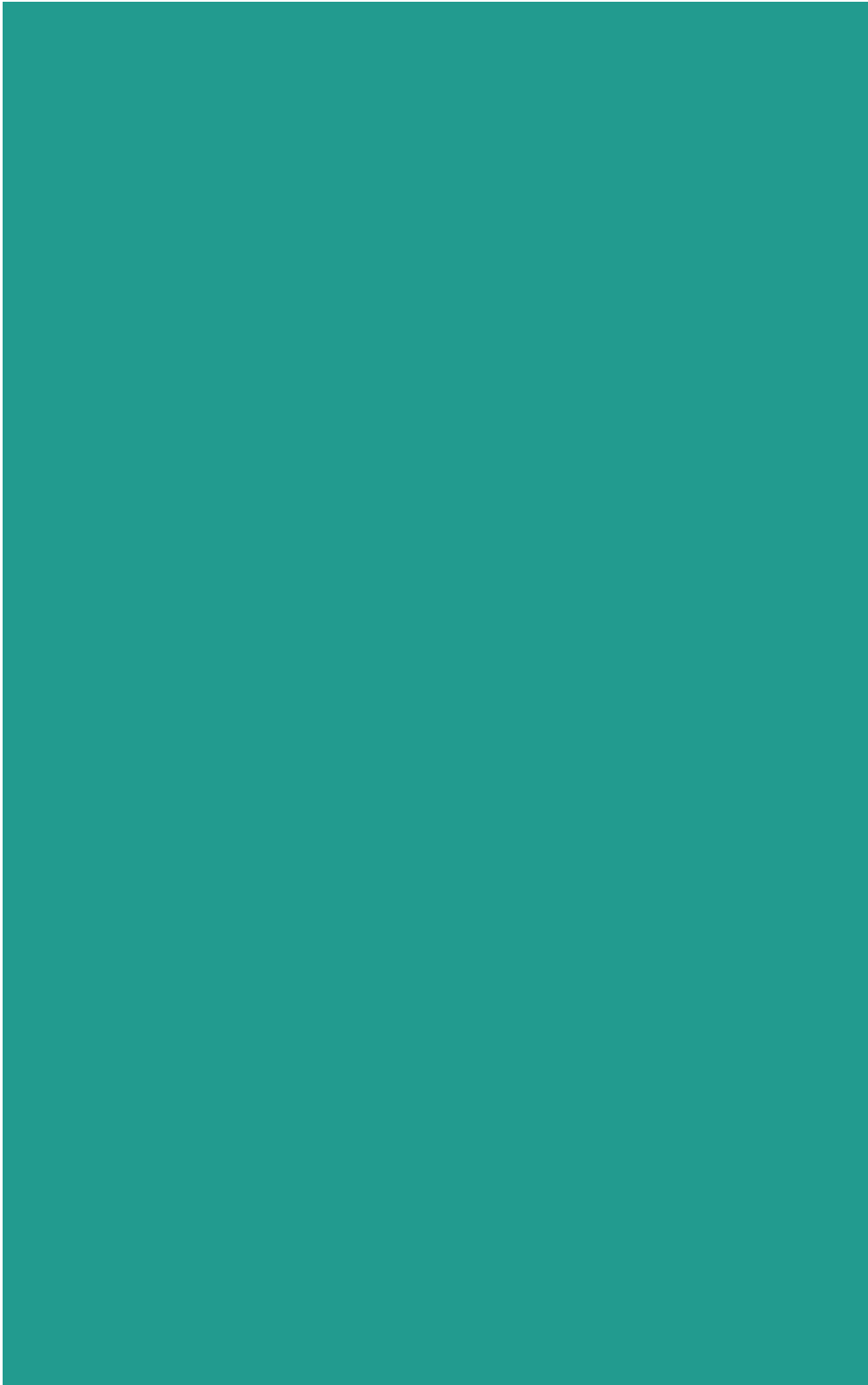
### 3.4 CONCLUSION

All the bridges crossing the Nieuwe Maas, connecting the north of Rotterdam with the south all have played or are still playing an important role in the development of the city. Each bridge displays a solution to a mobility problem of its own time and is a monument and image for the city of Rotterdam for the period it was built and still is today.

In terms of traffic the bridges still play an important role to this day as they are, together with the Maastunnel, the only way to cross the Nieuwe Maas. When put together, the bridges form an important part of the skyline of Rotterdam and have a high iconic value which has brought prosperity to the city of Rotterdam. When constructing a new bridge across the Nieuwe Maas, one has to keep the symbolism of the other bridges in mind.



*Figure 3.13: A composition of all the current bridges crossing the Nieuwe Maas river in Rotterdam (own illustration)*





# 4 SITE ANALYSIS

## 4.1 LOCATION

The Urban Traffic Plan by the municipality of Rotterdam mentions four options for a possible crossing over the Nieuwe Maas. Two of which are major location in the city, while the other two are smaller crossings. In the figure below (figure 4.1) the main traffic artery is shown, the connection between the north and the south of Rotterdam via the Erasmusbrug. The Nieuwe Maas acts as a barrier between the north and the south. The chosen location for a crossing is the proposed location in the west of the city. This location is the area between the old Delfshaven and the Maashaven, or more specifically between the Westzeedijk and the Sluisjesdijk.



Figure 4.1: An illustration showing the main possibility for crossing the Nieuwe Maas river in Rotterdam (own illustration)

## 4.2 TRAFFIC FLOWS

The new location for a bridge crossing will be in the west, allowing different traffic and thus relieving pressure on the routes in the city center. With the addition of a crossing possibility for public transport the western connection could be the missing link in order to complete the network of sustainable transport, which in the current situation is not sufficient. The west connection would really open up the connection with the south and would allow for different traffic flows.

An important aspect in creating the west crossing is the completion of the public transport network. Since the Maastunnel can only be used by cars, cyclists and pedestrians, the nearest option for public transport to cross the Nieuwe Maas is over the Erasmusbrug. As well as public transport the use of bikes and walking need to be stimulated, the new crossing must be suitable for both.



Figure 4.2: An aerial view showing the possible routes for every mean of transport in the western location (Google, 2017)

Figure 4.2 shows the crossing possibilities for all means of transport. Indicated in red is the public transport, which in the north follows the Westzeedijk from the west towards the city center. In the south there is only one connection running over the Erasmusbrug towards the city center, thus being a very one-sided connection. There is a possibility to cross the Nieuwe Maas via the Maastunnel but this connection but the old age of the tunnel has made this connection unfavorable.

As seen below in figure 4.3 the public transport network of Rotterdam lacks some vital connections between the north and the south, since the only connection is via the Erasmusbrug.

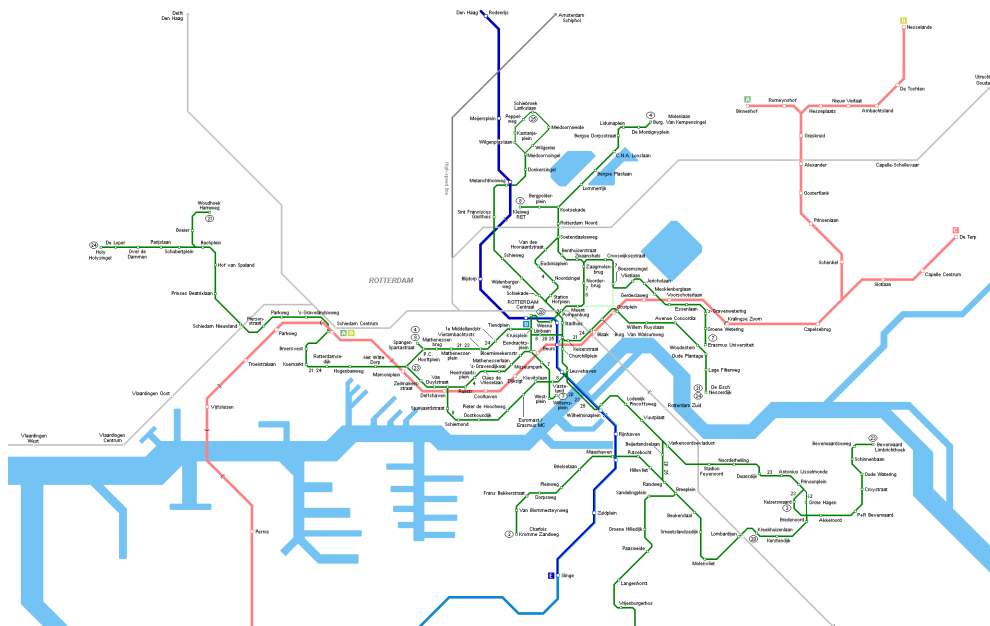


Figure 4.3: A map showing the public transport network in and around Rotterdam (Rotterdam, 2017)

### 4.3 NAUTICAL ACTIVITY

The Nieuwe Maas measures about 400 meters in width, so a bridge crossing the Nieuwe Maas must overcome this length. Also, because it is a busy waterway, nautical traffic has to be taken into account. The deck has to clear a certain height above the water as well as an openable part to allow for bigger ships to cross the bridge. The figure below show the main waterways in the south of the Netherlands and an overview of the amount of ships passing through.

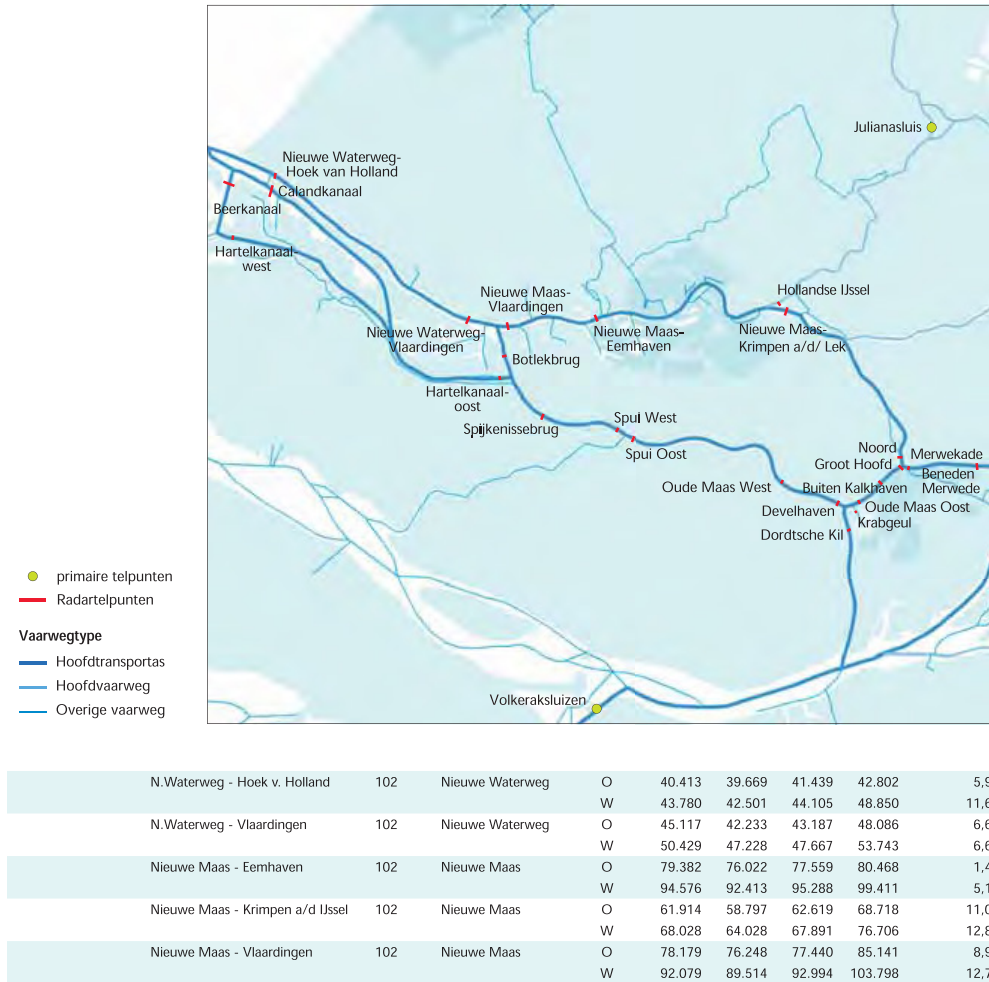


Figure 4.4: A map showing the amount of shipping passes in the Nieuwe Maas (RWS, 2008)

The transport vessels which travel through the Nieuwe Maas need to go about unhindered. The Willemsbrug west of the design location has a clearance of just over 11 meters, which will be the guideline for the clearance for the new bridge. Since the Willemsbrug is a fixed bridge, any nautical traffic that wants to pass through has to travel south of the Noordereiland and pass through the Koninginnebrug. The biggest object that will have to cross the bridge will be the monster cruise ships which will dock at the Cruise Terminal at the Wilhelmina pier (figure 4.5). Public transport requires a slow sloping deck to cross the water and by demand of the municipality there has to be a possibility for pedestrians and cyclists to cross. In the north the bridge landing will have to connect to the Westzeedijk in some order and in the south there has to be a connection to the existing Sluisjesdijk.



Figure 4.5: An aerial view of the Lloyd pier in the north of the location (Google Maps, 2017)

#### 4.4 URBAN CONTEXT

In the north of the design location is lies the Lloyd pier (figure 4.6). The Lloyd pier is part of the Lloydkwartier where still some old warehouses remain. The harbour inside the Lloydkwartier is the Schiehaven, which was used for the transport of bulk goods. The former warehouses lose their function as warehouses and are being transformed into places for housing en commercial area. New additions to the Lloyd pier are the Lloydtower and the STC building by the Shipping and Transport Group. Further development of the pier is well underway.



Figure 4.6: An aerial view of the Lloyd pier in the north of the location (Google Maps, 2017)

Parallel to the Westzeedijk is a zone with a lot of open space (figure 4.7). The west part of the area has some housing and commercial area but the eastern part is mostly covered in concrete and is an open space. The slab of concrete has some minor use as place for events. In the west is the historic wharf 'De Delft' which is rebuilding an historic ship from the eighteenth century. Many of the other companies which had their headquarters and buildings in the Lloydkwartier have moved their business elsewhere in the harbour of Rotterdam, thus leaving empty spaces behind.



Figure 4.7: An aerial view of the quay in the north of the location (Google Maps, 2017)

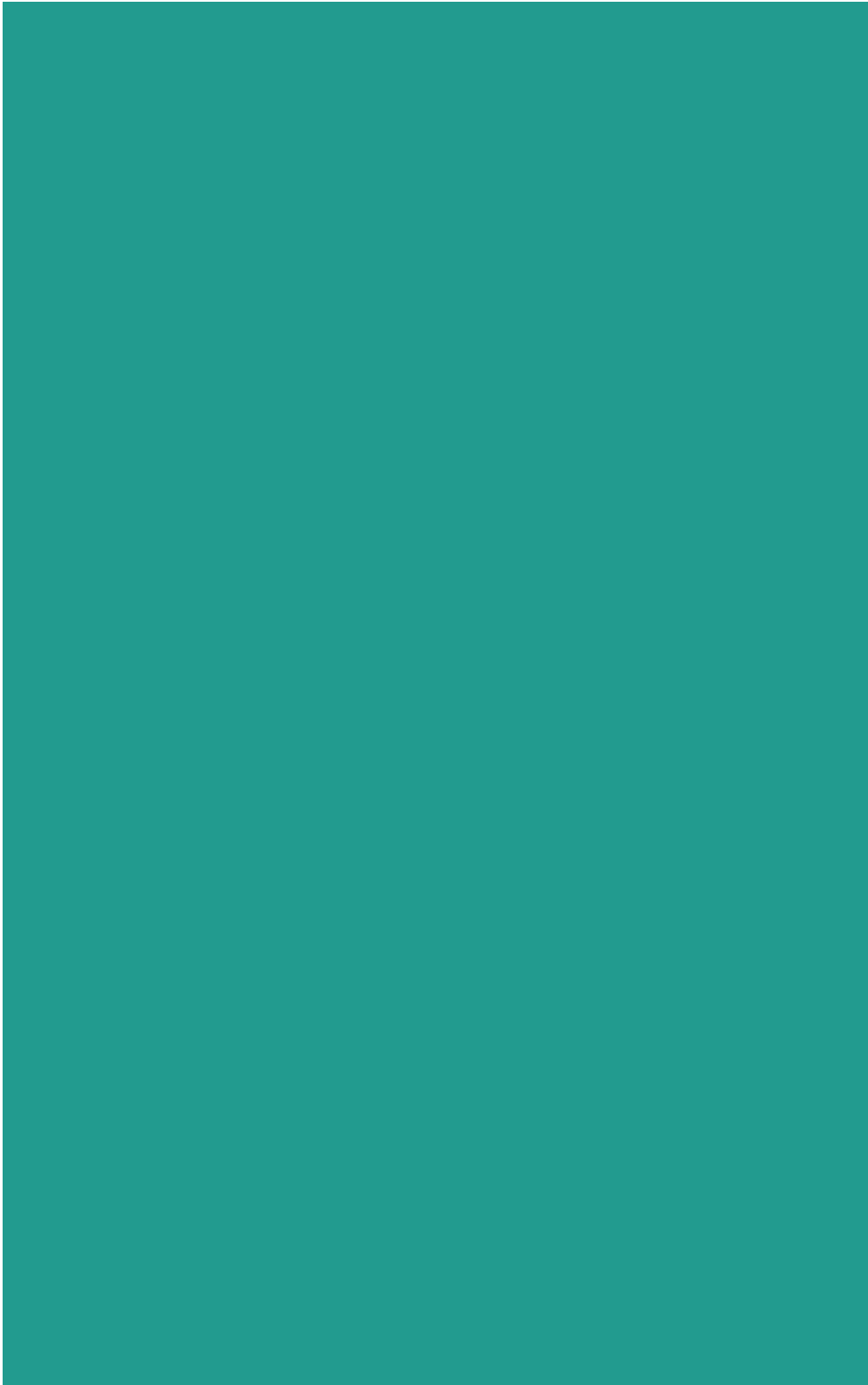
In the south of the design location lies the Waalhaven (figure 4.8). The origin of the Waalhaven dates back to the nineteenth century and is one of the oldest parts of the old city harbours of Rotterdam. The pier in the north of the Waalhaven, the Sluisjesdijk is the oldest part. In the beginning of the twentieth century, during the expansion of the Waalhaven, the buildings on the Sluisjesdijk were demolished and replaced by newer commercial buildings, most of which still exist today. However there are a lot of possibilities available for this pier. Most of the activities in the old part of the city harbour are moved out of the center and towards the Maasvlakte, thus leaving a lot of opportunity and space behind. The Sluisjesdijk offers a lot of space for design.



Figure 4.8: An aerial view of the Sluisjesdijk pier in the south of the location (Google Maps, 2017)

#### 4.5 CONCLUSIONS

There are some conclusions that can be drawn from this analysis. First of all the Nieuwe Maas river, with a width varying between the 390 and 420 meters, it is a big barrier to overcome. The depth of the Nieuwe Maas, ranging from about 3 meters near the quays to about 11 meters in the main waterway, does allow for major ships to pass through. Because of the height of the bridge deck, there is a need for landings. These landings, one in the north and one in the south, need to be incorporated in the urban landscape without any major disturbance. On the north bank, there has to be a connection with the Westzeedijk as this is a main artery in the area. On the south bank however, the Sluisjesdijk is now a dead end street, which will be of influence of the direction of the bridge landing.



# 5 BRIDGE ANALYSIS

## 5.1 BRIDGING TYPES

The elements of any structure, whether that is a house, a dome, an arch or a bridge, are either in tension or in compression. These forces may or may not be seen by the naked eye but can easily be recognized. A rope is a very good example of an object that creates tension in your arms and rope itself when pulling it. Another example is when you push against a wall, the force you feel in your arms is compression. In summary, the effort to lengthen a structure is called tension, the effort to shorten a structure is called compression.

In a structure such as a bridge there are often multiple elements in play of which some are subject to tension and others to compression, depending on the type of bridge and the loads that are applied. Different structural types of bridges are addressed below.

### 5.1.1 BEAM BRIDGE

When early humans beings had to cross a stream of water which was too deep to walk through, a tree which had fallen across from one bank of the stream to the other bank offered a good solution. When such a tree was not available, the early humans could help nature a bit by chopping down the tree or using large branches to get across. This version of the beam bridge can be seen as the most simple way of crossing. This developed in more advanced versions where two beams were laid across a stream side by side and secondary beams are used to create a pathway across, allowing for more people or animals to use the bridge. When a river was too broad to cross at once, piers were created in the river by piles of rocks, thus creating a double span bridge.

Depending on the length of the span needed to cross a river or obstacle, a material or method is used. For example a simple concrete slab can span up to 12 meters while a steel girder construction can span up to and well over a 100 meters. For an overview of different bridge types and optimal span lengths see figure 5.1. Because of the limited span possibilities of a beam bridge there is a need for multiple supports when developing a long bridge crossing.

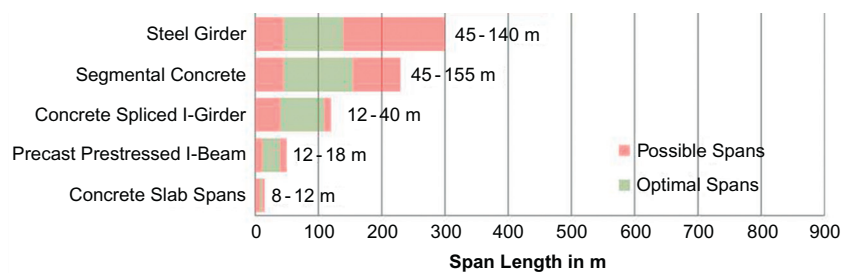


Figure 5.1: An indication of the possible and optimal span length in beam bridges (Pipinato, 2015)

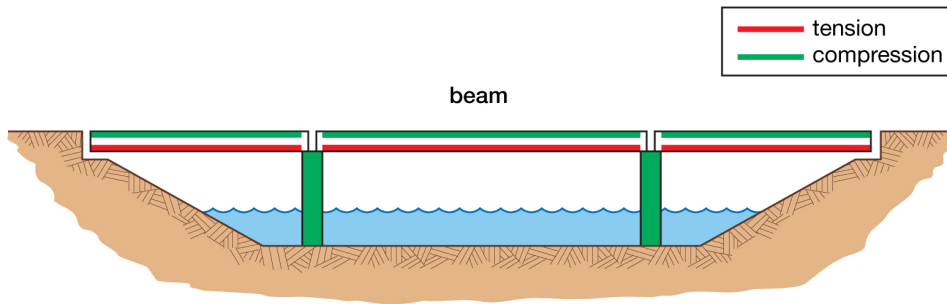


Figure 5.2: The tension and compression indicated in red and green show the structural principle of a beam bridge (Encyclopædia Britannica, Inc.)

The structural principle of a beam bridge is very simple. Each individual span is subject to loads which causes the slabs or beams which make up the bridge to bend. This causes compression in the top part of the beam and tension in the lower part of the beam. The supporting abutments or pillars are subject to compression and transfer the loading forces to the foundation.

Figure 5.3 shows the Coronado Bridge in San Diego, CA which crosses the San Diego Bay linking San Diego with Coronado. The Coronado Bridge uses a pre-stressed concrete and steel girder system and has a total length of 3407 meters divided over 32 spans.



Figure 5.3: The Coronado Bridge in San Diego, CA is a beam bridge which uses concrete and steel girders to cross the San Diego Bay.

### 5.1.2 TRUSS BRIDGE

The truss bridge is a structural type of bridge which uses triangular shapes in which the individual elements can be used as compression members or tension rods. Truss bridges are one of the oldest types of modern bridges. Because of the simplicity of these bridges engineers in the eighteenth and nineteenth century could relatively easy calculate the load forces on the bridge which made it an efficient type of bridge in terms of material use. In essence the truss bridge is a beam bridge, but the



beams are replaced by trusses which increases the height of the beam without adding to much material. This changes the overall appearance of the bridge because the trusses are visually 'open' but also a lot higher than solid beams. This increase in height adds a lot of strength to the truss bridge and leads to longer possible span lengths, as seen in figure 5.4.

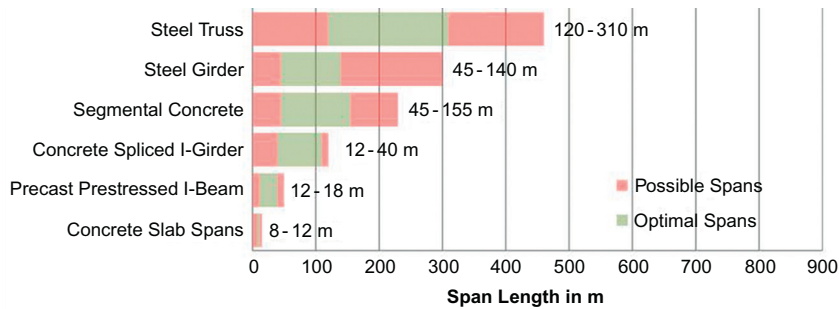


Figure 5.4: An indication of the possible and optimal span length in beam bridges (Pipinato, 2015)

The truss as a whole acts as a deep-flanged beam. The upper horizontal section of the truss takes the role of the upper flange of a steel profile and, accordingly, the lower horizontal section of the truss takes the role of the lower flange as seen in figure 5.5. The web of the steel profile are being represented by the diagonal bracing elements connecting the upper and lower sections of the truss. These diagonal bracing elements are much lighter than the web of a steel profile and thus use less material. By creating triangles in the 'web' construction the truss as a whole can be very rigid and strong. Truss bridges are often made of steel because of its high strength and the property of using it for both tension and compression, but there are also various examples of the use of wood in truss bridges.

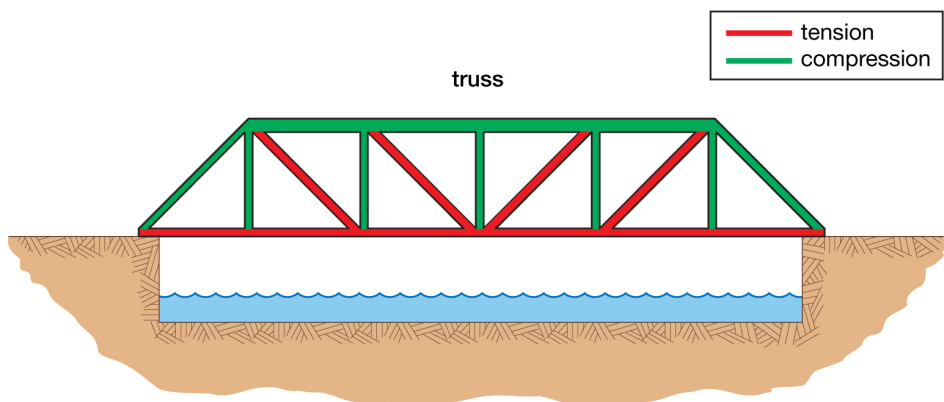


Figure 5.5: The tension and compression indicated in red and green show the structural principle of a beam bridge (Encyclopædia Britannica, Inc.)

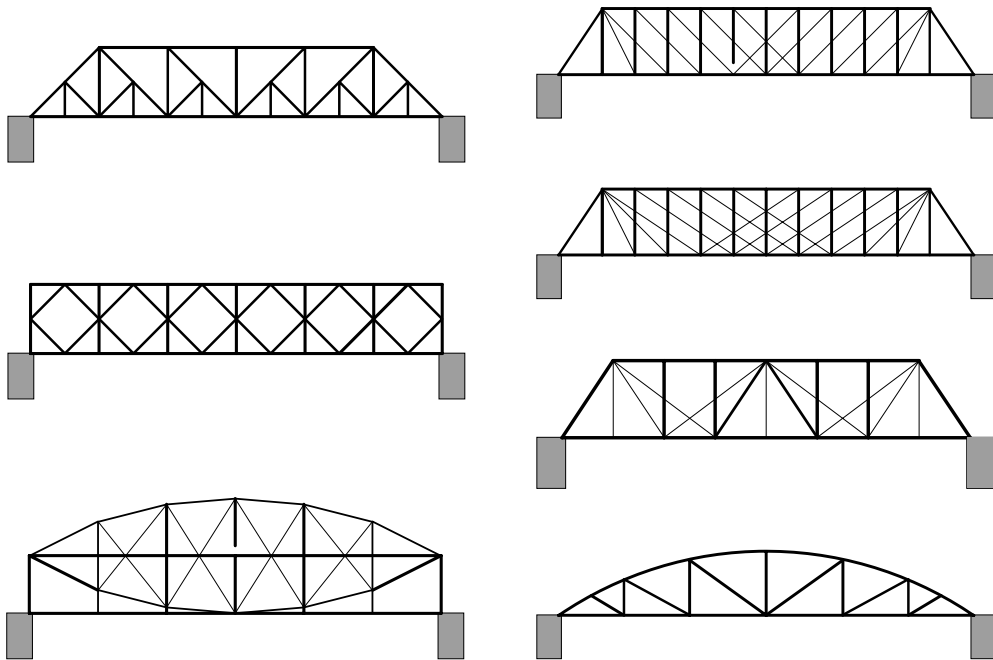


Figure 5.6: *Different possibilities for inclined and diagonal bracing bars in truss bridges (own illustration)*



Figure 5.7: *The Walnut Street Bridge uses a steel truss to connect the center of Chattanooga, TN with the North Shore*

### 5.1.3 ARCH BRIDGE

The arch bridge is a structure which in essence purely relies on compression and was a bridge type that was very common in the time of the Roman Empire where only materials as stone was available (Bennett, 1999). These materials are good in handling compression forces so to use this property the Romans had to use arch shapes to ensure compressive forces at any time. Using a circle and wedge shaped elements lined up with the center of the circle, the Romans could build a simple but very effective arch. The keystone, which was placed last, would connect the two halves which were in essence leaning against each other.

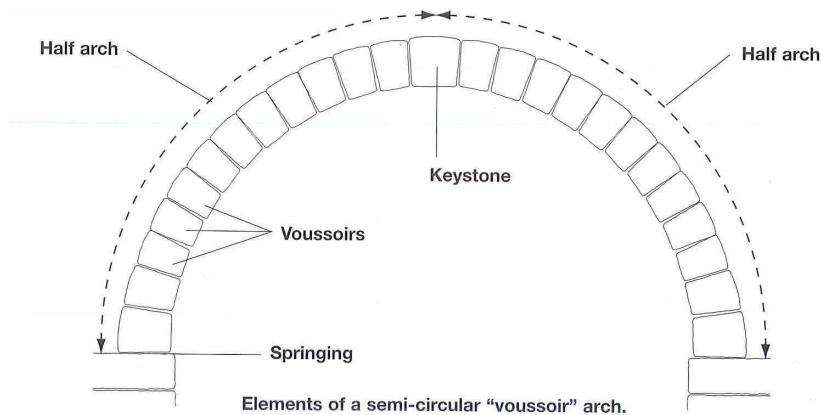


Figure 5.8: The elements of the 'Voussoir' arch used by the Romans (Bennett, 1999)

A variation on the semi circular arch is the segmental arch. The segmental arch describes a segment of a much greater circle and is a much flatter arch. The arch does not press on the ground in vertical direction but also with great horizontal force. This causes the need for strong abutments on the banks of the river crossing. In comparison with a circular arch the segmental arch uses less material and rises less high, but further above the river.

Modern day arch bridges are mostly made out of steel and concrete or a combination of both. Steel bridges have some advantages over concrete bridges, mostly because of the lower weight of the overall construction and elements (Bennett, 1999). Arch bridges can be subdivided in three categories of which the deck arch bridge has the most resemblance with the historic arch bridge. The deck arch bridge has a road deck which lies completely above the arch structure. The arch structure itself lands on two abutments which are on the banks of the river, or in case of a multiple arch structure, on piers in the river itself.

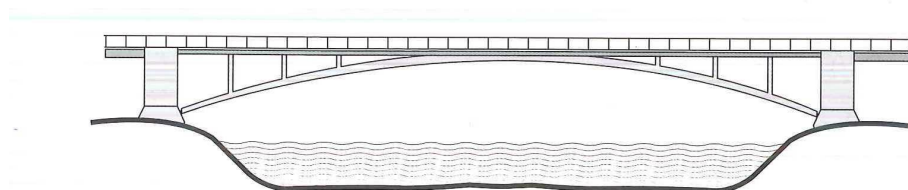


Figure 5.9: The deck arch bridge (Bennett, 1999)

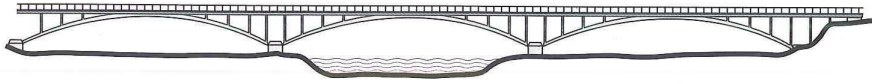


Figure 5.10: A sequence of deck arch bridges (Bennett, 1999)

There are multiple variations on the classic arch shape which explore the possibilities of lightweight construction, horizontal span, vertical clearance and abutment possibilities. A popular variation is the sickle arch or through arch. The through arch bridge is an arch bridge where the bridge deck does not lie on top and over the arch but goes through the arch structure. The bridge deck is partly suspended from the arch and partly supported by columns from underneath.

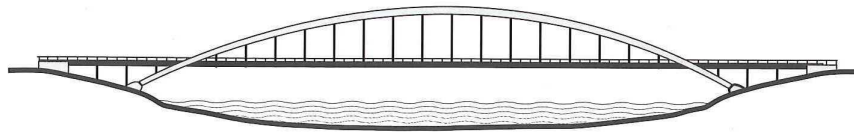


Figure 5.11: A sickle-shaped of through arch bridge with suspended deck (Bennett, 1999)

Another variation of the arch bridge is the bowstring or tied arch bridge. In this type of arch bridge the deck goes through the arch of the bridge. The bridge deck is suspended from the arch. The main alteration on the arch bridge is the use of the span of the bridge deck as a tie rod to keep the arch together. This captures the horizontal forces and diminishes the need for abutments on the riverbanks.

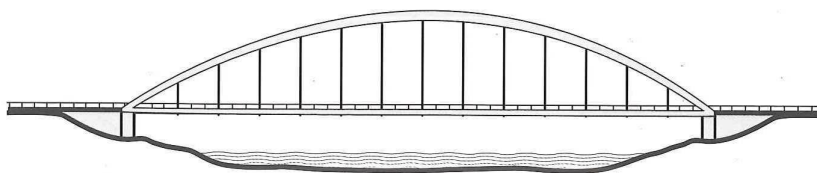


Figure 5.12: A bowstring or tied-arch bridge with suspended deck (Bennett, 1999)

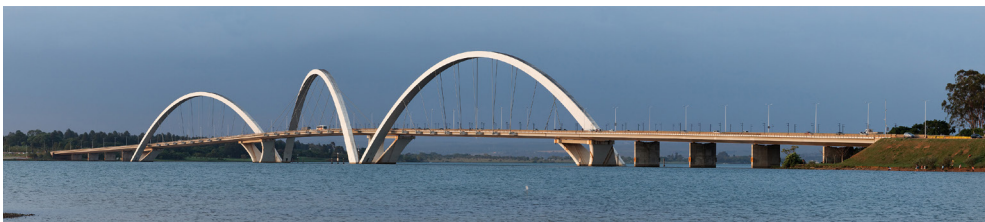


Figure 5.13: The Juscelino Kubitschek bridge is a steel through arch bridge with suspended deck which crosses Lake Paranoá in Brasília, Brazil (Wikimedia Commons, 2010)

#### 5.1.4 CANTILEVER BRIDGE

The cantilever bridge is a type of bridge which is constructed using cantilever beams which support a lighter central girder. In the first bridges there cantilevers were simple beams that were projected horizontally towards each other but with the development towards multiple beam systems and truss systems, cantilever bridges made the same development. Modern day cantilever bridges can also be constructed box girders or pre-stressed concrete. The main principle of the cantilever bridge remains the same however.

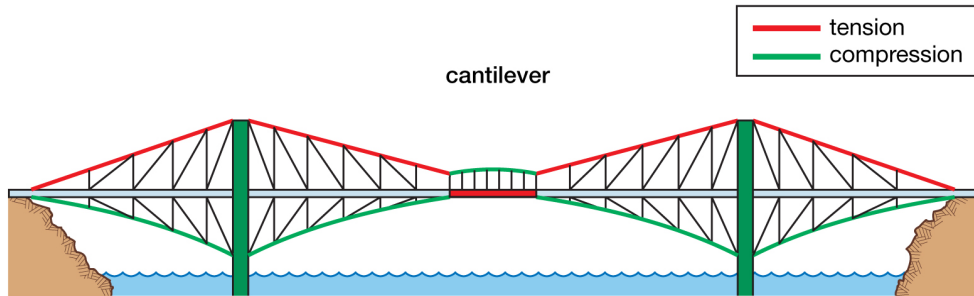


Figure 5.14: The tension and compression indicated in red and green show the structural principle of a cantilever bridge (Encyclopædia Britannica, Inc.)

In figure 5.14 the structural principle of the cantilever bridge is made visible. A cantilever bridge normally consists of three spans. The two outer spans cross from the banks of the river to the first supporting pier where they extend beyond and form the cantilever arm. The two cantilever arms do not meet in the middle, but support central bridge part which is called the suspended span. The suspended span is an independent structural element and is placed last in the bridge construction. The main span of the cantilever bridge consists of the two cantilever spans and the suspended span.

The first large scale and most significant cantilever bridge was the Firth of Forth cantilever bridge in the east of Scotland. The Forth Bridge was a steel railway bridge which crosses 2467 meters over the Firth of Forth waterway and has a maximum span of 520 meters.

The longest span cantilever bridge however is the Quebec Bridge, a road, rail and pedestrian bridge across the lower Saint Lawrence River in Quebec, Canada. After collapsing twice during construction the Quebec Bridge was completed in 1917 with a span of 549 meter which to this day is still the largest cantilever bridge span in the world.

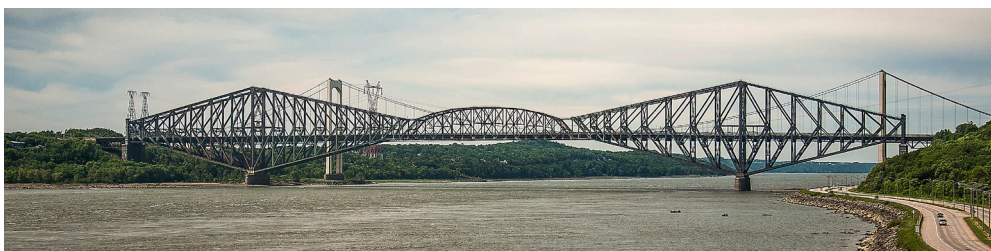


Figure 5.15: The Quebec road, rail and pedestrian bridge across the lower Saint Lawrence River in Quebec, Canada (Wikimedia Commons, 2010)

### 5.1.5 SUSPENSION BRIDGE

A suspension bridge is a type of bridge where the bridge deck is suspended from cables and is therefore capable of spanning greater distances than a normal beam bridge. The first suspension bridges used rope to suspend the bridge deck but this soon evolved up until the development of the Brooklyn Bridge which uses steel cables to suspend the bridge deck. Nowadays steel cables are made from individual steel wires and are twisted into a cable strand which are able to withstand enormous loads and are the driving force behind the suspension bridge, the bridge type with the longest span in the world (Bennett, 1999).



Figure 5.16: The tension and compression indicated in red and green show the structural principle of a suspension bridge (Encyclopædia Britannica, Inc.)

The cables in a suspension bridge can only work in tension. The towers in the construction are of vital importance however, because they allow the suspension to maintain its shape. The suspensions cables are anchored in the banks and resist the tension pull in the cable and the bending movement of the vertical towers. The bridge deck is designed as a truss or a stiff box and allows the load in the bridge deck is to be distributed towards the tension cables. The stiffness of the deck also allows for the suspensions cables to maintain a constant distance and divide the load.

The steel suspension cable is made up from a strand of single steel wires. Because the total weight of the suspension cable would be too high to handle off site, the strand of steel wires is made at the location of the bridge itself. A spinning wheel runs back and forth between the two river banks, delivering a steel cable at each end. The wires are tightly wrapped together and protected against the elements.

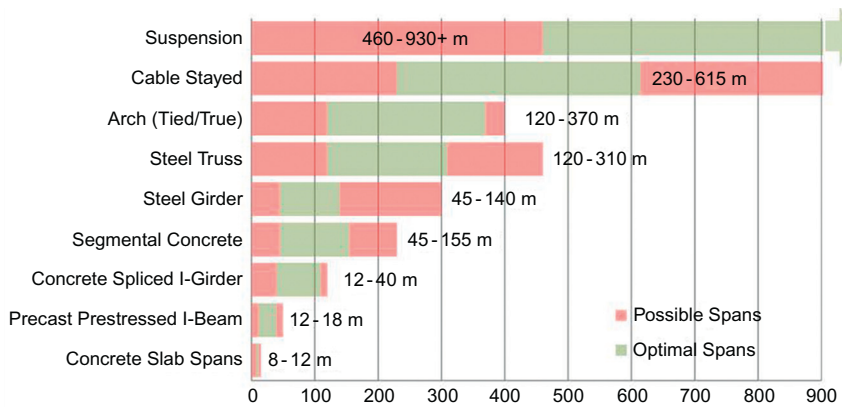


Figure 5.17: An indication of the possible span length in suspension bridges (Pipinato, 2015)

Suspension bridges are capable of spanning enormous lengths. The optimal and possible span length are visible in figure 5.17. One of the most well known examples of a suspension bridge is the Golden Gate Bridge in San Francisco. The Golden Gate Bridge spans across the Golden Gate strait from San Francisco in the south to Marin County in the north. The total length of the bridge is 2737 meter with the longest span being 1280 meters. The bridge was opened to the public in 1937 and is still regarded as one of the most beautiful and most often photographed bridges in the world. On an engineering level however the Golden Gate Bridge was not very innovative, the bridge is just very big.

The largest suspension bridge in the world is the Akashi Kaikyō Bridge in Japan. The Akashi Kaikyō Bridge crosses the Akashi strait between the Japanese mainland and the Awaji Island. The total length of the bridge is 3911 meter but with a main span of 1991 meter. One meter more than the original design due to an earthquake in 1995, which moved the towers one meter apart.



*Figure 5.18: The Akashi-Kaikyo Bridge is a suspension bridge with the largest main span in the world and crosses the Akashi strait near Kobe, Japan (Wikimedia Commons, 2015)*

#### 5.1.6 CABLE-STAYED BRIDGE

The most recent development in large span bridges are the cable-stayed bridges. Further developed during World War II the cable-stayed bridges proved soon to be more effective than suspension bridges over shorter spans (Bennett, 1999). The cable-stayed bridge uses fewer suspension cables which connect directly from the deck to one or more pylons. This lapses the need for a large connected suspension cable.

The loads in the bridge deck are primarily vertical forces. These forces are being transferred through the cables towards the main pillars where the tensional forces in the cable are converted to compression in the main pillars. There are two developments which greatly contributed to the success of cable-stayed bridge design. The first are strong box girders that make up the bridge deck. These strong box girders make for a very stiff bridge deck. This has numerous advantages in not only cable-stayed bridges, but in

suspension bridges as well. In cable-stayed bridges the stiff bridge deck allows for the use of single fan stays in a cable-stayed bridge design. Another development is a new method of combining the single steel wires into the tension cables. The steel wires are specially wound to restrict their unwinding under tension and thus limiting stretching under cycle loading.

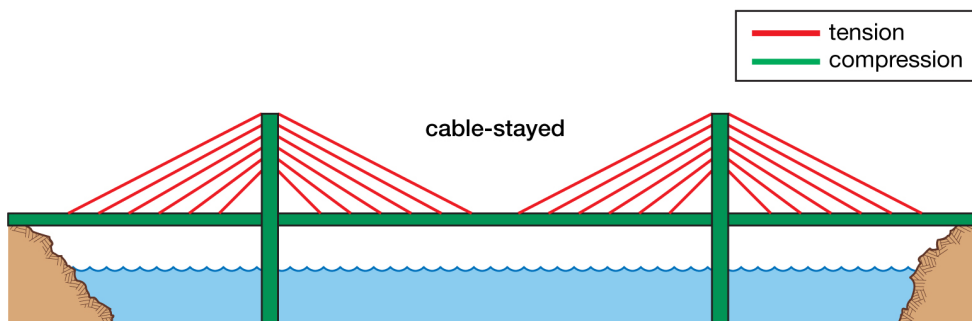


Figure 5.19: The tension and compression indicated in red and green show the structural principle of a cable-stayed bridge (Encyclopædia Britannica, Inc.)

Because of the stiff bridge deck and the possibility of the use of single cables the cable-stayed bridge has a lot of elegant design possibilities. These can be exploited further with a possibility of cable arrangements as seen in figure 5.20.

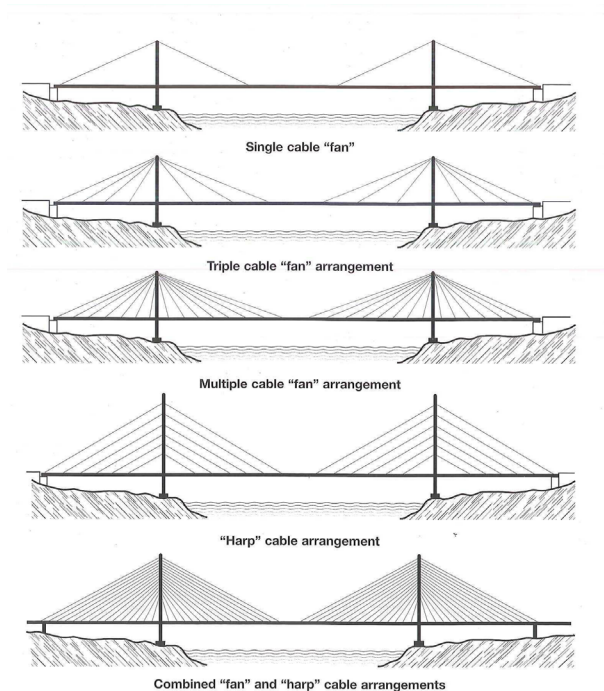


Figure 5.20: The different design possibilities of the cable arrangement in a cable-stayed bridge (Bennett, 1999)



A difference in the structural principle of a cable-stayed bridge compared to the suspension bridge is the angle at which the tension cables are connected to the bridge deck. With a suspension bridge the cables connecting the bridge deck to the suspension cable are roughly horizontal. The cables in a cable-stayed bridge are connected directly to the pylon towers and are connected to the bridge deck at an angle. This creates a compression load in the bridge deck, which is dependent on the angle of the cable. The horizontal forces which act on the pylon towers should be in balance to allow for the pylon to be as slender as possible.

Because a cable-stayed bridge allows for many design solutions there are many notable designs. The Alamillo Bridge in Seville, Spain is a cable-stayed bridge with a single pylon which combines the cantilever principle with a cable-stayed design. The bridge stretches 200 meters across the Guadalquivir River.



*Figure 5.21: The Alamillo Bridge in Seville crosses the Guadalquivir river in Seville, Spain (Wikimedia Commons, 2015)*

## 5.2 MOVABLE BRIDGE TYPES

Movable bridges are often used in crossing waterways as an alternative for an expensive, high bridge while still being able to provide necessary clearance for boats to pass. Although in some cases the cost of construction and maintenance can be twice as high as a non-movable bridge with similar geometry the option for a movable bridge can be more desirable (Baus, 2008, p192).

### 5.2.1 DRAW BRIDGE AND BASCULE BRIDGE

The most common types of movable bridge are the drawbridge and the bascule bridge. These bridges use a counterweight so that the center of gravity of the structural part of the bridge coincides with the axis of rotation used in the structure (Baus, 2008, p193). While the drawbridge has a counterweight which normally balances high in the structure, the bascule bridge uses a counterweight which follows the same horizontal line as the bridge deck. The point of rotation lies between the deck and the counterweight, thus dividing the bridge into a fore and aft arm. While being more or less in balance with each other, the dead load of the fore arm or bridge deck is higher than the possible live load of the aft span to ensure that the bridge cannot suddenly open while not being operated. The bascule bridge is a type of bridge which can open and close quickly and thus can get out of the way of approaching vessels fast. Also, most of the superstructure of the bridge is outside of the navigation channel when opened, lowering the possibility of severe damage in the event of a collision (Koglin, 2003, p50).

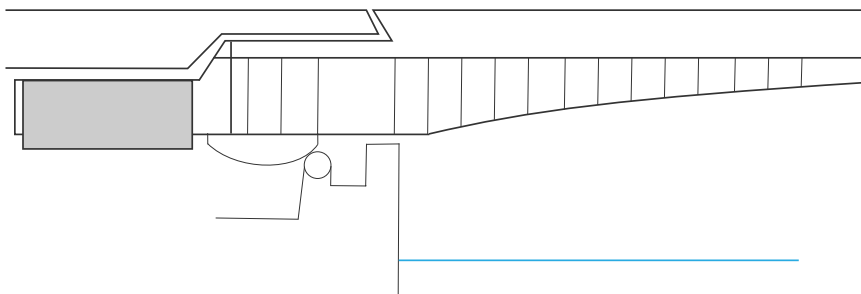


Figure 5.22: The principle of a typical bascule bridge (own illustration)

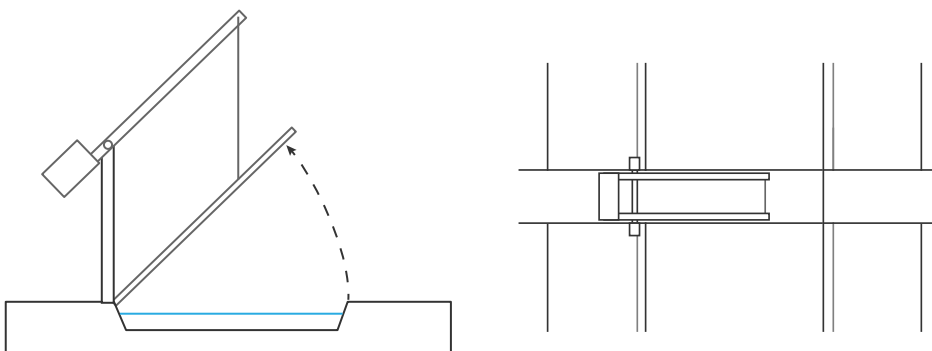


Figure 5.23: The principle of a typical drawbridge (own illustration)

Drawbridges are a simple method of crossing a narrow obstacle of stream, but are rapidly limited in their size. Therefore they are not commonly used in large span bridge design. Bascule bridges are capable of a larger opening.

The bascule bridge has three different types. The first one is the fixed-trunnion type, which in origin is a design by Joseph Strauss, who was also the main designer for the Golden Gate Bridge. The fixed-trunnion bridge is a bascule bridge that rotates around a large axle. An example of this type of bridge is the Lefty O'Doul Bridge in San Francisco which connects China Basin and Mission Bay.



Figure 5.24: The Lefty O'Doul Bridge is a drawbridge connecting China Basin and Mission Bay in San Francisco, CA (Wikimedia Commons, 2015)

The second type is the rolling lift trunnion, also known as the Scherzer rolling lift. The mechanism behind this method of the bascule bridge resembles a rocking chair. The bridge deck including the counterweight roles away from the edge and makes for a wide opening.

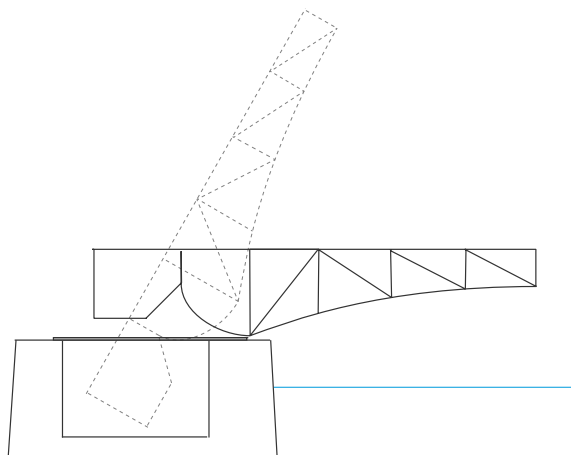


Figure 5.25: The principle of a Scherzer type bascule bridge (own illustration)



Figure 5.26: The Broadway Bridge in Portland, OR crosses the Willamette river and features a double-leaf bascule bridge (Wikimedia Commons, 2009)

The third and final type is a rare model which was implemented a few times. The most notable bridge of this type is the Broadway Bridge in Portland, Oregon as seen in figure 5.26. A bridge still in use today and the largest bascule bridge of this type. It crosses the Willamette River in Oregon with length of 531 meters. The largest fixed span is 91 meters while the double-leaf bascule span is an enormous 85 meters.

### 5.2.2 SWING BRIDGE

A second example of an movable bridge is the swing bridge. The swing bridge uses a load equilibrium over a vertical axis. The point of rotation of a swing bridge is equal to this vertical axis. There are different possibilities for the geometry of this type of bridge, but all with the same downside. Since the construction has to turn aside, there is a need for extra space around the structure of the bridge (Baus, 2008). Another disadvantage is the time it takes to open the bridge and due to many moving parts it requires more maintenance than the typical bascule of vertical lift span bridge. An advantage of a swing bridge however is that it does not move upright when opening, thus increasing the wind load directed on the bridge deck. There can however develop substantial rotational wind moments on a swing span (Koglin, 2003).

Usually the pivot pier is in the middle of the span because of the load equilibrium, but this can change for the sake of the design as long as the bridge structure is well balanced. The downside of course of a center-balanced bridge deck is the limitation in horizontal clearance of the waterway.

The openable bridge deck has no limitations in shape or material. There are various examples of the use of trusses, cantilever types or cable-stayed bridge decks.

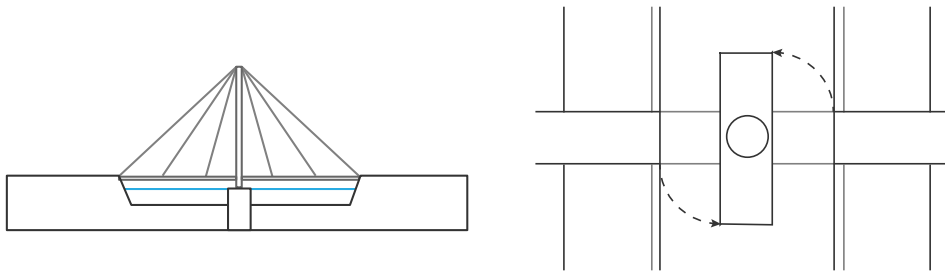


Figure 5.27: The principle of a swing bridge (own illustration)

The Media City Footbridge is a footbridge in Manchester, UK. The swing bridge has an asymmetrical shape and spans 65 meters across the Manchester Ship Canal and can be seen in figure 5.28. The Media City Footbridge uses a steel bridge deck and a cable-stayed system to cross the river.

The largest swing bridge in the world can be found in the Suez Canal in Egypt. The El-Fedran Railway bridge features a double swing bridge, each with a span of 170 meters, together span 340 meters across the canal. The first bridge was completed in 1942 and rebuilt several times over the last decades. The current bridge was completed in 2001.



Figure 5.28: The Media City Footbridge is an asymmetrical swing bridge across the Manchester Ship Canal in Manchester (Wikimedia Commons, 2014)

### 5.2.3 VERTICAL LIFT BRIDGE

The vertical lift bridge uses a simple method of opening by simply lifting the bridge deck horizontally. The length of the bridge deck can be very large and is only limited by the maximum length of a simple span bridge. This allows for a large opening for vessels to pass through. This is an advantage over single or double bascule bridges and swing bridges, which are becoming increasingly unstable and require careful alignment when opening and closing (Koglin, 2003). The downside of this type of bridge is that

the vertical clearance is limited by the height of the supporting pillars. Although the height of an opened bridge is rarely a problem, there have been reported collisions of a vessel navigating a partially opened bridge (Koglin, 2003). An alternative solution for this is not to lift the bridge deck over passing ships but to lower it beneath the keel depth of the ships. This however has the downside of extra wear on the bridge deck due to corrosion and water damage (Baus, 2008).

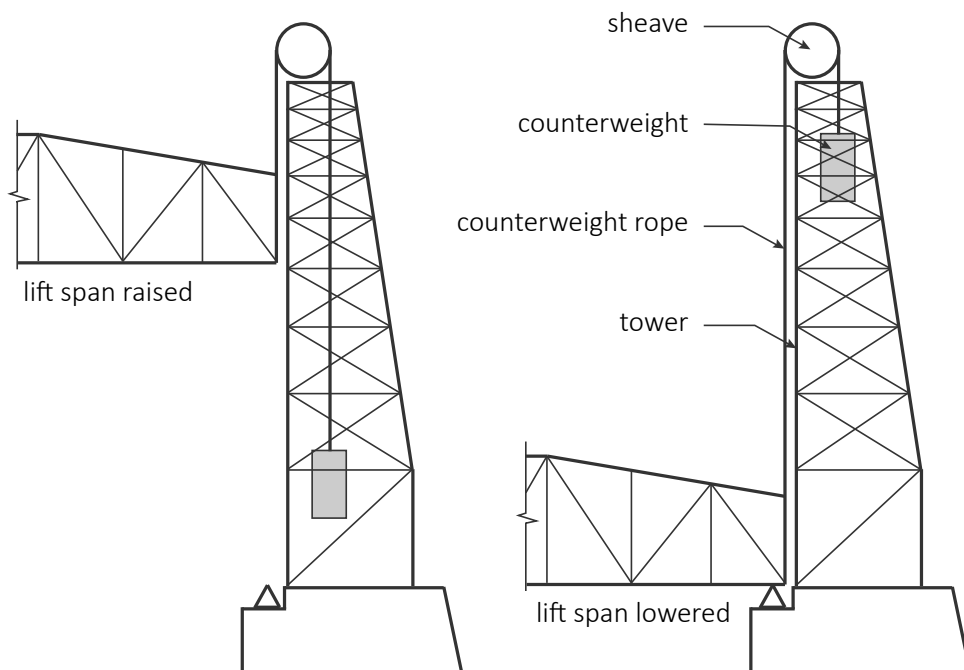


Figure 5.29: The principle of a vertical lift bridge (own illustration)

The structural principle of a vertical lift bridge is very simple. The deck consists of a simple span which is raised straight up, without tilting the deck. A vertical lift bridge is supported by towers, either two towers at each end of the bridge deck or four towers, one in each corner. In each tower there are rotating sheaves which are connected to the bridge deck on one end and to counterweights on the other end, see also figure 5.29. Alternatively, there are multiple methods to connect the span to the counterweight and sheaves. A well used method is the Waddell type span drive, which uses multiple sheaves and a machinery house on top of the bridge deck. The downside of this method is that the multitude of sheaves causes elevated wear on the operating ropes, see also figure 5.30. The weight of the bridge deck is roughly similar to the total weight of the counterweight elements. This is in contrast to the weight distribution of bascule bridges where counterweight is usually a lot heavier than the bridge deck because of the asymmetrical design.

The largest vertical lift bridge still in use today is the Arthur Kill Vertical Lift Bridge, see figure 5.31, which connects Staten Island, NY with Elizabeth, NJ. The railroad bridge was completed in 1958 and has a movable span of 170 meters between two 55 meter towers. When lifted the span has a 41 meter clearance underneath.

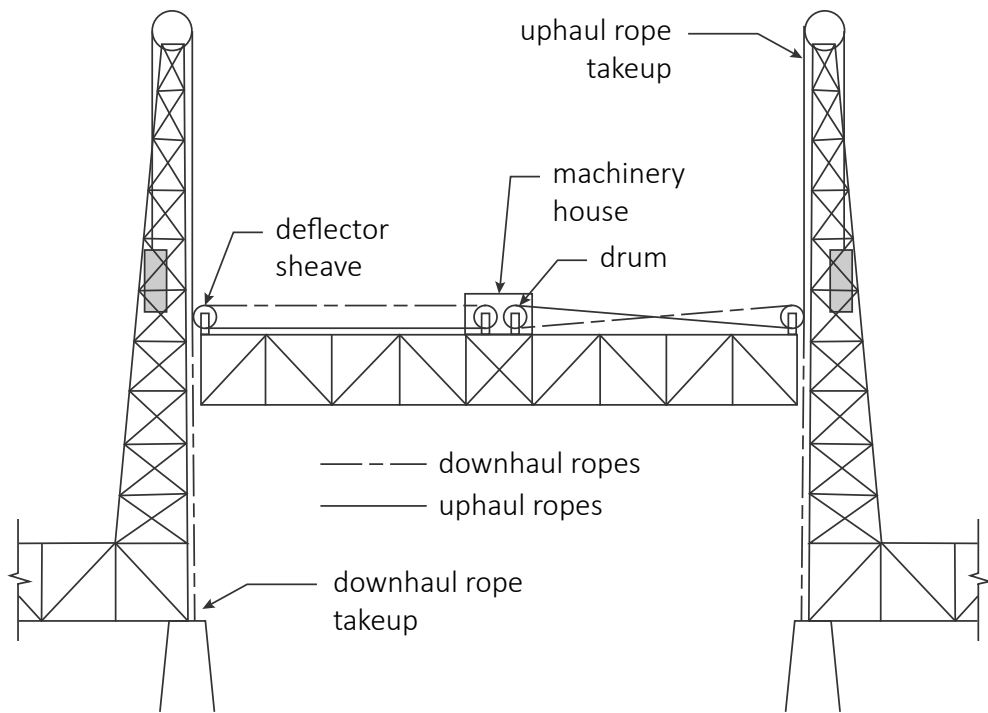


Figure 5.30: The Waddell type span drive applied to a vertical lift bridge (own illustration)



Figure 5.31: The Arthur Kill Vertical Lift Bridge is a railroad only vertical lift bridge which connects Staten Island and New Jersey via a 170 meter long truss span (Wikimedia Commons, 2006)

## 5.2.4 ALTERNATIVE MOVABLE BRIDGES

The most common used types of movable bridges are bascule bridges, swing bridges and vertical lift bridges. In the United States these three types of bridges make up about 90 percent of all active bridges which still exist today. There are several other types of movable bridges.

### 5.2.4.1 TRANSPORTER BRIDGE

A transporter bridge, which can also be referred to as a ferry bridge or a aerial transfer bridge, transfers part of the roadway across a body of water, see figure 5.32. On both banks of the water a bridge structure is placed with a connecting structure which crosses the water. Along this structure, which can consist of steels cables or a truss, the part of the roadway of gondola is sent from one bank to the other. The transporter bridge is a seldom used type of bridge due to the limited capacity of the carriage.

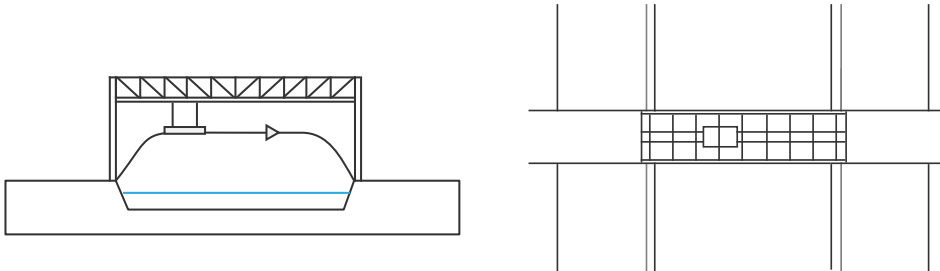


Figure 5.32: The principle of a transporter bridge (own illustration)

### 5.2.4.2 PONTOON BRIDGE

A pontoon bridge is a bridge that utilizes connecting floats to cross a body of water. The floats are connected with a deck on top which can be temporary or permanent. When applying a temporary bridge deck it is possible to remove part of the pontoon bridge and thus creating an opening for boats to go through. The maximum load of the bridge has a very wide range and is dependent on the buoyancy of the individual floats.

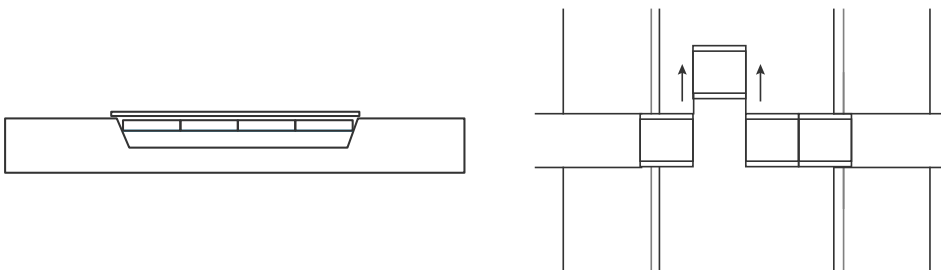


Figure 5.33: The principle of a pontoon bridge (own illustration)



### 5.2.4.3 RETRACTABLE BRIDGE

A retractable bridge is a bridge where the deck can be rolled back in case of opening. An alternative of the retractable bridge is the rolling bridge or folding bridge. The major downside of any retractable bridge is that the bridge deck has to move in a certain horizontal direction, almost always interfering with a certain traffic flow, either the nautical traffic or the road traffic. In case of a folding bridge this downside is limited but still present.

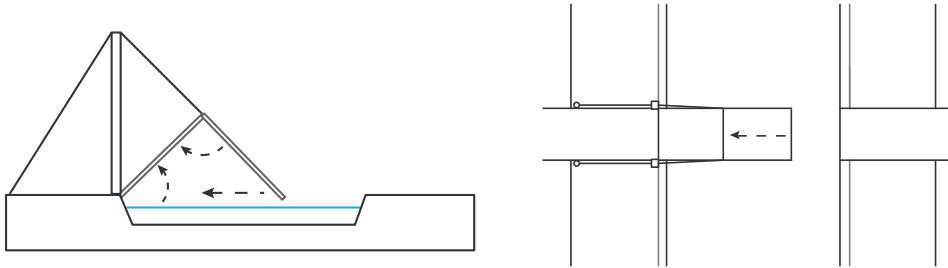


Figure 5.34: The principle of a folding bridge (own illustration)

### 5.3 BRIDGE LANDINGS

In order to cross a body of water a bridge has to have a certain height above the water. This allows for the bridge deck to always be above water level in case of a rise in water level. Also, in case of heavy nautical traffic, the bridge deck rises even further to allow for the majority of the nautical traffic to pass freely. The rise in height of the bridge deck does however mean that a slope has to be implemented in the design of the bridge to accommodate the height difference and connect the bridge to the surrounding environment. These bridge landings are bound to the limitations of road traffic and their ability to ascend and descend a certain height over a distance, in other words, a maximum slope.

#### 5.3.1 BICYCLE SLOPES

The rule of thumb for the slope used in a ramp for a bicycle lane is percentage = 1 : ( 10 x height) or length = 10 x h<sup>2</sup>. These rules of thumb are calculated by ing. Roos in 1946. In 1967 the Royal Dutch Touring Club adopted this rule as a recommendation for the maximum slope in the construction of bike ramps. Another recommendation of ing. Roos was the use of plateaus in the slope to put less strain on cyclists.

In addition to this research, Van Laarhoven added the recommendation to use a plateau in the event of a rise of 5 meters or more. Van Laarhoven also added the recommendation of a steep beginning of a slope, while decreasingly rise after that. The idea behind this is that cyclists would accelerate when approaching the slope and the descending gradient would lead to a constant cycle speed and effort (Ter Braack, 2009).

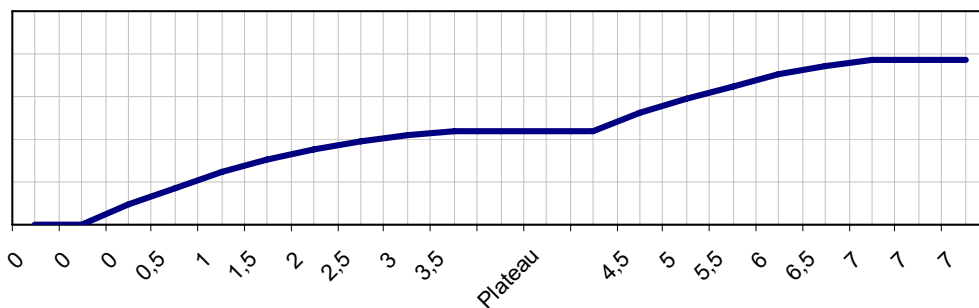


Figure 5.35: Schematic representation of the slope gradient (Ter Braack, 2009)

In 1986 the Rijkswaterstaat, as part of the Dutch Ministry of Infrastructure and the Environment, issued the RONA, 'Richtlijnen voor het ontwerpen van niet-autosnelwegen' ('Guidelines for the design of non-motorways'), in which the results of the research of Van Laarhoven are used. The RONA is a simplified model with standardized values. The RONA is followed up by the report 'Guidelines for bicycle traffic' published by the CROW in 1993 and 2006.

The CROW, 'Centrum voor Regelgeving en Onderzoek in de Grond-, Water- en Wegenbouw en de Verkeerstechniek', ('Centre for Regulations and Research in Soil, Water and Road and Traffic Engineering'), uses the RONA research as a basis but further investigates the research done by Van Laarhoven, also implementing wind speed in the model. The three models by Roos (1946), Van Laarhoven (1984) and the CROW (1993/2006) were put side-by-side by Ter Braack. The different models can be seen in figure

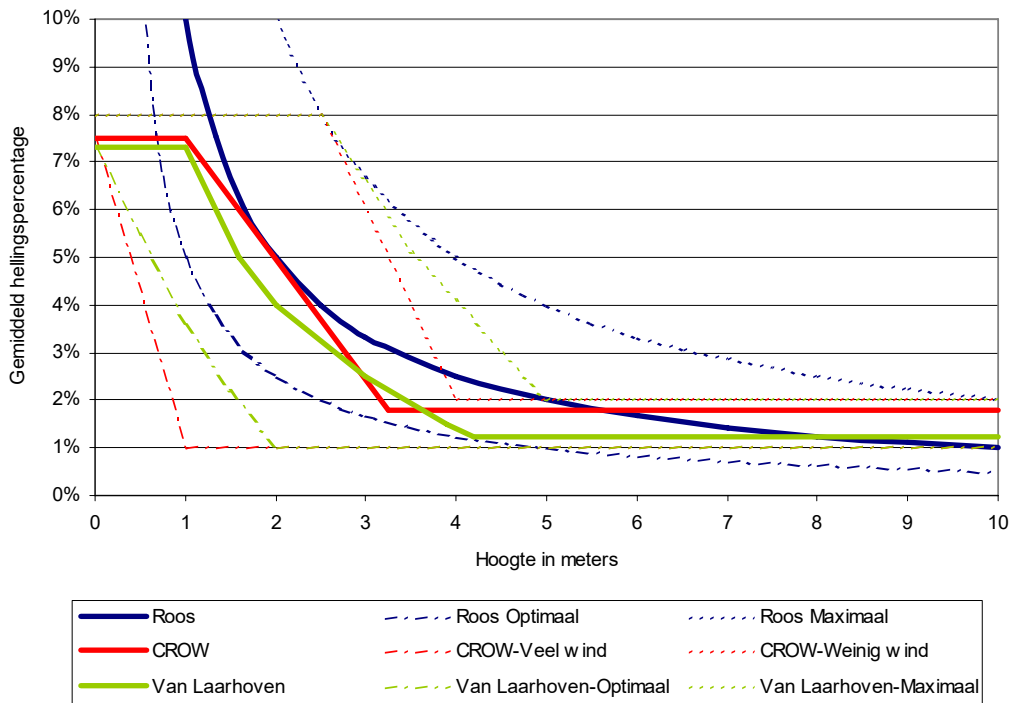


Figure 5.36: The different models for a slope gradient by Roos, Van Laarhoven and the CROW (Ter Braack, 2009)

The overall model of Ter Braack can tell us some important information. The first important note is that there is a maximum inclination for any slope. For short slopes with a height difference of only one meter, the inclination can be rather steep, but this number is rapidly decreasing when the height difference rises. For slopes with a height difference of more than four meters a gradient of no more than 2 percent is desirable.

There are some alternative solutions for a bicycle slope. The first alternative is a flight of stairs. A flight of stairs is a good alternative for pedestrians because they do not have to walk the full length of the slope and have a faster route to the top. The Dutch Building Regulations does prescribe some requirements for the use of a flight of stairs. The stairs must preferably be made of concrete and have a gutter for bicycles one both sides. The most important requirement however is that a flight of stairs can only be used when a bicycle slope is not possible.

Other possibilities are the use of an elevator, escalator or bicycle lift. These methods are pretty uncommon and only applied in public buildings like train stations.

When designing a bicycle slope there are some points to take in mind (Ter Braack, 2009). Safety in a public environment is very important when choosing a certain route. A good overview of the surroundings is important. The bridge deck and slope must be open and transparent, so the cyclist can oversee the situation and what is ahead. This goes hand in hand with the width of the road deck. When to flows of cyclists have to share the road in opposite direction, the road has to be wide enough to accommodate both flows. The CROW suggests a width of a bicycle path of at least 3,5 meters. A final focus point is the connection of the slope and the surrounding area. Ter Braack suggests a smooth transition between the slope and the surroundings to avoid great difference in speed.

### 5.3.2 PUBLIC TRANSPORT SLOPES

The rules for the slopes used in public transport services like trams and metro rails are a bit more free. This can be explained by the fact that trams and metros are not powered by human force but by mechanical force and is only limited by the comfort level of the people riding the tram or metro.

The maximum slope for some railways in the world are well over 10 percent, sometimes with special provisions. The Handbook Tunnelbouw prescribes the maximum and recommended slope for trams and metros. The maximum slope for a metro is 4 percent in a tunnel, or 3,3 percent in the open air. When approaching a station the slope has to have an inclination of maximum 1 percent. The recommendations for trams are a bit more generous, with a maximum of 4,5 percent and incidentally 5 percent. The recommended slope for a tram is 3,3 percent. The note for both transport systems is the reduced slope when the tram or metro track is taking a bend.

The maximum slope of the Erasmus bridge is limited to 1:28 (Hewett, 2007), which equals a slope of 3,6 percent. This can be assumed as the maximum average slope for the trams of Rotterdam.

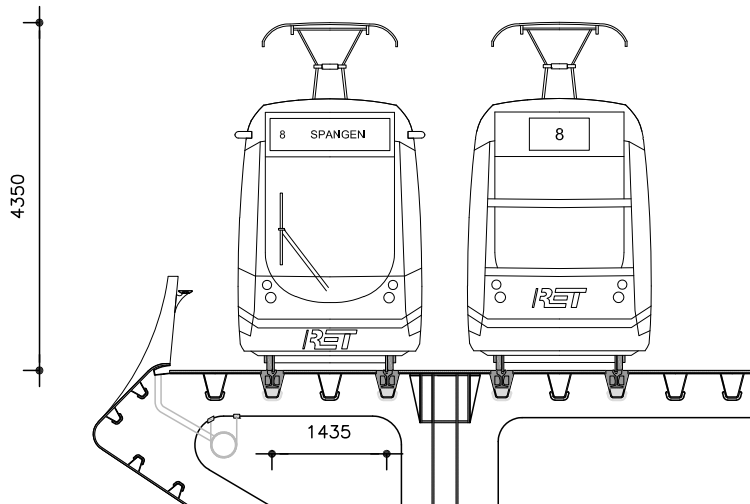


Figure 5.37: Dimensions of the RET trams in Rotterdam (own illustration)

arc radius (m)	designed speed v (km/h) with a = 0,65 m/s <sup>2</sup> and cant D			
	D = 0 mm	D = 30 mm	D = 75 mm	D = 150 mm
25	14,5	16,5	*	*
35	17,1	19,6	*	*
50	20,5	23,4	27,1	*
75	25,1	28,7	33,3	39,8
100	29,0	33,1	38,5	46,0
150	35,5	40,5	47,2	56,4
200	41,0	46,8	54,4	65,0

Figure 5.38: Chart displaying the possible speeds with a given arc radius (Handboek Tunnelbouw, 2015)

## 5.4 CONCLUSION

The analysis of the different bridging leads to the following assessment of which type is the most suitable for crossing the Nieuwe Maas at this location. When looking at span type, steel girder bridge has a high potential in crossing the river, given the posed span. When looking at the movable part of the bridge there are multiple opportunities, but given the condition of a cruiseship that needs to pass the bridge, a vertical lift bridge is a viable option.

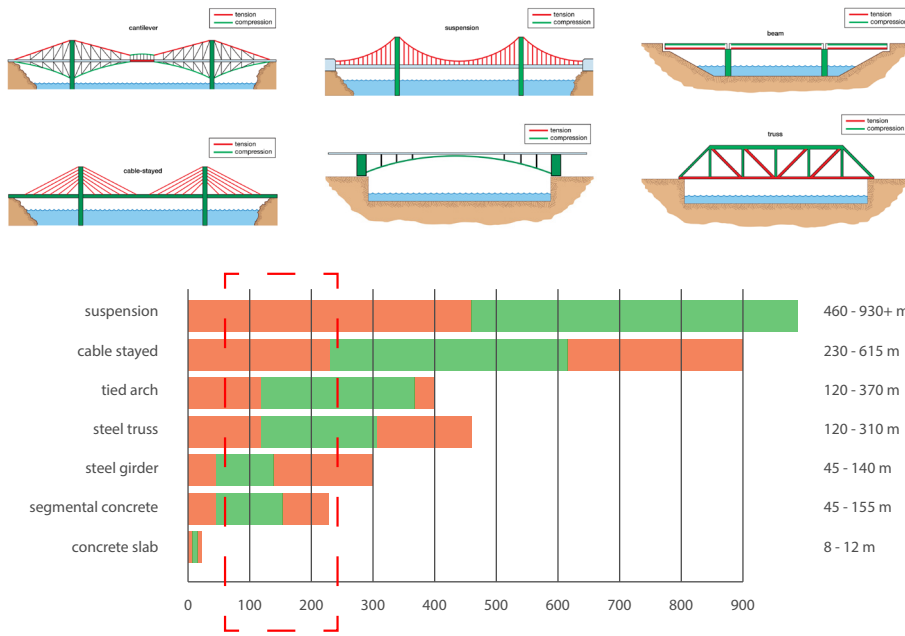


Figure 5.38: Dimensions of the RET trams in Rotterdam (own illustration)

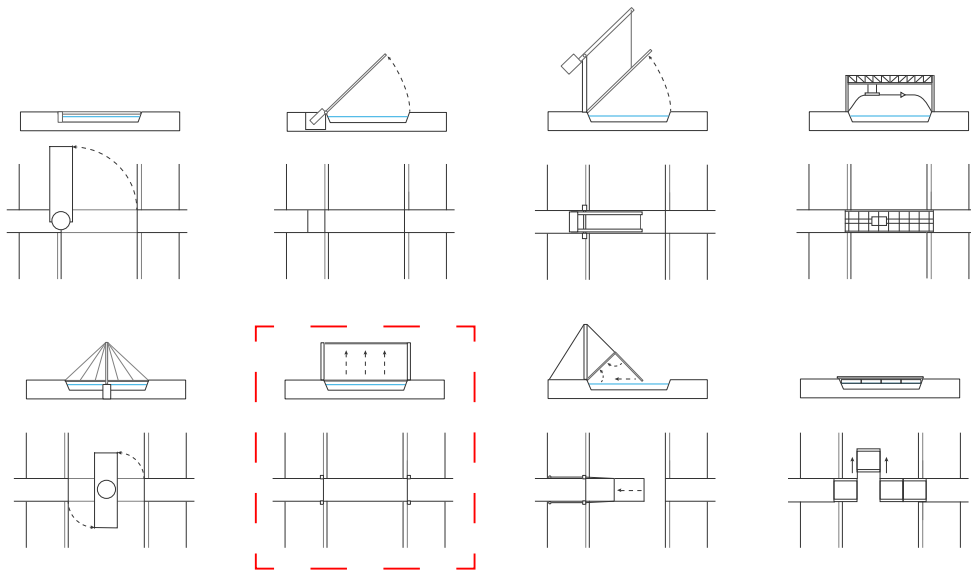


Figure 5.39: Dimensions of the RET trams in Rotterdam (own illustration)



# 6 DESIGN GUIDELINES

## 6.1 DESIGN ENVELOPE

The design location for the proposed bridge design in the West part of Rotterdam.



Figure 6.1: Aerial view of the design location in the west of Rotterdam (Google Maps, 2017)

The Nieuwe Maas river acts as a strong barrier between the north and south part of the city of Rotterdam. The Nieuwe Maas river is approximately 400 meters across.

On the north bank of the river there is a green park in the Nieuwe Werk area (figure 6.2). Opposite of the Nieuwe Werk, on the south bank, is the Kop van Charlois. Also a green park which gives way to the residential area of Oud-Charlois, Charlois and Carnisse. Along the north bank the Westzeedijk adds some green to the area, but the banks of the river are grey and covered in concrete.

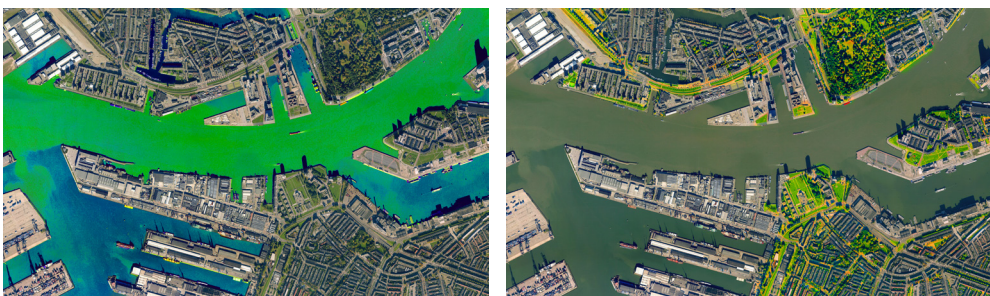


Figure 6.2: Water and green areas in the design location in the west of Rotterdam (own illustration)

In the area, there are a lot of buildings and building complexes. Both for residential as well as commercial use. Most buildings on the south bank are part of the old part of the Rotterdam harbour and are still in use today as warehouses or office buildings.

The main route on the north bank is formed by the Westzeedijk street. The Westzeedijk originates at the Marconiplein crossing and takes the traffic flow downwards past the Dakpark and Merwe-Vierhaven, another part of the old city harbour. The traffic flow than can either reenter the city or use the old Maastunnel to cross the Nieuwe Maas and enter the south bank.

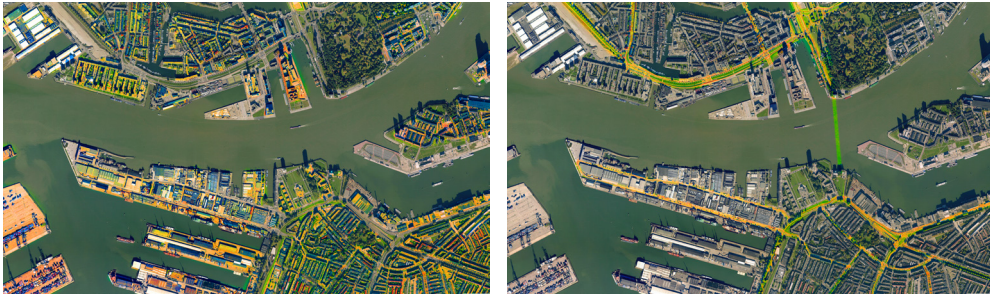


Figure 6.3: Buildings and main routes in the design location in the west of Rotterdam (own illustration)

Looking at the buildings on the Delfshaven, Waalhaven and Charlois area, most the buildings on the waterfront are built in the second half of the twentieth century. Moving further away from the water, one can see the residential areas of Delfshaven and Charlois, most of which was built in the first half of the twentieth century. A few exceptions can be made here, for example the part of historic Delfshaven features buildings from the nineteenth century and before.



Figure 6.4 Housing and age around the design location in the west of Rotterdam (own illustration)

Shown below are the old parts of the city harbour. Following the construction of the Maasvlakte and second Maasvlakte, most of the business and transshipment has left the inner city of Rotterdam.



Figure 6.5 Commercial buildings in the design location in the west of Rotterdam (own illustration)



The connection between the north bank and south bank can happen in a multitude of ways. The Westzeedijk is the main route on the north bank and can be seen as a starting point for the route. There are however some points of interference on the north bank. For example the most western point for connection would cause the bridge to go through a dense residential area. On the south bank this connection would line up with the top of the Maashaven pier. Creating a potential crossing route more to the east would result in a crossing at the exact same location as the Maastunnel, causing interference. The ideal location would be somewhere in the middle of these extremes.



Figure 6.6: Possible crossing possibilities (own illustration)

Along the Nieuwe Maas there are some points on the quays with a high potential. Much like the end of the Wilhemina pier these locations are of high value and preferable need to be preserved. The same goes for the route along the quays. For a long time these location have disregarded and unused. The quays have a great potential in usage.



Figure 6.7: Locations with a high potential in the design location (own illustration)

The location with the highest potential for a crossing is the option in the middle. On the south bank the bridge crossing would connect half way through with the Sluisjesdijk, leaving the end of the pier open for a multitude of possibilities. On the north bank it would connect to a now vacant area alongside the Nieuwe Maas. The open space is now used for markets and some public events, but could remain this purpose with the installment of a bridge crossing. The bridge to be has stay away from the Lloydpier of the Schiemond harbour. This is done to ensure the quality of the Schiemond area. Indicated in red is the design envelope.

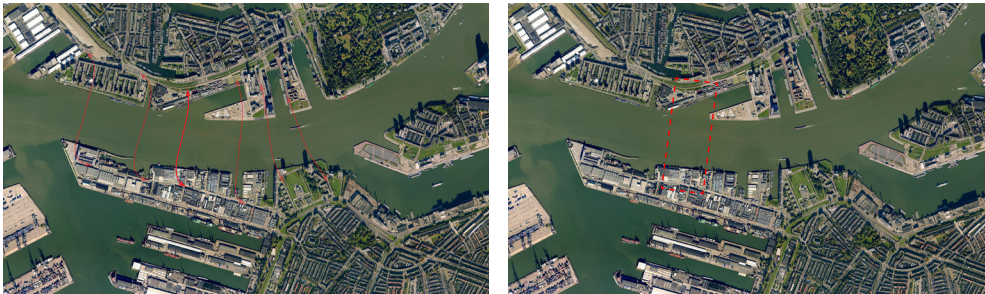


Figure 6.8: The chosen design envelope (own illustration)

## 6.2 DESIGN BOUNDARIES

The design envelope for the bridge crossing spans more than 400 meters across the Nieuwe Maas. Indicated on the left of the image is the north bank and part of the Delfshaven area (figure 6.9). Indicated in the distance is the Schiefabriek and the Lloydtower, in the Schiemond harbour. The pier of the Lloydquay of the Schiemond harbour stretches towards the design envelope.

On the right side of the diagram the pier of the Maashaven is visible. The Maashaven area consists mostly of low warehouses and some office buildings. The main connection route on this pier is the Sluisjesdijk.

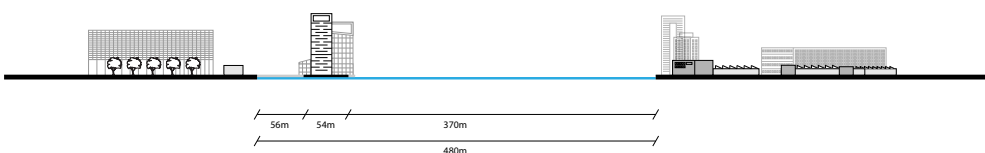


Figure 6.9: A cross section of the design location (own illustration)

The design envelope indicated in red stretches across the water and into the north and south bank of the Nieuwe Maas. Although the Nieuwe Maas is roughly 400 meters across, the design envelope is a bit longer due to the choice to make the crossing and the space needed for the bridge landings.

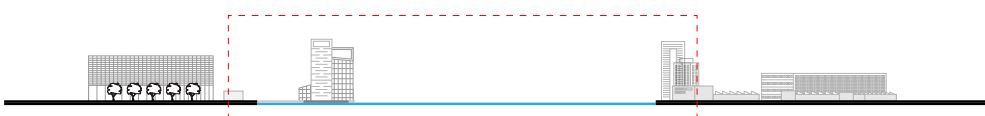


Figure 6.10: The chosen design envelope (own illustration)

The analysis of the structural possibilities of creating a bridge across a body of water led to the decision of creating a vertical lift bridge. This type of bridge is capable of creating a large opening for nautical traffic to pass through. The main span of the bridge deck can be similar to other bridge types, but the possibility of a large opening can be used as an advantage. A vertical lift bridge has a very distinct feature in the form of a set of towers which hold the mechanism in place (figure 6.11). These towers will be of major impact for the surrounding area, both visually as structurally. It is therefore of great importance that they complement both the function of the bridge as well as the surrounding area.

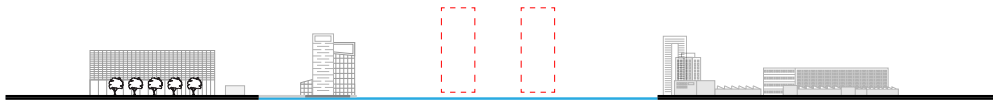


Figure 6.11: The design envelope for the towers of the vertical lift bridge (own illustration)

The analysis into different types of bridge decks and their optimal and possible span length led to the conclusion that one or more piers are needed to support the bridge deck, since it is not economically viable to create a single span across the river (figure 6.12). Because the vertical lift bridge mechanism requires at least two piers for the towers, and maybe some additional piers for support of the bridge deck, a division of piers across the river has to be made.

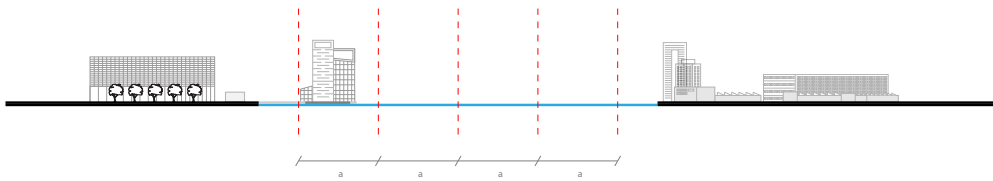


Figure 6.12: The design envelope for the piers (own illustration)

The Nieuwe Maas is a very busy waterway in the south west of the Netherlands and connects the North Sea, via the harbour of Rotterdam with the hinterland. In order for the bridge to be a success, it must not be an obstacle or a major bottleneck in this route. When looking into the other bridges which are currently present in the waterway near Rotterdam, we can derive some conclusions on the possible dimensions (figure 6.13). Also the amount of ships passing through and the number of times the dimensions and clearance under the bridge are not sufficient, leads to a set of recommended dimensions for the new bridge.

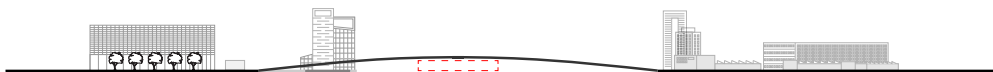


Figure 6.13: The design envelope for the clearance for the nautical traffic (own illustration)

The municipality of Rotterdam has the ambition to create a green city with ample opportunity for cyclists, pedestrians and a functional network of public transport systems, while reducing car use for short trips. The new bridge must therefore be easily accessible for cyclists, pedestrians and different means of public transport. Each of these methods of transport has their own possibilities and requirements. In

order to make a successful bridge on the design location, there are some things to keep in mind. The most important aspect is the slope or inclination of the bridge ramp (figure 6.14). On the one hand an easy slope will be positive for cyclists and pedestrians as they can cross the bridge with ease, on the other had an easy slope means a longer ramp which may or may not fit the location.

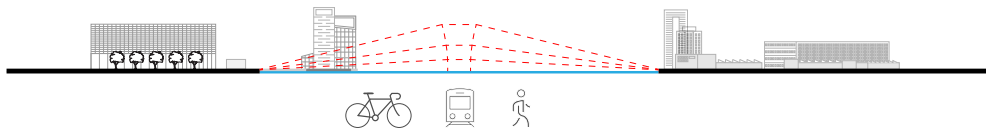


Figure 6.14: The design envelope for the slope of the bridge (own illustration)

The ramps are of vital importance of the bridge as they make the connection between the two sides of the river. Because of the size however the ramps make a big impact to the surroundings. It is therefore of vital importance that they connect to the urban grid as well as the quays. This is an opportunity to add value on all aspects and bring the different elements of the design envelope together.



Figure 6.15: The design envelope for the landings of the bridge and the quays (own illustration)

The last design boundary that has to be taken in account is the nautical traffic. As stated earlier the Nieuwe Maas is a very busy waterway with both commercial traffic as well as recreational boating. The design boundary for the clearance underneath the bride deck is an important factor here. However, since not all nautical traffic will be able to pass the bridge with this given clearance, an openable and movable part will be added to the bridge. This opening will be dimensioned to the ocean class of large cruise ship that will have to pass the bridge.

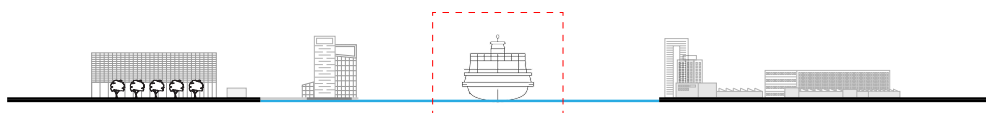


Figure 6.16: The design envelope for the nautical traffic (own illustration)

### 6.3 DESIGN METHODOLOGY

The used methodology for the design of the bridge can be seen in figure 6.17. The first step in the research was an analysis of the city of Rotterdam. This analysis had two main focus point, the first of which was the future plan and strategic vision for the city of Rotterdam. The municipality of Rotterdam set out this vision in different reports, in which they described the future of the city and the steps and measures it would take to get there. The second main focus point of the analysis of the city of Rotterdam was to determine what was already there, what elements were present at the location and what elements needed to be taken into account. This was done in the shape of an analysis of the site, the nautical activity present on the location and the current infrastructure and architecture on both the scale of the location as well as the scale of the city. These two focus points together formed the first half of the research, which focused on the project location. The outcome of the analysis of the project location formed the base for the strategic guidelines for the design of the bridge.

The other half of the analysis is an in-depth view on how to construct a bridge. This analysis breaks down into several pieces, the first of which are of a technical nature. The analysis dives into the different kinds of bridge structures and the advantages and disadvantages of each of these different structures. The second point is a short look into the landings of the bridge. Since we face different traffic flows which each their own demands, an optimum or compromise has to be found. The third aspect is the research into a possible opening of the bridge and the opportunities. The outlines for this were the set of boundaries which were derived from the analysis of the nautical activity, which stated the amount and raw size of the ships passing through the Nieuwe Maas. The two parts of the analysis of the location and on the construction of bridge overlapped in the last part of the analysis where the current bridges in Rotterdam were examined. All together the analysis on the construction of bridges formed the base for the technical guidelines that were used during the design of the bridge. As seen below (figure 6.17), the technical guidelines, together with the strategic guidelines formed the guide for the design of the bridge across the Nieuwe Maas.

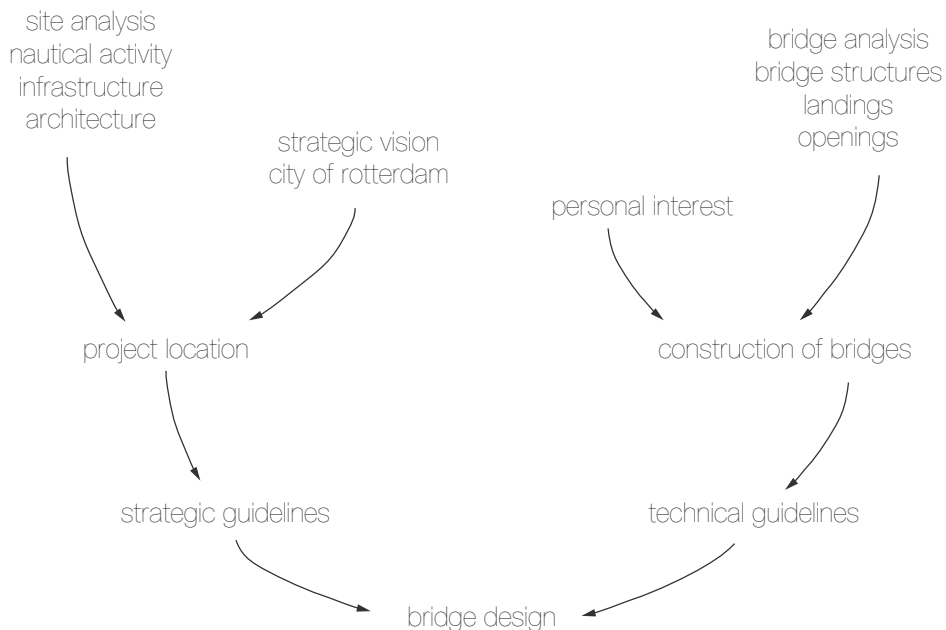
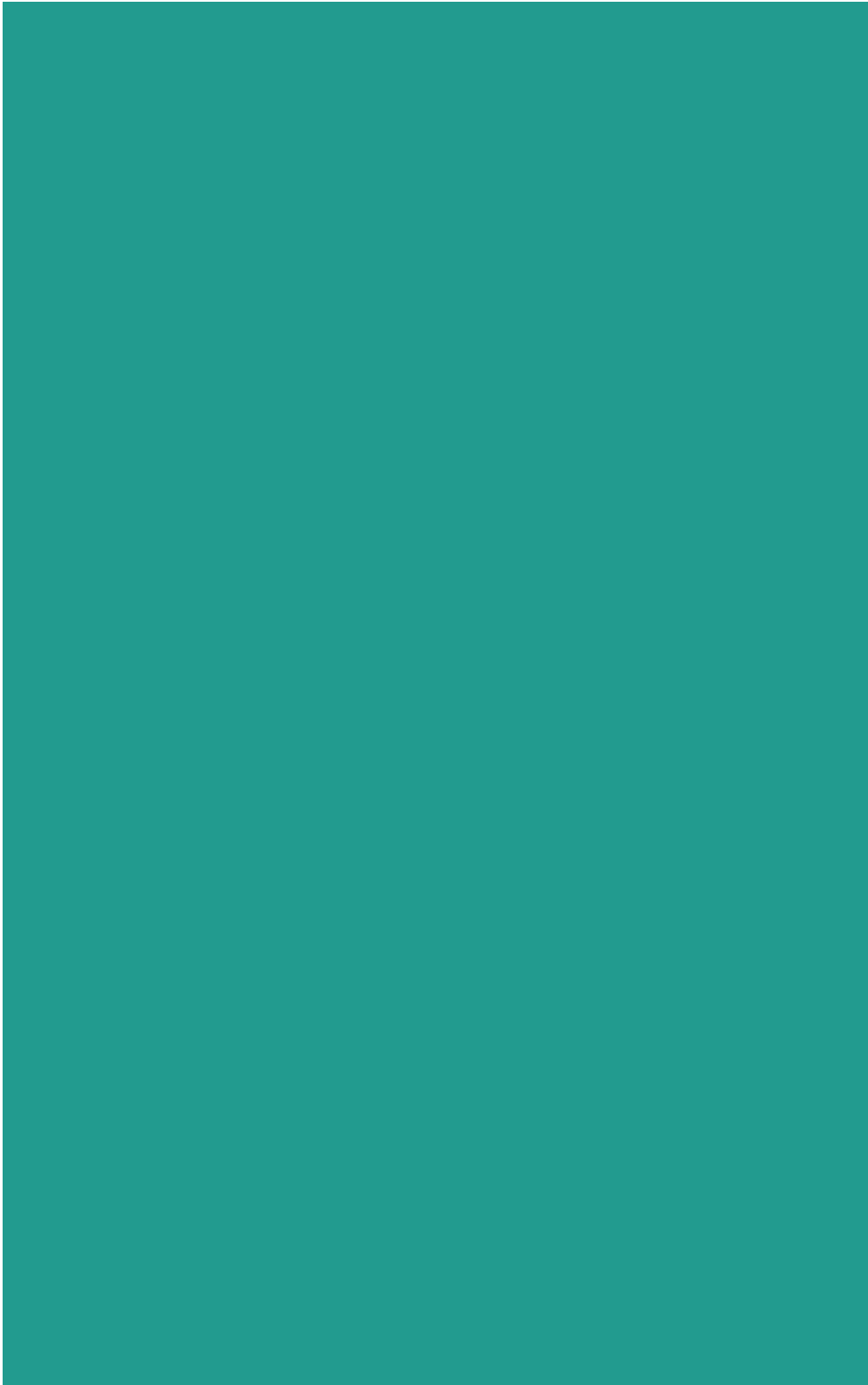


Figure 6.17: Used methodology (own illustration)



# 7 DESIGN STUDY

## 7.1 DESIGN BRIEF

The analysis of the project location and the analysis of bridge typology and construction together formed the basis for the strategic and technical guidelines for the construction of a bridge crossing the Nieuwe Maas river. This can then be used as a program of requirements for the bridge. The most important rules and guidelines are as follows.

Following the wish of the municipality, a new bridge shall be constructed on the western location. This location is due west of the current Maastunnel and will make a connection between the north and south of Rotterdam, and more zoomed in, a connection between the areas of Delfshaven and Maashaven.

The new bridge must accommodate various streams of pedestrians, cyclists and a sustainable form of public transport.

The bridge will not only act as a new connection between the north and the south of Rotterdam, but will also act as the new gateway for the city. When entering the Maas, as well as the city of Rotterdam from the west, the new bridge will be the first encounter as seen from the water. The bridge must welcome new arrivals from the water, but must also welcome different people from the north and the south of Rotterdam.

Each of the city bridges in Rotterdam has its own background and its own reasons why it was built and each bridge is therefore a symbol of its own in the history of Rotterdam. Following the analysis and research this bridge too must be a symbol of its own time in the city of Rotterdam.

As a construction guideline the bridge must be constructed in such a way that it poses as little disturbance as possible for the nautical traffic. The main nautical route in the middle of the Nieuwe Maas must therefore be free of piers or other obstructions. Also a vertical clearance of 12 meters for the main span must be used, which is using the Erasmusbrug as a normative.

## 7.2 LOCATION

There are multiple locations possible for a bridge crossing between the Delfshaven and Maashaven area (figure 7.1), each with their own advantages and disadvantages. The first option for the bridge crossing stretches from the end of the Sluisjesdijk pier, through the residential area in the northwest and makes a direct connection with the Parklane. Downside of this connection is that part of the residential area has to be demolished to make way for the bridge landings. The second option is slightly more to the east and this crossing will make a connection from the Sluisjesdijk towards the small Schiehaven harbour. The connection will pass next to the residential area, so demolition of buildings is kept to a minimum. The third option connects half way the Sluisjesdijk with an unused part of the Schiemond harbour. On the north quay are little commercial and residential buildings that can form an obstruction for the bridge landings. Also, because the area is now mostly unused this can be seen as an opportunity to raise the value of the location. The fourth option for a bridge crossing connects the beginning of the Sluisjesdijk with the center of the Schiemond harbour. The bridge landings will make use of the unused area parallel to the Westzeedijk but will probably also interfere with the buildings on the Lloyd pier. Although part of the Lloyd pier is now not covered in buildings, there are plans to create more residential and commercial buildings, which interfere with the bridge landings. Option number five for a bridge crossing is at the start of the Lloydpier and making a direct connection towards the head of Charlois. This is a direct connection and will probably result in the shortest connection and span, but will require the bridge



Figure 7.1: Possible locations for the bridge crossing (own illustration)

landings to be incorporated in the surrounding residential areas, which will probably lead to resistance from the current residents. The sixth and final option is a crossing from the Parkhaven to the Dokhavenpark. This connection is an optimal one in terms of length and position and will probably make for an effective crossing, but this option will interfere with the Maastunnel as it crosses the Nieuwe Maas at exactly the same location.



Figure 7.2: Focus points in the design location for the bridge crossing (own illustration)

When choosing a location for the bridge crossing there are some aspect that one has to keep in mind. On the west location in Rotterdam, between Delfshaven and Maashaven there are some key elements that can be of high value (figure 7.2). An important aspect was the preservation of key point along the Nieuwe Maas river. The piers and parks along the river are high value locations and their preservation can boost the location and its surroundings. Also the quays which are present along the river can play a major role in the design. When using the quays as public domain and incorporating them into the design the value of the location can be boosted. The crossing possibility with the most potential is therefore the option which on the one hand offers a high value pier option while on the other hand respects the quays and can add to their value. The most promising option is option number three, this option provides space on the Sluisjesdijk for a high value pier, while on the other hand gives ample opportunity near the Westzeedijk area as well as the Sluisjesdijk for recreational areas on the quays.



## 7.3 CONCEPT

In the start of the design phase a concept is formed to which most of the design decisions can be checked. This concept is not a fixed element, but more a guiding theme. This concept, or guiding theme, is subject to development throughout the design process. Within the guidelines set by the research and the analysis, the guiding theme converges into a final design.

### 7.3.1 USAGE

The bridge will be used primarily by cyclists and pedestrians. An optically very slender structure across the water should therefore suffice to transport these groups to the other side of the water. Since there are no cars and heavy traffic to keep in mind, the image and language of the bridge can be rather subtle. The construction must however withstand the forces of nature as well as the sustainable means of transport that will cross the bridge. The addition of the tram line across the water will have some consequences on the structural behaviour of the bridge. This however must be taken into calculation as this will add opportunities for expansion of the transport possibilities in the future.

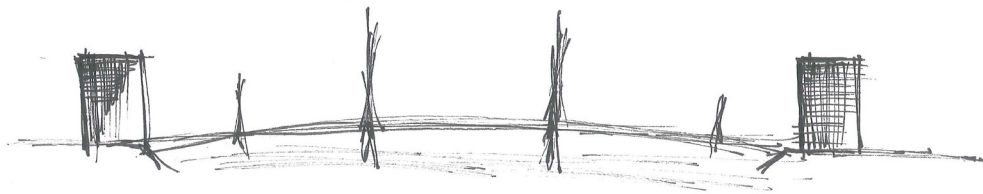


Figure 7.3: An early sketch for the design of the bridge (own illustration)

### 7.3.2 STRUCTURE

The overall structure of the bridge will for a great part be determined by the superstructure needed for the vertical lift mechanism. The vertical lift mechanism will be housed in either two or four towers that need to exceed the height of the vertical clearance needed for ships to pass in the open position. This set of towers will determine the overall view and look of the bridge (figure 7.3). Since the bridge will act as the new entrance to the city of Rotterdam, on the one hand it must act as a gateway to the city center, both inviting for people entering the city as well as defending what is behind.

The two main towers will carry the deck, assisted by secondary piers. The deck will follow a fluent line from one bank to the other and will only be interrupted when the openable part of the bridge breaks the line. The openable part of the bridge will have the same lines as the rest of the deck, despite its different function. This continuity of the bridge deck will ensure that both banks are equal to each other. There will be a difference between the east side and west side of the structure, meaning that the superstructure will not be symmetrical. This is to ensure that the bridge acts as an entrance to the city, welcoming those who enter and defending those in the city.

### 7.3.3 MOVABLE PART

The movable part of a vertical lift bridge may be the most important part, since it defines the vertical lift

bridge as a whole. The different parts of a bridge, the span, the deck and the openable part all need to be integrated into one single structure which is the vertical lift bridge. It is key that the design elements are integrated into the same design and speak the same design language. The size and dimensions of the movable part are primarily determined by the desire of allowing cruise ships to pass the bridge and be able to dock at the Wilhelmina pier in the center of Rotterdam.

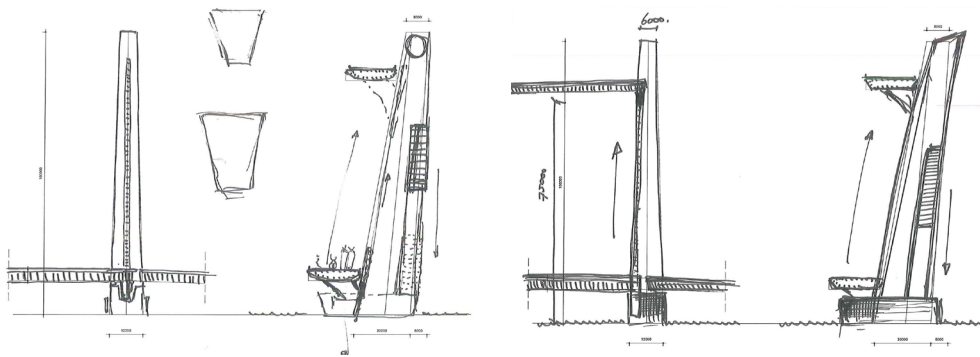


Figure 7.4: An early sketch for the design vertical lift bridge mechanism (own illustration)

## 7.4 DESIGN EXPLANATION

The design of the bridge can be broken down into multiple elements. Although the bridge as a whole is designed with the before mentioned concept in mind, the different elements of the bridge ask for different methods and interpretation is this concept. The design of the bridge, as mentioned before, breaks down in the following elements. The two main towers will be the most defining elements of the bridge, housing the mechanics for the movable part and supporting the bridge deck. The movable part will be similar to the deck concerning the function, but may differ in mechanical sense. The bridge landings will make the connection between the bridge and the quays. Since the north and the south quays are not identical, the outcome of the design process might not be similar, although they are based on the same concept.

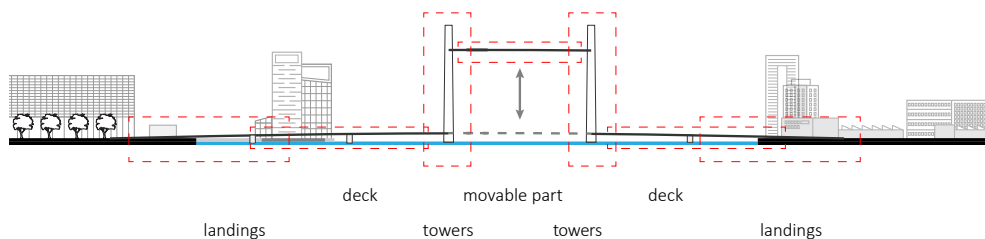


Figure 7.5: The different design parts that make up the bridge (own illustration)

### 7.4.1 STRUCTURE

The first and most notable element of the bridge will be the vertical lift structure and mechanism (figure 7.6). A vertical lift bridge consists of a set of either two or four symmetrical towers. For this vertical lift bridge the choice was made to go with a set of two towers. These two towers will stand on two piers

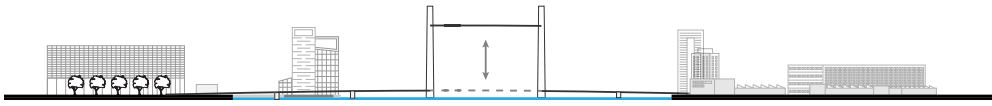


Figure 7.6: The structure for the vertical lift bridge mechanism (own illustration)

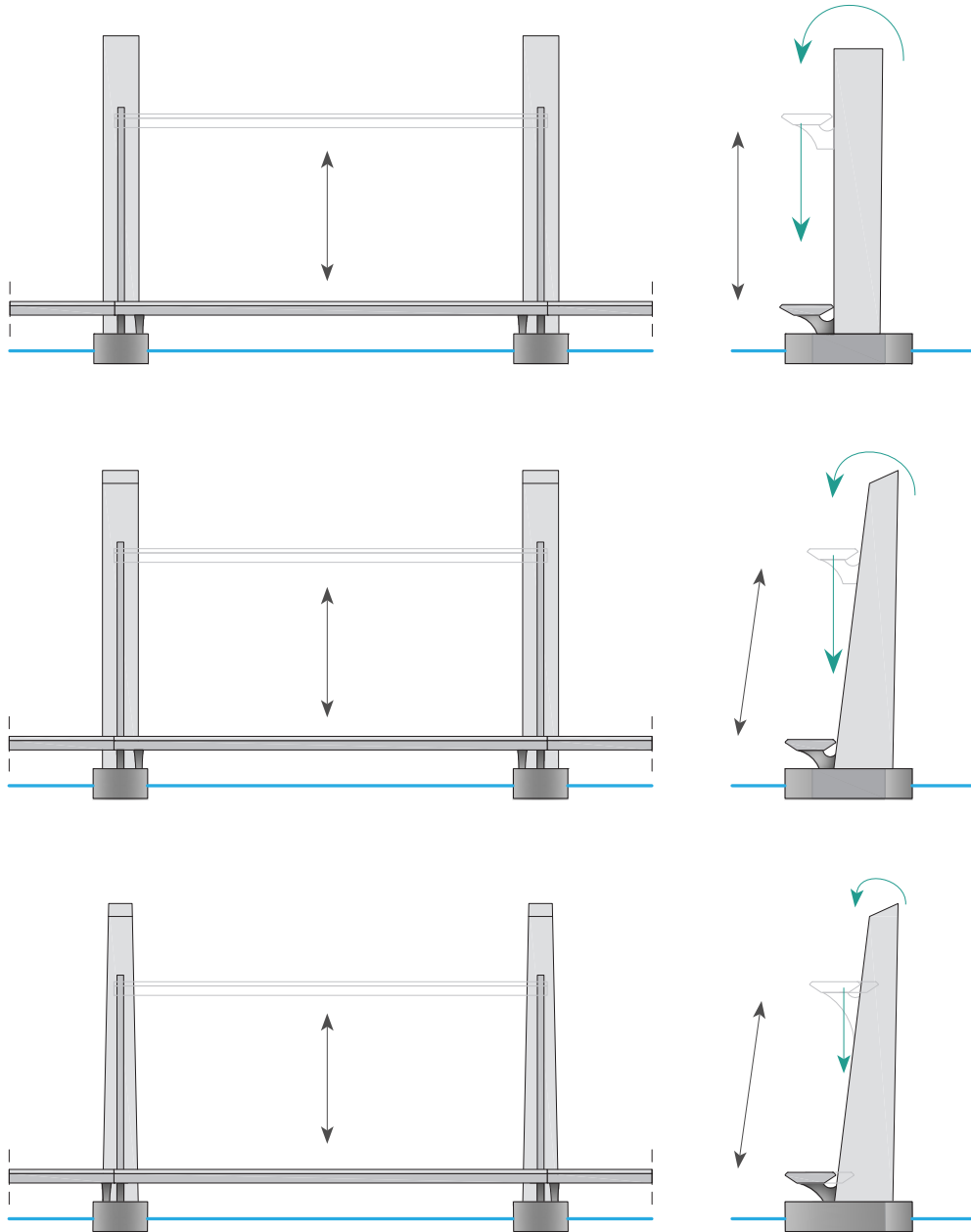


Figure 7.7: Optimization of the vertical lift bridge towers (own illustration)

in the middle of the Nieuwe Maas river and will carry the main deck across the water. As seen from the water the view of the bridge is very symmetrical and open. When looking from the side of the bridge, for example from the quays, the bridge acts more asymmetrical. Because there are only two towers in the structure, the bridge deck needs to pass next to the lift towers. Because the deck is placed next to the towers, the towers need to be structurally optimized in order to cope with the forces of rising the deck (figure 7.7). The towers are tilted slightly backwards, on the one hand to cope with the structural forces and momentum caused by the rising bridge deck and on the other hand to emphasize the asymmetrical shape of the vertical lift bridge. The asymmetrical setup of the bridge is explained in figure 7.8, where the design location is placed between the world and the city of Rotterdam. The design of the bridge leans towards to non-similar entities.

In the second step in the optimization process the towers are slimmed down towards the top. Also the shaped is slightly more adjusted in a way that the tower, despite its size, looks more slender than it actually is. The top is tilted towards the front a bit to emphasize this slenderness. The second benefit of the tilted back towers in the decreased momentum in the lift mechanism itself. Not only the momentum in the tower decreased, but by lowering the angle of the rail for the vertical lift mechanism the momentum between the deck and the lift mechanism decreases, thus reducing wear and tear. In the last optimization step the deck is curved back towards the main towers. Again, not only does this adds to the asymmetrical shape of the bridge as seen from the quays, but will bring the weight of the bridge deck within reach of the main towers, thus lowering the momentum. Further aspects on the optimization of the bridge deck will be discussed in the following paragraphs.

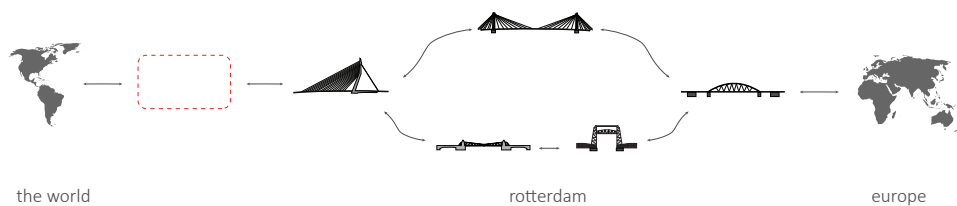


Figure 7.8: Location of the bridge as new entrance to the city of Rotterdam (own illustration)

#### 7.4.2 ROUTE

In the chosen design envelope there must be found an optimal crossing possibility for the bridge to cross the water. However, there are some aspects that one has to keep in mind. The first is the possible disturbance of the nautical activity on the river. The deck of the bridge must have a clearance of at least twelve meters above the waters to allow most of the ships to pass unhindered. The second aspect is that the construction of the a bridge is an expansive matter, so it must be done as efficient as possible. In order to make the crossing as optimal as possible it is decided to cross the river at 90 degree angle, thus minimizing the body of water that needs to be crossed and minimizing the span length. Applying a 90 degree angel with the shores is also optimal for the ship captains, as they have the least obstruction. The third aspect is determining the route that the traffic which is crossing the bridge will take. When analyzing the traffic flows and routes in the city of Rotterdam the conclusion was that there had to be a connection between the west and the south areas in Rotterdam The Westzeedijk in the north of the design location is a busy street which goes both ways. The Sluisjesdijk in the south is a dead end street. The end of the Sluisjesdijk pier needs to keep its high value so, opposite to the north bank where the routes swings to the left en right, on the south bank the route goes towards the residential areas. The head of the Sluisjesdijk pier does not turn into a through route.

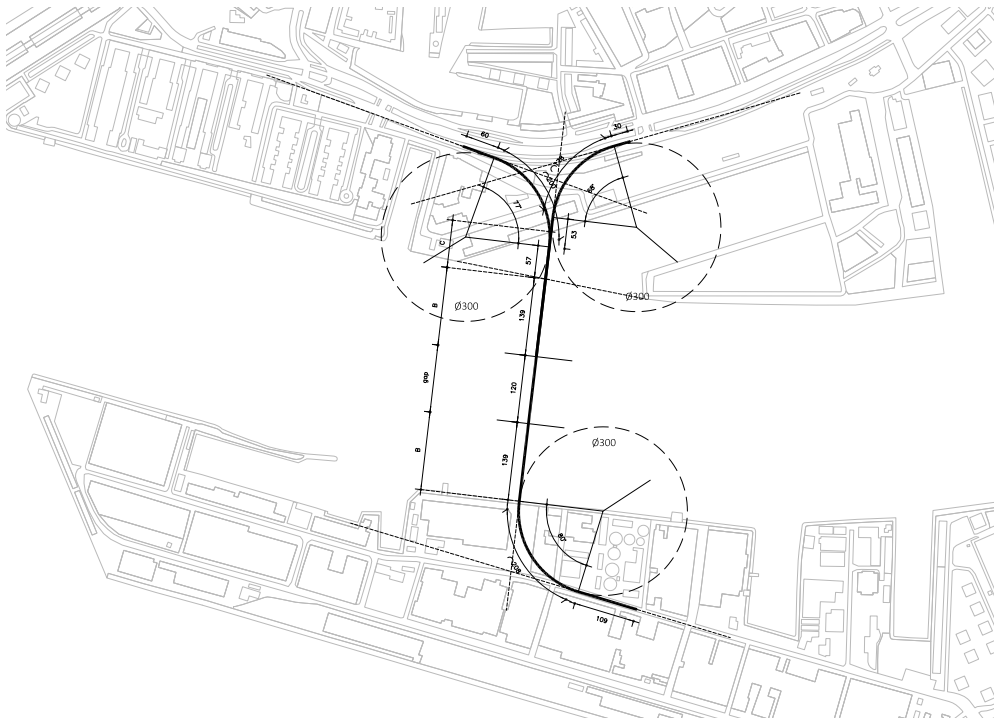


Figure 7.9: Determining the optimal route across the Nieuwe Maas river (own illustration)

When looking to the different traffic stream which will make use of the bridge, the tram has the most strict rules for design, so they will be used as the design guidelines. The route is computed using turn circles with a radius of 150 meters for the public transport network. This is an optimized turning circle which ensures the flow through of the tram network.

On the north bank the route of the bridge crossing splits into two routes. Routing to the left is the route for the tram, cyclists and pedestrians, routing to the right is the route for cyclists and pedestrians. Due to the length of the bridge landing a choice was made to create a deviation in the route to enhance flow through in all directions.

After determining the main shape of the route, some refinements need to be made. The rough shape as seen in figure 7.9 is the optimized shape based on the restrictions caused by the application of a tram on the bridge. The flow of the route is further refined in figure 7.10 using the remaining traffic flows such as cyclists and pedestrians. With the addition of optimal turning circles of the cyclists and pedestrians, the flow of the route is further defined. On the north bank the route splits in two directions, to follow either the Westzeedijk to the west towards the Parklane, or to the east towards the city center. The tram line follows the route to the west and connects to the current tram line which connects Spangen in the west of Rotterdam through the center with the north. Just west of the bridge landing there is an existing turning loop which even allows future tram lines to turn after crossing the bridge. The route is subdivided for slow traffic, such as cyclists and pedestrians. Only creating a single route for all traffic flows would lead to long routes due to the length of the bridge landings. This can lead to dissatisfied users of the bridge. In order to satisfy cyclists and pedestrians and increase the flow through for these groups a division in the deck and routes is made. As seen in figure 7.10 the divided route follows the different optimal turning corners and makes for a fluid design and optimum flow through on the location.

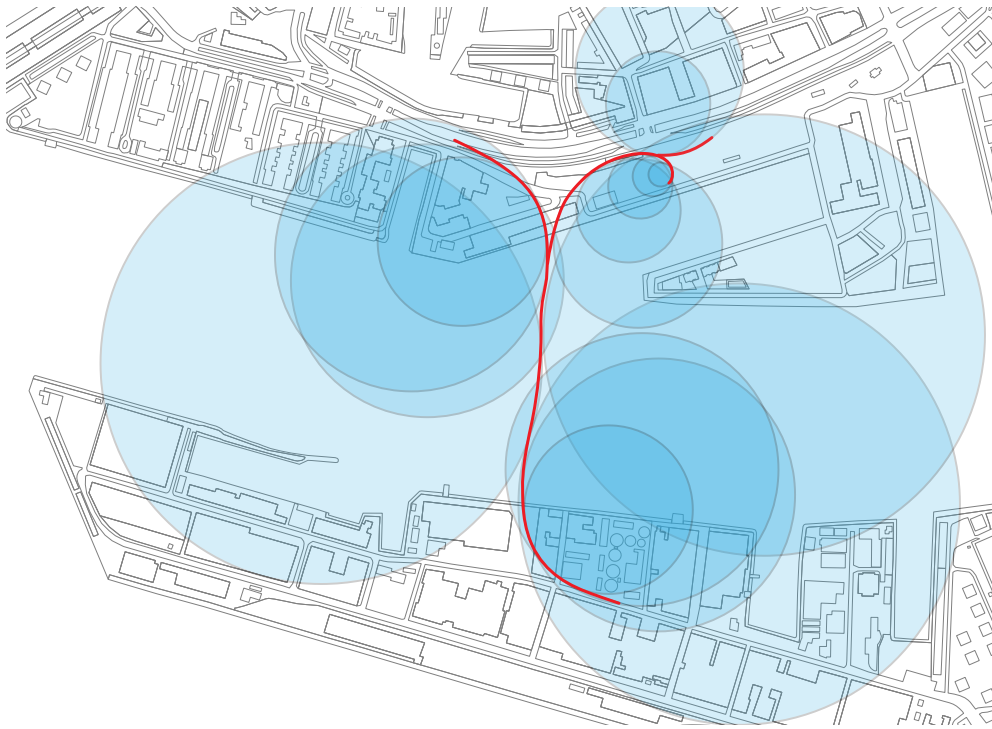


Figure 7.10: Refinement of the route across the Nieuwe Maas river (own illustration)

### 7.4.3 LANDINGS

The landings of the bridge make up quite a bit of the overall length of the bridge. This is due to the gentle slope that is needed to transport cyclists across the body of water. On the north bank the landing of the bridge is split into two sections, one carrying the tram towards the west and one carrying cyclists and pedestrians to the east. In the current situation, there are different traffic streams on the north bank. The tram line which leads from west to east and the other way round, and the cycle paths and sidewalks, which follow the Westzeedijk and its side streets. These traffic flows are indicated in figure 7.11 in red, yellow and blue. With the addition of the bridge, the traffic flows become a bit distorted. The tram line can continue along the Westzeedijk but also has the possibility to take a turn at the bridge and cross the Nieuwe Maas. The same goes for the cycle route. Cyclists have the option to follow the Westzeedijk, but with the addition of the bridge, the cycle route moves closer to the water, into the design location and follows the curvature of the landing to eventually cross the bridge.

For the south bank the procedure of the design of the landings is quite similar, but the outcome shows some differences. This is due to the fact that the Sluisjesdijk is a dead end pier and that incoming traffic is therefore one-sided. Approaching from the east will enter the tram line and cyclist and pedestrian streams. The landing will take these flows and transport them over the river. For the pedestrian and bicycle traffic however there will be the possibility to get closer to the water before crossing the bridge. The banks at the river, both in the north as well as in the south, can be used for transport of the slow traffic flows, such as pedestrians and cyclists, but can also be used for recreation by people who visit the location.

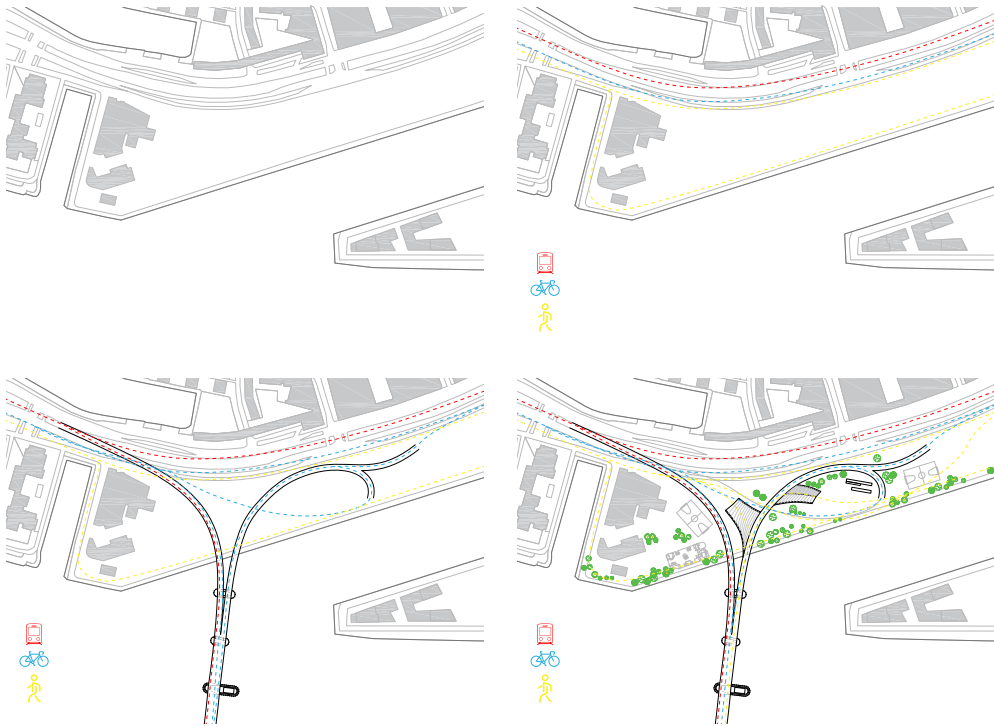


Figure 7.11: Refinement of the landings on the north bank (own illustration)



Figure 7.12: Refinement of the landings on the south bank (own illustration)

#### 7.4.4 TOWERS

The main towers of the vertical lift bridge define a major part of the look, feel and image of the bridge. In order to create the tower that follows the proportions of the surrounding area and has a certain relationship with the surrounding buildings, a variant study was executed in order to find the optimum bridge (figure 7.13). The variables in this study are the height of the tower, which is dependent of the vertical clearance needed for the variety of ships to pass and the mechanical elements inside the towers. Also the horizontal clearance is of importance. From a nautical point of view, a wider gap between the towers is more optimal, since it allows ships to pass unhindered. The limitation for a horizontal clearance is a structural one, since a longer span results in higher forces in the bridge deck, which causes the need for a stronger and thicker deck and construction. An increased thickness of the deck would also influence the lines and proportions of the bridge.

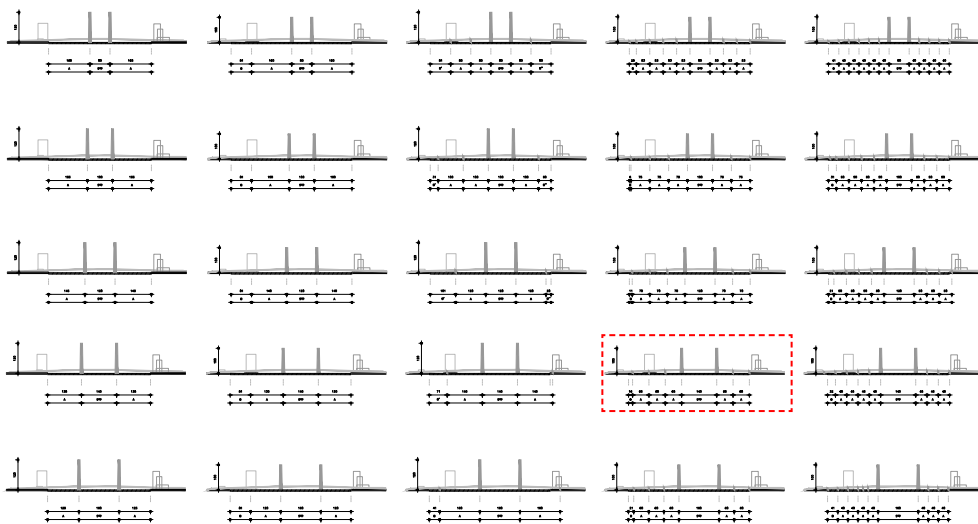


Figure 7.13: Study into the proportions set by the elements of the bridge (own illustration)

Next to the main towers are secondary supports which uphold the bridge deck between the openable part and the north and south quays. These secondary pillars also have their influence on the proportions and rhythm of the bridge. When looking at the surrounding buildings and high rises the emphasis of the bridge has to be on the width, instead of the height of the bridge. With a bridge crossing a body of water of more than 400 meters in width, the addition of two long, slender towers, which are placed close to each other does not complement the location. A strong wide statement has to be made.

Seen in figure 7.14 a comparison is made between the design location in the west of Rotterdam and the location of the Erasmusbrug in the center of Rotterdam. The Erasmusbrug, at the time of construction, was the largest construction at its location. The buildings which are currently present on the Wilhelminapier are all built after the completion of the Erasmusbrug. It is therefore quite difficult to envision the future surroundings of the new vertical lift bridge on its location. In figure 7.14 a comparison future view is envisioned by placing the high rise buildings currently present on the Wilhelminapier next the vertical lift bridge on the location. Although in the current situation the new bridge may be the tallest structure on the site, the hope is that it will soon be surpassed by high rise buildings. The new bridge will still stand out from the high rise buildings thanks to its wide stance, with which it will differentiate itself from the tall vertically oriented high rise buildings on the Sluisjesdijkpier.



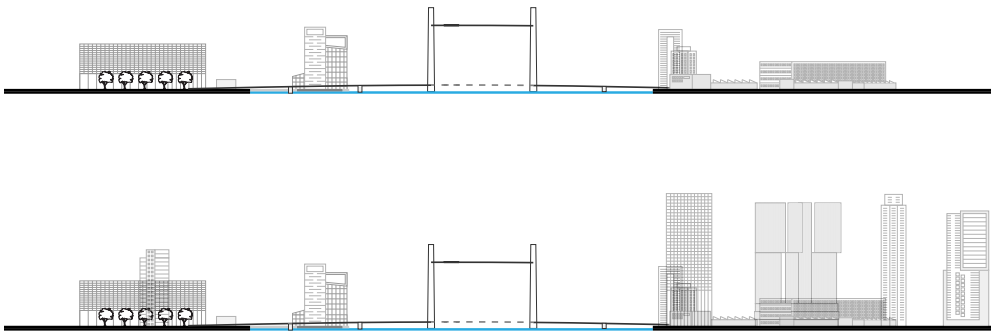
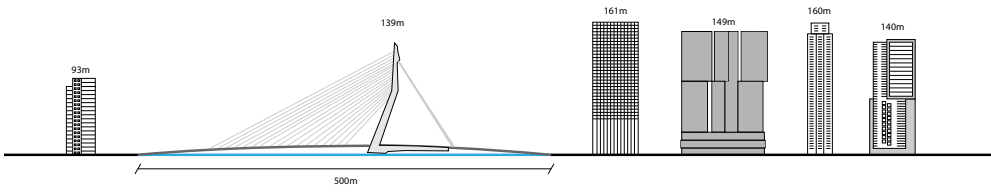
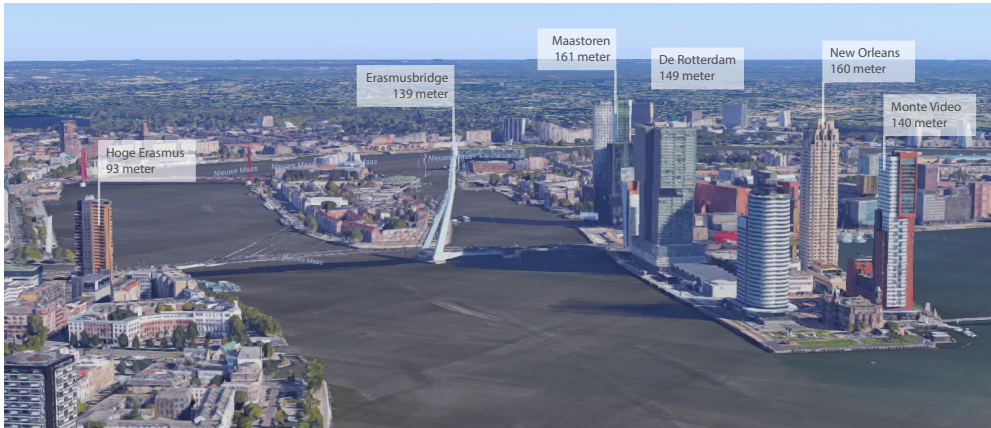


Figure 7.14: Study into the proportions of the bridge in its surrounding (own illustration)

## 7.4.5 STAIRS

The different traffic flows in the location are all spread out over the location in order to create a diverse place and separate the fast traffic flows, like the tram from the slow flows like the pedestrians. The stream of cyclists also have a diverse path as they can choose between multiple options to cross the bridge. In order to further facilitate the slow traffic streams, another division is made. The first group within the slow traffic are the people who will use the bridge mainly for transport. This group will use the bridge merely to get to the other side. The second group however, will cross the bridge much more slowly, or maybe not cross the bridge at all. This group will use the quays for recreation and social meetings. They will enjoy the view of the bridge and the green quays. This will, for a part, be made possible by the stairs leading up to the bridge.

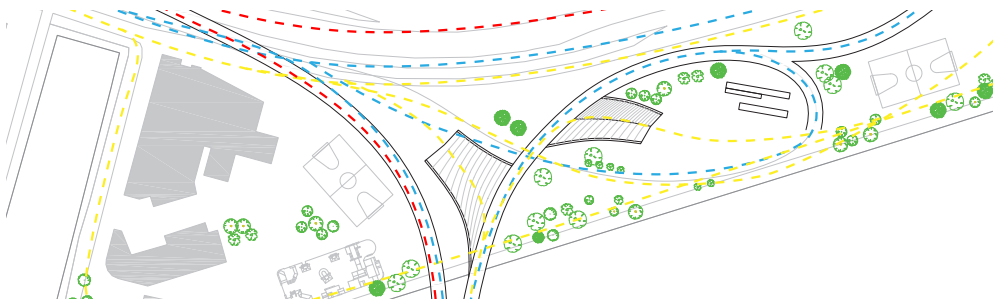


Figure 7.15: Study into the proportions of the bridge in its surrounding (own illustration)

As seen in figure 7.15, there are multiple traffic flows crossing the location. The green quays, but especially the new stairs leading up to the bridge deck have the double function of the transport of people but also a recreational function. In the most simple version a stairs can be used to transport people across a height difference. In this case however the stairs can also be used for recreational purposes. The stairs are equipped with gentle slopes and wide stairs and steps. The long stretched stairs can be used for relaxing and has places where people can reside and relax.

As seen in figure 7.16, there are multiple options for traveling up and down the flight of stairs. When using the gentle slopes that make up the stairs, one can stroll gently towards the bridge. When you are a bit in a rush, you can also walk straight towards the bridge deck, combining the slopes with the steps.

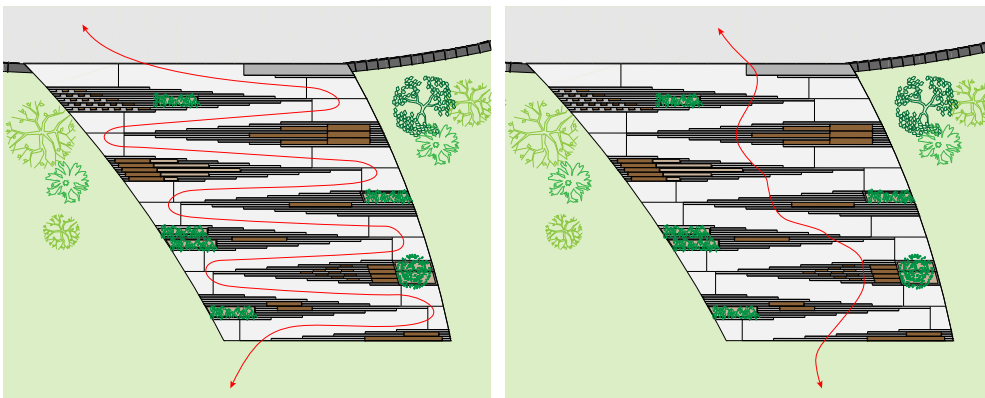


Figure 7.16: Different possibilities for traveling up and down the stairs (own illustration)

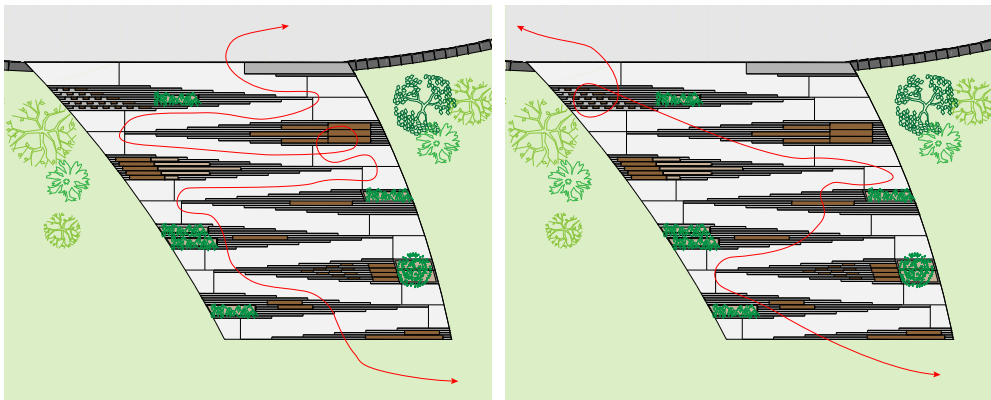


Figure 7.17: Different possibilities for residing on the stairs (own illustration)

When looking at figure 7.17 you can see that the stairs can also be used for leisure and residing. Upon the stairs there are multiple options to sit down and relax on one of the benches or near the green roof elements which houses plants and trees.

#### 7.4.6 BUILDING SEQUENCE

In order to create a feasible design, the building sequence needs to be taken in to account. An important factor is the nautical traffic that needs to go with as little disturbance as possible. Another factor are the individual elements that either need to be built on site or transported to the site.

The first step in the construction of the bridge is the building of the bridge piers (figure 7.18). There are two piers for the main towers and three piers for the secondary pillars, which uphold the deck, which brings the total to five piers.

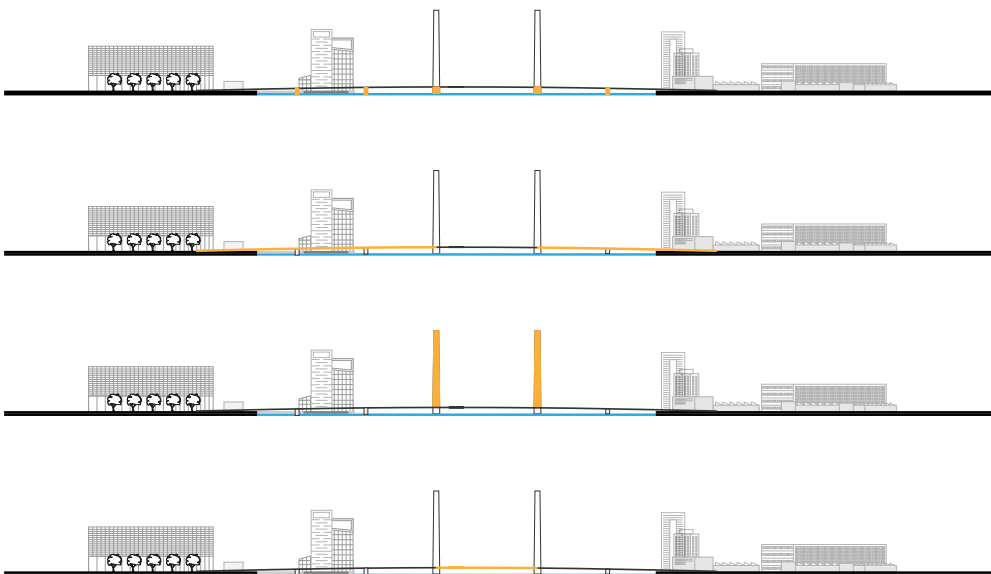


Figure 7.18: Different steps in the building sequence of the bridge (own illustration)

The second major step in the construction process is the placement of the main deck. The deck itself is prefabricated at another location and is being brought in by ship to the construction site. The sections of the bridge deck, which stretch from pier to pier, are then hoisted into place on top of the secondary piers. Also the connection with the banks are made. The bridge deck connects to the land and the landing. The stairs, which allow for pedestrians to enter the bridge are built and connected to the deck. The third step in the building process is the construction of the main towers. The main towers are made from segmental concrete elements, which are stacked on top of each other. A crane, which is positioned on the main pier allows for easy assembly of the elements. The concrete elements are transported to the construction site by cargo barge and assembled on site (figure 7.19).

The final step of the building process is the placement of the openable part of the vertical lift bridge. This part is also prefabricated off site and brought in with a large barge. The two large cranes which are placed on the main piers lift the movable bridge deck from the barge and hoist it into place. After the placement of the large bridge elements the cranes can be taken down. The bridge is completed with the placement of the final small elements.

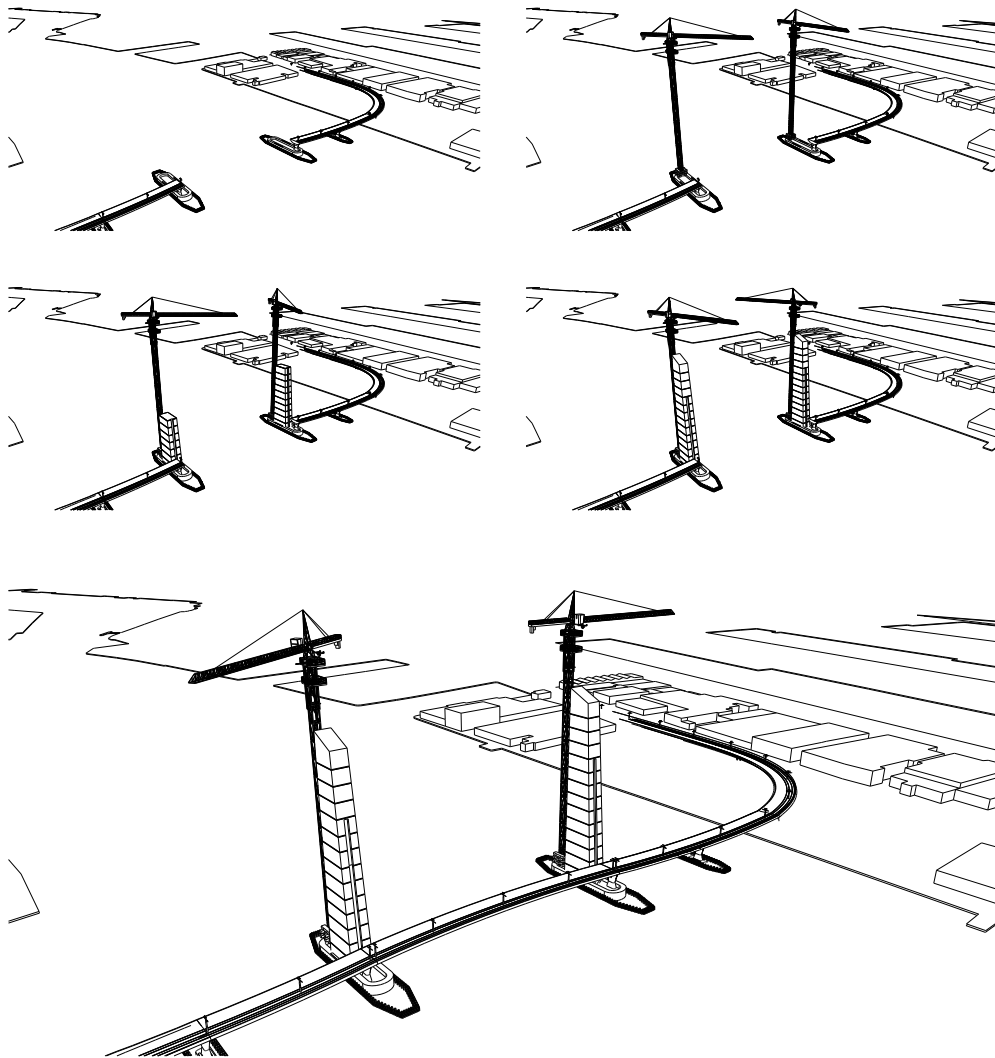


Figure 7.19: Different steps in the building sequence of the bridge (own illustration)

### 7.4.7 DECK

The bridge deck houses the various traffic streams that need to cross the river. The fast and slow traffic preferably all have their own lane in which they reside. In figure 7.20 there are two options for the layout of the bridge deck. The variant on the left has a symmetrical layout, with a double lane tram rails in the center. Next to that are two bicycle paths and a walkway. The variant on the right has an asymmetrical layout in which the dual lane tram rails are moved to one side of the bridge. Next to that is a wide bicycle path which travels in both directions and a roomy walkway. The right option is preferable over the left one as it accentuates the asymmetrical setup of the bridge and provides a better connection to the routes along the quays and landings.

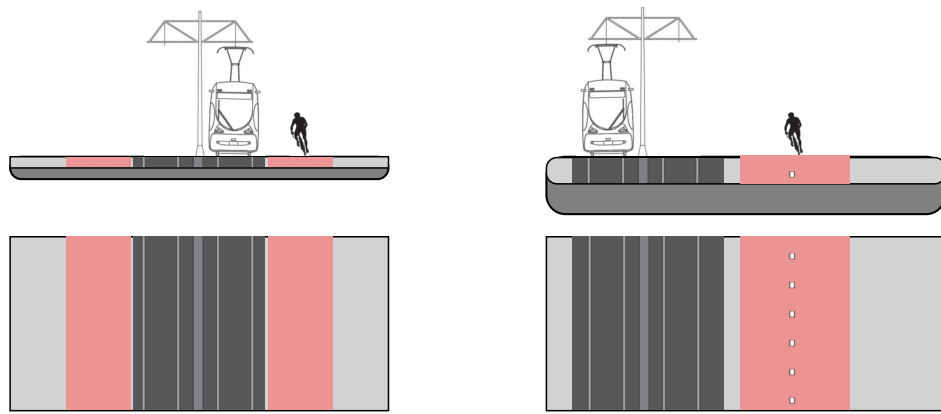


Figure 7.20: Various layout possibilities for the bridge deck (own illustration)

The deck is constructed from different segments. The bridge is a steel box girder with an orthotropic steel deck which acts as a monocoque structure (figure 7.21). The main girders run along the length of the segments, with a cross-plate element which provides additional stability. The deck plate which encloses the whole segment as a monocoque transfers outside forces through the ribs to the main girders. On top the deck a wearing surface is added to provide traction for bicycles and pedestrians. The rails are embedded in the ribs, so that the top surface of the deck is smooth.

Within the box elements, there is space for a maintenance route and piping for electricity and drainage.

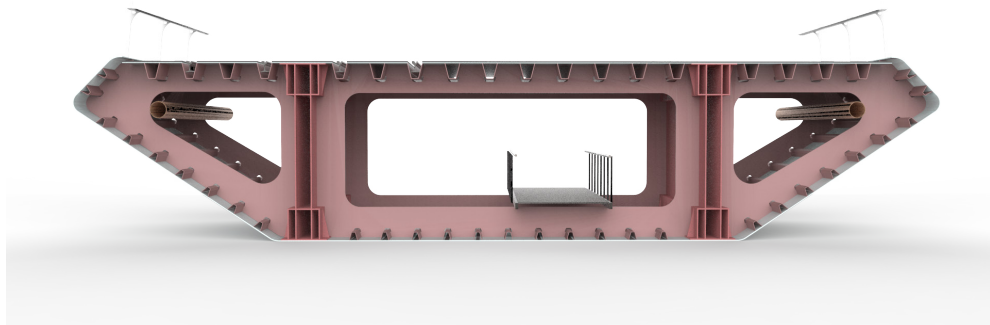


Figure 7.21: Cross section of the segment of the bridge deck (own illustration)

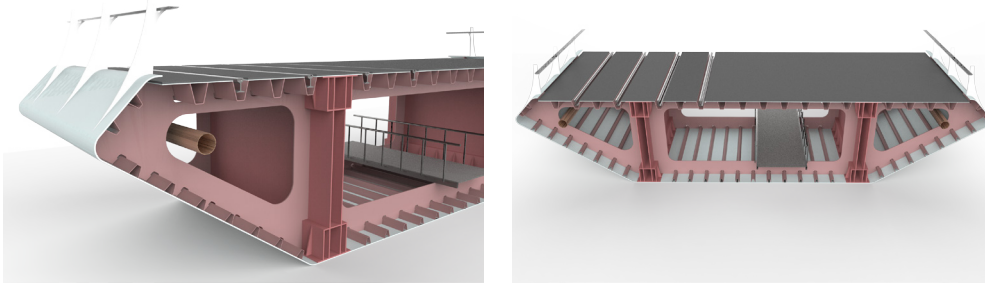


Figure 7.22: Cross section of the segment of the bridge deck (own illustration)

#### 7.4.8 VERTICAL LIFT MECHANISM

The mechanism for the vertical lift bridge is embedded in the tower bridge towers (figure 7.23). The mechanism works with a system of sheaves, much like an elevator. The main system works via a counterbalancing system with the bridge deck on one hand, and the counterweight on the other half. This mechanism on the left in seen in figure 7.23. In the top of the tower there is a large sheave which balances both the weights. Long, twisted steel cables run from the movable bridge deck, over the main

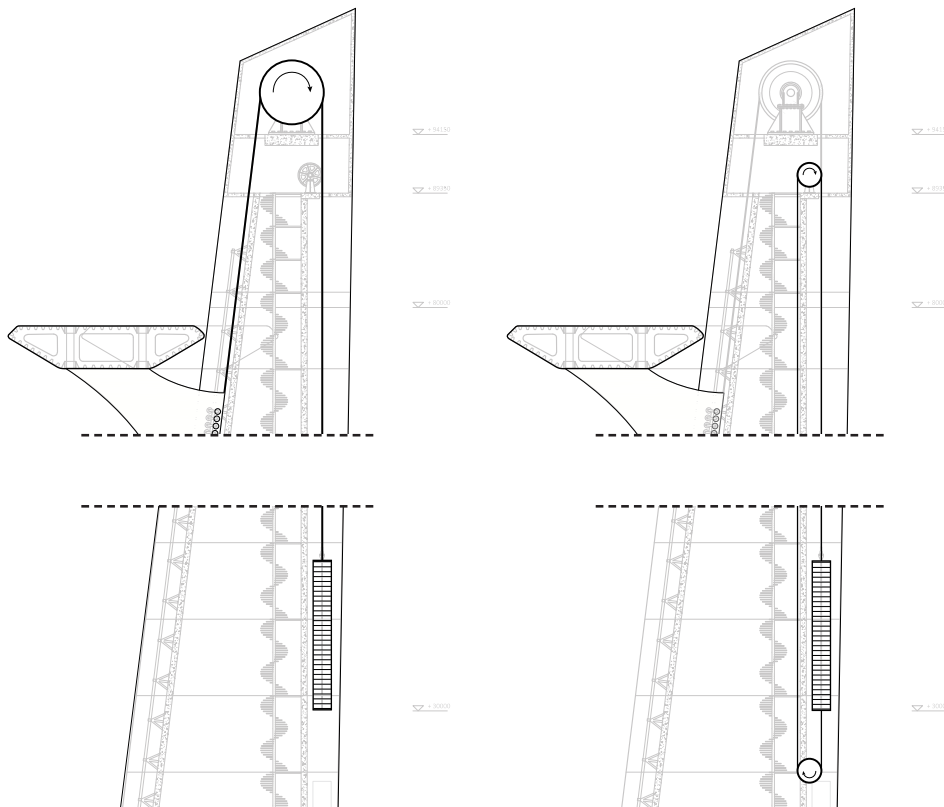


Figure 7.23: Mechanism for the vertical lift bridge within the bridge tower (own illustration)

sheave and down again to the counterweight. The movable bridge deck is upheld with a cantilever mechanism that is connected to a rail in the tower via a set of rollers. This way the movable bridge deck acts as a cart that can ride up and down the tower.

The mechanism on the right in figure 7.23 shows the secondary mechanism that is necessary for the lifting mechanism of the vertical lift bridge. A secondary set of cables is connected to the counterweight, and a set of sheaves on the top and bottom of the tower. An electrical motor drives this set of cables and thus controls the counterweight. This way it is possible to move the deck of the vertical lift bridge up and down. By locating the lower sheave in the base of the tower, it is possible to place the engine room in the base of the tower, which is convenient in terms of space and weight.

## 7.5 DETAILS

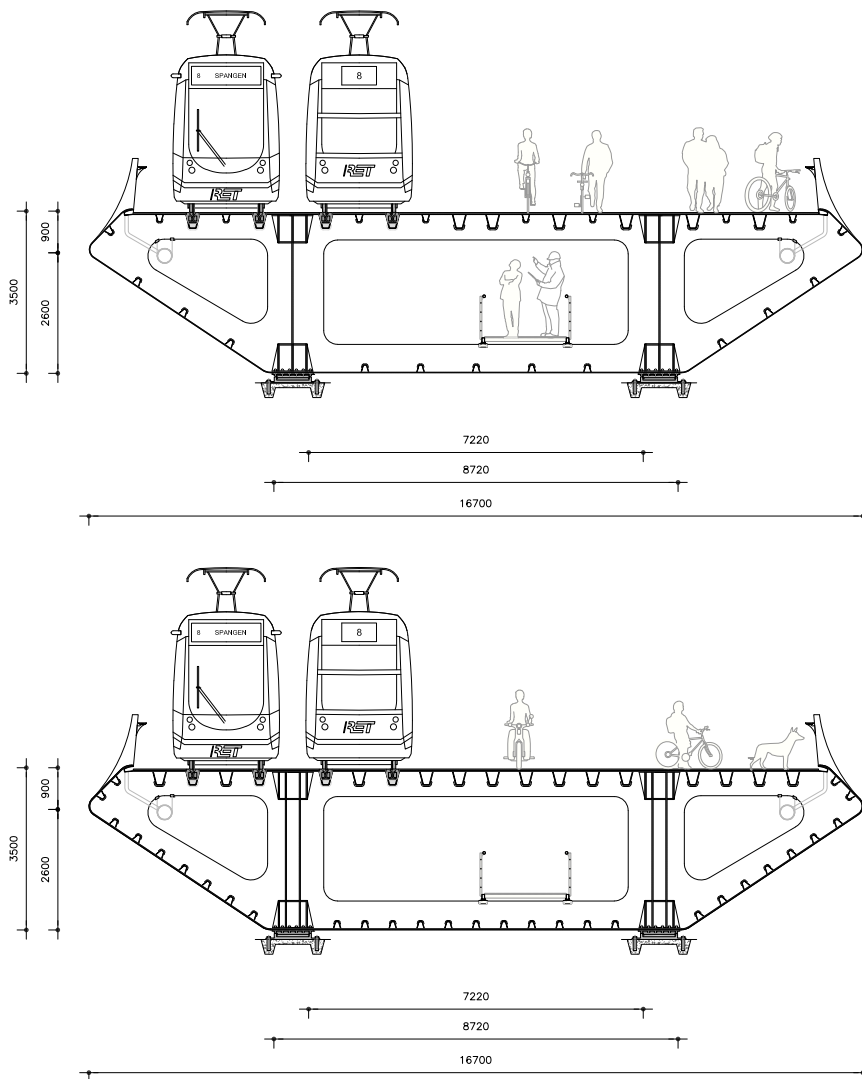


Figure 7.24: Cross section of the bridge deck (own illustration)

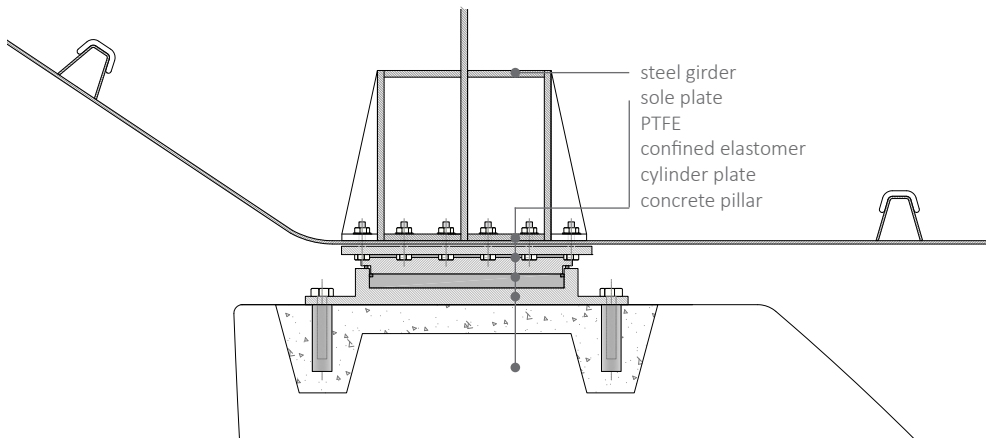


Figure 7.25: Connection detail between deck and pillar (own illustration)

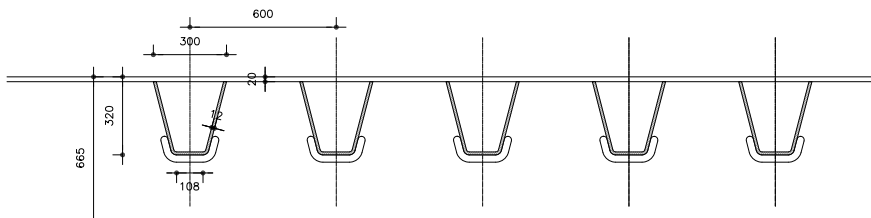


Figure 7.26: Connection detail between deck and pillar (own illustration)

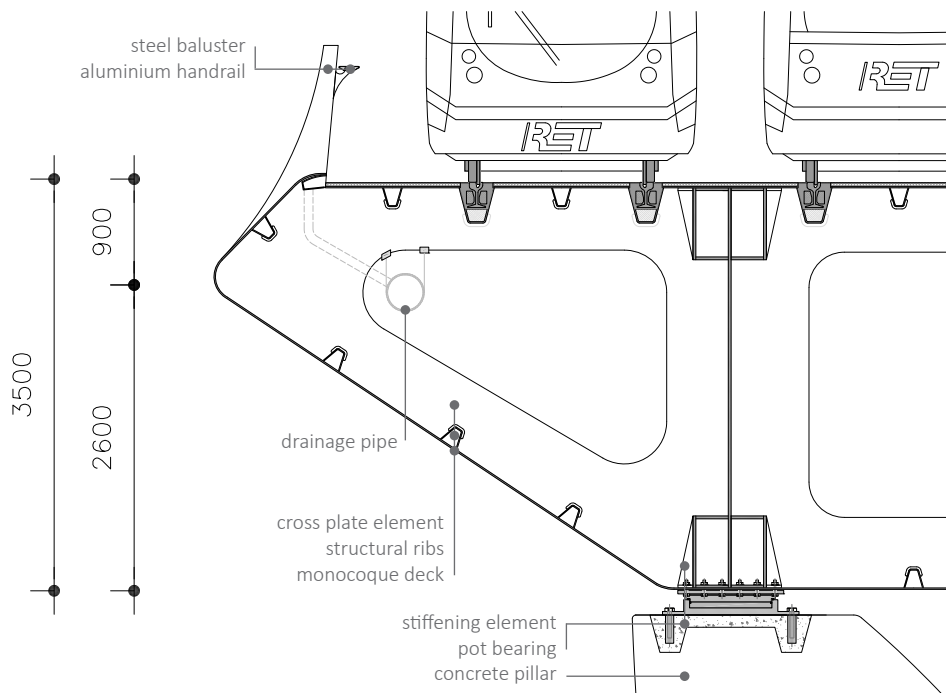


Figure 7.27: Connection detail between deck and pillar (own illustration)



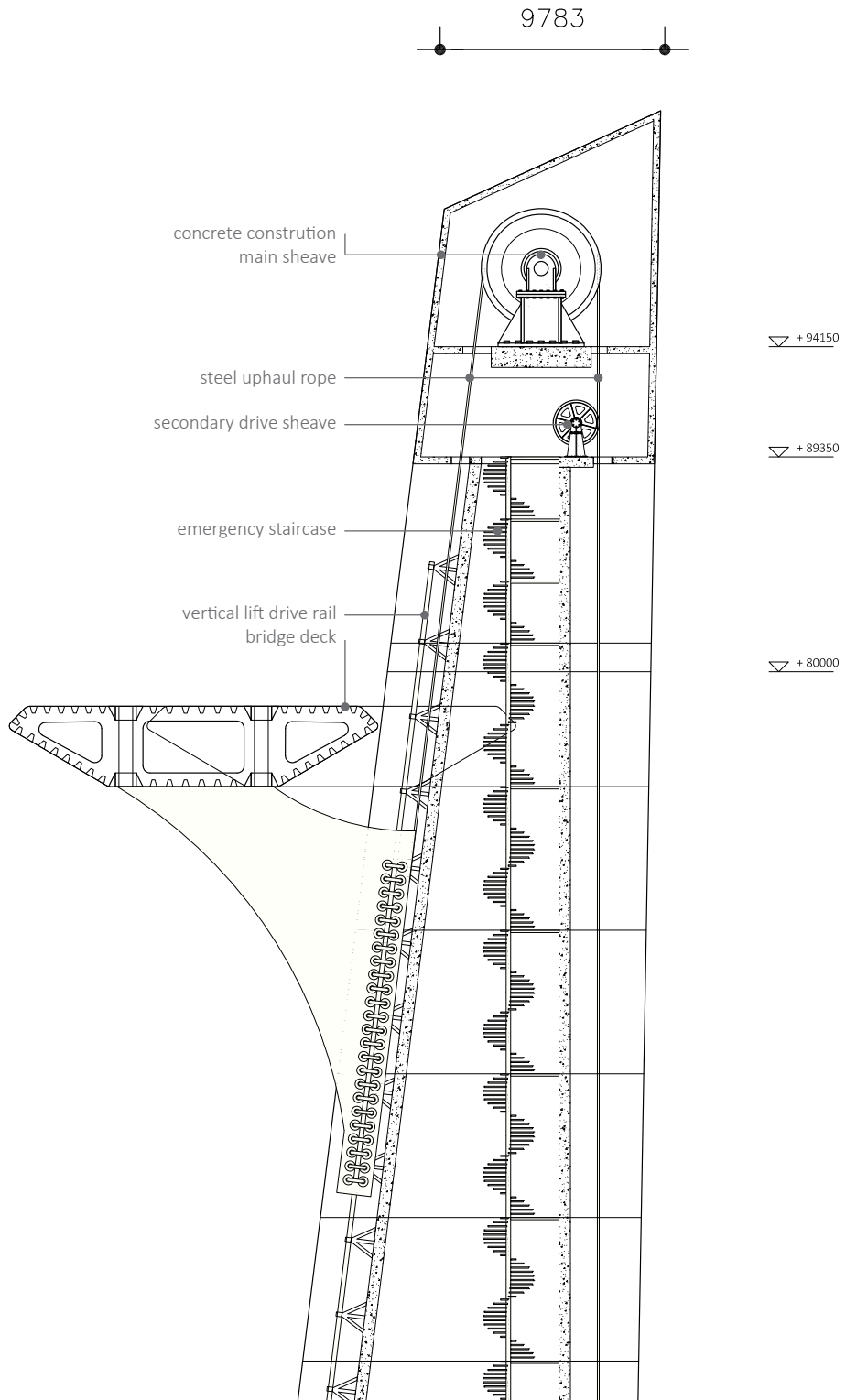


Figure 7.28: Section cut of the main tower - side view (own illustration)

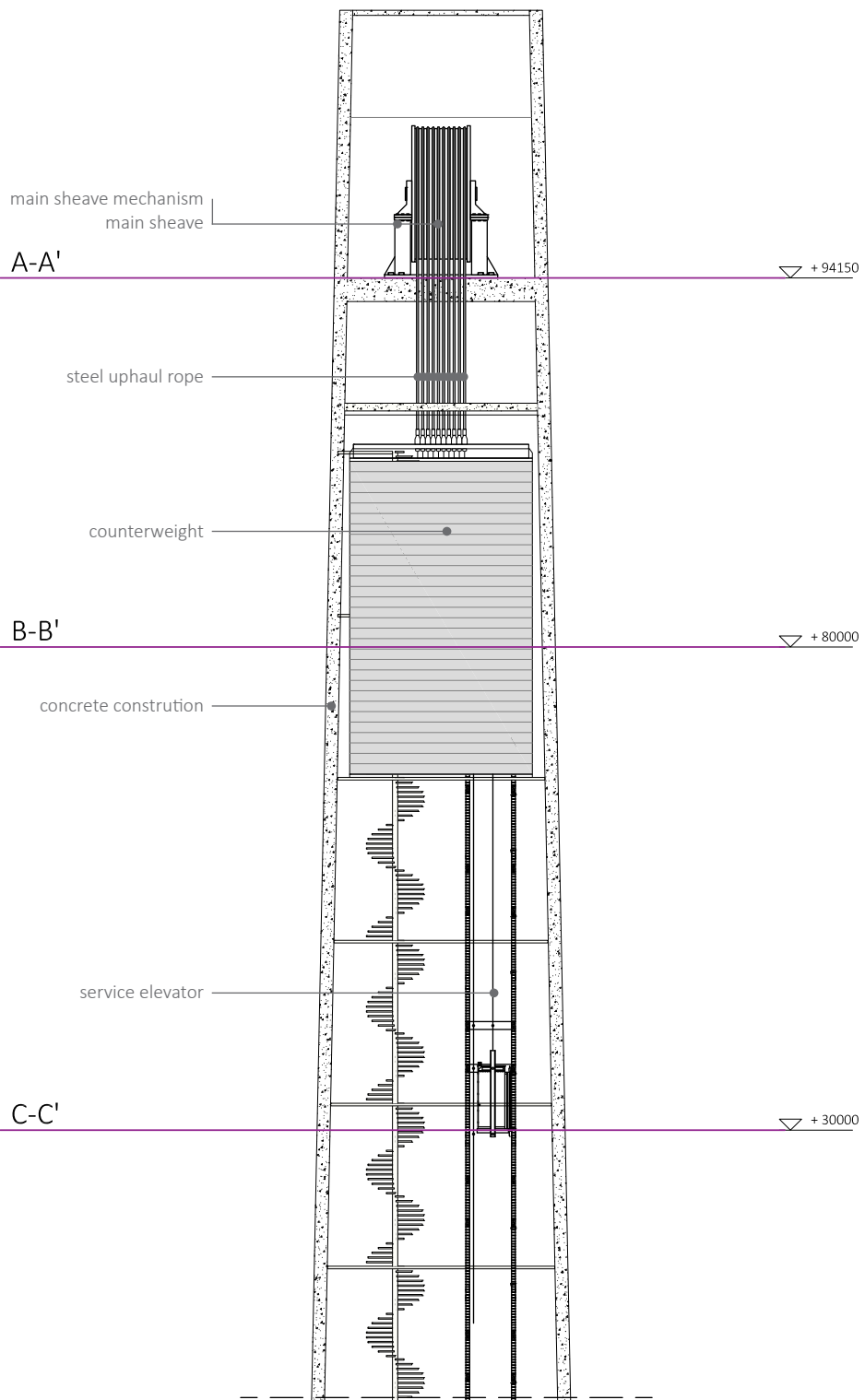


Figure 7.29: Section cut of the main tower - back view (own illustration)

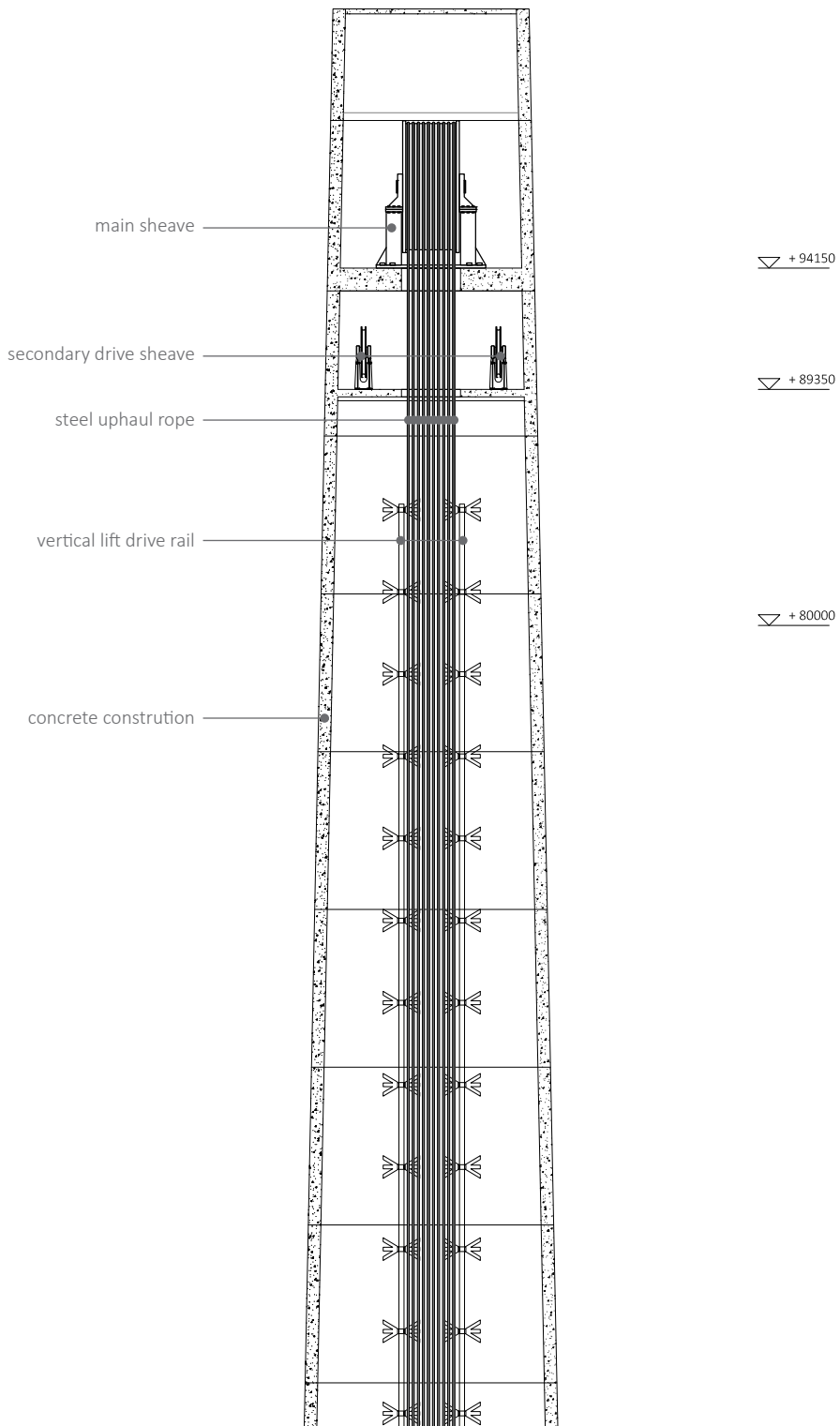


Figure 7.30: Section cut of the main tower - front view (own illustration)

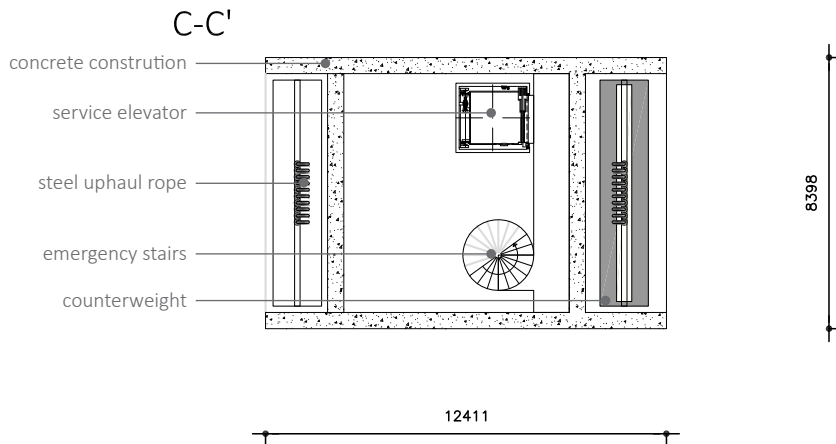
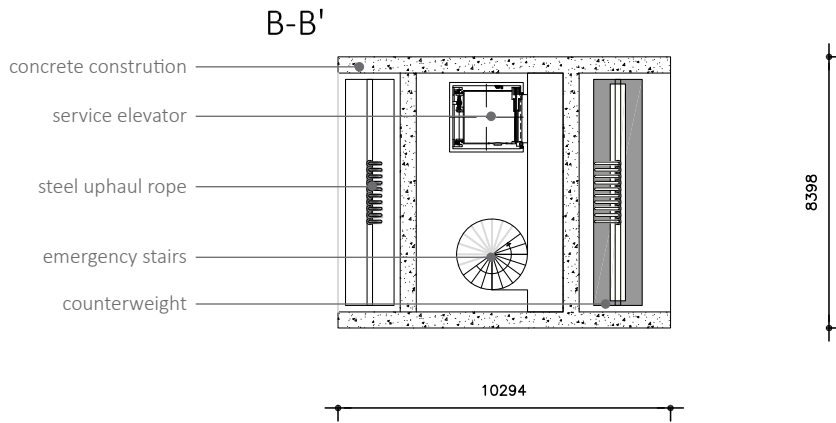
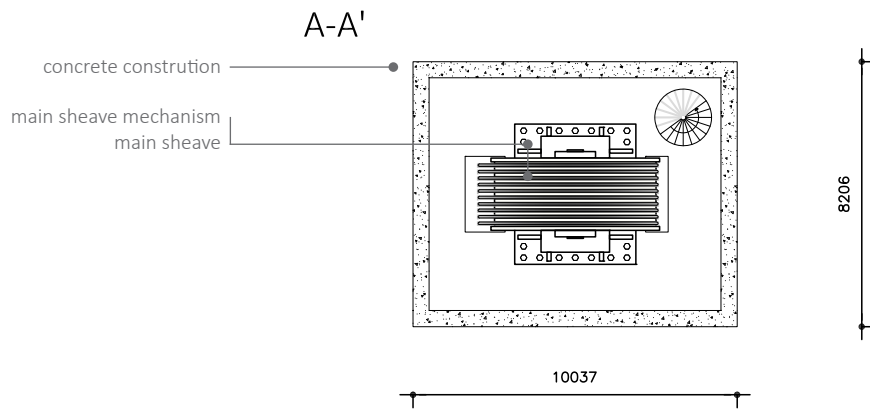


Figure 7.31: Section cuts of the main tower - plan view (own illustration)

7.6 DRAWINGS

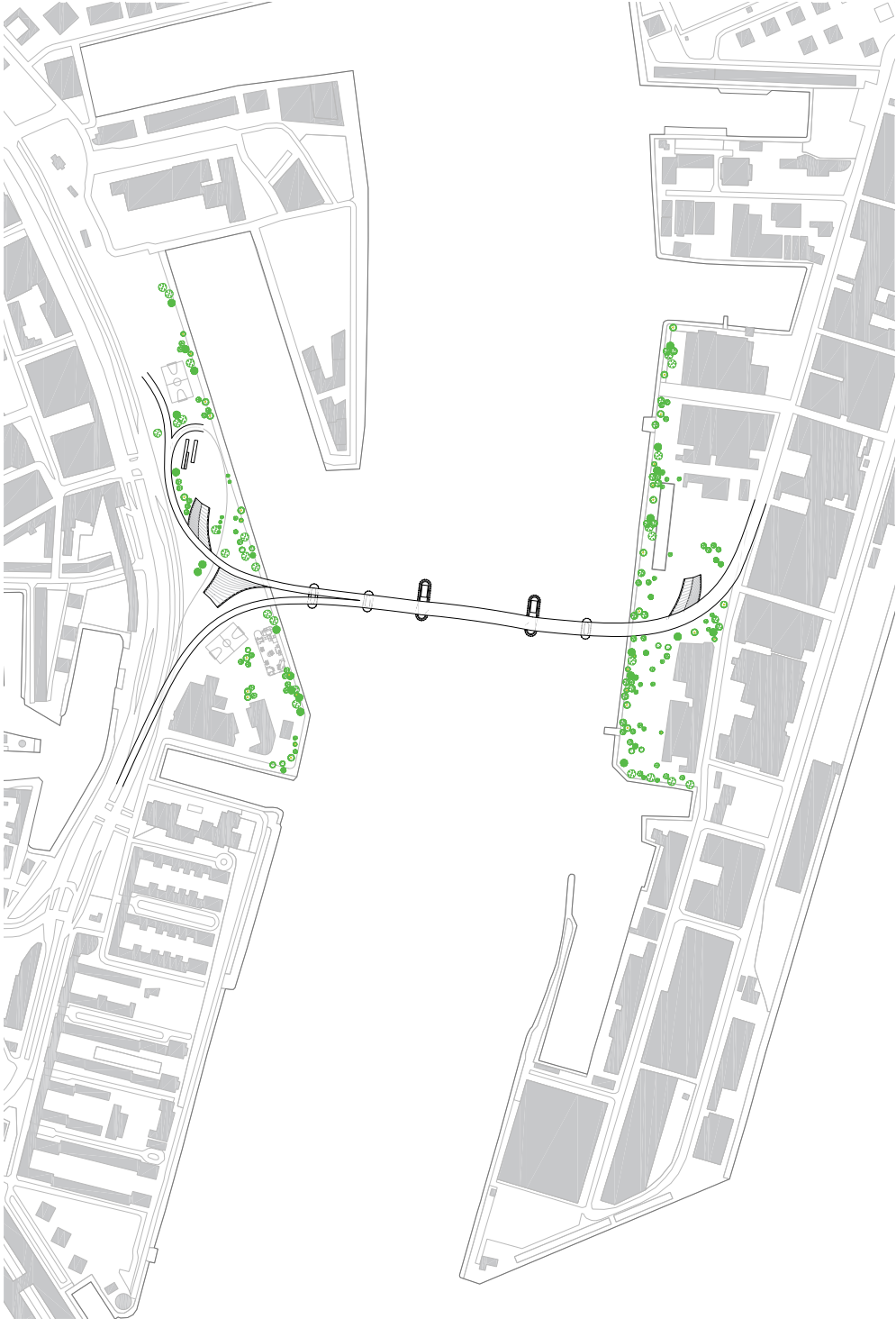


Figure 7.32: Plan view of the location with the new bridge (own illustration)

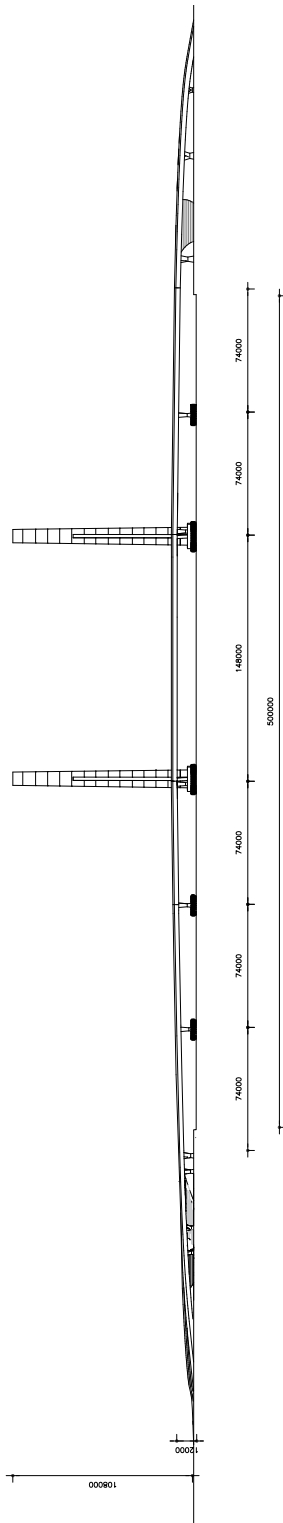


Figure 7.33: Longitudinal view of the location with the new bridge (own illustration)

7.7 IMPRESSIONS



Figure 7.34: Impression of the bridge in closed position (own illustration)



Figure 7.35: Impression of the bridge in opened position (own illustration)





Figure 7.36: Impression of the bridge in opened position (own illustration)



Figure 7.37: Impression of the bridge in opened position (own illustration)



Figure 7.38: Impression of the bridge during night time (own illustration)



Figure 7.39: Impression of the bridge in opened position (own illustration)



Figure 7.40: Impression of the bridge during night time (own illustration)

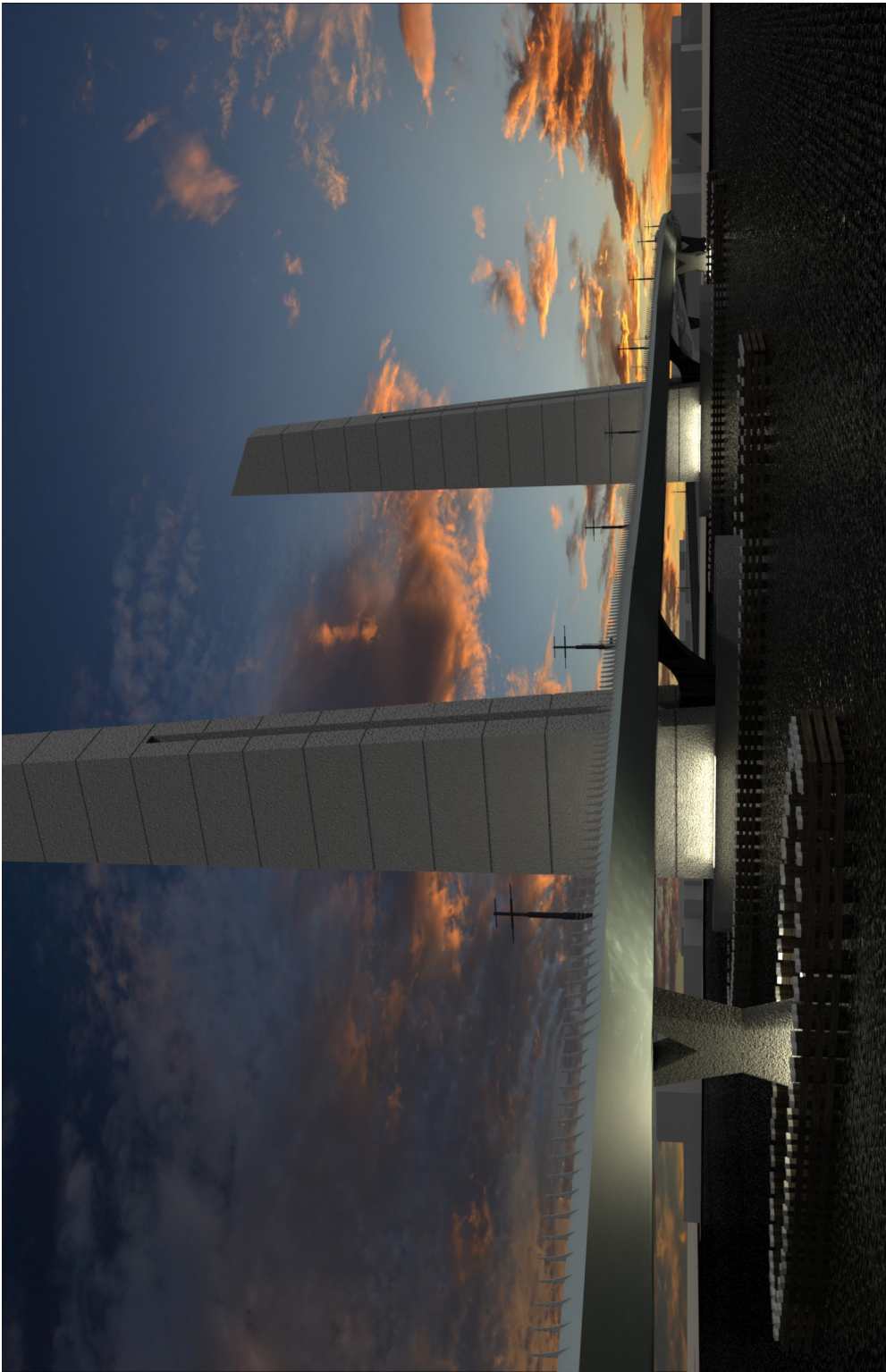


Figure 7.41: Impression of the bridge during night time (own illustration)

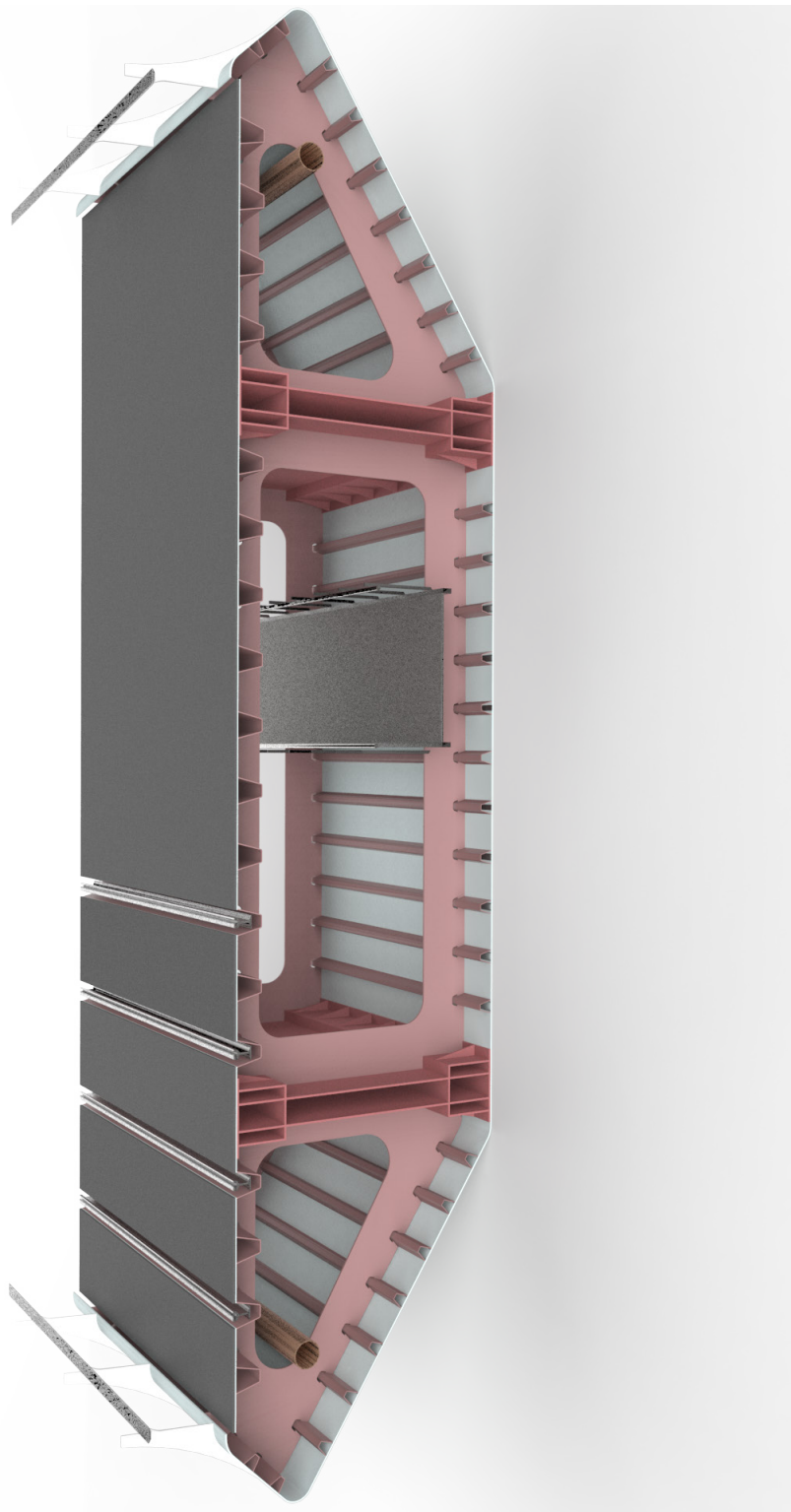
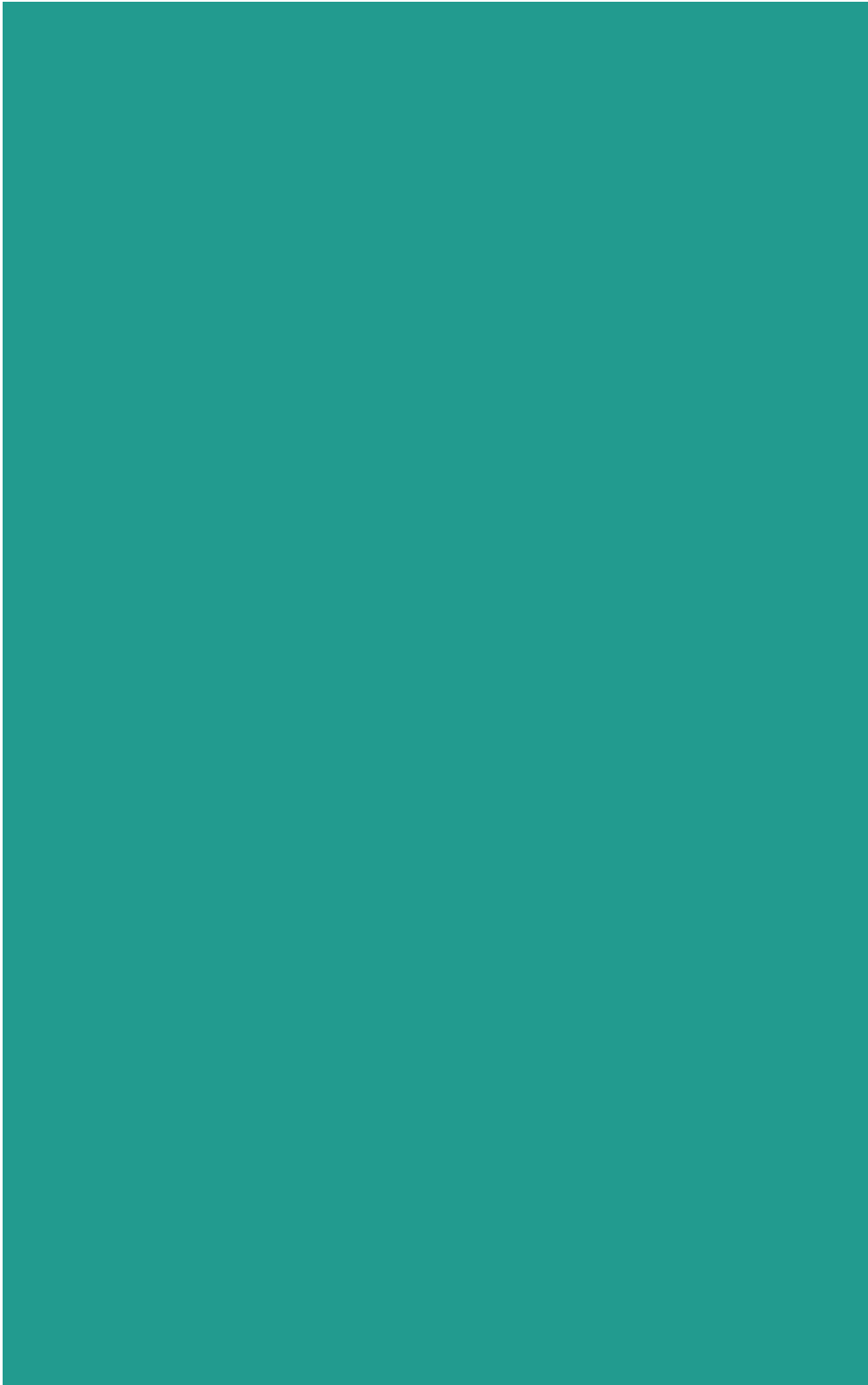


Figure 7.42: Impression of the orthotropic bridge deck (own illustration)





# 8 FINAL REMARKS

## 8.1 CONCLUSIONS

Following the analysis it became clear that the city of Rotterdam is in need for a new crossing over the Nieuwe Maas river. The western location, between Delfshaven and the Waalhaven is the perfect location for a new bridge. By making a connection between Schiemond and the Sluisjesdijk pier, the western part of Rotterdam now has a direct connection to the south of the city and vice versa. The Erasmusbrug, which is now the main route between the north and the south will now be less of a bottleneck in the day-to-day traffic.

By expanding the public transport network with a brand new connection the network becomes more branched and is ready for the future. Also the addition of a high quality route for pedestrians and cyclists it is now possible to move about in the city of Rotterdam without much disturbance. With these alternative transport options, the car will not have to be the primary mean of transport, so the boulevards in the city will be less clogged and there will be a transition to green mobility.

The Schiemond area is now a largely unused area in the middle of the city. Along the Westzeedijk lies a vast open space with no particular function. With the new bridge connecting the Schiemond with the Sluisjesdijk, the open space is now transformed into a new, green public space with room for walking, residing and recreation on the quays of the Nieuwe Maas. The different traffic flows, fast and slow, run along the quay, intertwine and cross the river. The formerly open space is now available again for the people of Rotterdam.

The steam powers ocean liners of the The Holland America Line set Rotterdam in the map as one of the largest harbours of the world. For more than a decade the largest cruise ships in the world have docked at the Wilhelminapier in the center of Rotterdam. This design for the new bridge respects the cruises ships and thanks to the choice of the design of a vertical lift bridge, it allows even the largest cruise ships in the world to pass, so the connection between Holland and America remains unhindered.

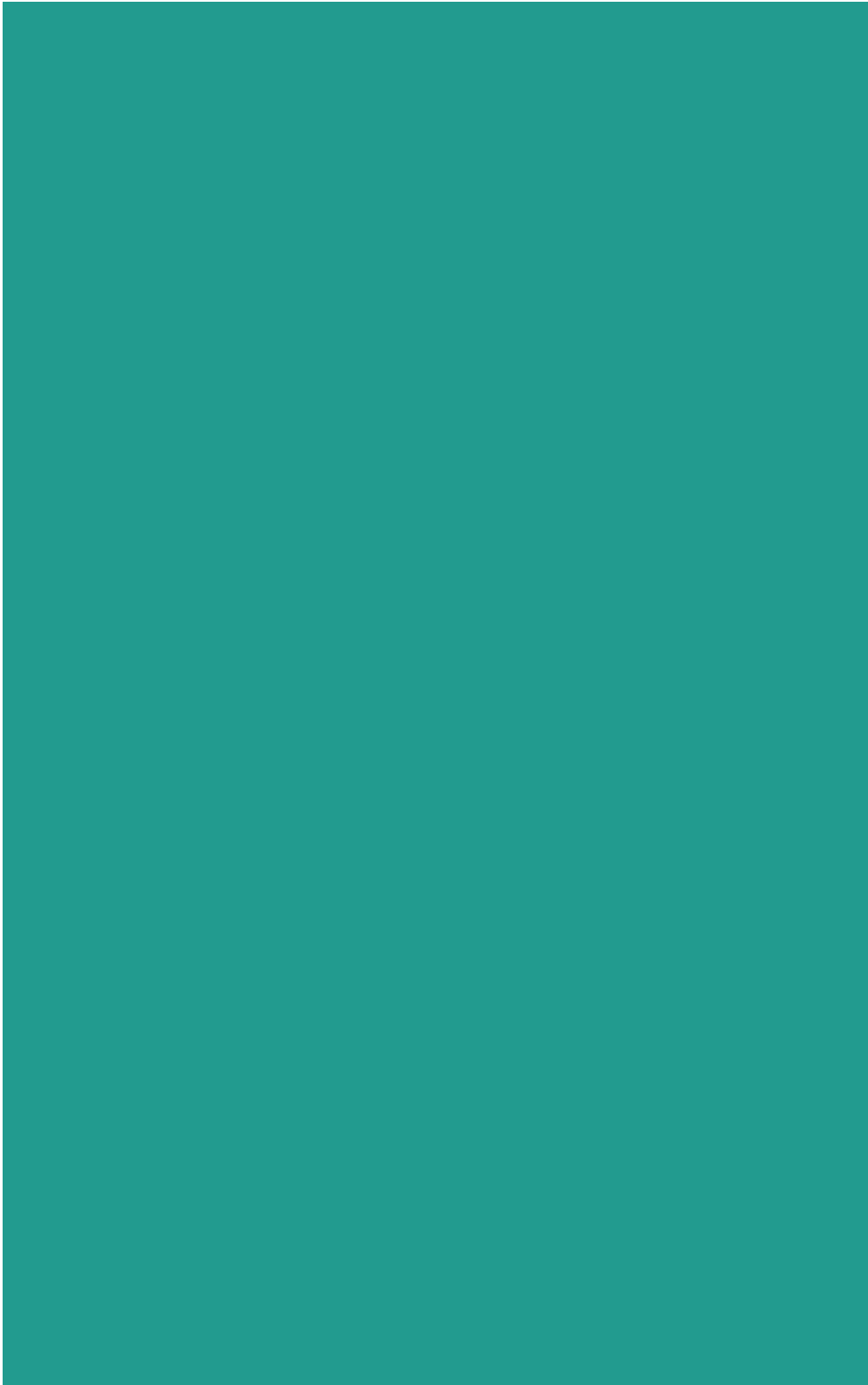
In total the new bridge fulfills the ambitions set out by the municipality of Rotterdam. The new connection provides breathing space for the west en south areas as well as an viable option for public transport. The quays are made useful for the public again and the city gains a new green boulevard along the Nieuwe Maas. The city of Rotterdam has gained a new entrance to the city and a striking addition to the skyline.

## 8.2 RECOMMENDATIONS

For further research it may be rewarding to look into other materials for the design of the bridge. The bridge is now designed with structural steel and concrete, two well known materials in the bridge industry. There are however more materials available such as wood and different types of reinforced polymers. The design for this bridge was done using conventional materials in order to focus on the design and use of the bridge.

The choice to allow cruise ships to pass the bridge and dock in the center of Rotterdam has had a huge impact on the design of the bridge. Although the city of Rotterdam is very fond of their heritage and cruise ships, they have an enormous negative impact on the environment. If the choice had been made to ban these ships from the center, this would have had a big impact on the design of the bridge.

The structure of the bridge is designed using standard calculation methods. With the increasing use of parametric design tools and calculation programs there is the possibility to optimize the design of the bridge in terms of material en structure, which could have a positive effect on the design.



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