CROSSING THE IJ
Research by design, in planning and technical measures to create a bridge over the IJ.

Graduation report, P4
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This research is aimed to explore the potential of creating a realistic design for a bridge over the IJ. Analysis and literature studies were done both in order to determine the challenges proposed by preconditions on site and the strategies and resources needed in order to answer those challenges. In using a strategy where two bridges divide the traffic load over the area, the connection between the Westerdoksdijk and Overhoeks had proven to show the most potential for current and future use. Because of the need for an opening and the preference not to create a visual obstruction over the water, a cable stayed system was used to support the bridge. Creating a bridge that answers to the challenges and allows for the residents of Amsterdam to cross the IJ without closing it down for the public.
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INTRODUCTION

In this chapter an introduction to the project is given, along with background information about some of the circumstances and preconditions present on the project location. While introducing the project multiple challenges will come up. These will be superficially pointed out in this chapter, in-depth explanation and analysis is discussed in chapter 3.

The area of Amsterdam Noord is expanding, while it has a poor low-speed traffic connection with the center of the city, because of extreme preconditions on site.

The ferries crossing the IJ are used intensively, to a point where traffic flow is interrupted due to a lack of capacity. The future holds redevelopment of areas in Amsterdam Noord; this means more people will have to cross the IJ at a daily basis in the years to come.

Looking at the predicted growth of the area, an improvement of the connection between the city center and Amsterdam Noord is of the utmost importance to the vitality of the area and its use. In late 2014, the spatial planning committee (DRO) of Amsterdam was given the assignment to officially investigate possibilities to create a permanent connection over the IJ. This indicates a realistic interest from the municipality in the development of a permanent connection between the banks of the river.

There are multiple ways to address the challenges present, of which all ways will have their own advantages and disadvantages. The aim of this project is to find a well-fitting, realistic solution, which will be tested in a design.

1.1 INFRASTRUCTURAL CHALLENGE IN AMSTERDAM

Amsterdam is the largest city in the Netherlands and it is well connected to multiple systems of transport. The origin of the problem surrounding the IJ becomes more apparent when we look at the development of the city over time.

History

In the beginning stages of development, “Aemstelredamme” (Amsterdam) was settled around the mouth of the river Amstel (image D). In these early days, before the reclamation of surrounding areas, the IJ was still a large saltwater inlet. The settlement grew over time, with a harbor at the river mouth serving as an important hub for trading/exchange.

Fig. 1: first series of images showing the development of Amsterdam (Amsterdam Historisch Museum, 2010).

The city of Amsterdam started expanding along the river banks of the Amstel, eventually moving into the countryside. In 1613, the “Grachtengordel” started developing, creating a radial orientation of the city, oriented around the river mouth.

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1 DRO stands for Dienst Ruimtelijke Ordening, which is an organization working together with the city of Amsterdam. Their main occupation is handling spatial planning issues.
From 1393 until 1844, the peninsula of Volewijck was the only part of Amsterdam situated on the other side of the IJ. The reclamation of the areas around Volewijck started in 1844, but didn’t really take off until the year 1900. This was the year Johan van Hasselt started a design for the areas situated to the North of the IJ, including lots of space for industry and dwelling, it also included the first idea for a bridge across the IJ.

Population of the area started in 1916 (image K), due to the flow of Belgian refugees as a result of the First World War.

Looking at images K though O, the development of the city is depicted throughout the 1900’s. The difference of development between Amsterdam’s north and central area is clearly visible. This difference is an effect of the north part of the IJ being used primarily as an area for industry, due to safety measures for the city.

Working in the industry on the north side of the IJ, in earlier days, meant living on the north side of the IJ. As houses were built near the industrial zones for the workers to live in, creating a satellite village of Amsterdam. This was done to avoid an expensive connection between inner city and Amsterdam Noord. The zoning has eventually changed and industry has been phased out of Amsterdam Noord over time, but there still is no river crossing. While at this moment in time, with current plans for redevelopment of Amsterdam Noord, the area is becoming an interesting place for dwelling, culture, as well as cultural and modern industrial functions. The area is becoming a part of the inner city and geographically, that makes sense. However, it has no connection to the city center itself.

Transport connections
Looking at the internal connections between the different districts in Amsterdam, a lot of work has been done to create a better connection between the different parts of the city. Projects like the Noord-Zuid line, the redesign of the infrastructural surroundings behind the central station, are completed to improve the connection throughout the city.

In the spatial development strategy (structuurvisie), it is shown that the municipality of Amsterdam prefers the use of both public transport and bicycles for transportation of its inhabitants. This preference is due to the fact that it takes up less space to transport people this way and it is easy to manage these ways of transport.

The majority of people in Amsterdam already prefer the use of either bicycles or public transport to transport themselves within the city. This is due to the flexibility of bicycles, the good availability of public transport and the added troubles when using a car in the center of Amsterdam (congestion, detours to reach destination, low availability and cost of parking, etc.). Although it is easier to find a parking spot in Amsterdam Noord, detours and the inefficiency of traveling by car do not change.

Generally speaking, both the municipality and the people of Amsterdam share preferences for the way to travel within the city limits.

The lack of a direct connection over the IJ means that the people wanting to cross rely on ferries to transport them. Travelling elsewhere to avoid waiting for the ferry, would mean covering a significant distance, which makes it an inefficient way to travel over the IJ in the current situation.
1.2 PROJECT LOCATION

The river the IJ is located in Amsterdam, reaching from the Coentunnel to the IJmeer. It is part of a waterway connecting ocean to the inner waterways of the Netherlands (with the help of the locks situated in Ijmuiden). The IJ is used for a variety of activities; including a variety of leisure related uses, commercial shipping, and public traffic connections.

The IJ
The river is divided into different waterways. Figure 4 shows the commercial waterway (orange) as well as the turning point for cruise ships (brown) on the part of the IJ near the train station. The part of the waterway that stands out is the turning point for cruise ships. A large circle located just off the banks of the Java-island.

![Commercial waterways on the IJ](van Erk, 2015)

This area has been especially dredged out to allow for the ships to be able to turn around, as the largest cruise ships need to use the width of the IJ to do so.
The blue area in the figure below indicates the area outside of the commercial waterway. This area is more shallow than the waterway, but suitable for leisure vessels and most commercial vessels to use.

Urban context
Looking at the development over time, the biggest challenge in connecting the banks of the IJ are in the middle part of the river. The connections in use today show the most activity behind the train station, as this is the most important transport hub in the city. The focus will be on this central part of the IJ.
Looking at the areas adjacent to the river, different activities are present. The residential districts Overhoeks, Disteldorp, Gentiaanbuurt, IJplein and Vogelbuurt are the most central areas in Amsterdam Noord, which would benefit directly from a permanent connection to the center of Amsterdam.
On the south side of the river, the Houthavens, Zeeheldenbuurt, the Western islands and the Java island are the residential districts positioned most central on the IJ. These districts would also benefit directly from a permanent connection.
The area around the train station experiences a lot of traffic. This is both due to the fact of the train station being a main transport hub for the city, and its location in the center of the city. Creating a connection between the banks of the IJ near the train station would mean an increase in traffic. This would also mean an increase in chance of accidents and dangerous situations, while the placement of multiple crossings would divide the traffic load over different parts of the city. Also, the spatial planning committee has shown plans for a cycling route around the IJ. Benefitting of multiple connections and encouraging people to use the crossings.

1.3 CHALLENGES

The design of creating a well-suited crossing over the IJ is challenging, because of the preconditions on site.

The first challenge is the river and its nautical activity, which is used by all sorts of vessels. These vessels have different dimensions, purposes, frequencies of passing and difference in impact they cause on the IJ. All vessels can create a challenge when building a crossing over the water. In order for the vessels to be able to pass, they need a clearance, dependent on their dimensions, to be able to pass a crossing. However, on the IJ, traffic can be very busy because of events such as SAIL. Allowing the bigger vessels to pass is a different problem, which comes up while designing the crossing. The dimensions of the vessels will determine the space they need to navigate the opening part of the crossing. Keeping in mind that some of the vessels on the IJ are of enormous proportions, there is a challenge in creating an opening large enough for those vessels.

During the presentation of the outcomes generated by the first rounds of study the spatial planning committee, we found
out that the committee was open to allow for outcomes of the studies to alter the size of the vessels allowed on the IJ. They classified the need for an opening in three ways:

- Normal size: 19 meters of opening, enough for sail ships to pass through.
- Large size: 50 meters of opening, allowing for medium cruise ships to be able to pass.
- Monster size: 80 meters of opening would allow for large cruise ships to pass.

The second factor is the site. Many people will be using a crossing if one was available, on the condition of it being well placed. In cooperation with the site location, the accompanying strategy on directing traffic is very important. A good solution to deal with the traffic is paramount to the success of the project.

The third challenge is space, which is inherent to the site. To be able to use the crossing, people will have to be able to rise to the height at which a crossing is possible. This requires a way of getting to that height, without significantly increasing the effort the people will need to exert to do so. Methods of reaching certain height require space for that particular method to be implemented. Both the method of ascending and its required space are important to think of, because we do not want the amount of effort required for using the crossing to be too high, nor do we have a lot of room to create all types of solutions. The effort required is a big factor for passengers in deciding which way to travel. Because we want the people to be able to use the crossing with a lot of ease, the space required to create an appropriate method of ascending will have a large impact on the design and its effects.

1.4 OBJECTIVE

We will address this difficult and multifaceted task by researching the potential solutions for resolving the challenges that go with the preconditions. The research will provide an insight in the challenges which we will use to test the solutions in a design.
METHODOLOGY

In this chapter, the scope of the study, the research question and the methods used for research during this project are explained.

2.1 STUDY SCOPE

Decisions were made to focus on certain aspects, narrowing down the realm of possibilities but creating a research fitting with the timeframe of the project.

Focus solely on bridges
Where a definition of a crossing can have many shapes and forms, the decision was made to focus solely on bridges. Bridges are the simplest solution to cross an obstacle, in contrast to e.g. tunnels, cable railways or other, more exotic manifestations which can be covered by the term crossing:

- To avoid the nautical activity on the IJ, tunnels have to run deep. Resulting in a very long tunnel which is difficult to fit into the location, slopes would get very long or run very steep to reach the needed depth for the tunnel to run.
- Tunnels are very expensive to build, in this case especially, as the tunnel would have to be drilled, this is difficult in practice and thus brings risk and cost to the implementation.
- In tunnels, cyclists have a hard time to get an overview. People are not used to travel long distances in a tunnel. The perception of travelling through a tunnel is different in a negative way; feeling of enclosure, less social security, etc.

Focus on pedestrians and cyclists/low speed traffic
A better connection between the banks of the IJ is needed, but the problem is only clearly present in low speed traffic groups.

- When people are travelling by car, the effort it takes to take a detour is minimal, good connections are available for automotive traffic.
- The preference of travelling by bicycle or by public transport has been emphasized by the spatial planning committee.
- The need for a better connection between Amsterdam Noord and the city center originated in the low traffic group, as their crossing options are limited and the capacity of the ferries was not keeping up with the amount of passengers anymore.

Focus on strategy and site location
A strategy had to be formed to address the current traffic situation and its problems. The spatial planning committee has shown us different sites and has spoken to us about the different strategies. It was important to find a strategy to make this project realistic and to give a scenario in which to create a design.

The space needed for a successful placement of a bridge is of big influence to its placement and the way it fits into the context at the site. Research into room required for landings, physical demands from a cyclist’s point of view and building code or guidelines has to be done to ensure a realistic scenario can be produced.

Focus on dimensions of and need for an opening
The need for an opening in the bridge is present, due to the fact that the IJ is part of the open mast route (a water route known and renowned for the ability to pass by with sailboats, and other vessels which have a mast on them). The question is to which extend the opening has to be able to open.

2.2 RESEARCH QUESTION
How can the current infrastructural challenge on the IJ in Amsterdam be resolved with the use of a bridge and how can this bridge over the IJ be designed considering the preconditions on site?

2.3 METHODS USED IN RESEARCH

The methodology used in this project is explained in this chapter. The research in the project consists of two literature analyses and a design study. The first analysis (focuses on the location) acts as boundary condition for testing the results of the second analysis (focus on bridge construction) as well as provides an optimal strategy and site location for the project. The analysis focusing on bridge construction will provide technical guidelines for design.

The design study will test the guidelines provided by the research by attempting to create the optimal bridge considering the preconditions on site.

2.3.1 LITERATURE ANALYSIS: PROJECT LOCATION

Research on the project location was done in order to find solutions to the infrastructural challenge on the IJ. Several distinguished researches have followed the initial project location research, these are all part of the overlapping subject and therefore mentioned as sub-researches.

2.3.1.1 PROJECT LOCATION SCOPE

In this chapter we aimed to explore the context of the project location, the river the IJ in Amsterdam. To this end we conducted an analysis of the areas surrounding the IJ in order to find out its valuable sites, important districts and points where the importance of the project is emphasized.

For this analysis we focused on the following points of interest:

1. Layout of the districts; expressed in a geographical layout of the connected areas which served as an underlay for the other points of interest. Also, this layout was used to estimate impact of strategy assessment.
2. Future development plans for Amsterdam Noord; the plans the municipality has lined up for the area were of enormous importance to the assessment of potential locations for a crossing.
3. High value and old architecture; expressed in a map used in deliberations, stating the buildings which were specified to not be interfered with.
Materials used: Maps of Amsterdam, provided by spatial planning services of Amsterdam, have been used in this study to analyze the cycling track network; An interactive map showing all buildings in the Netherlands was used to determine the age of the buildings in surrounding areas; interactive maps provided by the municipality of Amsterdam were used to research architectural value, future projects and travel routes in the area.

2.3.1.2 INFRASTRUCTURE

In this chapter we aimed to explore the connection between the different districts surrounding the project location. To this end we conducted an analysis of the cycling track network in the areas surrounding the IJ and their connections to the districts located further away from the river.

For this analysis we focused on the following points of interest:

1. Current cycling track network; expressed in the mapping of important traffic connections and their importance to their surroundings. The influence of current cycling track networks on the potential placement sites was very noticeable during decisions.
2. The connections between districts; expressed in the pointing out of certain roads which would serve a role of particular or specific importance.
3. Ferry lines and their connections to the cycling track network; expressed in a map of the current ferry lines and their future development prediction was of great help to point out potential sites of importance.

Materials used: Maps of Amsterdam, provided by spatial planning services of Amsterdam, have been used in this study to analyze the cycling track network and potential connection sites; information found online from different sources has been used to research the current and future role of ferries.

2.3.1.3 NAUTICAL ACTIVITY

In this chapter we aimed to explore the dimensions and frequencies of vessels passing by on the river. To this end we focused on the following points of interest:

1. The dimensions of the vessels; expressed in a classification for vessels, was be used in design guidelines and served as an underlay for deliberations/ decision making.
2. Frequencies of vessels; expressed in a matrix, together with size and classification. The frequency determines the importance of the vessels due to their possible impact.
3. Regulations about classification of waterways and their nautical activity; expressed in a classification for the river, it put the river’s importance in perspective during the research process.

Materials used: New classification of the inner waterways, for determining dimensions according to the CEMT; Maps of the classification of the inner waterways in the Netherlands, for researching the waters classification; New panama regulations, to research the larger vessels’ dimensions; Website information from the municipality was used to determine the ferries’ dimensions and capacities.

2.3.1.4 SITE LOCATION AND STRATEGY

In this chapter we aimed to explore the possible strategies and their potentials. To this end we conducted research in the form of potential site analysis and deliberation with parties involved.
For this analysis and deliberation we focused on the following points of interest:

1. Status of the research being done by the spatial planning committee; Expressed in an update on process and progress, we received a lot of useful information to use in research and design.
2. Potential site locations; expressed in a series of potential locations for a crossing.

Materials used: information found in previous research; Maps of Amsterdam, provided by spatial planning services of Amsterdam.

### 2.3.2 LITERATURE ANALYSIS: CONSTRUCTION OF BRIDGES

Research on the constructions of bridges was done in order to create a scope of the possibilities to build a bridge. Construction systems were analyzed and their properties were tested to the context of potential site locations for the bridge on the river the IJ. Separate research was done on landings of bridges, to determine the guidelines and regulations on building a functional landing for a bridge.

#### 2.3.2.1 BRIDGE STRUCTURES

In this chapter we aimed to explore the dimensions and systems of bridge typologies in order to map the possibilities for construction and system’s workings in the design study. To this end we focused on the following points of interest:

1. The typology of bridges; expressed in an analysis, researching the way different bridge systems work and how they are put together.
2. Potentials of systems; expressed in analysis, researching the span feasible in different typologies.
3. Impact of different design on their context; expressed in analysis, looking at the geometrical and typological impact of the various designs on their context.

Materials used: Pictures of various bridges, sourced from structurae.net; Various informational websites on bridges, found on the internet; Discussions with tutor to clarify systems.

#### 2.3.2.1 LANDINGS

In this chapter we aimed to explore the research on building landings for bridge structures, in order to create design guidelines. To this end we focused on the following points of interest:

1. Slope inclination requirements; expressed in an explanation of referenced research.
2. Space requirements for landings; expressed in analysis of predecessors.
3. Security measures in design; expressed in an explanation of referenced research.

Materials used: Journal articles found online, through reference of the cyclists association (C ter Braack & Boggelen, 2009; Fietsersbond, 2004); Research reports “hellingen in fietsroutes”(C. ter Braack & Andriesse, 2009)
RESULTS

During this research, analyses and/or literature reviews on different subjects have been completed. This chapter shows the results from the analyses and/or literature reviews and these results have been arranged and bundled by subject focus. The aim of the analyses was to have a full understanding of the problem and subsequently, to create guidelines for the design to be tested.

3.1 ANALYSIS/ LITERATURE REVIEW PROJECT LOCATION

The project location holds the most information we need in order to create a good set of guidelines for the design in terms of strategy and site placement. Different points of interest are determined to help determine the guidelines.

PROJECT LOCATION SCOPE

The river the IJ is located in Amsterdam, reaching from the Coentunnel to the IJmeer. It is part of a waterway connecting ocean to the inner waterways of the Netherlands (with the help of the locks situated in Ijmuiden). The IJ is used for a variety of activities; including a variety of leisure related uses, commercial shipping, and public traffic connections.

Urban context

Looking at the development over time, the biggest challenge in connecting the banks of the IJ are in the middle part of the river. The connections in use today show the most activity behind the train station, as this is the most important transport hub in the city. The focus will be on this central part of the IJ.

Looking at the areas adjacent to the river, different activities are present. The residential districts Overhoeks, Disteldorp, Gentiaanbuurt, IJplein and Vogelbuurt are the most central areas in Amsterdam Noord, which would benefit directly from a permanent connection to the center of Amsterdam.

On the south side of the river, the Houthavens, Zeeheldenbuurt, the Western islands and the Java island are the residential districts positioned most central on the IJ. These districts would also benefit directly from a permanent connection.

![Fig. 6: Districts located around central part of the IJ (van Erk, 2015)](image)
The area around the train station experiences a lot of traffic. This is both due to the fact of the train station being a main transport hub for the city, and its location in the center of the city. Creating a connection between the banks of the IJ near the train station would mean an increase in traffic. This would also mean an increase in chance of accidents and dangerous situations, while the placement of multiple crossings would divide the traffic load over different parts of the city. Also, the spatial planning committee has shown plans for a cycling route around the IJ. Benefitting of multiple connections and encouraging people to use the crossings.

Future development
The areas around the IJ have different purposes and many of the areas around the IJ have been strategically reclassified by the department of environmental planning of the Amsterdam municipality. Many areas are being reclassified, e.g. as housing zones instead of industrial/commercial zones.

Fig. 7: Part of the interactive map “Housing plans” (de Haan, 2014), showing the central area of the IJ.

North
The north banks of the IJ have changed a lot over the last decades. As the city has expanded, the first buildings in Amsterdam Noord were built just after the start of the 19th century. Ever since the 1900’s the built environment in Amsterdam Noord has been expanding, many living quarters have been constructed since and Amsterdam Noord has become an important district for Amsterdam. It now covers 49.01 km², it is made up of 17 neighborhoods and has 88,420 inhabitants.
The buildings located on the northern banks of the IJ are mostly built in the late 1900’s or early 2000’s. These buildings are generally commercial and most of them house companies or cultural associations. This is partially because of the zones on the banks being more easily accessible to traffic over water. A building site on the banks of the IJ costs a lot more as well, so it is less efficient to build residential buildings on those sites. This is because there is less demand for expensive housing in Amsterdam, in relation to the demand for low or medium cost housing.

South
To the south banks of the IJ, the center of Amsterdam is situated. This is the busiest part of Amsterdam, which is noticeable on the water’s edges. Especially in the center of the IJ, due to the situation of the train station. This station is used by 250,000 commuters on a daily basis, a number which will increase to 300,000 according to ProRail (ProRail, 2015).

Along the rest of the south bank of the IJ, lots of activities are found. Starting at the left, a total of eight ports are located on the IJ. This port area ends with the oude houthaven, which is situated just before the beginning of the bend in the waterway. The center or the last three ports, the “Houthavens”, will be reclassified as a housing zone, as can be read from figure 5. After the port area, the urban context changes to a housing area which includes the newly built IJdok. The housing area thins out toward the banks of the IJ, due to the fact that the district is made up of islands and there is a large road on the bank. When we pass the IJdok, railway tracks divide the banks from the city center, leading us to the train station. This is where we reach the peak of activity. Due to the presence of 4 lanes of traffic, 2 bicycle lanes and a wide pedestrian lane at the very outer edge of the bank, with an elevated level where public transport departs. At the other side of the train station, commerce and public buildings are the main functions situated directly on the banks of the IJ. This is not only because of the location of the train station, but also because of the situation of the cruise terminal, which is situated on the right side of the train station, just before the beginning of the Java-Island. The cruise terminal has a big impact on the use of the IJ, and the functions the buildings on the banks of the IJ have gotten over the years. After the cruise terminal, the direct urban context reverts to a housing area once again: the islands. The islands are the last stretch of land before we reach the oranjesluizen, the locks which connect the IJ to the buiten-IJ, mouthling into the IJmeer.
The infrastructure available in the area around the center of the IJ was analyzed on routes to the closest connection across the IJ. Hypothetical routes the people would travel to are shown in the image below. The connecting zone around the center of the IJ focusses on the bend in the river. Especially the districts at the edge of the water are connected to the train station through the ferries at the Buiksloterweg.

Fig. 9: Routes to the nearest crossing over the IJ (van Erk, 2015).

Looking at routes currently available for traffic to cross the IJ, a distinction is made between low-speed and high-speed traffic crossings.

Fig. 10: Map from Google Maps (Google Inc., 2015), with the location of the crossings over the IJ highlighted in orange.

A list of all the crossings currently available over the IJ (listed by placement over the IJ starting from left to right):
Aside from the tunnels, which can only be used by motorbikes/cars/etc., no permanent crossing over the IJ is present. From Amsterdam Central Station, the closest connection to a permanent low-speed connection, is 7.2 km away.

Realistically, people will not travel this distance to reach a permanent connection. If another way of crossing is closer by, even if it means having to wait for a certain amount of time, people will prefer to wait over having to take a detour, taking up valuable time in their daily schedule. In order to cross the IJ without having to travel too much, people are reliant on the ferries to take them across the IJ.

Fig. 11: Travel route to reach the Oranjesluizen (Google Inc., 2015)

If not for the ferries, the people crossing the IJ would have to take another route, allowing them to cross the IJ without the use of ferry lines. The route to cross by bicycle takes people around the central part of the IJ, to the Zuider IJdijk, where they use the Oranjesluizen to cross over to the Noorder IJdijk, reaching Amsterdam Noord.

Ferry lines
The ferry-lines travelling the IJ allow for people to cross the river. There are multiple different ferry lines, connecting different areas. An estimated total of 40,000 people using the ferries to cross the IJ each day in 2014 (Fietsersbond Amsterdam, 2014), add up to a total of over 14 million people a year. The current Buiksloterwegveer deals with a daily traffic load of 16,000 persons (Wijkvereniging Overhoeks, 2014) is expected to increase with 9% in each of the coming years, resulting in a 40% increase in daily traffic load in the year 2018 (Goudappel Coffeng, 2015b). When looking at possibilities for transport across the IJ in the future, taking into account the estimated growth of Amsterdam Noord, the current solution will not suffice. The research by Goudappel Coffeng shows a quite dramatic increase in users from 2014 to 2018.
Fig. 12: Ferry use expressed in person-equivalents for a Tuesday in December 2014 (Coffeng, 2015)

Fig. 13: Ferry use expressed in person-equivalents for a Tuesday in the summer of 2018 (according to the research’s maximum scenario) using two extra vessels during morning and afternoon rush (Goudappel Coffeng, 2015c).

The images shown above illustrate the use of the ferry service the Buiksloterwegveer. The second diagram shows comparable usage, due to the use of multiple extra ferries in the scenario. Below, a graph shows the amount of ferries needed during the day to handle the amount of traffic.

At peak moments during the morning and at the end of the day, 4 ferries are needed to handle the traffic, during the day the number varies between 1 and 4, averaging an overall need for 2.15 ferries during any hour in the day.
A short term solution for the lack of capacity of the ferries is to add a ferry operation on one of the other routes in the area to the buiksloterwegveer route. The research by Goudappel Coffeng shows the need for four ferries simultaneously on the buiksloterveer route, which would mean an extra ferry would have to be added to the ferry-fleet operating on the IJ as the buiksloterveer route currently has two ferries assigned to it. On the 4th of march 2015, the city council has decided to start tender for a new ferry to add to the fleet (dir. of Communications of the municipality of Amsterdam, 2015). This is done to not put the other ferry routes at a disadvantage or to even have to shut them down, in order for the buiksloterwegveer route to remain operational.

NAUTICAL ACTIVITY

On the river itself, vessels use the waterways for different purposes. Commercial shipping routes, leisure vessel docks and cruise ship terminals are all present on the IJ. To understand the challenge of allowing space for vessels to pass the bridge, we have researched the nautical activity on the IJ.

To create a clear picture of the vessels using the waterways, we have categorized the vessels according their dimensions.

The first category of vessels includes vessels used for leisure. The category is split up into two sections. Category 1a includes vessels used by people for leisure, and other vessels not used for commercial purposes, < 20 meters in length, 10 meters in width and 10 meters in height. These vessels are found on the IJ frequently throughout the day, but the presence is highly depending on the weather, peoples' agenda's, their working hours, events and the day of the week. A lot of these vessels are designed to be just below the requirement dimensions, capability and/or capacity for a license.

Category 1b includes vessels for which a license is required. All vessels with properties > class 1 dimensions; < 40 meters in length; < 19 meters in width; < 35 meters in height, are included in this class. Because of the IJ being a large waterway, the presence of these vessels is very common, although not in the same numbers as the class 1 category. This class is made up of sail yachts, large motorized yachts and particularly in Amsterdam, a lot of decommissioned service boats are found in this category.

Category three includes the ferries, ranging from 20 to 60 meters in length with an estimated capacity of up to 800 persons, during the Sail event, extra safety measures are implemented on the ferries, increasing the capacity to 1100 persons. The ferries operate day and night across the IJ. They are completely included in the city's public transport infrastructure and the most used ferry lines depart every 7,5 minutes during rush hour. These vessels have a fixed route and will only actively avoid commercial traffic when moving across the waterway. They do this by timing their moment of...
crossing and the rest of the traffic on water has to anticipate the captains’ route and timing. The ferries will warn everyone on the water by blowing their horn when they depart (only during daytime, during nighttime the ferries are all well-lit and people can’t overlook them.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Size</th>
<th>Destination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highly dependent on weather</td>
<td>L: to 23m (1) / 40m (2)</td>
<td>Differs (personal agenda)</td>
</tr>
<tr>
<td></td>
<td>H: normal &lt;10m</td>
<td></td>
</tr>
<tr>
<td></td>
<td>exceptional &gt;35m</td>
<td></td>
</tr>
<tr>
<td>Constantly</td>
<td>L: between 20m and 30m (estimation)</td>
<td>Differs (follow routes)</td>
</tr>
<tr>
<td>(24/7 service)</td>
<td>H: &lt;10m</td>
<td></td>
</tr>
<tr>
<td>Dozens a day</td>
<td>Up to: L: 195m (3)</td>
<td>Mostly passing through, some docks along the IJ</td>
</tr>
<tr>
<td></td>
<td>B: 22,2m (4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H: 9,1m (5)</td>
<td></td>
</tr>
<tr>
<td>Few, exceptional events (Sail etc.)</td>
<td>L: Common: up to 90m, exceptional: &gt;100m</td>
<td>IJhaven and Amsterdam Noord docks (6)</td>
</tr>
<tr>
<td></td>
<td>B: Up to 20m</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H: up to 82,1m (7)</td>
<td></td>
</tr>
<tr>
<td>Depending on season, up to 20 times/month (*)</td>
<td>Up to: L: 295m (8)</td>
<td>Passenger Terminal Amsterdam (East of CS)</td>
</tr>
<tr>
<td></td>
<td>W: 32,3m (9)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D: 12m (10)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H: 58m (11)</td>
<td></td>
</tr>
</tbody>
</table>

The commercial vessels are included in category number four. These are vessels which move large amounts of (mostly crude) material over Europe’s waterways. The vessels have a height of less than 10 meters, and differ greatly in length, with a maximum of 195 meters. These vessels carry loads all over Europe across the water. The biggest vessel able to traverse the IJ is under CEMT (Conférence Européenne des Ministres de Transport) class VIb. Characteristics: length 185-195m; width 22,8m; depth 2,5-4,5m; height 7-9,1m; capacity 6400-12000 tons (Wikipedia, 2015).

Category five is the specialty class, it includes every other vessel or ship, larger in dimensions than mentioned in category three, which is not purposefully designed to be a cruise ship. Ships like the Sedov, a 109 meters long, 14,70 meters wide yacht, fall under this category.

The sixth category includes the cruise ships, which come in a variety of different sizes and shapes. Often in design and construction, the new panamax (Panama Canal Authority, 2015) vessel requirements are used as a guideline on size. On July 1st this year, the IJ has hosted the biggest cruise ship up to now. It was the MSC Splendida, measuring 333 meters in length.

In Europe, a class system called the CEMT-classes is used to determine the classes of European waterways. The biggest class mentioned in this system is the CEMT VII class, its maximum height is 9,10 m. The CEMT class of the IJ and its surrounding/ adjacent waterways are Va and Vb (Centrale Informatievoorziening Rijkswaterstaat, 2015).
The new classification of inland waterways (Conférence européenne des ministres des Transports, 1992), determined the minimum height under bridges on the inland waterways to be 9.10 meters on the CEMT class of Va and Vb. The Dutch norm is also 9.10 meters, but Rijkswaterstaat derives the dimension from the Rijnvaarthoogte. The Rijnvaarthoogte takes to the highest navigable water level into account, providing the same clearance height as the new classification of inland waterways.

One added classification of the IJ is the fact that the river is part of a so called “standing mast route” (Rijkswaterstaat, 2014). This means sailboats and other tall ships have to be able to pass any bridge found on the IJ, in order for the river to remain part of this route.
SITE LOCATION AND STRATEGY

Looking at the current situation and the traffic problem, the first rational place for a permanent connection one would think of is from the back of the central train station to the Buiksloterweg, as this connection would replace the busiest ferry line (the Buiksloterwegveer). It would create a connection between a central point in Amsterdam Noord and the train station on the southern bank.

During an interview with Amsterdam’s spatial planning committee, we were told that, from their perspective, the location behind the train station was not an option or even open for discussion. This is because of the iconic value of the train station and the central part of the IJ.

Fig. 17: The traffic load on the IJ during the opening of the SAIL 2015 event.

Fig. 18: Image showing the view over the IJ from directly behind Amsterdam’s central train station. (Google Inc., 2015)
The spatial planning committee looks at the IJ as a central point on interest for the city, a well-known area of leisure and open space for everyone to enjoy. The term “waterplein” was used to describe a function of the IJ in the context of the city of Amsterdam. “The IJ is like a city square, but over water. It is an open area in the vicinity of the city center, for everyone to cherish and enjoy” (Schaap & Bloemendal, 2015).

Several other possibilities were discussed as there are multiple options of (re-)directing traffic over and around the IJ. The figure below shows a selection of possible locations for a crossing the spatial planning committee was considering at the time of the deliberation.

Because of the spatial planning committee’s aim to keep the IJ open and keep the iconic state of the area behind the train station, the option of using multiple crossings was selected to be the strategy which would be the foundation to use in the project. The goal is to alleviate the problematic area around the train station from a part of its traffic load. At the same time we would provide the people travelling between the city center and Amsterdam Noord with a permanent connection across the IJ. One of the six locations shown in figure 6 would become the site for designing a crossing.

Locations B and E are closer to the train station, yet far enough to not directly increase the traffic intensity around the train station. Both locations have a good connection to the city center’s cycling track network on the south
banks and are not too far to travel. Due to the distance of locations B and E to the train station, the connection to the existing cycling track network in the city center and the fact of them not blocking a vessel’s line of sight at any important place on the river, these locations are promising for a realistic site location.

Location E has a great connection on the south bank; it has space on the Java island and the crossing can be designed in a way that it has no interference with the cruise ships’ route. On the northern bank, it would land in an existing and well developed housing, facilities and commercial zones. The placement of a landing could be a problem because of the connection point on the northern bank on location E. The landing cannot be placed over water, as this would cause the waterways on the river to become narrower. Between the Java island and the Vogelbuurt the river is already quite narrow, width which is needed for the larger commercial ships to navigate the bend in the IJ safely. Taking into account the nautical activity during spring and summer, which means a lot of leisure vessels use the areas on the side of the waterway.

Looking at the crossing direction from the landing site, we can see that the Javalaan-Noordwal connection has very little room on the Noordwal side. The Java-island has plenty of space on the head of the island, and would make a good base for a landing.

Location B would connect a relative open section on the southern bank, called the “Stenen Hoofd”, an open area currently used for various cultural activities. The area has an excellent traffic connection to the train station, the city center, and the outer band of the canal district. On the banks of Amsterdam Noord the site can connect to an area with large parts destined for (re-) development to residential areas. Currently, most buildings are in use for companies, some of these buildings are to be taken into account, as they will remain on site in the future. The zone directly on the banks of the water has partly been transformed already. A green zone has been introduced on the waters’ edge, extending towards the location as a peninsula. A cycling path has been placed through the green zone, over the peninsula. The spatial development committee is considering placing a cycling path on the northern bank of the IJ. The plan is to build a permanent connection over the river and create a cycling route around the IJ. This cycling path would then be the cyclists’ main connecting route to the city.

The left view in the figure above depicts the current view from the Westerdoksdijk over the IJ. The Stenen Hoofd is clearly present when looking out over the IJ from the location.
The green zone implemented on the northern banks of the river is shown on the right side of the image. This area is designed to be an open green zone for people to enjoy, conform the plans for redevelopment of the northern bank.

Locations A and F would create a connection far enough from the train station as to not directly cause an increase in traffic around the station. However, the locations are placed too far from the train station to alleviate traffic intensity. The locations are too far to travel in order for people to use them.

Looking at the nautical activity, locations C and D are too close to the bend in the river. These sites would create a hazardous situation for vessels as a clear line of sight is needed while navigating through the bend in the river to be able to spot nautical activity and other possible problems.

The closest options for a crossing would also cause an increase of traffic in the area around the train station, instead of alleviating it.

**CONCLUSION: SITE LOCATION**

The strategy of using multiple bridges to create a good connection for low speed traffic over the IJ, has the benefits of dividing the traffic load between two sites. It alleviates the traffic load on the area of the train station and provides the people of Amsterdam with a well-balanced pair of connections available to suit their needs. Looking at the locations A through F, the sites B and E provide the right set of circumstances to implement this strategy.

Looking at the future development in Amsterdam Noord in relation to the potential of the possible site locations, the location in Overhoeks (location B) is one of the most interesting locations. It is near the EYE and the other large commercial and cultural buildings, connects to an area which will be redeveloped in the near future and furthermore, it acts as a portal for the districts located further inland. The landing site is currently very challenging, but the spatial planning committee has shown plans to redevelop the banks of the IJ in Overhoeks, to accommodate a cycling route along the IJ.

In comparison, the northern location for connection E lands in a well-developed neighborhood, where existing buildings are situated. There is not a lot of room on the northern banks, nor can any room be created by adding to the banks, because of the river being so thin at the location already. Placing a landing for a bridge would mean removing buildings from the site, which gives two options; removing residential buildings from the 70’s (not depreciated), or removing a shopping area which was built in the 00’s.

The Westerdok is the southern bank connection on location B. It is well located to create a connection point in the cycling track network. It has a great connection to the train station as well as a good connection to the outer ring of
the city center’s cycling track network. There is also the space of the Stenen Hoofd, which can be used for a landing.

The southern connection on location E is on the Java island. This connection is great for the connection in the current state of development as well as in the future. Like the Westerdok, the Java Island has a great connection with the cycling track network and there is lots of space on the potential landing site.

Due to the development of Amsterdam Noord, the most potential is in location B. It already connects to a better site from the commercial companies’ point of view, and the area of Overhoeks has a lot of inhabitants currently. Beside the fact that creating a bridge at both location B and E creates a good connection in the current cycling track network, Location B has the advantage of the space available on both sides.

Fig. 24: The project site location shown in orange (van Erk, 2015).
3.2 LITERATURE REVIEW: CONSTRUCTION OF BRIDGES

Orientating on bridge structures is done in order to know what types of structures are being used currently. As a lot of bridges have already been built, we first focus on analyzing the existing structures to find out what measures have potential to be implemented in our project design. Analyzing predecessors allow us to create a scope of the existing measures and test them to our preconditions.

Different types of structures are used to support bridges. We will point out the difference in the following chapter by going over the systems for bridges and analyzing their designs.

BRIDGE STRUCTURES

Looking at pedestrian bridges, size matters. The structural elements of bridges are inherent to the type of structure. Bridges are one of the most pure forms of structural design. In most bridges the structural solutions for crossing the apparent obstacle is shown as the main feature in the design of the bridge.


BEAM/ GIRDER SYSTEM

Taking a look at a pedestrian beam/girder bridge shows us one of the most basic forms supporting a surface. Like in building construction types, primary beams are used to span the length of the crossing and secondary beams are used to create a span between the primary beams. This is done in order for the deck to make a small span between the secondary beams, to complete a useable suspended surface. This is a typical construction method in normal buildings.

Due to the fact that the beams are typically made of a material with a high yield strength, and low elasticity, they can span a larger length and due to their geometrical design, they can take lots of additional load. Using these beams, the deck itself only has to span a relative small distance, decreasing the height of the deck and thereby the weight of the total package. Specially designed girders can be used to achieve large spans. An example of the beam or girder system is shown in figure 21 below.

Fig. 25: a photograph of Albright bridge (Wilson, 2002)
Main structure
In smaller span beam/girder bridges the main structure is made up of a system of beams, supported by a set of columns to reach the height from water level. On this set of beams a deck is placed to create a surface usable for crossing.

Dimensions
In a purely engineering way of thinking, a support system is created for optimal efficiency. The use of a beam system in spans is limited by the maximum dimensions of beam profiles which can be produced. Practically this means if the rule of thumb of a multiple section span floor beam is used, which states height = 1/20 x span, the maximum span would be around 20 meters. Increasing the height of the profiles any further would mean creating custom beams.

Landings
The structure of beam/girder systems may only apply to the part of the bridge which is used to create the span. Depending on the context, a landing will have to be implemented.

TRUSS SYSTEM
Another system used to create spans is the truss system. A truss is made up of multiple girders, connected by column, with an added diagonal strut added to them. This makes for a girder-type support which is able to handle much more load due to the large height of the section of the truss. An example of a truss bridge is shown in figure 22 below.

Fig. 26: a photograph of the Yough Street pedestrian bridge (Wilson, 2001)
As pointed out in figure 23, it is possible to create different configurations for truss systems. The system which is implemented depends on the use of the truss, the dimensions, the design and the context. Multiple configurations can be used in one design because the system can be designed to any specific purpose or goal.

Main structure
The main structure of the truss is much higher in comparison to the beam/girder system, so it is much more noticeable. This type of system is mostly used as a logical constructional solution in utilitarian bridges. In a constructional way it does show clearly how the system works, but it is purely the constructional function which is shown. Most often, no esthetical additions or ways of making it look better are used to improve the esthetics of the structure when using this type of system.

Dimensions
If a truss system is implemented, the possible span is seemingly endless, as long as the height of the truss is no issue. The longest spanning truss system bridge is the Quebec Bridge in Quebec, Canada. Its longest span is 549 meters.
In pedestrian bridges, an efficient truss depth and width for design is determined to be 1/20, 1/25 in explicit cases (James G. Bauer; Steven Herth, 2011). The reason this system is mentioned under small span pedestrian bridges, is because when the dimensions are kept in the realm of dimensions used for pedestrian bridges, the span would be able to reach about 80 meters.

Landings
As with the beam/girder system, truss systems may only apply to the part of the bridge which is used to create the span. Depending on the context, a landing will have to be implemented.

RIGID FRAME/ PORTAL SYSTEM

The oldest way of building bridges is to create a monolithic structure, having a direct connection between the deck and the foundation of the structure. This system is characterized by the fact that the entire structure is one solid piece. In the system we can distinguish three different types of configurations; single span, V-shaped and batter post.

Although the principles are the same, the differences are quite obvious. A single span is mostly used on roads and land-based infrastructure. To create support in the middle of the span, these configurations usually have a slight arch; it’s geometry to direct forces to its foundation. The arch makes it more interesting than, for instance, a truss system.
The design is efficient in material use, because of the narrow cross section in the middle of the span. This reduces the need for huge amounts of material to be added at the abutments. This configuration is very efficient in smaller spans, but when spans become too large, the configuration stops being efficient, at which point other configurations are more suitable to use.

The V-shaped frame creates a possibility to create a span with multiple supports, as the V-shaped supports the deck at two places while it only needs one foundation.

Because the force is divided over two support points, the bending moment in the supports is less in comparison to a normal column. This also allows for the deck structure to be reduced in height, because of the reduction in span distance.

The batter-post configuration provides an advantage when the bridge has to be built over obstacles/terrain which causes problems placing foundation for supports. Due to the fact the columns and the abutments are not connected in the same place, the foundation has to be built in a different way, creating an angled foundation for the columns. The columns carry the bridge in a similar way to the V-shape columns, but the batter-post configuration is used only for single spans.
Main structure
The rigid frame bridges have a large variety in design and/or physical appearance. A lot of bridges have been built over many years, ranging from well-known historical designs to modern sleek designs. All designs use the same principal of support, which allows for a large span when combined with modern production techniques (high strength pre-stressed concrete, steel fiber reinforcement, fiber reinforced polymers, etc.).

Dimensions
The system is capable of creating large spans, dependent on the sectional properties of the material it is constructed with. A restriction in use for this system, is that it is very well suited for use in certain environments. Embankments, canyons and other locations with steep banks form a perfect site for placing a rigid frame structure. This is due to the height required for the columns to transfer the loads efficiently to the foundation. Depending on the distance to span, the height is determined. Due to the angle of the columns, the span would get smaller, but the columns could cause an issue with the height of the bridge’s deck.

Landings
Because of the horizontal length the columns need to reach the angle at which they become efficient, that first span of the bridge is taken up by the columns. On a location where the bridge deck has to be a certain distance from the water, the columns would have to be put further away from the section to span. Instead of that space being used for the landing, the start of the bridge itself would take up space on the river bank. The landings would have to be designed on what remaining space there is left, which could be a problem in space is an issue on the site.

ARCH BASED SYSTEM
The geometry of an arch is very efficient at transferring loads to its foundations. When load is put on an arch, the arch has to deform either by buckling or by moving its ends away from the load. In the latter case, it has to do so in order for a load to be able to flatten the arch.
A lot of variety is present in arch based support structures. Other support structure systems can resemble arch based systems, this is because of the efficiency an arch has in transferring loads. Smaller arch bridges are directly supported, where larger bridges are often suspended. The arch can be constructed in different ways, ranging from simple bent hollow steel profiles to extensive truss structures forming an arch.

Using the geometrical advantage of an arch, very big spans can be built. The largest span arch based bridge is the Chaotianmen Bridge in Chongqing, China, spanning 552 meters, suspended from a giant arch.

In comparison, a bicycle bridge next to the Amsterdam central train station is very small, but it still uses a suspended arch support structure. The arch supports the internal zone of the bridge, which is suspended on evenly distributed points along the arch.

Main structure
The arch based support structure can be used in two main different ways, loads can be transferred to it directly, in which case the bridge deck is resting on the arch, or indirectly, in which case the deck is mostly suspended from the arch.
Dimensions
Creating large spans is possible with an arch structure, as long as the arch is sturdy enough to transfer the load to its foundation.

Landings
Placement of the supporting arch can vary in relation to the level at which the bridge’s deck is placed. The height of the bridge deck can vary, as long as the arch is relatively even balanced. Landings will have to reach the approximate height of the deck and the ends of the arch are lower than the bridge’s deck level.

CABLE STAYED SYSTEM

When the support structure itself is too heavy to be efficient, or if other reasons prevent all systems mentioned above, bridge decks can be suspended in order to create a span. A cable stayed system works by suspending the bridge deck from pylons using cables. The load on the bridge deck is transferred through the cables to the pylon, which transfers the loads to its foundation.

CABLE STAY

The cable stayed system works on the condition of the forces in the pylons being balanced. The load on the bridge deck is mainly vertical, due to the cables being connected to between the deck and the pylon, a horizontal component comes into play. In order for this horizontal component to be balanced, the pylon needs to be able to take the bending force created or the horizontal force has to be taken up in another way. The larger the distance between the pylon and the point where cables connect to the deck, the smaller the angle between the cable and the pylon, resulting in a larger horizontal component of the force.

Using suspension as a support system, dimensions of the structures can be increased as long as the cables are strong enough and the pylon is able to handle the pressure and will not buckle under the load. Sizes of cable stayed bridges vary from small to enormous. The longest cable stayed bridge is the Jiaxing-Shaoxing Sea Bridge in Shaoxing, which spans 10.138 meters with the use of six pylons, supporting eight lanes of freeway.
An advantage of the cable stayed system is the unhindered clearance under the bridge. Due to the fact that the deck is suspended, no support structure needs to be placed under the bridge deck itself. It is also possible to suspend the deck from a point not located in the line of the deck itself; this does create an extra horizontal component to the system.

Dimensions
The dimensions of a cable stayed system are determined by the strength of the cables and the ability of the pylon to take up the forces in the system. As long as the pylon is balanced, only pressure acts on its section, making it possible for the pylon to be slender. The horizontal forces on the pylon define the span possible. To keep the horizontal forces as low as possible, the angle the cables have to make in order to support the span have to be maximized. This can be achieved by using taller pylons for larger spans.

Landings
As the pylons can be placed outside the footprint of the deck, landings do not have to be obstructed by the placement of those pylons. This makes for a relatively versatile system when looking at implementation options on a location.

SUSPENSION SYSTEM

The suspension system shares a lot of characteristics with the cable stayed system, in both systems, the deck is suspended. In suspension systems, the cables connecting to the deck are suspended from a main cable, which spans the length of the bridge.

In a suspension bridge, horizontal forces occur as well. The way they are created are different from a cable...
stayed system. The horizontal forces are created at the connection between the suspension cables and the main cable. The horizontal components of the load on the deck create a situation totally opposite of the way an arch works. The forces create a tensile force in the main cable, pulling the pylons together. This way the pylons experience a horizontal force which has to be balanced.

The largest spanning suspension bridge is the Akashi Kaikyō Bridge in Japan, its main span is 1991 meters and its pylons are 282.8 meters high.

![Fig. 36: Photograph of the Akashi Kaikyō Bridge (Rötzel, 2005)](image)

Dimensions
Suspension bridges can create the largest spans out of all bridge types. The dimensions can be scaled up to fit any needs. It’s a matter of engineering the most efficient dimensions to create a well-functioning suspension bridge.

Landings
In bigger bridges, the pylons are placed at approximately a quarter of the length of the bridge. This is done to create a balance in the system. This also means the landings have little restrictions in design. In smaller bridges, the pylons can be placed in a way relative to the placement of pylons in a cable stayed system.

LANDING DESIGN

In order for cyclists to rise to a certain height, a slope is needed. In bridges we call these slopes landings, as it is the part of the bridge where it connects to the surrounding environment.

In 1946 ir. L. Roos published a paper on research for design guidelines for bicycle slopes, he wrote to government officials and various services what requirements they set for their cycling paths. During this research, he also measured a number of cycling slopes in the Netherlands, focusing on the ones troublesome for people to use. Based on the data he had gotten during the research, he advised to set a permanent relation between the height and length of the cycling slopes. This was when he has given us the formula of Roos; length of slope = 1/10 * difference in height. It serves as a general rule of thumb while designing cycle path slopes in general (C ter Braack & Boggelen, 2009). Ir. L. Roos also determined the maximum slope of bicycle slopes, which is 6% in long slopes, and 8% in short slopes. In 1967, the Dutch tourist association (ANWB) took Roos’ guidelines and officially used them in recommendations for the building of cycling slopes.

In 1982 and 1983, ir. A.J.M. van Laarhoven published his findings from extensive research on bicycle paths,
intersections and other meeting points with cyclists involved (Laarhoven, 1982; Laarhoven & Provincie Gelderland Dienst Wegen Verkeer en Grondzaken, 1983). Van Laarhoven advises a slope percentage of 1.25% on all slopes used to travel a vertical distance greater than 4m. Ir. A.J.M. van Laarhoven’s research shows an interesting approach, although it has one big drawback: it is theoretical research. Despite the theoretical nature of the research, in 1986, Rijkswaterstaat took van Laarhoven’s research and put the recommendations in the RONA, the dutch guidelines for designing non-highways (Richtlijnen voor het ontwerpen van niet-autosnelwegen). As far as Ir. L. Roos’ research, it has very useful information in it, but it might be a bit outdated, as it was published in 1946.

The research done by C. ter Braack, during his internship at Goudappel Coffeng, shows a great deal of information. In the research, the slopes of cycling routes and/or obstacles have been analyzed and rated to the guidelines provided by the research of ir. Roos and ir. A.J.M. van Laarhoven. The validity of this inventory has been checked by interviewing users of the slopes. During these interviews users showed a general preference for slopes with a lower percentage of incline. Although, some slopes which had a significantly high percentage would be given a higher appreciation by users (C. ter Braack & Andriesse, 2009).

![Graph showing the comparison between ir. Roos’ and ir van Laarhoven’s research to current CROW guidelines](image)

Fig. 37: Graph showing the comparison between ir. Roos’ and ir van Laarhoven’s research to current CROW guidelines (C. ter Braack & Andriesse, 2009).

Showing that, other factors play a role besides the length or inclination of a slope. Design and safety in use for the people are factors why a slope does not have to be as long as ir. Roos or ir. van Laarhoven have depicted. However, the design guidelines provided by using the rules of thumb both engineers supplied is a very helpful tool in estimating the dimensions of the landings.

PREDECESSOR RESEARCH
Two extreme examples of cyclist slopes in the Netherlands were researched in order to get a feeling for the dimensions and scale. The bridges researched are the Nesciobridge in Amsterdam, and the Snelbinder in Nijmegen. These were chosen for their mention in the report “Hellingen in fietsroutes” (C. ter Braack & Andriesse, 2009), in which they were at opposite ends of dimensions regarding angle of slope and its evaluation by users in the research.
Nesciobridge

The Nesciobridge connects Amsterdam Oost to IJburg by spanning the Amsterdam-Rijncanal. It is one of the longest cyclist and pedestrian bridges in the Netherlands, measuring 779 meters in total. Its span measures 163.5 meters between its two pylons placed on the banks of the canal. The clearance between the canal and the deck is 10 meters, leaving enough room for the commercial vessels to pass.

![Photograph of the Nesciobridge](Sepp, 2007)

The bridge has separate landings for the cyclists and pedestrians, creating a safe climb for both parties. Where the pedestrians have to take a set of revolving stairs to reach the deck, the cyclists climb using the landings. Which are 265 (south side) and 240 (north side) meters in length. Because of the landing on the north side starting from the IJdijk, it has about 4 meters less difference in height.

The overall slope is 2.34%, at a height difference of 9.8 meters. The south side landing has a slope of 3.16% at a height difference of 14.5 meters. The start of the south side landing is much steeper than the rest of the landing and two plateaus are incorporated in the landing, to give the cyclists a period of rest.

Snelbinder

The snelbinder is not exactly a bridge in itself, but a cycling route which has been attached to an existing railway bridge. This bridge consists of a long route, which slowly lifts from street level in Nijmegen, to arrive in Lent 2020 meters later. The span of this bridge is incorporated in the length of the slopes, as the bridge is sloped slightly as well.

![Scematic showing the footprint of the Nesciobridge](van Erk, 2015)
The structure has a length of 2020 meters, with a span of 235 meters. The two landings rise 10 meters in height to access the bridge deck. The north landing has a length of approximately 870 meters, with a slope of 1.1%. The south side is about 1150 meters in length, with a slope of 0.52%. The height difference on the north side is about 10 meters, the south side has a height difference of 6 meters.

**POTENTIAL OF STRUCTURE SYSTEMS**

Looking at all the support systems, concluding which is the best in this case is a matter of testing all of the systems to the boundary conditions and revising the potential of the structure.

The beam system is not applicable, as it is not capable of creating large spans, and a 140 meter span is required for crossing the commercial channel.

The truss system is able to span the distance, but would create a big visual barrier on the waterway. Using such a system does not correspond well to the way the spatial planning committee and the people of Amsterdam look at the IJ.

The rigid frame system would be a possibility, but incorporating a moveable section is a challenge. The V-shaped support frames could be used to create multiple spans to allow for an opening section, however, those spans could get in the way of the clearance needed over the commercial channel. The batter-post frame is not applicable in this scenario, there is no room to facilitate the support columns and they would interfere with traffic. A single span may not be capable of spanning the 140 meters efficiently.

Using an arch to support the bridge’s deck, it’s possible to span the length. But an opening cannot be created under an arch bridge. Also, the arch required for supporting the structure, would be located over the river, obstructing the community view the same way as a truss system would.

A suspension bridge could easily span the IJ, but a mixed system would be needed to incorporate an opening. It does have the advantage of not blocking the view, as the pylons can be located on the banks of the IJ.

The cable stayed system can be used to span the distance, leaving the view over the IJ open for people to enjoy. The opening can be added to the bridge, as the cable stayed system can be used twofold, to create a span on each side, adding an opening in between the two.

The potential of the cable stayed system is highest, because it allows for a slender section over the crossing, and has the possibility to be configured along with an opening. The non-suspended structures cannot create a slender span, a long enough span, are in the way of the waterway, or are to obstructive to the sightlines over the IJ.
3.3 GUIDELINES FOR DESIGN

The results of both the research in bridge construction and the project location are the foundation on which the design study is to be performed. The points of interest which were focused on during research can be used to evaluate the research and provide results. Interpreting the results gives us a set of guidelines to be used in the design.

1. The project site is located at location B; connecting the Stenen Hoofd to the district Overhoeks. In research this had the most potential as a connection, due to the development of Amsterdam Noord, the most potential is in location B. It already connects to a better site from the commercial companies’ point of view, and the area of Overhoeks has a lot of inhabitants currently. Beside the fact that creating a bridge at both location B and E creates a good connection in the current cycling track network, Location B has the advantage of the space available on both sides.

2. The potential of the cable stayed system is highest, because it allows for a slender section over the crossing, and has the possibility to be configured along with an opening. The non-suspended structures cannot create a slender span, a long enough span, are in the way of the waterway, or are to obstructive to the sightlines over the IJ.

3. No more cruise ships on the IJ. Since this project is about finding an optimal solution using a bridge over the IJ and not about creating the largest span possible in pedestrian bridges, we concur with the spatial planning committee’s opinion that 3 strategic implementations of a moveable bridge are available:
   - A 19 meter moveable section, placed on the IJ on the north side, allowing leisure vessels and sail yachts to pass.
   - A 50 meter moveable section, allowing for medium cruise ships to pass.
   - An 80 meter moveable section, allowing for monster cruise ships to pass.

   The presence of a moveable section is vital for preventing the bridge to become the only obstacle on a mayor route for sail ships between the sea and the inland waterways of the Netherlands. But after deliberation with my tutors, we have decided to opt for the option of a 19 meter moveable section.

4. Taking into account the research done by van Laahrhaven and Roos, but mainly supported by the field research done by Braack and Anriesse. The angle of slope to aim for is 2%. Their work shows a better appreciation by the users, for landings which are well designed and provide a clear oversight of what is coming. This way the users feel safe in using the landing. By using extra wide bicycle paths, more room is given to the cyclists, which should improve the safety aspect on the landing.
4.1 CONTEXT

The bridge will connect the Westerdoksdijk to the cycling path to be developed on the bank of the district Overhoeks.

4.2 PREFERENCES AND REQUIREMENTS

The key factors to migrate into the design are the long span (140 meters), the landing (which should have a gentle slope (2%) and clear oversight in use) and the moveable section of the bridge. These key factors were derived from the research completed during the project.

Prior to starting a final design, a list of preferences and requirements (programma van eisen in dutch) is issued. This list is the checklist on which the design will be tested afterwards.

List of preferences and requirements for a bridge over the IJ in Amsterdam:

- The bridge creates a connection between the city center of Amsterdam and Amsterdam Noord and is to be realistically useable as an alternative to the ferry connections present on the IJ currently.
- The load bearing and dimensional capacity of the bridge is large enough to support the use of 6000 persons per hour (Peak capacity of buksloterwegveer, multiplied by 24 (number of crossings each hour x3)).
- The bridge is connected to the cycling track network in a decent way (useable under peak traffic conditions).
- The bridge has a column free span of 140 meters over the commercial waterway, with a clearance of at least 9,10 meters.
- The bridge is able to be used by all types of people in a comfortable way, including the elderly, people with disabilities, and children.
- The bridge has the least amount of visual obstruction possible.
- The bridge is an addition to the city of Amsterdam in terms of design and architecture.

4.3 DESIGN EXPLANATION

Designing the bridge, information is taken from the predecessor research and implemented in the design process. Concepts were thought up, both from out of the blue and as an outcome of predecessor research, to aid the decisions in design necessary to allow for progress when needed. These concepts act as an anchor to keep ideas and solutions for problems encountered in the design process from differ too far from each other, which would result in a problem in the eventual design. Also, the concepts keep the design within the boundaries of the concept, allowing for a testable factor in all scale sizes.

PRECONDITIONS TO THE DESIGN

Safety first

A bridge is designed for use by people without delivering any direction of use. In order for the bridge to be used, it has to be expected for people to be used without harm or accidents. To prevent accidents, clarity of use is a very important factor in allowing people to use the bridge to cross the water.
Safety comes in many forms, ranging from good overview in the eye of the users, to detail design in preventing harmful objects to be present on the bridge.

Clarity and overview
In the use of the bridge, users have to have a clear overview of the bridge. As it is a part of the road system, all be it for low speed traffic, oversight is paramount to avoid traffic accidents. This will be achieved in a clear routing of the landings, extra measures in designing the bridge deck and its surface. Lighting will be an important feature.

Building code
In every form of construction, a code has to be followed. This design will be no exception to that rule. The design will have to comply with building codes NEN 1991-2 +C1/NB building code (NEN bouw & Nederlands Normalisatie-Instituut, 2011a), and NEN-EN 1990+A1+A1/C2 (NEN bouw & Nederlands Normalisatie-Instituut, 2011a).

CONCEPT

Opening part
The boundary conditions of the site demand a large span, openable bridge section to be incorporated in the design for a bridge over the IJ. This is done to allow the passage of giant cruise ships and less giant, but still large, commercial sea-going cruises. From the spatial planning services of Amsterdam, I have learned that their opinion is for the IJ to be seen as a public square, like in cities around the world. Only in this case, the square would consist of a large body of water in the urban environment.

When I thought about their view of the IJ, I sought reasons for allowing huge trucks or convoy exceptionelle to cross a square in the middle of a city. They would have a hard time getting there, and they ruin the use of the square for normal residents. I immediately have to say there is a big difference in defining a square on land, or on water, but the reasoning is the same. It comes down to what is more important to the city, its own inhabitants and their ease to move around the city, or the income from cruises which want to dock in the city center so the tourists can disembark and be in the center of Amsterdam, without having to take secondary forms of transport.

In my own philosophy, the cities’ inhabitants should come first, thus my concept is to move the cruise ship terminal to the west of the IJ, removing the issue of large span opening parts entirely. A 19 meter moveable section will be included in the design, to allow for leisure vessels and larger sail ships (e.g. for the Sail event) to reach the IJ. If I would want to create a bridge with openings that allow those giants to pass through, the bridge would have to be a lot sturdier, resulting in design measurements more equivalent to bridges used for all kind of traffic (cars, busses, trams, etc.). This would be such overkill for a pedestrian bridge, I have already stated in my concepts, the giant vessels will be excluded from travelling so close to the city center. I was wary about making this decision, because it means the revised passenger terminal on the east of the Central Station, would not be able to be taken in use anymore. However, this is a decision in my project, and although it makes my project deviate a little more from a real life scenario, I found out the spatial planning services and the aldermen of the municipality of Amsterdam, which overlooked the “Sprong over het IJ” (Amsterdam, 2015) planning campaign, were not that shocked about the idea, as it is a real life consequence of building a low speed traffic bridge over the IJ.

Difference in purpose
The way support structure is handled within our faculty has always been a fascination I have had, few students attending to our faculty use the structural part of their design as a part which expresses their design. Support structure has a subordinate role in the way most students take to a design project, whilst that role can be very important in a design project’s outcome.

The concept of difference in purpose makes people see the role every part of the design fulfills. The main role of a part of the design is made apparent to the users of the bridge. The deck and its surface serve the role of providing the surface for the people to cross from one side of the IJ to the other, while the supporting structure allows for the placement and
support of the deck.

The difference in purpose will be made apparent by difference in shape, as well as difference in material. The idea is to design the support structure as a part which only supports the span over the IJ itself and design stand alone, superelements for the support of the bridge.

Lightweight appearance
In my predecessor research I have seen a variety of ways to allow for a large span crossing. The crossing in my design should look sleek and lightweight, as it should have little loads to carry. The structural parts, which serve a clear and defined role in the design, should also comply with this concept. Optimization of the structural system has to provide a system as sleek as possible, to keep the bridge looking as lightweight as possible. In use, it should feel like the user is safe to cross, but crossing on a lightweight structure. This also collaborates with the notion of spatial planning services, not obstructing the view over the IJ for its users, making it a place everyone can enjoy

STRUCTURE OVERVIEW

The overall structure of the bridge will be made up of 4 components; the pylons, the deck, the landings and the opening. Placement of the pylons will be as close to the banks as possible, leaving room for the back stay cables of the pylon to connect to their foundations. The deck will start from the foundation on the Westerdoksdijk, spanning the width of the commercial waterway, where it connects to the first post of the opening part of the bridge. The second part of the deck will leave the second pylon of the opening part of the bridge, to the foundation on the Overhoek site. The landings will be fitted to not interfere with the current cycling track network or any high value buildings on either site.

Fig. 41: Structure overview (van Erk, 2015)

The design for the routing is set up to accommodate both cyclists and pedestrians.

Fig. 42: Routing on the bridge (van Erk, 2015)

PYLON DESIGN
Main support structure
Designing the main support structure, a difference in purpose had to be apparent in visibility. I designed the support structure as an infinite loop, which includes the pylons and the main span’s deck girders. The support structure for the landings will be stand-alone structures, sharing the same design form as the infinite loop does. This form will be straight lines connected by curved corners. Together with a circular section, it will look like a loop of steel is shaped to support the bridge’s deck.

Fig. 43: Studios 10 and Buro Happold’s design called Infinity Loop Bridge was an inspiration for the design (Buro Happold & Studios 10, 2012)

Support structure iterations
The first option was I intended to use was an arch support structure. These arch structures are able to create a large span due to the circular shape of the arch, which transfers forces through the support structure in an effective way. The arch had one very big drawback however; it would create a large amount of geometry over the water, which would absolutely negate the concept of creating a lightweight-looking crossing over the IJ.

Secondary, the suspension bridge system is able to support the walkway. This system would also have a much lower geometrical obstruction over the waterway in comparison to an arch support structure. Because the only large geometric parts in the suspension bridge system are the towers, or pylons, from which the main cable is spanned. This means the only thing in direct sight over the waterway is the cable system. However, there is no possibility to implement an opening section of the walkway, except for the option of creating multiple sections of suspension, which means adding more suspension towers to the design. These suspension towers would then create a geometrical obstacle over the waterway, and would negate the concept of a lightweight looking crossing. Another drawback of the suspension bridge system, in this case is, although being able to create the large span without much trouble, the lightness of the walkway would be an issue in stability for the design itself. The suspension bridge system in combination with a lightweight walkway would see a relative large reaction to the load on the system due to use and wind load. As I am no structural engineer, I am not able to do the required calculations to prove the stability of the system, while taking into account factors like resonance, natural structural frequency pairing with external periodic frequencies, etc. This was however only the final nail in the coffin regarding the suspension bridge system, as the impossibility to implement an opening section in the system had ruled out the system already.
The third system I looked at, was the cable-stayed system. Through research in bridge structures, we determined the most potential in supporting the large span on this location is a cable-stayed system. Using a cable stay system, a large, column free span is able to be supported, while it is still possible to incorporate an openable section of the bridge. The structure of the deck itself will consist of circular steel beams to be able to carry the load on the bridge deck. The connection to the cable stayed system will allow for the deck to be constructed in a common way used in cable-stayed systems.

Due to the fact that the suspension bridge system had solved the problem of both having enough clearance under the design as well as not creating a large geometric obstruction over the IJ, I was looking at a system with those same benefits and added the requirement of an opening section of the bridge.

The cable stayed system is able to support the walkway by transferring load through cables into a pylon, similar to the way this happens in a suspension bridge. However, in a cable-stayed bridge, the load is transferred by cable from each individual connection to between the walkway and the pylon. As where the suspension bridge system transfers the load from the walkway to the main cable first, then the main cable transfers the load to the pylons.

When I started drawing up configurations of pylons for the suspension bridge, the first architectural challenge turned up. The shape, size and overall design of the pylons would determine a great deal of the bridge’s esthetics. Starting at a straight pylon, the side view of the design starts to show the statement the bridge has as an overall design.

The straight pylons show a neutral stance, have a clear supporting role in the design and their role is visibly clear. However, the pylons seem detached from the design, they look like neutral, support members which is not the image I want the design to show. The design is about creating a connection, a cross-over between two sections of a city. The design language of straight pylons, for me, creates an image of absence, a way to say: these elements were placed here to fulfill the task of supporting the structure, but if it were possible, I would have not wanted them in plain sight. This is not the image I wanted to show in my design of the support structure; I wanted to show a support structure which contributes to the design’s concepts, collaborating in the creation of an image the crossing would show. The main goal is to connect the two parts of
the city; the support structure should show that as well.
This is why I started to sketch a load of configurations for the pylons, focusing on just the pylons, what image they show by stance and shape.

Going through the configurations I sketched for the pylons, I started favoring the pylons in slanted position. The pylons angled towards each other show a connecting motion which sums up the entire reason for a bridge to be designed at this site.
The movement suggested by the angle of the pylons is amplified by a bend in the pylons themselves. The curvature increasing as the pylon gains height makes for a clearly visible gesture of connection.
However, having a bend in the pylon would mean it will be eccentrically loaded by the compression forces from the bridge deck, causing it to buckle under lower pressure. The final design for the pylon is as follows; straight and slanted, with rounded curves in the corners.

To keep the pylons from reaching oversized dimensions, the span to height ratio of the pylons was assumed at a 2:1 ratio. This was done due to the angle of the cables and the force to be transferred. The smaller the angle between cable and walkway, the greater the horizontal force will become on the pylon. This would translate in a larger moment in the pylon due to horizontal forces combined. And the pylon would need to withstand more pressure due to the horizontal forces being counteracted by the back cables.
With the span divided into two sections, north and south of the opening part, there will be two pylons holding supporting their own sections of the walkway. As the sections differed in span, the span supported by the southern pylon is larger than the span supported by the northern pylon, the idea rose to decrease the size of the northern pylon, to fit the scale of the sections.
This brings on another facet in the story told by the pylons. Now there is one pylon smaller than the other, a synonym for inequality, a distinct difference. Multiple reasons support this inequality. The larger pylon is on the bank of the city center, the older and most heavily used part of Amsterdam. In comparison, Amsterdam Noord is a new addition versus the rich and versatile history already residing in the center of Amsterdam. With the completion of this bridge, a new part of Amsterdam is welcomed into the low-speed network of Amsterdam. Although the area of Amsterdam Noord has a great opportunity for development, the center has already proven its worth over many years. There is a connection between both areas, illustrated by the size difference of the pylons, a mother and daughter relationship is depicted. So aside from the waterways boundary conditions determining a size of span, the relationship of both areas involved complies with the visual language of difference in size of the pylons.

MAIN DECK

The deck is the part of the bridge which will be in plain view of the cyclists and pedestrians using the bridge to cross over. This is also the part which will have the most effect of wear and tear from users. The deck has to be able to withstand the loads on it, but it also has to deal with the most external factors. All weather effects and abuse by wear will be of effect on it. The deck is also the determining part of the safety of the bridge. The deck is the main guideline for users on how to use the bridge, where to walk, where to cycle, what is within and outside of limits.

Structure of the deck

The deck structure is designed to be made up out of individual 20 m long sections, this way, the sections can be prefabricated in controlled working environments, rather than being placed together on site. The configuration of the deck will consist of FRP deck boards, supported by beams which span the width of the deck and connect to the girders. Finishing will be done by a plastic profile, which will be connected to the beams and the foot of the railing. The girders in the configuration are part of the infinite loop, so they have a different look compared to the configuration of the deck itself.
At first, I wanted to create a deck fully made of FRP. I decided not to do that, because it takes a long time to understand all the ways of calculating, production methods and characteristics of the material in order to be able to start creating a design out of FRP. Bridges have been built out of steel for a long time, and nowadays steel is still used as the most common materials to build bridges. So I decided to create a deck made up of a steel support structure, with an FRP deck for durability reasons.

In configuring the bridge deck structure, I looked at the loads mentioned in NEN-EN 1990 + A1 + A1/C2 (NEN bouw & Nederlands Normalisatie-Instituut, 2011a) and NEN 1991-2 + C1/NB (NEN bouw & Nederlands Normalisatie-Instituut, 2011a), to find the maximum load used in calculations was 80kN. Looking at the specs of the FRP boards, I have set the heart-to-heart distance at 1.25 meters.

The deck boards are supported by steel IPE 330 profiles, spanning the width of the deck. These beams are connected to the girders, 800 mm high circular profiles, by being bolted to a welded console. A bolted connection is used for ease of assembly.

On the console, there is room for bolting down the railing’s balusters. On the foot of the balusters, there will be a possibility to screw down the plastic trim which serves as a cover for the consoles, has recesses which fit the balusters, and the trim has plastic in it. The trim will be made of 1.25 meter long sections, so they are easy to handle, as the covers and balusters will be the only thing installed on-site.
The biggest decision in this project has to do with the capacity of a bridge to be built to create enough room for the ships to pass. As stated in the boundary conditions, these vessels have to make way for the desires of the residents of the city to cross the IJ comfortably.

To emphasize the difference in traffic between channels on the waterway itself, the opening part of the bridge would be placed on the edge of the commercial channel on the waterway. Also due to the height regulation of commercial vessels, no moveable part is needed over the commercial channel. So boats which exceed the height regulation, and would have to wait for the bridge to open, could safely wait outside of the commercial channel in order for the bridge to open.

In order for the opening to be able to function properly, it has to be supported on a foundation. If the opening would be supported by the cable-stayed system alone, it would be prone to moving if opened and cannot be supported in a steady enough manner to guarantee safe operation. This is due to the cable-stayed system having to deal with the large point load at the maximum of its span. This is where the deflection is also at its maximum. So, as a necessary precaution, foundation pylons have to be placed at both sides of the moveable part of the bridge.

The safety aspect of the opening part will be dealt with in a differentiating way.

Because of the concept of the support structure, the bridge has a very narrow midsection. Despite the support pillars it has beneath the moveable part, the bridge should still look very lightweight. The support girders have to be seen as continuous elements on this section of the bridge as well.

Due to safety measures, the moveable part of the bridge can't just open up. There has to be a physical boundary that blocks the section from traffic in order to open the bridge safely. Else a user could not notice any warnings and drop down the opening.

The openable section will be driven by a panama wheel, which pulls down the counterweight of the flap, causing the flap to open.
Designing the actual moveable section of the bridge entails lot of skills which I don’t possess. The mechanical engineering to be done on the system is out of my reach and I have used external parties to aid me in the design of them.

**LANDING DESIGN**

The part of the walkway which connects to the main land is the landing. It allows the people to get onto the bridge. Also, the research I did in slope angle and clarity of low-speed traffic bridges shows that a low angle, overview while traversing the landing and length of the landing itself are the leading characteristics for the bridge to be positively reviewed by the users.
The first design I drew up for the landing was focused on its length needed to create an agreeable slope angle in order to reach the height of the bridge needed at the point where it crosses the channel on the IJ (10m from the water). The landing was placed on the site across the street from the water on the Westerdok. There is a clear patch located there which has no buildings. So no existing buildings would have to make way in order for the landing to be placed.
Fig. 50: Top view of the landing (van Erk, 2015)

Fig. 51: Cross section of the landing and its support structure (van Erk, 2015)
My final design of the landings utilizes a 375 meter long slope, which moves around the pylons in a spiral, crossing under the deck of the crossing. This is done to decrease the footprint of the landing itself and to have a clear path of the landing at any time. The landing will be supported by columns which are placed at the inside of the spiral. This is so the users still have a clear and continuous line of sight over the IJ, and to visually keep the design as lightweight as possible. It looks like the landing is floating on water.

**LOGISTICS**

The logistics of building the bridge are a part of the design to plan well. Figuring out the logistics at an early stage allows for the design to be realistic and provides a dimensional restriction in the design.

The pylons will be placed in their foundation in one piece, with the cap of the pylons securing the two parts of each pylon by joining them at the top. The cables will be anchored in this cap.

The bridge main span is made up of 20 meter long sections, measured heart to heart. These sections will be suspended from the pylons using a connector between the deck elements. Using the system of separate elements in the span, the system is placed one element at a time.

In the buildup of the landings, a similar system is used. Instead of the connectors, superelements are placed, which also provide the needed support for the landing. The sections of landing are placed in between the super elements by crane, making the construction follow the same logistic as the bridge deck, constructing piece by piece.

The most important element in this structure is the first element of the bridge deck, which doubles as the last element of the landing. Because the landing is attached to this deck element, the point where the bridge deck turns into the landing is hard to determine for the users, creating a feeling of one single flowing deck.
Structure of the deck

The deck structure is designed to be made up out of individual 20 m long sections, this way, the sections can be prefabricated in controlled working environments, rather than being placed together on site.

The configuration of the deck will consist of FRP deck boards, supported by beams which span the width of the deck and connect to the girders. Finishing will be done by a plastic profile, which will be connected to the beams and the foot of the railing. The girders in the configuration are part of the infinite loop, so they have a different look compared to the configuration of the deck itself.

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The deck boards are supported by steel IPE 330 profiles, spanning the width of the deck. These beams are connected to the girders, 800 mm high circular profiles, by being bolted to a welded console. A bolted connection is used for ease of assembly.

On the console, there is room for bolting down the railing’s balusters. On the foot of the balusters, there will be a possibility to screw down the plastic trim which serves as a cover for the consoles, has recesses which fit the balusters.
and the trim has plastic in it. The trim will be made of 1.25 meter long sections, so they are easy to handle, as the covers and balusters will be the only thing installed on-site.

Fig. 54: Detail section of deck girder (van Erk, 2015)

Fig. 55: Side view of stay cable connection on deck girder (van Erk, 2015)
Fig. 56: Detail of pylon foundation (van Erk, 2015)

Fig. 57: Detail of cable stay on top pylon (van Erk, 2015)
Fig. 58: Detail of back cable stay foundation (van Erk, 2015)
4.4 SIMULATION

I have used hand calculations to determine the dimensions of the beams needed and I have checked them with a program called karamba.

Fig. 59: The description karamba gives about their program on their website, (KARAMBA 3D, 2015).

Using the software I was able to verify the program’s working order and results with my hand calculations. This was necessary in order to use the program reliably in calculating the deflections of the pylon later on.

In this chapter I will take you through the calculations and explain how I got to my final dimensions.

For the calculations, I used the Young’s Modulus of construction steel S235; E = 2.1*10^5.

LOAD CASES

I inventoried the calculations necessary for determining the dimensions of the system.

In the NEN 1991-2 +C1/NB building code (NEN bouw & Nederlands Normalisatie-Instituut, 2011a), paragraph 5 states the load for calculation to be used in pedestrian and cyclist bridges. These loads are as follows:

- An evenly distributed load $q_{f,k} = 2.0 + \frac{120}{L+30} \text{kN/m}^2$, where load $2.5 \text{kN/m}^2 \leq q_{f,k} \leq 5.0 \text{kN/m}^2$, this is because the bridge is longer than 10m. For bridges shorter than 10 meters, an evenly distributed load is maintained of $q_{f,k} = 5 \text{kN/m}^2$, this is because the presumption in this load is a simulation load of a continuously tight mass of people covering the entire bridge.
  The longest length of the bridge deck is 140m, this makes the load: $q_{f,k} = 2.0 + \frac{120}{170} = 2.71 \text{kN/m}^2$

- A pointload $Q_{fvd}$ placed arbitrarily on the bridge deck of 7.0 kN, distributed over a 0.10 x 0.10 m area, $Q_{fvd}$ should not be considered in case load for a service vehicle for a pedestrian bridge (as explained in paragraph 5.3.2.3 of the NEN 1991-2 +C1/NB (NEN bouw & Nederlands Normalisatie-Instituut, 2011a) is considered.

- In case of a permanent obstruction for vehicles to access the bridge is absent, a load model consisting of a two-axle load configuration of 80kN and 40kN using a 1,3 meter wide axle and a 3,0 meter length. The contact surface of each of the axel ends should be 0.2 x 0.2m.
Fig. 60: diagram of load case for service vehicles (NEN bouw & Nederlands Normalisatie-Instituut, 2011b)

Explanation of the diagram above:

\[ X = \text{longitudinal direction of bridge} \]
\[ Q_{sv1} = 80\text{kN} \]
\[ Q_{sv2} = 40\text{kN} \]

According to the NEN-EN 1990+A1+A1/C2 (NEN bouw & Nederlands Normalisatie-Instituut, 2011a) building code, the multiplication factors for loads to use in design are:

**Permanent/Static load:**

- Favorable: \( \gamma_{G,\text{inf}} = 0.95 \)
- Unfavorable: \( \gamma_{G,\text{sup}} = 1.05 \)

**Variable load:**

- Favorable: \( \gamma_Q = 0 \)
- Unfavorable: \( \gamma_Q = 1.35 \)

**DECK BEAM CALCULATIONS**

Since the deck beam is the first member of the system transferring the load, I determined the dimensions of these beams to start with.

A rule of thumb gives us the first indication for dimension. Since this rule of thumb would give an indication for height of the beam, I would use the thinnest beam possible to start the check of the calculations.

Rule of thumb for hot-rolled steel I-beams in floors, single span: \( 1/20 \times \text{length of span} \) (Dept. of Structural Design, 2015).

\[
\frac{7000\text{mm}}{20} = 350\text{mm}
\]

Using the rule of thumb my estimated height of the beams to use for the primary deck beams should be in height. We will
use the IPE 330 profile in calculation to check the tension in the profile with the load applied. The specifications of this beam needed are:

IPE 330  
$I_y = 11.77 \times 10^7 \text{ mm}^4$
$W_y = 7.13 \times 10^5 \text{ mm}^5$
$G = 481.671 \text{ N/m}$

The threshold for deflection is 0.4%; $U_{end} = 7 \times 0.004 = 0.028 \text{ m}$, or 28 mm

The static load on the beam consists of the following:

- The main deck, 42 kg/m², the beams distance is 1250mm and are 7 meters in length. Resulting in a total area of $1.25 \times 7 = 8.75 \text{ m}^2$. The static load put on the beam by the deck is $q_{st,deck,main} = 8.75 \times 42 \times 9.81 = 3605.175 \text{ N}$, or 3.6 kN/m².

- As an assumption of the load created as a result of the top layer of the bridge’s deck and other finishing materials, including assembly, a weight of 5kg/m² will be added. Resulting in a load of $q_{st,deck,div} = 8.75 \times 5 \times 9.81 = 429.1875 \text{ N}$, or 0.4 kN/m².

- Bringing the total static load of the deck to: $q_{st,deck} = 3.6 + 0.4 = 4 \text{ kN/m}^2$

The formula for the deflection by a divided load on a beam resting on two points at both far ends is:

$$\text{Deflection} = \frac{5}{384} \frac{ql^4}{EI}$$

With the dynamic load $q_{dyne} = 5 \times 1.25 = 6.25 \text{ kN}$, adding the factor of unfavorable static load $\gamma_Q = 1.35$:

$$\text{Additive deflection} = \frac{5}{384} \frac{8.4 \times 2401 \times 10^{12}}{2.1 \times 10^5 \times 11.77 \times 10^7} = 10.62 \text{ mm.}$$

10.62 mm < 28 mm, which is sufficient.

Taking into account the entire load, its own weight and the dynamic load included, with $q = (G \times l + q_{st}) \times 1.05 + q_{dyne} \times 1.35 = ((0.481671 \times 7) + 4) \times 1.05 + 6.25 \times 1.35 = 16.17 \text{ kN}$

$$\text{Total deflection} = \frac{5}{384} \frac{16.17 \times 2401 \times 10^{12}}{2.1 \times 10^5 \times 11.77 \times 10^7} = 20.45 \text{ mm.}$$

20.45 mm < 28 mm, which is sufficient.

So looking at the deflection of the beam, an IPE 330 profile would satisfy demands. The next thing to check is the bending and shear stresses. The formula for bending stress is:

$$\delta_d = \frac{M_d}{W_y}$$

The formula for shear stress is:

$$\tau_d = \frac{0.5 \times q \times l \times 10^3}{\text{surface of web plate}}$$

$$\tau_d = \frac{0.5 \times 16.17 \times 7 \times 10^3}{330 \times 7.5} = 22.87 \text{ N/mm}^2$$

22.87 N/mm² < 62.6 N/mm², which is sufficient.
The bending moment in the middle of the beam: \( M_d = \frac{(16.17 \times 7^2)}{8} = 99.04 \text{ kNm} \).

\[
\delta_d = \frac{99.04 \times 10^6}{7.13 \times 10^5} = 138.91 \text{ N/mm}^2 < 235 \text{ N/mm}^2, \text{ which is sufficient.}
\]

This means that the IPE 330 beam is proven as strong enough to handle the loads of the deck.

Using karamba, I found a deflection of 20.96 mm, which is more the 20.45 mm the calculations show. The reason for this might be that karamba uses an incremental calculation of the forces on a mesh, derived from the information (profile’s cross section and structural characteristics, etc.) entered in the program. In order to do this, it adds the load on the beam in very small incremental steps, calculating its deflection after every iteration, before creating a new mesh with the new deflection results.

The closeness of the results do validate the results from the

![Image](image.png)

**Fig. 61: Calculation results for the deck’s beams from karamba (own image).**

### DECK GIRDER CALCULATIONS

The beams transfer their load to the girders, thus the next step is to check what profile the girders need to have in order to handle the load.

The same rule of thumb for hot-rolled steel I-beams in floors can be applied to give an indication.

\[
\frac{20000 \text{ mm}}{20} = 1000 \text{ mm}
\]

We will use a circular hollow profile in calculation to check the tension in the profile with the load applied. The specifications of this beam needed are:

- **Height** = 800 mm
- **Wall thickness** = 20 mm
- **\( I_y \)** = 3729.5 \( \times 10^6 \) mm^4
- **\( W_y \)** = 745.9146269 \( \times 10^5 \) mm^5
- **\( G \)** = 3747.42 N/m
- **\( A \)** = 49008 mm^2
To calculate the second moment of area (I_y) and the elastic section modulus (W_{el; y}), I used the calculations on the site www.engineersedge.com, as a reference (Engineers Edge, 2015). I calculated the own load by multiplying the mass of constructional steel by the volume of the object.

The threshold for deflection is 0.4%; \( U_{end} = 20 \times 0.004 = 0.08 \) m, or 80 mm

The load of the main deck is half the width of the section, this means the load is half of the entire load on the 20 meters of deck. The total load is built up of exactly 20 beams, each carrying the same load as mentioned in the deck beam calculation, thus each point where the beams are attached to the girder causes half of the total load of the beams on the girder; \( 14.5 \text{kN} \times 3.5 \text{m} = 50.75 \text{kN} \). This will be used as a distributed load \( q_{beam} = 50.75 \text{kN} \).

The formula for the deflection by a divided load on a beam clamped between two points at both far ends is:

\[
\text{Additional deflection} = \frac{1}{384} \frac{ql^4}{EI}
\]

With the dynamic load \( q_{beam} = 50.75 \text{kN} \);

\[
\text{Addional deflection} = \frac{1}{384} \frac{50.75 \times 16 \times 10^{16}}{2.1 \times 10^5 \times 3729.5 \times 10^7} = 27 \text{ mm}.
\]

27 mm < 80 mm, which is sufficient.

Looking at the total deflection, the load created by weight of the profile has to be added to the equation, multiplied by a factor of \( y_Q = 1.05; 3.74742 \text{kN} \times 20 \text{m} \times 1.05 = 129.5 \text{kN} \).

\[
\text{Total deflection} = \frac{1}{384} \frac{ql^4}{EI}
\]

\[
\text{Total deflection} = \frac{1}{384} \frac{129.5 \times 16 \times 10^{16}}{2.1 \times 10^5 \times 3729.5 \times 10^7} = 68.87 \text{ mm}.
\]

68.87 mm < 80 mm, which is sufficient.

Using karamba, I have found a deflection of 57.13 mm. Once again, I believe that is due to the way karamba adds load in its calculations. I will treat the outcomes of the karamba model as verified to use for the calculations of the pylon.

Fig. 62: Karamba’s calculation results for the deflection of the girder (own work).
So looking at the deflection of the girder, the proposed 800mm x 20mm hollow circular profile would satisfy demands. The next thing to check is the bending and shear stresses. The formula for bending stress is:

\[ \delta_d = \frac{M_d}{W_y} \]

The bending moment in the middle of the beam: \( M_d = \frac{(129.5 \times 20^2)}{8} = 6475 \text{ kNm} \).

\[ \delta_d = \frac{6475 \times 10^6}{745.91 \times 10^6} = 86.8 \text{ N/mm}^2 < 235 \text{ N/mm}^2 \], which is sufficient.

This tells us the dimensions of the girder are adequate to take the loads.

**CABLE CALCULATIONS**

The cables have to be determined; this will be done by determining the normal load which passes through the cables. All but the outer cables have the same force running through them.

As the second to last cable, looking from the pylon, has the maximum load caused by the system and also had the smallest angle between the deck and the cable itself. We can presume it will have the biggest load in the cable itself. Newtons' first law tells us that all forces sum 0, when an object is in balance. So, since we know the angle of the force and the angle it makes with the deck, this force can be calculated.

Force is 1036.1 kN.
Angle is 28.3 degrees.

Force divided by the sine of the angle will give us the force in the cable.

Hence the force is 1036.1/ \( \sin(28.3) \) = 2185.46 kN

Knowing that the force is 2185.46kN, I have added the \( \gamma_Q = 1.35 \) factor. Giving us a breaking strength of 2950kN.

I have found a cable made by the company casar. It is the superlift cable, of which the 50mm variant has a breaking load of 3121.2 kN, or 318.27 metric tons.
PYLON CALCULATIONS

The karamba calculations show a deflection of 582.5 mm.

Fig. 65: Deflection of the deck with all elements in the model. The number shows the maximum deflection of all points on the deck (own work).

4.5 DISCUSSION

Looking back at the design study, a lot of decisions were made on design matters. The research had resulted in guidelines for design, which were used during the process of development. All key factors of the research have been implemented in the design, and the requirements have been satisfied. The preferences are hard to test and evaluation from a 3D model can only give so much information. Besides the fact that the bridge could fulfill the need for a permanent connection between Amsterdam and Amsterdam Noord, the bridge is a great addition to the skyline of Amsterdam. The open character of the design does not block any sight lines over the IJ. On the contrary, the bridge provides a completely new way for the people of Amsterdam to experience the IJ.
During the design process, the support structure of the bridge was formed and its dimensions were determined from rules of thumb. In later stages, the dimensions were calculated by hand, those hand calculations formed the base for a parametric model in final stages of the design, allowing for quick adjustments in dimensions and calculation in the simulations which were done. The simulation has shown the structure of the bridge to comply with the building codes, defining the design to be validated according to the demands set for it. The method used in calculation was validated by checking its results in earlier stages of the process. Validating the results from the calculation of the pylon.

CONCLUDING REMARKS

5.1 REMARKS ON RESEARCH

In chapter 3.1 we saw that the preconditions on the river concerning nautical activity were the biggest challenge to find a potential solution for. In attendance on the presentation of the preliminary results of the research done by the spatial planning committee of Amsterdam, the issue was discussed briefly with the attending audience. It was surprising how easily the spatial planning committee accepted the plans for not letting cruise ships use the IJ to reach their passenger terminal. Their final response was that during the research, this was the challenge they struggled with most and that they had assigned an engineering firm to look into the possibilities for creating an opening large enough. Knowing that designing a bridge with dimensions as small as a pedestrian bridge, the physics of creating an 80 meters moveable section in the bridge are very challenging. I deliberated with my tutors and came to the conclusion of removing the cruise ships from the challenge. This had two reasons: the design of a small opening in a bridge is possible to do with good guidance and the fact that a bridge with a small opening would make the design a lot more realistic.

In chapter 3.2 we saw the classification of 6 typologies for bridges. This was done to create an overview focusing on the main principles of these typologies. Even though 6 distinctions in classifications were made, a lot of bridges were found and discussed which could not be placed in one of those typologies, simply due to the fact that they were designs using a mix of support structures.

We also saw that the research done in the field of infrastructure for cyclists is very limited. This was surprising, because the Netherlands is the country in the world which makes the most use of bicycles in transportation.

5.2 STRENGTHS AND WEAKNESSES

In chapter 3.3, the decision is made to not allow cruise ships to pass the bridge. Although this decision concurs with my own perception on the situation, it does take away the biggest challenge included in this project. This is not a weakness in the design itself, or in the research, but more of a weakness in the development of the project. Leaning more towards creating a design in early stages, the decision was made in context of creating a realistic project. Although I had found it interesting to research the possibilities in creating a large enough opening for cruise ships, I am glad to have created a realistic design in the context of the project.

In chapter 4 we saw the landing taking shape. The design’s landings run a length of 375 meters, with a gentle slope. The landings are designed to spiral up, allowing the people crossing the bridge to enjoy the great scenery of the IJ and the surrounding landscape. This landing is a strong point in my design, because it uses space available on site, to translate the opinion of the spatial planning committee into an experience.
5.3 RECOMMENDATIONS FOR FURTHER RESEARCH

For further research my first recommendation, is to look at large openings in bridges. In this project, we have taken on a set of extreme circumstances on the site of which a crossing was already difficult to design. As mentioned in the remarks on research, it is not clear if it is possible to create an opening large enough for cruise ships to pass with the dimensions of a pedestrian and cyclist bridge. Negating the fact that creating an opening of those proportions is highly unlikely to be efficient, it is a very interesting challenge.

The second recommendation, is to research modern materials for use in a design for a bridge of these proportions. With proportions so uneven between the required length to span and the dimensions of pedestrian and cyclist bridges, modern materials like FRP could provide an advantage in creating the span more efficiently.


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