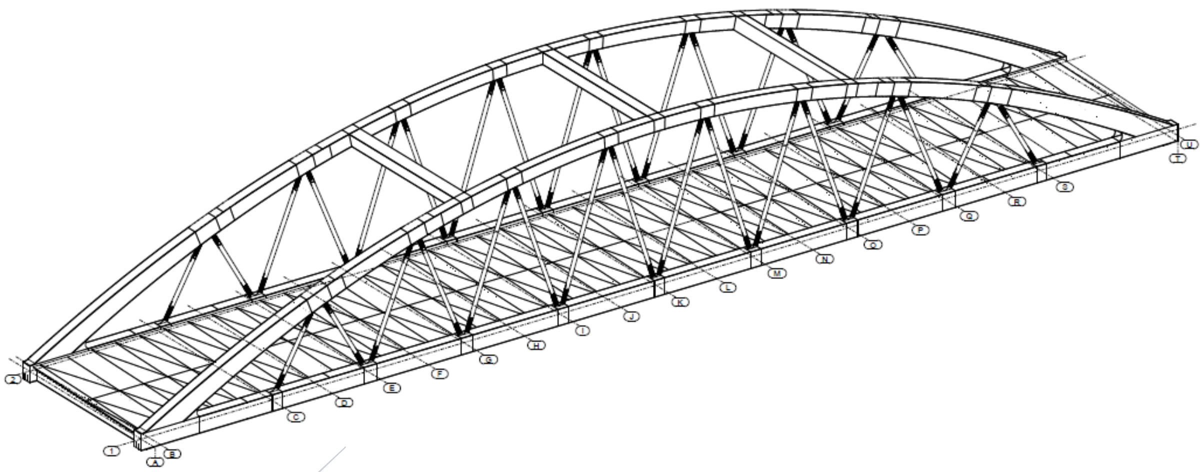
17-6-2022

Research Report

Transportation and Assembly of Temporary Bridge - Albert Channel



Michiel Zwanenburg,
Graduation Student, Civil Engineering
HZ UNIVERSITY OF APPLIED SCIENCES – ASK ROMEIN HILLEBRAND

General Information	
Document	**Research Report - Graduation Internship**
Status	Final
Date	17/06/2022
Pages	60
Author	Michiel Zwanenburg
Student Nr.	00078232
University	HZ University of Applied Sciences
Education	Civil Engineering
1st Examinator / Supervisor	Repko, A.
2nd Examinator	Ansiliero de Oliveira Coelho, M.
Company	ASK Romein Hillebrand
In-Company Supervisor	Deckers, D.

Preface

This document is the basis for the research of the graduation thesis of Michiel Zwanenburg, a student of Civil Engineering at the HZ University of Applied Sciences. This research looks at the transport and installation of a temporary bridge over the Albert Channel in Antwerp. The graduation thesis has been executed as an assignment from ASK Romein Hillebrand and started on 07/02/2022.

For my thesis, I have researched the transport and installation methods possible for the bridge over the Albert Channel. This research covers the possible approaches to effectively transport the bridge (in sections) to the installation site. Once arrived at the installation site, the bridge has to be assembled. I have looked at the temporary supports required to position and connect the sections. These temporary supports will create an unusual load scheme that will be checked to verify the load resistance of the bridge's construction.

During this research, I had access to internal and external resources of ASK Romein Hillebrand, from whom I have received assistance. My in-company supervisor Daphne Deckers is my primary contact who assists me with this research by discussing my findings and comparing them to their initial ideas. Daphne helped me steer in the right direction with this research, as it will benefit both my research and the usability of the results for ASK Romein Hillebrand.

My guidance from school comes from Albert Repko. As my supervisor and 1st Examinator, he has guided me in reaching a desired quality level of research results. During the internship, I have had multiple meetings with Mr Repko to discuss my progress. I have adapted my process with his basic feedback to accomplish the desired result.

This document is the final product of my graduation internship, and education in Civil Engineering (Bachelor)

Michiel Zwanenburg,
Flushing,
17/06/2022

Summary

While writing this report, the construction is ongoing of the Oosterweel Connection project of the ring of Antwerp ongoing. This project is about completing the ring of Antwerp from West to North around the city. This project aims to improve the connectivity around the city and the port of Antwerp. A collaboration between different companies manages the project under the name 'ROCO'. The project is part of a bigger development project in Belgium enacted by the state.

In this project are parts of the ring road redeveloped. In order to replace the road, the old road must be demolished. In this research, we are zooming in on the viaduct of Merksem, which is going to be replaced with a lowered road section. This is a problem as the viaduct is part of the ring of Antwerp. To minimise the impact on traffic, ROCO is going to construct a temporary reroute. This temporary route will replace the 3-lane road and make it possible to work on one direction of the ring without cutting off the traffic.

A bridge is required to go over the Albert Channel for this temporary route. ROCO designed a tied arch bridge which has to function for 10 years until the completion of the new connection. ASK Romein Hillebrand is tendering for this contract and therefore needs to work out how this bridge is going to be built and transported.

In this report, the transportation and installation of a temporary bridge over the Albert Channel are analysed and worked out. The bridge cannot be transported in one piece as it has to pass under several bridges when it is transported from the construction facility of ASK Romein Hillebrand in Flushing to Antwerp. Different options are analysed to analyse the best method of transport, 3 options to transport the arch and 2 options to transport the bridge deck. A multi-Criteria Analysis chooses the best option; this option is further worked out.

The transport and installation methods are analysed to verify the feasibility of the best options. In this analysis are aspects checked as bending, internal 3D stress, support locations, stability, and internal forces. Tools such as SCIA Engineer 21.1, AutoCAD, Eurocode 1, and excel for hand calculations are used for this analysis.

This research shows that the best way to transport the bridge is to remove the arch from the deck and transport each arch in 3 sections on top of the bridge deck. This is the cheapest and easiest way to transport the bridge and later assemble it. The bridge will be set next to the channel in Antwerp, where it will be assembled. The order of assembly is to place the side arch sections first on support towers; a support tower will temporarily support these sections, and the hangers will be placed next. Continuing, the middle arch section will be placed on top of the support towers and slowly lowered while the hangers are installed underneath (from the middle to the sides). For this, the hangers are checked on buckling to verify if they are able to support the bridge's arch. Continuing can the arches be welded together, after which the crossbeams can be installed. When the crossbeams are installed, the support towers can be removed. Now the remaining hangers, which were obstructed by the support towers, can be installed.

As a measure to comply with the stress-free installation requirement is a construction proposed around the main beam of the bridge to transfer loads of the arches' support towers around the main beam to a support tower underneath. This method avoids unusual and heavy loads and stresses on the main beam, which is undesired.

Now the bridge is complete, can it be moved over the channel to its final position for at least the next 10 years. The purpose of the bridge after its 10-year lifespan is still unclear.

Abstract

At the moment of writing this report, the construction is ongoing of the Oosterweelverbinding. The project is to complete the ring of Antwerp. A section of the currently existing ring, the Viaduct Van Merksem, will be demolished and replaced by a lowered road section during this project. The problem is that the ring sections cannot be closed for longer than a few hours at night as there is a lot of traffic on the ring. To overcome that problem, they will construct an extra three-lane road which can act as a diversion to close one of the two directions and work on that section of the road. This diversion route will only be needed for about ten years, after which it will be demolished or repurposed.

Part of this route is a 150 meters long arch bridge over the Albert Channel. ASK Romein Hillebrand is competing in acquiring this contract to build this bridge. The overall design of the bridge has been supplied by the client THV ROCO and has been kept simple as it will have a limited timeline.

The most challenging part of this project is determining the effort required to transport the bridge from the construction site to the installation site. There are multiple limiting factors regarding transport. The most impacting limit is the height limit originating from the bridges over the Albert Channel, under which the bridge has to pass to get to its installation site.

This report will discuss multiple different options regarding transport. The main focus is separating the arch from the bridge deck to reduce the height. Because the height is limited, the bridge will be divided into multiple sections. The division of the bridge sections will significantly influence the amount of work that must be done on-site. The on-site work will significantly affect the costs; therefore, it should be well-thought-out.

Table of Contents

Figures

Tables

Equations

1 Introduction

This chapter introduces the background and reasoning of the project 'Oosterweelverbinding', giving information about the importance of the overall project. Furthermore, it will state the challenges and problems ASK Romein Hillebrand faces. At last, the goal of this research will be described, accompanied by the research questions that must be answered to accomplish the goal.

1.1 Background information

Antwerp is an old city with clues dating back from the Roman era of settlements along the Scheldt. Today's City was mainly developed in the Middle Ages when the town received its city rights. The city's growth was boosted in the 16th century during a Golden Age when the city grew from around 18.000 inhabitants in the 14th century to 100.000 inhabitants in 1560.

Nowadays, the city has 530.000 inhabitants, with a density of about 2600 persons/km^2, and in the metropolitan area live about 1.2 million people. Antwerp is the second biggest city in Belgium, and it is, with its port, a major economic hub for Belgium and provides many jobs, which does result in high volumes of traffic in and around the city. (Statbel.be, sd)

The city has built a ring road to diverge the traffic from the centre to outside the city. The current ring road around Antwerp is clockwise from North to West of the city. This ring consists of 3 lanes in each direction, a tunnel (Kennedy tunnel) going under the Scheldt, five major highway junctions, and eight connections to the city. These connections on the narrow 3-lane road result in 140.000 daily drivers over the ring. The ring has only three lanes and is often congested, especially during rush hours. (Statbel.be, sd)

Figure 1 - Ring Road of Antwerp (Photonews, sd)

The Belgian state Vlaanderen is working on its 'Toekomstverbond', which are the future development plans of the state. Part of this development is the 'Oosterweelverbinding' (Oosterweel Connection), consisting of 4 different focus areas. See Figure 2.

The goal of the Oosterweel connection is to complete the ring road of Antwerp, which is currently not connected from the western part to the northern part of the ring. This connection will be crucial to the new development plans as it will increase the connectivity between the Western part of Antwerp and the Northern part of Antwerp.

The ring of Antwerp is notoriously known for its bad traffic on the difficult and cramped ring road. The new Oosterweel connection will help alleviate the traffic and improve the flow as there will be two options to drive around Antwerp, providing options depending on their destiny.

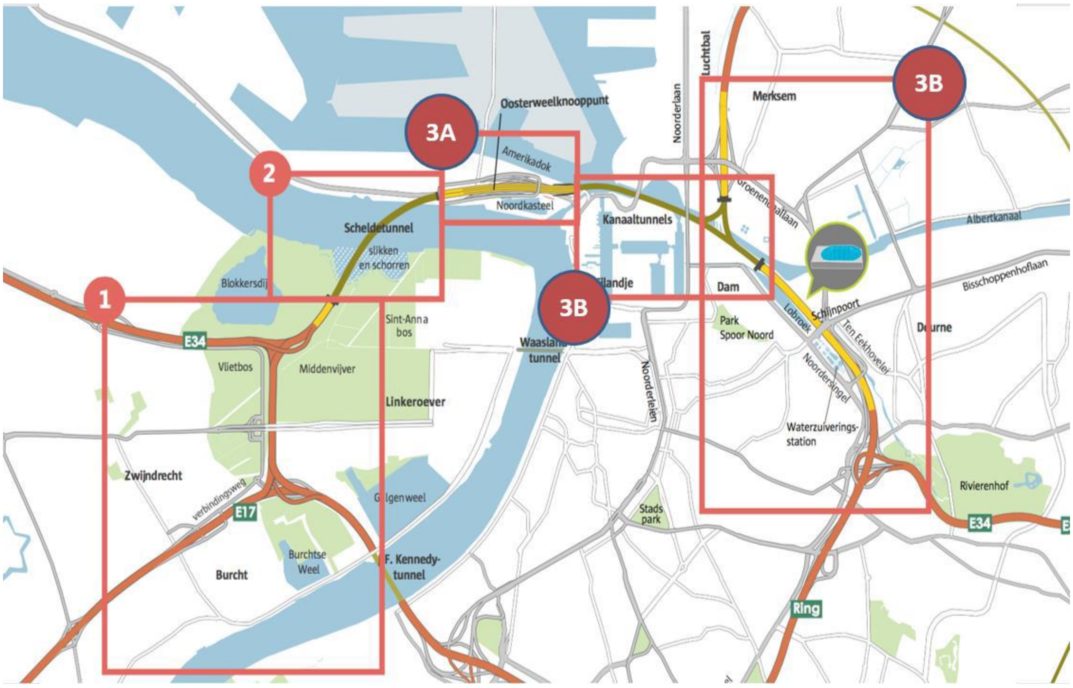


Figure 2 - Oosterweelverbinding project map

1.2 Context of thesis: Arch Bridge over Albert Channel

The new ring section's design will primarily consist of tunnels and lowered road sections. The new road will be constructed as close as possible to the current location of the present road infrastructure, or at some places, it will be built under the existing road(s).

Consequently, the current roads have to be partially/wholly removed during the construction, which will harm the connectivity of this part of the ring road. A temporary diversion will be constructed to compensate for this impact so the traffic flow can continue without creating additional significant congestion. This is important as the redesign of the road sections will take place over the span of 10 years.

The temporary road will be a 3-lane one-way road that can be used in either direction when construction takes place on that side of the road. This diversion will consist of several structures, among which in order: a viaduct over the Groenendaallaan, a viaduct with an on and off-ramp at the location of the Werminval, a tied arch bridge over the Albert Channel, a viaduct along the Lobroekdok (Lobroek dock) and a viaduct along the Sportpaleis (Sports-Palace) towards Schijnpoort.

Hillebrand is tendering to construct the tied arch bridge over the Albert Channel. As the bridge is temporary, it must be simple to transport and build. This temporary bridge will be 150 meters long and only exist for about ten years.

The overall design and planning of this bridge have roughly been calculated in order to be able to tender for this project properly. However, little research has been done on how the bridge will be transported, assembled, and installed. This research will look at the transport possibilities to get the bridge from the construction facility near Flushing to the final destination over the Albert channel in Antwerp.

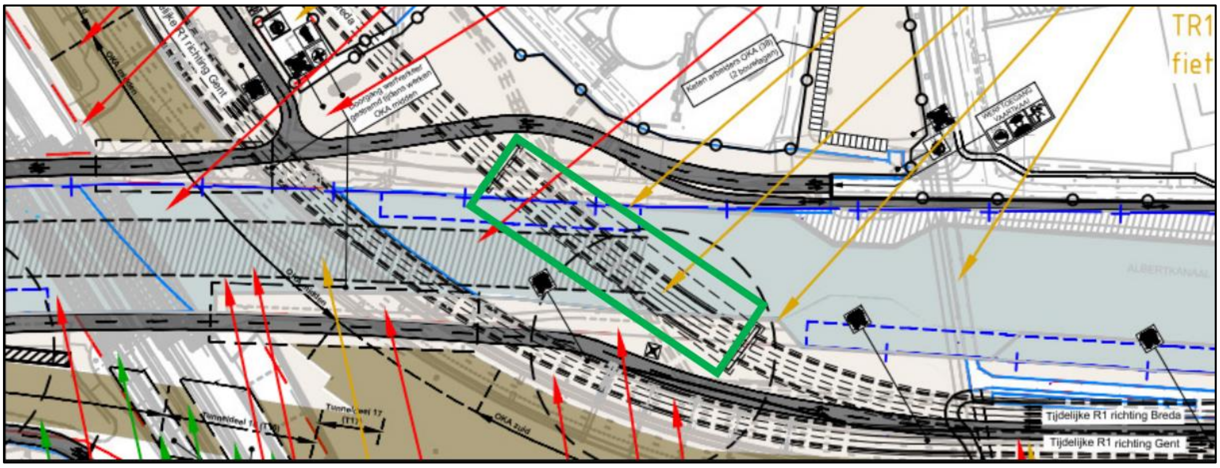


Figure 3 - Location of the Bridge

The transportation of the bridge will be challenging due to its size; it is 150 meters long, 23,36 meters high, and 24,7 meters wide. ASK Romein Hillebrand would be able to build this bridge in a complete state and transport the bridge in one piece to the installation site. However, due to transport limitations, this is not possible.

The bridge must pass through multiple locks, movable and permanent bridges. The permanent bridges will most likely be a problem as these bridges will not have a height clearance of 26+ meters when considering the bridge's height on top of a transport barge. Because of the height limit, the bridge arch has to be transported separately from the bridge deck to pass under the bridges.

This thesis will look into the transportation options to get the bridge from Flushing to Antwerp and how to transport these options. After which, the installation method will be worked out. For the installation method will be looked at the assembly order, required supports, strengthening measures and additional measures to aid the assembly of the bridge, after which it can be installed over the Albert Channel.

1.3 Problem Statement

As the bridge is most likely unable to be transported as one structure, it is the first step to determine the most optimal option for transport. This division will have the most influence on the assembly phase of the project.

The second part of the assignment is to look into the assembly method and determine which additional supports, strengthening and stability measures, and additional hardware/equipment are required.

1.4 Goal

This research aims to compare different transportation methods and select the best method based on several criteria. The most important criteria are feasibility and costs. This is because ASK Romein Hillebrand has to place a competitive bid to win the project and still make a profit.

A requirement from the client is that the bridge should be constructed and assembled in a stress-free state; this means that no internal stress may remain from the construction of the bridge. The stress-free state will be accomplished by placing temporary supports for the different bridge sections. The location and amount of support will depend on the method of transport and what is required to achieve a stress-free state. Based on the desired method, calculations and models determine the number of supports needed and what loads these will carry. Where the bridge deck is supported, loads will be locally introduced. These loads must be checked by calculation to determine if the bridge deck is strong enough to resist them and if strengthening measures are required.

The end result of this assignment will be an option consideration where the most optimal transport method is chosen. An installation plan is worked out based on the optimal transport method, which complies with the stress-free requirement. The total result will be a complete transport and installation analysis, which indicates the required measures or focus points for placing the bridge over the Albert Channel.

1.5 Research Questions

Based on the goal of this research are research questions set. These research questions will be a guiding line through the research process to achieve the desired results. The research questions are divided into the main research question which will cover the research goal, along with several sub-research questions to mark a research path. Each sub-research question will be related to the primary research goal and will assist in reaching an educated answer to the main research question.

1.5.1 Main Research Question

What is the best and most efficient way to transport, assemble and install the bridge on location, and what strengthening measures are required to make this possible?

1.5.2 Sub Research Questions

1. How and where will the bridge be constructed, transported, and built?
2. What are the interests of the stakeholders regarding transport and building?
3. What are the boundary conditions and requirements for transport?
4. What is the baseline variant for divisions for transport?
5. What alternative possibilities are there?
6. What is the preferred option for transport?
7. What appliances and measures are required to make the installation possible?
    a. How many (extra) supports are required per section?
    b. In what locations are supports required?
    c. Which strengthening measures are needed for the construction?
    d. What measures can be implemented to improve/ensure stability during build phases, and how can this be verified?
    e. What is required to install the bridge ‘stress-free’?

2 Theoretical Framework

2.1 Current Situation

If you want to go from West to North of Antwerp, the only (toll-free) option is to drive through the city or follow the ring around the city. The other option is taking the toll road R2, which goes through the port of Antwerp. Depending on the departure location and the destination, this will not be a viable/logical option. This is why a lot of traffic goes through the city or takes the ring.

Antwerp has implemented a Low Emission Zone (LEZ) policy to improve the city's air quality. This LEZ prevents vehicles from entering the city, emitting considerable amounts of CO^2, smoke, and particulate matter. Vehicles and their drivers that are not allowed in the city have to either pay for a permit, use public transport to get into the city via a P&R or drive around the city via the ring.

The ring should be the fastest way for people to drive around the city to get from or to work and for cargo traffic to spread cargo from the port of Antwerp all over the city and other places in Belgium. The ring is currently the border between the LEZ, not to exclude vehicles from the ring. This makes the ring the only option for vehicles that are not allowed in the LEZ to drive around the city. Because of the high density of people living in Antwerp and the large number of people living in Antwerp, the ring is often clogged by commuters during rush hours and busy during the rest of the day.

Figure 4 - Low Emission Zone (LEZ) in Antwerp (Stad Antwerpen, sd)

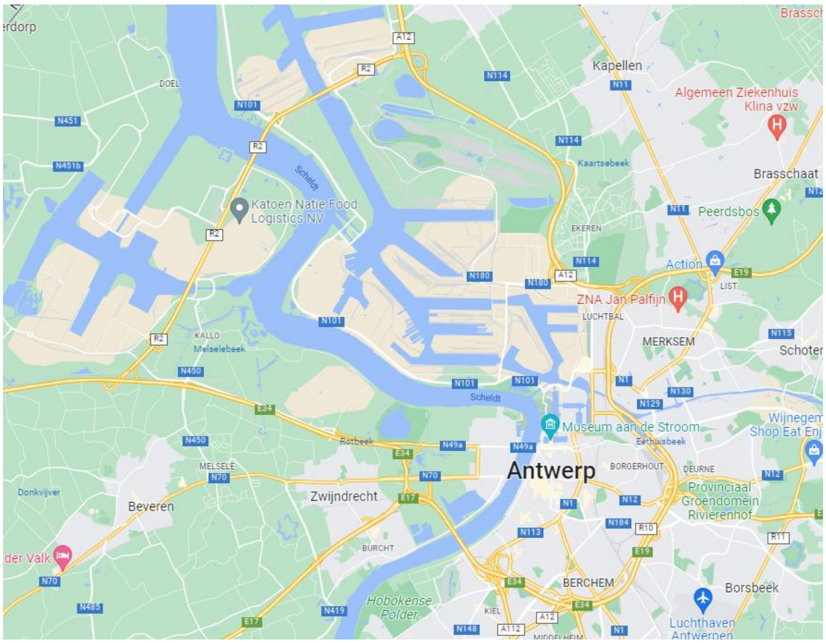


Figure 5 - Overview of highway network North-West of Antwerp (google.com/maps, 2022) [Highways are in yellow]

Figure 5 shows the highway network around the city and ports. The R2 splits off from the E34 and connects to the A12, which goes to the Netherlands. Figure 6 shows the current route around the city via the ring road. This route is the current way to get around the city and is notoriously known for its congestion.


Figure 6 - Current ring road around Antwerp (google.com/maps, 2022) [Highways are in yellow, Ring Road highlighted in red]

When the Oosterweel connection is finished, a lot of traffic should be able to drive over the connection avoiding the congestion on the other parts of the ring. This would relieve stress on the different parts of the ring road, leading to temporary reductions in travel time for commuters over the ring road.

2.2 How and where will the bridge be constructed, transported, and built?

The bridge will first be constructed at the construction facility of ASK Romein Hillebrand in the Sloe area in Flushing East. The Sloe area is an industrial harbour connected to the Western Scheldt. The construction facility was previously a shipyard which is now being converted to a construction facility. The location is ideal for constructing large steel constructions because of the quay access. This makes it possible to transport large and heavy structures over the water.

Figure 7 - Satellite image of ASK Romein Hillebrand facility (Google Maps)

The main fabrication hall of the facility is highlighted with a red rectangle. It was previously a construction hall for ships. The building was made to launch the ships out of the building. This can be used as an advantage to transport large constructions out of the building. Transport via the water is generally the easiest way to move large structures. A significant advantage of this project is that the bridge can be transported via water to its final location.

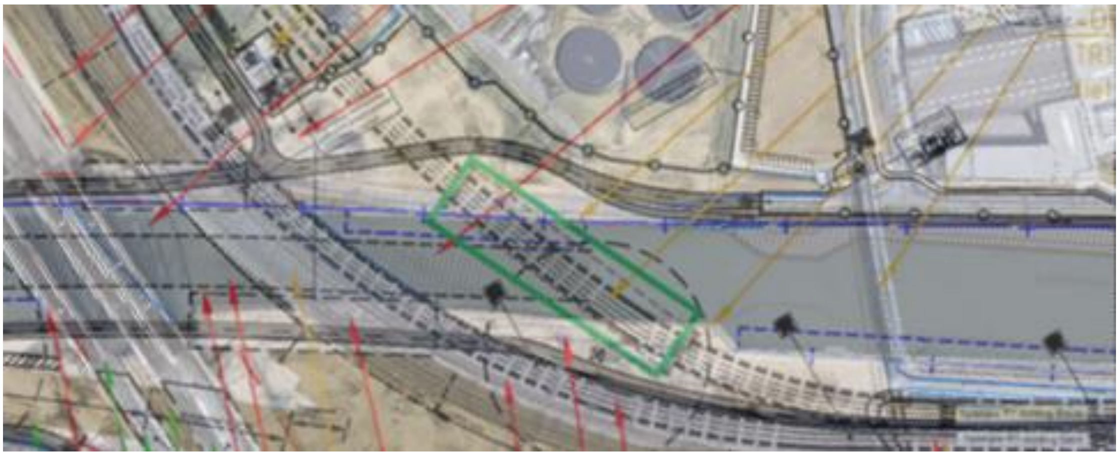


Figure 8 - Location of the Bridge overlayed on a Satellite image

The transportation of the bridge will most likely have to happen in different sections as it is a very large structure. If this is the case, it should be considered that there is a need for an assembly site near the final location to build the bridge. This will be hard to find as it is in the city and there is not much space. Luckily the client ROCO will provide an assembly site which they will prepare for construction.

When the assembly site is known, it is essential to create a construction plan. This is a crucial step as it will affect, among others, the transportation order. The construction plan and the method of transport affect each other as the way of transportation determines how much and what size the parts are that have to be installed on-site.

2.3 Stakeholders

This project's stakeholders influence the location, design, and impact of construction from the new Oosterweel connection.

Among these stakeholders are:

- ASK Romein Hillebrand
- THV ROCO
- The Belgian government
- The Flemish state government
- Road authorities
- The municipality of Antwerp
- Authorities Port of Antwerp
- Local inhabitants
- Local businesses

2.3.1 What are the interests of the stakeholders regarding transport and building?

Each stakeholder has different interests in this project. These interests are briefly described below:

ASK Romein Hillebrand

The interest of ASK Romein Hillebrand is to deliver an excellent product to put itself on the map. The bridge will be one of the largest structures constructed by Hillebrand at the moment of writing, and it desires to have more projects on this scale. Therefore, it is in Hillebrand's interest to deliver good quality, on time and within budget.

THV ROCO

As the client is THV ROCO most interested in a cheap and elegant solution regarding the placement of the bridge without much disturbance to the surroundings, THV ROCO will be the responsible party reporting to the authorities.

Port Authorities

Because the bridge will be transported through and installed in/near the port area of Antwerp, is it in their interest to see the bridge installed as fast as possible to minimize the disturbance to the daily coming and going of cargo vessels.

Road Authorities

In the Road Authorities' interest, the transport and installation of the bridge are not disturbing the traffic flow on the already congested ring of Antwerp.

Municipality of Antwerp

The municipality of Antwerp has the same interests as the Road and Port Authorities to minimize the operation's impact on the economy of the city of Antwerp by hindering traffic.

State Government

The state government's interest as a primary investor is to complete the project before the deadline and within budget.

Belgian Government

The Belgian government's interest as a primary investor is to complete the project before the deadline and within budget.

Local Inhabitants/Business Owners

The local inhabitants and business owners' main interest is to have as little disturbance by the bridge as possible. Disturbances would include noise from constructions, roadblocks, etc. These interests are high, but their influence is low; therefore, it should be considered but not assumed as an obligation.

More detailed research is required to verify and select the interests of importance, which will be definitive in choosing the right option. These interests can be used for multi-criteria analysis; more on this in chapter 2.7.

2.4 What are the boundary conditions and requirements for transport?

The bridge will be transported over the water due to its size and the easily accessible route via the western Scheldt, through the port of Antwerp to the 'Albert Channel' over which the bridge will be built.

On the route over the Western Scheldt, there are no limitations to size as much larger vessels use the waterway daily. The water on the Western Scheldt can be rough, with waves of about 1 to 2 meters. Luckily those weather conditions are not common, and the water conditions will get more favourable the further land inwards. In addition, the transports must comply with the Western Scheldt Shipping Regulations for the entire trip over the Western Scheldt.

The main limitations of the route will be the last part of the route in the Port of Antwerp. The bridge will be built over the Albert Channel, which is connected to the Port of Antwerp. The Port of Antwerp has locks protecting the port area from the tidal influence, as the difference in high- and low water levels in Antwerp can be up to 5.2 meters. (Francken, Wartel, Parker, & Teverniers, 2004) Over the port area and channel are multiple movable and permanent bridges. These bridges form a height and width limit to what can pass through to reach the final construction site. Mainly the height will be limited as it will be unlikely that all permanent bridges will be over 26 meters high in a city area like Antwerp.

From the Scheldt through the port of Antwerp are three possible routes available to get to the installation site:

Figure 9 - First and Shortest route through the port of Antwerp (google.com/maps, 2022)

Table 1 - Size limitations First Possible Transportation Route

Bridge/Dock/Lock	**Name**	**Passage size [m]**				**Movable Bridge**
		Height	**Width**	**Depth**	**Length**	
Bridge	Straatsburgbrug	9.1	58.65	-	-	No
Bridge	Noorderlaanbrug	9.1	63	-	-	No
Bridge	Viaduct van Merksem	9.1	50	-	-	No
Lock	Royerssluis	-	22	6.41	180	N.A.
Limiting length 180 m		**Limiting Width 22 m**			**Limiting Height 9.1 m**	

Note: Further research pointed out that the Royerssluis is out of service until 2026, so this route cannot be used to transport the bridge. (Maritiem Courant, 2021)

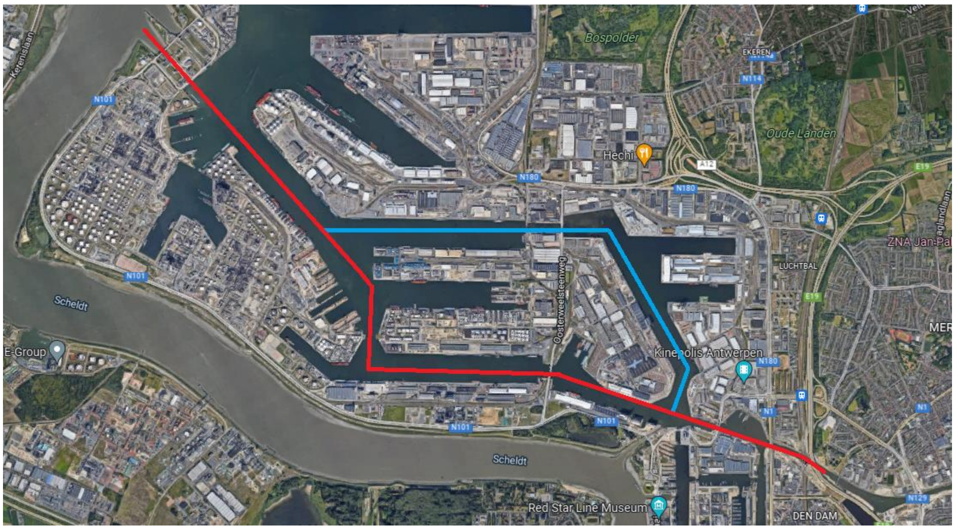


Figure 10 - Second Possible Route Through Port of Antwerp (google.com/maps, 2022)

Table 2 - Size limitations Second Possible Transportation Route [RED Route]

Bridge/Dock/Lock	Name	Passage size [m]				Movable Bridge
		Height	Width	Depth	Length	
Bridge	Straatsburgbrug	9.1	58.65	-	-	No
Bridge	Noorderlaanbrug	9.1	63	-	-	No
Bridge	Viaduct van Merksem	9.1	50	-	-	No
Bridge	Noordkasteelbrug	6.5	56	8.3	-	**Yes**
Lock	Van Cauwelaertsluis	2	35	9.83	270	**Yes**
Limiting length 270 m		**Limiting Width 35 m**			**Limiting Height 9.1 m**	

Table 3 - Size Limitations Second Possible Transportation Route [Blue Route]

Bridge/Dock/Lock	Name	Passage size [m]				Movable Bridge
		Height	Width	Depth	Length	
Bridge	Straatsburgbrug	9.1	58.65	-	-	No
Bridge	Noorderlaanbrug	9.1	63	-	-	No
Bridge	Viaduct van Merksem	9.1	50	-	-	No
Bridge	Oosterweel Brug (2x)	4.8	35	-	-	**Yes**
Lock	Van Cauwelaertsluis	2	35	9.83	270	**Yes**
Limiting length 270 m		**Limiting Width 35 m**			**Limiting Height 9.1 m**	

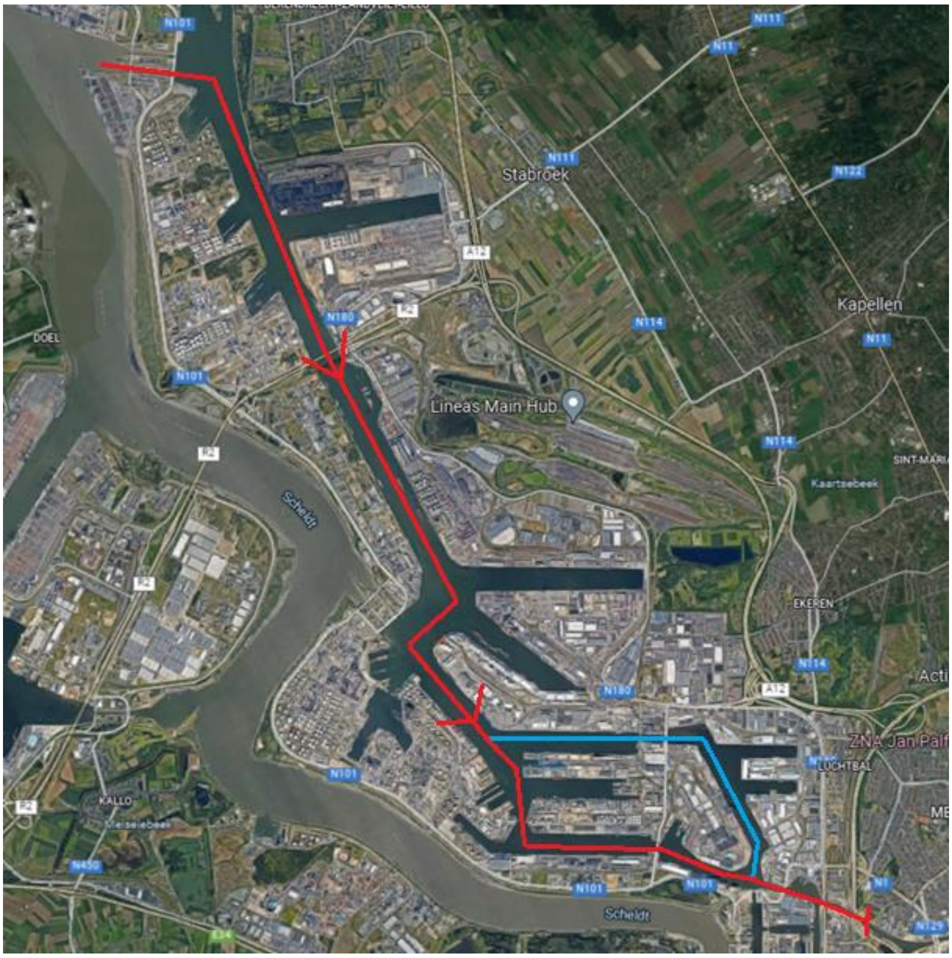


Figure 11 - Third Possible Route Through Port of Antwerp (google.com/maps, 2022)

Table 4 - Size Limitations Third Possible Transport Route

Bridge/Dock/Lock	Name	Passage size [m]				Movable Bridge
		Height	Width	Depth	Length	
Bridge	Straatsburgbrug	9.1	58.65	-	-	No
Bridge	Noorderlaanbrug	9.1	63	-	-	No
Bridge	Viaduct van Merksem	9.1	50	-	-	No
Bridge	Noordkasteelbrug*	4.8	35	-	-	**Yes**
Bridge	Lillobrug	9	80	-	-	**Yes**
Lock	Berendrechtsluis	-	68	13.58	500	**Yes**
Lock	Zandvlietsluis	2	57	13.58	500	**Yes**
Limiting length 500 m		**Limiting Width 35 m**			**Limiting Height 9.1 m**	

*The alternative to the Noordkasteelbrug is the Oosterweel bridge on the blue route. For limitations, see Table 3.

The Albert Channel has a guaranteed depth of 3,4 meters. (Puri, 2015) This should be sufficient as the expected draft of the barges is ±3 meters. (According to a transport proposal from Sarens, see chapter 4.2)

The tables show that the only re-occurring limitation for this transport will be the height. This is due to several movable and permanent bridges; the height limit will be taken from the permanent bridges as the movable bridges will be able to open up. Therefore, a limit is assumed of 9.1 meters.

Once arrived at the installation site, THV ROCO facilitates a local temporary construction yard to place the bridge deck so the arch can be mounted. THV ROCO prepares this location to accommodate the massive loads from the bridge.

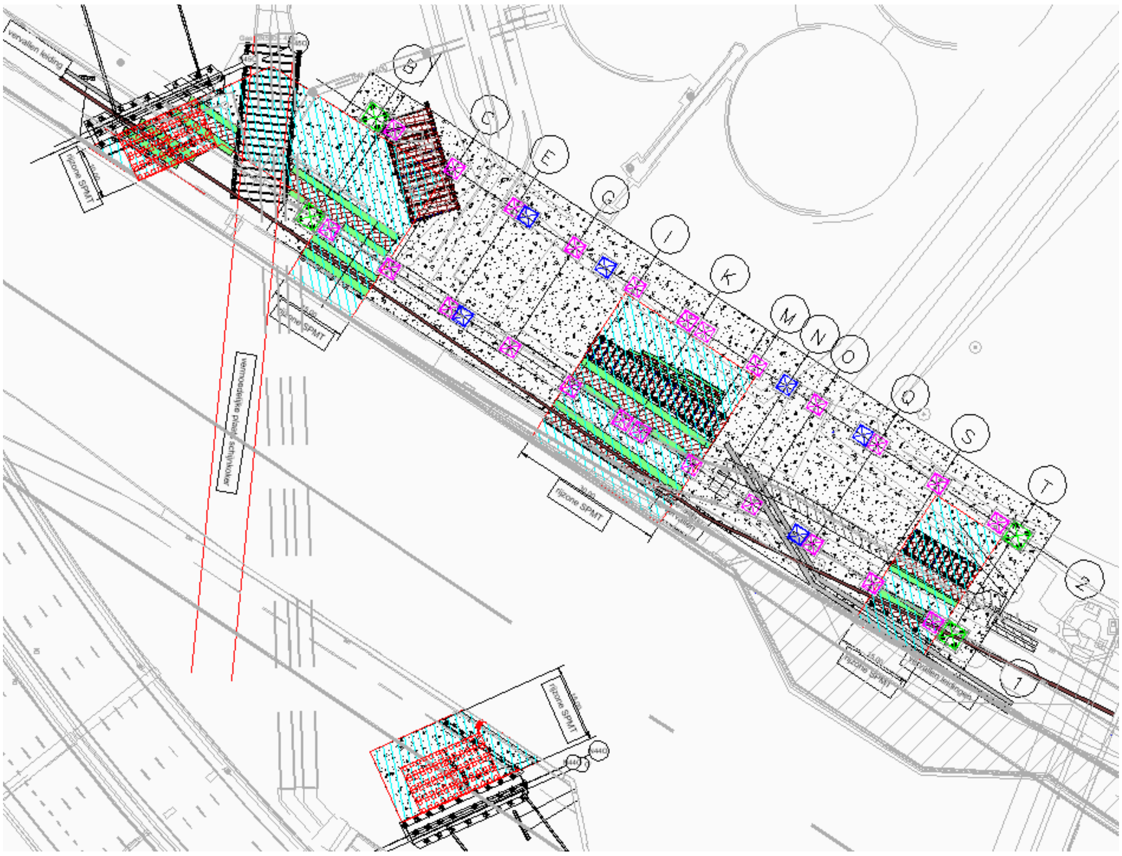


Figure 12 - On-site yard to assemble the bridge

After the completion of the bridge, one end of the bridge will be moved onto a pontoon which will bring that end to the other side of the channel, after which the bridge will be driven to its final position.

Sources of Size limitations in Table 1, Table 2, Table 3 and Table 4.

- Straatsburgbrug (wiki/Straatsburgbrug, 2021)
- Noorderlaanbrug (wiki/Noorderlaanbrug, 2021)
- Viaduct van Merksem (vrisawf.alsic.be/Albertkanaal, 2022)
- Lillobrug (wiki/Lillobrug, 2021)
- Berendrechtsluis (wiki/Berendrechtsluis, 2021)
- Zandvlietsluis (wiki/Zandvlietsluis, 2020)
- Oosterweel Brug (2x) (wiki/Oosterweelbrug, 2021)
- Van Cauwelaertsluis (wiki/Van_Cauwelaertsluis, 2020)
- Noordkasteelbrug (wiki/Noordkasteelbrug, 2021)
- Royerssluis (wiki/Royerssluis, 2022)

2.5 What is the baseline variant for divisions for transport?

In chapter 2.4 are two possible routes described to transport the bridge. These routes have a height limitation, meaning the bridge cannot be transported in one piece from its construction facility to the final location. As a result, will the bridge be built in sections, and will it be assembled on-site. This bridge division will allow it to pass under the permanent bridges over the Albert Channel.

ASK Romein Hillebrand has an idea on how they want to divide and transport the bridge. This idea will be further referred to as the Baseline idea. The idea is to divide the bridge deck into two sections and each arch into three sections. The bridge deck will be welded on-site, after which the arches will be placed on temporary support towers to weld them together. When this is finished, the crossbeams will be placed, after which the bridge will be completed.

The division of the bridge results in the following sections to be transported from Flushing to Antwerp by barge:

Table 5 - Sections and Sizes of Baseline Variant for transport

Section		Size [m]*		
Amount	Name	Length	Width	Height
2	Bridge deck sections	75	24.7	2.20
4	Arch sections (Side)	50	1.5	3.25
2	Arch sections (middle)	56	1.5	4.25
3	Crossbeams	21.7	1.6	1.76
32	Hangers**	22	0.5***	

* The sizes are indicational
** The largest hanger size is mentioned; length and diameter vary per hanger.
*** The hangers have a tubular shape; therefore, when laid down, the diameter will be both the width and height in transport.

The bridge deck will be divided into axis K as this is the middle of the bridge. This will need to be welded back together on-site. The arch will be divided at 2 points, the first just before axis G, and the second just after axis O. These locations are chosen as scaffolding is already required in these locations to weld the crossbeams in place. This would make it possible to weld both connections with the same scaffolding structure. The same applies to the temporary support structure placed underneath the arch until completion. This support can also support the crossbeam while it is being welded in place.

In an attempt to simplify and shorten the welding volume on-site, it is chosen to keep a certain length of the arch's base on the bridge deck itself. This would simplify the on-site construction to install the arch sections stress-free.

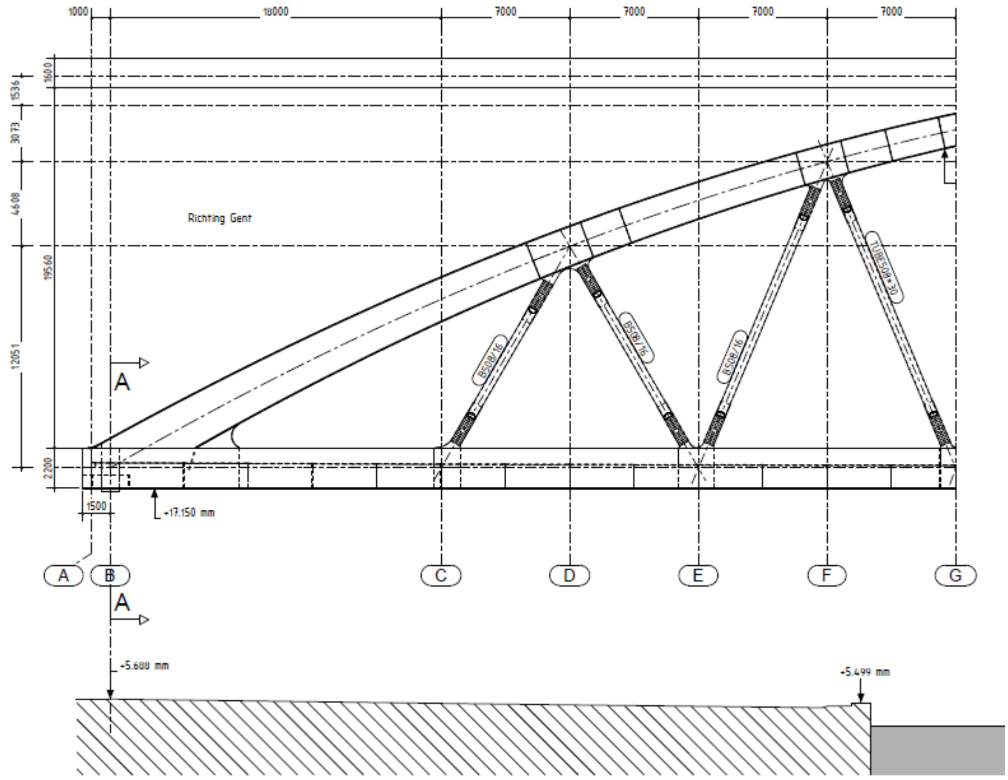


Figure 13 - Bridge Axis A to G (South end of the bridge)

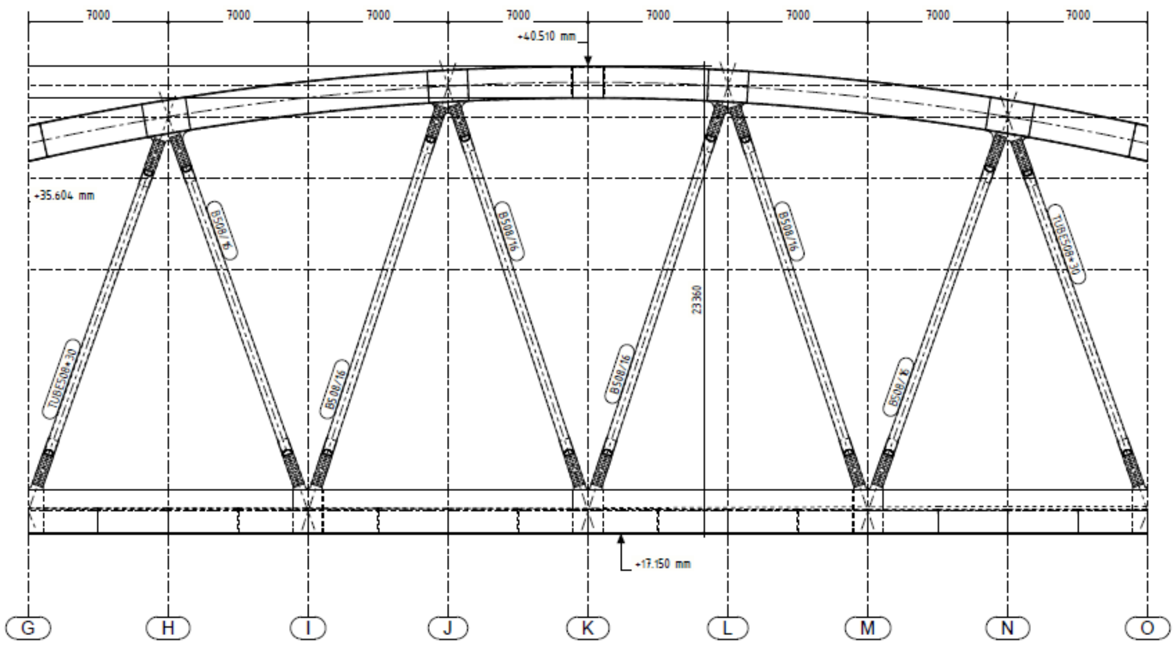


Figure 14 - Bridge Axis G to O (Middle part of the bridge)

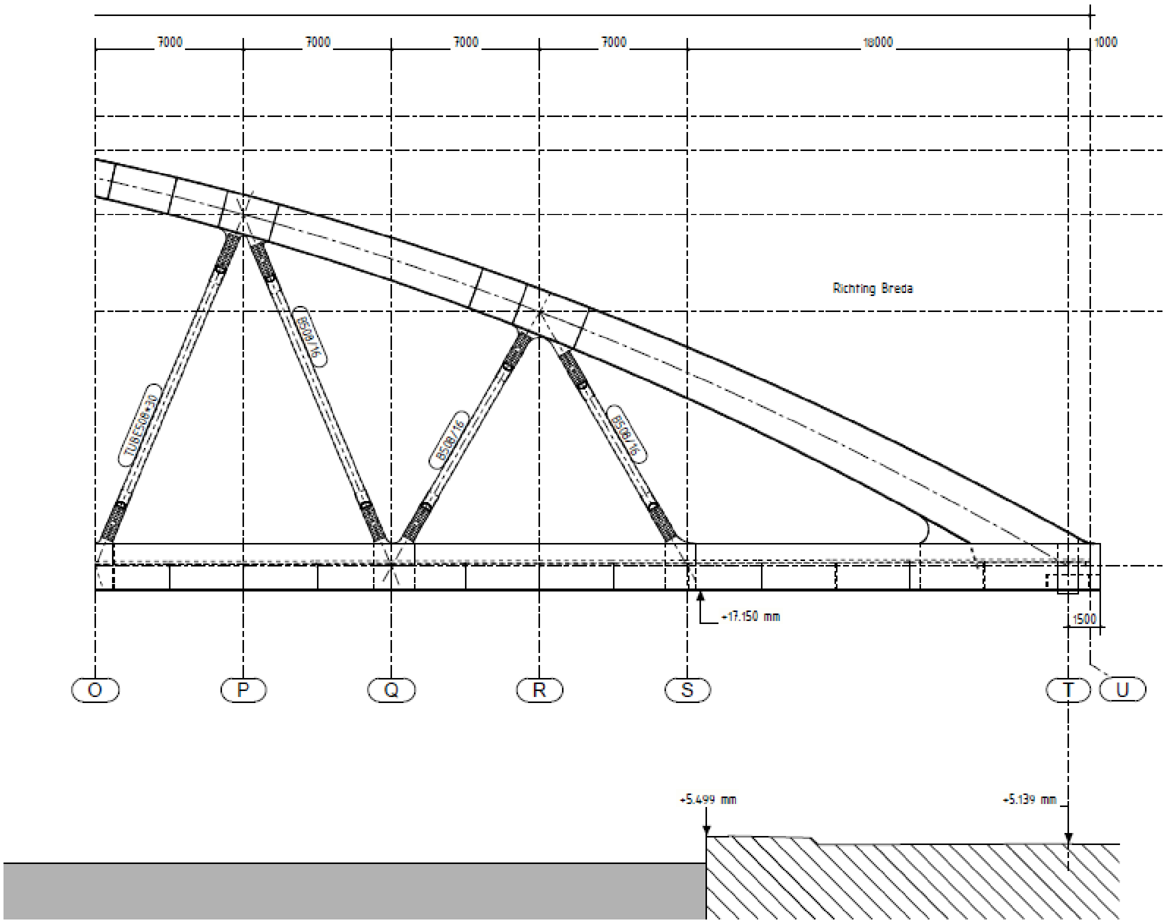


Figure 15 - Bridge Axis O to U (Northern end of the bridge)

2.6 What alternative possibilities are there for transport?

The initial/baseline idea for transport is just one of the multiple options. Because it is a baseline idea, it would be wise to look at alternative options. Below are several alternative options mentioned. From these options will the best variant be chosen using a multi-Criteria Analysis following the criteria mentioned in chapter 2.7.

The options mentioned below are divided into 1) the bridge deck (including the base of the arches) and 2) the arches. The hangers and crossbeams are always expected to be mounted separately on-site. The baseline variants are mentioned per topic again below as option one and indicated with '[B]'.

All options mentioned below are un-verified and broadly described. Via an MCA will the best option be chosen. Additional research will have to be conducted on the final option and work the option out in detail.

Only one additional deck option is added because a baseline option is already an option where the bridge will be transported in two sections. Dividing the bridge up into more sections would only add complications and costs. In addition, are no other materials considered an optimisation for the bridge. Other materials could be a concrete-steel deck. However, this would add a lot of additional mass, which would require a stronger bridge construction. This would be undesirable as it would cost a lot more

2.6.1 Deck Option 1: Two bridge deck sections [B]

The first option is to split the bridge into two deck sections. The transport is doubled but smaller than when the bridge deck is transported in one piece.

It is currently difficult for ASK Romein Hillebrand to construct the bridge in one piece in their construction hall as it cannot be transported out of the construction hall yet, due to a ramp in front of the large construction hall limiting the accessibility for barges. As a result, the bridge deck is built in two sections which can be transported out of the construction hall and be temporarily stored outside in Flushing, after which they will be loaded onto barges.

The sections will be transported to Antwerp as one piece, and on location, the sections will be aligned and placed on support towers. Once the sections are aligned within the margin, they can be welded together to make one large deck. After that, the joint will be painted with the corrosion protection system of the rest of the bridge.

2.6.2 Deck Option 2: One bridge deck

The second option is to construct the bridge deck in two pieces due to the same problem as option 1, but then weld the bridge deck together outside in Flushing. This would be possible as the completed bridge deck can be loaded onto the barges from the outside storage/construction site in Flushing.

However, this option does require that the bridge deck has to be set on supports twice (once in Flushing and once in Antwerp) to apply to the stress-free installation requirement. This will include extra costs; however, it can be considered beneficial to align the sections in Flushing where ASK Romein Hillebrand has all their equipment and tools ready if any problems occur during the alignment. Then it is also possible to perform the steel conservation of the joint between both pieces in Flushing.

This approach reduces the risk of delays from aligning the bridge deck in Antwerp, which simplifies the transport phase, from the original alignment on-site to 'just' placing the bridge deck on its supports. By doing this, the on-site job will be reduced to a one-day task, according to the assigned construction manager of this project.

Having the bridge transported in one section will have additional benefits as other components and sections can be transported on top of the bridge deck so they can spread the load more evenly compared to the situation when the bridge deck is split into two sections. This also has some benefits for the unloading and installation of the arch sections on top of the deck because the middle sections can be placed in the middle of the bridge, which has as a result that the cranes can be placed very close to the final location.

2.6.3 Arch Option 1: Deliver the Arch in pieces [B]

Because of the height limit, ASK Romein Hillebrand created a plan to divide the arches in order to be able to transport them under the permanent bridges over the Albert Channel. Option 1, the baseline idea of ASK Romein Hillebrand is to divide each arch into three sections. The six arch sections and three crossbeams are positioned on-site and welded together to form the complete arch.

The advantages of this approach are that the sections are relatively small and easy to handle. The side arches will weigh about 125 Tons, and the middle sections about 130 Tons. The lighter sections will be easier to lift and align by crane.

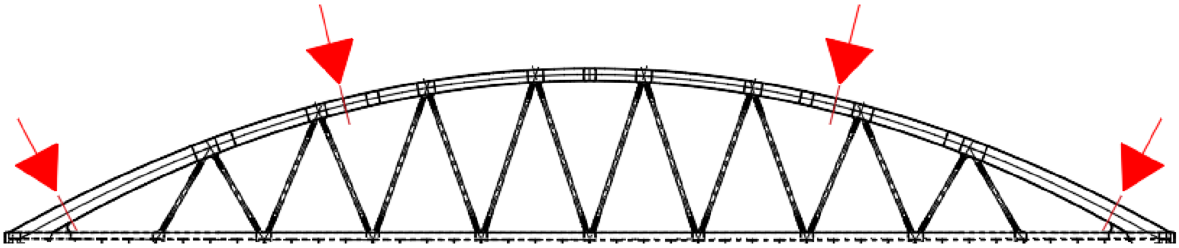


Figure 16 - Arch Option 1 [B] - Separation lines indicated in red with arrows

2.6.4 Arch Option 2: Deliver the Arch flat on its side.

An advantage of the arches design is that the width of the arch is constant (1,5 meters); this makes it possible to lay down the arches on their side and transport the entire arch construction laid flat on the barge. This would make it possible to lay down all sections (including the hangers) on one barge and transport it to Antwerp, easily avoiding a height limit.

For this approach, the strength of the arch has to be checked for the resistance against the rotation, as this would introduce different internal loads and stresses than what it is designed to withstand. Also, a detailed lift plan should be put together, requiring a somewhat complex lift and rotation sequence. The disadvantages of this method are that the construction will most likely have to be strengthened in order to be rotated, and large cranes are required to lift and rotate the near 400 Ton arch.

2.6.5 Arch Option 3: Divide the Arch into two

As a measure to minimise the on-site welding, the complete arch structure could be split in two. If the arch were split between axis K and L, the arch could be laid down. This would increase the length but reduces the height significantly. (See Figure 17)

The arch will be welded together, except for the one connection in the middle. A disadvantage is that the structure will be heavy to lift (Around 200 Tons), and thus a large crane would be needed on-site to lift the structure on supporting towers.

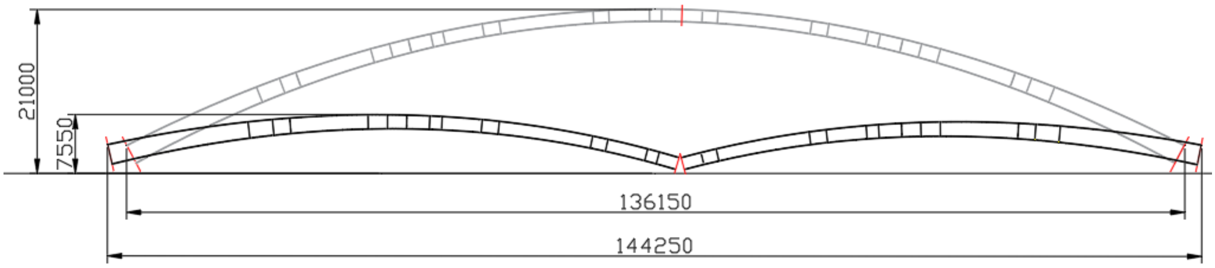


Figure 17 - Height comparison Option 2

2.6.6 Alternative Option for Construction: Bolting instead of welding

One of the disadvantages of on-site construction is that it is relatively expensive to bring people and equipment to the site. The longer an operation takes, the more expensive it gets, as equipment often needs to be rented.

This includes but is not limited to:

- General Facilities
- Heavy-duty outdoor tools
- Mobile Crane(s)
- Access platforms
- Scaffolding
- Tents (For welding and conservation)

In order to reduce the amount of work to be executed on-site, the option can be chosen to use a bolted connection for all section connections. This would simplify the on-site work and make it easier to conservate on-site.

Besides the ease of construction, would it also provide an easier way of dismounting the bridge as it would remove the need for grinding through the steel welds. This will reduce the cost of disposal significantly and the chance of contamination during deconstruction.

A downside of this method is that it will be difficult to use bolts and nuts because the arch is a square box profile. To overcome this, either one of three things need to change/be added.

1. An access hole/manhole near the bolted connection, this manhole could reduce the strength of the arch if not calculated well. A strengthening measure could be introduced to achieve the required strength. (Calculations/models are required to confirm)
2. The advantage of an H-shaped beam instead of a tubular section is that the bolts and nuts are accessible from the outside. The downside is that it slightly complicates the connections between the crossbeams. (Calculations/models are required to confirm) However, due to the fact that the arch is under compression, it is more susceptible to buckling compared to a square box profile.
3. Threads need to be cut into the plating itself because nuts are not possible to connect inside the box girder. This will add complexity to the arch's construction as it needs to be more accurate. (Calculations/models are required to confirm)

A disadvantage of bolting is that it requires tighter margins of the arch to line up the holes for the bolts to go through.

2.6.6.1 Conclusion

In general, doing as much welding as possible while working at the construction facility in Flushing is more efficient. This is because all the welding equipment is present, there are cranes in the workshop to lift the pieces, and no extra measures are required as the construction already takes place in an environment where welding is permitted.

When working on-site, it is more desired to have as many bolting connections as possible because it requires no additional supporting infrastructure. This includes power or fuel to weld and tents around the welding spot, which are required to obtain a specified high quality of weldings.

However, when replacing a welded connection with a bolted connection, additional checks must be performed. This is because by adding bolt holes, the structure is weakened. Additionally, a stricter tolerance has to be maintained to line up the bolt holes properly.

Considering the stricter margins, which cost more construction time to comply with and the extra materials needed (especially with the current steel prices), it is not recommended to look into bolted connections given the extra labour and costs involved.

2.7 Which transport variant is preferred based on the requirement and interests?

In chapters 2.5 and 2.6, five options are described for transporting the bridge (or part of the bridge). Based on the interest of stakeholders mentioned in chapter 2.3.1, a list of criteria can be created to summarize the needs and wishes of all stakeholders. Based on that list of criteria, a Multi-Criteria Analysis (MCA) can be created as a tool to find the best suiting option/method. In the MCA is, each option/method graded based on the criteria. Each criterion can have its rating on how important it is compared to other criteria.

Based on the need of the stakeholders are, the following criteria set:

- Transport costs
- Difficulty to lift
- Installation Time
- Installation Costs
- Installation Complexity
- Hindrance to traffic
- Hindrance to shipping

These criteria can be consolidated into the following final criteria for the MCA:

- Costs
    - The costs are a factor of time, costs, and type of equipment.
- Feasibility
    - Feasibility is combining the challenges in lifting and installation.
- Hindrance
    - Hindrance is combining the hindrance to traffic as well as to shipping.

2.8 SCIA Model in-put

To verify the different construction phases, an SCIA model is created. This model consists of a 3D model of the structure and all the loads acting on the structure. The output of the calculation software SCIA is the stability, the internal forces and the deflections of the structure. This model is based on the design drawings provided by ASK Romein Hillebrand (see Appendix.J). The design is simplified to fit within the limitations of SCIA. The model limitations include straight beams and profiles

Design Simplifications:

- Because SCIA is not capable of irregularly shaped profiles nor capable of creating arcs, the arch is divided into three different profiles and 16 sections. In this way is model represents the arch as close as possible to the real design while still manageable in the software.
- The bridge deck in the original design is sloped from left to right. However, no traffic load and climatic impact are considered in this model. Therefore, the bridge deck is simplified to a levelled surface.

Basic Data:

National Code:	- Eurocode EC – EN
National Annex:	- Belgian NBN-EN NA
Material:	- Steel
Steel Quality:	- S355
Unit set:	- Metric
Acceleration of gravity	- 9.810 m/s^2

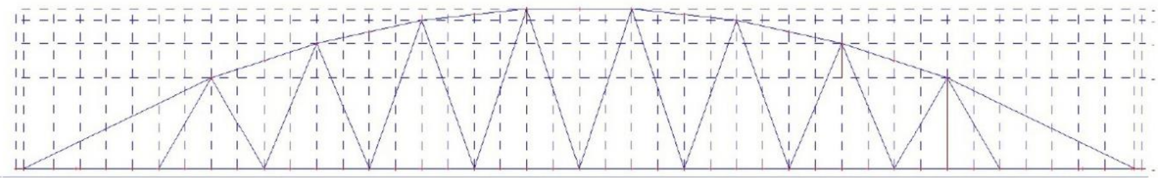


Figure 18 - Wire Frame Side View Bridge - SCIA Model

The SCIA model is used to model and calculate all different installation phases to verify loads, deflections, and stresses. For this model, the self-weight and wind loads are considered. These loads are further explained in chapter 4.3.1 SCIA Model Load.

A more detailed description of the entire SCIA model with input data, profiles and the model can be found in Appendix.B.

3 Methodology

The chapter Methodology describes the research method and how the best options are chosen. The chapter covers what research is done, and the tools used to achieve a desirable result.

3.1 Project Activities

To start this project, a meeting with my supervisor took place. During this meeting, the details of the assignment were discussed. Onwards from this meeting, the main research question is set together with several sub-research questions to mark a clear starting point and path towards answering the main research question. During this meeting, I received the available data, which was primarily used to find an answer to the first four sub-research questions. The information that was already available information was provided and filtered.

It was important to find the answer to the first four sub-research questions as these questions covered the theoretical framework. The advantage of these sub-research questions is that most of the data could be found in the provided documents or be acquired by desk research. As a start, the data my supervisor provides is discussed, and Hillebrand's intentions are written down on how to approach this project and its challenges.

Continuing, there was data gathered about the construction facility, the assembly site, and the final position of the structure. Based on this data, transport routes were set up, which determined the transport limitations. The route itself is based on Google maps and nautical charts. The limitations were found by desk research to find the size limitations from each of the bridges and locks that the bridge has to pass. Based on the limitations, several transport variants are thought out, making it possible to transport the bridge to the final location.

Based on the needs of stakeholders, three criteria with each two sub-criteria were set to determine the best variant to transport and assemble the bridge. With the criteria, a multi-criteria analysis has been set up where each variant is graded to find the best suiting option to transport and build the bridge.

Now that the best options are known, several things have to be checked. These include transport height, temporary support structures and stability of building phases. The bridge is modelled in SCIA Engineer 21.1, providing detailed calculations and visualisations of the internal forces and deflections. The results are used to verify the different building phases. The model also indicates the deformations and forces of the different assembly phases.

Besides the SCIA models are several hand calculations done to verify if the chosen installation method is viable. These hand calculations are simplified to check the stability and resistance of the structure. Among these calculations are the buckling check and the wind load.

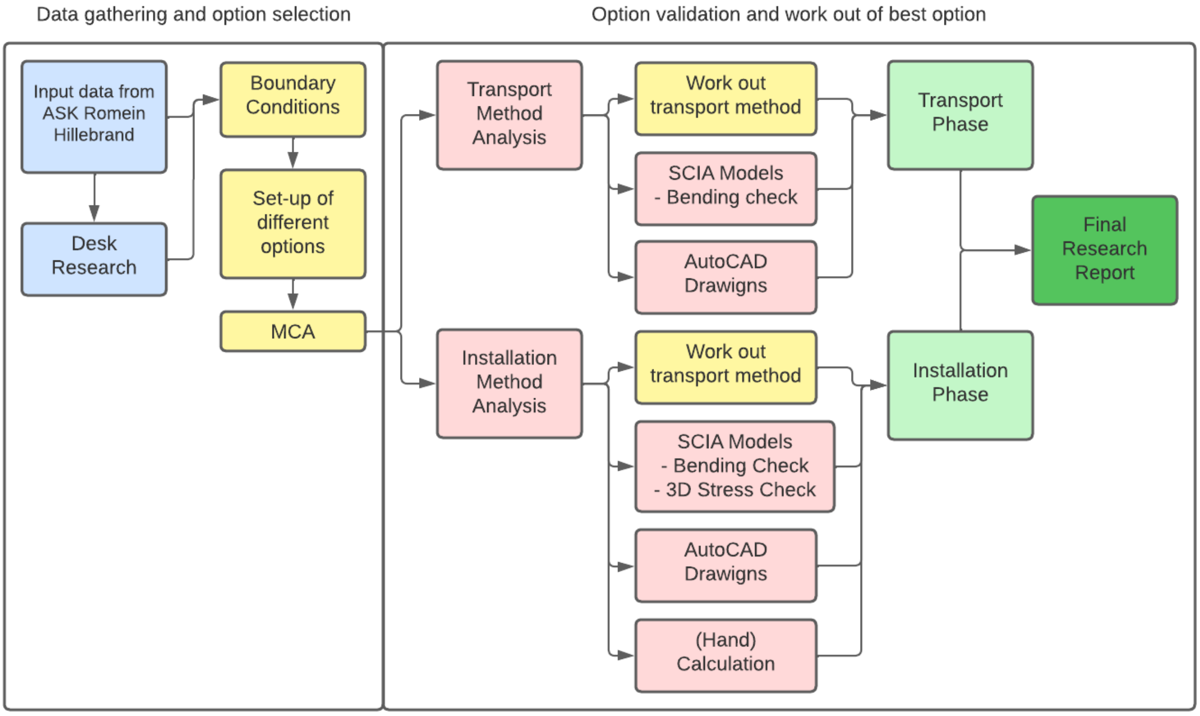


Figure 19 - Simplified flowchart of work process

Figure 19 shows the path and order of the activities. The blue boxes indicate the input of data. This is the first phase of the project where information is gathered. This data is used (in the yellow boxes) to set the boundary conditions based on which different options are created to consider. After the Multi-Criteria Analysis, the process is split between the topics of Transportation and Installation. These two topics are then worked out and (partially) validated to confirm the feasibility

3.2 Multi-Criteria Analysis

The Multi-Criteria Analysis (MCA) is used to determine the most optimal/best suiting approach to transport the bridge in which form of sections. The analysis is based on the criteria set in chapter 2.7. The MCA is split up into two topics, one is the bridge deck, and the second is the arches. Each topic is graded and compared according to the same criteria, and the MCA results of both topics determine the most optimal transportation method.

3.2.1 Criteria

Costs

The price on a tender bid is a crucial factor in the likeliness of winning the bidding competition. This is why it is crucial to have a proper estimation of the costs to have a competitive bid and win while making a profit from the project, as this is what keeps a company alive.

For this analysis, the costs are split up between the transportation costs and the assembly costs, as these are the two factors influenced by the option selection. The costs will not include the costs of building the bridge as this will not be affected by the different options in any meaningful way.

- **Transport costs**
  Oversized transportation is often an expensive part of a project, as it requires permits, expertise, and large equipment. ASK Romein Hillebrand regularly works with a Belgian company called Sarens which does a lot of transport and lifting assignments for ASK Romein Hillebrand. The transportation is outsourced to another company, as ASK Romein Hillebrand does not have the equipment.
  As a simplification, only the higher costs are included in this analysis.
  - Transport Barges
    > Large Barge (Or combination of smaller barges)
    > Small Barge
  - Self Propelled Modular Transporters (SPMT)
  - Tug
  - Crane
    > Large Crane (600T)
    > Medium Crane (350T)
    > Small Crane (200T)
- **Assembly Costs**
  Based on the principal idea of the transport costs are the assembly costs split out over multiple topics.
  - Support towers
    > Heavy Support Towers
    > Light Support Towers
  - (Crawler) Crane
    > Large Crane (850T)
    > Medium Crane (600T)
  - Welds to be executed on-site
    (Welds are measured on a cost per meter)

The costs are based on the equipment's day rate and estimation of how many days the equipment would be needed. The costs are a rough estimation to keep the calculation simplistic, as it is only be used in the option selection.

Feasibility
The feasibility covers the difficulty of lifting and installing the different sections. Especially for this criterion, it is important to make the difference as each requires an entirely different method of lifting and assembly. Furthermore, these criteria are split up to cover most of the process. The first part is about the difficulty of lifting, and the second is about the installation complexity.

- **Difficulty to lift**
  Bridge deck
  The bridge deck has to be transported by the use of SPMTs. These modular transporters are designed to move large and, most importantly, heavy equipment. The SPMTs can jack themselves up and down for a specific height. If it is required/desired to lift the deck higher, hydraulic jacks are the solution.
  Arches
  The arch section(s) have to be lifted in place by a (mobile) crane which has to be positioned next to the bridge deck. Another challenge to this topic surfaced later in the process when the client informed ASK Romein Hillebrand about where the bridge may be assembled. This location has only room for a crane on one side of the bridge. This means that the mass of the

sections to lift influences the difficulty to lift as it has to be lifted over the entire width of the bridge, which is elevated on support towers.

- **Installation Complexity**
  Bridge deck
  The installation complexity of the bridge deck is mostly relatable to transport limitations and whether the bridge deck has to be welded together or not. This is due to the need to align the bridge deck on-site to a specified accuracy in order to weld the bridge sections together.
  Arches
  The arch sections' installation complexity is mostly relatable to the size and mass, influencing the ease of positioning and aligning the sections. A larger section may mean fewer sections to place, but it increases the difficulty as the handleability of the sections decreases with the increase of mass.

Hindrance to surroundings
The hindrance mostly influences the surroundings to road traffic and shipping traffic as the assembly site is not located next to housing but rather a water treatment plant. Combining that with the fact that all options have little to no variation in Hindrance to the surroundings by construction noise or other.

- **Hindrance to traffic**
  As the bridge itself is transported over the water, it is the only variable factor for all options the equipment that must be transported by road. This includes tools, equipment, and the mobile crane. The assumption can be made that the crane transport will be the only influential factor in road traffic.
- **Hindrance to shipping**
  The bridge will be assembled next to the channel it will be placed over. This makes it easy to transport the bridge via the channel. However, when offloading the bridge (sections) onto land by SMPT, it will be desired to have no waves caused by shipping in the channel. This would result in a halt to shipping in the channel while sections are offloaded from the barges. The longer or more offloading cycle(s), the greater the Hindrance to shipping.

3.2.2 Scoring

A simple comparative grading system will do scoring of the criteria. This means that each sub-criteria will be compared to the other options. For the arch, this will result in a grading of 1-2-3 as there are three options, and the bridge deck grading will be 1-2.

Each criterium has two sub-criteria. The scores of each criterion are based on the scoring of the sub-criteria. The best option will receive the highest score, and the worst option will receive the lowest score. The only deviation is the scoring of the costs, which is based on what option is cheaper. To mark the importance of each main criterion, a weight factor determines how important the criterion is relative to the other criteria. All factors add up to 100%.

Feasibility	55%	-	Feasibility is the most important factor of this MCA as it will determine the project's flow. The feasibility will have a close relation to the costs.
Costs	30%	-	The costs are the second most important factor of this project. As mentioned before, ASK Romein Hillebrand is a private company which has to make a profit. Besides that, is it important to place a competitive bid to win the project's contract.
Hindrance	15%	-	The hindrance to shipping and traffic is the least important factor of this MCA, while it must be considered and ideally minimised. It is in the client's interest that the bridge will be built and, if possible, for a low price.

3.2.3 Sensitivity Analysis

Feasibility and Hindrance criteria are based on a comparison between the options and are thus less susceptible to influence from the outside. In the sensitivity analysis are the uncertainties discussed regarding the input of to the MCA. As only the cost input is based on defined values, the sensitivity analysis mainly focuses on the cost aspect of the MCA.

3.2.3.1 Cost Sensitivity

Due to the current aftereffects of the pandemic of covid-19 and the ongoing conflict between Russia and Ukraine, a lot of prices are very uncertain. Both events contribute to the steep inflation, increasing the prices of raw materials such as iron, oil, and gas. This influences the cost analysis of this project and the various options.

In the MCA, the costs are estimated and purely indicative. However, the effects of these events on the economy are considered. The day rates of equipment are susceptible to change. This is due to the increasing costs of fuel, labour, maintenance, and materials.

For the deck options, will this not influence the outcome of the result. This is because they both have the same expenses, only in different amounts. If the costs increase, the gap between the two options will increase, and if the costs decrease, the gap will be reduced. But one option will always be more expensive than the other.

It is more difficult to predict the outcome for the arch options. The fact that arch option 1 would not require separate transport gives it a major advantage. Due to that advantage, the outcome of which one is the best will not change. The size of equipment needed mainly differentiates the second and third places. It may be safe to assume that if the day rate rises for the medium crane, then the day rate rises too for the large crane in equal amounts or ratios. If this is the case, then the resulting order would not change.

Until the moment of writing this report, the biggest effect of covid-19 and the Russia-Ukraine Conflict is the effect on the steel prices. But this is not part of this investigation.

3.2.3.2 Feasibility and Hindrance Sensitivity

The feasibility and Hindrance criteria are mainly based on comparing the two and three options. This approach is chosen as the criteria cannot be graded with defined values. In this chosen approach, it is possible to list each option's positive and negative aspects. From these lists can be determined what option is better than the other(s).

The approach is taken for the feasibility and hindrance criteria to reduce the influences from outside sources. The fluctuations in the economy are affecting the costs. In addition, the weather could be considered an impactful outside factor. However, the installation window is more or less in the same time period for all options, and this could only be influenced by installation time, which may only differ a few days. For that reason, are weather conditions also not considered as they would be the same for all options with the operating limits also being similar if not the same.

4 Results

4.1 MCA Results

In order to make an educated choice, the MCA is completed. Based on the three criteria mentioned in chapter 3.2, each options score is given. The MCA is combined for the bridge deck, and the arch as both option choices are graded by the same criteria. The scoring indicates the best option to choose based on the criteria. The score for the deck is based on a 2-point system, and for the arch is the score based on a 3-point system. The higher the score, the better. The scores are based on several factors shown in Table 6 - MCA Result.

The best/winning results in Table 6 and Table 7 are highlighted in blue.

Results

Deck – The MCA results show that option 2 for the Deck would be a better approach. This option is to transport the entire bridge deck in 1 piece. For this, five extra days are calculated in costs for the supports to weld the deck in Flushing. The advantage is in the feasibility as it reduces the risks of delays on-site by difficulties in alignment or setbacks in the welding process of welding the bridge together.

Arch – The MCA results show an interesting consistency in the grading. The best option for the arch would be the baseline variant option 1 (see Figure 20), which consists of transporting each arch in 3 sections. The main advantage is that the sections are light and easy to handle, which also results in a smaller crane required. It does require a longer duration with a crane on-site, but this is compensated by a lower cost of a smaller crane. In addition, this option takes advantage of the support towers already required to place the crossbeams in this configuration.

Table 6 - MCA Result

MCA						
		Options				
Criteria	**Weight of Criteria**	**Deck Option 1. [B]**	**Deck Option 2.**	**Arch Option 1. [B]**	**Arch Options 2.**	**Arch Options 2.**
Costs	30%	2	1	3	1	2
Feasibility	55%	1	2	3	1	2
Hinder	15%	1	2	3	1	2
Final Score		**1.3**	**1.7**	**3**	**1**	**2**

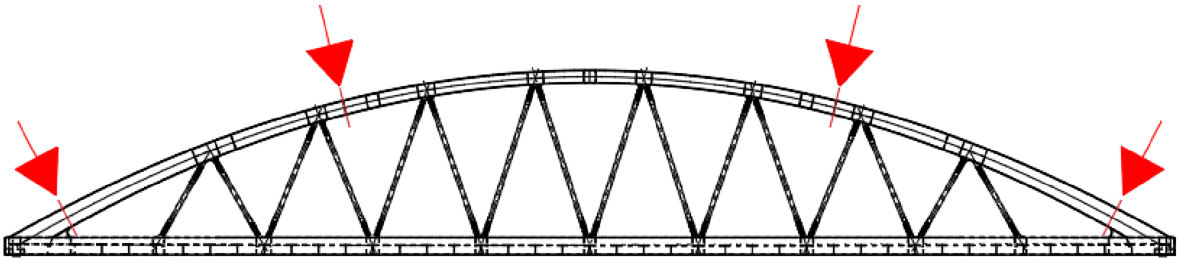


Figure 20 - MCA - Best Variant (Red Arrows point to separation line of different sections)

Table 7 - MCA Results - Expanded

Criteria	Breakdown	Scores: Deck Option 1. [B]	Deck Option 2.	Arch Option 1. [B]	Arch Option 2.	Arch Option 3.
Cost		**2**	**1**	**3**	**1**	**2**
	Transport Costs	€ 57.600	€ 57,600	€ 11,600	€ 50,400	€ 50,400
	Installation Costs	€ 264,000	€ 305,000	€ 152,300	€ 142,400	€ 135,200
Feasibility		**1**	**2**	**3**	**1**	**2**
	Difficulty to lift	1	2	3	1	2
	Installation Complexity	1	2	3	1	2
Hinderance To Surroundings		**1**	**2**	**3**	**1**	**2**
	Hinderance to traffic	1	1	3	1	2
	Hinderance to shipping	1	2	3	1	1

The explanation for each scoring can be found in the appendix 'MCA Score Justification'**.**

4.2 Transport Method Analysis

Resulting from the MCA Results now, the best transport and installation options are known. Based on these options, a transport method is worked out. This transport method covers the transport from Flushing to Antwerp. For this, the embarking and disembarking are described, and the height clearances are checked.

A company called Sarens is hired to provide the equipment and expertise to transport the bridge from Flushing to Antwerp. Sarens is a regular partner of ASK Romein Hillebrand to transport and lift objects. Sarens will be responsible for rigging and compliance with the Western Scheldt – and Port of Antwerp Regulations.

To verify different options, methods, and stages in this chapter, multiple SCIA Engineer models are created. The input details of these models can be read in chapter 4.3.1 SCIA Model. The key difference between the models used for installation and transportation is that the transportation models do not include the wind loads as the models only require self-weight to calculate bending and internal stresses for verifications of height clearances and internal stress resistance.

4.2.1 Transport Bridge deck

SPMTs will move the bridge deck from the construction site onto barges. This will be done by using a yet-to-build RORO jetty (Roll On, Roll Off). The bridge will be driven onto two sets of barges. These barges are rented from the transport company Sarens.

The bridge on top of the barge will have a height of about 8,8 meters above the waterline. This is the combined height of the barge above the water line (±1.5 meters), the height of the SPMTs (1,25 meters) and the bridge itself (±6 meters). The 30 cm remaining gab will be a buffer for differences in the channel's water level and up-and-down movements as the barge still is a floating vessel that moves. See Figure 21.

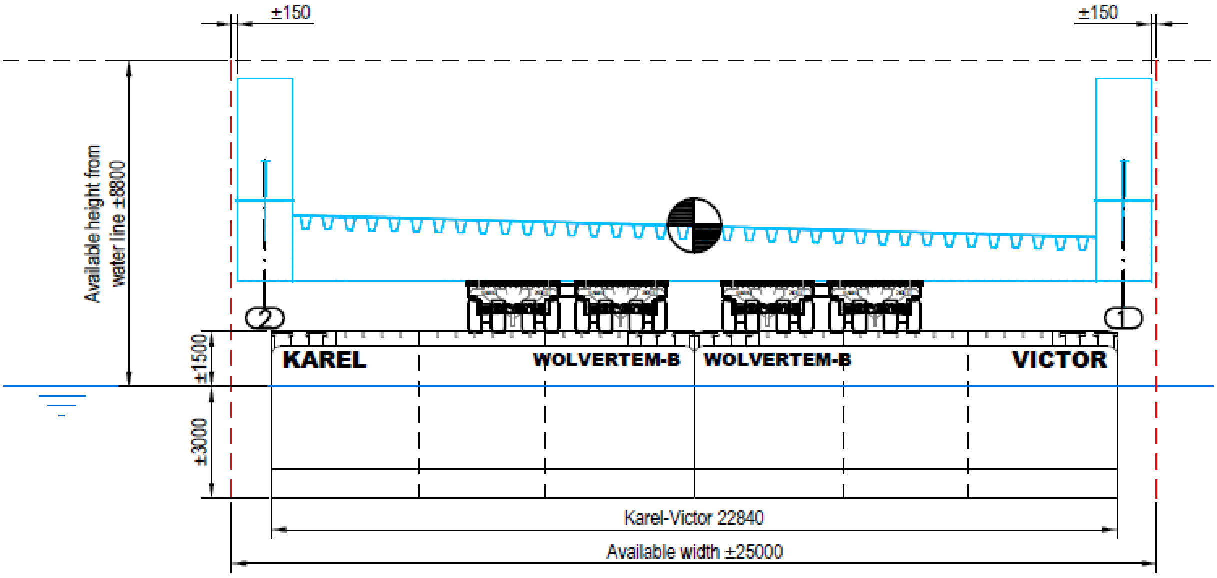


Figure 21 - Bridge on Barge with Height Dimensions
(Location of SPMTs is not definitive in this figure!)

4.2.1.1 Embarking Bridge Deck

Two groups of four SPMTs will move the bridge from the construction site onto a barge. The two groups of SPMTs will only support the bridge during the transport to and on the barges. This is important as the transport company will likely use two sets of barges to transport the bridge. This will create the possibility of movement in between the barges. Because of this movement, supporting the bridges at only two locations over the full length would be better.

There are two groups of SPMTs to support the bridge, and an analysis has to be executed to check the bending of the bridge deck and what location of the SPMTs would be optimal to have the least amount of bending and still be able to pass over the corner of the RORO Ramp. The SPMTs that will likely be used have a platform of 8,4 meters long. In a conservative approach, will the supporting platform be reduced to 7 meters because the SCIA model is based on a spacing of 3,5 meters by the rafters of the bridge deck.

Figure 22 - Example of SPMT (Kamag 2400 ST) (Sarens Equipment data - Transport, 2022)

In the initial proposal of SARENS to perform the transport are, the centre of the SPMTs located 33 meters from the centre of the bridge (Figure 23). However, this would result in a maximum deflection at both ends of the bridge of 865 mm (See Figure 24), which is more than the minimum height clearance of ±630 mm.

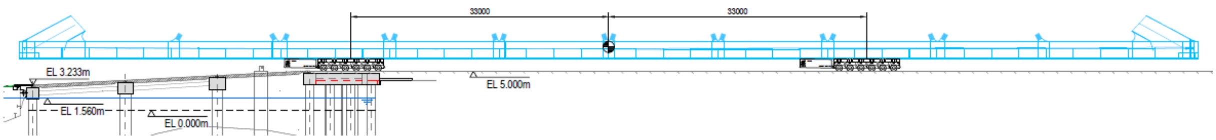


Figure 23 - SPMT Spacing (33m from the centre of the Bridge)

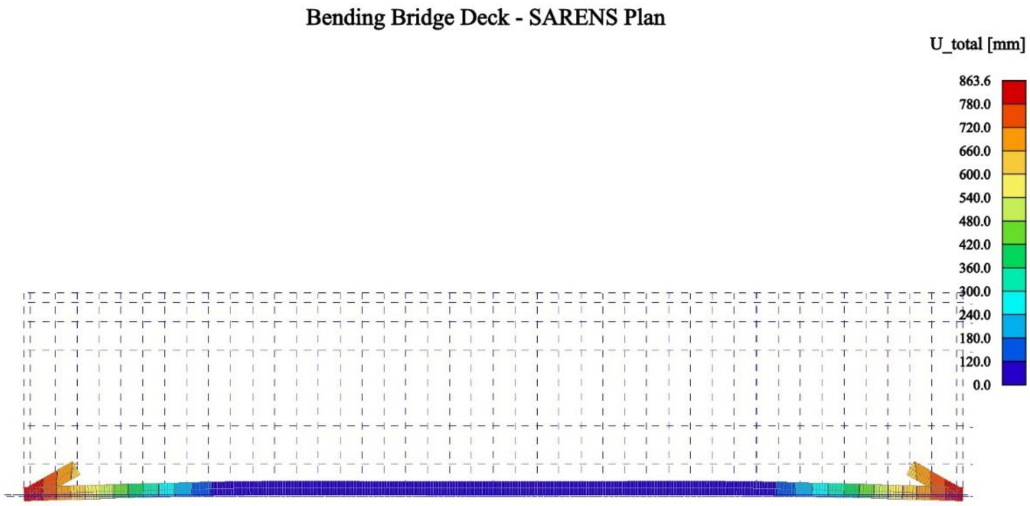


Figure 24 - Bending Bridge Deck – Sarens Proposal

Several models are made to find the minimum amount of bending to find a better suiting alternative setup. These models showed that if the SPMTs were located at 56 meters from the centre of the bridge, then the maximum bending would result in 260 mm. See Figure 26. By doing this, the spacing between the bridge deck and the edge of the RORO ramp is reduced. A scaled drawing checks this spacing see Figure 25, (the drawing can be found in more detail in Appendix.E), which indicates that there is 402 mm height clearance when the bridge is not bending. When subtracting the maximum bending of 259.4 mm, only 142,6 mm remains. This, however, can be increased by raising the SPMTs a bit as they are not fully extended in this situation. This would add an additional ±400 mm if this is required/desired.

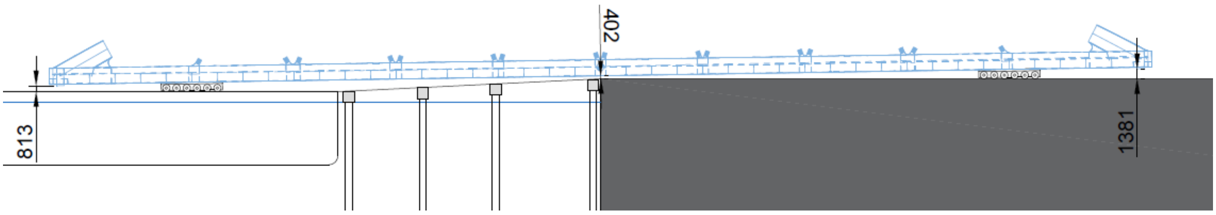


Figure 25 - Height Clearance Bridge Deck - SPMT Spacing 54m (No Bending included)

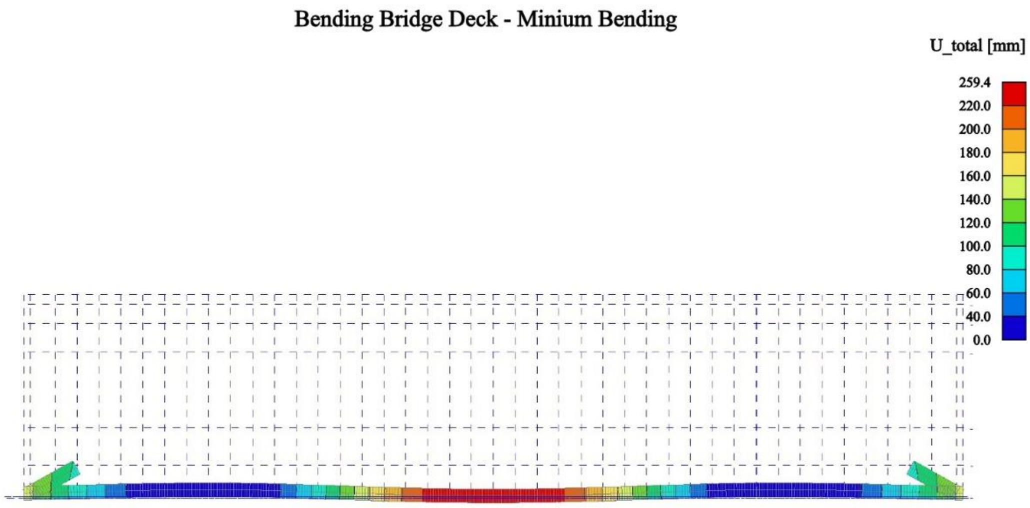


Figure 26 - Bending Bridge Deck - Minimum Bending

4.2.2 Transport Arches

According to the MCA, transporting the arches in 3 sections is the cheapest and easiest way to transport the arch structure. The arches are relatively small in size and easy to handle. The relatively small size allows the arch sections to be transported on top of the bridge deck because there is enough space available. This will reduce the costs significantly. However, the arch sections are too high to place upright on the bridge deck. As a result, the construction manager is looking at transporting the arches on their side laying them down on the bridge deck. This does mean that the sections have to be rotated, which is not ideal, but it will be cheaper than an extra transport.

Figure 27 shows the deck layout of the bridge with the arches on top of the bridge deck. The sections are spaced at 1500 mm from the main beam in order to keep space to build the support towers without needing to move the arch sections. The arch sections are spread out over the bridge deck and are as close as possible to their final location. This is to minimize the crane movement when rotating and lifting the sections in place. In addition, the sections are oriented so that the crane can rotate them by lifting and rotating them towards the crane. This results in a more controlled lifting sequence which will be easier for the crane operator to manage and control. (The crane zone is marked in green at the top site of the figure)

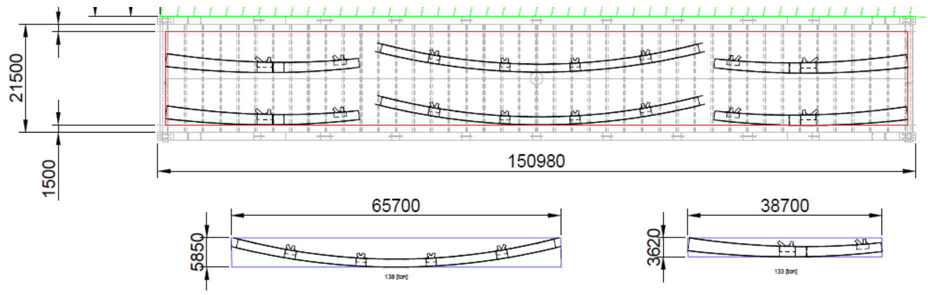


Figure 27 - Deck Layout - Transport Arches on Bridge Deck

If the arches are to be transported on their side, additional attention must be paid to the stiffness and strength of the arch sections when they are lifted on their side and rotated. This would introduce a new load/stress situation which is not considered in the original design. By using SCIA, it is possible to model the 3D stresses and deformation when the arch sections are lifted in a horizontal orientation.

In this simplified approach, only the stresses and deformations are modelled in the horizontal orientation. When a complete rotation and lifting sequence is created, a full stress analysis must be conducted to verify the strength in every different stage and orientation. This analysis must be executed with the final lifting locations considered. The lifting sequence is not included in this research and should be executed once ASK Romein Hillebrand has acquired the contract.

In this basic test, two different lifting scenarios are considered for both the arch's side section and the middle section. For this basic analysis are the lifting points considered at 1) both ends of the section and 2) at 25% and 75% of the length. 1) Lifting at ends would be preferred as this location has already the temporary connection plates and possible reinforcements which could be used/utilised. In addition, is this location easily accessible by the support tower later to remove any lifting hardware from the arch. 2) Lifting points at 25% and 75% of the length are considered as this would allow for the most optimal load distribution, which reduces the stresses in the arch. This option would be optimal in load distribution but should only be used if 1) is unavailable as it adds extra positions to clean up after installation.

The viewing angle of Figure 28, Figure 29, and Figure 30 are looking down at a 45^o to show the stress in the top and in the sides of the section.

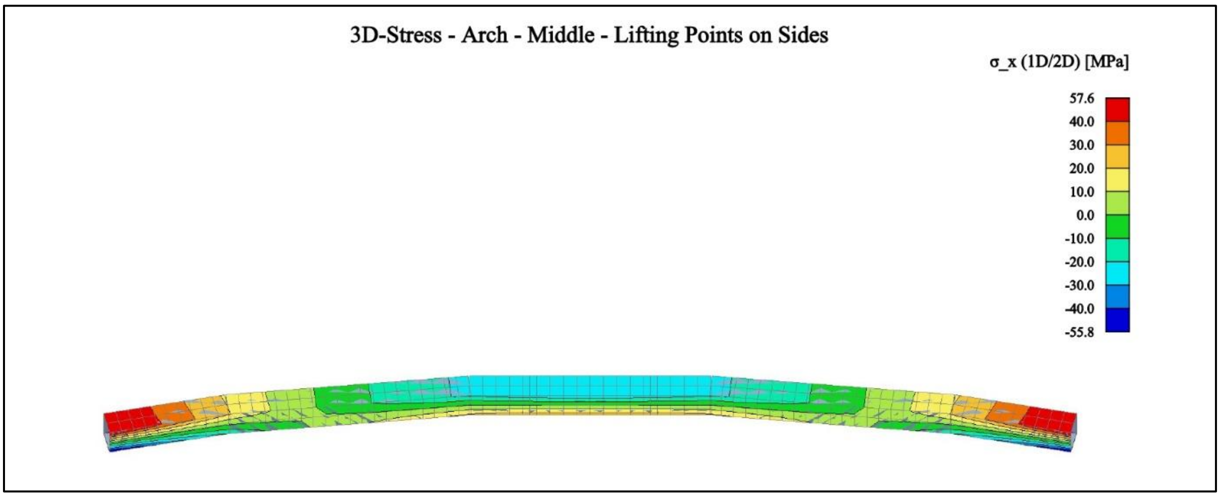


Figure 28 - 3D-Stress in Middle Arch Sections - Lifting points on the sides

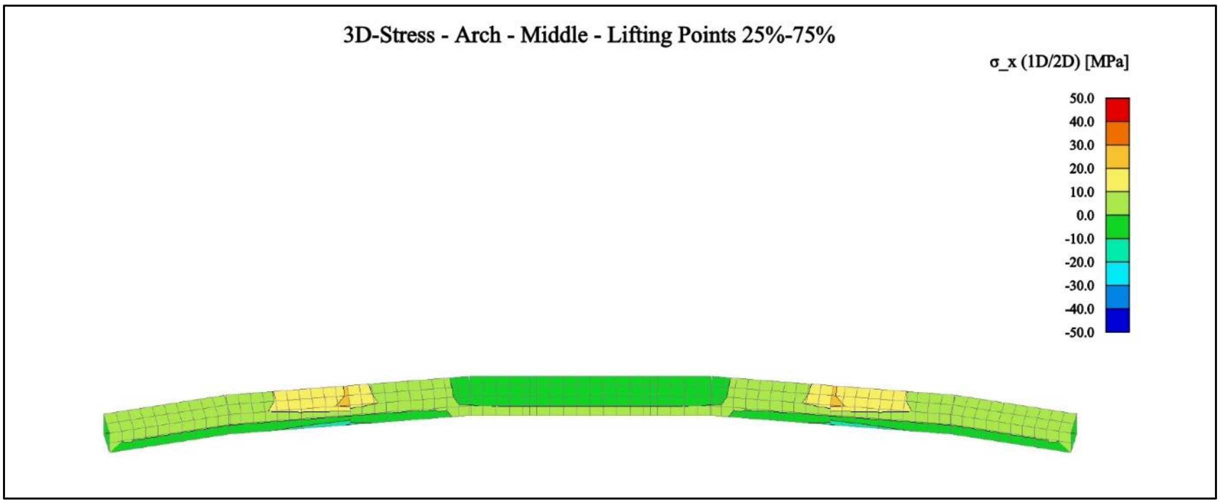


Figure 29 - 3D-Stress in Middle Arch Section - Lifting Points at 25% and 75% of the length

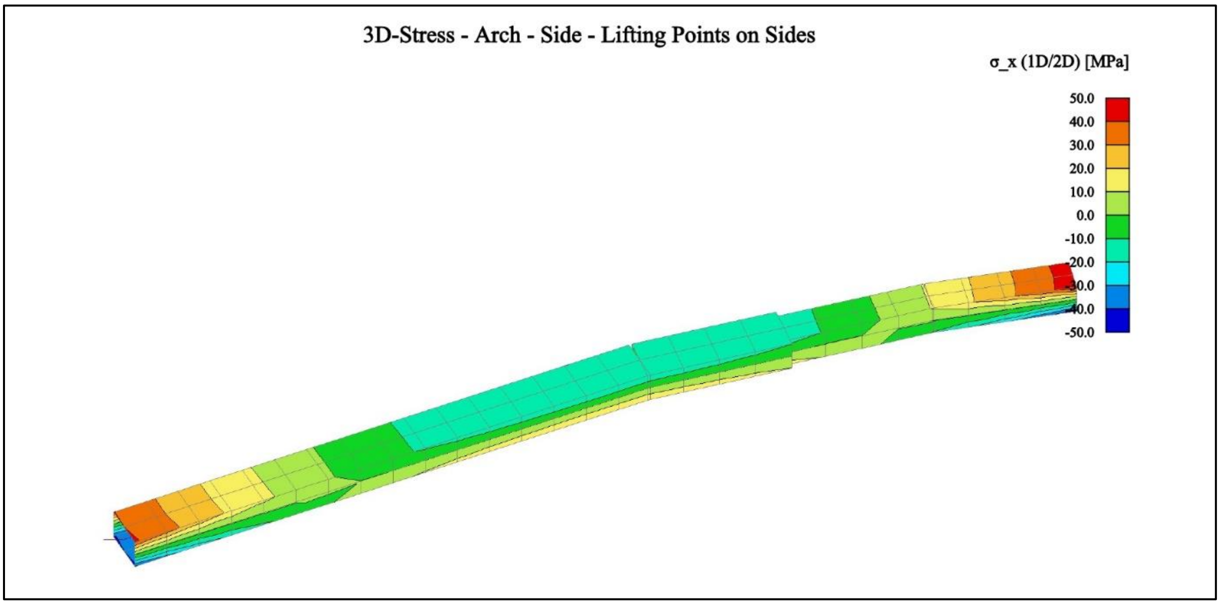


Figure 30 - 3D-Stress inside Arch Sections - Lifting points on the sides

Figure 28 and Figure 29 show the internal 3D-Stress of the middle arch section in MPa. The positive stress (light green-yellow-red) indicates the compression in the profile, and the negative stress (green-light blue-dark blue) indicates tension in the profile. The internal stresses are caused by the self-weight of the arch. The difference in stresses is mainly due to better load distribution in Figure 26, as the arch acts as a cantilever. While in Figure 25, the self-weight only acts from one side to the support.

The same analysis is executed for the side arch sections. Two models are made, one with the side lifting points and one with the lifting points at 25% and 75% of the length. The model results show a similar stress distribution to the middle arch. In Figure 30 is the most extreme model shown. This model with the side lifting points has a maximum internal stress of 46.1 MPa.

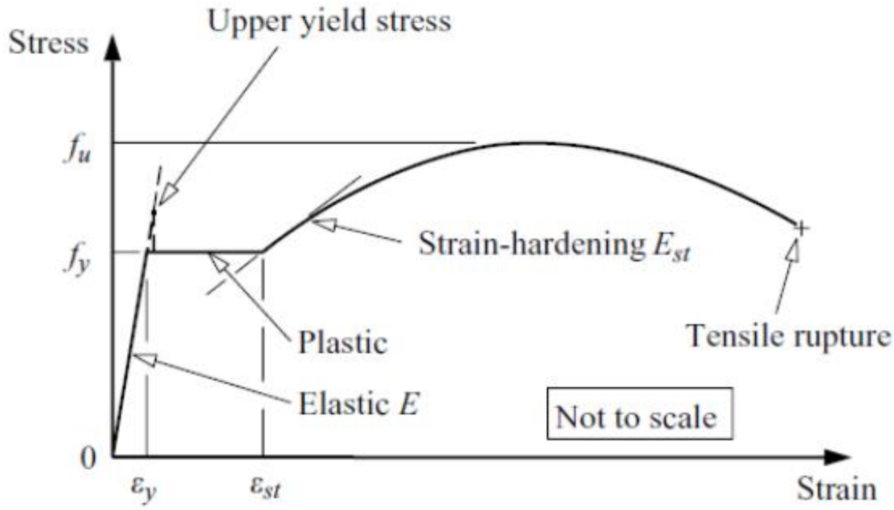


Figure 31 - Steel Stress-Strain Diagram (Introduction to material properties of steel)
The steel quality of the bridge is S355, this means that the steel has a yield stress of f_y= 355 MPa. (See Figure 31)

The most extreme scenario is when the section is lifted from the sides. This configuration's maximum internal stress in the middle section is 57.6 MPa. The side sections are 46.1 MPA; these are well within the limit of 345 MPa (The yield strength has to be reduced from 355 to 345 because of the plate thickness.), which means that the arch sections can be lifted in horizontal orientation.

4.2.3 Transport of Other Components

Hangers and crossbeam

The hangers and cross beams can easily be laid on the bridge deck or the barges. However, it is required to spread the load on top of the bridge deck as the SPMTs only support the bridge at two locations.

Support Towers

Ideally, the support towers of the bridge deck are already transported (by truck or small barge) to the assembly site before the bridge arrives. If the towers are placed and aligned in advance, the bridge can be placed directly on the support towers when it arrives.

The towers for the arches can be transported on the bridge deck as they do not have to arrive on-site in advance.

4.2.4 Return of Equipment

The transport of the equipment which is no longer necessary can be returned either by road or by barge. Given that there is a barge at the assembly site to move the bridge over the channel (See Installation Phase 10 in chapter 4.3.8.8), it will most likely be a cheaper option to load all equipment on the barge and transport it back to Flushing once the project is completed.

4.2.5 Resulting Transport Phases

The results of the transport method analysis result in the following two transport phases.

4.2.5.1 Phase 1: Transportation

In this phase, the entire bridge is transported from Flushing to Antwerp by barge.

Embarking onto the barge

First, the bridge will be made ready for transport in Flushing prior to this phase, SPMTs will lift and transport the bridge. The first SPMT group will drive until it is completely on the first barge, the second SPMT group will push the barge out by driving further towards the edge of the RORO Ramp, and then as soon as possible will, the second barge is floated in between the barge and the RORO ramp. Now both SPMT groups will drive to their designated position on the barge.

Disembarking from the barge

A similar method will be used to offload the bridge in Antwerp. However, there is no RORO ramp in Antwerp. The barges can use their ballast tanks to level with the quay wall. The client has prepared the area to accommodate the heavy transport over the area. This preparation includes the protection of pipelines and cable corridors.

4.2.5.2 Phase 2: Placing the bridge deck on supports

During the transport phase, a team has prepared the assembly area by prepping the present infrastructure. In this preparation, they also prepared the locations to place the support towers. Onsite the support towers are placed and aligned in advance so that the bridge deck can be transported and placed in one day.

The bridge deck has to be jacked up to a required height so that the SPMTs can drive the bridge deck over the support towers, after which it can lower the deck and place the bridge deck on its temporary supports.

4.3 Installation Method Analysis

Once the bridge deck is transported to the assembly site, it has to be assembled and installed. The installation will happen in phases which are described in chapter 4.3.8. In order to assemble and install the bridge, several measures and methods have to be worked out. Among them are temporary supports, stability, strengthening measures, and mounting hardware. This chapter covers the measures required to assemble and install the bridge.

4.3.1 SCIA Model Load

Multiple SCIA Engineering Models are created to verify different phases and calculate loads in support towers and connections. These loads are then used to calculate and verify multiple aspects of the bridge structure and support structures/equipment.

This chapter briefly describes input aspects of the SCIA model. Appendix.B contains a complete overview of the SCIA Model input data used to create the bridge model.

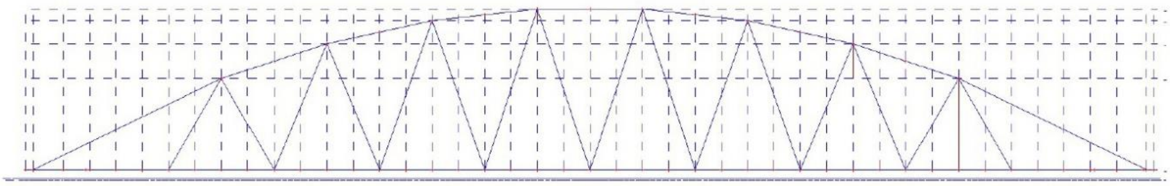


Figure 32 - Wire Frame Side View Bridge - SCIA Model

Load Cases

BG1	- Self-Weight (z-axis)	- Permanent load	- Automatically Calculated in SCIA
BG2	- Static Wind load (x-axis)	- Variable load	- Hand Calculated using Eurocode 1

More specific and in-depth data about the models and profiles can be found in Appendix.B.

Wind load

The wind load* is calculated according to Eurocode 1. The peak pressure of the wind load is calculated considering the basic velocity pressure, mean wind, and turbulence. This results in a peak pressure of 501.31 N/m^2. In addition, the shape factor is calculated as the shape of the profile (round or square) has an effect on how strong the wind will interact with that profile. The effective wind load per profile/member is calculated by multiplying the peak pressure with the width of a profile and the shape factor. These results can be seen in Table 8, and the entire calculations can be found in Appendix.C.

Table 8 - Wind load per profile

Wind load per member			
Profile	Shape Factor [-]	Wind load [kN/m]	Application
CS1, CS2, and CS3	2.40	1.93	Main Beam
CS4	2.35	1.88	Arch 1 and 3
CS5	2.20	1.76	Arch 1 and 3
CS6	2.10	1.68	Arch 2
CS7 and CS8	0.70	0.18	Hangers

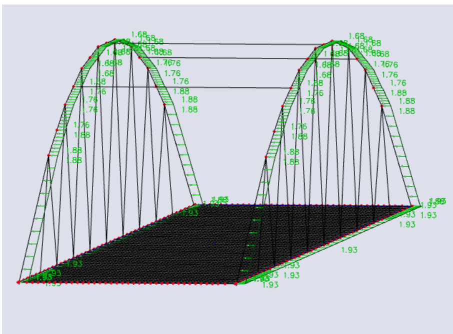


Figure 33 - Wind load direction (Wind load indicated in green)

**The wind load is only calculated perpendicular to the bridge as this would result in the maximum horizontal load.*

4.3.2 Stress-Free Installation

"It is desired to assemble the bridge stress-free, meaning that when the stress-free-state variable of a structural element is set, the internal force and deformation of the element are unique at the completion state of the structure regardless of its construction process;" (Qin, et al., 2020)

The stress-free state is a building phase where the structure is welded together with no forces applied to the welds because these forces generate residual stresses in the construction. This can be accomplished by building support towers that hold the components' weight until the bridge is fully assembled. In general, these supports will be strategically placed to support the element in its final position.

The bridge deck must be supported at additional points. These points will be carefully chosen to reduce the internal stresses as much as possible. Several set-ups will be modelled to define the most optimal layout. The arch sections will be supported at the joint by support towers. These towers carry the main mass down to the supports under the bridge. The hangers can be placed under the arches to support the arch section to acquire a stress-free state in the arch. However, this setup must be checked on both the hangers and the internal stresses in the arch. More on this in chapter 4.3.3 Temporary Supports.

In addition, temporary connection points are required to interconnect the arch sections relative to each other as well as to the bridge deck. These connections do not have to carry the full load as this will be mainly done by the support tower, but these connections are required to fix the relative position. This is to prevent stresses in the welds during the welding phase. More on this in chapter 4.3.6, Mounting Hardware.

4.3.3 Temporary Supports

4.3.3.1 Support Bridge Deck

Once in Antwerp, the bridge will be rolled off the barges using the same method as before by two groups of SPMTs. After this, the bridge will be placed on support towers, which will distribute the bridge's load as much as possible to create a stress-free state.

The bridge will be placed by SPMTs on the support towers, for the towers should be just higher than the SPMTs, which are 1,25 meters high at minimum. The segments Hillebrand is planning to construct are 1 or 2 meters high. Therefore, the bridge will be placed on the 2m sections.

Support Tower Layout

Several extra supports may be required to support the bridge deck during assembly to comply with the stress-free state. Several SCIA models are made to compare the different set-ups to find the best support layout.

There are four different set-ups considered: (See Figure 34)

1. Supports at both ends of the bridge and in the middle. - 6 supports total
2. Supports at every other hanger connection (starting from the second) - 12 Supports total
3. Supports at every other hanger connection (starting from the first) - 14 Supports total
4. Supports at every hanger connection. - 22 Supports total

Because the bridge is symmetrical, it is important to have a symmetrical support set-up as it will ensure that both sides are assembled within the same conditions.

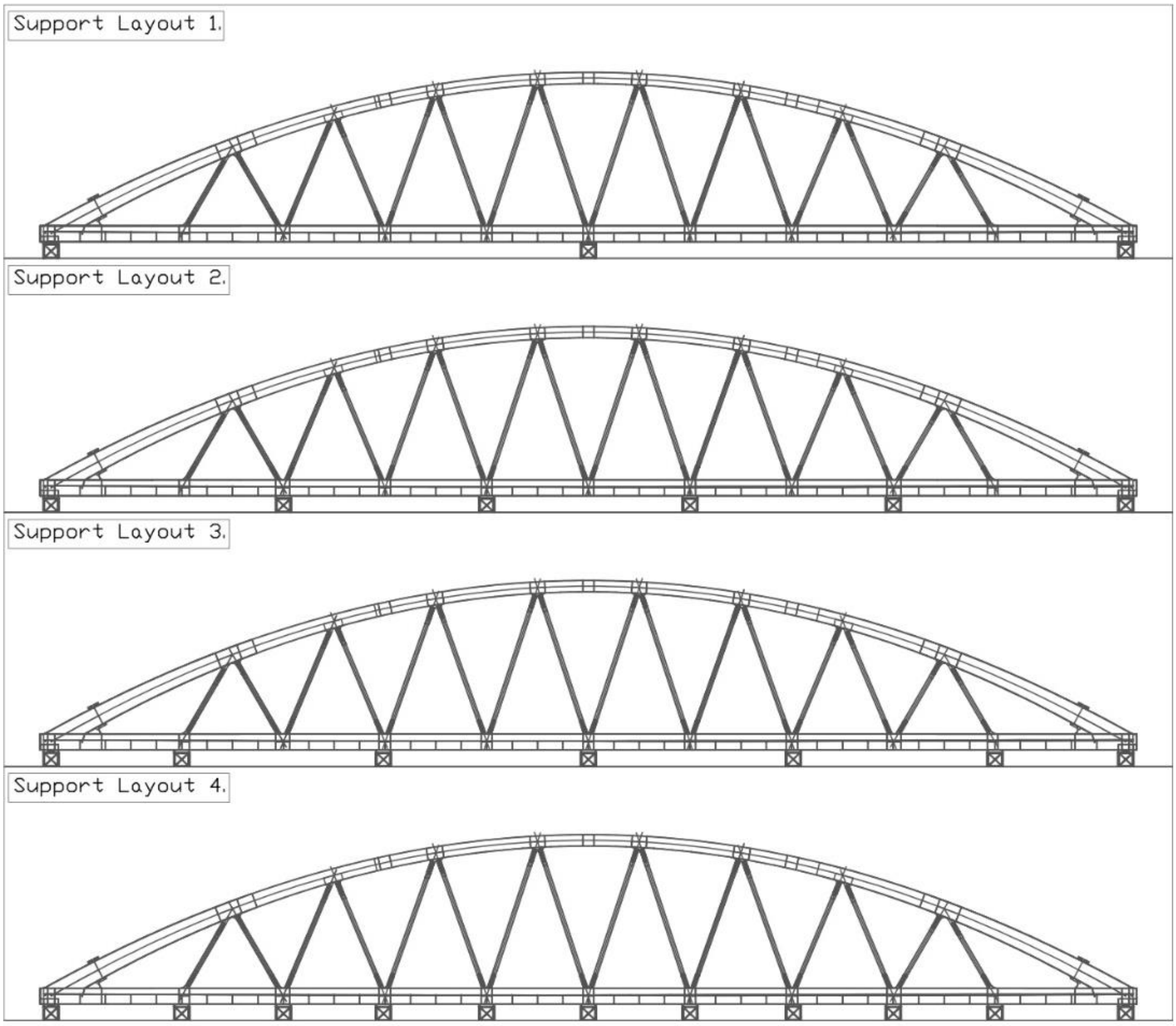


Figure 34 - Support Layout 1, 2, 3, and 4

Model Results

The model is based on a self-supporting arch, meaning no arch support towers are present, and the hangers support the entire arch. The results show that the more supports are introduced, the lower the internal stresses in the bridge. This is an expected result as more supports provide better load distribution, and the loads in the structure do not have to 'reach' far for support.

The model result for Support Tower Layout 4 is shown in Figure 35. This layout results in maximum stress in the arch and bridge deck of only ±40 MPa. Adding more supports would not make much sense from an economic view as it would add towers that only support the minimal load of the bridge deck spanning between the support towers.

The stresses in the hangers are much greater than in the rest of the structure. In the model results, the intense stresses can be seen by looking at the red parts of the hangers, which are red due to the horizontal wind load acting on the bridge. (The image is facing the windward side) This positive stress indicates tension. The feet of the hangers are in dark blue as that part of the hanger is under compression by the self-weight of the arch and hangers.

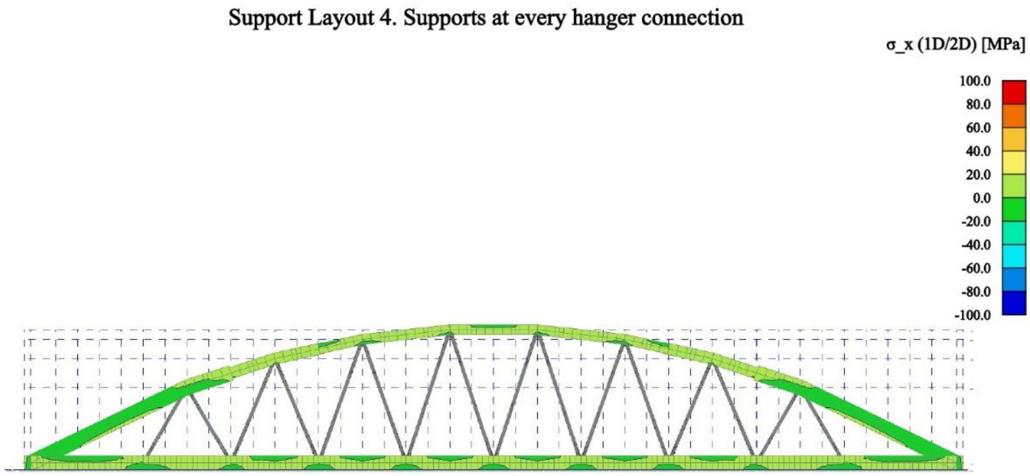


Figure 35 - 3D-Stress - Support Layout 4

Support layout 4 requires 22 support locations, on the connection point where hangers will be mounted and on the ends of the bridge. These locations are chosen as the weight of the arch will be resting partially on the hangers, and in this way, the load of the arch can also be directed into the support towers below the deck.

All layouts of the support towers are modelled to visualise their difference. The results of these models can be found in Appendix.F.

4.3.3.2 Support Arches

The arch sections are placed on support towers to keep the sections in place to weld them into one continuous arch. These support towers will be strategically placed to be used for both the arch sections and the crossbeams between the arches. (For the middle crossbeam, an extra (lighter) support tower will be built to only support the crossbeam.)

According to the original design drawings (See Figure 36), is it to be noticed that the intended locations of the support towers of the arch and deck do not line up. This would mean that the arch's support towers must be placed on top of the main beam. However, this would be undesirable as strengthening measures to the beam would most likely be required, and it does not assist in the stress-free state.

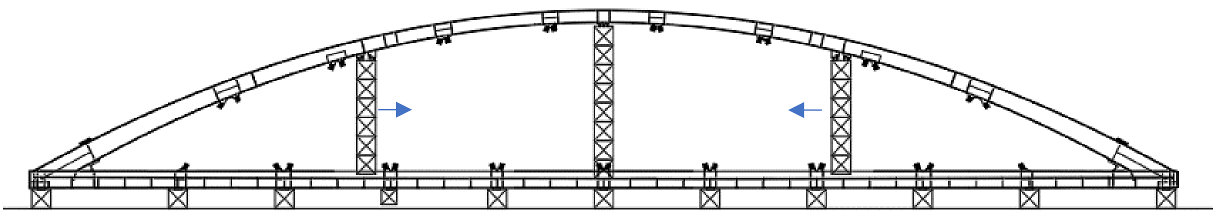


Figure 36 - Initial Sketch of the bridge with arch support

Instead of welding mounting points on the main beam of the bridge for the support towers, the option is discussed in a meeting to create a form of frame around the main beam, which transfers the loads and moments around the main beam to the support tower underneath the main beam. This method would eliminate unnecessary welding to the main beam and temporary loads on top of the main beam. However, for this should, the connection point should be moved more towards the cross beam.

Figure 37 and Figure 38 are sketches of this concept. These figures show what the configuration would look like. On the outside is a continuous support, while on the left side, the support is moved towards the middle of the bridge. This connection is achieved by welding filler plates between the deck and the support tower. This would prevent stresses on the bridge deck and allow the connection to absorb loads and moments from the support tower above. The outside of the support tower can be strengthened by adding H beams bolted or welded to the side of the support, as shown in Figure 37 on the right side of the structure. This could be necessary to transfer the moments in this construction. The main beam will still be supported by the tower below as it was intended and should not be affected by the loads of the arch support tower.

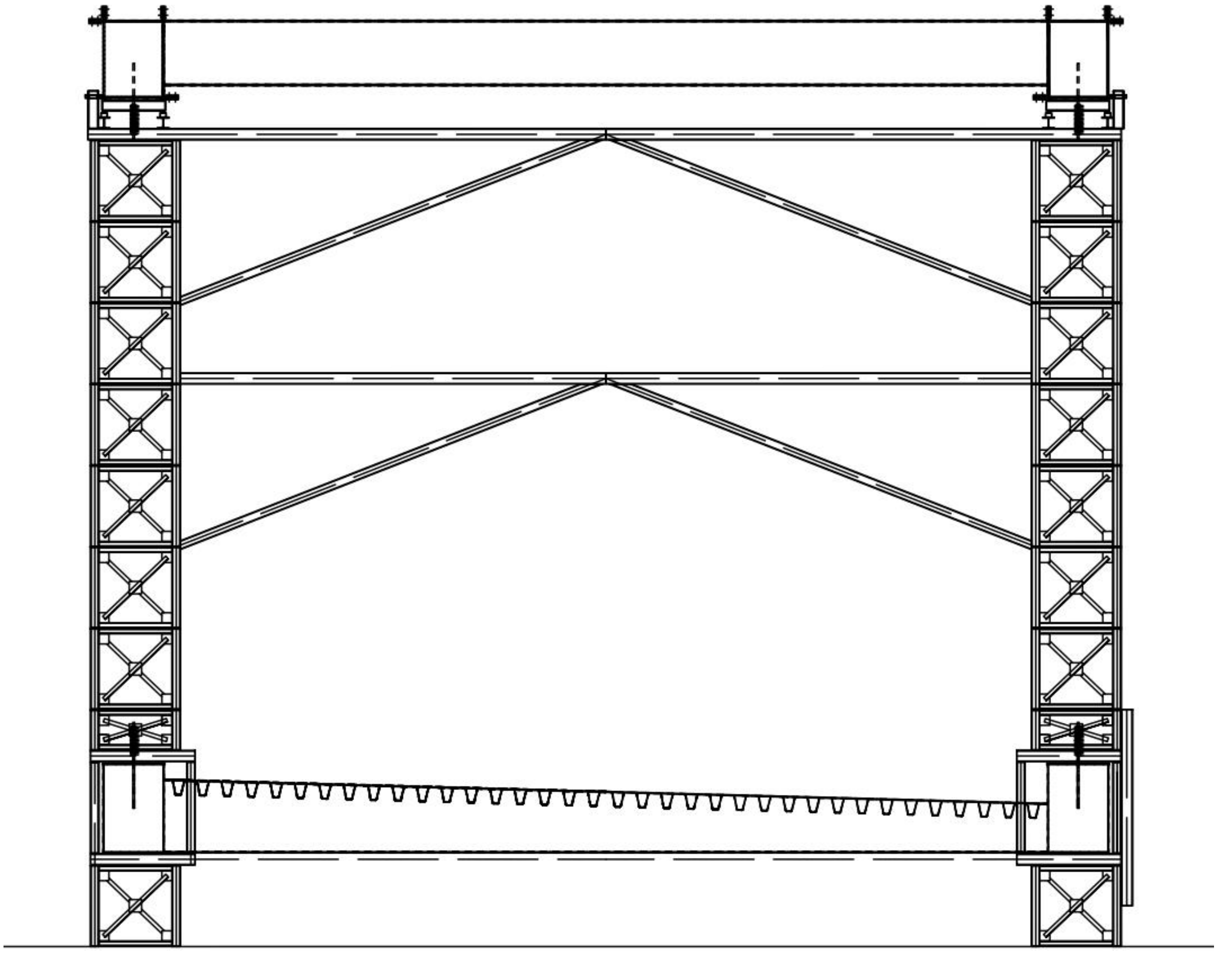


Figure 37 - Support Towers

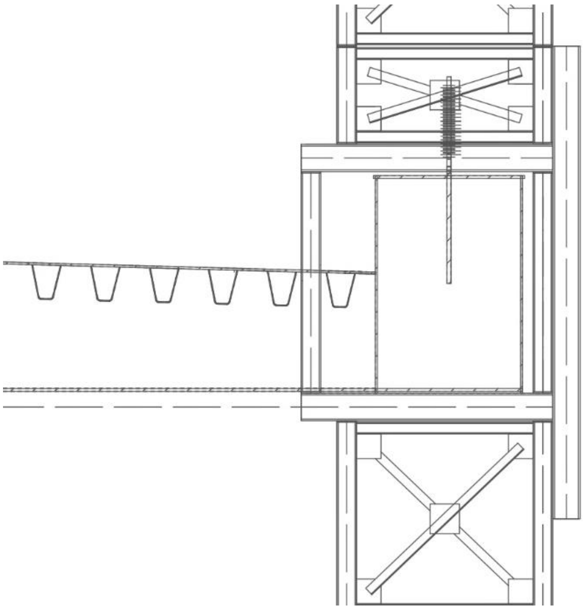


Figure 38 - Support Tower Around Main Beam

The support towers are designed by ASK Romein Hillebrand and made in-house. The spacing between the columns' track centre will be 2000 mm, and there will be two different height modules, one of 1000 mm, and one of 2000 mm. This modular block system is a standardization they want to apply when building this bridge and other future projects.

4.3.3.3 Loads on Support Towers

The load on the support towers must be checked to verify the load resistance of the towers. The load on the lower support towers (below the bridge deck) and the upper support towers (which support the arch sections) are calculated using the SCIA model.

The supports are numbered from left to right in the longitudinal direction; numbering supports 1 to 11. There are two rows of eleven supports. One row will be rigid in the horizontal (x) direction perpendicular to the bridge. And the first tower will also be rigid in the longitudinal direction (y) of the bridge. All supports will be rigid in the vertical (z) direction. (See Figure 39)

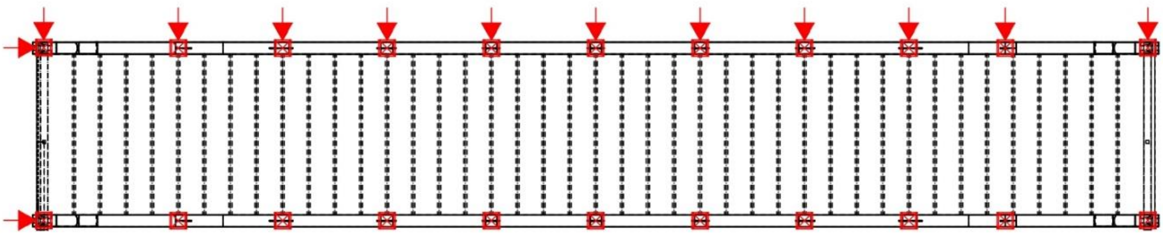


Figure 39 - Indication of axial support. (All support towers, support in the vertical direction)
The arrows indicate the horizontal direction in which the support towers are fixed

Lower Support Towers

The load on the lower support towers is calculated using the load of the complete bridge on top of the support towers. This situation is the most extreme load case. That is why the following loads are used as the normative loads.

Table 9 - Loads per support tower

Support No.	Vertical Load (z-axis) kN	Horizontal Load (Wind Load) kN	Rigid in axis	Note
1	1330	93	x-y-z	→ End Support
2	1110	311	x-z	
3	1180	157	x-z	
4	1340	141	x-z	(+ Support of Arch)
5	1090	108	x-z	
6	1140	107	x-z	→ Mid Support
7	1090	111	x-z	
8	1340	147	x-z	(+ Support of Arch)
9	1180	167	x-z	
10	1110	315	x-z	
11	1330	61	x-z	→ End Support

Axis x – Perpendicular to bridge (wind direction)
(x-axis is only fixed on one side of the bridge due to expansion by temperature fluctuations)
Axis y – Longitudinal Direction of the bridge
(Z axis is only fixed in one support due to expansion by temperature fluctuations)
Axis z – Vertical Direction (self-weight)

Upper Support Towers

The load of the arch sections is calculated from two different models, one considering the side arches supported by the arch base and the support tower, and one model considering the middle arch section on support towers. This is done to remove the influence of the different sections on each other because they are not connected yet in the most extreme scenario.

Loads from the side arch - 620 kN
Loads from the middle arch - 740 kN
Total load of arches = 620 + 740 = 1360 kN

Loads in the structure around the main beam

To properly design the structure around the main beam, should the self-weight of the support towers be included in the loads.

The segments have the following mass:
2m segment - 12 kN
1m segment - 9 kN

The support towers have seven 2m segments and one 1m segment. Two additional 2m segments are considered to compensate for the extra elements on the top of the support tower and horizontal bracings.

This results in a total mass of 9*12+1*9 = 117 kN. For simplification, will this be rounded up to 120 kN
This results in a total load diverging around the main beam of 120+1360 = 1480 kN

Load on the bottom segment

To verify the strength of the support tower segment is the maximum load calculated in support 4 and 8. The assumption is that the structure around the main beam would weigh the equivalent of 2m segments as it is about 2.2 meters high and about 2.5 meters wide.

The total mass on the lower support tower is 1480+2*12 = 1504 kN (Rounded up to 1510 kN)

Tower selection

ASK Romein Hillebrand is planning on creating two types of support tower modules with the following capabilities:

1)	Vertical Load Resistance of	1125	kN
	Horizontal load Resistance of	375	kN
2)	Vertical Load Resistance of	1687.5	kN
	Horizontal Load Resistance of	525	kN

This results in the following tower set-up:

Table 10 - Tower Module Selection

Support	Vertical Load [kN]	Horizontal Load [kN]	module selection
1	1330	93	**2**
2	1110	311	**1**
3	1180	157	**2**
4	1510	283	**2**
5	1090	108	**1**
6	1140	107	**2**
7	1090	111	**1**
8	1510	283	**2**
9	1180	167	**2**
10	1110	315	**1**
11	1330	61	**2**
Arch*	1480	142	**2**

* The support towers for the arches are valid for the tower on top of the construction around the main beam

4.3.4 Stability Measures

During installation, the entire structure is exposed to wind loads. These wind loads introduce a horizontal force against the structure. The wind loads affect the towers that support two arch sections the most. Support towers support the arch sections. These towers must transfer the wind loads on the structure to the foundation on which the bridge is currently standing.

The total wind load on one arch is 306 kN; 148 kN is to be transferred to the ground via each support tower. The total wind load on the bridge deck is 289 kN. This load will be equally spread over one row of support towers fixed in the wind direction, resulting in 289/11 ≈ 27 kN per tower.

The towers next to each other are connected by crossbeams to spread the load between the arch support towers as much as possible. The crossbeams should be positioned so that they will not obstruct movement over the bridge for equipment as areal platforms are required to bolt the hangers. This will spread the load over the two towers to significantly decrease the rotation and deflection in the structure.

The cross beams and diagonal bracing are shown in Figure 37. These cross beams will be connected to the standard modular system of ASK Romein Hillebrand. How these beams will be connected to the standard system is determined by ASK Romein Hillebrand. It may be assumed that they will use a standardised system which can be attached to the modular support towers.

4.3.5 Strengthening Measures

4.3.5.1 Cross-sections of Main Beam and Arch

As the bridge deck and arch sections will be supported in numerous locations, would it be required to examine every support location to check if the main beam or arch is stiff enough to withstand the concentrated loads. These checks would include buckling and shear stress resistance. These checks are not included in this research as it would result in a complete detailed calculation of the entire bridge, which is out of scope.

4.3.5.2 Hangers

As the hangers will support the arch section during construction, it is crucial to check if the hangers can support the mass of the arch sections without buckling. For this, a hanger check is done. This check shows that in this situation, the hangers themselves can resist the moment and compressive forces. In addition, does the check indicate that the connection plates should be thicker to resist the moment forces in the support locations. See Appendix 8.6; in this appendix are the complete calculations that check the buckling resistance for the hangers and the hangers' connection.

Buckling check results

Table 11 - Buckling Check Results

Hanger No.	Hangers		Hanger plates			
	Buckling check result	Check	Buckling check result	Check	Plate thickness [mm]	[mm]
1	0.1506 ≤ 1.0	OK	0.8259 ≤ 1.0	OK	45	45
2	0.1608 ≤ 1.0	OK	0.7535 ≤ 1.0	OK	40	40
3	0.1394 ≤ 1.0	OK	0.8909 ≤ 1.0	OK	40	
4	0.1373 ≤ 1.0	OK	0.8610 ≤ 1.0	OK	55	60
5	0.1495 ≤ 1.0	OK	0.8292 ≤ 1.0	OK	60	
6	0.2184 ≤ 1.0	OK	0.8292 ≤ 1.0	OK	45	45
7	0.2072 ≤ 1.0	OK	0.8629 ≤ 1.0	OK	45	
8	0.2268 ≤ 1.0	OK	0.8839 ≤ 1.0	OK	45	45

The results of the buckling check indicate a significant safety margin in the hangers' buckling resistance. This margin is due to the large and thick profiles chosen for the hanger in the design. However, the hangers' connection plates did not pass the buckling check because of the weak moment resistance in the plates. The simplest way to strengthen the hanger plates is to use thicker plates. Hanger 2 and 3, 4 and 5, 6 and 7, share the connection plate; therefore, the largest plate will be decisive for these combinations. The thickness is increased with an interval of 5 mm, and the results can be read in Table 11.

Each arch has 16 hangers; because of the symmetry, only half is calculated, starting from the side (no.1) to the middle (no.8).

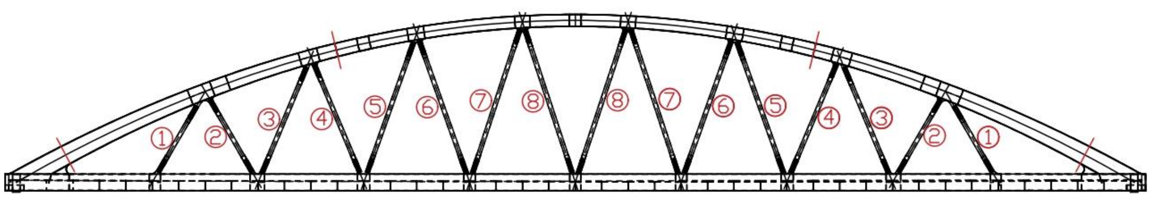


Figure 40 - Numbering of Hangers

4.3.6 Mounting Hardware

The arch sections have to be connected to each other during the welding phase; this is needed to align the sections and weld them together without having stresses in the welds, which should not be present for the stress-free installation. A temporary connection creates the fixation. This connection consists of plates that are welded on each arch. Between these plates will two connection plates be bolted. This bolted connection forms a temporarily fixed connection between the arch sections.

The temporary connections must withstand 142 kN of Horizontal forces and 1351 kN of vertical forces. With this set-up, the temporary connections would be capable of keeping the arch in place without the support towers' support. The temporary connectors will have to be installed in extension to the plates as they will transfer the loads similarly to when the arch would be welded.

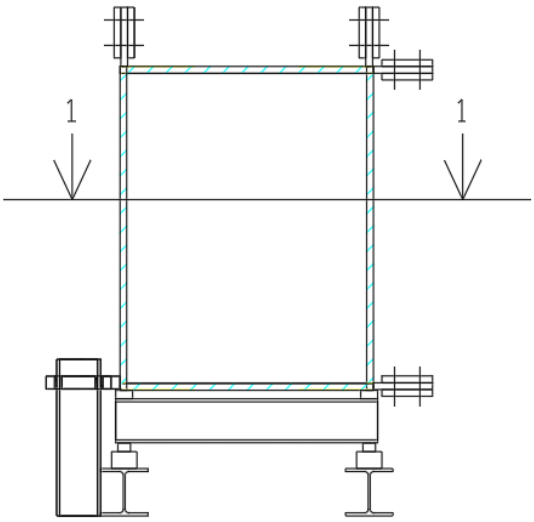


Figure 41 - Cross Section Arch at Support Point, with Temporary Connectors

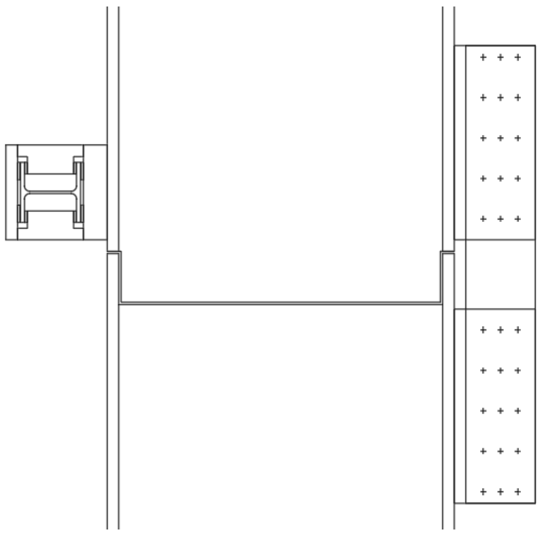


Figure 42 - Cross Section 1-1 of Connection Point, with Temporary Connectors

4.3.7 Crane set-up

A challenge in the bridge assembly phase is that there is only room for a crane zone on one side of the bridge. The challenge is that the arch sections have to be lifted more than 25 meters away from the crane. In addition, the crane zone has the smallest width next to the middle arch section, which is the heaviest section to lift.

Sarens possesses a crane capable of lifting the arch sections of 140 Tons to a distance of 32 meters from its centre point and up 28 meters to place the arch sections on the support towers. However, the crane requires a raised counterweight which extends at least 15 meters behind the centre point to get the great mass over at the required location. This crane is the DemagTC-2800*.

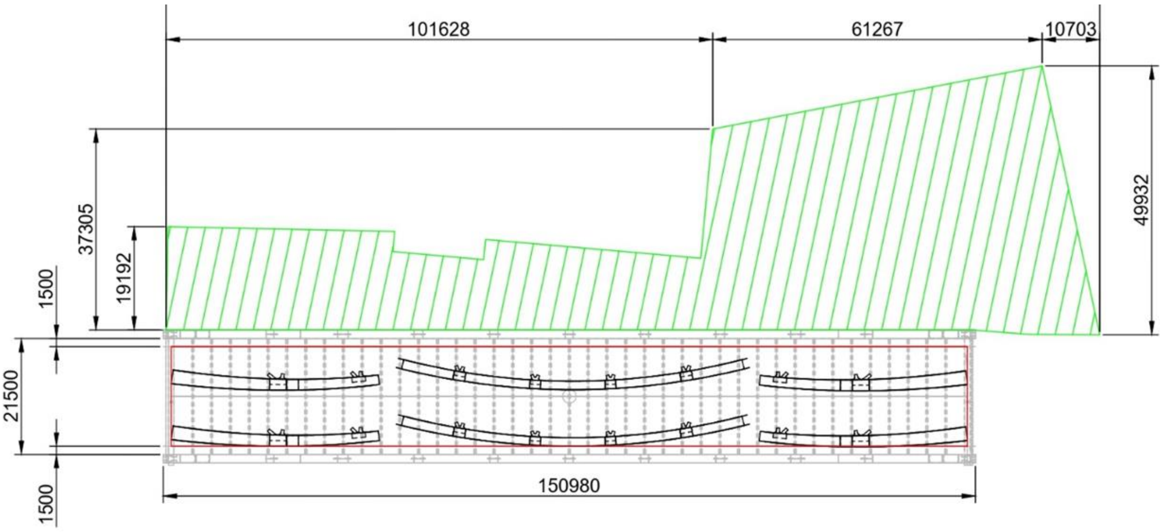


Figure 43 - Crane Zone (Green)

The extra counterweight creates a problem as there may not be enough room to swing around. The extra room should be checked with the client who provides the area if it is possible to extend the crane zone. The benefit is that this area would not require any soil preparations as the load will not be resting on this extended area.

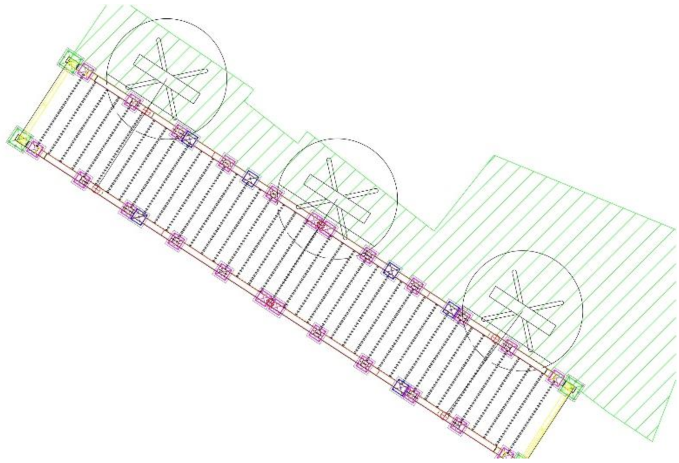


*Figure 44 - Crane zone with Demag TC-2800**

Figure 45 - Demag TC-2800 (Sarens Equipment data - Transport, 2022)*

4.3.8 Resulting Installation Phases

The installation method describes the different phases of installation. Several Phases could happen together or overlap to save time; this will be mentioned in the Recommendations.

The phases are listed in chronological order continuing from phase 2 of the transport phases. A total overview of the phases with models and drawings can be found in the Appendix.I to visualise this process.

4.3.8.1 Phase 3: Building supports for the arches

After the bridge is placed on its support, the support towers of the arches can be assembled and placed. Ideally, two towers are built together as crossbeams will connect them to resist the horizontal wind loads. It will take a bit of time to build the cage around the bridge deck and weld it. As soon as a cage is finished, the entire tower can be built.

4.3.8.2 Phase 4: Placing the outer arch sections

The arches will be built from the outside to the middle. This is beneficial for multiple reasons. The largest span of the arch is at the base. This will cause 27.9 mm of sagging. The sagging will make the section longer than it will be in its final form.

The installation will go as follow:

- The arch section is set upright by the crane.
- The arch section is lifted to its final position and placed on the arch base and a support tower.
- The arch section is mounted on a temporary connection at the arch base.
- The arch section is jacked up at the tower side, opening the area below.
    - This jack-action is required to open up the height below the arch section to place the hanger, which has a fixed length.
- The section will be lowered, after which the next hanger can be placed.
    - This step repeats itself until all hangers, but the last, are in place.

The final situation of Phase 4 can be seen in Figure 46 or in the Appendix.I with more detail.

Figure 46 - The end result of phase 4

The arch section farthest away from the crane should be placed first, so the closest hanger section will not hinder/block the accessibility to optimise the crane movement and minimise the hindrance.

4.3.8.3 Phase 5: Placing the middle arch sections

The middle arch section will be the last piece of the arch to be placed. The middle section is the longest and heaviest section of the arch, so several things must be considered. Because of the section's length and mass, the arch will sag 117.4 mm (According to an SCIA Eng. Model). This sagging will cause the section to be 33,4 mm longer than it will be in its final shape. When sagged, the arch section will not fit between the two side sections.

As a solution, the section will be placed on jacked-up support, which is 117.4 mm higher than the final position. In this way, there is enough clearance to place hangers under the arch. These hangers will help support the section and shape it back to the intended curve. Extra space is created by jacking up the support of the middle arch section for the 33,4 mm extra length.

The installation will go as follow:

- The arch section is set upright by the crane.
- The arch section is lifted to its jacked-up supports on the two support towers.
- The middle hangers are placed to support the arch
- The next hangers are placed following a pattern from the middle to the side of the section
    - After placing a hanger, the jack can be lowered to fit the next hanger.
    - The outer hangers are not placed yet.
- When all hangers are placed, should the jack be lowered, so the support is at the final height.
- The arch sections will now be connected via the temporary connection plates.

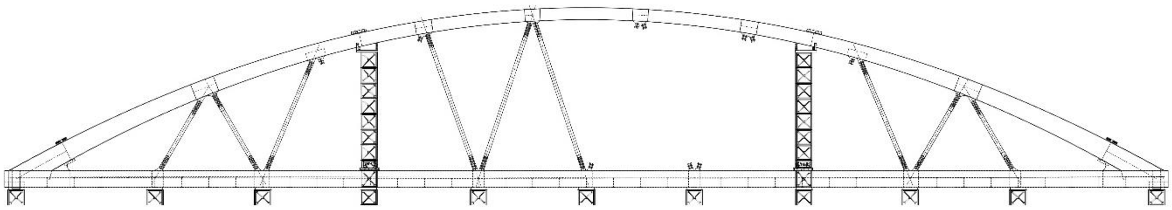


Figure 47 - Phase 5 Halfway Placing the Hangers

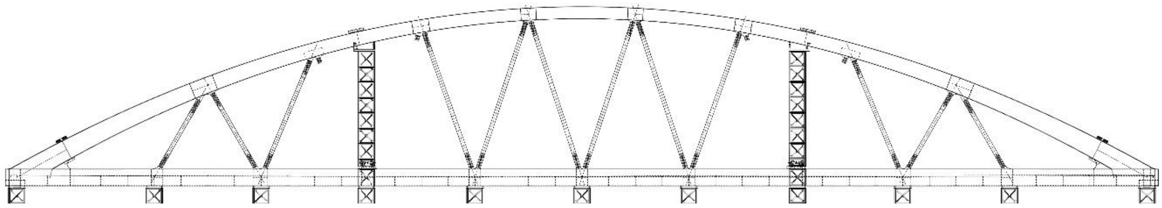


Figure 48 - End Result Phase 5

4.3.8.4 Phase 6: Welding the arches

Once all arch sections are placed, and in a stress-free state, the sections can be welded together. The arches will be accessible by scaffolding that is built out from the support tower. This will create an accessible platform from which welders can weld the sections together.

4.3.8.5 Phase 7: Placing the crossbeams

Once the full arches are complete, the crossbeams can be placed. To do this, a temporary support tower has to be built in the middle of the bridge. After which, the beams can be lifted and placed on temporary supports and welding them to the arch.

4.3.8.6 Phase 8: Conservation

Now the full arch is completed, all temporary connectors can be removed by grinding them off. When they are all removed, the arch can be conservated. This will be done by painting all welds and grinding spots. In addition, all damages to the paint that have occurred during installation are to be repaired in this phase.

4.3.8.7 Phase 9: Removing support towers

Once the crossbeams are welded to the arch, there is no need for the support towers which support the arch. At this point, the towers can be disassembled and made ready for transport. When the towers are removed, the last hangers can be placed, which were obstructed by the support towers. At this moment, the bridge should be fully self-supporting, and the assembly should be finished.

4.3.8.8 Phase 10: Moving the bridge over the channel

The bridge will be jacked-up again at both ends of the bridge, just inwards of where the final supports are located. Clearing the bridge from the support towers.

One end of the bridge will now be driven towards the channel, while the other end will be driven towards the final location.

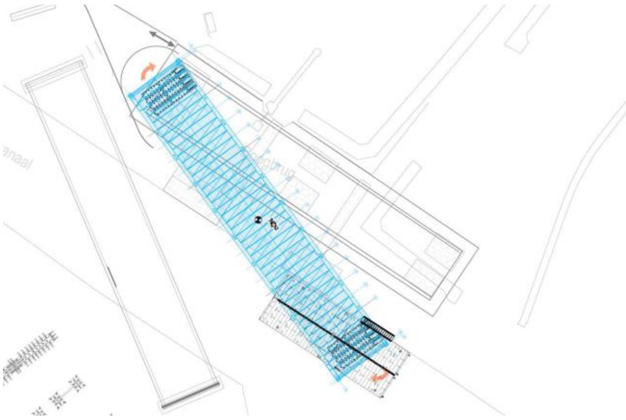


Figure 49 - Movement of Bridge to final location 1/2

The south side of the bridge will be driven onto a barge again. The barge will move this end of the bridge over the channel while rotating the bridge parallel to its final position.

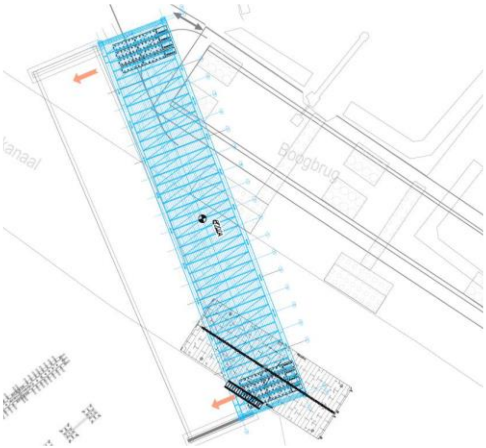


Figure 50 - Movement of Bridge to final location 2/2

The bridge will drive perpendicular toward the final position, where final checks will be held to ensure that the support base of the bridge is within margins and aligning up with the final structure.

4.3.8.9 Phase 11: Placing the bridge in its final position.

The bridge is now hanging over its final supports. When all supports are checked and aligned, can the bridge be jacked down, and will the bridge be handed over to the client after a final inspection.

5 Conclusions

The assignment given by ASK Romein Hillebrand was to research the transportation options and installation methods and find the best methods. In this research, it was essential to keep the criteria of costs and feasibility in mind as ASK Romein Hillebrand has to place a competitive bid to acquire this project.

To structure the approach of creating and analysing different methods is the project split up into two different topics of the bridge. The first was the bridge deck, and the second topic was the arch. This division was created as it was possible to mix and match different methods of both topics. This split can be found throughout the report.

The method selection is based on a multi-criteria analysis (MCA). These criteria are set by the client's interests and ASK Romein Hillebrand. It was important to factor in several sub-criteria to better define the criteria in the MCA. Two MCAs were created to find the most optimal solution for the bridge deck and the arch.

The results of the MCA regarding the bridge deck show that it would be better to transport the bridge deck in one piece instead of the baseline variant where the bridge would be transported in two sections. This benefit comes mainly from the reduced risk of on-site work in Antwerp, where the deck sections should have needed to be aligned. This time-consuming process can be done in advance by aligning and binding the bridge in Flushing at the production facility, where all tools and materials are available.

Moving on to the selection of arch sections, does the MCA results show that the baseline variant from ASK Romein Hillebrand was the most optimal solution. Each arch is a heavy, long, and flexible structure, and by splitting each arch into three sections, more handleable components are being created. It does add the inconvenience of long weld lengths on-site, but it substantially reduces the equipment requirements to place the sections. A major contributing factor is that the assigned crane area is only on one side of the bridge, which means that the arch sections on the far side should be lifted by a crane about 30 meters up and 24 meters away. For this, you need a quite substantial crane. Another main benefit is that the arches can be transported on the bridge deck, making the transport cheaper.

On the arch, sections and crossbeams are lifting points, and temporary connection plates are required to lift the sections in place and keep them in position while being welded together. In addition are cross-sectional checks required to check for internal buckling and shear stress resistance. The profiles are not designed to be supported by the hangers nor the support towers, so additional strengthening plates may be required inside the arch. Due to limitations in time and resources, these temporary connections, lifting points and strengthening plates are not included in this report.

During the assembly, support towers are required to position, support, and keep the arch sections in position. According to the original design, these support towers should be placed on top of the bridge's main beam. This, however, is not desired as it would introduce unusual stresses, which are not allowed according to the stress-free requirement. To avoid the stress by the arch supports, the split point is moved more inwards to the middle of the bridge, allowing the support tower to be placed in line with the bridge deck support towers. In addition, to avoid strengthening requirements for the main beam, it is advised to consider additional construction for the support towers where the arches support tower may be built on top. This construction would transfer the loads around the main beam to the support tower underneath. To achieve this, supports have to be constructed through the bridge deck. These supports should be checked on moment resistance and vertical load resistance. Once ASK Romein Hillebrand has finalised its support modules design, these checks must be performed.

The hanger is a key solution to accomplish the stress-free state of the arches. To achieve a stress-free state, additional supports are required to reduce the stresses in the arch. This is accomplished by using the hangers as support. The hangers will be installed before the arch is welded together and will assist in keeping the shape of the arch. For this, the hangers are checked on compressive and lateral buckling. The results of this check indicate that the hanger profiles themselves are capable of handling the compressive load, while the connection plates would require thicker plates to resit the moment forces in the connection.

To summarise, the best way to transport and assemble the bridge is to transport the bridge deck as one piece with the arch sections on top. The best way to divide the arch is to construct three sections per arch assembled and welded on-site. The hangers are used to achieve a stress-free state. They will assist in keeping the arch stress-free and in shape. However, for this, the hanger plates have to be thickened. To avoid having the arch support tower placed on the main beam is suggested to move the connection towards the middle of the bridge to line up the support towers. In this configuration, a construction can be made to support the tower around the main beam, avoiding loads and stresses in the main beam. At last, lifting, temporary connections, and strengthening plates have yet to be calculated on a more detailed level. It would be required to calculate this in detail per support location/connection basis.

In conclusion, the best method to transport the bridge is to divide it into one bridge deck and 6 arch sections, which will need to be assembled on-site in Antwerp. Support towers and hangers are used to reduce the internal stresses when assembling the arch to assist in the assembly.

6 Discussion and Recommendations

6.1 Discussion

- The SCIA model is used to calculate the loads and stresses, but it is based on straight profiles and beams. This deviates from the actual design of the bridge; therefore, the results may differ from the real-world loads and stresses. Therefore, the results of this report may be questioned. However, the way the model is build-up is the best approach to get the most accurate results. The arch is divided into 16 sections connected to 17 points. These 16 points are accurate to the arch, ensuring that the model's arch is as accurate as possible yet still manageable for the model to work with. In addition, it is the variable cross-section of the arch adapter for having three different profiles that make up the model's arch.

6.2 Recommendations

- The moment resistance in the construction around the main beam should be calculated and checked with the loads as the structure around the main beam is going to transfer loads of the arch down to the foundation.
- The local strength of the cross-sections needs to be checked at all points where a support is located. This means for the arch that at each hanger connection point and lifting point, the cross-section should be checked on cross-sectional shear resistance and a buckling check as the profile consists of 4 relative slim welded plates. This also applies to the main beam, where the checks should be executed on each support point, which is a hanger support point. Strengthening measures can include steel plates welded extra on the inside of the beam to strengthen the specific location.
- A more detailed analysis should be executed to check the required strength of the temporary connection points. This can reduce the amount of metal required to have a sufficient connection.
- The arch sections will be transported on top of the bridge deck. For this, a check should be executed to indicate if the bridge deck is strong enough to have all the arch sections, support towers and hangers on top. In addition, should the bending check be redone with this load on top to check the amount of bending by the bridge and if it still can pass over the edge of the RORO ramp. If the bending exceeds the available spacing, then a crane must load the arch sections after the bridge deck is loaded onto the barges.
- Several phases in the assembly process could happen simultaneously. This could be checked to optimise the construction time on-site. In addition, could this be further optimised by hiring an extra smaller crane which could place the hangers while the large crane is placing the other arch sections. This could reduce the time that the large crane is required on-site as it is an expensive piece of machinery. This should be considered when looking for the most optimal planning.

References

bigge.com/crane-rental. (2022). Retrieved from https://www.bigge.com/crane-rental/operated-and-maintained/

devaltowing.com/dayrate. (2022). Retrieved from https://www.devalltowing.com/services/rates/

(2010). *EN 1991-1-4: Eurocode 1: Actions on Structures - Part 1-4: General actions - Wind Actions.* Brussels: European Union.

Francken, F., Wartel, S., Parker, R., & Teverniers, E. (2004). *Factors Influencing Subaqueous dunes in the Scheldt Estuary.* Geo-Marine Letters.

google.com/maps. (2022). Retrieved from https://www.google.com/maps

GVA.be. (2021, March 5). *GVA Antwerpen*. Retrieved from GVA.be: https://www.gva.be/cnt/dmf20210304_96735149

Introduction to material properties of steel. (n.d.). Retrieved from http://site.iugaza.edu.ps/malqedra/files/lecture-2-13.pdf

KNMI. (2019, 09 03). *Klimaatbericht Lichte lucht, Zware Lucht*. Retrieved from KNMI: https://www.knmi.nl/over-het-knmi/nieuws/lichte-lucht-zware-lucht

KUDU-Engineering. (2022).

lisa.blue/help/wind_zone_eurocode_belgium. (n.d.). Retrieved from https://www.lisa.blue/help/wind_zone_eurocode_belgium/en_GB

Maritiem Courant. (2021, April). *Maritiemmedia.nl*. Retrieved from https://maritiemmedia.nl/royerssluis-antwerpen-is-nu-vier-jaar-dicht/

N307 Roggebot-Kampen. (n.d.). Retrieved from Ijsseldelta Programma: https://www.ijsseldeltaprogramma.nl/project/n307-roggebot-kampen/

Photonews. (n.d.). Retrieved from https://www.photonews.be/

PM4DEV. (2016). *Project Quality Management.* management for development series. Retrieved from https://www.pm4dev.com/resources/free-e-books/5-project-quality-management/file.html

Port of Antwerp. (2020, June 12). *Newsroom.Port of Antwerp*. Retrieved from Port of Antwerp: https://newsroom.portofantwerp.com/grootste-containerschip-ter-wereld-in-haven-van-antwerpen#:~:text=Het%20containerschip%20HMM%20Algeciras%20is,%2Dcontainers)%20aan%20boord%20hebben.

Puri, R. (2015, Januari 31). *Albertkanaal in cijfers en weetjes*. Retrieved from Puri Media: https://renepuri.wordpress.com/2015/01/31/albertkanaal-in-cijfer-en-weetjes/

Qin, S., Wei, K., Jingxi, Q., Yuan, R., Xu, L., & Dan, Q. (2020). *Stress-Free-State based structural analysis and construction control theory for staged construction bridges.* ResearchGate.

Rijkswaterstaat. (n.d.). *Richtlijnen Kuntwerken*. Retrieved from Rijkswaterstaat: https://www.rijkswaterstaat.nl/zakelijk/werken-aan-infrastructuur/bouwrichtlijnen-infrastructuur/kunstwerken

ROCO, T. (2020). *Rekennota Oosterweelverbinding - Perceel 3b.*

sarassitransport.com. (2015). Retrieved from http://www.sarassitransport.com/wp-content/uploads/2015/10/LCR-03-PC-A0.pdf

Sarens Equipment data - Transport. (2022). Retrieved from Sarens: https://www.sarens.com/equipment/equipment-data/transport.htm

Stad Antwerpen. (n.d.). *LEZ-Automaten*. Retrieved from Slim naar Antwerpen: https://www.slimnaarantwerpen.be/nl/lez/lez-automaten

Statbel.be. (n.d.). *Statbel.be*. Retrieved from Statbel.be: https://statbel.fgov.be/nl

vrisawf.alsic.be/Albertkanaal. (2022). Retrieved from https://vrisawf.alsic.be/Albertkanaal?KL=nl

wiki/Berendrechtsluis. (2021, May 20). Retrieved from https://nl.wikipedia.org/wiki/Berendrechtsluis

wiki/Lillobrug. (2021, March 14). Retrieved from https://nl.wikipedia.org/wiki/Lillobrug

wiki/Noorderlaanbrug. (2021, March 14). Retrieved from https://nl.wikipedia.org/wiki/Noorderlaanbrug

wiki/Noordkasteelbrug. (2021, March 14). Retrieved from https://nl.wikipedia.org/wiki/Noordkasteelbrug

wiki/Oosterweelbrug. (2021, March 14). Retrieved from https://nl.wikipedia.org/wiki/Oosterweelbrug

wiki/Royerssluis. (2022, March 14). Retrieved from https://nl.wikipedia.org/wiki/Royerssluis

wiki/Straatsburgbrug. (2021, April 23). Retrieved from https://nl.wikipedia.org/wiki/Straatsburgbrug

wiki/Van_Cauwelaertsluis. (2020, November 8). Retrieved from https://nl.wikipedia.org/wiki/Van_Cauwelaertsluis

wiki/Zandvlietsluis. (2020, September 05). Retrieved from https://nl.wikipedia.org/wiki/Zandvlietsluis

Wind Zone Eurocode Belgium. (2010, 12). Retrieved from Lisa.blue by work4cad: https://www.lisa.blue/help/wind_zone_eurocode_belgium/en_GB

Appendix

A. MCA Score Justification
    I. Cost Breakdown
        a) Sources of cost data
    II. Feasibility Score Justification
        a) Feasibility Score Deck
        b) Feasibility Score Arch
    III. Hindrance Score Justification
        a) Hindrance by Deck Scoring
        b) Hindrance by Arch Scoring
B. SCIA Model Data
    I. Profile Data
C. Calculations Wind Load - Eurocode 1
    I. Input Data
    II. Wind Loads
    III. Shape Factor
    IV. Wind Load Calculated per Member
D. Deck Layout
E. SPMT Layout
F. Different Support Layouts
G. Hanger Check
    I. Buckling Check Hangers
        a) Internal Forces
        b) Buckling Calculation Method
        c) Worked Out Buckling Check–Hangers
        d) Results Buckling Check
    II. Buckling Check Hanger Connection Plate
        a) Internal Forces
        b) Buckling Calculation Method
        c) Worked Out Buckling Check–Hanger Connection
        d) Results Buckling Check Hanger Connection
    III. Conclusion Hanger Check
H. Detail drawings
I. Installation Phases
J. Bridge drawings

Appendix.A MCA Score Justification

Appendix.A.I Cost Breakdown

This appendix shows what the costs are made up of. Note that these costs are indicative, do not have a definitive value, and should not be used for budgeting.

Table 12 - MCA Cost Breakdown Deck Options

			Deck Option 1. [B]			Deck Option 2.		
What		**Cost per day**	**Amount**	**Duration**	**Cost**	**Amount**	**Duration**	**Cost**
Transport Costs								
Barge	Large Barge	5,000	2	1	**10000**	2	1	**10000**
	Small Barge	3,000			**0**			**0**
SPMT		8,800	2	1	**17600**	2	1	**17600**
Tugs		30,000	2	1	**30000**	2	1	**30000**
Assembly Costs								
Support towers	Heavy Tower	1,000	16	10	**160000**	16	13	**208000**
	Light Tower	500	10	10	**50000**	8	13	**52000**
Welding and Conservation		600*	1	90	**54000**	1	90	**45000**

Table 13 - MCA Cost Breakdown Arch Options

			Arch Option 1. [B]			Arch Options 2.			Arch Options 3.		
What		**Cost per day**	**Amount**	**Duration**	**Cost**	**Amount**	**Duration**	**Cost**	**Amount**	**Duration**	**Cost**
Transport Costs											
Barge	Large Barge	5,000			**0**	1	1	**5000**	1	1	**5000**
	Small Barge	3,000			**0**			**0**			**0**
Tugs		300,000			**0**	2	1	**30000**	2	1	**30000**
Crane	Medium	6,200			**0**	2	1	**15400**	2	1	**15400**
	Small	5,800	12	1	**11600**			**0**			**0**
Assembly Costs											
Support towers	Heavy Tower	1,000	4	8	**32000**			**0**	2	4	**8000**
	Light Tower	500			**0**	6	5	**15000**	8	3	**12000**
Crawler Crane	Large Crane	20,000			**0**	1	4	**80000**	1	3	**60000**
	Medium Crane (600T)	14,000	1	4	**56000**			**0**			**0**
Welding and Conservation		600	1	107	**64300**	1	79	**47400**	1	92	**55200**

All costs are in euros, and durations are per day (1 day = 10 work hours).

Table 14 - Total estimated costs per option

Option	Transport	Assembly	**Total**
Deck Option 1. [B]	€ 57,600	€ 264,000	**€ 321,600**
Deck Option 2.	€ 57,600	€ 305,000	**€ 362,600**
Arch Option 1. [B]	€ 11,600	€ 152,300	**€ 163,900**
Arch Options 2.	€ 50,400	€ 142,400	**€ 192,800**
Arch Options 3.	€ 50,400	€ 135,200	**€ 185,600**

Appendix.A.I.a Sources of cost data:

Transport Costs

Barge

Large Barge	€ 5,000	(devaltowing.com/dayrate, 2022)
Small Barge	€ 3,000	(devaltowing.com/dayrate, 2022)
SPMT	€ 8800	(sarassitransport.com, 2015)
- SPMTs - 48 axles	€ 7700	
- Supervisor	€ 600	
- Operator	€ 500	
Tugs	€ 15,000	Based on previous project of ASK Romein Hillebrand
Crane		
Large Crane	€ 14,000	(bigge.com/crane-rental, 2022)
Medium Crane	€ 7,700	(bigge.com/crane-rental, 2022)
Small Crane	€ 5,800	(bigge.com/crane-rental, 2022)

Assembly Costs

Support towers

Heavy Tower	€ 1,000	(Asset of ASK Romein Hillebrand)
Light Tower	€ 500	(Asset of ASK Romein Hillebrand)
Crawler Crane		
Large Crane	€ 20,000	(bigge.com/crane-rental, 2022)
Medium Crane (600T)	€ 14,000	(bigge.com/crane-rental, 2022)
Welding and Conservation		
- Offsite Welding (10hrs/day)	€ 600	
- Onsite Welding (10hrs/day)	€ 500	
- Cost per hour		
- Offsite	€ 60,- /hr	Based on calculations from ASK Romein Hillebrand
- Onsite	€ 50,- /hr	Based on calculations from ASK Romein Hillebrand
- Hours per meter	21,5 hrs	Based on calculations from ASK Romein Hillebrand

(Costs for welding and conservation include work hours, equipment and materials)

Welding length and duration per option:

Deck Option 1:	42 meters	90 days
Deck Option 2:	42 meters	90 days
Arch Option 1:	50 meters	107 days
Arch Option 2:	37 meters	79 days
Arch Option 3:	43 meters	92 days

(Welding duration can be reduced by having multiple welders on-site at once, this does not affect the costs)

Appendix.A.II Feasibility Score Justification

This appendix explains the scores given to the options in the criteria 'feasibility'. A brief explanation will be given, followed by a summarising list of positive (p.) and negative (n.) aspects, followed by a conclusion and score. In the case of the arch options is the best advantage marked as positive and are the other two marked as negative.

Appendix.A.II.a Feasibility Score Deck

Table 15 - MCA Feasibility Score Deck Options

Deck Option 1. [B]	Deck Option 2.
Difficulty to lift	
The bridge deck sections have to be lifted and transported by two SPMTs from the production site onto the barge and from the barge onto the local assembly site. **List of (dis)advantages:** p. Bridge deck can easily be moved by SPMTs n. Two sections to move p. Smaller SPMT groups required n. Twice the time required to move and lift Each section needs two SPMTs to transport the bridge deck sections. As there are two sections, it takes longer to load and off-load the sections.	The bridge deck section has to be lifted and transported by two SPMTs from the production site onto the barge and from the barge onto the local assembly site. **List of (dis)advantages:** p. Bridge deck can easily be moved by SPMTs p. Only one section to move n. Larger SPMT groups required p. shorter time required to move and lift Because the bridge is transported in one section, it will be faster to load and offload the bridge.
Score: 1	**Score: 2**
Installation Complexity	
The bridge deck has to be lined up on the assembly site within a specified accuracy to be able to weld the sections together. The complexity is in the alignment part, which could take more time on-site and could cause a delay. This option will get a lower score due to the alignment needed on-site, which could cause delays. **List of (dis)advantages:** n. Having to line up the sections on site p. No pre-alignment required	Because of the current location layout of the production site, it is not possible to construct the bridge in one of the construction halls and transport it outside for the hall. However, it is possible to build the bridge in two sections and connect them outside at the production site. This would introduce extra costs by having to set the bridge on supports two times, once at the production site and once at the assembly site. The advantage is that it would simplify the on-site set-up as the bridge can be offloaded at set-on supports in one go, and no accurate alignment is needed. **List of (dis)advantages:** p. Only one section to line up on-site n. Pre alignment/setup at facility Flushing However, the 2-time set-up will take a bit more time in total. It will make the on-site assembly easier. Therefore, this option will get a higher score.
Score: 1	**Score: 2**

Appendix.A.II.b Feasibility Score Arch

Table 16 - MCA Feasibility Score Arch Options

Arch Option 1. [B]	Arch Options 2.	Arch Options 2.
Difficulty to lift		
The arch sections are already oriented in the upright position, which means that the sections can easily be lifted from the deck to their final position.	The arch sections are transported separately, and, on their side, this would mean that the arches have to be rotated first and after which lifting points have to be re-positioned to be able to lift the arch to its final location. The effect of self-weight has to be considered as the arch will be longer due to sagging. To overcome this problem, either lifting points in the middle are required or a heavy support tower (Which is capable of supporting half of the arches' weight.)	The arch sections are transported separately but upright; the arches can be lifted directly from their supports onto the bridge. The effect of self-weight has to be considered as the arch will be longer due to sagging. The same solution can be applied to option 2 To overcome this problem.
List of (dis)advantages: p. Relatively small/light sections to lift p. Medium Crane required p. Decent handleability The sections are relatively small compared to the other options; they are easier to handle due to their smaller mass. Therefore, the highest score of 3 is given.	**List of (dis)advantages:** n. Large/Heavy arch to lift n. Two medium or one large crane(s) required n. Very hard to properly handle Because the arch is so long and heavy, it is hard to handle, and a very large or two medium-sized cranes are required to lift the arch. Therefore, the lowest score is given.	**List of (dis)advantages:** n. Large/Heavy sections to lift n. Two medium or one large crane(s) required n. Large/difficult to handle The sections are large and heavy, which makes it hard to handle and lift the section. Therefore, a score of 2 is given.
Score: 3	**Score: 1**	**Score: 2**

Installation Complexity		
As the arch sections are smaller, they can be transported on top of the bridge deck (suggested by the construction manager). The sections are relatively small and are easier to handle as the sections are lighter and smaller in size. This makes it easier to position them properly. **List of (dis)advantages:** p. easy to transport (on bridge deck) p. The smaller sections are easy to lift and position on the temporary supports n. A lot of welding required This option will get the highest score as it is the least complex way to install the arch due to the smaller size and mass.	The arch sections have to be rotated, and the lift points have to be re-positioned. This makes the operation rather complex as the arch has to be supported while the lift points are relocated. Another complex task is the positioning of the arch as it is large and heavy, and there are three positions which have to be placed accurately. The first is in the centre to correct for the sagging, and the second and third points are the basis which has to be placed accurately in order to weld the sections together. **List of (dis)advantages:** n. separate transport and storage on-site required n. The large arch is hard to lift and position. p. Minimum welding required This option receives the lowest score as it introduces the greatest complexity.	The arch sections are large and heavy, making them difficult to handle. The sections are lighter than the arch in option two but heavier than in option 1. **List of (dis)advantages:** n. separate transport and storage on site required. n. The large sections are difficult to lift and position n. More welding required This option will be scored with 2 points as it will be easier than option two but more difficult than option 1.
Score: 3	**Score: 1**	**Score: 2**

Appendix.A.III Hindrance Score Justification

This appendix explains the scores given to the options in the criteria 'hinder'. A brief explanation will be given, followed by a summarising list of positive (p.) and negative (n.) aspects, followed by a conclusion and score. In the case of the arch options is the best advantage marked as positive and are the other two marked as negative.

Appendix.A.III.a Hindrance by Deck Scoring

Table 17 - MCA Hindrance Score Deck Options

Deck Option 1. [B]	Deck Option 2.
Hindrance to traffic	
The bridge will be transported via the water and will have little to no hindrance to traffic during transport. The assembly site is closed for traffic during the full assembly duration, so it hinders specific to the transport option. The support towers are most likely going to be transported via the road. This adds some heavy traffic to the local roads **List of (dis)advantages:** n. Support towers are transported via the road in advance. p. No other hindrance by this option Because both options have the same negative aspects, a score of 1 is given to both.	The bridge will be transported via the water and will have little to no hindrance to traffic during transport. The assembly site is closed for traffic during the full assembly duration, so it hinders specific to the transport option. The support towers are most likely going to be transported via the road. This adds some heavy traffic to the local roads **List of (dis)advantages:** n. Support towers are transported via the road in advance. p. No other hindrance by this option Because both options have the same negative aspects, a score of 1 is given to both.
Score: 1	**Score: 1**
Hindrance to shipping	
The bridge will be transported via the water on barges. The two sections will be offloaded from the barge by using 2 SPMTs this needs to happen twice as there are two sections during the off-loading of the bridge sections shipping needs to be halted to prevent waves from disturbing the offloading phase. **List of (dis)advantages:** n. Shipping in Albert Channel hindered during disembarking Because there are two sections to off-load, the shipping needs to be halted twice. Therefore, it will receive a score of 1.	The bridge will be transported via the water on barges. The bridge will be offloaded from the barge by using 2 SPMTs. During the off-loading of the bridge sections, shipping needs to be halted to prevent waves from disturbing the offloading phase. **List of (dis)advantages:** n. Shipping in Albert Channel hindered during disembarking The off-loading only needs to happen once; thus, shipping must be halted for one off-loading period. For this, a score of 2 is applied.
Score: 1	**Score: 2**

Appendix.A.III.b Hindrance by Arch Scoring

Table 18 - MCA Hindrance Score Arch Options

Arch Option 1. [B]	Arch Options 2.	Arch Options 2.
Hindrance to traffic		
The arch sections will be transported via the water and will have little to no hindrance to traffic during transport. The crane required to lift the arch sections will not be evasively large and will thus drive (by itself) over the road. **List of (dis)advantages:** n. Medium-sized crane to be transported via the road. The crane will have the least impact of all options thus will, this option receive the highest score.	The arch sections will be transported via the water and will have little to no hindrance to traffic during transport. The crane required to lift the arch sections will be the largest of each option and will be transported over the road in several sections by multiple trucks. **List of (dis)advantages:** n. Large-sized crane to be transported via the road. The crane transport will have the greatest impact on road traffic; thus, the lowest score is applied.	The arch sections will be transported via the water and will have little to no hindrance to traffic during transport. The crane required to lift the arch sections will be quite large and will thus drive by itself or transported in sections by multiple trucks over the road. (Depending on the model) **List of (dis)advantages:** n. Large-sized crane to be transported via the road. The impact of this option is in between the other options. Therefore a score of 2 is given.
Score: 3	**Score: 1**	**Score: 2**
Hindrance to shipping		
The arch sections will be transported on top of the bridge deck and will therefore have no effect on shipping. **List of (dis)advantages:** p. No hindrance to shipping as sections will be on the bridge deck A score of 3 is applied because there is no hinder.	The arch sections will be transported via the water to the assembly site. This is done separately and will require an off-loading moment where shipping is halted to prevent waves from disturbing the process. This needs to happen twice as there are two arches. **List of (dis)advantages:** n. Hindrance to shipping when off-loading from the barge A score of 1 is applied because shipping needs to be halted twice. (Because options 2 and 3 have the same amount of hinder, each option gets a score of 1)	The arch sections will be transported via the water to the assembly site. This is done separately and will require an off-loading moment where shipping is halted to prevent waves from disturbing the process. This needs to happen twice as there are two arches. **List of (dis)advantages:** n. Hindrance to shipping when off-loading from the barge A score of 1 is applied because shipping needs to be halted twice. (Because options 2 and 3 have the same amount of hinder, each option gets a score of 1)
Score: 3	**Score: 1**	**Score: 1**

Appendix.B SCIA Model Data

Appendix.B.I Members in SCIA

Name	Cross-section	Material	Length [mm]	Beg. Node	End Node	Type
S1	CS1 - O (1600; 50; 2200; 50)	S355	8000	K1	K2	plate rib -92
S2	CS2 - O (1600; 20; 2200; 50)	S355	18000	K2	K3	plate rib -92
S3	CS3 - O (1600; 20; 2200; 30)	S355	49000	K3	K4	plate rib -92
S4	CS4 - O (1600; 50; 2400; 50)	S355	27752.96	K5	K6	general 0
S5	CS4 - O (1600; 50; 2400; 50)	S355	7369.424	K6	K7	general 0
S6	CS5 - O (1600; 45; 1800; 45)	S355	7369.424	K7	K8	general 0
S7	CS5 - O (1600; 45; 1800; 45)	S355	7166.647	K8	K9	general 0
S8	CS6 - O (1600; 40; 1600; 40)	S355	7166.647	K9	K10	general 0
S9	CS6 - O (1600; 40; 1600; 40)	S355	7042.004	K10	K11	general 0
S10	CS6 - O (1600; 40; 1600; 40)	S355	7042.004	K11	K12	general 0
S11	CS6 - O (1600; 40; 1600; 40)	S355	7000	K12	K13	general 0
S12	CS7 - Buis (508; 16)	S355	13936.52	K14	K6	general 0
S13	CS7 - Buis (508; 16)	S355	13936.52	K6	K15	general 0
S14	CS7 - Buis (508; 16)	S355	18069.93	K15	K8	general 0
S15	CS7 - Buis (508; 16)	S355	20936.85	K10	K16	general 0
S16	CS7 - Buis (508; 16)	S355	22390.35	K16	K12	general 0
S17	CS7 - Buis (508; 16)	S355	22390.35	K12	K4	general 0
S18	CS8 - Buis (508; 30)	S355	18069.93	K8	K17	general 0
S19	CS8 - Buis (508; 30)	S355	20936.85	K17	K10	general 0
S20	CS1 - O (1600; 50; 2200; 50)	S355	8000	K18	K19	plate rib -92
S21	CS2 - O (1600; 20; 2200; 50)	S355	18000	K19	K20	plate rib -92
S22	CS3 - O (1600; 20; 2200; 30)	S355	49000	K20	K4	plate rib -92
S23	CS4 - O (1600; 50; 2400; 50)	S355	27752.96	K21	K22	general 0
S24	CS4 - O (1600; 50; 2400; 50)	S355	7369.424	K22	K23	general 0
S25	CS5 - O (1600; 45; 1800; 45)	S355	7369.424	K23	K24	general 0
S26	CS5 - O (1600; 45; 1800; 45)	S355	7166.647	K24	K25	general 0
S27	CS6 - O (1600; 40; 1600; 40)	S355	7166.647	K25	K26	general 0
S28	CS6 - O (1600; 40; 1600; 40)	S355	7042.004	K26	K27	general 0
S29	CS6 - O (1600; 40; 1600; 40)	S355	7042.004	K27	K28	general 0
S30	CS6 - O (1600; 40; 1600; 40)	S355	7000	K28	K13	general 0
S31	CS7 - Buis (508; 16)	S355	13936.52	K29	K22	general 0
S32	CS7 - Buis (508; 16)	S355	13936.52	K22	K30	general 0
S33	CS7 - Buis (508; 16)	S355	18069.93	K30	K24	general 0
S34	CS7 - Buis (508; 16)	S355	20936.85	K26	K31	general 0
S35	CS7 - Buis (508; 16)	S355	22390.35	K31	K28	general 0
S36	CS7 - Buis (508; 16)	S355	22390.35	K28	K4	general 0
S37	CS8 - Buis (508; 30)	S355	18069.93	K24	K32	general 0
S38	CS8 - Buis (508; 30)	S355	20936.85	K32	K26	general 0
S39	CS1 - O (1600; 50; 2200; 50)	S355	8000	K33	K34	plate rib -92
S40	CS2 - O (1600; 20; 2200; 50)	S355	18000	K34	K35	plate rib -92
S41	CS3 - O (1600; 20; 2200; 30)	S355	49000	K35	K36	plate rib -92
S42	CS4 - O (1600; 50; 2400; 50)	S355	27752.96	K37	K38	general 0

S43	CS4 - O (1600; 50; 2400; 50)	S355	7369.424	K38	K39	general 0
S44	CS5 - O (1600; 45; 1800; 45)	S355	7369.424	K39	K40	general 0
S45	CS5 - O (1600; 45; 1800; 45)	S355	7166.647	K40	K41	general 0
S46	CS6 - O (1600; 40; 1600; 40)	S355	7166.647	K41	K42	general 0
S47	CS6 - O (1600; 40; 1600; 40)	S355	7042.004	K42	K43	general 0
S48	CS6 - O (1600; 40; 1600; 40)	S355	7042.004	K43	K44	general 0
S49	CS6 - O (1600; 40; 1600; 40)	S355	7000	K44	K45	general 0
S50	CS7 - Buis (508; 16)	S355	13936.52	K46	K38	general 0
S51	CS7 - Buis (508; 16)	S355	13936.52	K38	K47	general 0
S52	CS7 - Buis (508; 16)	S355	18069.93	K47	K40	general 0
S53	CS7 - Buis (508; 16)	S355	20936.85	K42	K48	general 0
S54	CS7 - Buis (508; 16)	S355	22390.35	K48	K44	general 0
S55	CS7 - Buis (508; 16)	S355	22390.35	K44	K36	general 0
S56	CS8 - Buis (508; 30)	S355	18069.93	K40	K49	general 0
S57	CS8 - Buis (508; 30)	S355	20936.85	K49	K42	general 0
S58	CS1 - O (1600; 50; 2200; 50)	S355	8000	K50	K51	plate rib -92
S59	CS2 - O (1600; 20; 2200; 50)	S355	18000	K51	K52	plate rib -92
S60	CS3 - O (1600; 20; 2200; 30)	S355	49000	K52	K36	plate rib -92
S61	CS4 - O (1600; 50; 2400; 50)	S355	27752.96	K53	K54	general 0
S62	CS4 - O (1600; 50; 2400; 50)	S355	7369.424	K54	K55	general 0
S63	CS5 - O (1600; 45; 1800; 45)	S355	7369.424	K55	K56	general 0
S64	CS5 - O (1600; 45; 1800; 45)	S355	7166.647	K56	K57	general 0
S65	CS6 - O (1600; 40; 1600; 40)	S355	7166.647	K57	K58	general 0
S66	CS6 - O (1600; 40; 1600; 40)	S355	7042.004	K58	K59	general 0
S67	CS6 - O (1600; 40; 1600; 40)	S355	7042.004	K59	K60	general 0
S68	CS6 - O (1600; 40; 1600; 40)	S355	7000	K60	K45	general 0
S69	CS7 - Buis (508; 16)	S355	13936.52	K61	K54	general 0
S70	CS7 - Buis (508; 16)	S355	13936.52	K54	K62	general 0
S71	CS7 - Buis (508; 16)	S355	18069.93	K62	K56	general 0
S72	CS7 - Buis (508; 16)	S355	20936.85	K58	K63	general 0
S73	CS7 - Buis (508; 16)	S355	22390.35	K63	K60	general 0
S74	CS7 - Buis (508; 16)	S355	22390.35	K60	K36	general 0
S75	CS8 - Buis (508; 30)	S355	18069.93	K56	K64	general 0
S76	CS8 - Buis (508; 30)	S355	20936.85	K64	K58	general 0
Cross-Beam (Side)	CS9 - Cross-Beam Right Side - General cross-section	S355	23200	K25	K57	beam -80
Cross-Beam (Side)1	CS9 - Cross-Beam Right Side - General cross-section	S355	23200	K41	K9	beam -80
Cross-Beam (Side)2	CS10 - Cross-Beam Mid - O (1600; 30; 1600; 30)	S355	23200	K13	K45	beam -80
Trog8	Trog - General cross-section	S355	150000	N73	N74	plate rib -92
Trog9	Trog - General cross-section	S355	150000	N75	N76	plate rib -92
Trog10	Trog - General cross-section	S355	150000	N77	N78	plate rib -92
Trog11	Trog - General cross-section	S355	150000	N79	N80	plate rib -92
Trog12	Trog - General cross-section	S355	150000	N81	N82	plate rib -92
Trog13	Trog - General cross-section	S355	150000	N83	N84	plate rib -92

Trog14	Trog - General cross-section	S355	150000	N85	N86	plate rib -92
Trog15	Trog - General cross-section	S355	150000	N87	N88	plate rib -92
Trog16	Trog - General cross-section	S355	150000	N89	N90	plate rib -92
Trog17	Trog - General cross-section	S355	150000	N91	N92	plate rib -92
Trog18	Trog - General cross-section	S355	150000	N93	N94	plate rib -92
Trog19	Trog - General cross-section	S355	150000	N95	N96	plate rib -92
Trog20	Trog - General cross-section	S355	150000	N97	N98	plate rib -92
Trog21	Trog - General cross-section	S355	150000	N99	N100	plate rib -92
Trog22	Trog - General cross-section	S355	150000	N101	N102	plate rib -92
Trog23	Trog - General cross-section	S355	150000	N103	N104	plate rib -92
Trog24	Trog - General cross-section	S355	150000	N105	N106	plate rib -92
Trog25	Trog - General cross-section	S355	150000	N107	N108	plate rib -92
Trog26	Trog - General cross-section	S355	150000	N109	N110	plate rib -92
Trog27	Trog - General cross-section	S355	150000	N111	N112	plate rib -92
Trog28	Trog - General cross-section	S355	150000	N113	N114	plate rib -92
Trog29	Trog - General cross-section	S355	150000	N115	N116	plate rib -92
Trog30	Trog - General cross-section	S355	150000	N117	N118	plate rib -92
Trog31	Trog - General cross-section	S355	150000	N119	N120	plate rib -92
Trog32	Trog - General cross-section	S355	150000	N121	N122	plate rib -92
Trog33	Trog - General cross-section	S355	150000	N123	N124	plate rib -92
Trog34	Trog - General cross-section	S355	150000	N125	N126	plate rib -92
Trog35	Trog - General cross-section	S355	150000	N127	N128	plate rib -92
Trog36	Trog - General cross-section	S355	150000	N129	N130	plate rib -92
Trog37	Trog - General cross-section	S355	150000	N131	N132	plate rib -92
Trog38	Trog - General cross-section	S355	150000	N133	N134	plate rib -92
Trog39	Trog - General cross-section	S355	150000	N135	N136	plate rib -92
Trog40	Trog - General cross-section	S355	150000	N137	N138	plate rib -92
Trog41	Trog - General cross-section	S355	150000	N139	N140	plate rib -92
Trog42	Trog - General cross-section	S355	150000	N141	N142	plate rib -92
Trog43	Trog - General cross-section	S355	150000	N143	N144	plate rib -92
Purlin	Purlin1 - General cross-section	S355	23200	K21	K53	plate rib -92
Purlin1	Purlin1 - General cross-section	S355	23200	K65	K66	plate rib -92
Purlin2	Purlin1 - General cross-section	S355	23200	K68	K67	plate rib -92
Purlin3	Purlin1 - General cross-section	S355	23200	K69	K70	plate rib -92
Purlin4	Purlin1 - General cross-section	S355	23200	N1	N2	plate rib -92
Purlin5	Purlin1 - General cross-section	S355	23200	K29	K61	plate rib -92
Purlin6	Purlin1 - General cross-section	S355	23200	N3	N4	plate rib -92
Purlin7	Purlin1 - General cross-section	S355	23200	K20	K52	plate rib -92
Purlin8	Purlin1 - General cross-section	S355	23200	N6	N5	plate rib -92
Purlin9	Purlin1 - General cross-section	S355	23200	K30	K62	plate rib -92
Purlin10	Purlin1 - General cross-section	S355	23200	N7	N8	plate rib -92
Purlin11	Purlin1 - General cross-section	S355	23200	N10	N9	plate rib -92
Purlin12	Purlin1 - General cross-section	S355	23200	N11	N12	plate rib -92
Purlin13	Purlin1 - General cross-section	S355	23200	K32	K64	plate rib -92
Purlin14	Purlin1 - General cross-section	S355	23200	N14	N13	plate rib -92
Purlin15	Purlin1 - General cross-section	S355	23200	N15	N16	plate rib -92

Purlin16	Purlin1 - General cross-section	S355	23200	N17	N18	plate rib -92
Purlin17	Purlin1 - General cross-section	S355	23200	K31	K63	plate rib -92
Purlin18	Purlin1 - General cross-section	S355	23200	N19	N20	plate rib -92
Purlin19	Purlin1 - General cross-section	S355	23200	N21	N22	plate rib -92
Purlin20	Purlin1 - General cross-section	S355	23200	N24	N23	plate rib -92
Purlin21	Purlin1 - General cross-section	S355	23200	K4	K36	plate rib -92
Purlin22	Purlin1 - General cross-section	S355	23200	N25	N26	plate rib -92
Purlin23	Purlin1 - General cross-section	S355	23200	N28	N27	plate rib -92
Purlin24	Purlin1 - General cross-section	S355	23200	N29	N30	plate rib -92
Purlin25	Purlin1 - General cross-section	S355	23200	K16	K48	plate rib -92
Purlin26	Purlin1 - General cross-section	S355	23200	N32	N31	plate rib -92
Purlin27	Purlin1 - General cross-section	S355	23200	N33	N34	plate rib -92
Purlin28	Purlin1 - General cross-section	S355	23200	N45	N46	plate rib -92
Purlin29	Purlin1 - General cross-section	S355	23200	K17	K49	plate rib -92
Purlin30	Purlin1 - General cross-section	S355	23200	N47	N48	plate rib -92
Purlin31	Purlin1 - General cross-section	S355	23200	N49	N50	plate rib -92
Purlin32	Purlin1 - General cross-section	S355	23200	N52	N51	plate rib -92
Purlin33	Purlin1 - General cross-section	S355	23200	K15	K47	plate rib -92
Purlin34	Purlin1 - General cross-section	S355	23200	N53	N54	plate rib -92
Purlin35	Purlin1 - General cross-section	S355	23200	K3	K35	plate rib -92
Purlin36	Purlin1 - General cross-section	S355	23200	N55	N56	plate rib -92
Purlin37	Purlin1 - General cross-section	S355	23200	K14	K46	plate rib -92
Purlin38	Purlin1 - General cross-section	S355	23200	N36	N35	plate rib -92
Purlin39	Purlin1 - General cross-section	S355	23200	N37	N38	plate rib -92
Purlin40	Purlin1 - General cross-section	S355	23200	N39	N40	plate rib -92
Purlin41	Purlin1 - General cross-section	S355	23200	N42	N41	plate rib -92
Purlin42	Purlin1 - General cross-section	S355	23200	K5	K37	plate rib -92

Appendix.B.II Nodes

Name	Coord X [mm]	Coord Y [mm]	Coord Z [mm]	Name	Coord X [mm]	Coord Y [mm]	Coord Z [mm]
K1	85000	172000	1100	K41	108200	125000	19295
K2	85000	164000	1100	K42	108200	118000	20832
K3	85000	146000	1100	K43	108200	111000	21600
K4	85000	97000	1100	K44	108200	104000	22368
K5	85000	171000	1100	K45	108200	97000	22368
K6	85000	146000	13151	K46	108200	153000	1100
K7	85000	139000	15455	K47	108200	139000	1100
K8	85000	132000	17759	K48	108200	111000	1100
K9	85000	125000	19295.5	K49	108200	125000	1100
K10	85000	118000	20832	K50	108200	22000	1100
K11	85000	111000	21600	K51	108200	30000	1100
K12	85000	104000	22368	K52	108200	48000	1100
K13	85000	97000	22368	K53	108200	23000	1100
K14	85000	153000	1100	K54	108200	48000	13151
K15	85000	139000	1100	K55	108200	55000	15455
K16	85000	111000	1100	K56	108200	62000	17759
K17	85000	125000	1100	K57	108200	69000	19295.5
K18	85000	22000	1100	K58	108200	76000	20832
K19	85000	30000	1100	K59	108200	83000	21600
K20	85000	48000	1100	K60	108200	90000	22368
K21	85000	23000	1100	K61	108200	41000	1100
K22	85000	48000	13151	K62	108200	55000	1100
K23	85000	55000	15455	K63	108200	83000	1100
K24	85000	62000	17759	K64	108200	69000	1100
K25	85000	69000	19295.5	K65	85000	27000	1100
K26	85000	76000	20832	K66	108200	27000	1100
K27	85000	83000	21600	K67	108200	30500	1100
K28	85000	90000	22368	K68	85000	30500	1100
K29	85000	41000	1100	K69	85000	34000	1100
K30	85000	55000	1100	K70	108200	34000	1100
K31	85000	83000	1100	N1	85000	37500	1100
K32	85000	69000	1100	N2	108200	37500	1100
K33	108200	172000	1100	N3	85000	44500	1100
K34	108200	164000	1100	N4	108200	44500	1100
K35	108200	146000	1100	N5	108200	51500	1100
K36	108200	97000	1100	N6	85000	51500	1100
K37	108200	171000	1100	N7	85000	58500	1100
K38	108200	146000	13151	N8	108200	58500	1100
K39	108200	139000	15455	N9	108200	62000	1100
K40	108200	132000	17759	N10	85000	62000	1100

Name	Coord X [mm]	Coord Y [mm]	Coord Z [mm]
N11	85000	65500	1100
N12	108200	65500	1100
N13	108200	72500	1100
N14	85000	72500	1100
N15	85000	76000	1100
N16	108200	76000	1100
N17	85000	79500	1100
N18	108200	79500	1100
N19	85000	86500	1100
N20	108200	86500	1100
N21	85000	90000	1100
N22	108200	90000	1100
N23	108200	93500	1100
N24	85000	93500	1100
N25	85000	100500	1100
N26	108200	100500	1100
N27	108200	104000	1100
N28	85000	104000	1100
N29	85000	107500	1100
N30	108200	107500	1100
N31	108200	114500	1100
N32	85000	114500	1100
N33	85000	118000	1100
N34	108200	118000	1100
N35	108200	156500	1100
N36	85000	156500	1100
N37	85000	160000	1100
N38	108200	160000	1100
N39	85000	163500	1100
N40	108200	163500	1100
N41	108200	167000	1100
N42	85000	167000	1100
N43	85000	170500	1100
N44	108200	170500	1100
N45	85000	121500	1100
N46	108200	121500	1100
N47	85000	128500	1100
N48	108200	128500	1100
N49	85000	132000	1100
N50	108200	132000	1100
N51	108200	135500	1100
N52	85000	135500	1100
N53	85000	142500	1100
N54	108200	142500	1100
N55	85000	149500	1100
N56	108200	149500	1100
N73	91650	22000	1100
N74	91650	172000	1100
N75	92250	22000	1100
N76	92250	172000	1100
N77	92850	22000	1100
N78	92850	172000	1100
N79	93450	22000	1100
N80	93450	172000	1100
N81	94050	22000	1100
N82	94050	172000	1100
N83	94650	22000	1100
N84	94650	172000	1100
N85	95250	22000	1100
N86	95250	172000	1100
N87	95850	22000	1100
N88	95850	172000	1100
N89	96450	22000	1100
N90	96450	172000	1100
N91	97050	22000	1100
N92	97050	172000	1100
N93	97650	22000	1100
N94	97650	172000	1100
N95	98250	22000	1100
N96	98250	172000	1100
N97	98850	22000	1100
N98	98850	172000	1100
N99	99450	22000	1100
N100	99450	172000	1100
N101	100050	22000	1100
N102	100050	172000	1100
N103	100650	22000	1100
N104	100650	172000	1100
N105	101250	22000	1100
N106	101250	172000	1100
N107	101850	22000	1100
N108	101850	172000	1100
N109	102450	22000	1100
N110	102450	172000	1100
N111	103050	22000	1100
N112	103050	172000	1100
N113	103650	22000	1100
N114	103650	172000	1100
N115	104250	22000	1100
N116	104250	172000	1100
N117	104850	22000	1100
N118	104850	172000	1100
N119	105450	22000	1100
N120	105450	172000	1100
N121	106050	22000	1100
N122	106050	172000	1100
N123	106650	22000	1100
N124	106650	172000	1100
N125	107250	22000	1100
N126	107250	172000	1100
N127	86100	22000	1100
N128	86100	172000	1100
N129	88050	22000	1100
N130	88050	172000	1100
N131	88650	22000	1100
N132	88650	172000	1100
N133	89250	22000	1100
N134	89250	172000	1100
N135	89850	22000	1100
N136	89850	172000	1100
N137	90450	22000	1100
N138	90450	172000	1100
N139	91050	22000	1100
N140	91050	172000	1100
N141	86850	22000	1100
N142	86850	172000	1100
N143	87450	22000	1100
N144	87450	172000	1100

Appendix.B.III Profile Data

Profiles		Part	Size	Unit [mm]
CS1	Main Beam 1	Main Beam Part 1	B	2200
			thb	50
			A	1600
			tha	50
CS2	Main Beam 2	Main Beam Part 2	B	2200
			thb	40
			A	1600
			tha	20
CS3	Main Beam 3	Main Beam Part 3	B	2200
			thb	30
			A	1600
			tha	20
CS4	Arch 1	Side Arch Part1	B	2400
			thb	50
			A	1600
			tha	50
CS5	Arch 2	Side Arch Part 2	B	1800
			thb	45
			A	1600
			tha	45
CS6	Arch 3	Middle Arch	B	1600
			thb	40
			A	1600
			tha	40
CS7	Hangers	CHS508-16	D	508
			t	16
CS8	Hangers	CHS508-30	D	508
			t	30
CS9*	Crossbeam Side	Crossbeam Sides	B-1	1761
			B-2	1744
			A	1600
			thb - tha	30
CS10	Crossbeam Middle	Crossbeam Middle	B – A	1600
			thb – tha	30
CS11	Trog	Bridge Deck structure	B	350
			A	300
			T	8
CS12	Purlin	Bridge Deck structure	B	1200
			thb	18
			A	400
			tha	30

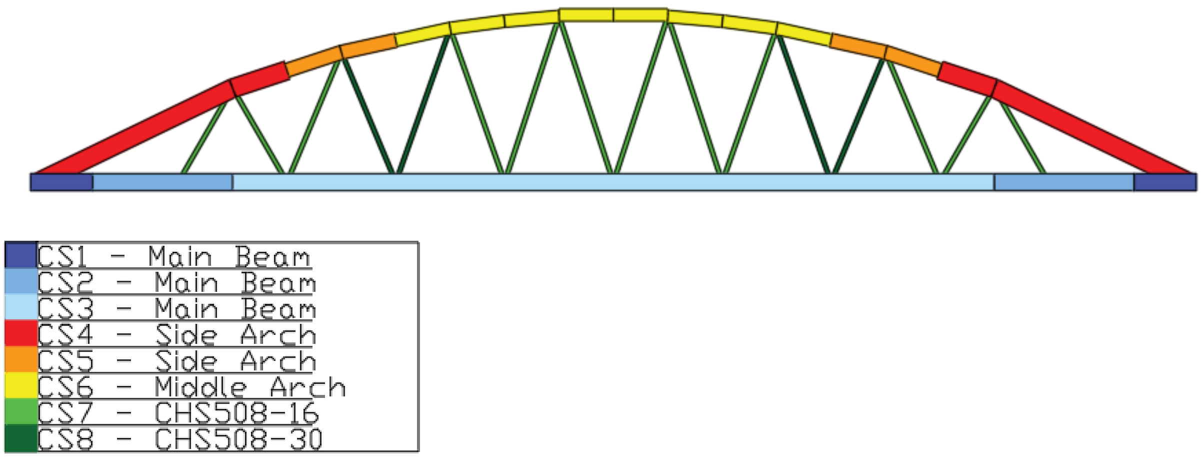


Figure 51 - Profile indication of SCIA Model

Appendix.C Calculations Wind Load - Eurocode 1

Appendix.C.I Input data

Total bridge length	b	=	150	m
Width of bridge	d	=	24.7	m
Height of structure	h	=	23.36	m
Height of supports	h_s	=	2	m
Maximum height	z	=	25.36	m
Terrain Category			IV	

Appendix.C.II Wind Loads

EC1 – 4.1) Basic Values

Determination of basic wind velocity

$v_{b,0}$ = 25 m/s (lisa.blue/help/wind_zone_eurocode_belgium)

Equation 1 - fundamental basic wind velocity

$$v_b = C_{dir} * C_{season} * v_{b,0}$$

Where
v_b - basic wind velocity
C_{dir} - directional factor
C_{season} - seasonal factor
$v_{b,0}$ - fundamental basic wind velocity

Eurocode defines: Unless C_{dir}, and C_{season} are mentioned in a national annexe. The value is 1,0
As a simplification, are the values C_{dir} and C_{season} equal to 1,0

v_b = $C_{dir}*C_{season}*v_{b,0}$
= 1*1*25
= **25 m/s**

EC1 – 4.2) Basic Velocity Pressure

Equation 2 - Basic Velocity Pressure

$$q_b = \frac{1}{2} * \rho_{air} * v_b^2$$

where
q_b - Basic velocity pressure
ρ_{air} - 1.36 kg/m^3 (max. air density Netherlands)

q_b = $1/2*\rho_{air}*v_b^2$
q_b = 1/2*1.36*25^2
= **425 N/m^2**

Maximum air density (according to KNMI) is chosen as a conservative approach. Data is from the Netherlands as it is a reliable source, and it is applicable to Antwerp as it is at the border

EC1 - 4.3) Mean Wind

EC1 - 4.3.1) Variation with height

The mean wind velocity $v_m(z)$ at a height z above the terrain depends on the terrain roughness and orography and on the basic wind velocity, v_b

Equation 3 - Mean Wind Velocity

$$v_m(z) = C_r(z) * C_0(z) * v_b$$

where	$v_m(z)$	-	Mean wind velocity at z
	$C_r(z)$	-	is the roughness factor given in EC1 - 4.3.2
	$C_o(z)$	-	is the orography factor, taken as 1,0

Eurocode 1: Defines in paragraph 4.3.3. The effects of orography (C_o) may be neglected when the average slope is less than 3°.

EC1 - 4.3.2) Terrain Roughness

The roughness factor $c_r(z)$ accounts for the variability of the mean wind velocity at the site of the structure due to:
- the height above ground level
- the ground roughness of the terrain upwind of the structure in the wind direction considered

Equation 4 - Roughness Factor [1]

$$[1]\ c_r(z) = k_r * \ln\left(\frac{z}{z_0}\right)$$ when $z_{min} \le z \le z_{max}$

Equation 5 - Roughness Factor [2]

$$[2]\ c_r(z) = c_r(z_{min})$$ when $z \le z_{min}$

where	$c_r(z)$	-	roughness factor
	z_0	-	is the roughness length
	k_r	-	Terrain factor depending on roughness length z_0

Equation 6 - Terrain Factor depending on roughness length z_0

$$k_r = 0.19 * \left(\frac{z_0}{z_{0,II}}\right)^{0.07}$$

where	$z_{0,II}$	=	1 m (terrain category IV, Table 19)
	z_{min}	-	is the minimum height defined in Table 19
	z_{max}	-	is to be taken as 200 m

Applicable = $z_{min} \le z \le z_{max}$

k_r	=	$0.19*(z_0/z_{0,II})^{0.07}$
	=	0.19*(1/1)^0.07)
	=	**0.19 [-]**
$c_r(z)$	=	$k_r*\ln(z/z_0)$
	=	0.19*ln(25.36/1)
	=	**0.61 [-]**

$v_m(z)$	=	$c_r(z)*C_o(z)*v_b$
	=	0.61*1.0*25
	=	**15.25 m/s**

EC1 - 4.4) Wind Turbulence

The turbulence intensity Iv(z) at height z is defined as the standard deviation of the turbulence divided by the mean wind velocity.

Equation 7 - Turbulence intensity at height z [1]

$$I_v(z) = \frac{k_l}{C_0(Z) * \ln\left(\frac{z}{z_0}\right)} \quad \text{when} \quad z_{min} \leq z \leq z_{max}$$

Equation 8 - Turbulence intensity at height z [2]

$$I_v(z) = I_v(z_{min}) \quad \text{when} \quad z \leq z_{min}$$

Where	$I_v(z)$	-	is the turbulence intensity
	k_l	-	Is turbulence factor.
	C_o	-	Orography factor as described in Eurocode 1: 4.3.3
	Z_0	-	Roughness length is given in Table 19 of Eurocode 1:

Eurocode 1: Defines in paragraph 4.4 Unless k_l is mentioned in a national annexe. The value is 1,0

As a simplification is, the values k_l equal to 1,0

Value to be taken

for Z_{max}	=	200 m
Applicable	=	$z_{min} \leq z \leq z_{max}$
$I_v(z)$	=	$k_l/(C_o(z)*\ln(z/z_0))$
	=	1/(1*ln(25.36/1))
	=	**0.31** [-]

EC1 - 4.5) Peak pressure

The peak velocity pressure $q_p(z)$ at height z, which includes mean and short-term velocity fluctuations, should be determined.

Equation 9 - Peak Velocity Pressure at height (z)

$$q_p(z) = (1 + 7 * I_v(z)) * \frac{1}{2} * \rho * v_m(z)^2$$

Where	$q_p(z)$	-	Peak velocity pressure
	$I_v(z)$	-	is the turbulence intensity
	ρ	-	is the air density
	$v_m(z)$	-	mean wind velocity

$$q_p(z) = (1+7*I_v(z))*1/2*\rho*v_m(z)^2$$
$$= (1+7*0.31)*1/2*1.36*15.25\text{^}2$$
$$= \mathbf{501.31173\ \ N/m^2}$$

Table 19 - Terrain Category

Terrain category		Z_0 [m]	Z_{min} [m]
0	Sea or coastal area exposed to the open sea	0.003	1
I	Lakes or flat and horizontal areas with negligible vegetation and without obstacles	0.01	1
II	Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights	0.05	2
III	Area with a regular cover of vegetation or buildings or with isolated obstacles with separations of a maximum of 20 obstacle heights (such as villages, suburban terrain, permanent forest)	0.3	5
IV	Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m	1	10

Appendix.C.III Shape factor

The shapes and sizes of different profiles have different effects on the wind load. For this, a shape factor has to be calculated and applied.

EC1 - 7.6) Structural Element with Rectangular Sections

The force coefficient Cf of structural elements of a rectangular section with the wind normally blowing to a face should be determined by Equation 10:

Equation 10 - Force Coefficient

$$c_f = c_{f,0} * \psi_r * \psi_\lambda$$

Where

c_f	-	Force Coefficient of elements with rectangular section
$c_{f,0}$	-	Is the force coefficient of rectangular sections with sharp corners and without free-end flow. Figure 52
ψ_r	-	Is the reduction factor for square sections with rounded corners. See Figure 53
ψ_λ	-	is the end-effect for elements with free flow

ψ_r = 1 [-]

It is assumed that the structure has no rounded corners; therefore, ψ_r is the value 1,0

The solidity ratio φ (see figure 7.37) is given by

Equation 11 - Solidity Ratio

$$\varphi = A/A_c$$

Where

A	-	sum of projected areas of the members
A_c	-	overall envelope area

Equation 12 - Overall Envelope Area

$$A_c = l * b$$

see Figure 55

= 3504 m^2

A = 794.40 m^2 See table [member data]

φ = A/Ac

= **0.23** [-]

For the following calculations is a difference made for each cross-section

Table 20 - Force Coefficient of Rectangular Sections with Sharp Corners

Section		Height (b) [mm]	Width (d) [mm]	d/b [-]	$c_{f,0}$ [-]
Main beam	(CS1-2-3)	2200	1600	0.73	2.40
Arch 1	(CS4)	2400	1600	0.67	2.35
Arch 1	(CS5)	1800	1600	0.89	2.20
Arch 2	(CS6)	1600	1600	1.00	2.10

All sections are joined on both ends; therefore, no end factor is present

ψ_λ = 1 [-]

c_f = $c_{f,0} * \psi_r * \psi_\lambda$

Table 21 - Force Coefficient of elements of rectangular section

Section		$c_{f,0}$ [-]	ψ_λ [-]	ψ_r [-]	c_f [-]
Main beam	CS1,2,3	2.40	1	1	**2.40**
Arch 1	CS4	2.35	1	1	**2.35**
Arch 1	CS5	2.20	1	1	**2.20**
Arch 2	CS6	2.10	1	1	**2.10**

7.9) Circular Cylinders

7.9.1) External Pressure Coefficients

(1) Pressure coefficients of sections depend upon the Reynolds numbers Re defined by Equation 13

Equation 13 - Reynolds Number

$$Re = b * v(z_e)/\nu$$

Where
- Re - Reynolds Number
- b - is the diameter
- $v(z_e)$ - is the peak wind velocity
- ν - is the kinematic viscosity of the air

b = 508

According to Eurocode 1 ν = 0.000015 m^2/s

Equation 14 - Peak wind velocity

$$v(z_e) = \sqrt{\left(\frac{2 * q_p(z)}{\rho}\right)}$$

where
- $q_p(z)$ - Peak velocity pressure
- ρ_{air} - Air Density

$q_p(z)$ = 501.31173 N/m^2 (Calculated in EC1 - 4.5)

ρ_{air} = 1.36 kN/m^3 (Max air density, (KNMI, 2019))

$v(z_e)$ = √((2*q_p(z))/(ρ))

= √((2*501.311725))/(1.36*10^3))

= **0.86 m/s**

Re = b*$v(z_e)$/ν

= 508*0.86/0.000015

= **2.91E+07** [-]

(2) The external pressure coefficients c_{pe} of circular cylinders should be determined from:

Equation 15 - External Pressure Coefficients

$$c_{pe} = c_{p,0} * \psi_{\lambda\alpha}$$

Where
- c_{pe} - External pressure coefficient for circular cylinders
- $c_{p,0}$ - is the external pressure coefficient without free-end flow
- $\psi_{\lambda\alpha}$ - is the end-effect factor

The hangers are connected at both ends; therefore, no end-effect factor is present.

$\psi_{\lambda\alpha}$ value is 1

Figure 7.27 gives	**S**	**=**	**1**
When	Re	=	1.00E+07
	α	=	0

7.9.2 Force Coefficients

The force coefficient Cf for a finite circular cylinder should be determined from Equation 16

Equation 16 - Force Coefficient

$$c_f = c_{f,0} * \psi_\lambda$$

Where	c_f	-	is force coefficient
	$c_{f,0}$	-	is force Coefficient without free-end flow
	ψ_λ	-	is the end-effect factor

All sections are joined on both ends; therefore, no end factor is present

ψ_λ = 1 [-]

Where	k	-	Equivalent roughness k
	b	-	width of member
	Re	-	Reynolds Number

k	=	0.02	mm	Spray Paint finish (Table 23)
b	=	508	mm	
k/b	=	3.94E-05	[-]	
Re	=	2.91E+07		

Figure 7.28 gives $c_{f,0}$ = 0.7 [-]

$c_f = c_{f,0} * \psi_\lambda$

$= 0.7*1$

= **0.7** [-]

(EN 1991-1-4: Eurocode 1: Actions on Structures - Part 1-4: General actions - Wind Actions, 2010)

Results of Shape Factor

Table 22 - Results of Shape Factor

Shape Factors			
Part of Bridge	**Profile**		**Shape Factor**
Main Beam	CS1-2-3	-	2.40
Arch Side	CS4	-	2.35
Arch Side	CS5	-	2.20
Arch Middle	CS6	-	2.10
Hangers	CS7	-	0.70

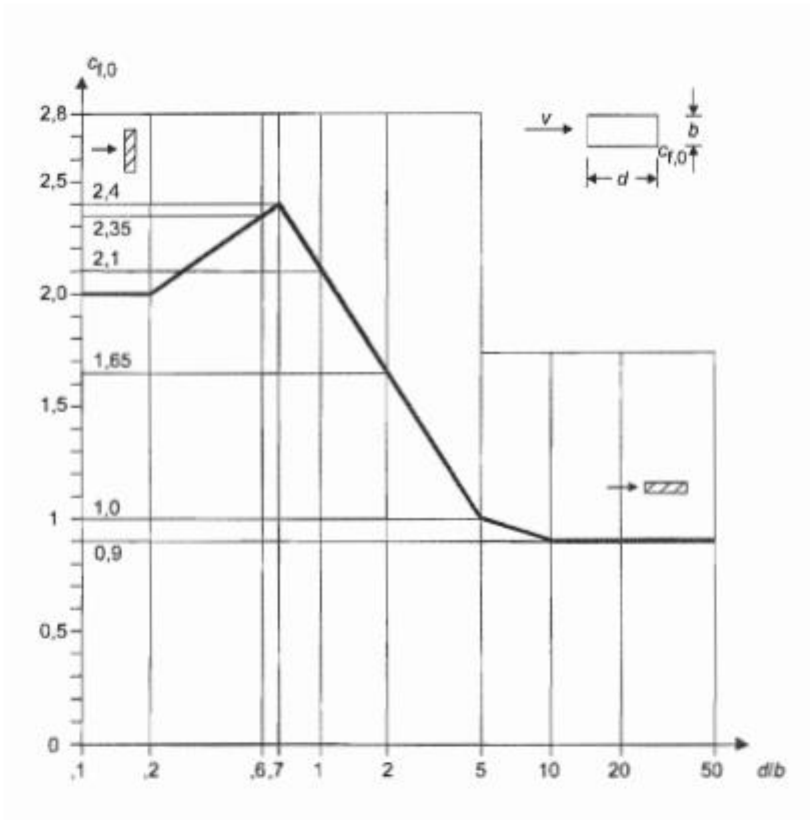
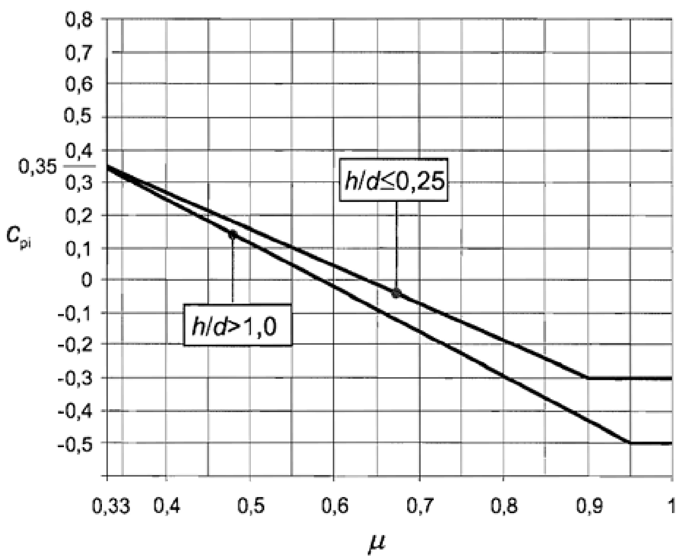


Figure 52 - Force coefficients $c_{f,0}$ of rectangular sections with sharp corners and without free and flow



NOTE For values between h/d = 0,25 and h/d = 1,0 linear interpolation may be used.

Figure 53 - Internal Pressure Coefficients for uniformly distributed openings

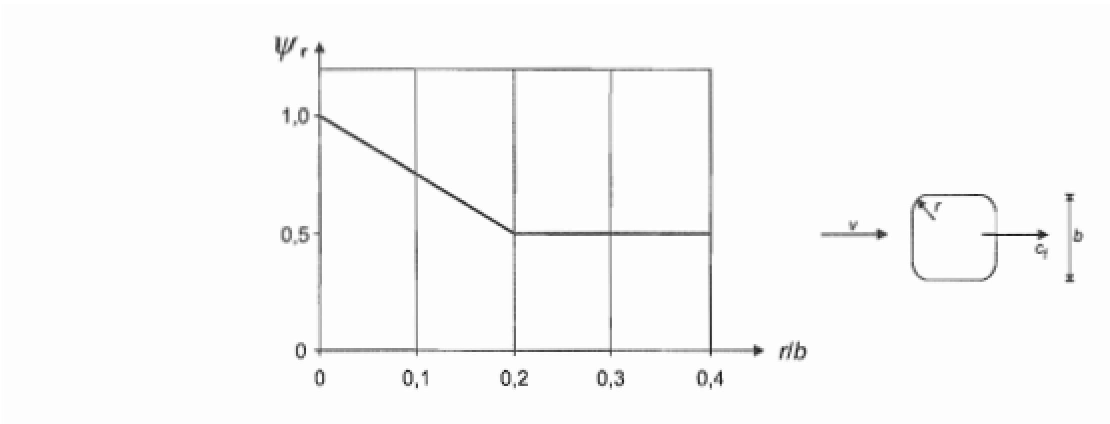


Figure 54 - Reduction factor ψ_r for a square cross-section with rounded corners

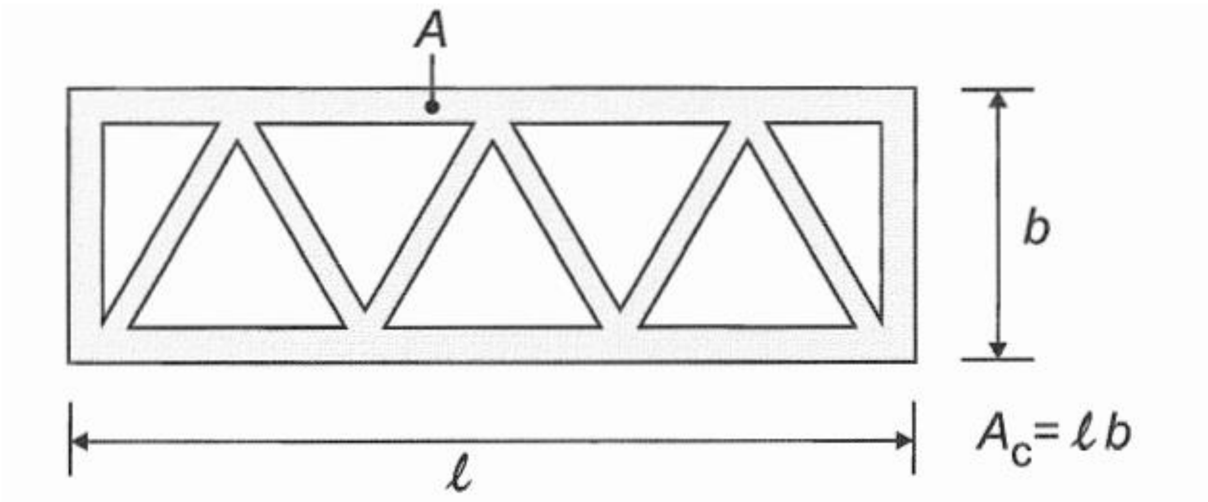


Figure 55 - Definition of Solidity Ratio φ

Table 23 - Equivalent Surface Roughness k

Type of surface	Equivalent roughness ***k*** mm	Type of surface	Equivalent roughness ***k*** mm
glass	0,0015	smooth concrete	0,2
polished metal	0,002	planed wood	0,5
fine paint	0,006	rough concrete	1,0
spray paint	0,02	rough sawn wood	2,0
bright steel	0,05	rust	2,0
cast iron	0,2	brickwork	3,0
galvanised steel	0,2		

Appendix.C.IV Wind load calculated per member

Based on the calculated wind load of 501.31 N/m^2 calculated in Appendix.C.II is the wind load per member calculated. The load per member is based on the shape factor multiplied by the wind load and the width of the profile. From this, the load is given in per member in kN/m. This load is inserted into the SCIA models to the referred member.

Table 24 - Wind load per member

General wind load per area			=	501.31 N/m^2		
Member	**Profile**	**Tag**	**Width [mm]**	**Width [m]**	**Shape Factor [-]**	**Wind load per member [kN/m]**
S1	CS1	Main Beam	1600	1.60	2.40	1.93
S2	CS2	Main Beam	1600	1.60	2.40	1.93
S3	CS3	Main Beam	1600	1.60	2.40	1.93
S4	CS4	Arch 1	1600	1.60	2.35	1.88
S5	CS4	Arch 1	1600	1.60	2.35	1.88
S6	CS5	Arch 1	1600	1.60	2.20	1.76
S7	CS5	Arch 1	1600	1.60	2.20	1.76
S8	CS6	Arch 2	1600	1.60	2.10	1.68
S9	CS6	Arch 2	1600	1.60	2.10	1.68
S10	CS6	Arch 2	1600	1.60	2.10	1.68
S11	CS6	Arch 2	1600	1.60	2.10	1.68
S12	CS7	Hanger 508-16	508	0.51	0.7	0.18
S13	CS7	Hanger 508-16	508	0.51	0.7	0.18
S14	CS7	Hanger 508-16	508	0.51	0.7	0.18
S15	CS7	Hanger 508-16	508	0.51	0.7	0.18
S16	CS7	Hanger 508-16	508	0.51	0.7	0.18
S17	CS7	Hanger 508-16	508	0.51	0.7	0.18
S18	CS8	Hanger 508-30	508	0.51	0.7	0.18
S19	CS8	Hanger 508-30	508	0.51	0.7	0.18
S20	CS1	Main Beam	1600	1.60	2.40	1.93
S21	CS2	Main Beam	1600	1.60	2.40	1.93
S22	CS3	Main Beam	1600	1.60	2.40	1.93
S23	CS4	Arch 3	1600	1.60	2.35	1.88
S24	CS4	Arch 3	1600	1.60	2.35	1.88
S25	CS5	Arch 3	1600	1.60	2.20	1.76
S26	CS5	Arch 3	1600	1.60	2.20	1.76
S27	CS6	Arch 2	1600	1.60	2.10	1.68
S28	CS6	Arch 2	1600	1.60	2.10	1.68
S29	CS6	Arch 2	1600	1.60	2.10	1.68
S30	CS6	Arch 2	1600	1.60	2.10	1.68
S31	CS7	Hanger 508-16	508	0.51	0.7	0.18
S32	CS7	Hanger 508-16	508	0.51	0.7	0.18
S33	CS7	Hanger 508-16	508	0.51	0.7	0.18
S34	CS7	Hanger 508-16	508	0.51	0.7	0.18
S35	CS7	Hanger 508-16	508	0.51	0.7	0.18
S36	CS7	Hanger 508-16	508	0.51	0.7	0.18
S37	CS8	Hanger 508-30	508	0.51	0.7	0.18
S38	CS8	Hanger 508-30	508	0.51	0.7	0.18

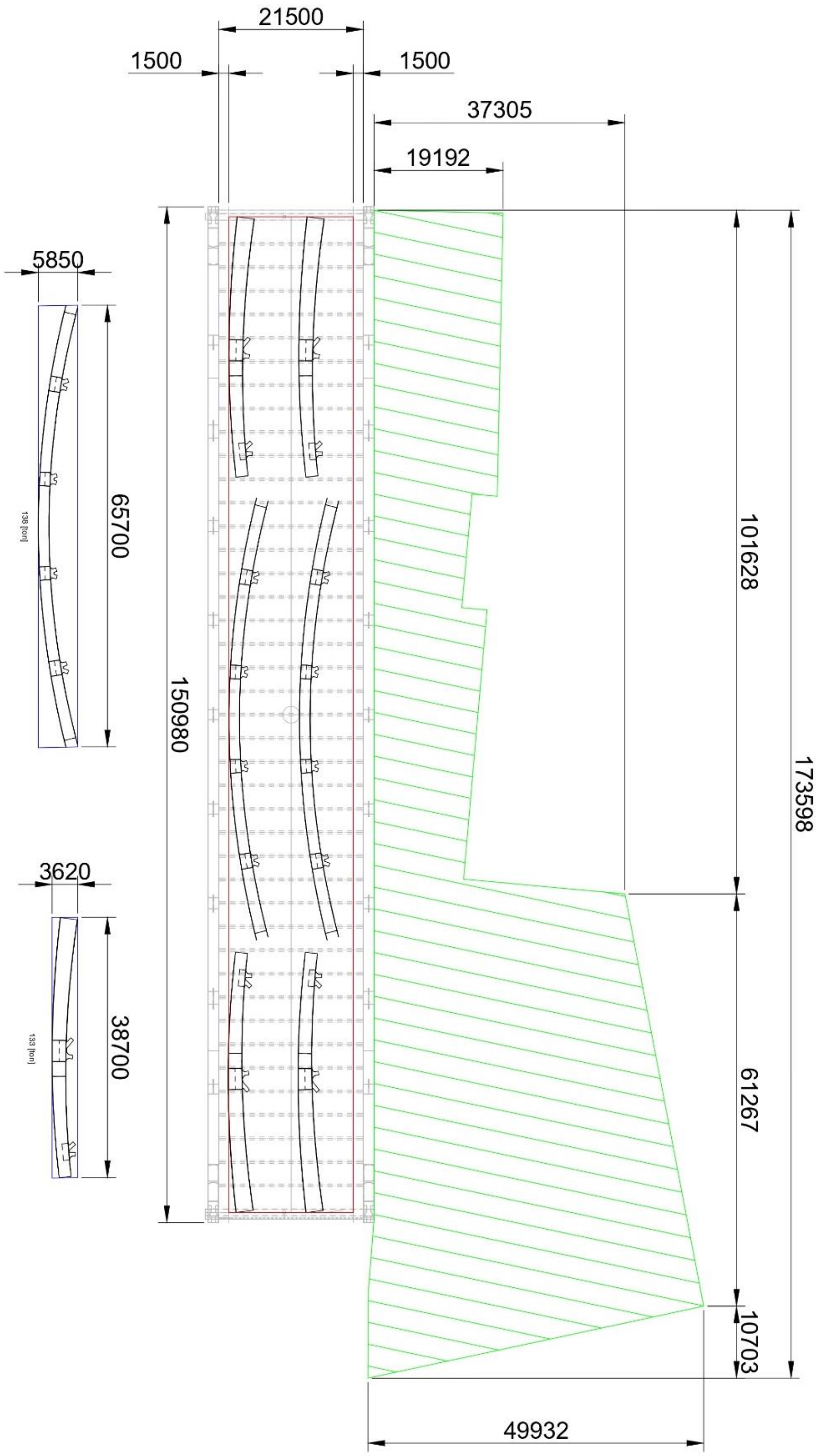
The results from Appendix.C.IV can be consolidated into the following table

Table 25 - Wind load results consolidated

Wind load per member [kN/m]	**Part of bridge**	**Profiles**
1.93	Main Beam	CS1, CS2, and CS3
1.88	Arch 1 and 3	CS4
1.76	Arch 1 and 3	CS5
1.68	Arch 2	CS6
0.18	Hangers	CS7 and CS8

Appendix.D Deck Layout

The arch sections are drawn on the bridge deck to indicate the space they take up. The green zone next to the bridge deck indicates the crane zone where a crane can be placed. More info can be found in chapter 4.2.



Appendix.E SPMT Layout

These drawings are to be used only for the SPMT Spacing over the length of the bridge. More detailed drawings about the barges and SPMTs can be found in Appendix.J.

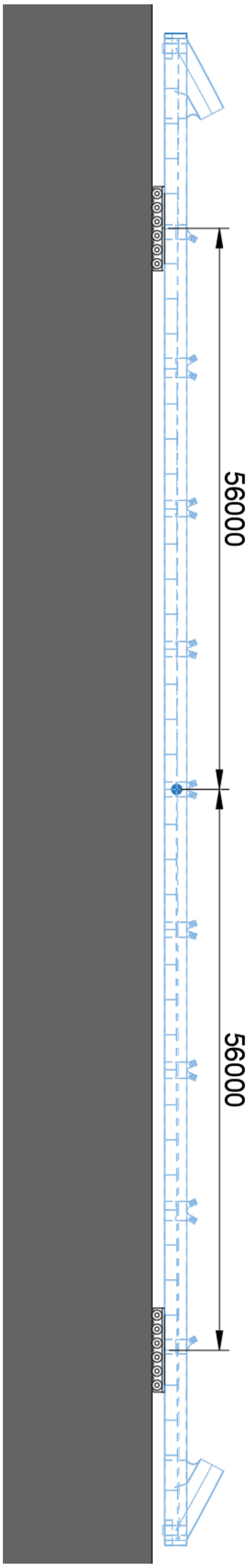


Figure 56 - SPMT Spacing

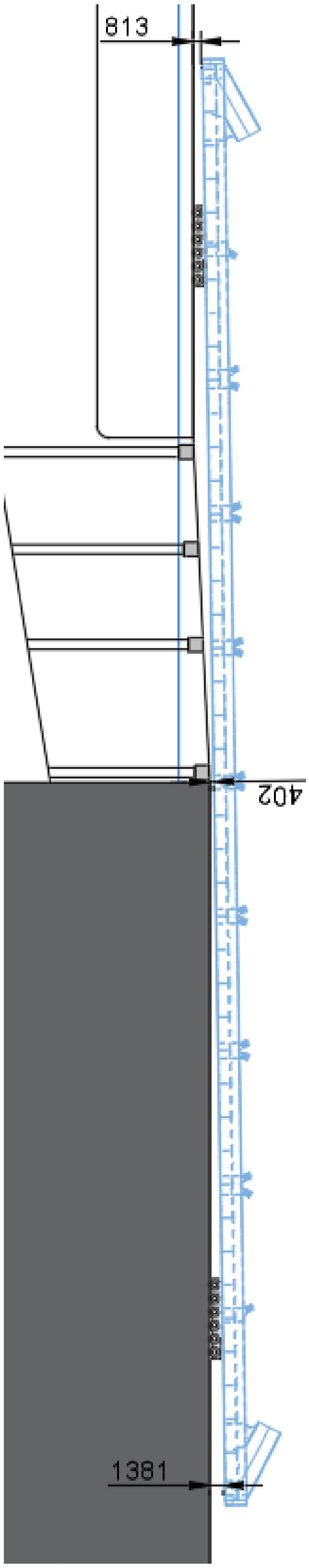


Figure 57 - Height Clearance over RORO Ramp

Appendix.F Different Support Layouts

This appendix contains all the different model results of the different support layouts. The layouts are shown in Figure 58, and the results of the models are shown in Figure 59, Figure 60, Figure 61, and Figure 62.

In order to better compare all the results, the colour scaling is set to the same values. In this way, the effects of additional supports are visible. The support locations are traceable in the 3D-stress results as each support point changes the tension in the beam (positive stress) to local compression (negative stress).

An additional point of attention should go to the stresses in the hangers. The stresses change dramatically with every configuration. In layout 1 can be seen the alternating pattern, be recognised as one hanger in blue (Compression) holding up the arch and the next hanger in red (Tension) holding up the un-supported bridge deck. This is working outwards from the middle support to the side supports. This effect reduces significantly the more supports are added.

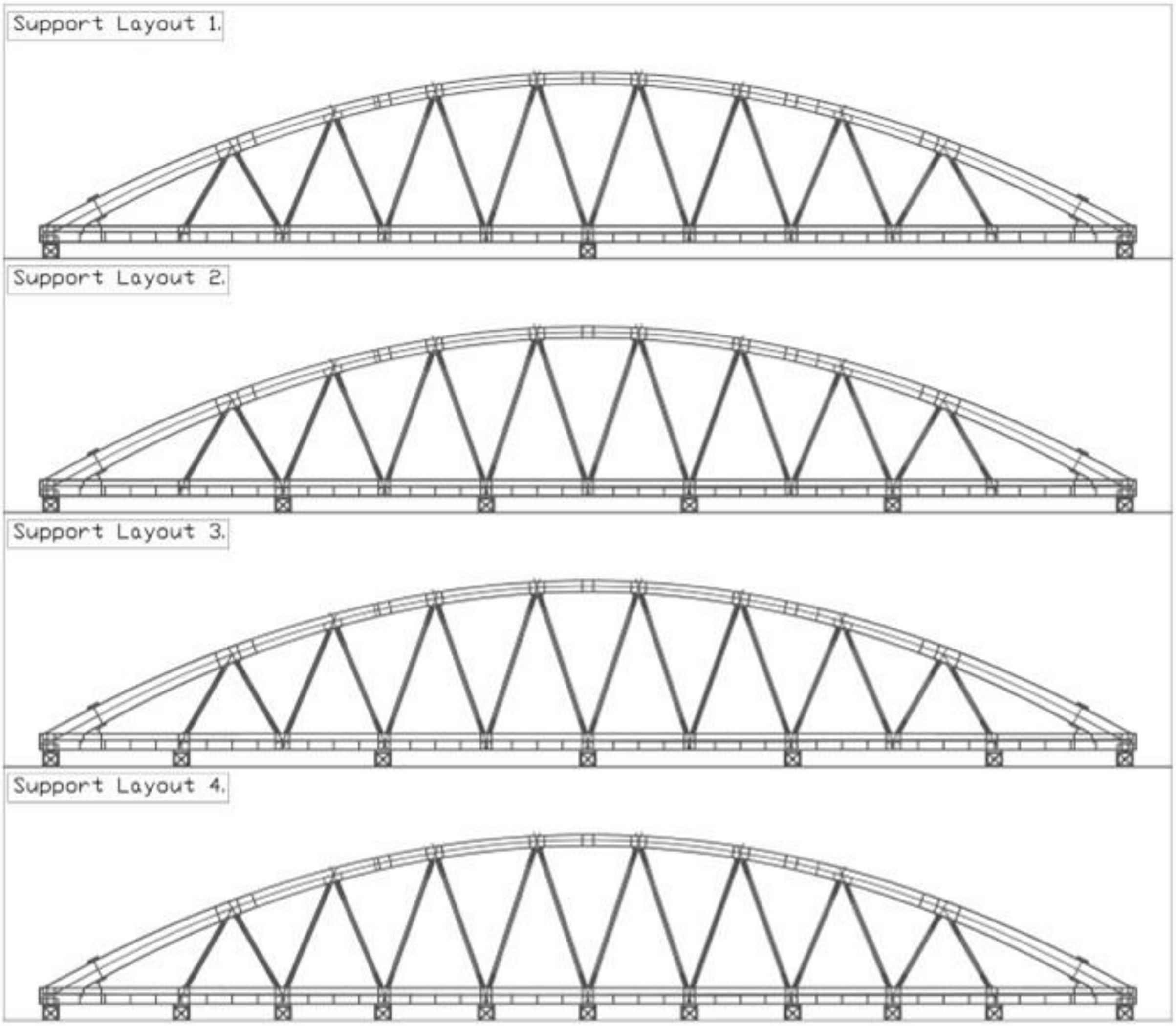


Figure 58 - Support Layout 1, 2, 3, and 4

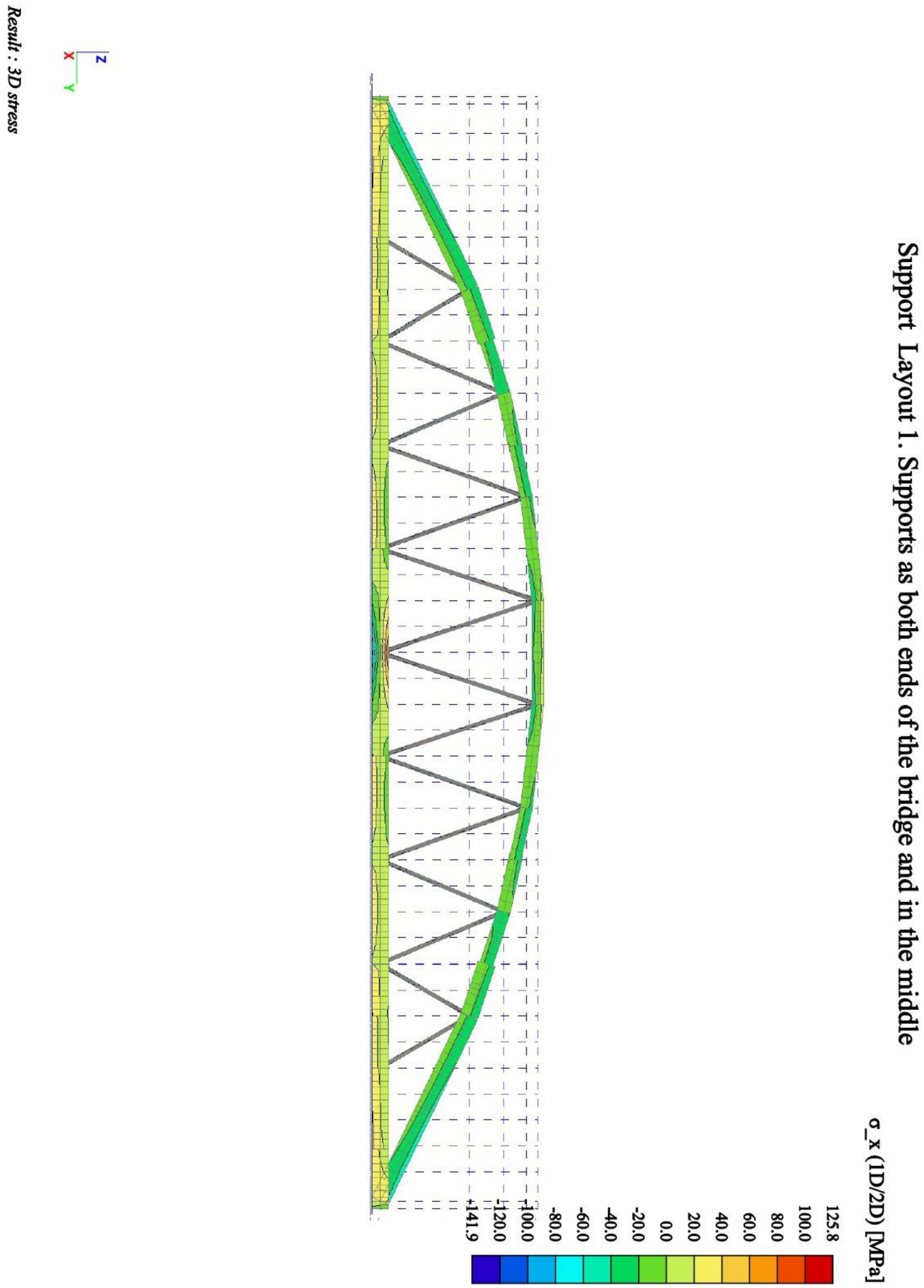


Figure 59 - Support Layout 1. 3D-Stress Results

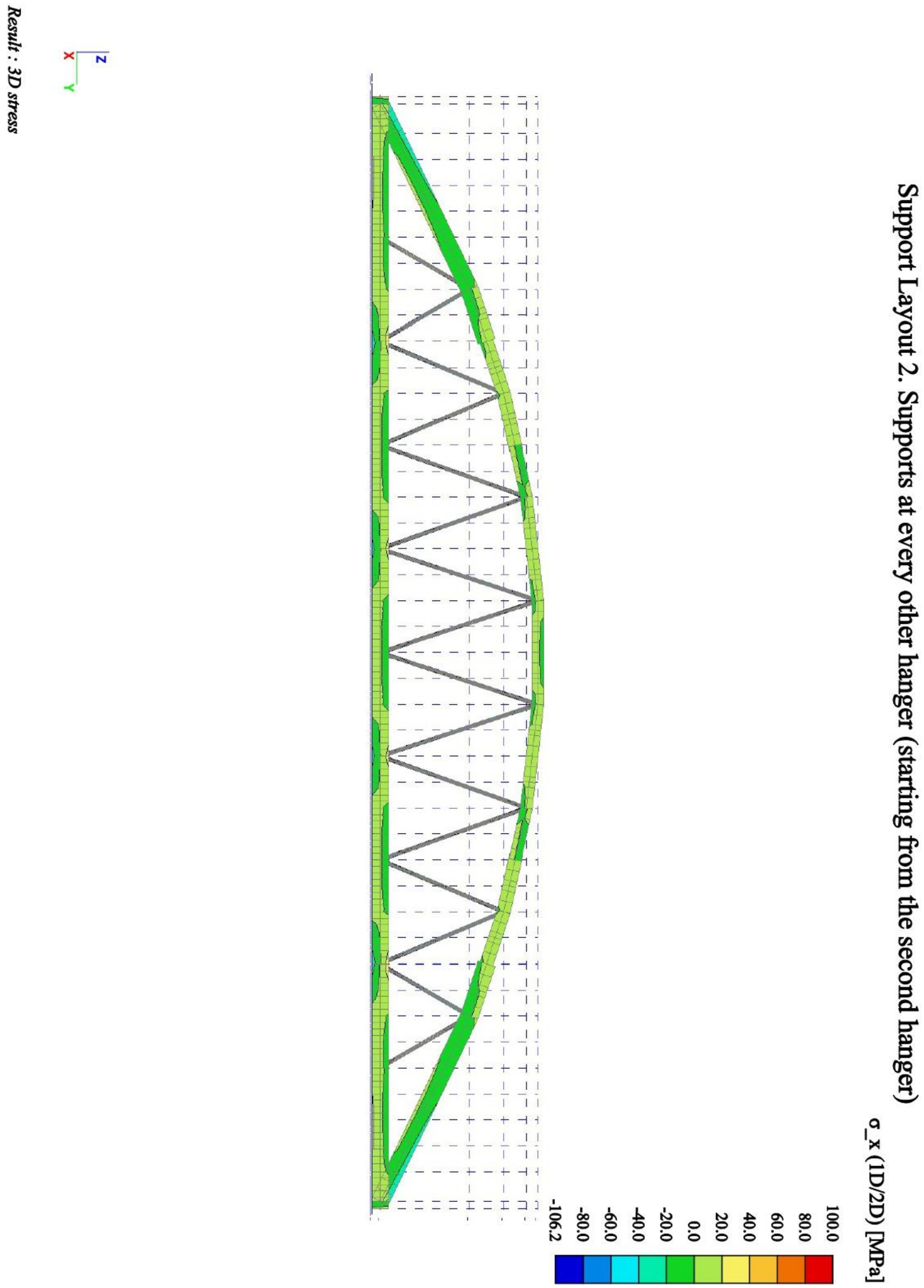


Figure 60 - Support Layout 2. 3D-Stress Results

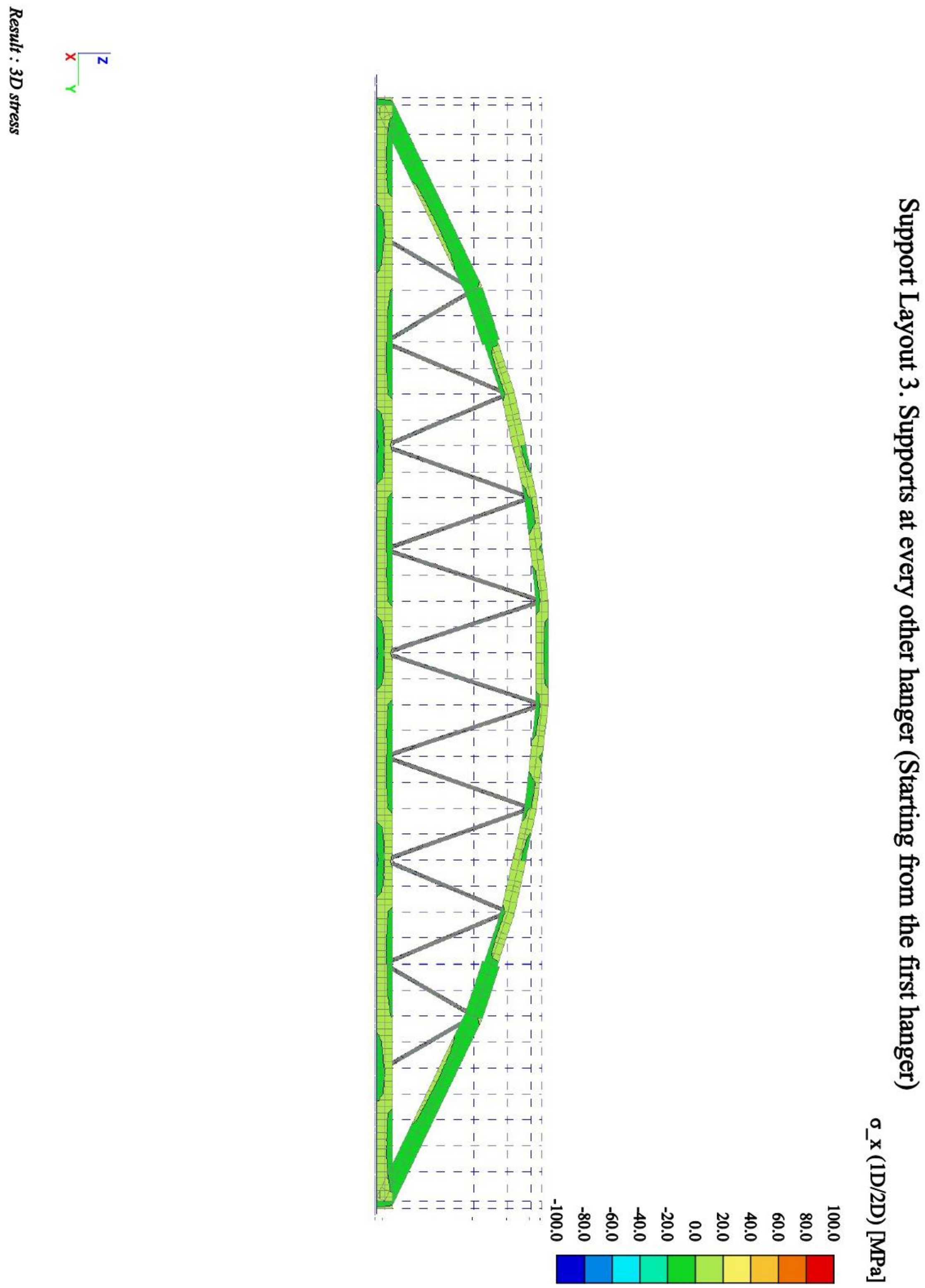


Figure 61 - Support Layout 3. 3D-Stress Results

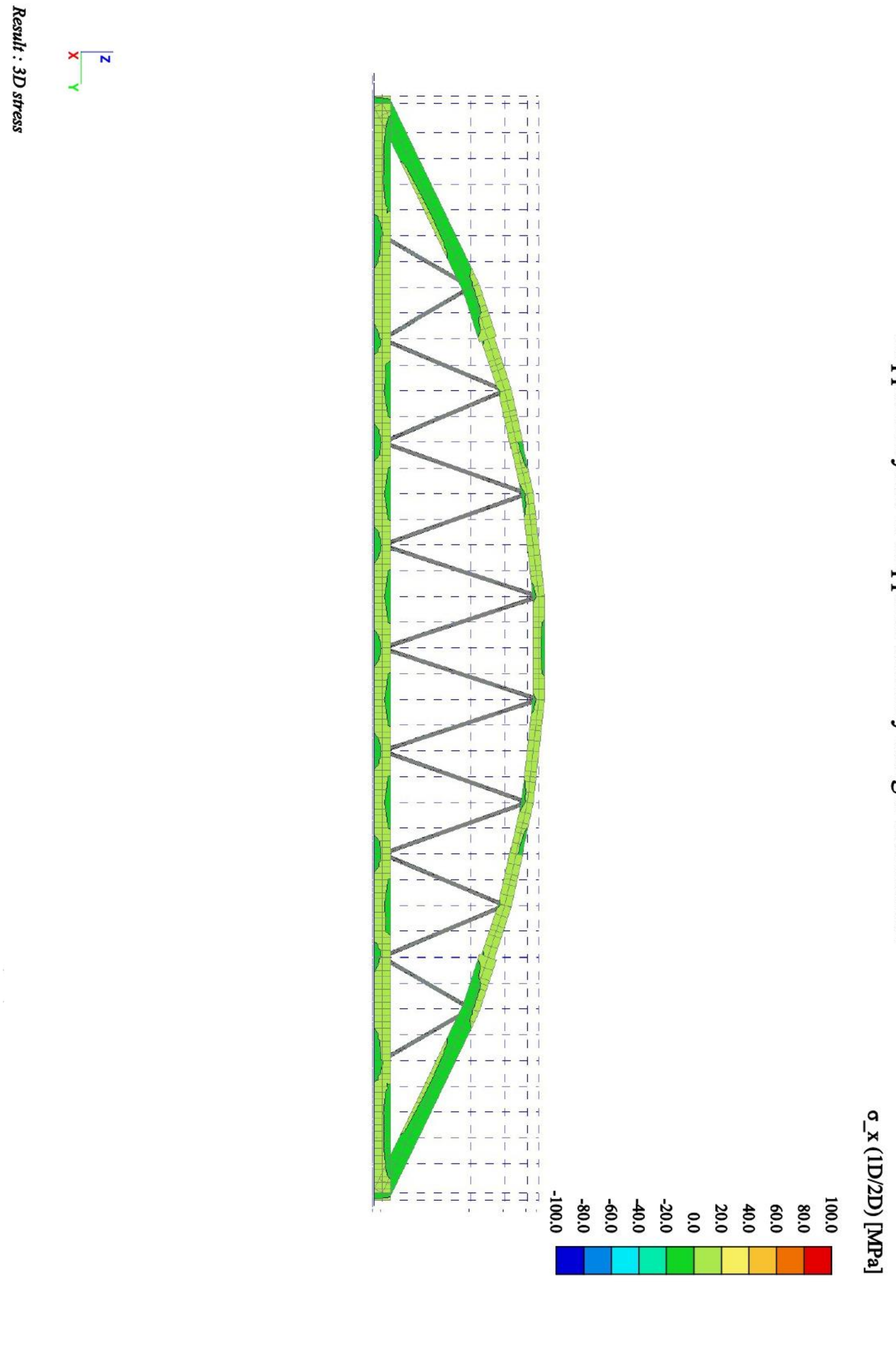


Figure 62 - Support Layout 4. 3D-Stress Results

Appendix.G Hangers Check

Appendix.G.I Buckling Check Hangers

The buckling check is executed to check whether the hangers are capable of supporting the arch during the different phases of construction and transportation.

Appendix.G.I.a Internal Forces

The internal forces are calculated using the SCIA Model, the forces are calculated in a model with self-weight, and the wind load is calculated in Appendix.C. The results from the SCIA models indicated that there are different internal loads in the hangers at different phases. Because the bridge structure and supports are changing in six different building phases, is the buckling check executed for each of the six phases to ensure that the buckling resistance can withstand the loads during the entire project.

The phases calculated are 4.2, 5.2, 5.3, 6, 9, and 10. The phases and load models can be found in Appendix.I for more detail.

Table 26 - Load input Buckling Check

	Phase - 4.2					**Phase - 5.2**				
Hanger	Moment				Normal Force	Moment				Normal Force
	Support 1	Support 2	Max. Negative	Max. Positive		Support 1	Support 2	Max. Negative	Max. Positive	
	[kNm]	[kNm]	[kNm]	[kNm]	[kN]	[kNm]	[kNm]	[kNm]	[kNm]	[kN]
1	-35.98	-5.93	-35.98	11.98	462.42	0				
2	-21.31	-23.48	-23.48	8.97	747.86	0				
3	-30.69	-20.99	-30.69	14.81	260.49	0				
4	0					0				
5	0					0				
6	0					-33.62	-28.68	-33.62	15.95	95.43
7	0					-25.86	-49.65	-49.65	13.24	580.85
8	0					-44.12	-14.62	-44.12	22.07	513.67

	Phase - 5.3					**Phase - 6**				
Hanger	Moment				Normal Force	Moment				Normal Force
	Support 1	Support 2	Max. Negative	Max. Positive		Support 1	Support 2	Max. Negative	Max. Positive	
	[kNm]	[kNm]	[kNm]	[kNm]	[kN]	[kNm]	[kNm]	[kNm]	[kNm]	[kN]
1	0					-35.97	-5.31	-35.97	12.34	452.60
2	0					-29.36	-24.43	-29.36	8.67	699.15
3	0					-20.96	-22.51	-22.51	14.72	170.70
4	0					0.00				
5	0					0.00				
6	-33.96	27.03	-33.96	16.61	274.8	-34.54	-27.51	-34.54	16.58	168.20
7	-34.74	-31.99	-34.74	17	276.46	-34.37	-32.74	-34.37	16.82	258.21
8	-33.86	-33.71	-33.86	16.58	279.66	-34.17	-33.03	-34.17	16.77	264.80

	Phase - 9					**Phase - 10**				
Hanger	Moment				Normal Force	Moment				Normal Force
	Support 1	Support 2	Max. Negative	Max. Positive		Support 1	Support 2	Max. Negative	Max. Positive	
	[kNm]	[kNm]	[kNm]	[kNm]	[kN]	[kNm]	[kNm]	[kNm]	[kNm]	[kN]
1	-29.36	-12.04	-29.36	11.65	338.65	38.53	-65.49	-65.49	39.36	1973.93
2	-20.99	-25.74	-25.74	9.53	541.07	-46.23	5.55	-46.23	16.16	
3	-28.71	-27.17	-28.71	13.30	222.20	-3.80	-48.81	-48.81	17.86	730.55
4	-51.23	-50.54	-51.23	25.29	531.01	-71.99	-22.65	-71.99	29.62	
5	-62.16	-53.29	-62.16	29.19	401.30	-37.58	-67.64	-67.64	33.86	187.42
6	-31.13	-33.93	-33.93	15.49	309.70	-32.33	-31.68	-32.33	15.23	
7	-35.13	-35.03	-35.13	16.33	283.55	-24.14	-41.76	-41.76	17.90	
8	-35.31	-33.14	-35.31	17.35	352.51	-32.01	-32.32	-32.32	18.39	

M_{Ed} is calculated by:

$$M_{Ed} = -M_{max.negative} + M_{max.poisitive}$$

Because the entire construction is symmetrical in two axes, is only half of one arch checked on buckling. The other hangers have a similar load and will eventually be checked by software with more detailed results when ASK Romein Hillebrand is going to build the bridge.

Appendix.G.I.b Buckling Calculation Method

Equation 17 is to check buckling resistance, and it comes from the old Dutch Steel Code NEN6770, a predecessor of the Eurocode 3. The Equation combines a Lateral Buckling check and an axial compression buckling check. The equation is a simplified approach on the conservative side; therefore, it is still applicable for a simple buckling check.

Equation 17 - Buckling Check

$$1.1 * \frac{M_{Ed}}{\chi_{LT} * W_y * f_{yd}} + 1.1 * \frac{N_{Ed}}{\chi * A * f_{yd}} \leq 1.0$$

Where:

M_{Ed}	- Internal Moment	- This Force is found in the SCIA model
N_{Ed}	- Normal/Compressive Force	- This Force is found in the SCIA model
W_y	- Internal Moment of Resistance	- This is a profile characteristic - Table 28
f_{yd}	- Steel Strength	- This is a property of the steel quality - Table 28
A	- Cross-sectional area of profile	- This is a profile characteristic - Table 28
$\chi_{(LT)}$	- Reduction Factor	- This value is read out of Figure 63

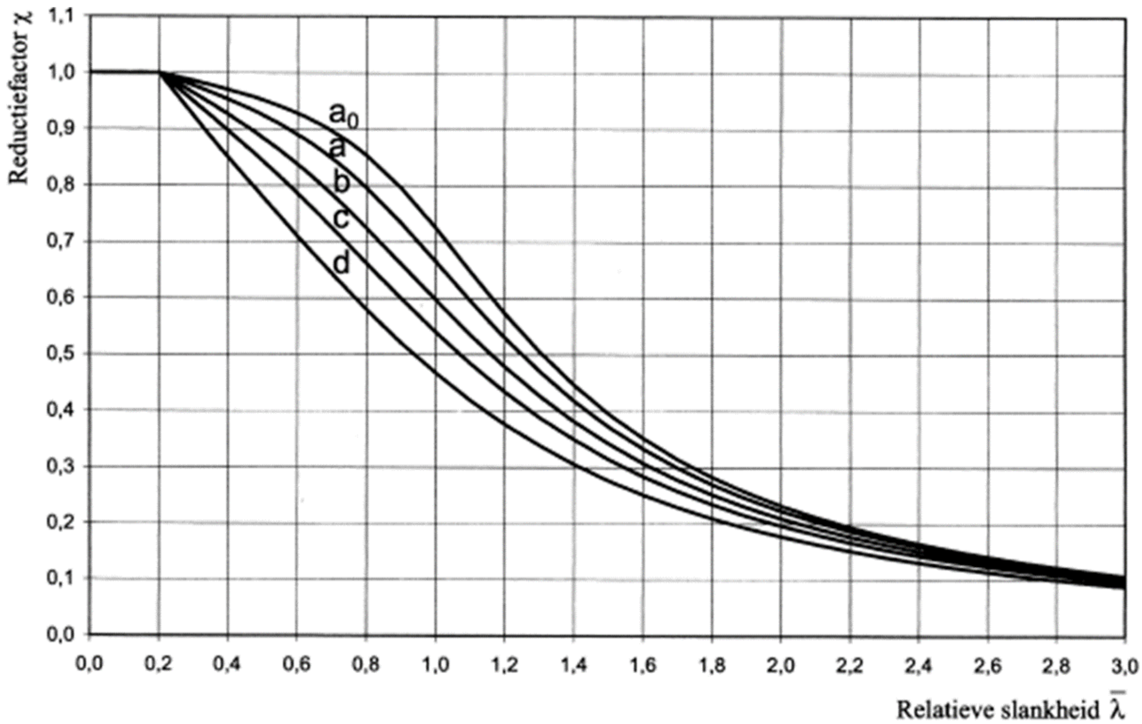


Figure 63 - Buckling Curves
Vertical Axis: Reduction Factor χ, Horizontal Axis: Relative Slenderness λ

Which buckling curve depends on the profile, see Table 27.

The relative slenderness for χ can be calculated by Equation 18.

Equation 18 - Relative Slenderness for χ

$$\bar{\lambda} = \frac{\frac{L}{\sqrt{\frac{I}{A}}}}{\pi * \sqrt{\frac{E}{f_{yd}}}}$$

The relative slenderness for lateral buckling (χ_{LT}) can be calculated by Equation 19.

Equation 19 - Relative Slenderness for χ_{LT}

$$\lambda_{LT} = \varsigma * \sqrt{\frac{\left(1.4 - 0.8 * \frac{M_1}{M_2}\right) * L_{cr} * h * f_{yd}}{b * t_f * E}}$$

Where:

L	- Length of hanger	- The value is from Table 26
I	- Moment of Inertia	- This is a profile characteristic - Table 28
A	- Area of Cross Section	- This is a profile characteristic - Table 28
E	- Elasticity Modulus	- This is a property of the steel
f_{yd}	- Steel Strength	- This is a property of the steel
ς	- Safety Factor	- This value is by the NEN code (1,32)
M_1	- Moment in support 1	- This value is from Table 26
M_2	- Moment in support 2	- This value is from Table 26
L_{cr}	- Buckling length	- This value is calculated with Figure 64
h	- Height of profile	- This is a profile characteristic - Table 28
b	- Width of profile	- This is a profile characteristic - Table 28
t_f	- Thickness flange	- This is a profile characteristic - Table 28

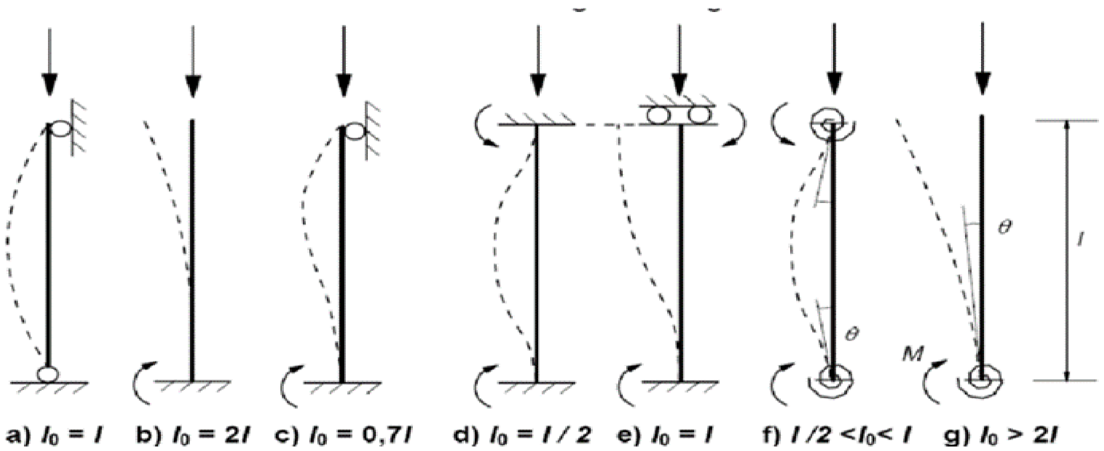


Figure 64 - Effective Buckling Length by Different Supports

In this setup, the effective buckling length is defined by the behaviour of the hangers' supports. In the model, are the connections considered fixed and not hinged. Following this model would give us situation d) of Figure 64, which will give L_{cr}=L/2.

Table 27 - Buckling Curve based on profile

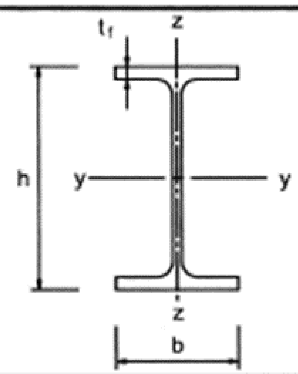
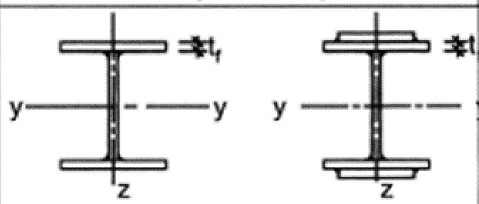
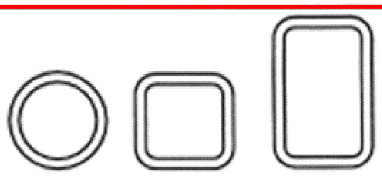
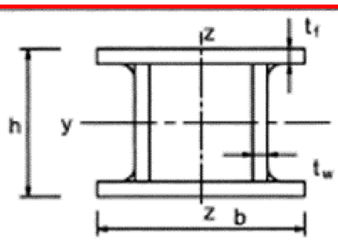
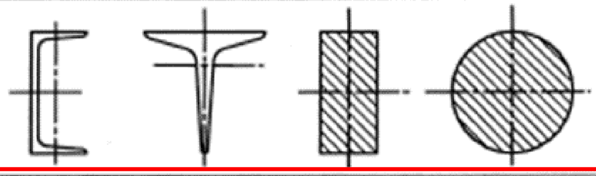
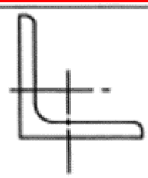
Cross section		Limitations		Axis	Buckling curve: S 235 S 275 S 355 S 420	Buckling curve: S 460
Gewalste profielen		$h/b > 1,2$	$t_f \le 40$ mm	y – y z – z	a b	a_0 a_0
			40 mm $< t_f \le 100$	y – y z – z	b c	a a
		$h/b \le 1,2$	$t_f \le 100$ mm	y – y z – z	b c	a a
			$t_f > 100$ mm	y – y z – z	d d	c c
Gelaste I-profielen			$t_f \le 40$ mm	y – y z – z	b c	b c
			$t_f > 40$ mm	y – y z – z	c d	c d
Tubes			Hot-rolled	Each axis	a	a_0
			Cold formed and welded	Each axis	c	c
Gelaste kokerprofielen			algemeen (behalve in het hieronder gegeven geval)	elke as	b	b
			dikke lassen: $a > 0,5t_f$ $b/t_f < 30$ $h/t_w < 30$	elke as	c	c
U-, T- en massieve profielen				Each axis	c	c
L-profielen				elke as	b	b

Table 28 - Profile Data CHS508-16 and CHS508-30

Profile DATA 508-16					**Profile DATA 508-30**				
Height	h	=	508	mm	Height	h	=	508	mm
Width	b	=	508	mm	Width	b	=	508	mm
Thickness	t	=	16	mm	Thickness	t	=	30	mm
Area	A	=	24730.6	mm^2	Area	A	=	45050.4	mm^2
Centroid $_z$	C_z	=	254	mm	Centroid $_z$	C_z	=	254	mm
Centroid $_y$	C_y	=	254	mm	Centroid $_y$	C_y	=	254	mm
	Moment of Inertia					**Moment of Inertia**			
	Iz	=	749090000	mm^4		Iz	=	1291730000	mm^4
	Iy	=	7.49E+08	mm^4		Iy	=	1.29E+09	mm^4
	Izy	=	0	mm^4		Izy	=	0	mm^4
	rz	=	173.4454	mm		rz	=	168.7523	mm
	ry	=	173.4454	mm		ry	=	168.7523	mm
	Section Moduli					**Section Moduli**			
$W_{z;el}$	S_{zt}	=	2952960	mm^3	$W_{z;el}$	S_{zt}	=	5092090	mm^3
$W_{y;el}$	S_{zb}	=	2952960	mm^3	$W_{y;el}$	S_{zb}	=	5092090	mm^3
	S_{yt}	=	2949170	mm^3		S_{yt}	=	5085560	mm^3
	S_{yb}	=	2964380	mm^3		S_{yb}	=	5111780	mm^3
$W_{z;pl}$	Z_z	=	3874390	mm^3	$W_{z;pl}$	Z_z	=	6863520	mm^3
$W_{y;pl}$	Z_y	=	3874390	mm^3	$W_{y;pl}$	Z_y	=	6863520	mm^3
	PNA_z	=	0	mm		PNA_z	=	0	mm
	PNA_y	=	0	mm		PNA_y	=	0	mm
		Steel					**Steel**		
Quality		S	355		Quality		S	355	
	F_{yd}	=	355	N/mm^2		F_{yd}	=	355	N/mm^2
	E	=	210000	Pa		E	=	210000	Pa
	γ_{M0}	=	1	-		γ_{M0}	=	1	-

Appendix.G.I.c Worked Out Buckling Check–Hangers

Table 29 - Work out of Hanger Buckling Check

Hanger 1 Phase 6				
Hanger no.	**1**		**Profile**	508-16
Length Hanger	L	=	13936.52	mm
Moment Support 1	M_1	=	-35.97	kNm
Moment Support 2	M_2	=	-5.31	kNm
Max negative Moment	M_{mn}	=	-35.97	kNm
Max positive Moment	M_{mp}	=	12.34	kNm
Max Axial Force	N	=	452.6	kN
Maximum Loads				
Max Internal Moment	M_{Ed}	=	48310000	Nmm
Max Compressive Force	N_{Ed}	=	452600	Nmm
Buckling Check				
	1.0	≥	$1.1*M_{Ed}/(\chi_{LT}*W_y*f_{yd})+1.1*N_{Ed}/(\chi*A*f_{yd})$	
	1.0	≥	0.172218045	
	Check	**=**	**OK**	
χ				
	i	=	$\sqrt{(I/A)}$	
		=	174.04	
	λ	=	L_{cr}/i	
		=	80.08	
	λ_1	=	$\pi*\sqrt{(E/f_y)}$	
		=	76.41	
	$\bar{\lambda}$	=	λ/λ_1	
			1.05	
Buckling Curve		=	a	
Buckling curve a, $\bar{\lambda} \rightarrow \chi$		=	0.63	
χ_{LT}				
Moment Support 1		=	-35.97	
Moment Support 2		=	-5.31	
	L_{st}	=	L/2	
			6968	mm
	β	=	MS2/MS1	
		=	0.15	[-]
	$L_{lat;buc}$	=	$(1.4-0.8*\beta)*L_{st}$	
		=	8933	mm
	ς	=	1.32	(Conservative value)
	λ_{LT}	=	$\varsigma*\sqrt{((L_{lat;buc}*h*f_{yd})/(b*tf*E))}$	
		=	**1.28**	
	Curve to use	=	a	
	χ	=	0.47	

Appendix.G.I.d Results Buckling Check

The results of each calculation can be found in Table 30. The results show that all hanger profiles are capable of withstanding the moment and normal forces with a clear safety margin.

Table 30 - Calculation Results Hanger Check

Hanger No.	Buckling check result					
	Phase 4.2	Phase 5.2	Phase 5.3	Phase 6	Phase 9	Phase 10
1	0.17 ≤ 1	N.A.	N.A.	0.17 ≤ 1	0.13 ≤ 1	0.69 ≤ 1
2	0.17 ≤ 1	N.A.	N.A.	0.18 ≤ 1	0.14 ≤ 1	0.12 ≤ 1
3	0.14 ≤ 1	N.A.	N.A.	0.09 ≤ 1	0.11 ≤ 1	0.31 ≤ 1
4	N.A.	N.A.	N.A.	N.A.	0.10 ≤ 1	0.07 ≤ 1
5	N.A.	N.A.	N.A.	N.A.	0.11 ≤ 1	0.09 ≤ 1
6	N.A.	0.11 ≤ 1	0.27 ≤ 1	0.14 ≤ 1	0.17 ≤ 1	0.06 ≤ 1
7	N.A.	0.36 ≤ 1	0.19 ≤ 1	0.18 ≤ 1	0.18 ≤ 1	0.05 ≤ 1
8	N.A.	0.36 ≤ 1	0.18 ≤ 1	0.18 ≤ 1	0.21 ≤ 1	0.07 ≤ 1

Table 31 - Results Hanger Check

Hanger No.	Buckling check per phase					
	Phase 4.2	Phase 5.2	Phase 5.3	Phase 6	Phase 9	Phase 10
1	OK	N.A.	N.A.	OK	OK	OK
2	OK	N.A.	N.A.	OK	OK	OK
3	OK	N.A.	N.A.	OK	OK	OK
4	N.A.	N.A.	N.A.	N.A.	OK	OK
5	N.A.	N.A.	N.A.	N.A.	OK	OK
6	N.A.	OK	OK	OK	OK	OK
7	N.A.	OK	OK	OK	OK	OK
8	N.A.	OK	OK	OK	OK	OK

Note that these results are only applicable to the tubular profiles! The hangers' connections are checked in Appendix.G.II.

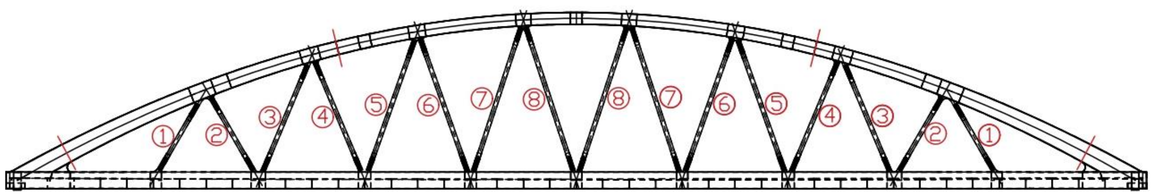


Figure 65 – Numbering Hangers

Appendix.G.II Buckling Check Hanger Connection Plate

The hanger plate is a weak link in the hanger construction. This plate (by design) 40 mm thick will have to transfer all the loads from the hanger to the main beam. The hanger plate is fixed in the main beam of the bridge as it is extended 1100 mm into the main beam, where it is welded to internal strengthening plates, which are perpendicular to the main beam. See Figure 66. However, the total connection of 2400 mm long only consists of 3 plates bolted together is a long distance to cover for plates under compressive and moment forces.

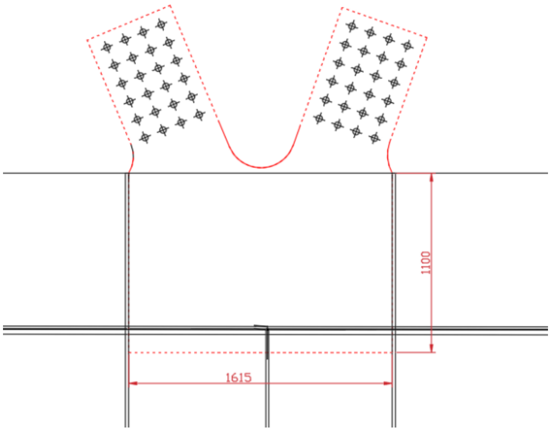


Figure 66 - Hanger Plate in Main Beam

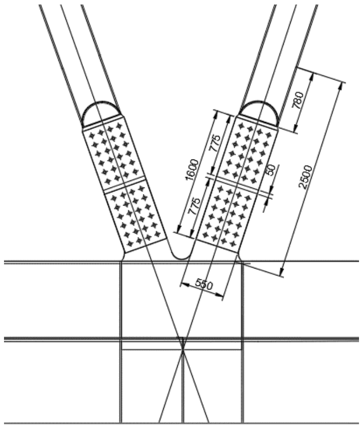


Figure 67 - Hanger Connection

Appendix.G.II.a Internal Forces

The internal forces of the hanger plates are very similar to the internal forces of the hangers. A key difference is that instead of the maximum moment present is the maximum moment taken in the weak direction of the hanger.

Because the hanger is by design 550 mm wide but only 40 mm thick, it can be assumed that the connection is rigid in the longitudinal direction but acts more as a hinge in the cross direction. (KUDU-Engineering, 2022)

The forces are calculated using the SCIA model for the Hangers' buckling check.

For this check, are the same loads considered from the same phases as for the hangers' buckling check. The loads can be found in Table 26.

General Data of Hanger Plates

Width	b	=	550	mm
Thickness	t	=	variable	mm
Area	A	=	variable	mm^2
	Steel Quality S355			
	f_{yd}	=	355	N/mm^2
	E	=	210000	Pa
	γ_{M0}	=	1	-

Appendix.G.II.b Buckling Calculation Method

Equation 20 - Buckling Check Hanger Plates

$$1.1 * \frac{M_{Ed}}{M_{Rd}} + 1.1 * \frac{N_{Ed}}{\chi * A * f_{yd}} \leq 1.0$$

Where:

M_{Ed}	- Internal Moment	- This Force is found in the SCIA model
N_{Ed}	- Normal/Compressive Force	- This Force is found in the SCIA model
M_{Rd}	- Moment Resistance	- Calculated by Equation 21
f_{yd}	- Steel Strength	- This is a property of the steel quality - Table 28
A	- Cross sectional area of profile	- This is a profile characteristic - Table 28
χ	- Reduction Factor	- This value is read out of Figure 63

Equation 21 - Moment Resistance

$$M_{Rd} = W_{weak} * f_{yd}$$

Where:

W_{weak}	- Internal Moment of Resistance	- Calculated by

$$W_{weak} = b * T^2/6$$

Where:

b	- Width of plate	- By design 550 mm
T	- Thickness of plate	- By design 40 mm

Equation 20 is based on Equation 17 but is adjusted for the specific case of the hanger connection. The argument can be made that the plate sandwich which makes out the hanger connection is not spreading the moment evenly, but only one plate is taking the entire moment forces. Therefore, in this equation is, only one plate thickness considered in the moment resistance of M_{Rd}.

In Equation 19 is an L_{CR} considered of L_{CR}=L*2,5; this is based on Figure 64, situation b. This situation is chosen as the hanger plate will be fixed on the main beam but could be considered a free-standing column as the hanger will provide no support to the connection plate. The factor of situation b is increased from 2 to 2,5 to compensate for the simplification of this calculation.

Hanger Plate 1 – Phase 6				
Hanger no.	**1**			
Length Support	L	=	4000	mm
Moment Support 1	M_1	=	-35.97	kNm
Moment Support 2	M_2	=	-5.31	kNm
Max negative Moment	M_{mn}	=	-35.97	kNm
Max positive Moment	M_{mp}	=	12.34	kNm
Max Axial Force	N	=	452.6	kN
Maximum Loads				
Max Internal Moment	M_{Ed}	=	48310000	Nmm
Max Compressive Force	N_{Ed}	=	452600	Nmm
Buckling Check				
	1.0	≥	$1.1*M_{Ed}/M_{Rd}+1.1*N_{Ed}/(\chi*A*f_{yd})$	
	1.0	≥	0.995305164	
	Check	=	**OK**	
	χ			
	L_{cr}	=	L*2.5	See table [x]
		=	10000	
	i	=	$\sqrt{(I/A)}$	
		=	38.97	
	λ	=	L_{cr}/i	
		=	256.60	
	λ_1	=	$\pi*\sqrt{(E/f_y)}$	
		=	76.41	
	$\bar{\lambda}$	=	λ/λ_1	
			3.36	
Buckling Curve		=	c	
Buckling curve c, $\bar{\lambda} \rightarrow \chi$		=	0.1	
Moment Resistance				
	M_{Rd}	=	$W_{weak}*f_{yd}$	
			65896875	Nmm
Plate Specifics				
Plate Thickness	**T**	**=**	**45**	**mm**
Section Moduli 3 plates				
	Iz	=	1871718750.00	mm^4
	Iy	=	112767187.50	mm^4
	Wz	=	6806250.00	mm^3
	Wy	=	1670625.00	mm^3
Section Moduli 1 plates				
	Wz	=	2268750.00	mm^3
	Wy	=	185625.00	mm^3

Appendix.G.II.d Results Buckling Check Hanger Connection

According to the calculations are only two connection plates resistant. The moment forces mainly influence this in the hanger present.

The moment resistance can be increased by choosing thicker plates in the hanger connection. Based on a 5 mm increase are the following dimensions passing the buckling check:

Table 32 - Buckling Check Hanger Plates

Hanger No.	Buckling check					
	Phase 4.2	**Phase 5.2**	**Phase 5.3**	**Phase 6**	**Phase 9**	**Phase 10**
1	0.994 ≤ 1	N.A.	N.A.	0.995 ≤ 1	0.826 ≤ 1	0.988 ≤ 1
2	0.697 ≤ 1	N.A.	N.A.	0.814 ≤ 1	0.753 ≤ 1	0.844 ≤ 1
3	0.965 ≤ 1	N.A.	N.A.	0.789 ≤ 1	0.891 ≤ 1	0.910 ≤ 1
4	N.A.	N.A.	N.A.	N.A.	0.861 ≤ 1	0.954 ≤ 1
5	N.A.	N.A.	N.A.	N.A.	0.829 ≤ 1	0.794 ≤ 1
6	N.A.	0.829 ≤ 1	0.848 ≤ 1	0.856≤1	0.829 ≤ 1	0.794 ≤ 1
7	N.A.	0.857 ≤ 1	0.867 ≤ 1	0.858≤1	0.863 ≤ 1	0.996 ≤ 1
8	N.A.	0.901 ≤ 1	0.846 ≤ 1	0.854≤1	0.884 ≤ 1	0.846 ≤ 1

Table 33 - Results Buckling Check Hanger Connection

	Phase Check with required Thickness					
Hanger No.	**Phase 4.2 Check**	**Phase 5.2 Check**	**Phase 5.3 Check**	**Phase 6 Check**	**Phase 9 Check**	**Phase 10 Check**
1	OK	N.A.	N.A.	OK	OK	OK
2	OK	N.A.	N.A.	OK	OK	OK
3	OK	N.A.	N.A.	OK	OK	OK
4	N.A.	N.A.	N.A.	N.A.	OK	OK
5	N.A.	N.A.	N.A.	N.A.	OK	OK
6	N.A.	OK	OK	OK	OK	OK
7	N.A.	OK	OK	OK	OK	OK
8	N.A.	OK	OK	OK	OK	OK
Hanger No.	**Thickness [mm]**	**Thickness [mm]**	**Thickness [mm]**	**Thickness [mm]**	**Thickness [mm]**	**Thickness [mm]**
1	45	N.A.	N.A.	45	45	70
2	40	N.A.	N.A.	40	40	50
3	40	N.A.	N.A.	40	40	50
4	N.A.	N.A.	N.A.	N.A.	55	60
5	N.A.	N.A.	N.A.	N.A.	60	60
6	N.A.	45	45	45	45	45
7	N.A.	50	45	45	45	45
8	N.A.	50	45	45	45	45

The table shows the required thickness to resist the loads on the connections per-phase basis. From this table is, for each hanger, the thickest plate selected as this would be the required thickness to withstand the load over all phases.

Because the hangers are mounted in pairs to the main beam (except for the outer hangers), is the most significant thickness required for the hangers' connections. (See Table 34).

Table 34 - Required Thickness of Hanger Plates in bridge deck

<table>
<tr><th>Hanger No.</th><th>Required Thickness [mm]</th><th>Thickness plates at the main beam [mm]</th><th>Thickness plates at the arch [mm]</th></tr>
<tr><td>1</td><td>70</td><td>70</td><td rowspan="2">70</td></tr>
<tr><td>2</td><td>50</td><td rowspan="2">50</td></tr>
<tr><td>3</td><td>50</td><td rowspan="2">60</td></tr>
<tr><td>4</td><td>60</td><td rowspan="2">60</td></tr>
<tr><td>5</td><td>60</td><td rowspan="2">60</td></tr>
<tr><td>6</td><td>45</td><td rowspan="2">50</td></tr>
<tr><td>7</td><td>50</td><td rowspan="2">50</td></tr>
<tr><td>8</td><td>50</td><td>50</td></tr>
</table>

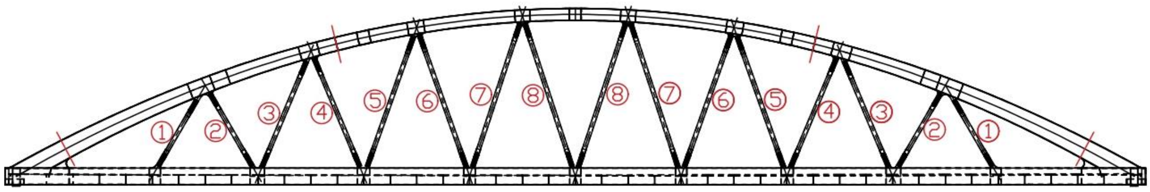


Figure 68 – Numbering Hangers

Appendix.G.III Conclusion Hanger Check

From the calculation result, we can conclude that the conservative buckling check verifies the strength of the tubular profiles. The results show that the hangers are quite well resistant against axial compressive- and Lateral buckling with a proper safety margin.

The hanger connections, however, are not resilient against the moment and compressive forces of the arch standing on top of them. This connection's main problem is the weak axis's moment force. To adjust for these moment forces, are the required thicknesses calculated.

Appendix.H Detail drawings

This appendix contains the following detailed drawings:

- Support tower modules
- Hanger Connection points
- Support point arch sections
- Support construction around the main beam
- Middle Arch Sections
- Side Arch Sections

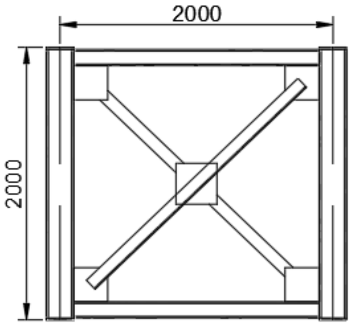


Figure 69 - Front View of Support Tower Module 2x2x2m

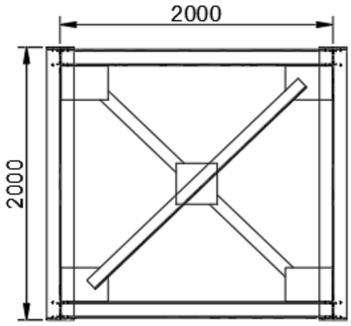


Figure 70 - Side View of Support Tower Module 2x2x2m

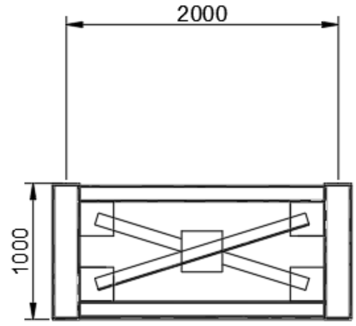


Figure 71 - Front View of Support Tower Module 1x2x2m

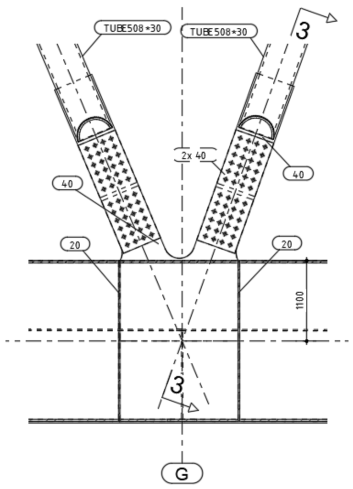


Figure 72 - Hanger Connection Point on Main Beam

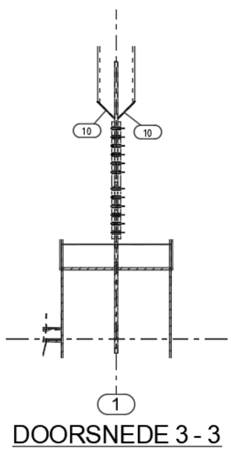


Figure 73 - Hanger Connection Point on Main Beam - Crosssection 3-3

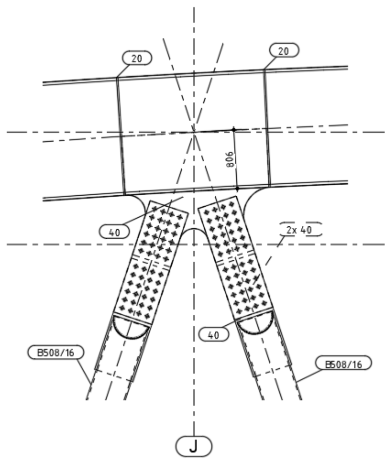


Figure 74 - Hanger Connection Point on Arch

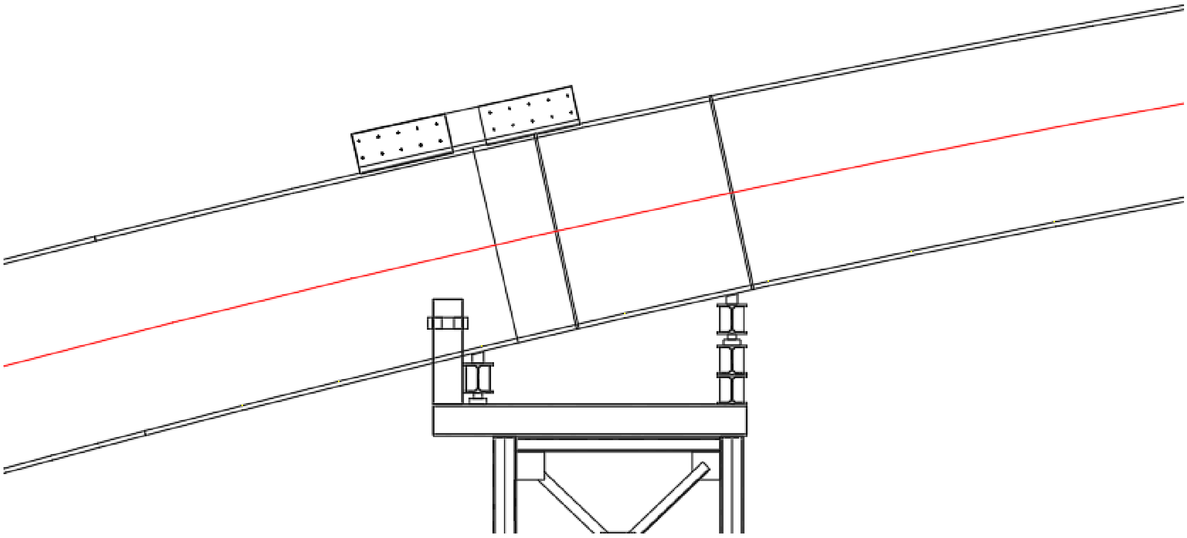


Figure 75 - Supports Point Arch Sections

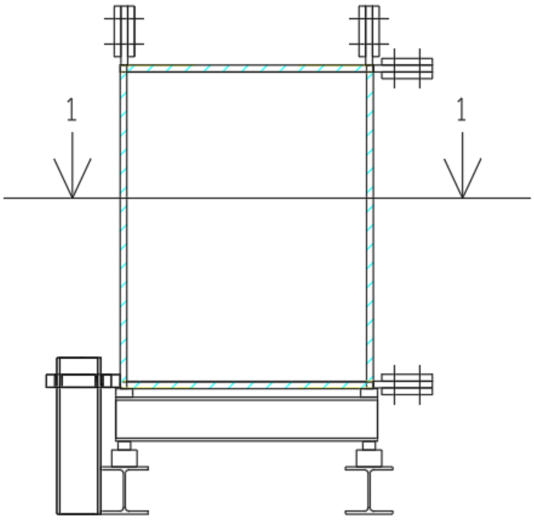


Figure 76 - Cross-section at Support Point Arch Section

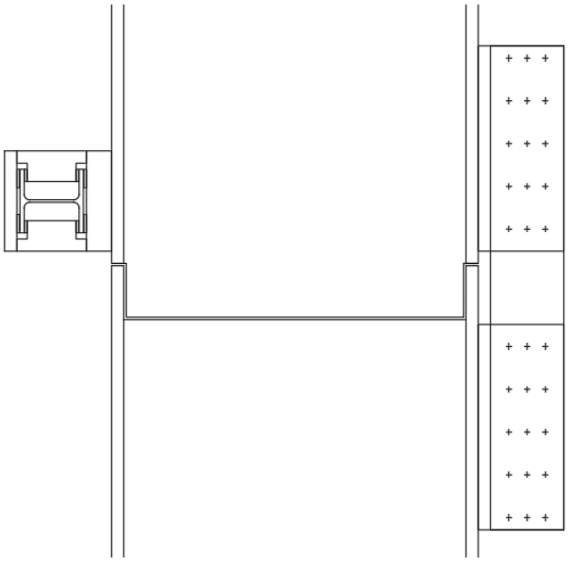


Figure 77 - Cross-section 1-1

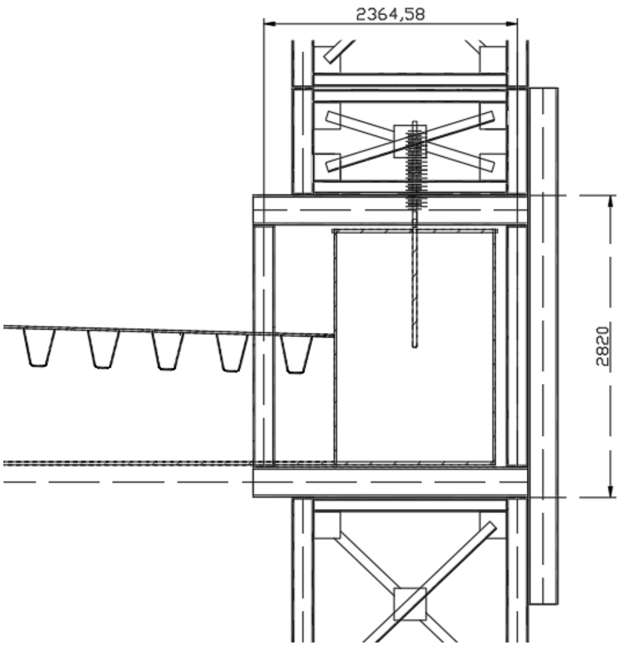


Figure 78 - Construction around the main beam

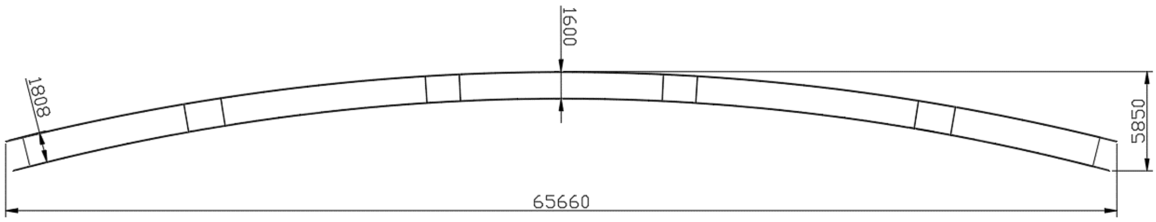


Figure 79 - Side View of Middle Arch Section

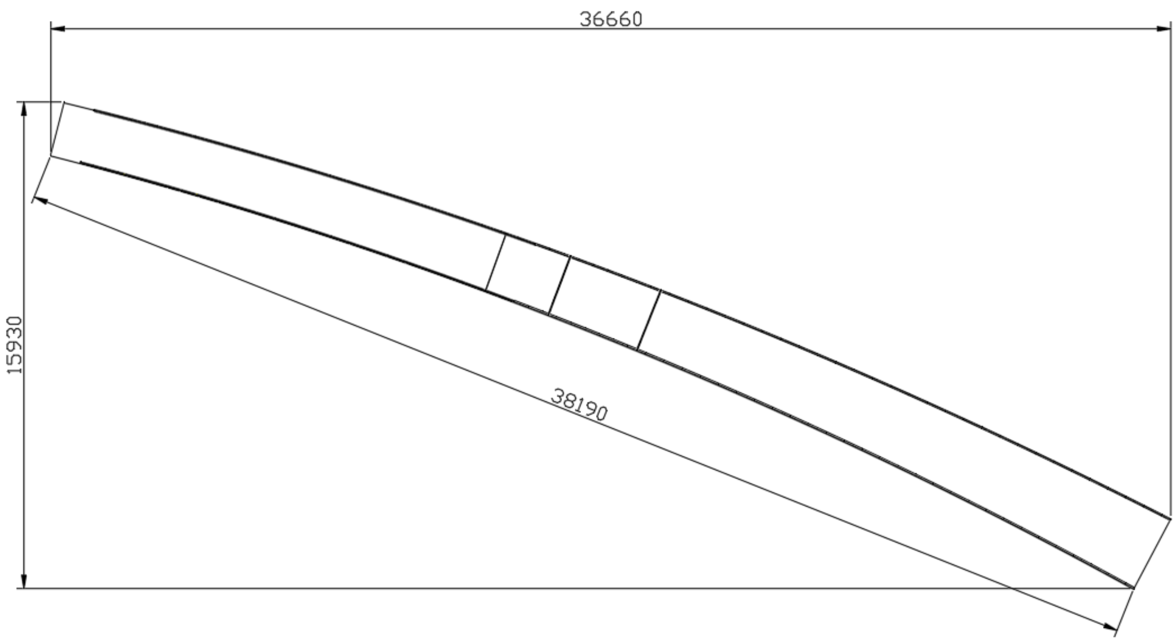


Figure 80 - Side view side arch section

Appendix.I Installation Phases

This appendix contains drawings and models of each installation phase, as mentioned in chapter 4.3, Installation Method.

1. Transportation
2. Placing the bridge deck on supports
3. Building supports for the arches
4. Placing the outer arch sections
5. Placing the middle arch sections
6. Welding the arches
7. Placing the crossbeams
8. Conservation
9. Removing support towers
10. Moving the bridge over the channel
11. Placing the bridge in its final position

The models are made using SCIA Engineer 21.1.1028.64 on a licence of ASK Romein Hillebrand. The drawings are based on provided drawings and modified using a student licence of Autodesk AutoCAD 2023

The drawing and model results are in the following order:

Phase	Name	Model/ Drawing	Model Calculation	View
Phase 1: Transportation				
1	SPMT Spacing	Drawing		Side
1	Height Clearance on RORO Ramp	Drawing		Side
1	Bending Bridge Deck - Minimum Bending	Model	3D Deformations	Side
1	Bending Bridge Deck - Minimum Bending - Absolute Values	Model	3D Deformations	Side
Phase 2: Placing the bridge deck on supports				
2	Bridge deck on Supports	Drawing		Side
2	Installation Site	Drawing		Top
Phase 3: Building Supports for the arches				
3	Support Structure Arches	Drawing		Side
3	Support Structure Arches	Drawing		Front
Phase 4: Placing the outer arch sections				
4.1	Outer Arch Sections on Supports	Drawing		Side
4.1	Outer Arch Sections on Supports - Bending	Model	3D Deformations	Side
4.1	Outer Arch Sections on Supports - 3D-Stress	Model	3D Stress	Side
4.2	Outer Arch Sections on Hangers	Drawing		Side
4.2	Outer Arch Sections on Hangers - Bending	Model	3D Deformations	Side
4.2	Outer Arch Sections on Hangers - Stress	Model	3D Stress	Side
4.2	Outer Arch Sections on Hangers - Normal forces	Model	1D Internal Forces	Side
Phase 5: Placing the middle arch sections				
5.1	Middle Arch Sections on Supports	Drawing		Side
5.1	Middle Arch Sections on Supports - Bending	Model	3D Deformations	Side
5.1	Middle Arch Sections on Supports - Stress	Model	3D Stress	Side
5.2	Middle Arch Sections on Supports and 3 Hangers	Drawing		Side
5.2	Middle Arch Sections on Supports and 3 Hangers - Bending	Model	3D Deformations	Side

5.2	Middle Arch Sections on Supports and 3 Hangers - Stress	Model	3D Stress	Side
5.2	Middle Arch Sections on Supports and 3 Hangers - Normal forces	Model	1D Internal Forces	Side
5.3	Middle Arch Sections on Hangers	Drawing		Side
5.3	Middle Arch Sections on Hangers - Bending	Model	3D Deformations	Side
5.3	Middle Arch Sections on Hangers - Stress	Model	3D Stress	Side
5.3	Middle Arch Sections on Hangers - Normal forces	Model	1D Internal Forces	Side
Phase 6: Welding the arches				
6	Welded Arches - Bending	Model	3D Deformations	Side
6	Welded Arches - Stress	Model	3D Stress	Side
6	Welded Arches - Normal forces	Model	1D Internal Forces	Side
Phase 7: Placing the crossbeams				
7	Self-Supporting Arches	Drawing		Side
7	Self-Supporting Arches - Bending	Model	3D Deformations	Side
7	Self-Supporting Arches - Stress	Model	3D Stress	Side
7	Self-Supporting Arches - Internal Forces	Model	1D Internal Forces	Side
Phase 8: Conservation				
8	No Drawings or Models are required for phase 8			
Phase 9: Removing Support Towers				
9	Complete Arches	Drawing		Side
9	Complete Arches - Bending	Model	3D Deformations	Side
9	Complete Arches - Stress	Model	3D Stress	Side
9	Complete Arches - Normal Forces	Model	1D Internal Forces	Side
Phase 10: Moving the bridge over the channel				
10	Complete Bridge Transport	Drawing		
10	Complete Bridge Transport - Bending	Model	3D Deformations	Side
10	Complete Bridge Transport - Stress	Model	3D Stress	Side
Phase 11: Placing the bridge in its final position				
11	Complete Bridge	Drawing		Side
11	Complete Bridge - Bending	Model	3D Deformations	Side
11	Complete Bridge - Stress	Model	3D Stress	Side

Phase 1 – Transportation

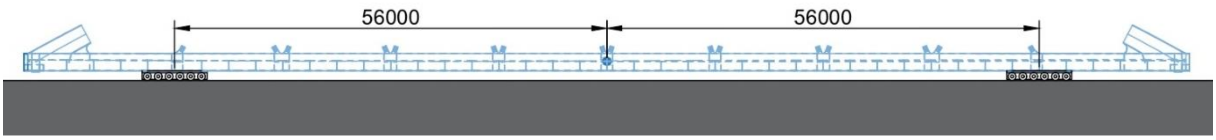


Figure 81 - SPMT Spacing [mm] - Drawing

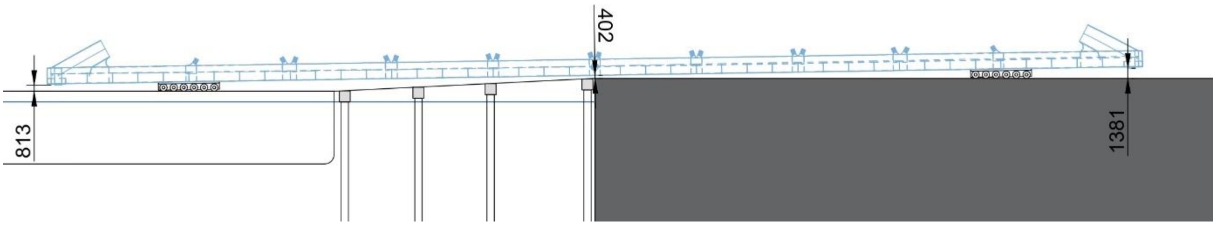


Figure 82 - Height Clearance on RORO Ramp [mm] - Drawing

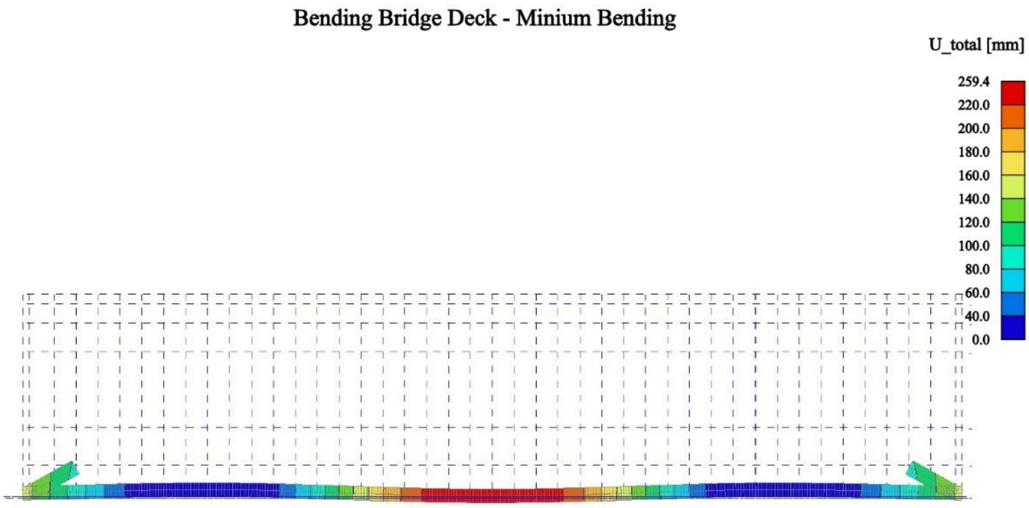


Figure 83 - Minimum Bending Bridge Deck - Bending - Model

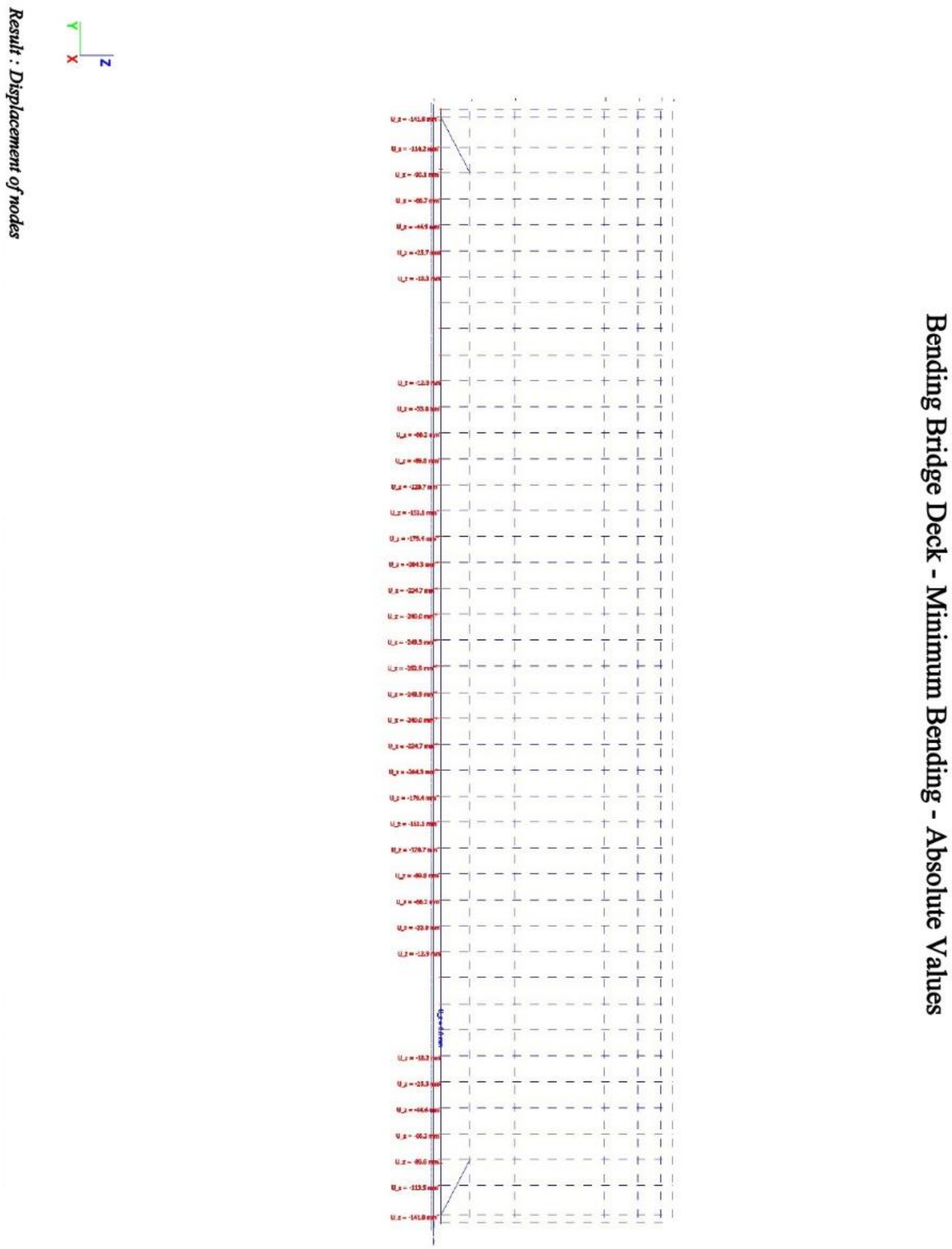


Figure 84 - Bending Bridge Deck - Minimum Bending - Absolute Values - Model

Figure 84 shows the maximum bending in absolute values. The values that should be noted are the maximum of 260 mm in the middle and 140 mm on the ends of the bridge.

(The locations lacking a bending value mark where the SPMTs support the bridge.)

Phase 2 – Placing the bridge deck on supports

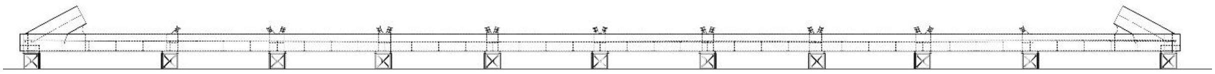


Figure 85 - Phase 2 - Bridge Deck on Supports – Drawing

Figure 86 - Installation Site

Phase 3 – Building supports for the arches

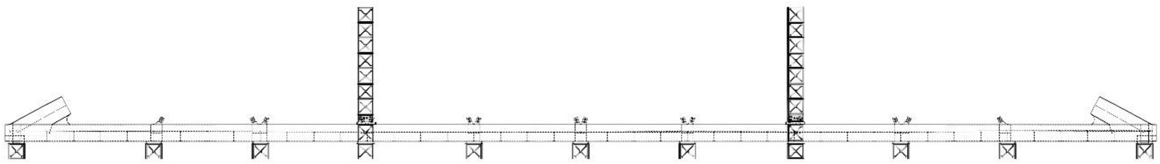


Figure 87 - Phase 3 - Support Structure Arches - Drawing

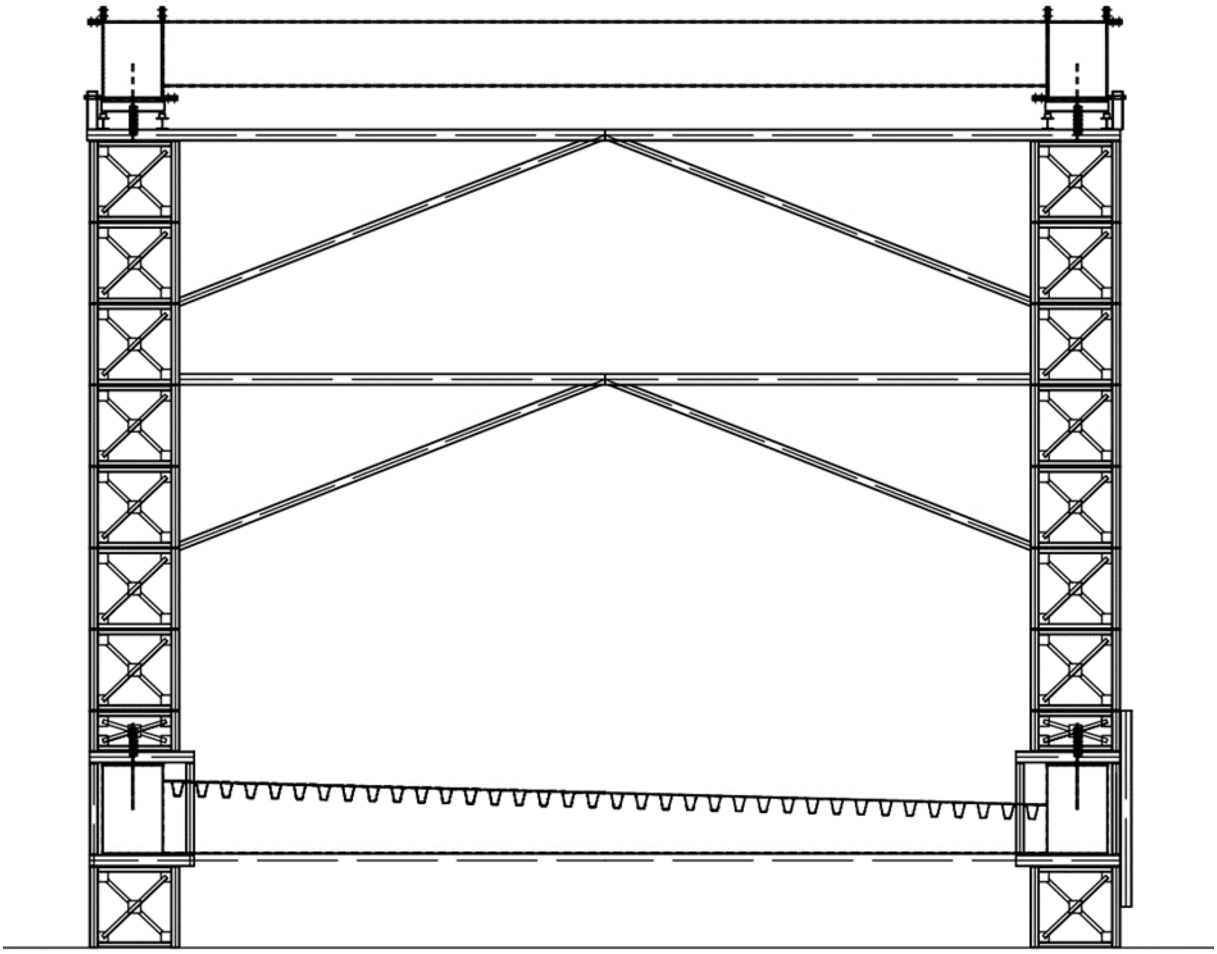


Figure 88 - Phase 3 - Support Structure Arches - Front View - Drawing

Phase 4 – Placing the outer arch sections

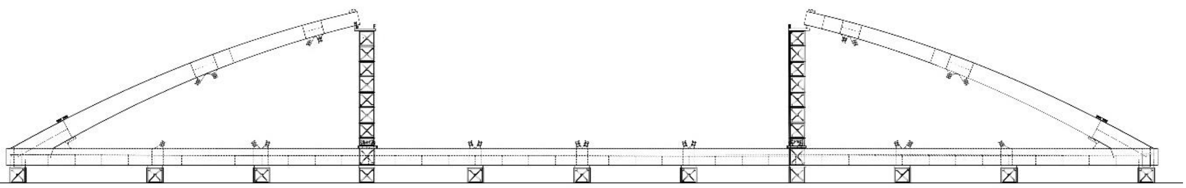


Figure 89 - Phase 4.1 - Outer Arch Sections on Supports – Drawing

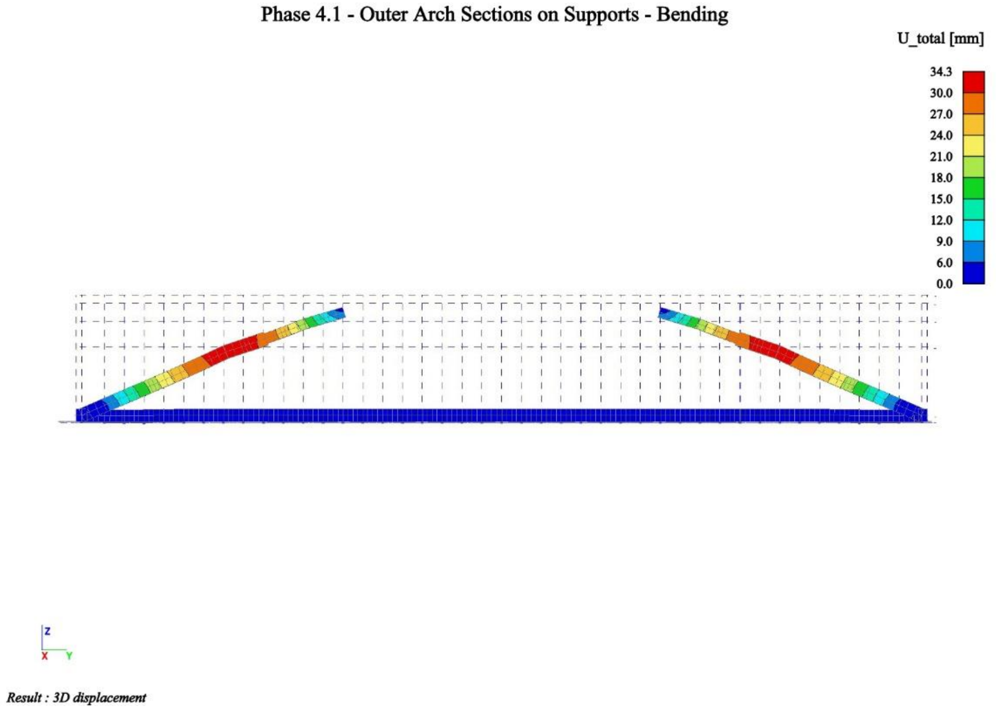


Figure 90 - Phase 4.1 - Outer Arch Sections on Supports - Bending - Model

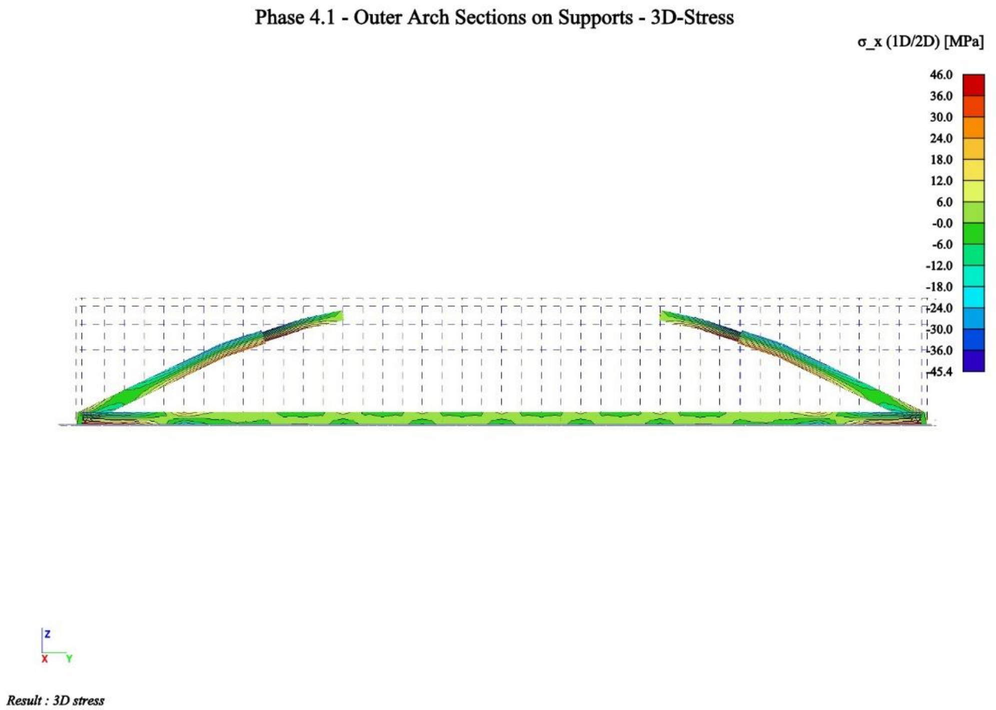


Figure 91 - Phase 4.1 - Outer Arch Section on Supports - 3D-Stress - Model

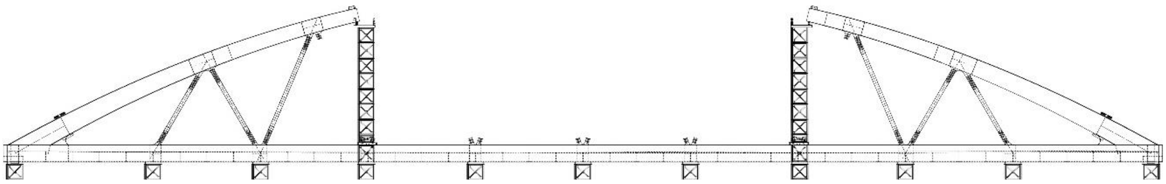


Figure 92 - Phase 4.2 - Outer Arch Sections on Supports – Drawing

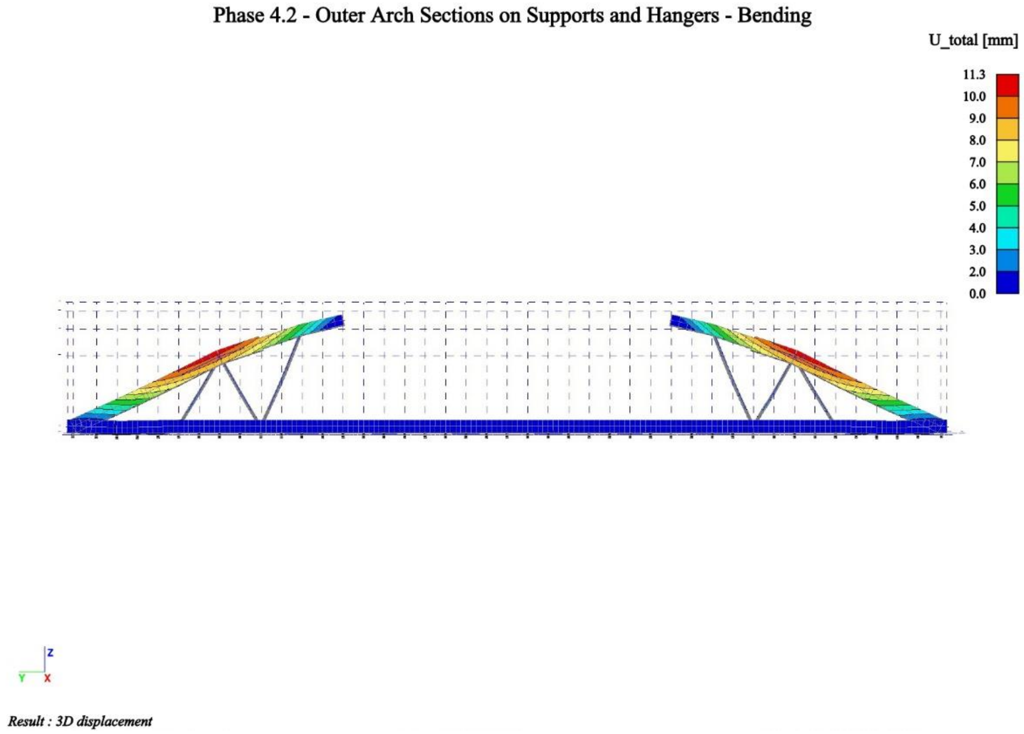


Figure 93 - Phase 4.2 - Outer Arch Sections on Supports and Hangers - Bending - Model

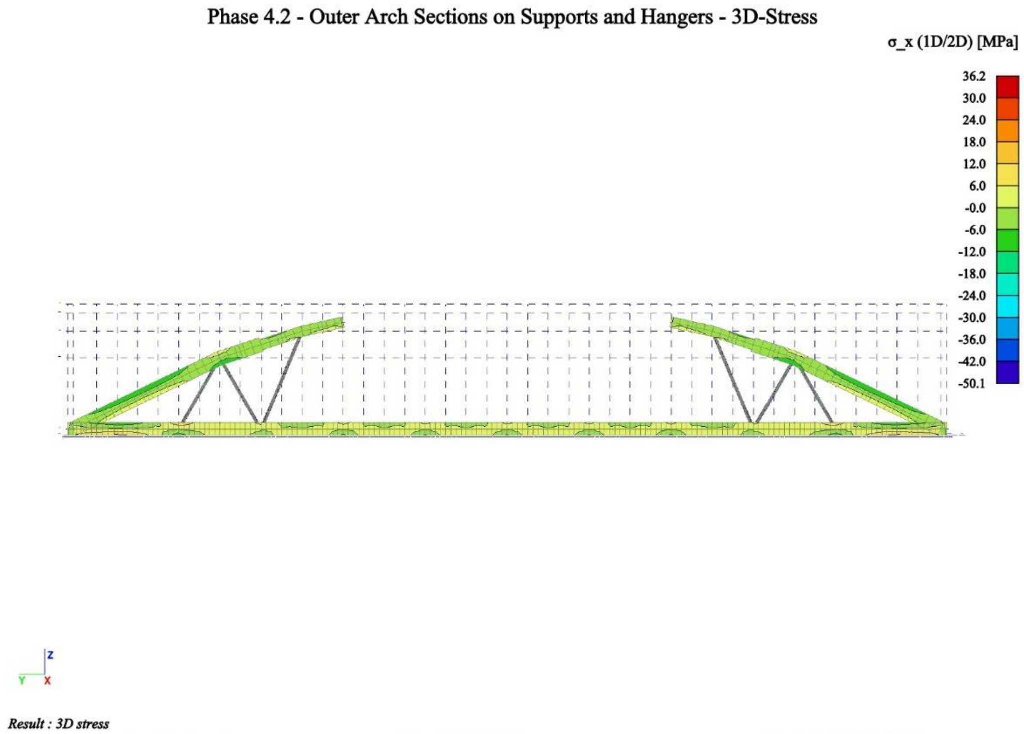


Figure 94 - Phase 4.2 - Outer Arch Sections on Supports and Hangers - 3D-Stress – Model

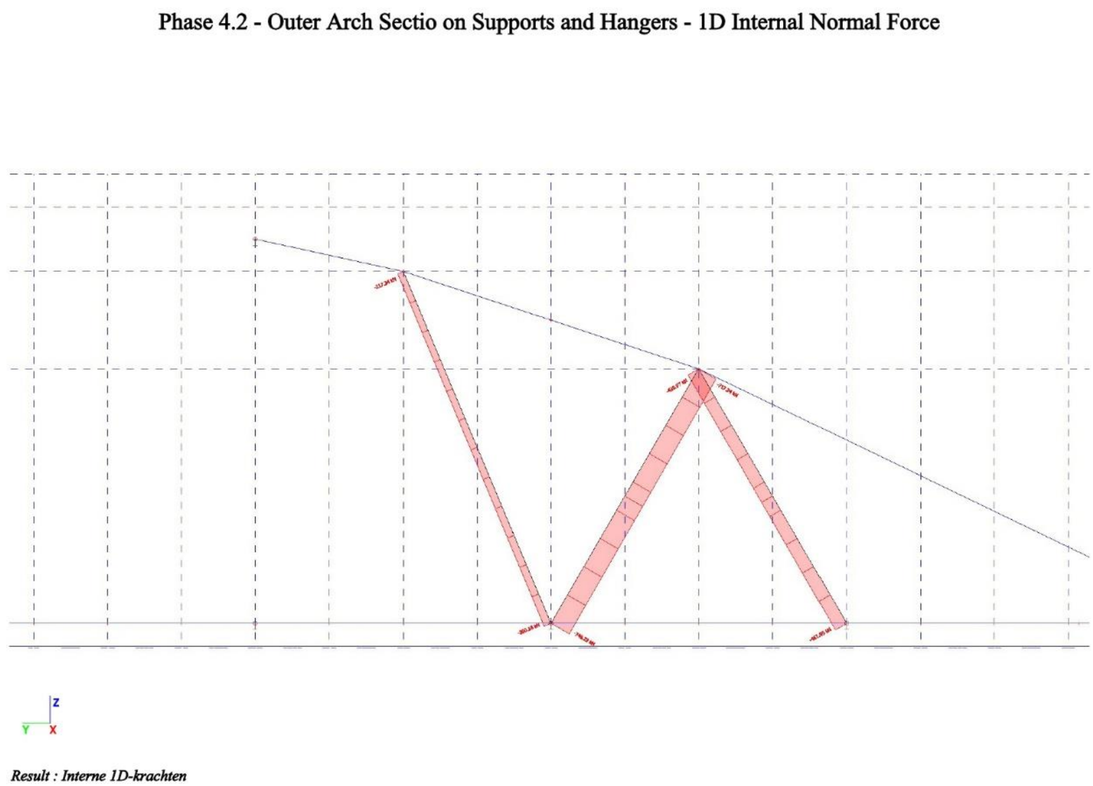


Figure 95 - Phase 4.2 - Outer Arch Sections on Supports and Hangers - 1D Internal Normal Force - Model

In Figure 95 are the following results from right to left:

Hanger no.	Normal Force Top	Normal Force Bottom
1	-430.97 kN	-461.95 kN
2	-717.24 kN	-748.22 kN
3	-217.34 kN	-260.18 kN

The models' results indicate that adding the hangers reduces the deflection and 3D-stress in the arch section. When comparing Figure 90 and Figure 93, you can see that the point of maximum deflection (in red) is more or less in the same location for both cases; however, due to the addition of the hangers, this deflection is reduced from 34.3 mm to 11.3 mm. The still present deflection is due to the hangers themselves deflecting under the load of the arch section. (The hangers' strength is calculated and checked in Appendix.G.)

In addition, the stress is in the arch significantly reduced from Figure 91 to Figure 94, from 46 MPa to near, ranging between -12 and 6 MPa. The remaining stress points are there because of the support locations. These stress points cannot be removed as the arch has to be supported, and it is uneconomical to support the entire arch over its full length. The legend of Figure 94 still ranges to 36.2 MPa but reflects the stress from the hangers supporting the arch.

Phase 5 – Placing the middle arch sections

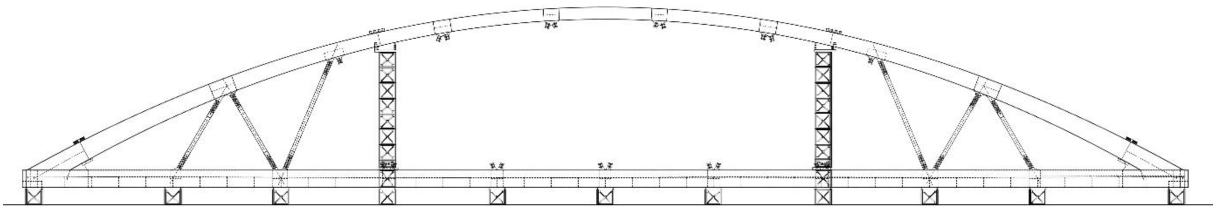


Figure 96 - Phase 5.1 - Middle Arch Sections on Supports- Drawing

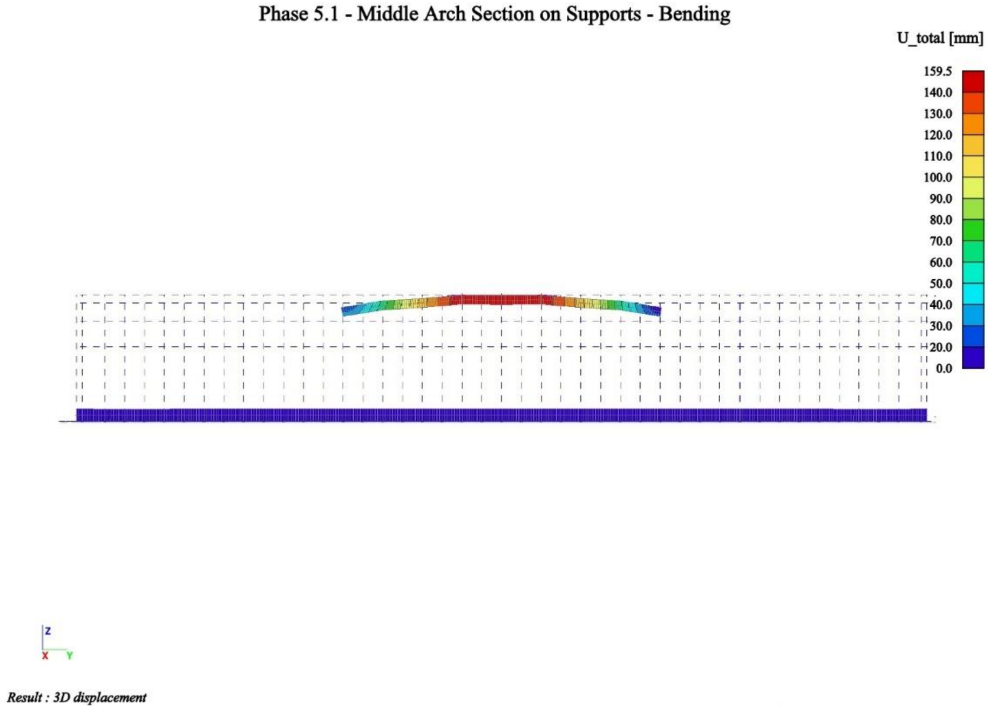


Figure 97 - Phase 5.1 Middle Arch Section on Supports - Bending - Model

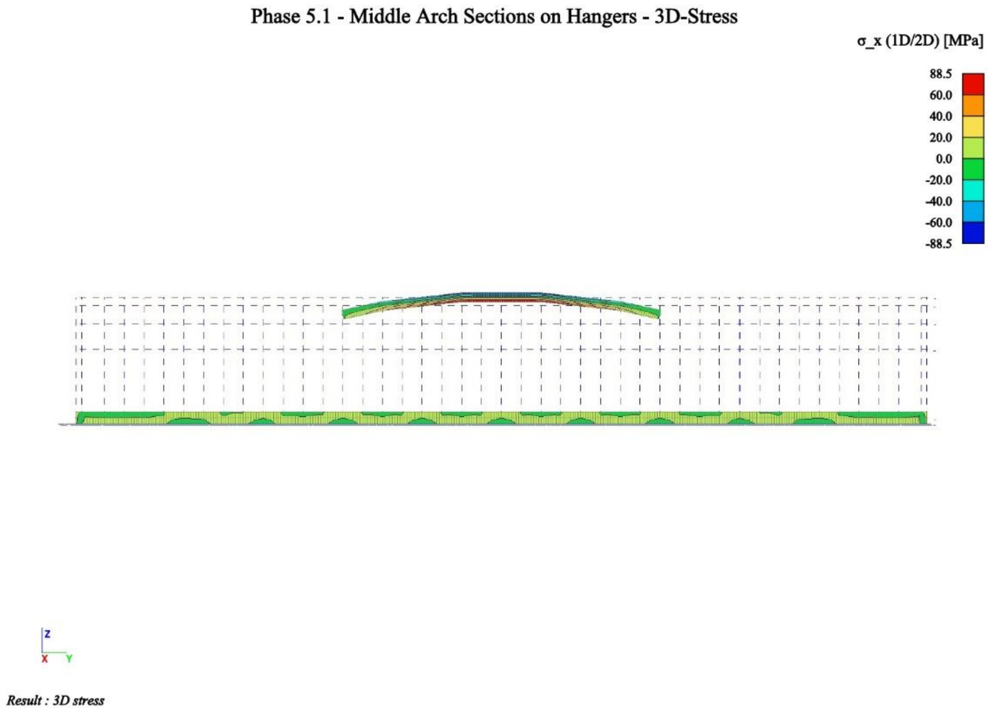


Figure 98 - Phase 5.1 - Middle Arch Section on Supports - 3D-Stress - Model

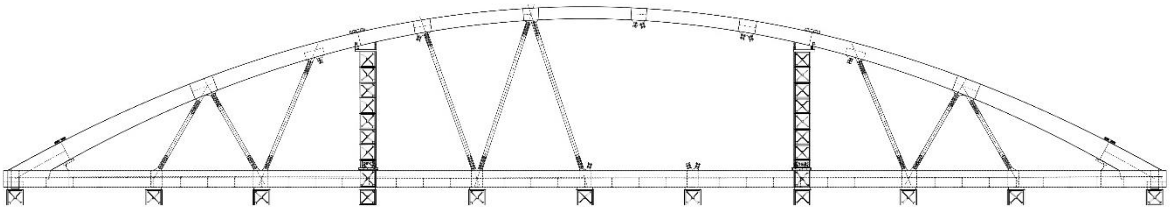


Figure 99 - Phase 5.2 - Middle Arch Sections on Hangers – Drawing

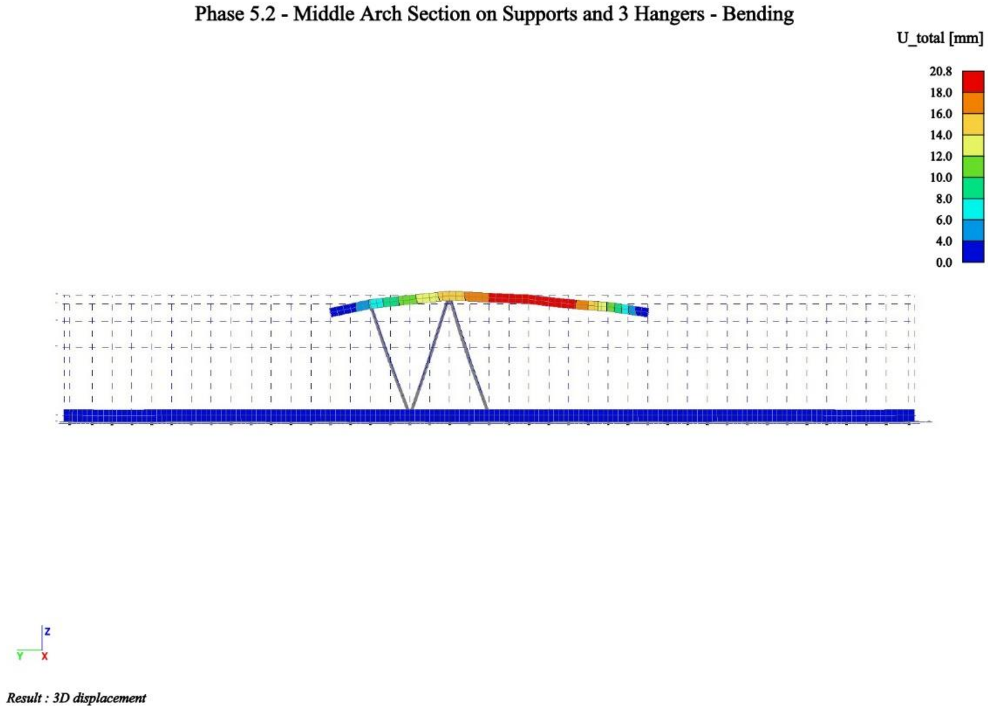


Figure 100 - Phase 5.2 - Arch Section on Supports and 3 Hangers - Bending – Model

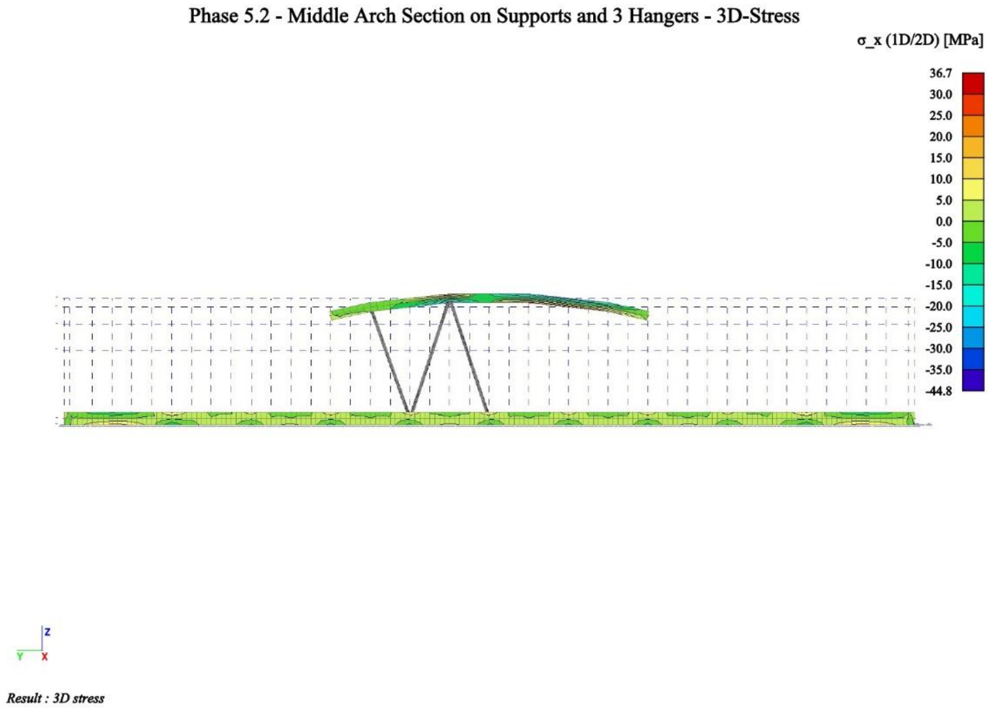


Figure 101 - Phase 5.2 - Middle Arch Section on Supports and 3 Hangers - 3D-Stress - Model

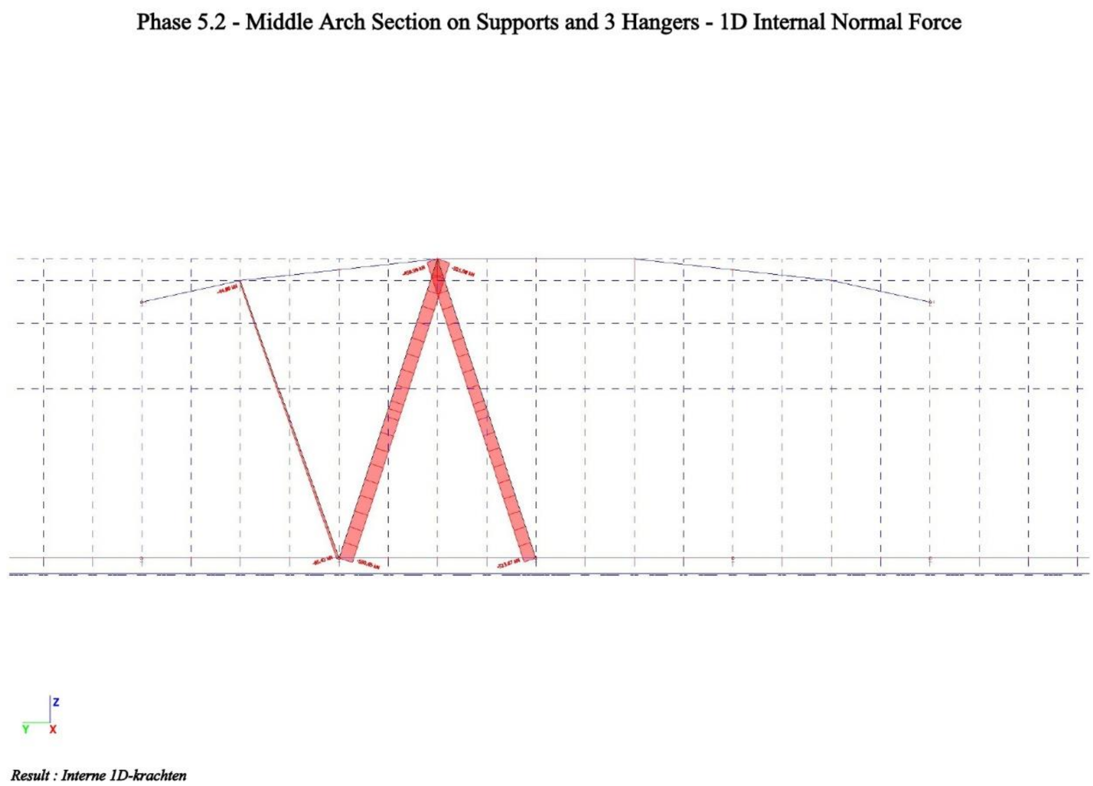


Figure 102 - Phase 5.2 - Middle Arch Section on Supports and 3 Hangers - 1D Internal Normal Force - Model

In Figure 102 are the following results from left to right:

Table 35 - Phase 5.2 - 1D Internal Normal Forces

Hanger no.	Normal Force Top	Normal Force Bottom
1	-44.70 kN	-95.43 kN
2	-525.98 kN	-580.65 kN
3	-438.99 kN	-513.67 kN

Figure 97 and Figure 100 are great examples of the effectivity of the hangers in relation to bending, and the full mid-arch section deflects 88.5 mm while adding just half of the hangers reduces this to 20,8 mm. The figure is also well visualised how much the hanger assists in keeping the shape of the arch, as the side with hangers follows more the intended shape while the side without the hangers is deflecting down by 20.8 mm.

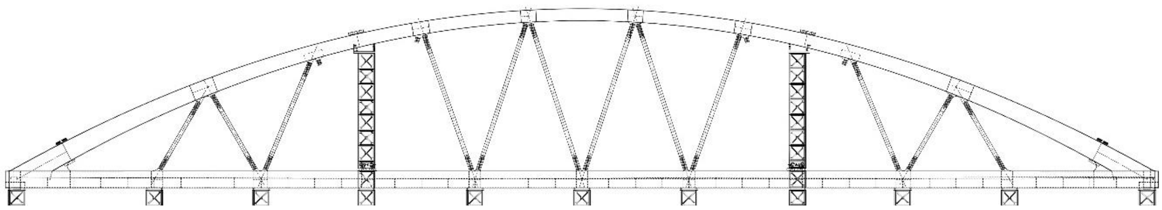


Figure 103 - Phase 5.3 - Middle Arch Sections on Hangers – Drawing

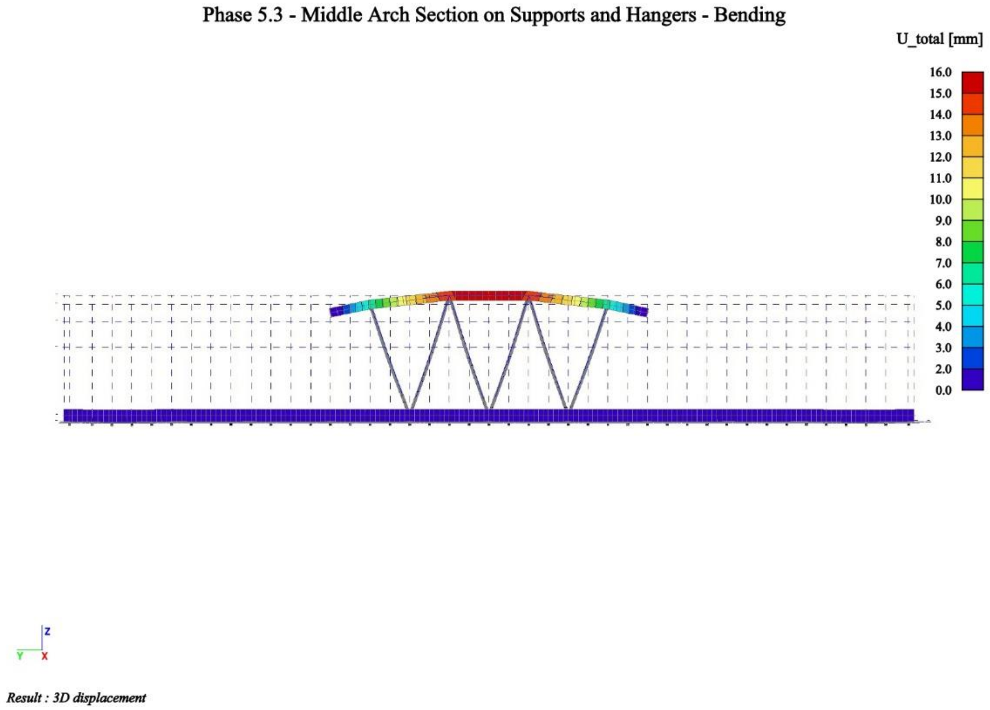


Figure 104 - Phase 5.3 - Middle Arch Sections on Supports and Hangers – Bending - Model

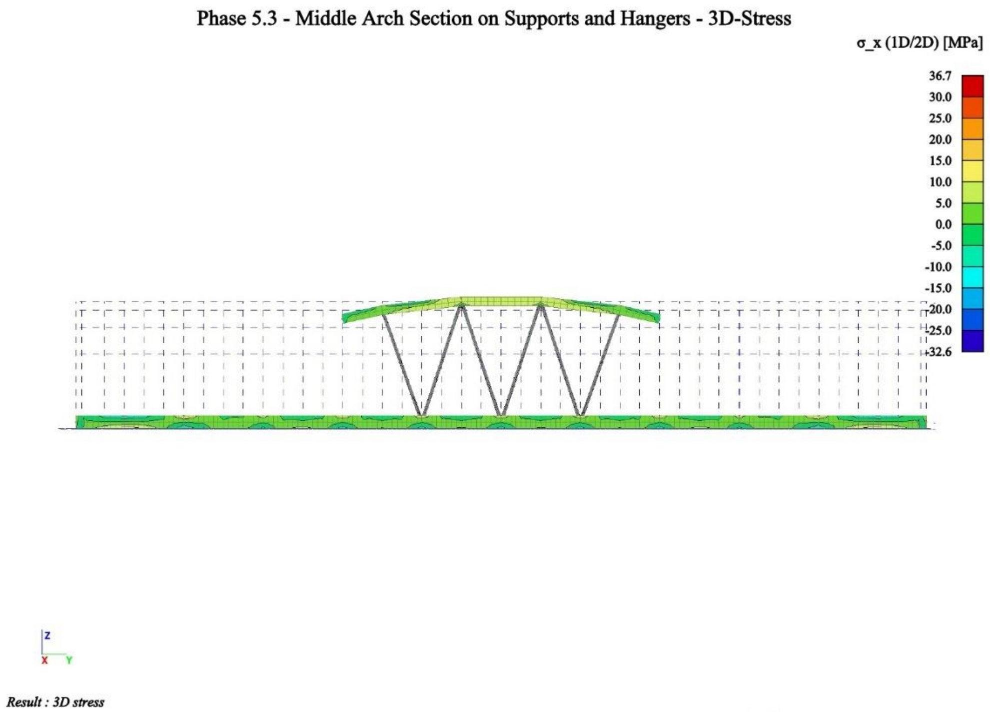


Figure 105 - Phase 5.3 - Middle Arch Section on Supports and Hangers - 3D-Stress - Model

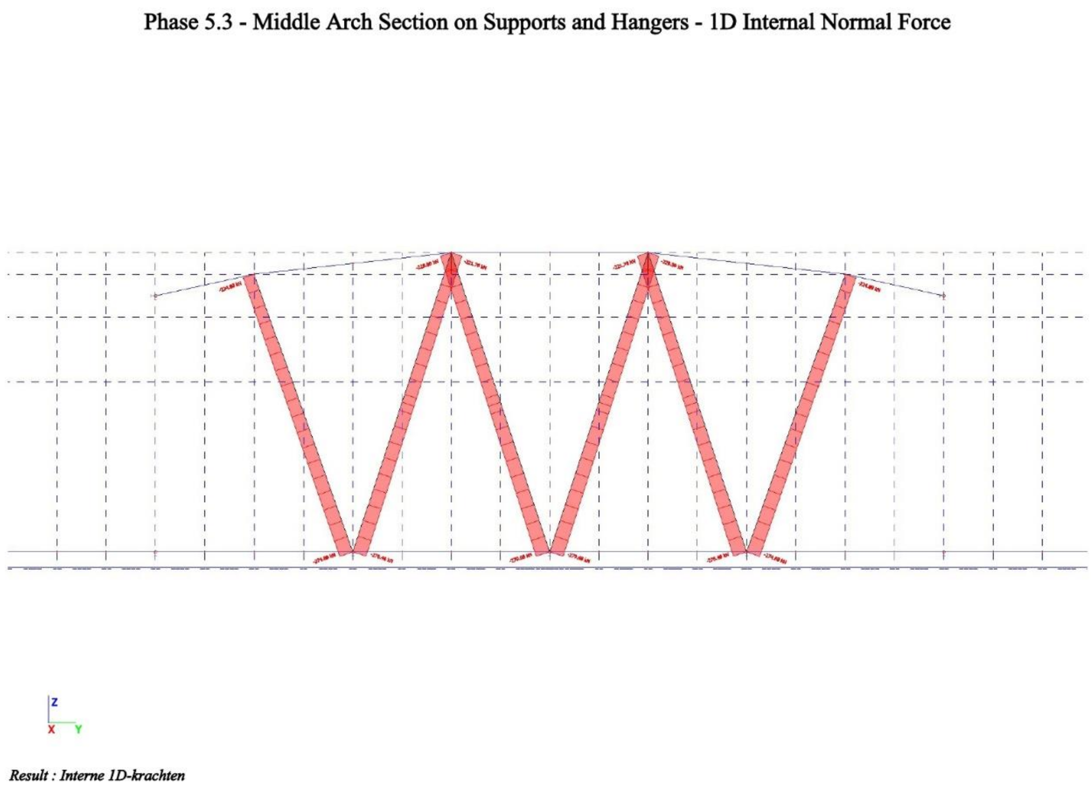


Figure 106 - Phase 5.3 - Middle Arch Sections on Supports and Hangers - 1D Internal Normal Forces – Model

In Figure 106 are the following results from left to right:

Table 36 - Phase 5.3 - 1D Internal Normal Forces

Hanger no.	Normal Force Top	Normal Force Bottom
1	-224.00 kN	-274.80 kN
2	-221.76 kN	-276.46 kN
3	-223.08 kN	-279.68 kN
4	-223.08 kN	-279.68 kN
5	-221.76 kN	-276.46 kN
6	-224.00 kN	-274.80 kN

Placing all hangers under the arch section gives this arch section a good and near-uniform load distribution over its support. This is due to its symmetry. The bending and stress in the top middle part of the arch are more present in the model than in the real situation. This is because the model assumes straight beams while the hangers have an arch shape which is better at spreading the stress than a straight beam.

Phase 6 – Welding the arches

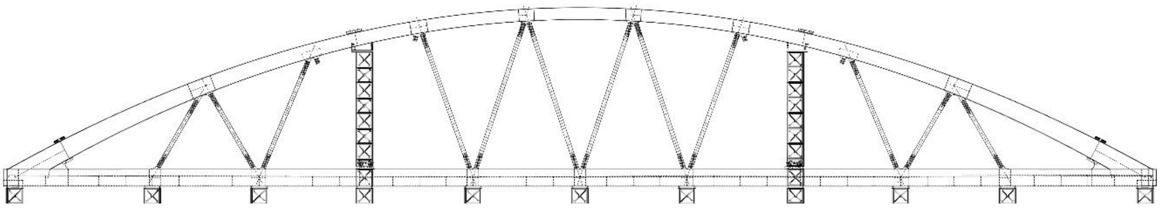


Figure 107 - Phase 6 - Arch Fully Welded – Drawing

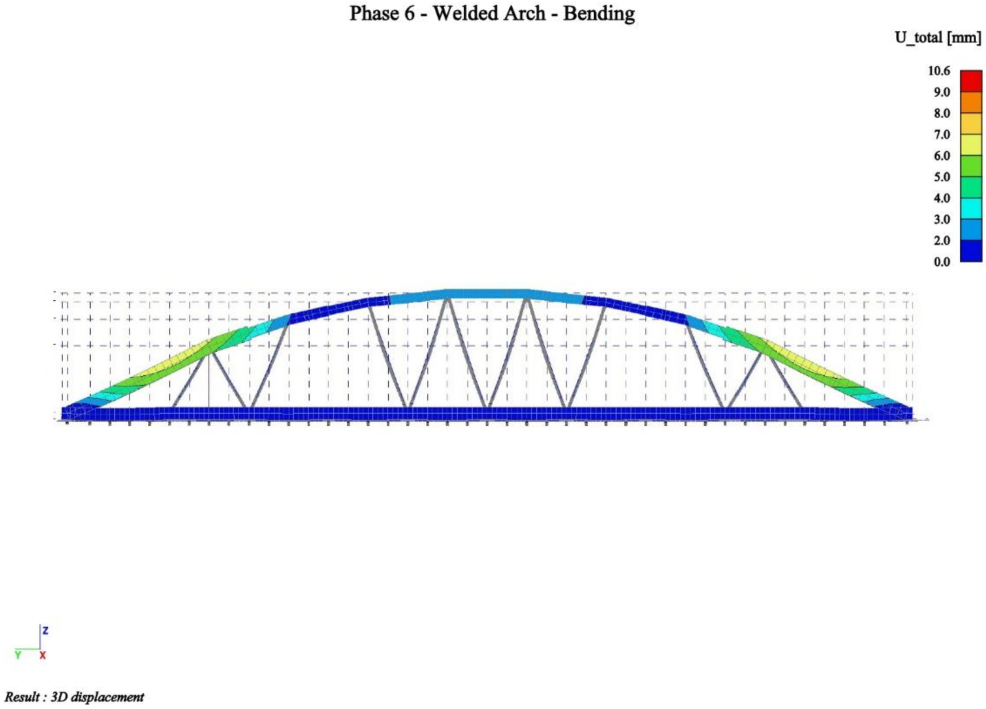


Figure 108 - Phase 6 - Welded Arch – Bending - Model

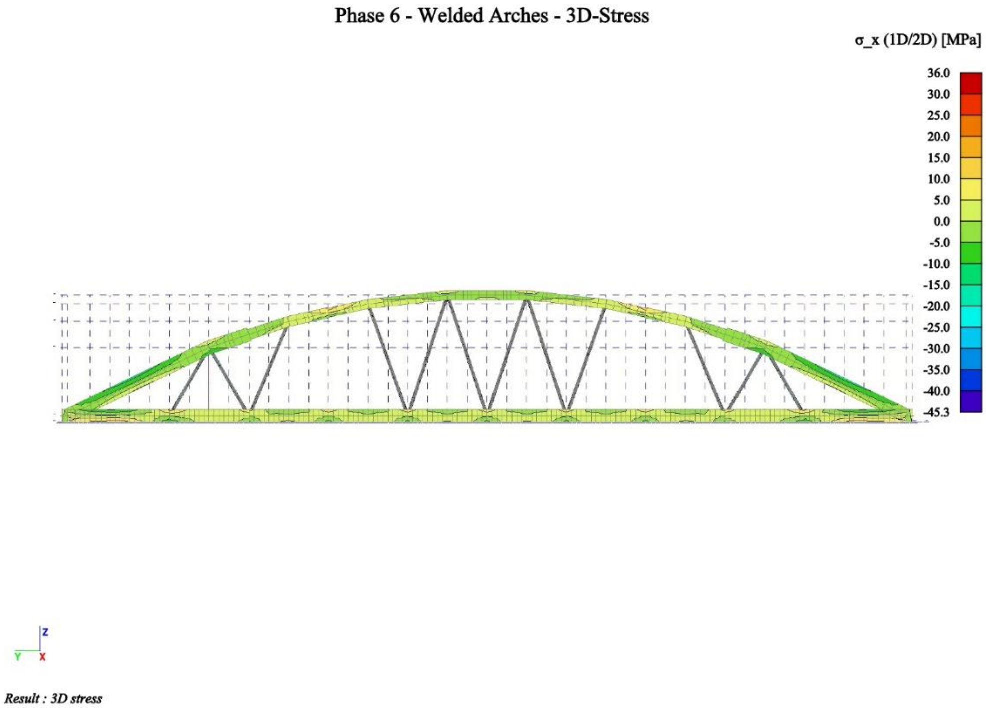


Figure 109 - Phase 6 - Welded Arches - 3D-Stress - Model

Phase 7 – Placing the cross beams

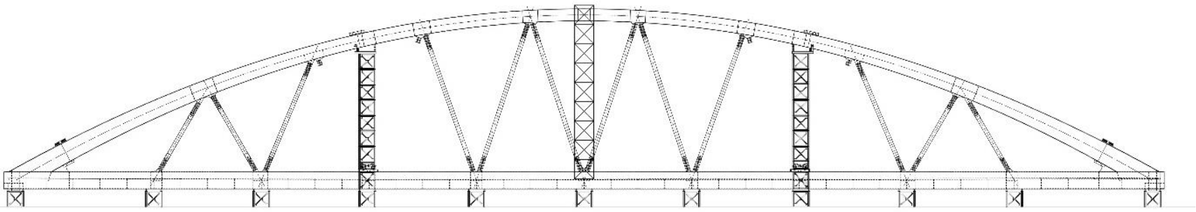


Figure 110 - Phase 7 - Arches with middle support – Drawing - Model

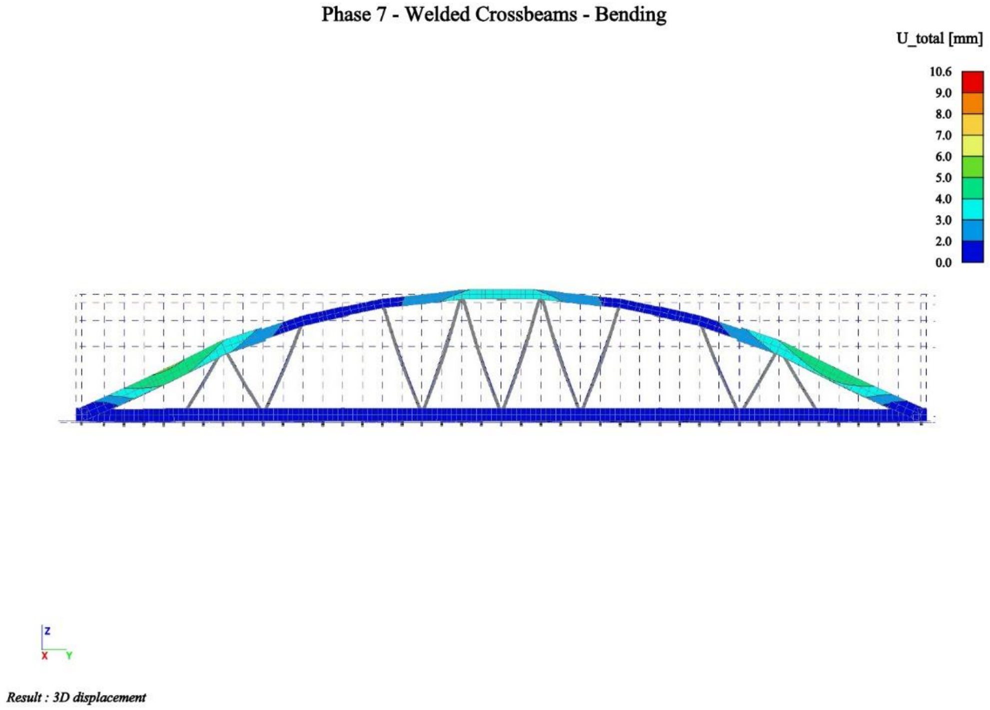


Figure 111 - Phase 7 - Welded Crossbeams – Bending - Model

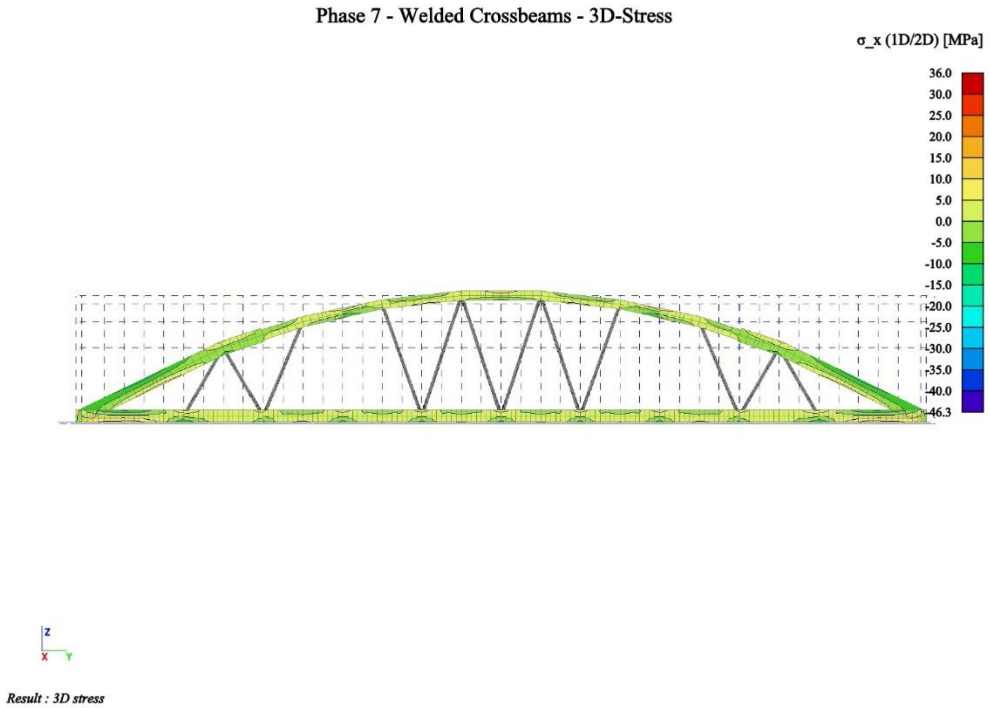


Figure 112 - Phase 7 - Welded Crossbeams - 3D-Stress - Model

Phase 9 – Removing support towers

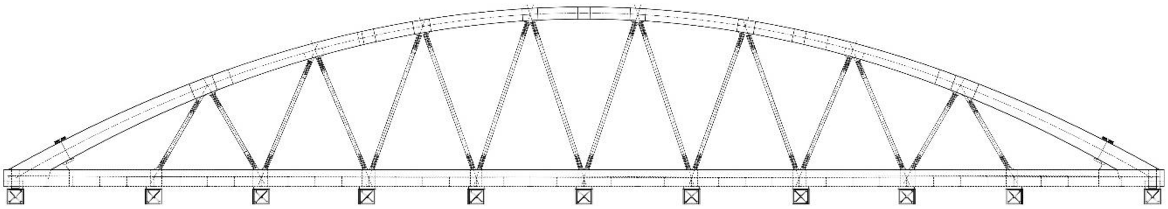


Figure 113 - Phase 7 - Complete Arch with Crossbeams – Drawings

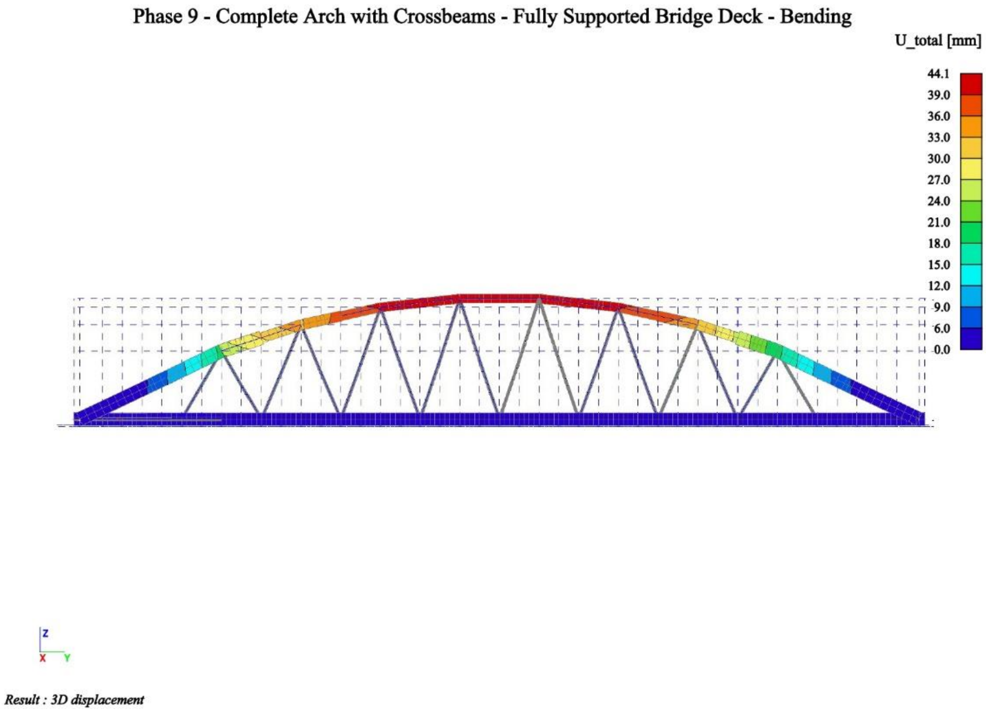


Figure 114 - Complete Arch with Crossbeams - Fully Supported Bridge Deck - Bending - Model

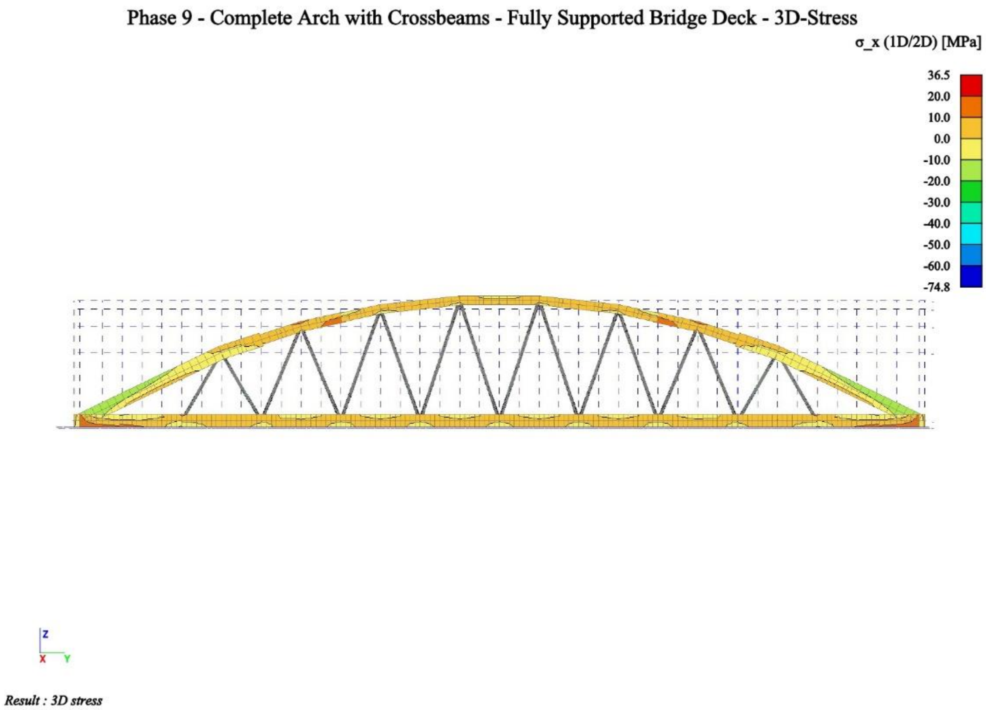


Figure 115 - Complete Arch with Crossbeams - Fully Supported Bridge Deck - 3D-Stress - Model

Phase 10 – Moving the bridge over the channel

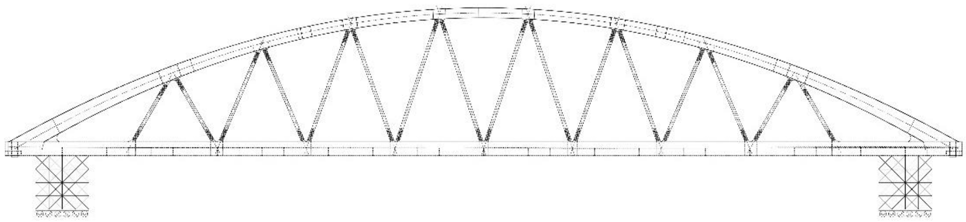


Figure 116 - Phase 10 - Complete Bridge - Transport to final position - Drawing

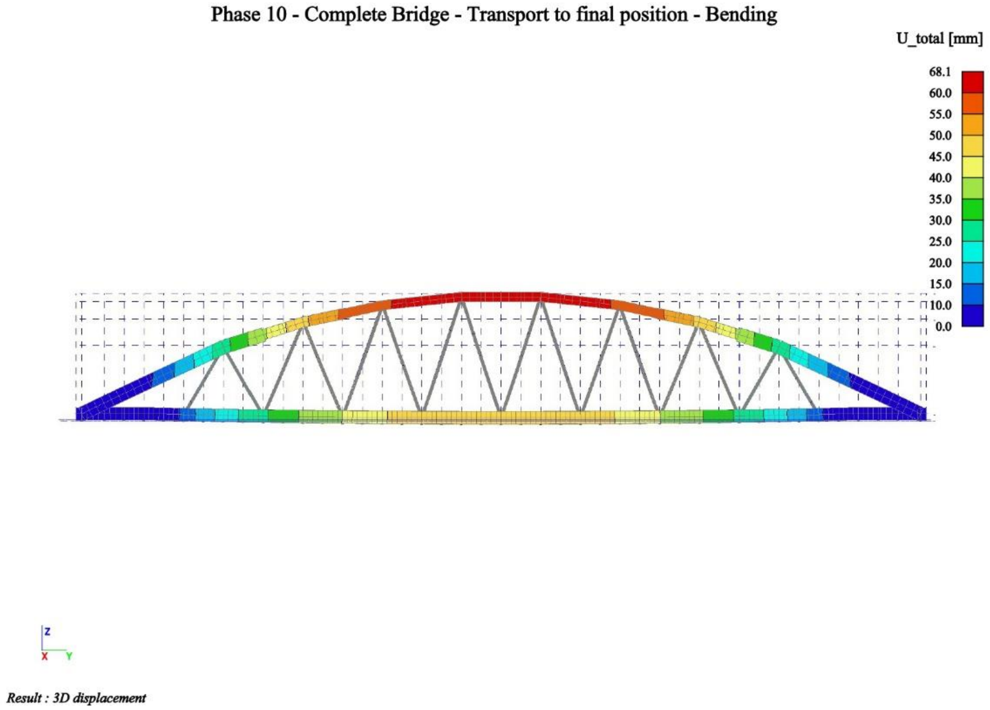


Figure 117 - Phase 10 - Complete Bridge - Transport to Final Position – Bending - Model

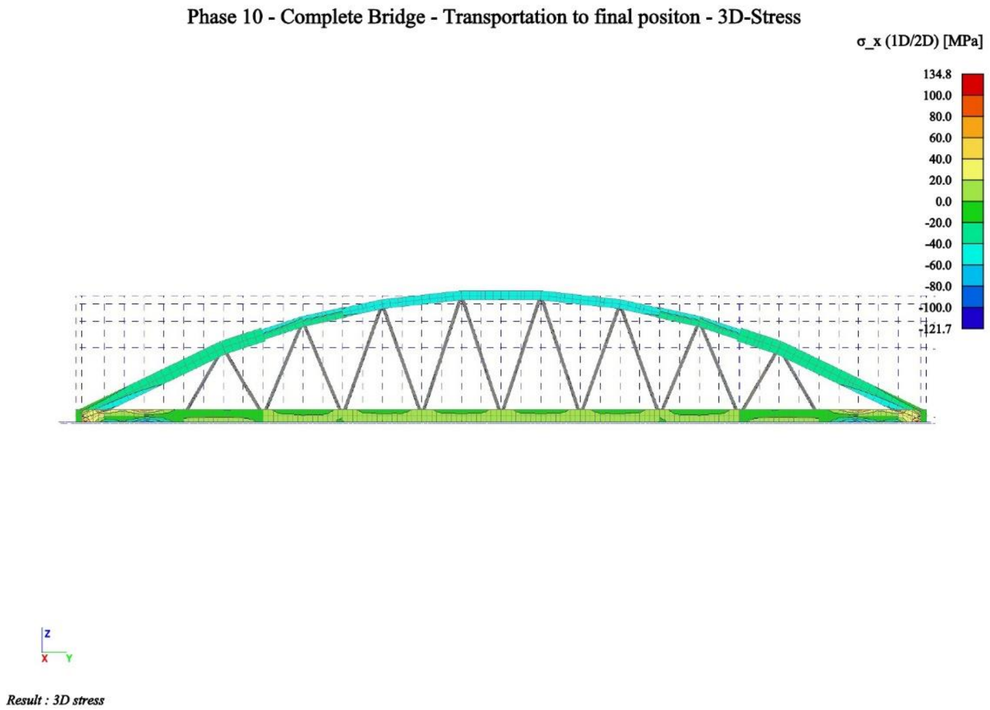


Figure 118 - Phase 10 - Complete Bridge - Transportation to final position - 3D-Stress – Model

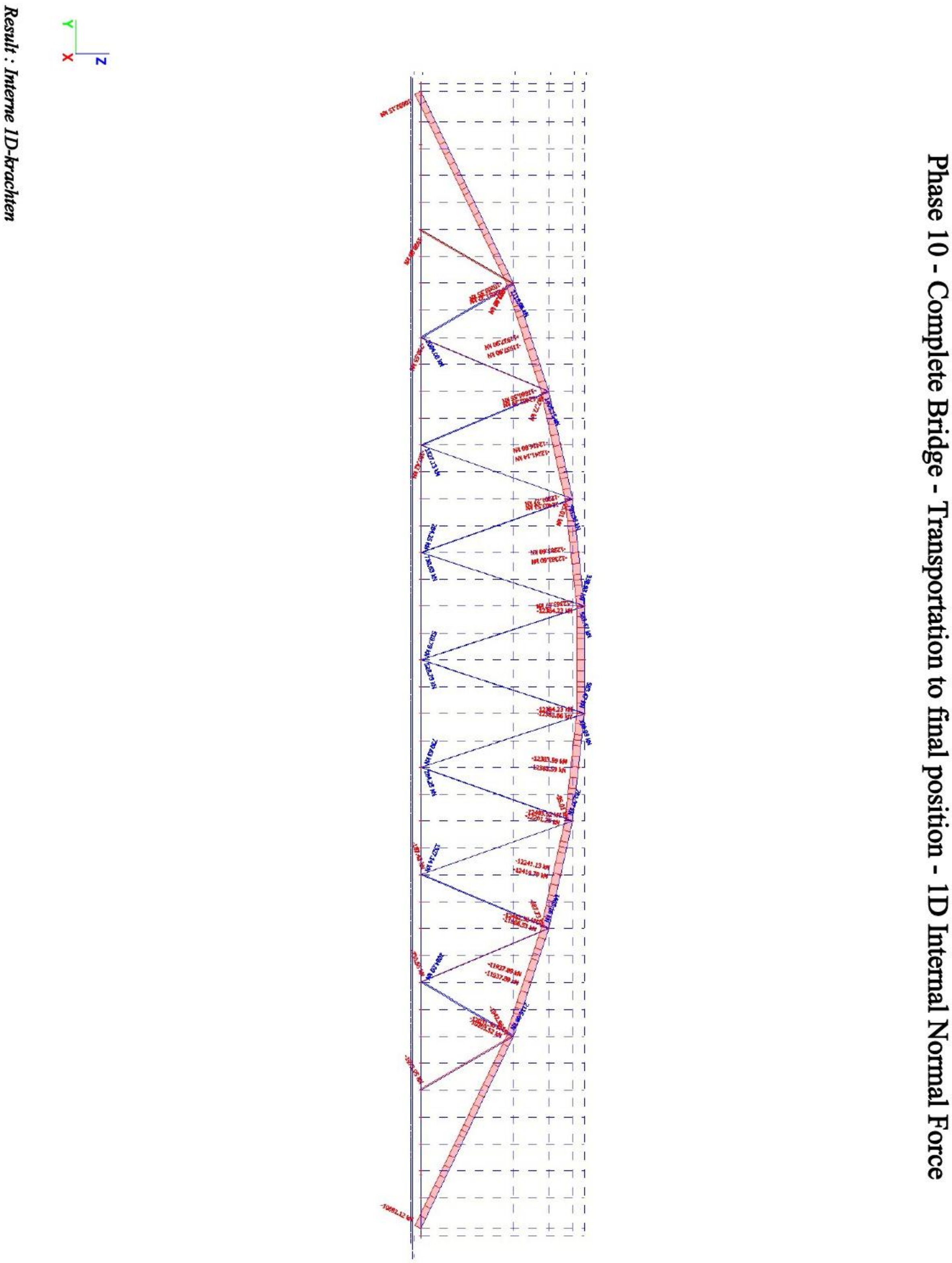


Figure 119 - Phase 10 - Complete Bridge - Transportation to final position - 1D Internal Normal Force - Model

An essential aspect to notice in this phase is the fact that the hangers 1, 3 and 5 are in compression due to the placing of the support from the SPMTs. The loads on hangers 1 and 3 are larger by quite a margin. These intense normal forces (compressive loads) will significantly impact the hangers' strength requirements. The hanger check in Appendix.G also indicates that this phase is the determining factor for the thickness of the hangers' connection plates.

Table 37 - Phase 5.3 - 1D Internal Normal Forces

Hanger no.	Moment				Normal Force
	Support 1	Support 2	Max. Negative	Max. Positive	
	[kNm]	[kNm]	[kNm]	[kNm]	[kN]
1	38.53	-65.49	-65.49	39.36	1973.93
2	-46.23	5.55	-46.23	16.16	
3	-3.80	-48.81	-48.81	17.86	730.55
4	-71.99	-22.65	-71.99	29.62	
5	-37.58	-67.64	-67.64	33.86	187.42
6	-32.33	-31.68	-32.33	15.23	
7	-24.14	-41.76	-41.76	17.90	
8	-32.01	-32.32	-32.32	18.39	

Phase 11 – Placing the bridge in its final position

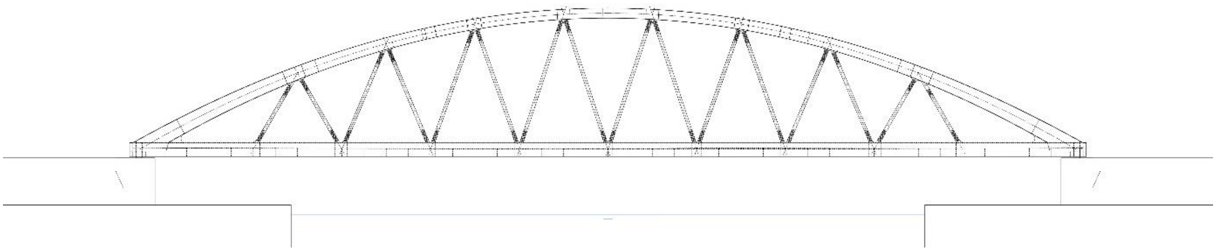


Figure 120 - Phase 11 - Complete Bridge - Final - Drawing

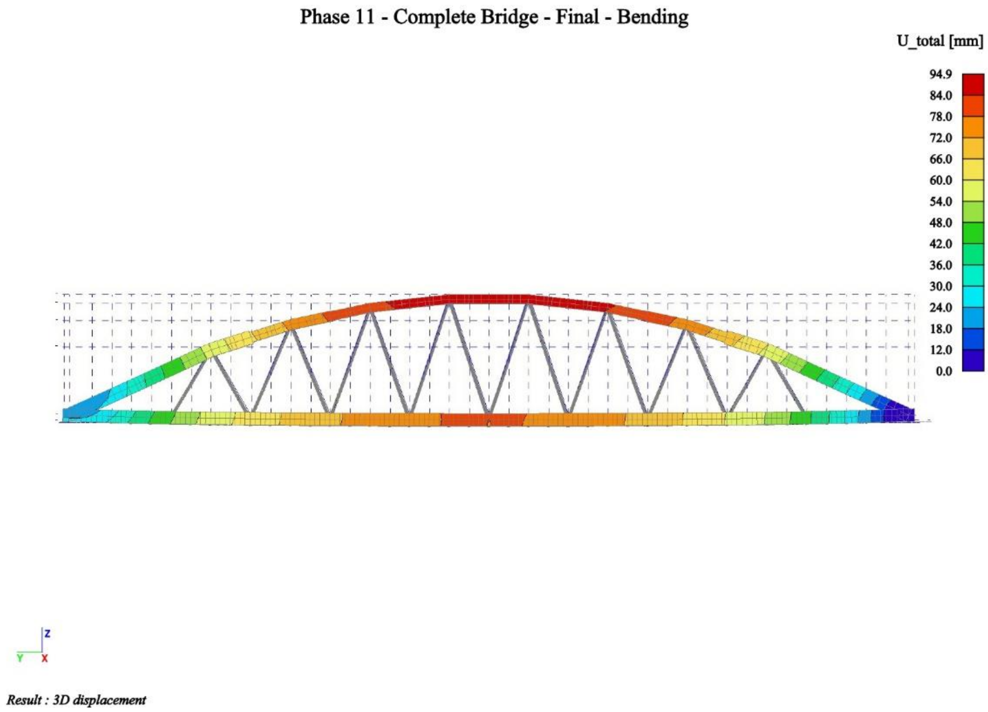


Figure 121 - Phase 11 - Complete Bridge - Final - Bending - Model

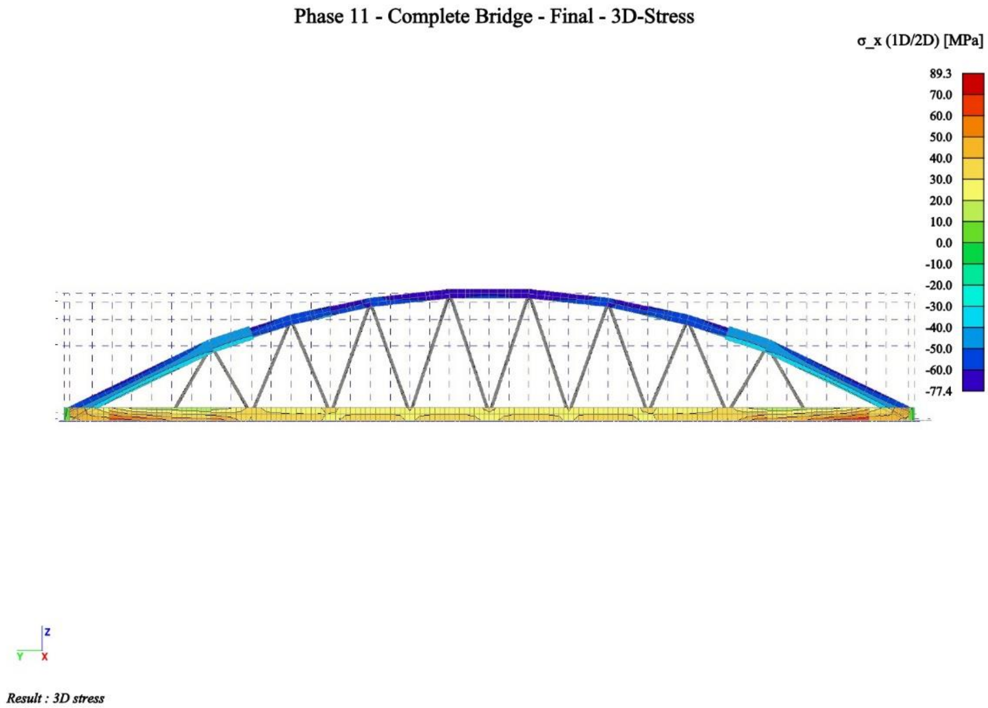


Figure 122 - Phase 11 - Complete Bridge - Final - 3D-Stress - Model

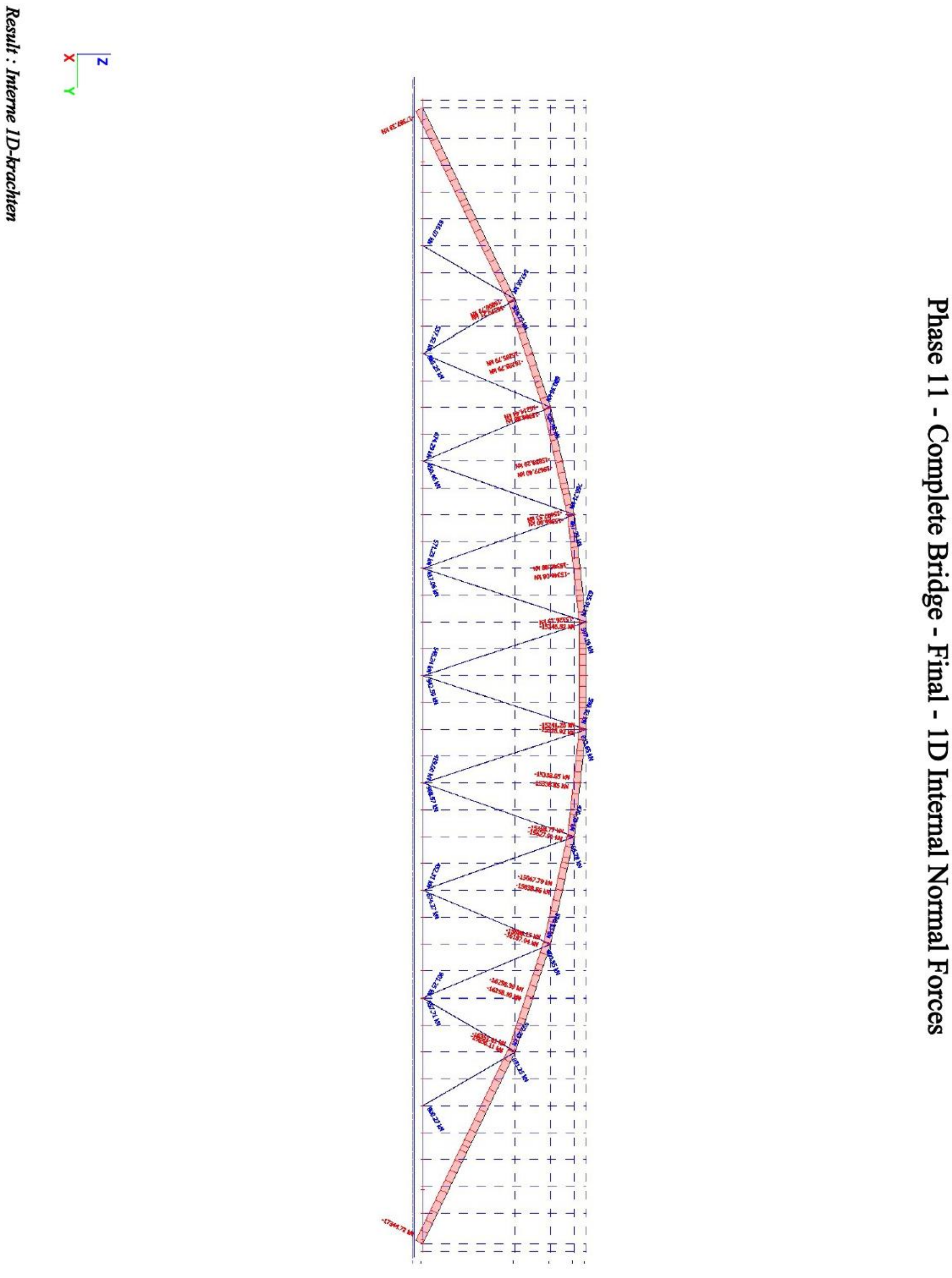
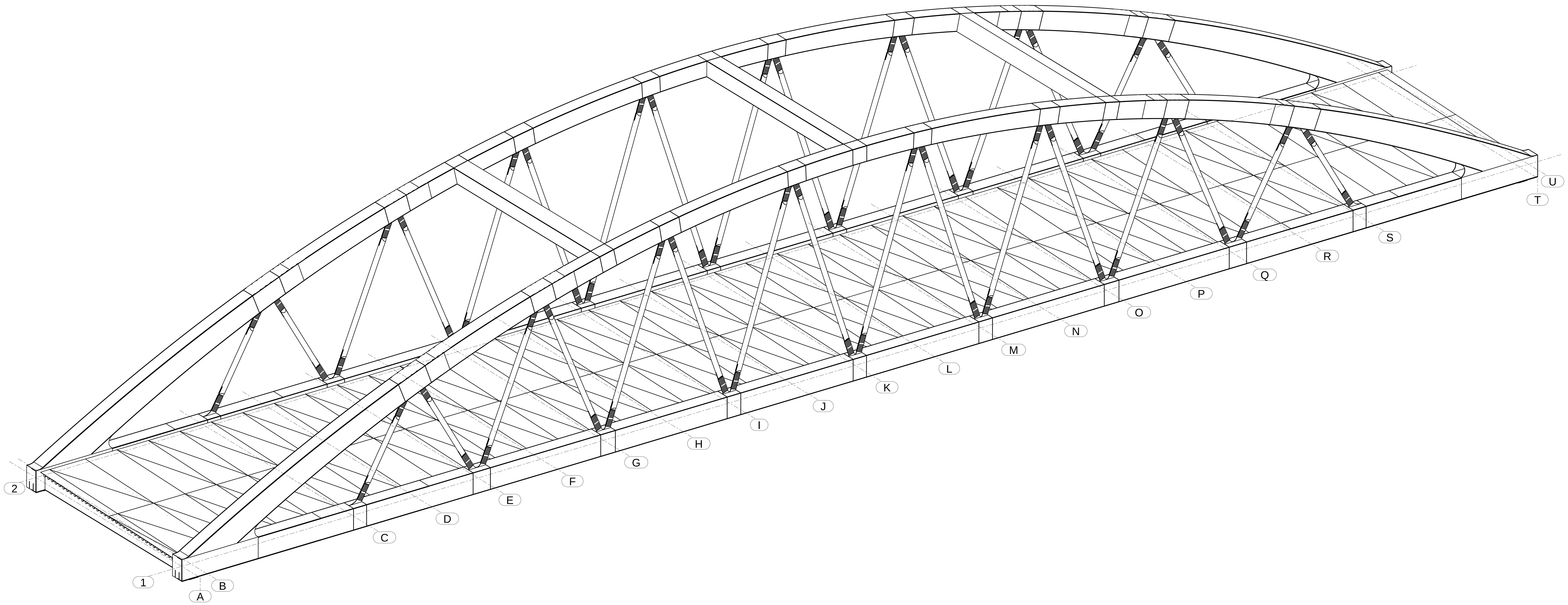


Figure 123 - Phase 11 - Complete Bridge - Final - 1D Internal Normal Force - Model

Appendix.J Bridge drawings

The drawings 13170-TEK-S-001-B to …-005-B in this appendix are provided by ASK Romein Hillebrand, and the drawings of GEN-00001-006_BRIDGE_RORO_GARR_01-02-02 are provided by Sarens

Drawing Name	Description
13170-TEK-S-001-B	
	3D representation of the bridge
13170-TEK-S-002-B	
	Side view of total bridge + Cross-sections of the bridge deck
13170-TEK-S-003-B	
	Side view of half of the bridge + Details Main Beam
13170-TEK-S-004-B	
	Side view of half of the bridge + Details Arch
13170-TEK-S-005-B	
	Top view of bridge deck + Details Deck Structure + Support indications
GEN-00001-006_BRIDGE_RORO_GARR_01-02-02	
	The approach Sarens proposed of loading on barges NOTE: SPMT spacing is different – See chapter 4.2.1



3D
SCHAAL: 1:150

Opmerkingen

Maten in m tenzij anders aangegeven
Hoeken aangegeven in graden (360 gradenstelsel)
* = Maatvoering informatief

Coördinaten

Coordinaten zijn in Belgische Lambert72

Hoogtemaatvoering

TAW: Tweede Algemene Waterpassing
LAT: ligt 0,77m onder TAW

REVISIE	DATUM	AUTEUR	CONTR.	GOEDK. INTERN	GOEDK. KLANT	BESCHRIJVING WIJZIGING
B	28.10.2021	SWA	-	-		3 rijstroken ipv 4 smallere brug
A	05.07.2021	SWA	-	-		brug niet langer als parkbrug
0	25.02.2021	SWA	-	-		1ste uitgave

lantis bouwen aan verbinding

THV ROCO

SITUATIE

Oosterweelverbinding

Rechteroever
Perceel 3a en 3b

Tijdelijke R1
Overzichtsplan objecten

OWK	ROS	KTU	SPL	OKA	R1N	R1O
----	----	----	----	----	----	----

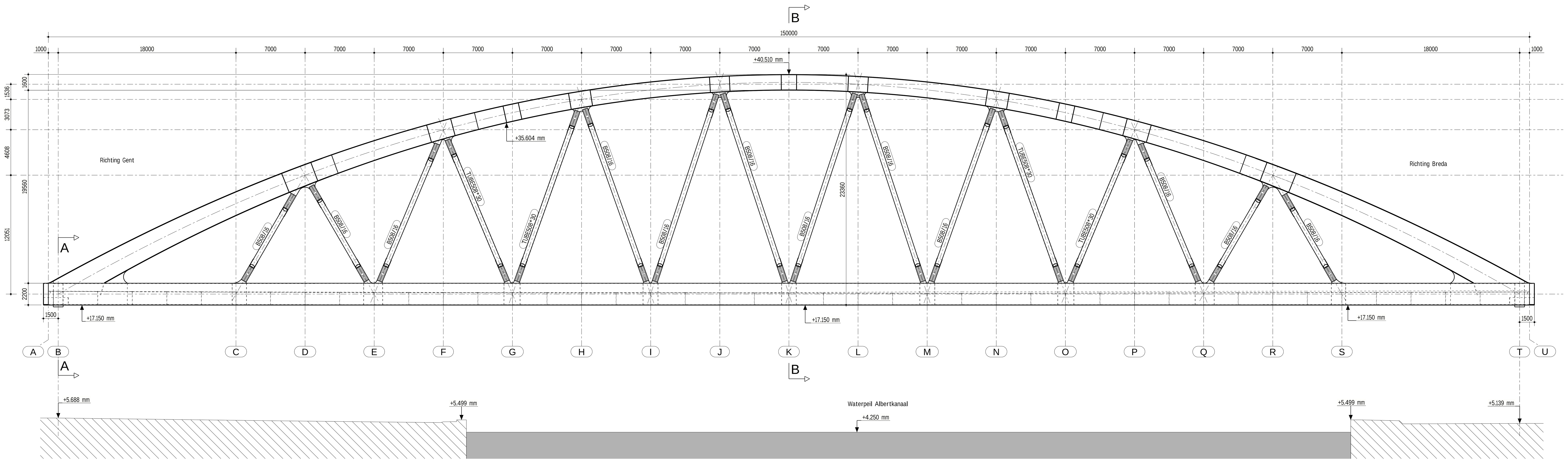
OBS	Deelsysteem	Activiteit	Contract Fase	Deelpakket
OWVA	00D.00	W10	OFF2	OWROPL00

AUTEUR	TYPE	NUMMER
ROCO	DWG	00001

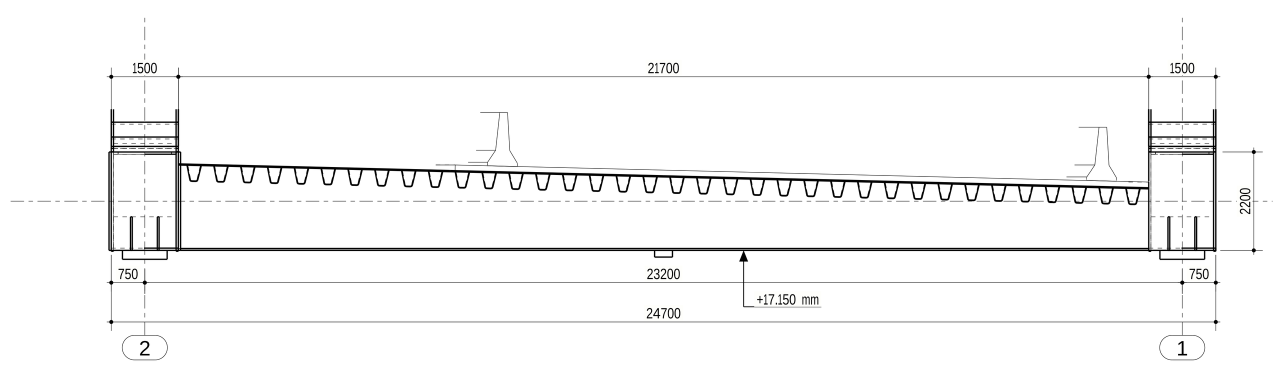
SUBTYPE	STATUS	REVISIE
NRI	S1	0.02

QR-Code

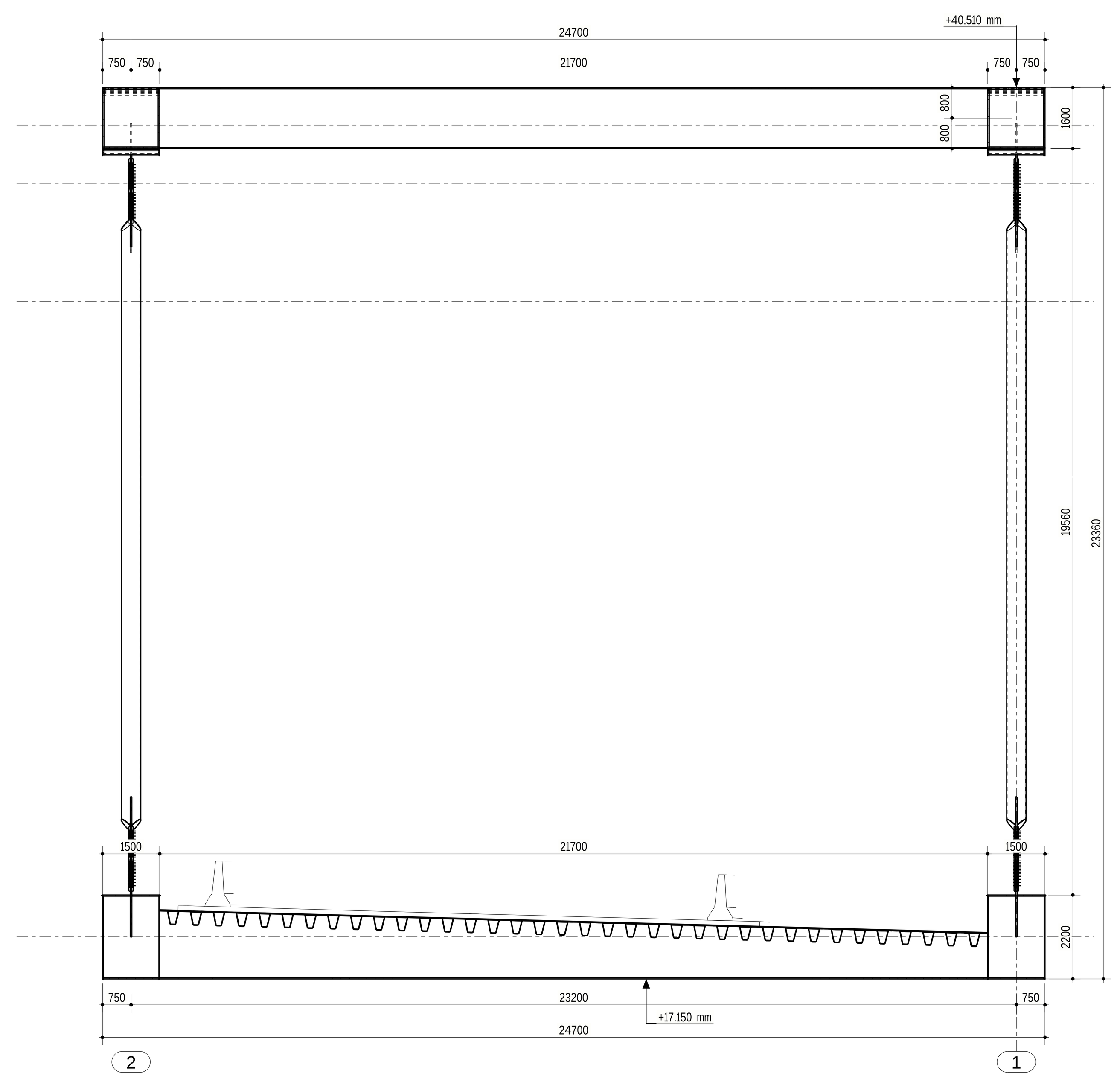
Auteur Persoon	Controleur ROCO	Goedkeuring ROCO	Goedkeuring Klant	Vervaldatum	A0
SWA	-	-	-	ROCO	



AS 1
SCHAAL 1:200



DOORSNEDE A - A
SCHAAL 1:100



DOORSNEDE B - B
SCHAAL 1:100

Opmerkingen

Maten in m tenzij anders aangegeven
Hoeken aangegeven in graden (360 gradenstelsel)
* = Maatvoering informatief

Coördinaten

Coordinaten zijn in Belgische Lambert72

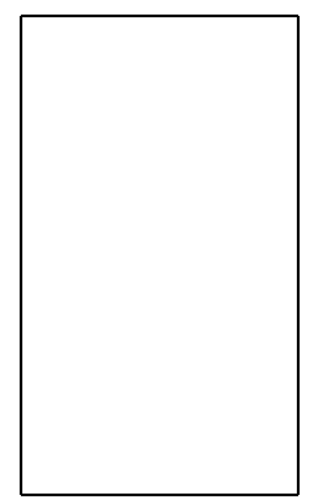
Hoogtemaatvoering

TAW: Tweede Algemene Waterpassing
LAT: ligt 0,77m onder TAW

REVISIE	DATUM	AUTEUR	CONTR.	GOEDK. INTERN	GOEDK. KLANT	BESCHRIJVING WIJZIGING
B	28.10.2021	SWA	-	-		3 rijstroken ipv 4 smallere brug
A	05.07.2021	SWA	-	-		brug niet langer als parkbrug
0	25.02.2021	SWA	-	-		1ste uitgave

lantis bouwen aan verbinding

THV ROCO



SITUATIE

Oosterweelverbinding
Rechteroever
Perceel 3a en 3b

Tijdelijke R1
Overzichtsplan objecten

OWK	ROS	KTU	SPL	OKA	R1N	R1O
----	----	----	----	----	----	----

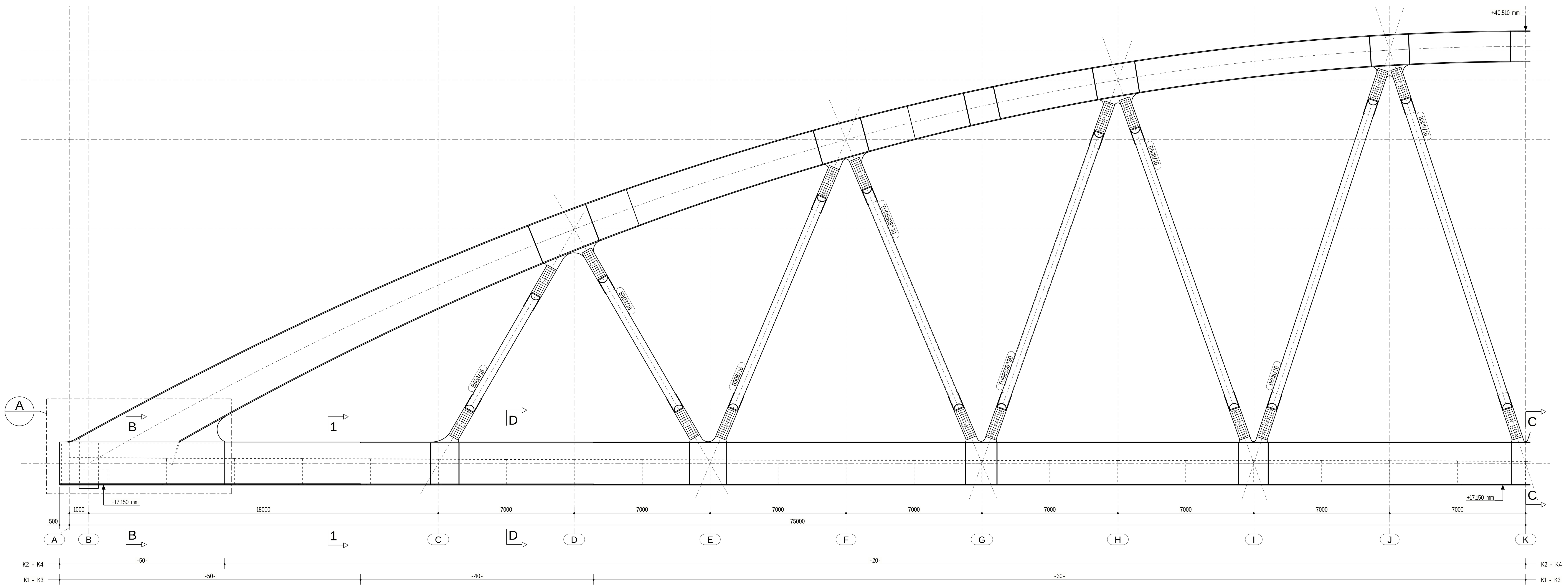
OBS	Deelsysteem	Activiteit	Contract Fase	Deelpakket
OWVA	00D.00	W10	OFF2	OWROPL00

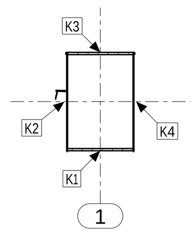
AUTEUR	TYPE	NUMMER
ROCO	DWG	00001

SUBTYPE	STATUS	REVISIE
NRI	S1	0.02

QR-Code

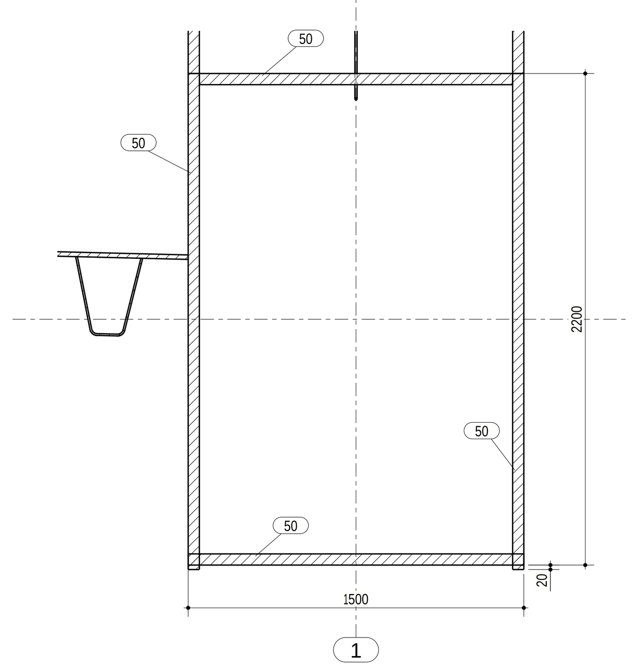
Auteur Persoon	Controleur ROCO	Goedkeuring ROCO	Goedkeuring Klant	Vervaldatum	A0
SWA	-	-	-	ROCO	



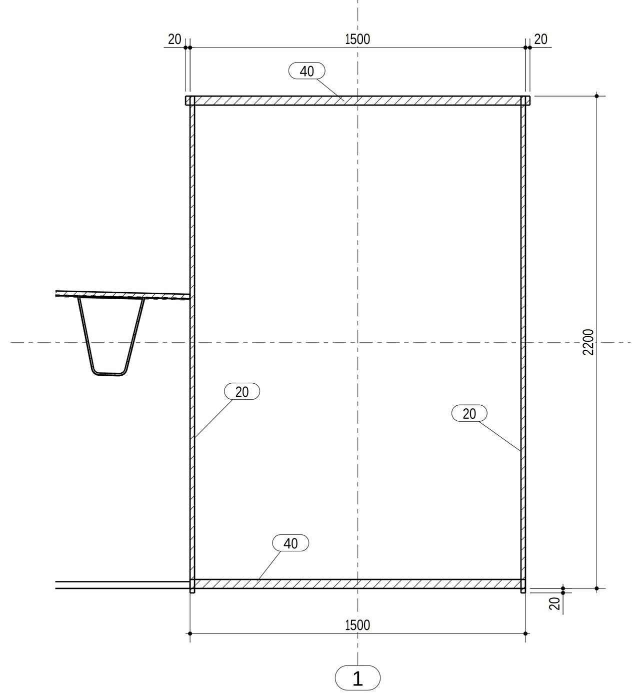


DOORSNEDE 1 - 1
SCHAAL: 1:100

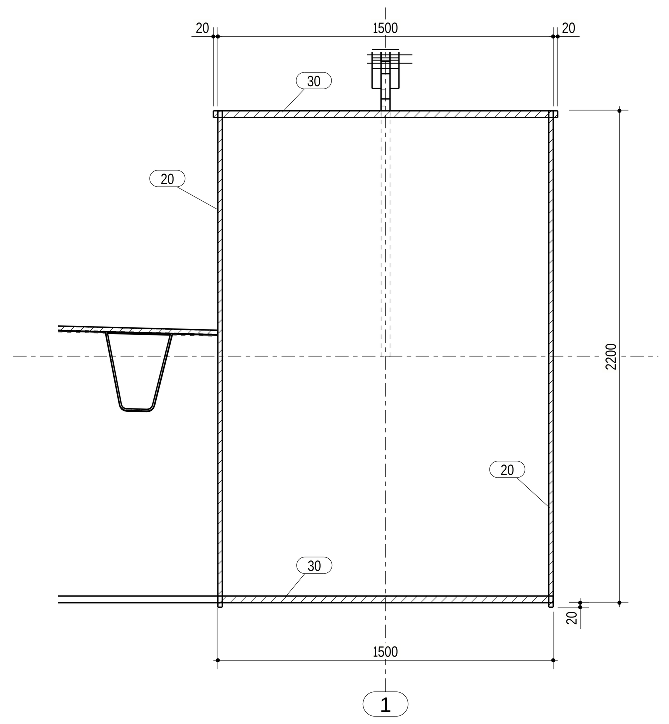
Aanzicht Hoofdligger en Verband
SCHAAL: 1:100



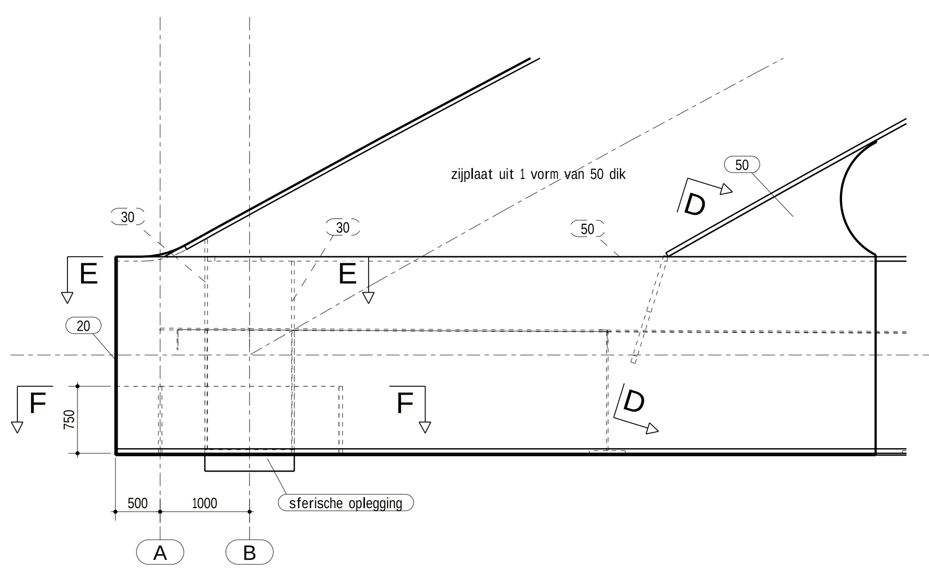
DOORSNEDE B - B
SCHAAL: 1:20



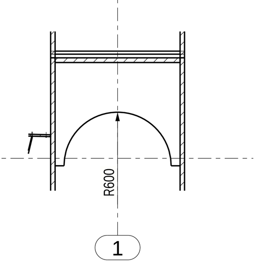
DOORSNEDE D - D
SCHAAL: 1:20



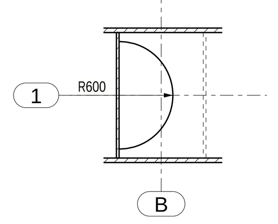
DOORSNEDE C - C
SCHAAL: 1:20



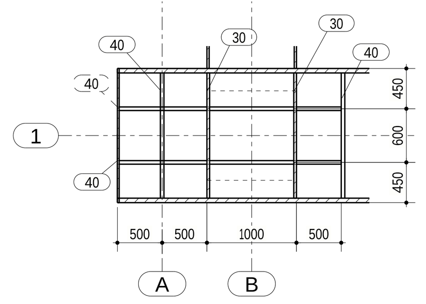
DETAIL A
SCHAAL: 1:50



DOORSNEDE D - D
SCHAAL: 1:50



DOORSNEDE E - E
SCHAAL: 1:50



DOORSNEDE F - F
SCHAAL: 1:50

Opmerkingen

Maten in m tenzij anders aangegeven
Hoeken aangegeven in graden (360 gradenstelsel)
* = Maatvoering informatief

Coördinaten

Coordinaten zijn in Belgische Lambert72

Hoogtemaatvoering

TAW: Tweede Algemene Waterpassing
LAT: ligt 0,77m onder TAW

REVISIE	DATUM	AUTEUR	CONTR.	GOEDK. INTERN	GOEDK. KLANT	BESCHRIJVING WIJZIGING
B	28.10.2021	SWA	-	-		3 rijstroken ipv 4 smallere brug
A	05.07.2021	SWA	-	-		brug niet langer als parkbrug
0	25.02.2021	SWA	-	-		1ste uitgave

lantis bouwen aan verbinding

THV ROCO

SITUATIE

Oosterweelverbinding
Rechteroever
Perceel 3a en 3b

Tijdelijke R1
Overzichtsplan objecten

OWK	ROS	KTU	SPL	OKA	R1N	R1O
----	----	----	----	----	----	----

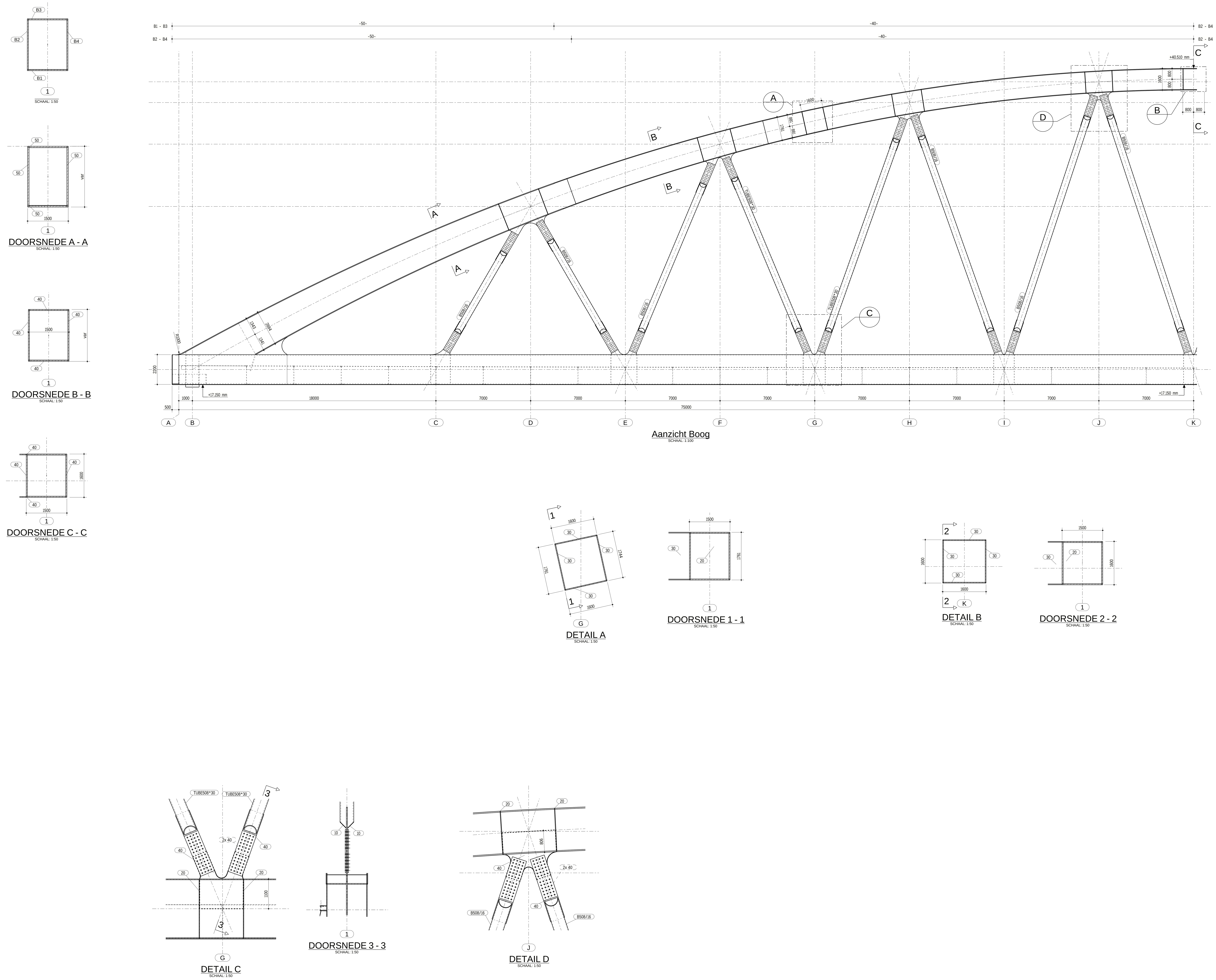
OBS	Deelsysteem	Activiteit	Contract Fase	Deelpakket
OWVA	00D.00	W10	OFF2	OWROPL00

AUTEUR	TYPE	NUMMER
ROCO	DWG	00001

SUBTYPE	STATUS	REVISIE
NRI	S1	0.02

QR-Code

Auteur Persoon	Controleur ROCO	Goedkeuring ROCO	Goedkeuring Klant	Vervaldatum	A0
SWA	-	-	-	ROCO	



Opmerkingen

Maten in m tenzij anders aangegeven
Hoeken aangegeven in graden (360 gradenstelsel)
* = Maatvoering informatief

Coördinaten

Coordinaten zijn in Belgische Lambert72

Hoogtemaatvoering

TAW: Tweede Algemene Waterpassing
LAT: ligt 0,77m onder TAW

REVISIE	DATUM	AUTEUR	CONTR.	GOEDK. INTERN	GOEDK. KLANT	BESCHRIJVING WIJZIGING
B	28.10.2021	SWA	-	-		3 rijstroken ipv 4 smallere brug
A	05.07.2021	SWA	-	-		brug niet langer als parkbrug
0	25.02.2021	SWA	-	-		1ste uitgave

lantis bouwen aan verbinding

THV ROCO

SITUATIE

Oosterweelverbinding

Rechteroever

Perceel 3a en 3b

Tijdelijke R1
Overzichtsplan objecten

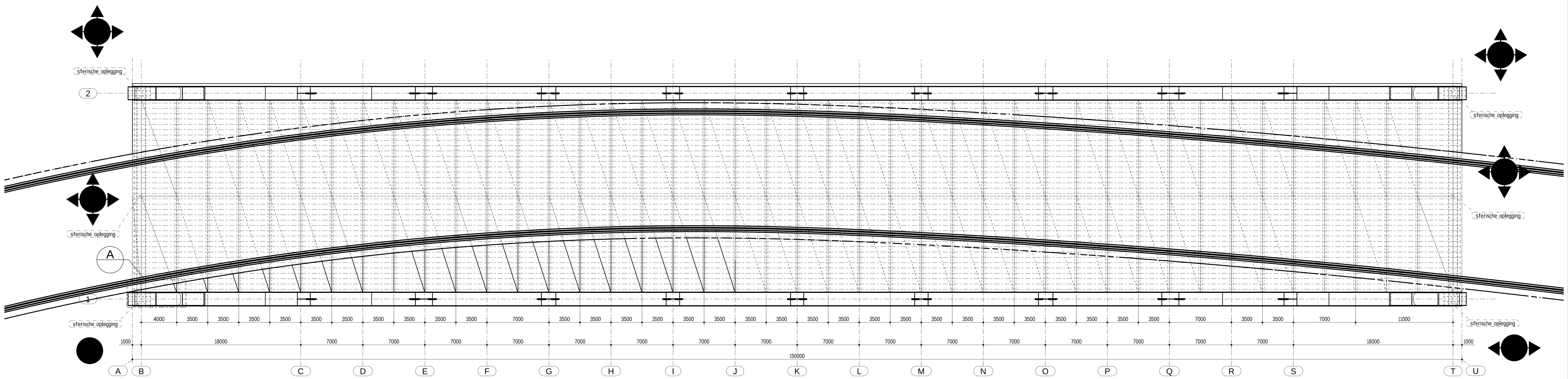
OWK	ROS	KTU	SPL	OKA	R1N	R1O
----	----	----	----	----	----	----

OBS	Deelsysteem	Activiteit	Contract Fase	Deelpakket
OWVA	00D.00	W10	OFF2	OWROPL00

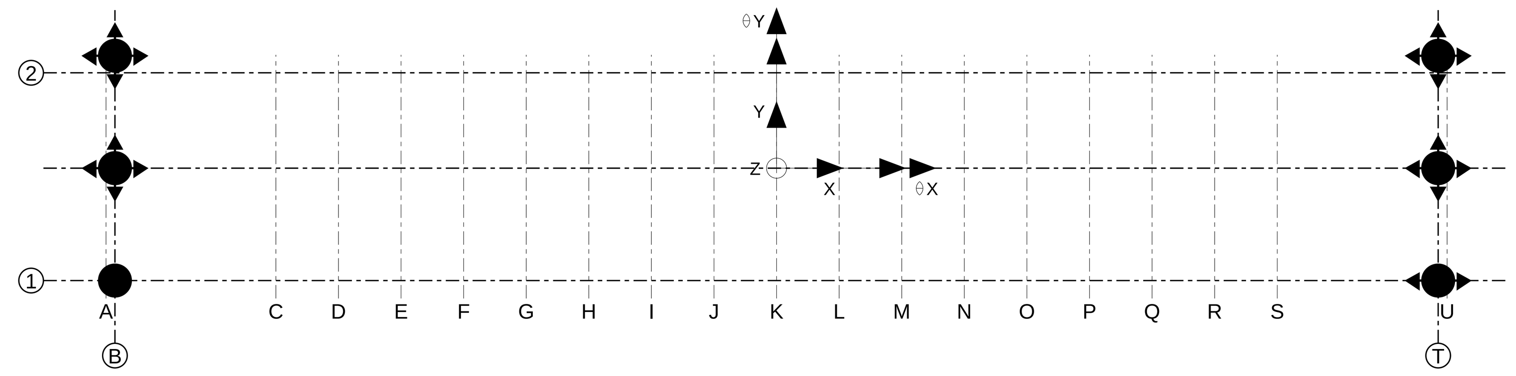
AUTEUR	TYPE	NUMMER	SUBTYPE	STATUS	REVISIE
ROCO	DWG	00001	NRI	S1	0.02

QR-Code

Auteur Persoon	Controleur ROCO	Goedkeuring ROCO	Goedkeuring Klant	Vervaldatum	
SWA	-	-	-	ROCO	A0

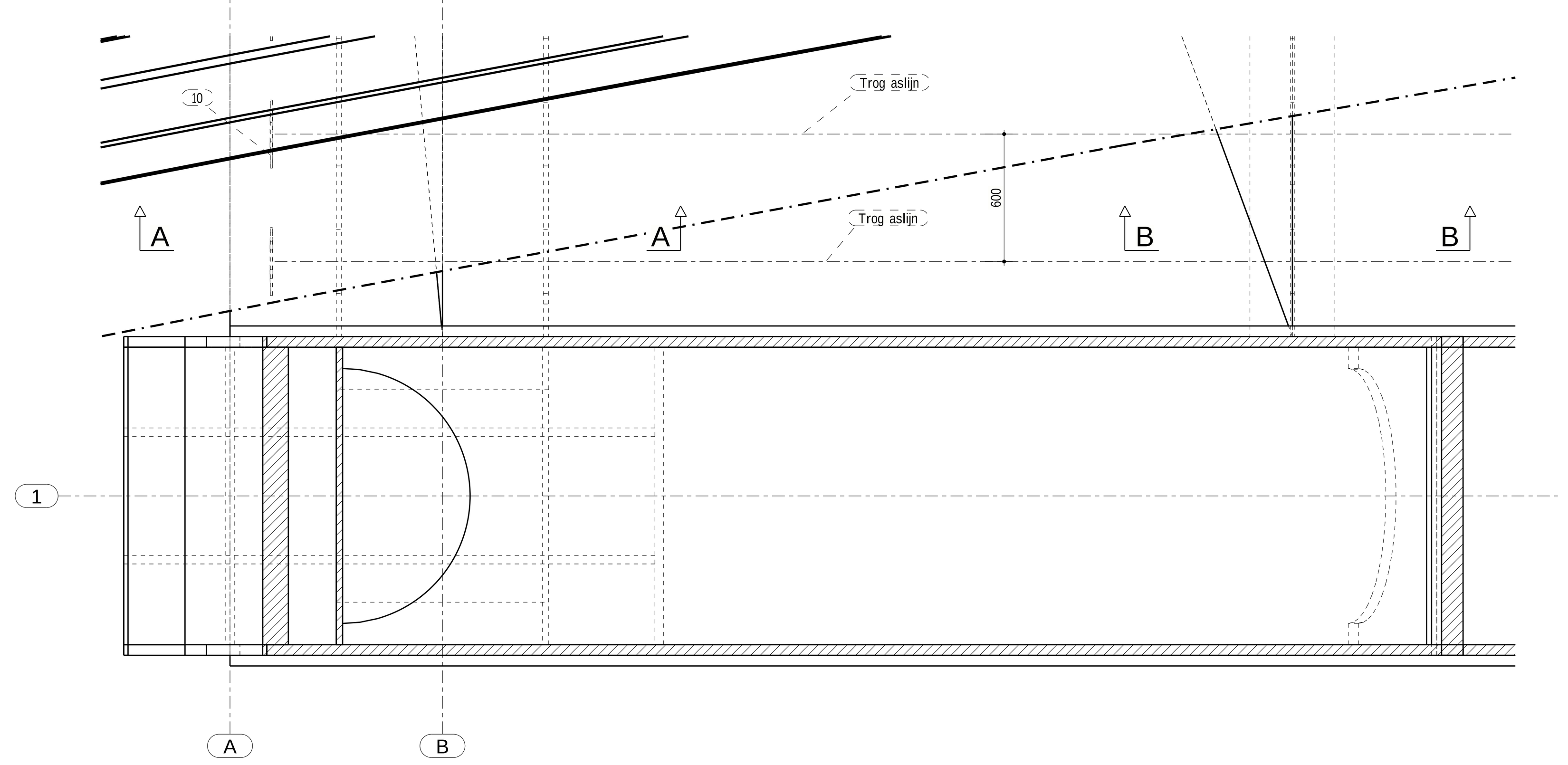


Bovenaanzicht - Dwarsdragers
SCHAAL: 1:200

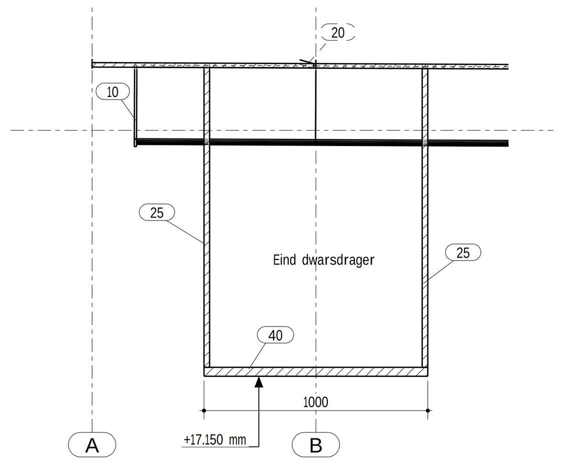


oplegschema
SCHAAL: 1:500

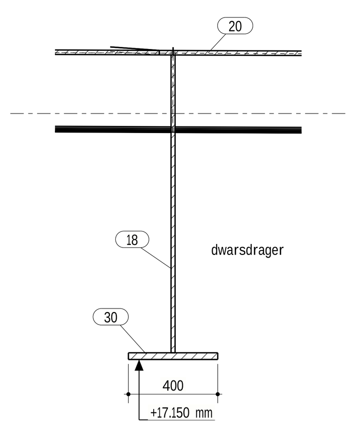
	Vrijheidsgraden			
	Ux	Uy	Uz	θ
	VRIJ	VRIJ	VAST	VRIJ
	VRIJ	VAST	VAST	VRIJ
	VAST	VAST	VAST	VRIJ



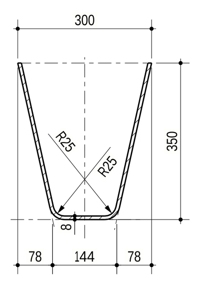
DETAIL A
SCHAAL: 1:20



DOORSNEDE A - A
SCHAAL: 1:20



DOORSNEDE B - B
SCHAAL: 1:20



Detail Trog
SCHAAL: 1:10

Opmerkingen

Maten in m tenzij anders aangegeven
Hoeken aangegeven in graden (360 gradenstelsel)
* = Maatvoering informatief

Coördinaten

Coordinaten zijn in Belgische Lambert72

Hoogtemaatvoering

TAW: Tweede Algemene Waterpassing
LAT: ligt 0,77m onder TAW

REVISIE	DATUM	AUTEUR	CONTR.	GOEDK. INTERN	GOEDK. KLANT	BESCHRIJVING WIJZIGING
B	28.10.2021	SWA	-	-		3 rijstroken ipv 4 smallere brug
A	05.07.2021	SWA	-	-		brug niet langer als parkbrug
0	25.02.2021	SWA	-	-		1ste uitgave

lantis bouwen aan verbinding

THV ROCO

SITUATIE

Oosterweelverbinding
Rechteroever
Perceel 3a en 3b

Tijdelijke R1
Overzichtsplan objecten

OWK	ROS	KTU	SPL	OKA	R1N	R1O
----	----	----	----	----	----	----

OBS	Deelsysteem	Activiteit	Contract Fase	Deelpakket
OWVA	00D.00	W10	OFF2	OWROPL00

AUTEUR	TYPE	NUMMER
ROCO	DWG	00001

SUBTYPE	STATUS	REVISIE
NRI	S1	0.02

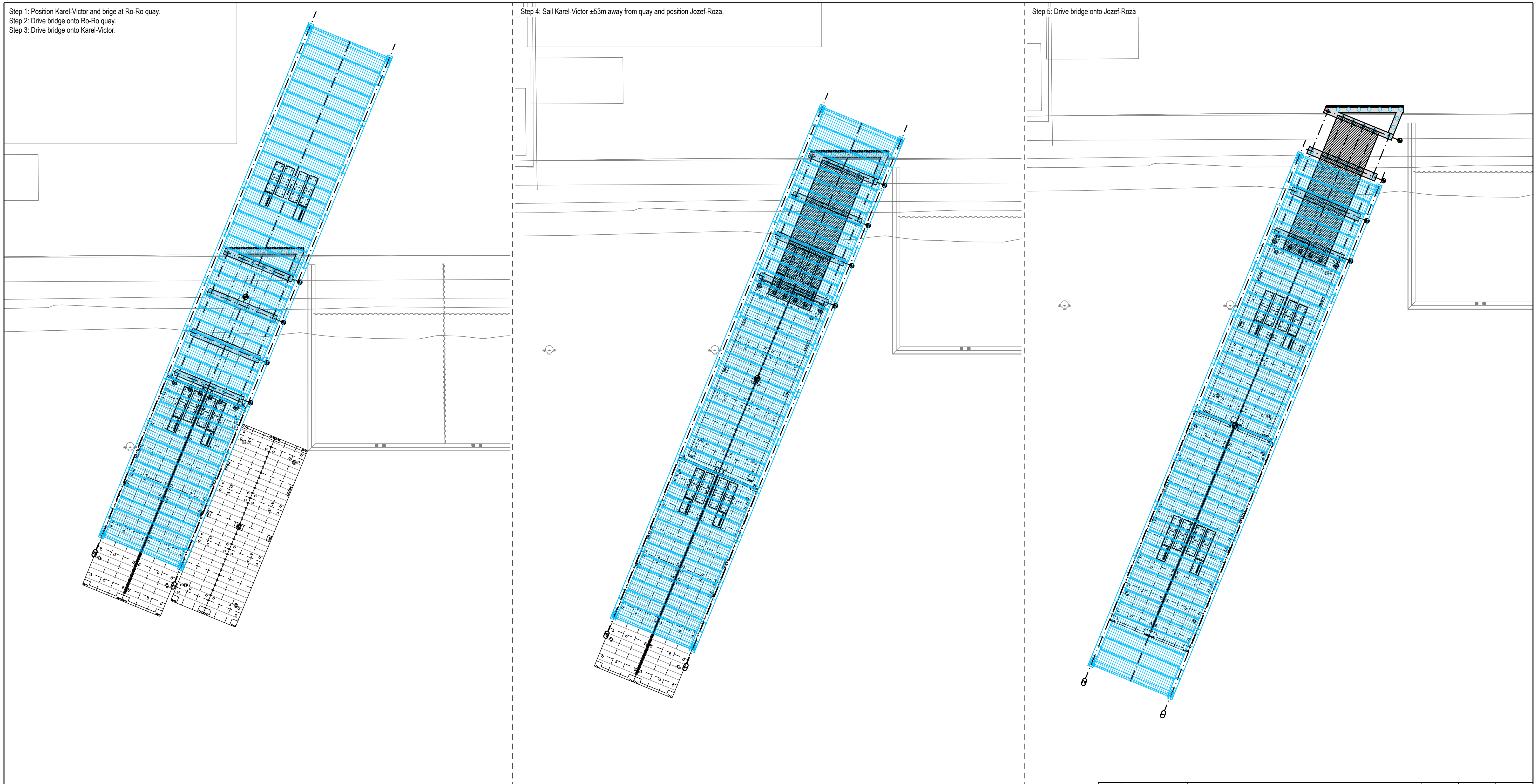
QR-Code

Auteur Persoon	Controleur ROCO	Goedkeuring ROCO	Goedkeuring Klant	Vervaldatum	A0
SWA	-	-	-	ROCO	

Step 1: Position Karel-Victor and brige at Ro-Ro quay.
Step 2: Drive bridge onto Ro-Ro quay.
Step 3: Drive bridge onto Karel-Victor.

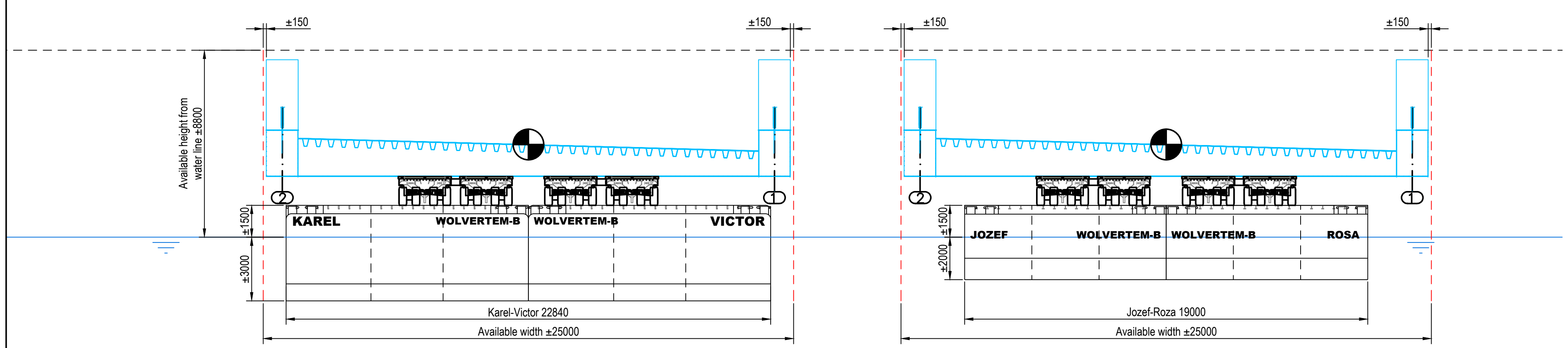
Step 4: Sail Karel-Victor ±53m away from quay and position Jozef-Roza.

Step 5: Drive bridge onto Jozef-Roza



Karel-Victor (Scale: 1/250)

Jozef-Roza (Scale: 1/250)



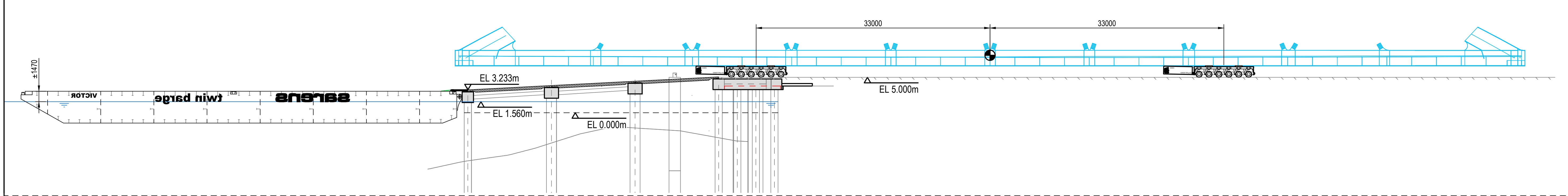
rev.	date	description	designed	verified	approved
-	28-03-2022	First Issue	ER	JO	JO

sarens

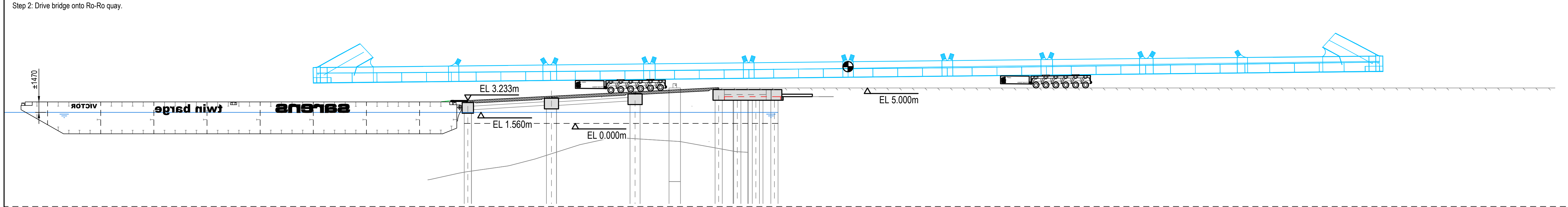
client: HILLEBRAND ASK ROMEIN

equipment:	48 Axle lines of SPMT + Barges Karel-Victor and Jozef-Roza				
description:	Load-out of Bridge (max.1700t) Top view & Front view				
site:	Hillebrand, Vlissingen, the Netherlands			proj.:	
owner:	SNL	drawing type:	General Arrangement	size:	A2
appr. state:	Concept	project:	GEN-00001-006	scale:	1/750
doc No.:	GEN-00001-006_BRIDGE_RORO_GARR_01			sheet:	01-02

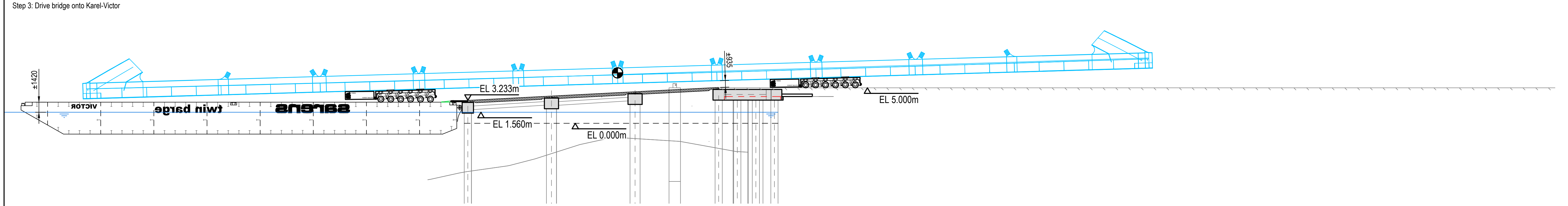
Step 1: Position Karel-Victor and brige at Ro-Ro quay.



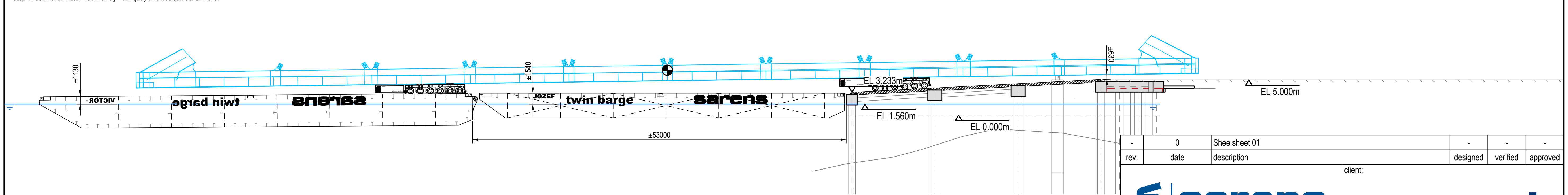
Step 2: Drive bridge onto Ro-Ro quay.



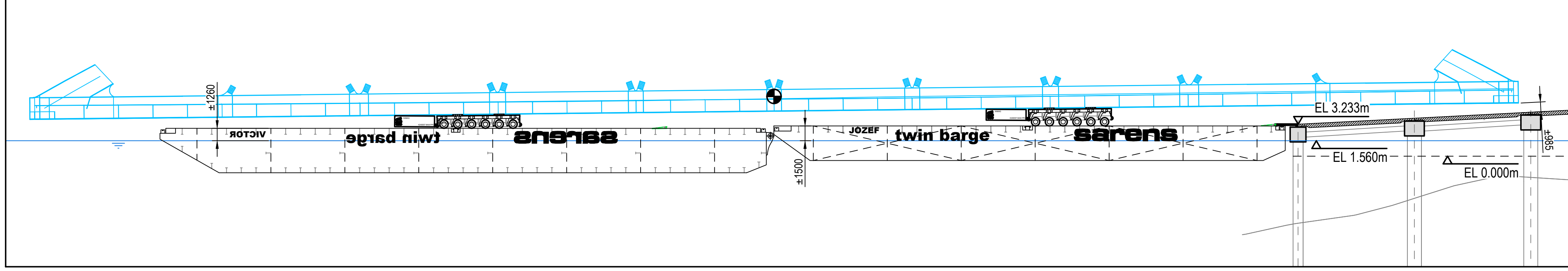
Step 3: Drive bridge onto Karel-Victor



Step 4: Sail Karel-Victor ±53m away from quay and position Jozef-Roza.



Step 5: Drive bridge onto Jozef-Roza



rev.	date	description	designed	verified	approved
-	0	Shee sheet 01	-	-	-

sarens

client: HILLEBRAND ASK ROMEIN

equipment:	48 Axle lines of SPMT + Barges Karel-Victor and Jozef-Roza				
description:	Load-out of Bridge (max.1700t) Side view				
site:	Hillebrand, Vlissingen, the Netherlands			proj.:	
owner:	SNL	drawing type:	General Arrangement	size:	A2
appr. state:	Concept	project:	GEN-00001-006	scale:	1/400
doc No.:	GEN-00001-006_BRIDGE_RORO_GARR_01			sheet:	02-02