# The jetty of the future

## Reducing the environmental impact of a jetty platform structure by designing for reusability

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by

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# Abstract

The significant adverse contribution of the construction industry to greenhouse gas emissions and natural resource depletion has to be reduced. Regarding jetty platform structures, this challenge can be faced by designing for reusability, a promising concept for environmental impact reduction. However, this principle is not yet being widely implemented, leading to the absence of reusable jetty structures. This research aims to identify the feasibility of designing a jetty platform for reusability and the contribution of reusability to the environmental impact reduction of jetty platform structures.

A jetty, that is being constructed in the port of Rotterdam during the execution of this research, was taken as a reference structure. By creating a design according to the Design for Disassembly requirements, while fulfilling similar functions as the reference jetty, a concept of a reusable jetty platform design was created. A numerical prediction model was created in the SCIA Engineer software so that the global behaviour and robustness of the structure were found when using simple connection solutions. Next, demountable connections were designed based on existing configurations from other applications. The practical aspects of assembly and maintenance were assessed through an interview with a maintenance expert from Port of Rotterdam. Furthermore, a brief study was done to investigate the possibilities of modularity and applicability to other jetties in the port. To quantify the environmental impact reduction, a life cycle assessment was performed, in which the impact of the reference structure was compared to that of three reusable structure variants: the reusable design, the modular reusable design and the modular reusable design using concrete with a lower impact.

Due to the use of simple connections in the reusable jetty design, discontinuities in the displacements are found between elements. These cause limitations in the flexibility of placing the superstructure and may cause deformations in pipelines when those are placed on the platform. Therefore, a solution was presented to mitigate the discontinuities. Also, the reusable jetty has to be constructed with a larger crane than is conventionally used, which may cause hindrance to the surroundings. However, the duration of construction will be reduced. The results of the life cycle assessment show that the initial impact of each reusable variant was larger than that of the reference jetty. However, already for reusing once in the structure's lifetime, this investment can be compensated when compared to replacing the reference jetty with a new structure. When assuming a structure is reused or needs replacement once during its lifetime, a tipping point was found when 24 to 44% of the structures are being replaced or reused, at which the investment is compensated. When not constructing the platform entirely directly, but adapting it when future requirements become more certain, potentially no investment is needed to be made.

From the results, it can be concluded that reusability contributes to lowering the environmental impact of the jetty platform when it needs replacement or reuse at least once during its lifetime or when the given percentage of the structures are being reused once during this time. Thus, reusability can be applied to reduce the environmental impact of jetty platform structures.

# Acknowledgements

As the final part of the Structural Engineering track within the Civil Engineering Masters, this graduation work marks the end of my studies at the Delft University of Technology. At the beginning of the thesis, the very broad task was given to me to find a technical solution to reduce the environmental impact of jetty structures in the port of Rotterdam, which lead me to the first challenge of defining a scope and narrowing it down to one realistic solution. This is how I finally arrived at reusability. As I have a passion for sustainability, this topic has fascinated me from the beginning. Furthermore, my enthusiasm for hydraulic structures and the interest of companies in my findings on this topic have kept me curious and motivated for this research.

I would like to thank Milan Veljkovic for all of his critical comments. His expert judgement and abundant experience have given my research the academic height that it would not have reached otherwise. Next, I would like to thank Henk Jonkers, for helping me specifically with the environmental impact quantification and for understanding the personal struggle that comes with doing such a research project for the first time. I would also like to thank Alex Kirichek for his judgement and the reminders to be proud of my work.

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*J.G.E. Kavelaars*
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# Contents

# List of Figures

# List of Tables

# 1 Introduction

In this chapter, the concept of reducing the environmental impact of structures by applying reusability is explained. Based on the state of the art and knowledge gap, a research objective, the main research question and three sub research questions are formulated. After this, the methodology is described on how to find an answer to the questions.

## 1.1. Context

By emitting large amounts of greenhouse gasses into the environment, the average global temperature has been increasing over the past decades. This increase is a danger for life on earth, as it disturbs ecosystem services, which are contributions of nature to the needs of people. To minimize the loss of ecosystem services, the temperature increase should be kept below 2°C, compared to pre-industrial levels, as described in the Paris Agreement [1]. To achieve this, the emissions of greenhouse gasses should be reduced significantly. Furthermore, raw material is becoming more and more scarce due to natural material resource depletion. To limit this, fewer materials should be produced using finite materials [1].

The construction industry contributes 40-50% to global greenhouse gas emissions. Concrete and steel are two of the most used materials in this industry, while they are also known to have a significant environmental impact [2]. The environmental impact of products is determined by the effect of the complete life cycle of the product on the environment [3]. Concrete has a large impact, as it is an energy-intensive material. Especially the raw material extraction and production of cement emits greenhouse gasses into the environment [4]. For steel, the entire production process consumes large amounts of energy, emitting significant amounts of greenhouse gasses [5]. Next to the high emissions, the construction industry contributes 40-60% to natural material resource depletion [6] and accounts for over 50% of the global waste generation [7], of which 30-35% of comes from concrete [6].

The environmental impact of the construction industry must be lowered. To achieve this, the construction industry has to move towards a circular economy, as visualised in Figure 1.1. Structures designed and built according to the circular economy principle promise to have a lower environmental impact compared to the conventional linear economy [8]. However, concerning construction, the application of the circular economy principle is currently limited [3].

In the construction industry, the linear economy means that new products are manufactured using raw materials and at the end of the product lifetime are treated as waste. However, when applying the circular economy principle to the construction industry, it is the aim to use the residual value of materials at the end of the product lifetime. A promising method in the circular economy is reuse, which means taking a product as a whole or an element of a product and using it in the existing form for a new purpose, without repeating the entire production process. This can be executed when the technical lifetime of construction elements is longer than the service lifetime of the structure itself, which is currently the case for many structural components [6]. Reusing means that the material is not remanufactured and thus less energy is required to obtain a product and decreasing the demand for raw material. Structures made of reused materials and elements will thus have a lower environmental impact compared to structures made of newly harvested materials or recycled materials [9].

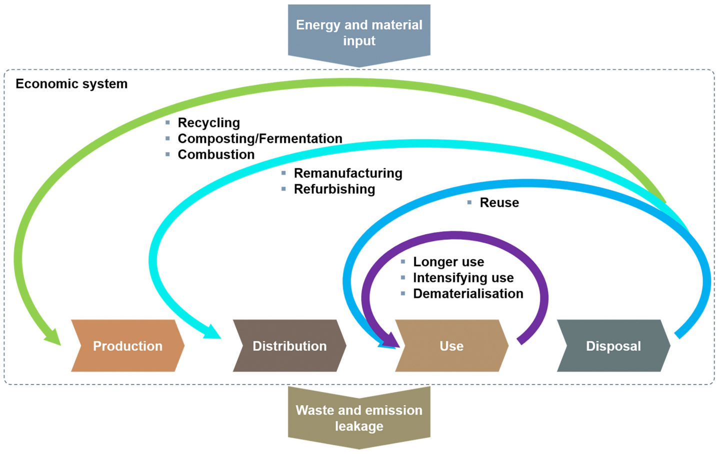



**Figure 1.1:** Circular economy [8]

By reusing structures or structural elements, certain steps in the life cycle of a structure can be skipped. As each step has a certain environmental impact, this leads to the expectation that reusing is effective in decreasing the environmental impact of structures. This is further explained in Section 1.1.1. However, reuse also adds new steps to the life cycle, which can also have an impact on the environment. Those can for example be disassembly, additional maintenance and repair and transport of the reclaimed elements [6]. These additional life cycle steps also have an impact on the environment. While it is expected that this impact is considerably lower than the saved impact, the environmental benefit of reusing is still a rough estimation [10].

A concept that can increase the potential of reuse is modularity. Structures that are designed for modularity can be easily adapted to changing requirements or can be used for a different purpose. This is obtained by making the structural elements of a standard and widely applicable size and creating the possibility to easily remove, replace or add elements to a structure. By allowing this, a structure can be built according to today's requirements and can be adapted when future requirements become more certain. This reduces the chance that elements are placed without being used during the lifetime of the structure or that elements are only being used for part of the lifetime, while they are deteriorating during the entire lifetime [9].

### 1.1.1. Structures in the circular economy

The life of a structure can be described using multiple life cycle stages. This life cycle starts at the raw material supply and ends with disposal or with reuse, recovery and/or recycling. To provide a clear view of the life cycle of structures, it can be divided into stages, each containing several substages. Substages A1-A3 form the product stage, followed by the construction process stage A4-A5. Next are the use stage B1-B7 and the end of life stage C1-C4. Beyond the stages of the life cycle of a specific structure, stage D is added, in which (parts of) the structure can be reused, recovered and/or recycled and be made into new structures [11]. An overview of the different life cycle stages is displayed in Figure 1.2.

The conventional life cycle of structures starts with raw materials at substage A1 and ends with disposal in substage C4, where the material is treated as waste and ends up at a landfill site. Reusing material means taking products from stage D and skipping substage A1, A2 and A3. The avoidance of substage A1, the raw material supply, is significant as steel and concrete are made of finite materials and are becoming more and more scarce. Substage A3 is the manufacturing of structural elements, which consumes a lot of energy and influences the environmental impact of a structure significantly, which is thus useful to avoid [6].

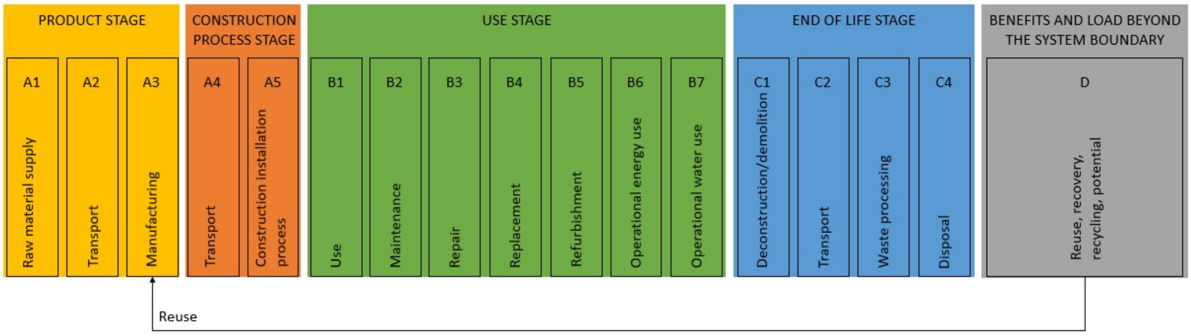



**Figure 1.2:** Life cycle stages as derived from [12]

Although the reuse of material is promising in terms of environmental impact reduction, it is not yet widely applied in port structures. To reclaim the building materials, the original structure should be deconstructed to the desired size. Often, the sizes of reclaimed elements do not align with the requirements of the new structure or with more practical size requirements such as limitations from transport. This especially raises challenges for the reuse of concrete, while this is one of the most used materials in construction [6]. Cutting the concrete members or connections for reuse is often not possible, as the connections are cast in situ and cannot be disconnected without damaging the elements. This is because the reinforcement is continuous and is bonded with the concrete. Removing the concrete from the reinforcement by breaking it is a procedure that is hard to execute and it is impossible to control the quality of the reclaimed element [10]. Concrete is thus only reusable if the structure can be disassembled to a size that is suitable for transportation and fits the requirements of a new structure. This means that connections between concrete elements should be demountable to make reuse of concrete practically feasible, making the connection between elements the most critical part of circular structures [13]. It is not yet common to design and utilise connections that are demountable between concrete and steel elements, yet this is crucial for enabling reuse of structures. Therefore, connections should be found that are fit for reuse, while still fulfilling their principal role of transferring loads between elements [10].

### 1.1.2. Reuse of jetty structures

A company that is looking to decrease the environmental impact of its structures is Port of Rotterdam N.V. (PoR). This is the company managing the port of Rotterdam, which is the largest port in Europe containing many marine structures to support its services. It is constantly in development and thus there is a frequent demand for new structures [14]. According to an asset manager of PoR (Appendix A), the company is looking for a more intelligent way to make their structures so that their environmental impact can be decreased. Currently, their focus lies on reducing the impact of the product stage, for example by using recycled materials or studying the potential of geopolymer concrete. However, reuse is not yet part of their scope.

Part of the PoR assets are inland shipping jetty structures. The primary functions of jetties are to enable berthing and mooring of ships and to support (un)loading equipment, pipelines, conveyor belts and vehicles. Jetties facilitating mooring of large ships such as inland vessels generally have a platform and separate mooring facilities, as indicated in Appendix C.1. This mooring facility, or berthing dolphin, absorbs the kinetic energy of the ship, while the platform enables the support of equipment [15]. In this research, the focus lies on the platform part of the structure. Regularly, the inland shipping jetty platforms consist of steel foundation piles and a concrete deck. While the superstructure is not always the same, the elements and loads on the jetty are often similar. Therefore, the structural elements of jetty platforms are also similar. This makes a jetty platform in the port suitable for reuse, especially when modularity is considered. The jetties in the port are designed to have a lifetime of 25 to 50 years. However, due to changing requirements, these structures often need replacement or adjustments before reaching the end of their lifetime. Due to this uncertainty in requirements, the platforms are made future-proof. By designing future-proof, possible future requirements of the jetty are taken into account. Therefore, the structures are often made larger and more robust than is initially needed, while the uncertainty of the future requirements is still large and thus there is a possibility that parts of the structure are constructed but unnecessary. Modularity can contribute to reducing the number of unused parts of the structure by allowing for easy adaptation when the future requirements become more certain. By exploring the possibilities and feasibility of a reusable jetty structure and assessing the potential environmental benefits compared to conventional jetty structures, the port can be inspired to develop toward the execution of circular marine structures.

## 1.2. State of the art and knowledge gap

It is PoR policy to reduce their $CO_2$ emission by 49% (compared to their emission in 1990) by 2030 and to be $CO_2$-neutral in 2050[1]. Their aim to be $CO_2$-neutral means that the port will at least remove as much $CO_2$ from the environment as it emits. In this, reducing the $CO_2$ emission is of great importance, corresponding with the aim to decrease their environmental impact. This policy is in line with the Paris Agreement. For their structures, the focus lies on using structural materials with a lower environmental impact than the conventionally used materials, which is for example realised by using recycled materials or geopolymer concrete [16]. This is a type of concrete in which the binder is an alkaline activated system based on fly ash and blast furnace slack [17]. The possibility of reusing structural elements is not yet considered. This is surprising, as from the literature discussed in Section 1.1, it was found that reusing has a large potential to decrease the environmental impact of structures, especially for their 100 inland shipping jetties that are all similarly made[2]. Furthermore, recycling concrete does not have great potential, as it can only be downcycled [7]. This approach is believed to be conservative and is used by PoR as this has proven to work. The approach is retrospecting in the requirements they set, as further discussed in Section 3.2. However, to fulfil the wish to lower the impact of their structures, this conventional way of thinking should change.

In the literature that was consulted, no examples of reusable jetties were found. However, potential benefits and suggestions for technical solutions for reusable structures in other applications are researched to some extend [6, 9, 10, 13, 15, 18–30]. The only literature on reusable port structures in general that was found is by Zwakhals [30], who stretches the need for increasing flexibility of quay walls, but does not provide further details of a reusable design. In other applications, the details of demountable connections and the potential of a modular system are recognised and researched, which can serve as inspiration for designing a reusable jetty.

Because of the absence of solutions for a reusable jetty structure, it remains unclear if this would be technically feasible and if the potential environmental benefit can be reached.

## 1.3. Objective and research questions

A gap is identified between the desire to lower the environmental impact of jetty structures and the lack of application of the reuse principle to those structures. To overcome this gap, research is performed on the potential role a reusable jetty design can have in environmental impact reduction. This can be achieved by determining the feasibility of reusable jetty structures and the environmental impact reduction that can be reached when applying a reusable design to one or multiple jetty structures. This is done to stretch the potential of applying the reuse principle to jetty structures in the port. The aim is to inspire for dynamic progression of the sustainable development of PoR. By designing a reusable jetty, PoR can be inspired to achieve its goal by implementing a principle that is more promising than recycling [9]. This increases the potential to reach the goals that were set considering the reduction of $CO_2$ emissions.

Based on this objective, research questions can be formulated. The main research question (RQ) is stated below, which is supported by the three sub questions (SQ1, SQ2 and SQ3)

*RQ. How and to what extent can reusability contribute to reducing the environmental impact of a jetty platform structure?*

SQ1. What technical innovations should be applied to the design of the reference jetty platform structure for arriving at a design of a reusable jetty platform structure?

SQ2. How can a numerical prediction method predict the structural behaviour of the reusable jetty platform?

[1] https://www.portofrotterdam.com/nl/over-het-havenbedrijf/missie-visie-en-strategie

[2] https://www.portofrotterdam.com/sites/default/files/2021-05/feiten-en-cijfers-haven-rotterdam.pdf

SQ2. How can a life cycle assessment quantify the difference in the environmental impact of the reference jetty platform structure and a reusable jetty platform structure?

## 1.4. Methodology

As reusable jetties do not yet exist, knowledge from other applications will be used to make the design. To arrive at a reusable structure, elements and element connections should be designed to allow disassembly, transport, and reassembly so that they can be applied in the future to other jetty structures. As mentioned in Section 1.1.2, connections are the most critical part of a reusable structure. The behaviour of the structure is researched by making and calculating a design, based on which demountable connections can be investigated.

Furthermore, to investigate the effectiveness of creating a reusable jetty structure, the potential environmental impact decrease will be quantified. It is expected that the initial environmental impact of a reusable jetty structure can be somewhat larger than that of the conventional jetty, due to for example extra material needed in the connections. It is researched if this larger initial environmental impact is realistically compensated by the longer and more flexible use of the structure.

The research is split into three main parts, which are: The analysis of the reference jetty, the reusable jetty design and the environmental impact quantification.

### 1.4.1. Analysis of reference jetty

To be able to make a fair comparison, a reference jetty is considered. The design of this reference jetty will be adapted to a reusable design, after an understanding of the structure is gained. The jetty structure that is chosen as a reference is the Neste jetty 2. It is located in the Europahaven, which is part of the port of Rotterdam.

The reference jetty consists of two separate parts, which are a platform and a slackening structure. This is according to the usual design of jetty structures in the port of Rotterdam. The platform is used as a reference structure for this research. The slackening structure does not influence the robustness or structural behaviour of the platform.

This jetty is recently tendered and is built during this research. This makes it a suitable reference, as it is designed according to the current state of the art. A visualisation of the situation with the jetty in its location can be seen in Figure 1.3.

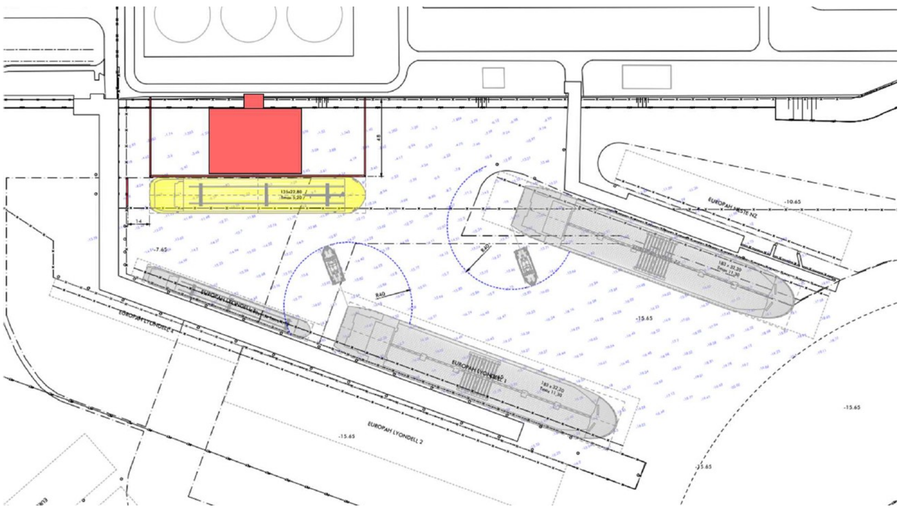


**Figure 1.3:** Situation of reference jetty in its location [31]

An analysis is carried out in which the reference jetty will be analysed to understand its structural behaviour. The data that is needed for this analysis is provided by Witteveen+Bos. From this study, the requirements and conditions on which the jetty design was based are identified. Examples of requirements that are found are functions of the jetty, required dimensions and the reliability class of the structure. Conditions are load and boundary conditions. The behaviour of the jetty is analysed by studying the calculation results from the structural model made in SCIA Engineer.

### 1.4.2. Reusable jetty design

To find technical solutions for a reusable jetty design, the reference jetty design is adapted according to the Design for Disassembly (DfD) requirements and calculated with a model based on the reference jetty model. Calculations are performed with a numerical prediction method according to the European Standards and are executed in SCIA Engineer. This is similar to the calculation method used for the reference jetty.

In line with the DfD requirements, a reusable design should consist of prefabricated elements and demountable connections. Therefore, prefab jetty design variants are made. In the design, it is aimed to find the least complex possible connections, while remaining to guarantee the robustness of the structure. This is achieved by modelling different connection types and gaining an understanding of the behaviour of the structure in those different conditions. The behaviour of the structure is analysed for the least complex combination of connections. Using simple connections has consequences for the superstructure. Those consequences are identified.

When the required behaviour of the connections is found, a preliminary connection design is made. This is performed to gain insight into demountable connections, to see if those can be realistically used in this application and how they can transfer the needed loads. It is also aimed to use connections that are already common or accepted in other practises, so that those are included in the norms and no further research is needed for applying the connection. This strives to reduce the threshold for PoR to use this solution and makes it possible to implement them in the near future.

The reference jetty is made with steel foundation piles and a concrete deck. Other materials are not considered in this research.

To examine the practical feasibility of the reusable jetty, an interview is conducted with Marc Wormmeester (Appendix A), an asset manager for PoR with over twelve years of experience with the maintenance of jetties in the port. Furthermore, a brief study is performed on the possibility of making the structure modular and applicable to all inland shipping jetties in the port.

### 1.4.3. Environmental impact quantification

The environmental impact of the reference and reusable jetty structure is quantified using a life cycle assessment (LCA). This is executed using the information on the material used for the designs and their end of life scenarios. LCA is chosen because it is included in the European Standard and official rules for using this method exist. Furthermore, because this is a widely excepted method, plenty of information exists on the method and its content [32]. The environmental impact is quantified using shadow costs and is expressed in euros so that the number can be interpreted. More insight on shadow costs is stated in Section 2.2.

The LCA is performed according to NEN-EN 15804 [11], which is worked out specifically for civil structures [12]. A tool that is made according to this is DuboCalc, which uses category 3 data from the Nationale Milieudatabase (NMD). Category 3 data is public data that is owned by Stichting Bouwkwaliteit (SBK), but is not yet tested according to the SBK protocol, whereas category 1 and 2 data is owned by the producers and industries of the products. The category 3 data and their assessment methods are public.

The LCA is performed for the impact categories given in Table 2.1, which are given per life cycle substage as presented in Figure 1.2. The data from the Nationale Milieudatabase (NMD), which is used in DuboCalc, only rarely includes numbers in the use stage of the materials. This is not an accurate representation of the use phase. However, for the comparison of the reference jetty and reusable jetty variants, the use phase is not critical. The comparison is based on the same intended functional lifetime for each design variant, due to which use, maintenance, replacement, repair and refurbishment are assumed to be similar for all structures.

## 1.5. Research outline

In Figure 1.4 an overview of the different topics can be seen, divided into chapters and research objectives.

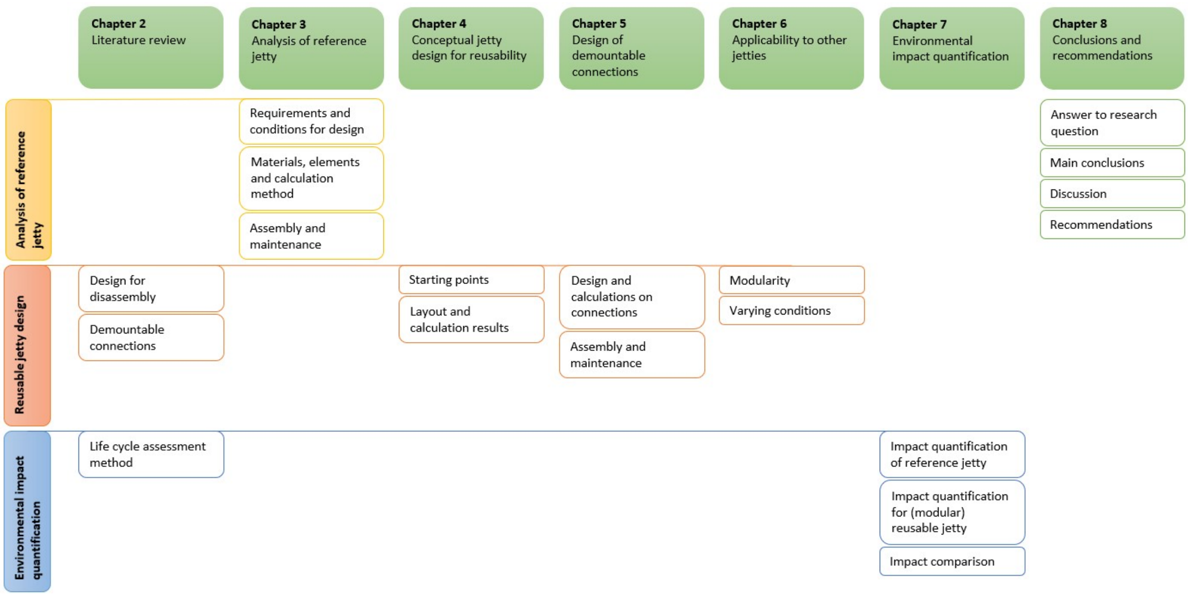



**Figure 1.4:** Structure of research

# 2

# Literature review

In this chapter, the literature study that is executed is summarised. In Section 2.1, the principles, current practice and possibilities of the Design for Disassembly principle are stated. Furthermore, a method for quantifying the environmental impact of structures, with special attention to circular structures, is described in Section 2.2.

## 2.1. Design for Disassembly

Although reusing material is promising in terms of environmental impact, it is not yet widely implemented in marine structures [10]. This is caused by the conventional way of designing and building structures, which does not consider reuse. When designing to allow reuse, not only the use of the structure is considered, but also the deconstruction process. This design concept is called Design for Disassembly (DfD). DfD is considered to be the most practical approach to increase the reuse of structures and structural elements when compared to other sustainable construction concepts [27]. Furthermore, according to Wormmeester (Appendix A), DfD structures have great potential to ease and reduce maintenance procedures, by creating the possibility to replace part of the structure. Wormmeester also mentions the great potential value of decreasing construction time and the time to adapt structures according to the client's wishes during the lifetime of the structure.

For the reuse of structures, the structure has to be disassembled, after which the structural elements can be transported to a new location, where they have to be connected again to form a structure. The design resistance of the structure should be the same for the second life cycle as for the first, as long as certain requirements are met. For connections, this means that maintenance and repair can be executed between disassembly and reassembly and that parts can be replaced if needed. Also, the loads on the structure during the encountered life cycle should not exceed the design loads. This requires that the user of the jetty is aware of the design loads and will organise (un)loading activities so that they are not exceeded. Moreover, when extreme loads such as fire or collision have occurred, the structure is no longer fit for reuse [27]. The statement that, when applying maintenance and repair, the DfD components will perform as they were originally designed for in their second life cycle, is proven in multiple experiments [27] [6].

The reuse potential, part of life cycle stage D in Figure 1.2, of a structure can be increased by making the design modular [33]. A modular structure has a design that can easily be adapted to for example new structural requirements. The design consists of modules, that can each be changed according to new requirements or wishes. When adaptation is needed, a module can for example be added, removed or replaced to change the global dimensions of the structure or to change its loading capacity. Instead of placing a new structure, a module can easily be changed. Moreover, in case of reuse of a structure, a modular system also means that the structure can be reused, but does not necessarily need to have the same dimensions. Each module can be placed differently relative to other modules, creating flexibility in the global dimensions of a structure [9]. Designing modular can result in higher material use and thus an increased initial environmental impact, which has to be earned back by the extended functional lifetime [17].

### 2.1.1. DfD requirements

When aiming for a reusable structure design, certain requirements should be met that do not usually apply to conventional structures. Those are the DfD requirements. For reuse of the structure at the end of the service life in a similar application, the requirements that apply are listed below [9].

1. Minimise the number of different types of components to reduce the number of different disassembly procedures
2. Make components sized to suit the means of handling
3. Use a standard structural grid to optimise material use and obtain components in standard sizes
4. Use prefabrication and mass production to reduce site work and ease the (dis)assembly process
5. Use lightweight materials and components
6. Use mechanical connections rather than chemical ones to allow easy separation of components
7. Design to use common tools and equipment and avoid specialist plant
8. Provide access to all parts and connection points
9. Provide realistic tolerances for (dis)assembly, which may be larger than tolerances for only one-time assembly
10. Use a minimum number of connectors to reduce the complexity of (dis)assembly
11. Use a minimum number of different types of connectors to reduce the complexity of (dis)assembly
12. Design joints and components to withstand repeated use
13. Provide a means of handling and locating components during assembly and disassembly
14. Identify points of disassembly
15. Provide spare parts and on site storage for them and parts during disassembly
16. Retain all information on the building components and materials

The elements forming a structure that is designed to be reused should be easy to handle in size and weight, which is stated in guidelines 1 to 5. This is important to allow transportation and to keep (dis)assembly procedures as simple as possible. If the structure is not reused as a whole, the elements should be in standard sizes as much as possible. This creates more opportunities for reuse compared to elements that have a more unique or uncommon shape. For concrete structural elements, prefabricated elements are especially applicable, as the elements are not made on site and will thus be transportable [9]. Another advantage of the use of prefabricated elements is that the quality the easier to control, resulting in higher strength and more durability. Furthermore, the amount of work on site is reduced, allowing for quick construction and noise reduction. For these reasons, the precast concrete industry is becoming more popular [28]. The above mentioned advantages make it more attractive to use prefab concrete elements for the purpose of reusing.

Guidelines 13 to 16 describe information management, which is needed to ensure that missing information is not creating additional work and challenges for reusing structural elements or is leading to disposal instead of reuse. This is important throughout the whole reusing process and during the entire lifetime of the structure. This topic is out of scope for this research, as this focuses on the structural aspects.

For (dis)assembling the elements, guidelines 6 to 12 are important. These focus on the connections between elements. This is elaborated in Section 2.1.2.

### 2.1.2. Demountable connections

The prefabricated structural elements of DfD structures should be connected so that they can be disassembled to be transported and handled on element level. This means that demountable connections should be made. However, those connections should still be able to fulfil their principal role, which is to transfer loads between elements. For connections involving concrete, other connection types than the conventional in situ joint should be explored to make a DfD design [21]. For this, three types of joints can be distinguished: Wet connections, semi-dry connections and dry connections.

**Wet connections**
Currently, prefabricated concrete elements are mostly connected using wet connections. A wet connection means that elements are connected with in situ cast concrete. Between the elements to be connected, reinforcement is sticking out to ensure continuity and concrete is poured. This creates a monolithic connection, meaning that forces and moments in all directions can be transferred. This technique is common practice and often used because there is a lot of experience in its design, construction and use. However, wet connections are unsuitable for disassembly [13].

**Semi-dry connections**
Connecting prefabricated concrete to concrete or concrete to steel can also be done by using semi-dry connections. Semi-dry connections use partly in situ concrete or injected grout. Disassembly and reassembly are feasible, as this injected material can be easily removed. Nevertheless, as some concrete or grout needs to be mechanically destroyed, the disassembly procedure requires precise execution and time. Semi-dry connections are being implemented because of sufficient available knowledge and experience and their ability to transfer loads and moments in all directions. They can have the equivalent strength of wet connections. However, some material will only be used in one life cycle because the injection material is not reusable. Furthermore, the possible damage due to destruction can lead to disposal or additional maintenance needed before reusing [10].

A semi-dry connection that is common is the hinged connection as shown in Figure 2.1. The bolt is anchored in one concrete element and connected to the other element on site. This steel bolt is protected by grout material such as mortar and is thus classified as semi-dry. Many examples of semi-dry connections using dowels or bolts exist and are part of the European Standards [21].

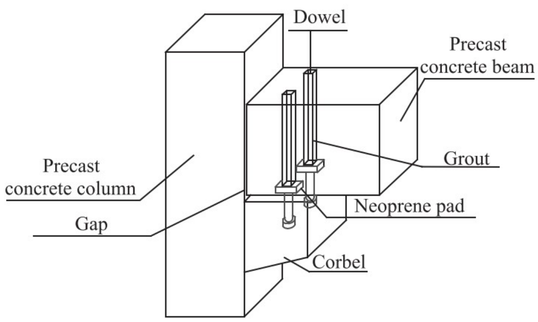



**Figure 2.1:** Dowel concrete connection [21]

Semi-dry connections are also applied in practice by commercial companies such as Peikko. They create bolted connections between concrete elements by adding steel shoe elements in the corners as shown in Figure 2.2. The elements are anchored in the concrete by rods welded to the steel element. Those form prefabricated elements that can be connected with bolts. Grout is added to increase stiffness, due to which the connection is semi-dry [34].

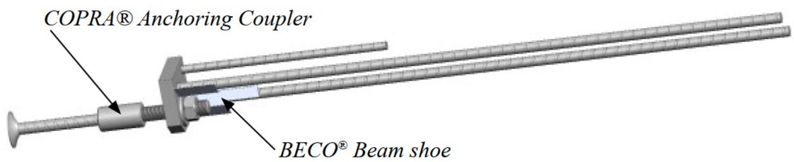
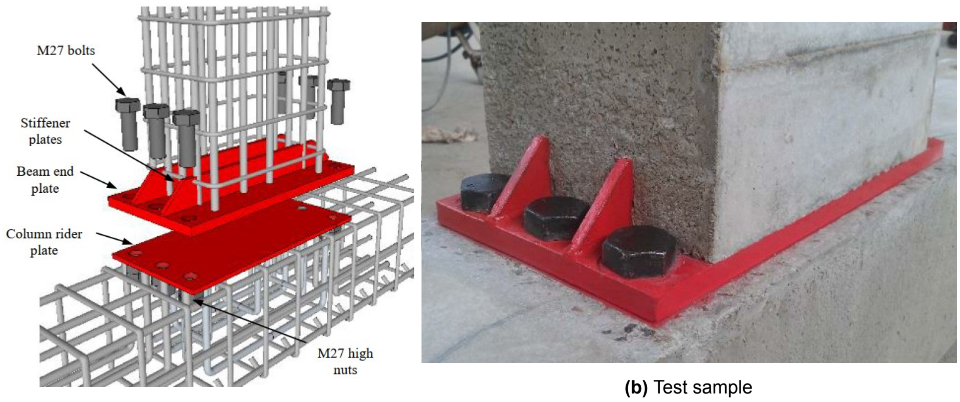



**Figure 2.2:** BECO shoe and COPRA bolt [35]

**Dry connections**
Dry connections are joints made without chemical bonds such as in situ concrete in the demountable part. Their on site construction is quick compared to wet connections. Most importantly, dry connections are easy to disassemble for reuse, making this connection type very promising for DfD [20]. Bolted joints appear to be excellent to use in DfD connections, as their behaviour is comparable to that of monolithic

joints. However, due to very little and mostly recent research on dry connections, their application remains limited [10]. Furthermore, in dry connections using steel elements such as bolts, the steel is exposed to the environment. This leads to wear of the steel and is thus not promising in terms of long use of the elements and will lead to substantial amounts of maintenance needed. This should be taken into account when designing for disassembly. Designing dry connections without steel elements that are exposed to the environment is favourable in terms of maintenance. However, this can only be applied to simple joints [20].

Some variants of rigid dry connection variants are designed and successfully tested. Their performance was at least as good as that of the equivalent monolithic wet connection, both for static and cyclic loading. A successfully tested variant is shown in Figure 2.3. An end plate is welded to the concrete beam reinforcement steel and a rider plate is welded to the reinforcement of the column. The end plate and rider plate are connected by bolts, from which the nuts are placed in the column.




**(a)** Layout of connection

**(b)** Test sample

**Figure 2.3:** Successfully tested dry column to beam connection with rider plate [13]

Dry concrete connections that do not transfer moments are more commonly used. Already for decades, concrete dapped end beam connections are being used, as shown in Figure 2.4. By transferring a shear force and possibly a normal force in one direction, no connectors such as bolts are needed. Although this connection has not been designed for disassembly, the basic way of connecting elements by laying them on top of another makes them suitable for disassembly. Only a material that prevents them from damaging each other while moving is needed, such as a rubber connection profile between the elements. Many configurations that use a similar concept exist [28].

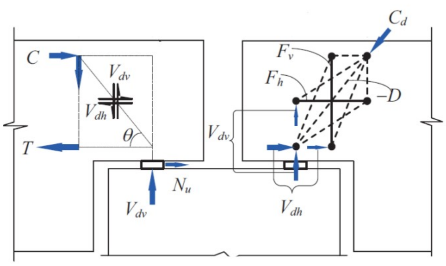



**Figure 2.4:** Dapped end beam connection [28]

## 2.2. Quantifying the environmental impact of structures

The demand for quantification of the environmental impact of structures is growing. This is because limiting the impact is increasingly becoming a criterion for consumer markets and government procurement. Both government regulations and businesses have recognized the value of quantifying the environmental impact with a life cycle analysis or Life Cycle Assessment (LCA). This analysis evaluates the impact of a product in all life cycle stages as shown in Figure 1.2. LCA is considered to be a tool to support decision making and is continuously improving [32]. The scope of performing an LCA can lie in one of the categories stated below. Each category has its manuals and guidelines [36]. The scopes that can be defined are:

- ”Comparative studies to assess variation in environmental performance”;
- ”Declaration of the environmental performance of a product from a life cycle perspective”;
- ”Studies of product development work” (Sperle, 2013, p. 21).

According to ’Building regulations 2012’, an LCA should include at least the basic environmental impact categories. Those can be expressed in equivalents (eq.) of certain pollutants [11]. The basic categories are shown in Table 2.1. The equivalent of each category has a corresponding monetary value expressed in euros called shadow costs. The shadow costs represent costs to compensate for the environmental impact that has been made and thus show the relative importance of each category. This makes it possible to sum up the impact of each category to a total impact expressed in euros that represents the impact of a structure. The shadow costs are estimated by calculating the Environmental Cost Indicator (ECI), which gives averaged numbers based on the use of finite resources and emission of harmful compounds. According to the ’polluter-pays-principle’, the environmental costs should become part of the costs of each product. However, this is not yet the case. Although it is an estimation, the ECI is given in a single value for clarity. Calculating the ECI is a Dutch method included in the ’Building regulations 2012’ [33].

**Table 2.1:** Impact categories of LCA

| Impact category | Abbreviation | Unit equivalent (UE) | Shadow costs per UE (€) |
|---|---|---|---|
| Global Warming Potential | GWP | kg $CO_2$ | 0.05 |
| Ozone layer Depletion Potential | ODP | kg CFC-11 | 30 |
| Eutrophication Potential | EP | kg $PO_4^{3-}$ | 9 |
| Photochemical Oxidation Potential | POCP | kg Ethene | 2 |
| Acidification Potential | AP | kg $SO_2$ | 4 |
| Abiotic Depletion Potential Fuel | ADP-fuel | kg Antimone | 0.16 |
| Abiotic Depletion Potential non-Fuel | ADP-non-fuel | kg Antimone | 0.16 |
| Human Toxicity Potential | HTP | kg 1,4-dichloro benzene | 0.09 |
| Fresh water aquatic ecotoxicity | FAETP | kg 1,4-dichloro benzene | 0.03 |
| Marine aquatic ecotoxicity | MAETP | kg 1,4-dichloro benzene | 0.0001 |
| Terrestrial ecotoxicity | TAETP | kg 1,4-dichloro benzene | 0.06 |

**Environmental impact assessment in the circular economy**

Initially, the LCA assumed the conventional life cycle, thus not including any end-of-life scenario other than demolition and waste creation. However, as the economy is becoming more and more circular, the focus on other principles should be increasing. It is of great importance to include these principles in the LCA, as the decision between alternatives will otherwise be based on an unfair comparison. The benefits of reusing and recycling are included in LCA by taking into account life cycle stage D [37].

LCA results for reusing should be further interpreted than the framework is currently suggesting. When comparing results of the environmental impact of those different principles applied to the same structure, those interpretations must be done similarly, so that the comparison is reliable. This can for example be done by considering the difference in lifetime of the structures to be compared and spreading the impact over the lifetime [6]. To include reuse in the life cycle of the structure, additional substages have to be added in the use phase, which are deconstruction, transport and construction. This is indicated in Figure 2.5.

The interpretation of LCA results is important for the comparison of DfD structures to alternatives. Although initially the impact of a structure can be increased, applying DfD will most likely decrease the environmental impact of a structure [10]. When the end of life scenarios are taken into account in the LCA, it is a fitting method to find this decrease in environmental impact. This is the case, as not only greenhouse gas emissions and energy consumption are considered, but also the use of nonrenewable resources is included in the impact category ADP-non-fuel [6].

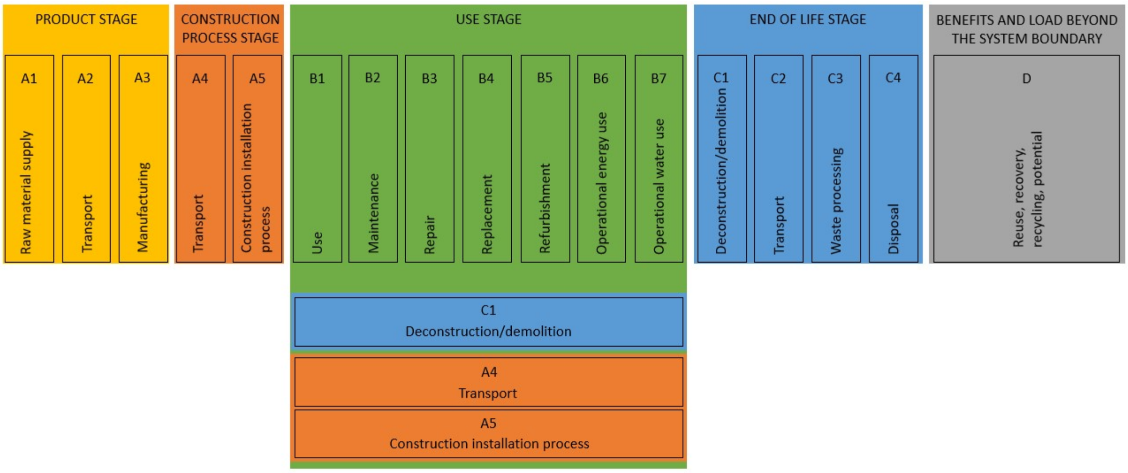



**Figure 2.5:** Life cycle stages including reuse

# 3

# Analysis of reference jetty

In this chapter, the analysis of the reference jetty is elaborated on. The overall functions of the jetty are described in Section 3.1. Next, its design requirements and conditions are summarized in Section 3.2, in which it is included how those can be modelled. The layout of the structure is described in Section 3.3, after which the model and calculations are worked out in Section 3.4.

## 3.1. General

During the execution of this research, the reference jetty is being built in the port of Rotterdam in the Netherlands, specifically for Neste Biofuels. This is a refinery that makes sustainable diesel from animal and vegetable fats [1]. Neste has access to a jetty with two berths. This capacity is insufficient so a new jetty is needed to facilitate the mooring of an inland vessel [31]. The different elements of the jetty are indicated in Appendix C.1. Part of this jetty is considered as a reference in this research. This part is called the platform. The platform has the main function to support loading equipment for (un)loading ships, enable temporary storage of cargo and facilitate transportation of cargo to and from the quay. The equipment is part of the superstructure, that is not included in the jetty design but has consequences for the design by for example imposed loads and allowable displacements. The approach jetty that is connecting the platform to the abutment is also taken into account for robustness calculations.

The platform and approach jetty stand free of the other part of the structure. This part is the slackening structure, that enables the berthing and mooring of ships, absorbs the dynamic loading from the ships and keeps these loads away from the platform. The slackening structure and platform do not influence each other. Therefore, it is feasible to analyse the platform as a separate structure without considering the slackening structure. The only influence that has to be taken into account is the escape routes from the slackening structure that are supported by the platform at two places. The jetty design is made future-proof, which means that it is made larger than it should be for the current intended use, to account for the uncertainty of the future use of the jetty. For this same reason, the foundation of three Marine Loading Arms (MLA's) is made, of which one will be used from the beginning and two will be possibly needed in the future.

## 3.2. Design requirements and conditions

The Eurocode norms and guidelines relevant for this project are listed in Appendix B. Technical requirements stated by the client (PoR) should be taken into account. The requirements are listed in the 'Technisch Programma van Eisen - Neste Biofuels', which was used for the design and calculations of the reference jetty [38]. Moreover, load conditions and soil conditions should be accounted for in the design calculations. All applying conditions are gathered from the 'Definitief Ontwerp Platform + toeloopbrug Neste Biofuels', the final design of the reference jetty platform and approach jetty [31].

[1] https://www.neste.nl/

### 3.2.1. Technical requirements

In Appendix B, all the requirements given by PoR for the jetty structure are listed. As only the platform will be considered in this research, the requirements of other parts of the structure are out of scope, which also holds for requirements that describe details irrelevant for this research. The requirements that will be accounted for in this research concern the load bearing structure.

To summarize, the relevant requirements given by the client describe the following. The scope of the project is to realise a jetty, suitable for the import of raw materials and the export of pretreated materials, renewable propane and renewable n-paraffin, to and from the design ships and all actions needed for that. The lifetime of the structure should be at least 50 years, during which the structure should be able to absorb all loads in all conditions as further described in Section 3.2.2 and 3.2.3. Furthermore, safety should be guaranteed to all users during construction, use, maintenance and demolition. Minimal maintenance should be needed during the design lifetime and all parts that need maintenance or replacement should be accessible. The design should take into account the constructability of the jetty, during which disturbance to the surroundings should be kept at a minimum. The reliability of the structure should comply with Eurocode Reliability Class 2. The dimensions and general layout are described in the requirements as well, including the requirement that all connections should be rigid to create a robust structure. The maximum allowable horizontal displacements ($u_{max}$) are given to be $1/300$ of the height of the structure, with a maximum of 100 mm. This gives $u_{max} = \frac{(31+0.7+0.5)\cdot 10^3}{300} = 105.68\ mm \leq 100\ mm = 100\ mm$.

### 3.2.2. Load conditions

The load conditions for the structure have been determined by PoR and are described in the technical requirements, as stated in Appendix B. The loads that work on the structure can be divided into two categories, permanent loads and variable loads, which are stated below. The different loads have to be combined in the design calculations, which is done with load combinations.

**Permanent loads**

The permanent loads that are taken into account are [31]:

- *Self-weight*: For determining the self weight of the structure, the volumetric weight of reinforced concrete is 2500 $kg/m^3$ and for the steel parts it is 7850 $kg/m^3$.
- *Concrete shrinkage*: The shrinkage is determined according to NEN-EN 1992-1-1 and is calculated to be 0.25‰ [39].
- *Support reactions from escape routes*: Escape routes from the slackening structure to the quay are supported by the platform at two positions, which imposes vertical and horizontal loads and a moment in this support point.

**Variable loads**

Multiple variable loads work on the structure. Those are [31]:

- *Construction load*: The governing construction load applies when the in situ concrete is being poured and is amplified by loads of employees and small tools. According to NEN-EN 1991-1-6 [40], an additional uniformly distributed load is accounted for in the SLS. This load is a result of the loads that are imposed by the self weight before the connections are working, which can cause stresses in the reinforcement.
- *Loads from pipelines on concrete supports or piperacks*: Pipelines are put on concrete supports or piperacks with a maximum centre to centre distance of 6.0 m. This load is considered a variable load, because it is mainly caused by liquids running through the pipelines.
- *Uniformly distributed load caused by additional equipment*: Uniformly distributed loads are caused by additional equipment that is not mentioned in the requirements. Outside the loading zone, also forklifts should be taken into account, which cause horizontal loads due to their weight and vertical loads due to movement. The horizontal load that is imposed is assumed to be 10% of the vertical load. Forklifts will be driving around both on the platform deck and the approach jetty.
- *Loads from supporting three MLA's, a fire monitor (FM) and four JIB cranes*: Three MLA's will be placed on the platform, three meters from the edge of the deck. Also, a fire monitor will be placed at 9.5 meters height above the platform. The bottom plate of the monitor imposes loads on the

structure. Furthermore, JIB cranes are installed. The positions of the MLA's, FM and JIB cranes are indicated in Appendix C.1. A smaller one and two larger ones. The MLA's, FM and JIB cranes impose horizontal and vertical loads. For the MLA's and the FM, a moment is imposed as well due to eccentricity.

- *Wind load*: The wind load is determined according to NEN-EN 1994-1-4 [41]. The height at which the wind velocity is taken is the top of the concrete deck, which includes the entire structure except for the MLA and JIP cranes. The height of the concrete ($h_c$) is 1.2 meters and the height from the ground level to the centre of the concrete ($h_{mv}$) is 6.5 meters. The basic wind velocity ($v_{v,0}$) is 27 m/s. With this information, a thrust is calculated and multiplied over the total height.
- *Temperature load*: Temperature load is determined according to NEN-EN 1991-1-5 [42]. The temperature loads on the concrete deck is governing compared to those on the concrete ribs. However, both are taken into account.

**Load combinations**

According to NEN-EN 1990 [43], three load combinations are determined. In Equation 3.1, the load combination is given for the characteristic case. In Equation 3.2 the load combination for the frequent loading case is given and in Equation 3.3 for the quasi-permanent case [43]. The values of the partial factors are given in Appendix D.1.

$$\sum \gamma_{G,i} G_{k,i} + \gamma_{Q,1} Q_{k,1} + \sum \gamma_{0,i} Q_{k,i} \tag{3.1}$$

$$\sum \gamma_{G,i} G_{k,i} + \gamma_{Q,1} Q_{k,1} + \sum \gamma_{1,i} Q_{k,i} \tag{3.2}$$

$$\sum \gamma_{G,i} G_{k,i} + \gamma_{Q,1} Q_{k,1} + \sum \gamma_{2,i} Q_{k,i} \tag{3.3}$$

In which,

$\gamma_{G,i}$ is the partial factor for the permanent load;
$G_{k,i}$ is the permanent load i;
$\gamma_{Q,1}$ is the partial factor for the leading variable load;
$Q_{k,1}$ is the leading variable load;
$\gamma_{0,i}$ is the partial factor for load combination 0;
$\gamma_{1,i}$ is the partial factor for load combination 1;
$\gamma_{2,i}$ is the partial factor for load combination 2;
$Q_{k,i}$ is the variable load i.

**Modelling assumptions**

All the previously described loads are included in the model. How they are modelled and what is their magnitude is described below. To take into account the uncertainties as mentioned in Section 3.2, factors are applied to the load cases, which are accounted for in the modelled loads. These factors are included in the magnitude of the loads [44]. All the modelled loads and the used load combination can be found in Appendix D.1.

- *Self-weight*: The self-weight of the structure is automatically generated in SCIA Engineer. Material properties are assigned to all elements that are added in the model. In the material properties, the volumetric weight is added. For the self-weight, one case is taken into account.
- *Concrete shrinkage*: The concrete shrinkage is modelled as a temperature load on all concrete elements. Based on the previously calculated shrinkage of 0.25‰, a temperature of -25 °C is modelled.
- *Support reactions from escape routes*: The support of the escape route will impose a horizontal and vertical load on the structure. Additionally, a moment is modelled to account for the eccentricity of the support of 0.25 m. The moments are rounded up to a whole number. Both an Ultimate Limit State (ULS) and a Servicability Limit State (SLS) are modelled, which are a result of the calculations that are done for the slackening structure. The loads are modelled as point loads and are given in Table 3.1.

**Table 3.1:** Loads from support reaction escape routes

| Case | Vertical $F_y$ [kN] | Horizontal $F_z$ [kN] | Moment $M_y$ [kNm] | Moment $M_z$[kNm] |
|---|---|---|---|---|
| ULS | 43 | 20 | 11 | 5 |
| SLS | 27 | 8 | 7 | 2 |

- *Construction load*: It is chosen to take only the use stage into account in the models used in this research. The assumption is made that the governing load combinations will happen during the use stage. The additional loads caused during construction are $1.0\ kN/m$, which is very small compared to the loads imposed during use, which are for example the loads from pipelines and forklifts. Before executing, the construction phase should be modelled and checked to guarantee safety in this phase. During construction, loads can be imposed on the elements due to activities such as lifting them, if the elements absorb these loads should be checked by the contractor.
- *Loads from pipelines on concrete supports or piperacks*: The loads from pipelines are modelled under the assumption that they will be supported by piperacks. Those are modelled with point loads at each end of the piperack. The point loads are: $F_z = 60\ kN$, $F_y = 8\ kN$ and $F_x = 12\ kN$. For the rack closest to the abutment, other loads are modelled, which are: $F_z = 167\ kN$, $F_y = 5\ kN$ and $F_x = 6\ kN$. The loads from the piperacks are divided into two load cases, in which all loads in z-direction are downwards, but the loads differ in x- and y-direction. In the first case, both are positive and in the second case both are negative.
- *Uniformly distributed load caused by additional equipment*: These loads are given by PoR in the technical requirements, as can be found in Appendix B. In the loading zone these are: $Q_{vertical} = 15\ kN/m^2$ and $Q_{horizontal} = 1.5\ kN/m^2$, rounded off to $2\ kN/m^2$. Outside the loading zone these are: $Q_{vertical} = 5\ kN/m^2$ and $Q_{horizontal} = 0.5\ kN/m^2$, rounded off to $2\ kN/m^2$. They do not apply at the piperacks, as no equipment apart from the pipelines will be placed there. The horizontal loads work both in x- and y-direction. The load is modelled in a chessboard pattern, separating it into different fields, causing different loading cases. Three cases are added to this in which a separate forklift is placed on the deck, two times at the approach jetty and one outside the loading zone of the platform. The loads from the forklift are stated by PoR and are $F_{z,front} = -32\ kN$, $F_{z,back} = -4\ kN$, $F_{x,front} = -10\ kN$ and $F_{x,back} = -1\ kN$.
- *Loads from supporting three MLA's, an FM and four JIB cranes*: The loads on the FM and MLA's are modelled in the centre of their position. The loads on the JIB cranes are modelled in four points per crane, which represent the anchor bolts on which they can be placed. The loads that are used in the model are given in Table 3.2. The horizontal loads all work in x-direction and y-direction separately or together, which is why three load cases are made, namely in x-direction, in y-direction and the 45°direction that is a resultant when they are both working. All loads are modelled as point loads.

**Table 3.2:** Loads from MLA's, FM and JIB cranes

| | $F_{vertical,down}$ [kN] | $F_{vertical,up}$ [kN] | $F_{horizontal}$ [kN] | $M_y$ [kNm] |
|---|---|---|---|---|
| MLA's | 250 | | 60 | 750 |
| FM | 20 | | 12 | 100 |
| Small JIB crane | 90 | 30 | 60 | |
| Large JIB crane | 200 | 100 | 60 | |

- *Wind load*: The wind is modelled with horizontal line loads acting on the sides of the concrete deck, with a magnitude of $F_{horizontal,1} = 3\ kN/m$ at the side that is perpendicular to the wind direction and $F_{horizontal,2} = 2\ kN/m$ at the side parallel to the wind direction. Furthermore, a vertical surface load is modelled on the entire deck of $F_{vertical} = 1\ kN/m^2$ downwards.
- *Temperature load*: This load is modelled as a temperature load in four different scenarios. Each scenario gives a temperature to the upper side of the element and one to the lower side of the element, creating a linear temperature distribution over the height of all concrete elements. The four cases that are taken into account are displayed in Table 3.3.

**Table 3.3:** Temperature loads

| Case | $T_{upper}$ [K] | $T_{lower}$ [K] |
|---|---|---|
| 1 | 25.3 | 2.8 |
| 2 | -14.5 | -7.6 |
| 3 | 35.2 | 18.3 |
| 4 | -30.8 | -25.7 |

### 3.2.3. Boundary conditions

Two different boundary conditions are applied to the structure. The first is at the interface with the quay and the second is the support of the foundation piles in the soil. For the connection to the quay, the approach jetty has to be taken into account. This part of the structure is connected to the platform deck and thus influences the behaviour of the deck. On the other side, it is connected to the quay at an abutment. The abutment is assumed to only restrict movement in the vertical direction, horizontal translations and rotations are free.

At the location of the reference jetty, ten cone penetration tests are carried out. Based on the soil is rather homogeneous when looking at the results of the tests at the different locations. Governing tests are taken for the platform piles and the piles under the approach jetty. A loose sand layer is found until approximately NAP -13.5 m to NAP -15.0 m, after which clay and sand layers were found alternately. At approximately NAP -20.4 m to NAP -22.0 m, a tight sand layer begins. The governing cone penetration test graphs for the platform and approach jetty can be found in Appendix D.2. From the graph, the results are interpreted as given in Table 3.4 and 3.5. The stiffness of the ground layers are expressed in Menard stiffness, which is found with Equation 3.4, in which $\beta$ is a material specific factor that is 0.7 for sand and 2.0 for clay [31].

$$E_m = q_c \beta \tag{3.4}$$

**Table 3.4:** Governing penetration test results platform [31]

| Layer | Material | Upper side layer [NAP m] | $\gamma_{dry}/\gamma_{sat}$ $[kN/m^3]$ | $q_c[MPa]$ | $\phi'$ [°] | $c'[KPa]$ | $E_m$ $[kN/m^2]$ |
|---|---|---|---|---|---|---|---|
| 1 | Sand, weak silt | -7.50 | 17/19 | 4.0 | 27.0 | 0.0 | 2800 |
| 2 | Sand, clean loose | -9.50 | 17/19 | 5.0 | 30.0 | 0.0 | 3500 |
| 3 | Clay, clean moderate | -13.50 | 17/17 | 0.5 | 17.5 | 5.0 | 1000 |
| 4 | Sand, strong silt | -15.75 | 18/20 | 6.0 | 25.0 | 0.0 | 4200 |
| 5 | Sand, moderate | -18.00 | 18/20 | 11.0 | 32.5 | 0.0 | 7700 |
| 6 | Clay, weak sandy moderate | -19.00 | 18/18 | 1.0 | 22.5 | 0.0 | 2000 |
| 7 | Sand, tight | -22.00 | 19/21 | 25.0 | 35.0 | 0.0 | 17500 |
| 8 | Sand, tight | -24.70 | 19/21 | 16.0 | 35.0 | 0.0 | 11200 |
| 9 | Sand, tight | -25.50 | 19/21 | 25.0 | 35.0 | 0.0 | 17500 |

**Table 3.5:** Governing penetration test results approach jetty [31]

| Layer | Material | Upper side layer [NAP m] | $\gamma_{dry}/\gamma_{sat}$ $[kN/m^3]$ | $q_c[MPa]$ | $\phi'$ [°] | $c'[KPa]$ | $E_m$ $[kN/m^2]$ |
|---|---|---|---|---|---|---|---|
| 1 | Sand, clean loose | -4.00 | 17/19 | 4.0 | 30.0 | 0.0 | 2800 |
| 2 | Sand, clean loose | -8.00 | 17/19 | 5.0 | 30.0 | 0.0 | 3500 |
| 3 | Clay, strong sandy | -14.50 | 18/18 | 1.0 | 27.5 | 5.0 | 2000 |
| 4 | Sand, clean moderate | -15.50 | 18/20 | 12.0 | 32.5 | 0.0 | 8400 |
| 5 | Clay, strong sandy | -16.80 | 18/18 | 2.0 | 27.5 | 0.0 | 4000 |
| 6 | Sand, clean moderate | -17.10 | 18/20 | 10.0 | 32.5 | 0.0 | 7000 |
| 7 | Clay, weak sandy moderate | -19.00 | 18/18 | 1.0 | 22.5 | 0.0 | 2000 |
| 8 | Sand, clean tight | -20.40 | 18/20 | 20.0 | 35.0 | 0.0 | 14000 |

**Table 3.7:** Modelling stiffness of soil layers approach jetty piles

| Layer | Upper side of layer [m+NAP] | $k_h$ [MN/m$^3$] | $k_h/\sqrt{2}$ [MN/m$^3$] |
|---|---|---|---|
| 1 | -4.00 | 8.7 | 6.1 |
| 2 | -8.00 | 10.8 | 7.7 |
| 3 | -14.5 | 4.0 | 2.8 |
| 4 | -15.5 | 26.0 | 18.4 |
| 5 | -16.8 | 7.9 | 5.6 |
| 6 | -17.10 | 21.7 | 15.3 |
| 7 | -19.00 | 4.0 | 2.8 |
| 8 | -20.40 | 43.3 | 30.6 |

In which,

$\gamma_{dry}$ Dry volumetric weight
$\gamma_{sat}$ Saturated volumetric weight
$q_c$ Penetration resistance
$\phi'$ Internal friction angle
$c'$ Cohesion
$\beta$ Material specific factor
$E_m$ Mernard stiffness

**Modelling assumptions**

This abutment is modelled as a line support at the outer edge of the approach jetty. The line support restricts translations in the vertical direction (z-direction).

Horizontal and vertical linear spring supports are used to model the behaviour of the soil. Horizontal springs are modelled in both x- and y-direction in each pile. The stiffness of the springs is determined per soil layer with the Menard stiffness, based on the governing cone penetration test results. With Equation 3.5, the stiffness can be calculated that can be used in the springs ($k_h$), based on the Menard stiffness, the radius of the steel piles ($R$), a reference radius ($R_0 = 300\ mm$) and the $\alpha$-factor of the soil type, which is 0.33 for sand and 0.67 for clay. The results are given per soil layer in Table 3.6 and 3.7. In the model, a safety factor of $1/\sqrt{2}$ is taken into account for the soil stiffness. The value that is used as a spring stiffness in the model ($k_h/\sqrt{2}$) is also given in the tables. Underneath each pile, a vertical spring is modelled that has an assumed stiffness of 100 MN/m. When taking the safety factor into account, this vertical stiffness can be modelled with a value of $100/\sqrt{2} = 70.7\ MN/m$. The spring supports that are modelled are given in Appendix D.2. Seen from the quay, the soil is declining, which gives the top layer of the soil to be 0.0, -1.5, -3.0, -5.5, -6.0 and -7.5 m NAP respectively per row of piles (corresponding with -6.0, -7.5, -9.0, -10.5, -12.0 and -13.5 m in the model). When modelling the springs, these heights are taken into account [44].

$$\frac{1}{k_h} = \frac{1}{3E_m}(1.3R_0(2.65(\frac{R}{R_0})^{\alpha} + \alpha R) \qquad (3.5)$$

**Table 3.6:** Modelling stiffness of soil layers platform piles

| Layer | Upper side of layer [m+NAP] | $k_h$ [MN/m$^3$] | $k_h/\sqrt{2}$ [MN/m$^3$] |
|---|---|---|---|
| 1 | -7.50 | 9.9 | 7.0 |
| 2 | -9.50 | 12.4 | 8.8 |
| 3 | -13.50 | 2.1 | 1.5 |
| 4 | -15.75 | 14.9 | 10.5 |
| 5 | -18.00 | 27.3 | 19.3 |
| 6 | -19.00 | 4.2 | 3.0 |
| 7 | -22.00 | 62.1 | 43.9 |

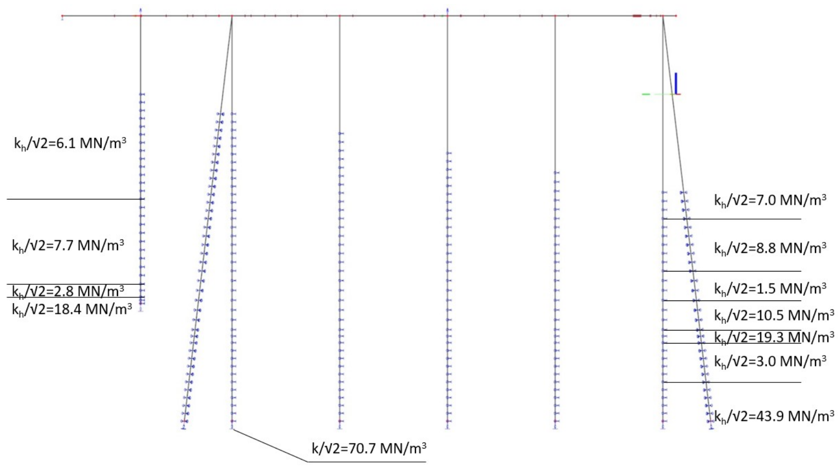



**Figure 3.1:** Soil modelled as springs in SCIA Engineer

## 3.3. Layout of structure

The jetty platform consists of two main elements, the concrete deck and the steel foundation. The deck is made of prefab and in situ concrete elements. It has a length of 35 meters and a width of 48 meters. The deck consists of a liquid-tight loading zone, surrounded by rising concrete edges. This loading zone spreads over the entire length of 35 meters and, seen from the shipping side, over a width of 28 meters. Outside the loading zone is room for pedestrians to walk and forklifts to drive. The concrete deck is supported by steel piles. From the platform to the quay, there is a concrete approach jetty, facilitating the transportation to and from the quay and support of pipelines [31].

### 3.3.1. Materials

The two main materials that are used in the platform are C35/45 concrete and steel with steel grade S355. In the concrete, reinforcement steel is used of class B500B. The material properties of the concrete, reinforcement steel and steel are stated in Appendix C.2.

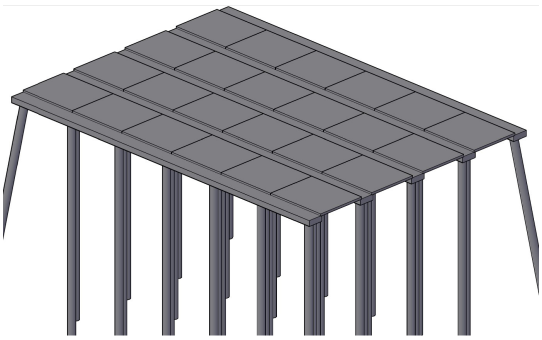
Due to the chloride environment in which the jetty will be used and the specific requirement to make the deck liquid-tight, additional specifications exist for the detailing of the concrete and the corrosion of the steel. Consequently, the maximum allowable crack width in concrete elements is 0.15 mm in the liquid-tight elements and 0.20 mm in the other elements. In the liquid-tight parts, the maximum rebar spacing is 100 mm and the minimum reinforcement rate is 0.47%. The reinforcement in the liquid-tight part is the first and second reinforcement layers seen from the top of the in situ concrete [31]. Furthermore, in Appendix C.2, the minimal concrete cover that has to be applied based on the environmental classes and the effectively applied concrete cover are stated, as well as the reduction of the steel element thickness due to corrosion. The steel piles will be provided with fibreglass strengthened coating until 2.0 m below the soil level, NAP -9.7 m, to reduce corrosion. The corrosion only applies to the outer side of the tubular pile elements [31].

### 3.3.2. Structural elements and connections

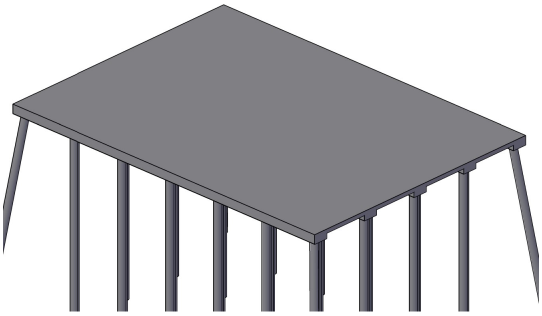
The platform deck is built up of five long prefab concrete plates that are supported by 35 steel foundation piles. The foundation piles are tubular with a diameter of 914 mm and a thickness of 16 mm. The four corner foundation piles are at an angle of 6:1, the others are placed vertically. The long concrete plates function as ribs in the structure and thus will be referred to as rib plates. On top of the rib plates, 26 prefab concrete plates of five different types are placed, bridging the distance between the rib plates. These plates form the basis of the deck and will be referred to as deck plates. The deck plates are placed towards the side of the rib plates, so that space is left between deck plates along the rib plates. To connect all concrete elements and to create a liquid-tight deck, a concrete compression layer is placed in situ on top of and in between the deck plates. An overview of the platform deck and foundation piles is displayed in Figure 3.2, together with an overview of all concrete elements used.

Three main connection types are used in the reference jetty structure. They can be grouped into steel foundation to prefab rib plate, prefab rib plate to prefab rib plate, and prefab rib plate to prefab deck plates. The connections between the concrete elements are all made with wet connections, in which in situ concrete fills the gap between the elements and reinforcement sticking out of the elements ensures continuity. The three types are elaborated in Appendix C.3.

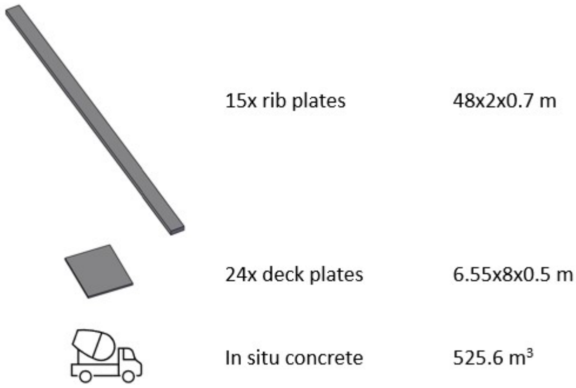
Part of the loading equipment is an MLA, of which three will be placed on the deck. This requires additional support to facilitate anchorage. Therefore three small beams are placed in between the rib plates [31].



**(a)** 3D view of placed prefab elements



**(b)** 3D view with in situ concrete




**(c)** All concrete used in reference jetty

**Figure 3.2:** Overview of reference jetty

The approach jetty is constructed similarly to the deck. Prefab concrete rib plates are placed parallel to each other and are supported by two tubular steel piles. The distance between them is bridged by prefab concrete deck plates. The elements are connected in situ by concrete that is poured on top of the deck plates and in between the deck plates on top of the rib plates. Over 6.0 m of the total 10.0 m of the width, the pipelines will be placed. They will be resting on concrete supports. The remaining width of 4.0 m functions as an approach jetty for walking and driving to and from the platform [31].

## 3.4. Model and calculation results

The platform design is calculated by modelling the structure and the geotechnical conditions given in Section 3.2.3 and exposing it to the load conditions as described in Section 3.2.2. The platform is modelled and calculated in SCIA Engineer. The structure is not cyclically loaded, thus only a static analysis is performed. For this research, the use phase is considered. The calculations are done both in ULS and SLS [31], in which the results are presented with displacement lines and force and moment lines. The magnitudes of the results are all given in Appendix C.3.1. Although only the platform is considered, the approach jetty is modelled as well, as it influences the boundary conditions of the platform.

During the use phase, the deck is working as a monolithic plate with stiffening ribs underneath. The deck is modelled as one 2D-plate element with a height of 500 mm and the rib plates as 1D rib elements with a height of 700 mm and are indicated as stiffening ribs. The rib plates and deck are rigidly connected, so that loads and moments in all directions can be transferred along the entire line. This line is modelled in the middle of the width of the rib plates. In the deck element, vertical regions are modelled at the lines where the sides of the deck plates touch. Those regions represent the intersecting edges of the prefab deck plates. A separate 2D-plate element represents the approach jetty, which also has a 1D rib element. The two 2D-plate elements are rigidly connected at their interface. The plates supporting the MLA's are modelled as 1D-bar elements, which are rigidly connected at the interface with the rib plates, meaning that forces and moments in all directions can be transferred in the two end points of the MLA supporting plates. The model is displayed in Figure 3.3. Details on all elements and cross-sections that are used and the layout of the model are given in Appendix D.3.

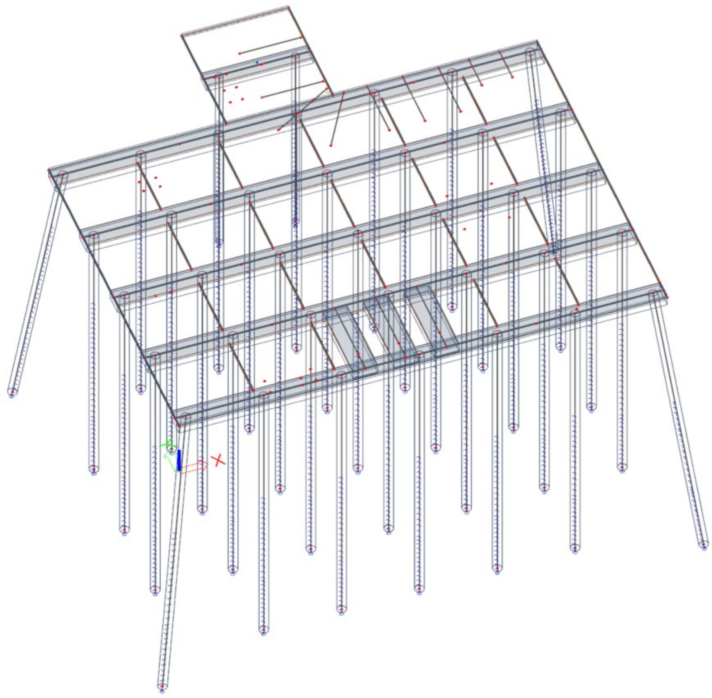
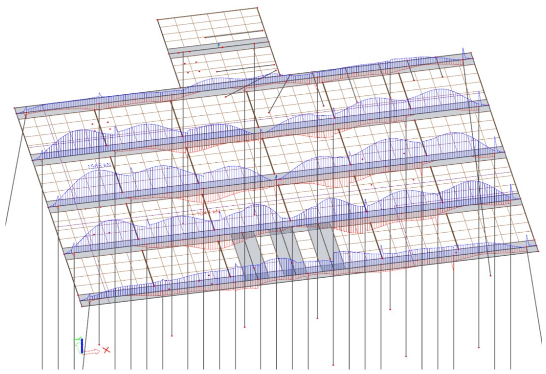


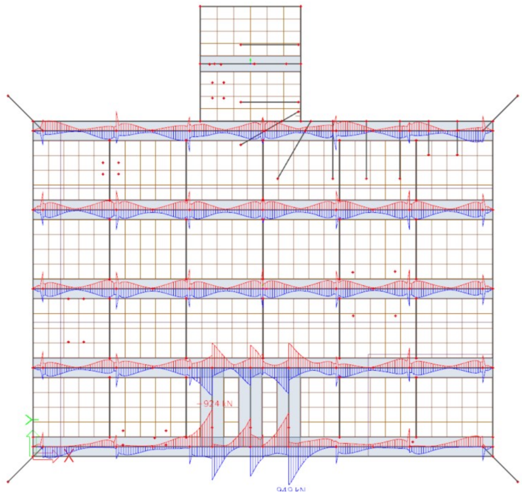
**Figure 3.3:** Overview of model reference jetty

**Ultimate limit state**

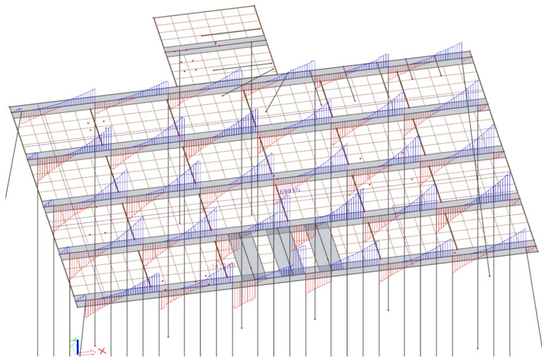
In the ULS, internal forces and stresses in the structural elements can be determined. The internal forces in the rib plates are displayed in Figure 3.4, which are the extreme internal forces that were found for all ULS load combinations. The normal forces are found to be not very diverse. Positive normal forces are dominant, meaning tension forces are highest in the rib plates. The normal forces are lowest in the middle of the rib plates. At the positions of the intersection between the rib plates and the plates supporting the MLA's some disturbances are found. However, the normal forces are not higher due to these disturbances. Both in y- and z-direction, the shear forces are highest at the positions of the piles and are smaller to zero in the middle of the span between the piles, which is expected as it is comparable with a continuous beam. The plates supporting the MLA's cause large disturbances and peak forces in the rib plates for the shear force in y-direction. The shear force in z-direction are disturbed here as well, but the forces are not much higher. From the moments in x- and y-direction, clearly the behaviour of a continuous beam can be recognised. Sagging and hogging bending moments cause tension in the upper part of the rib plates above the piles and the bottom part in the span between the piles. Disturbances by the MLA supporting plates are found, but do not influence the magnitude of the forces largely. For the moment in z-direction this disturbance is considerably large and causes peak bending moments in these points. The extreme internal forces can be found in Appendix C.3.1.



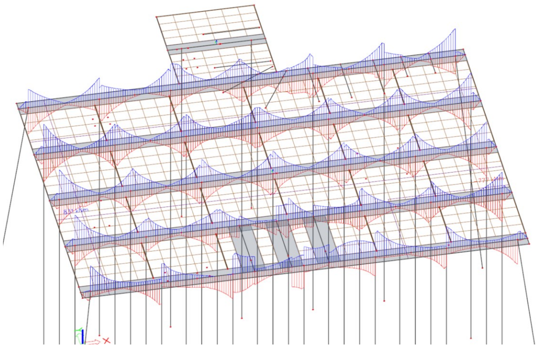
**(a)** Normal force



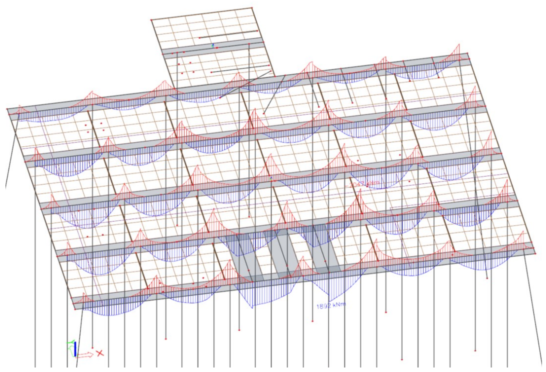
**(b)** Shear force in y-direction



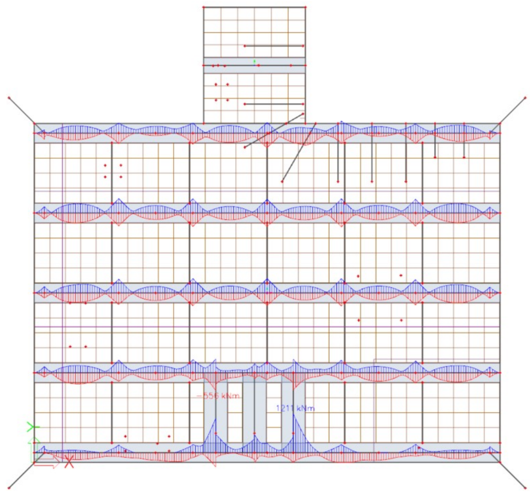
**(c)** Shear force in z-direction



**(d)** Moment in x-direction



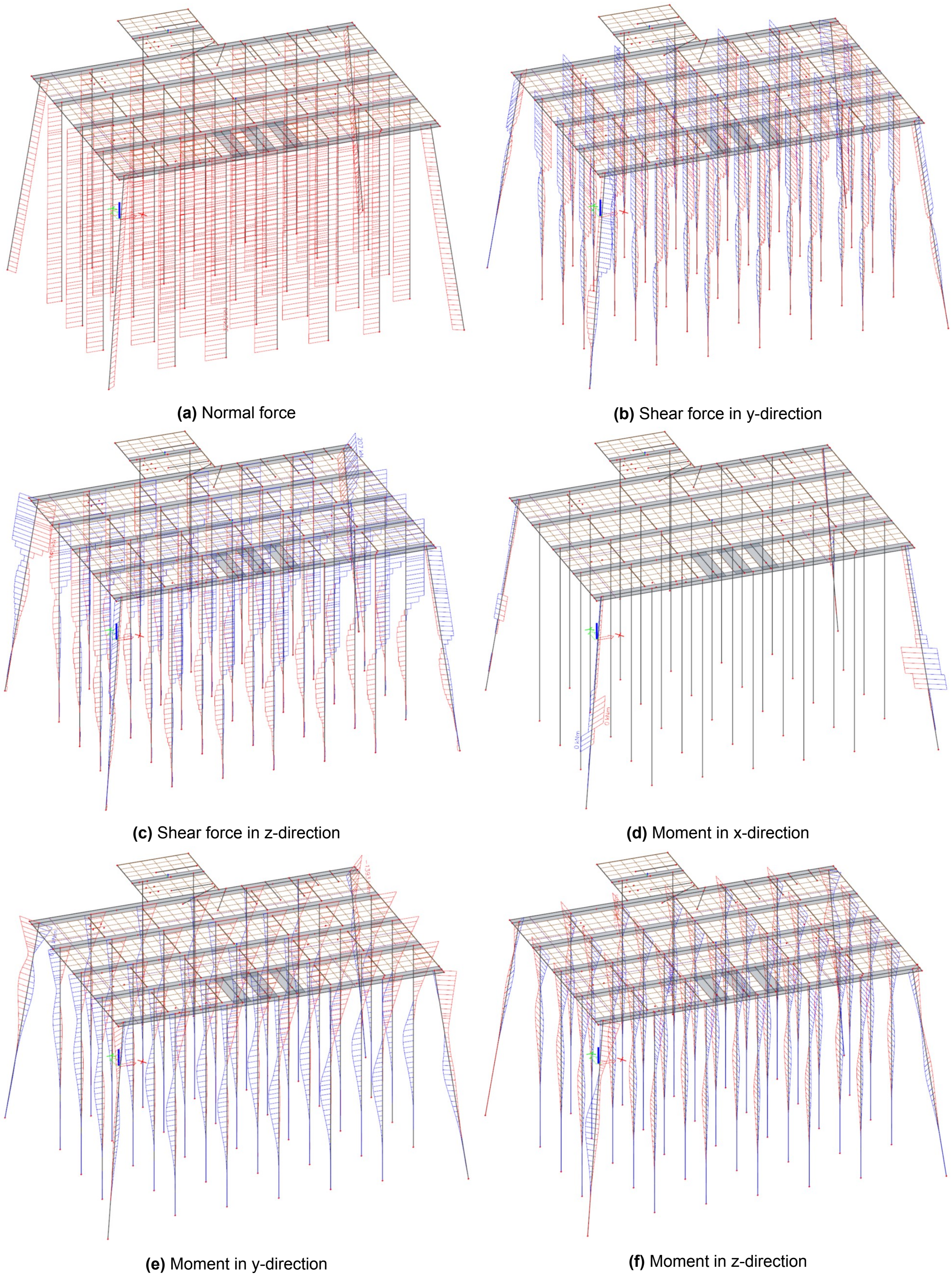
**(e)** Moment in y-direction



**(f)** Moment in z-direction

**Figure 3.4:** Internal forces in rib plates of reference jetty

The foundation piles are only loaded by their self-weight and by the loads that are transferred from the platform to the piles. The self-weight is in this case small compared to the effect from other loads. Due to this, the normal force in the piles is almost uniform over the length, which is a compression force at all positions in the piles. A very small constant increase is observed downwards, creating the peak to be at the bottom of the piles. Due to the loading from the top, the shear force is uniform over the length both in y- and z-direction. This uniformity is disturbed at the beginning of the soil, which is modelled by spring supports. As the stiffness of the spring supports varies over the depth, the shear forces are also varying. Moments in x-direction only occur in the piles that are placed at an angle. The shape of the moment lines in y- and z-direction are comparable, with the extremes at the top of the piles. The extreme internal forces are given and the governing forces for the pile to rib plate connection, thus in the top of the pile, are given in Appendix C.3.1.



**(a)** Normal force

**(b)** Shear force in y-direction

**(c)** Shear force in z-direction

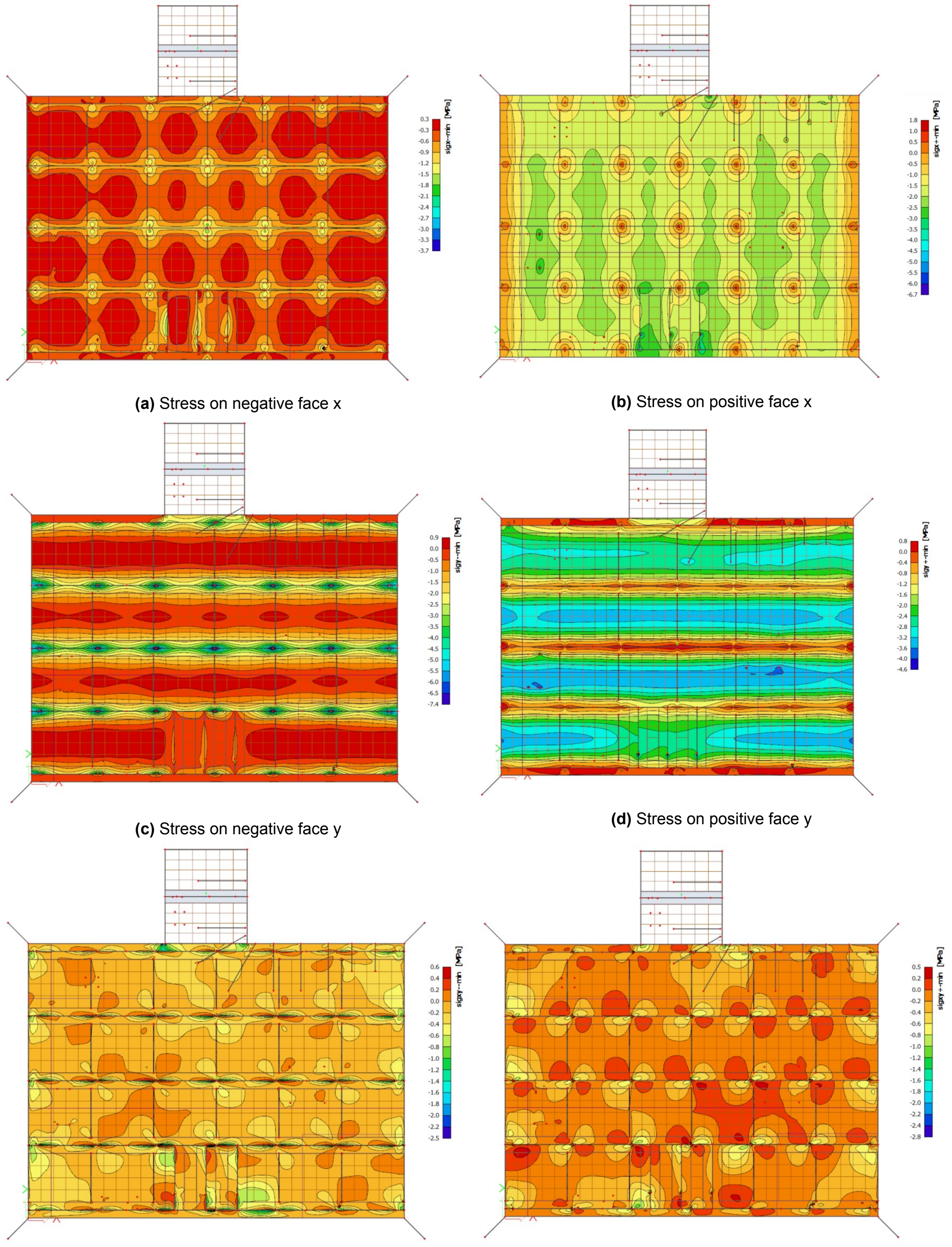
**(d)** Moment in x-direction

**(e)** Moment in y-direction

**(f)** Moment in z-direction

**Figure 3.5:** Internal forces in piles of reference jetty

Extreme stresses that are found in the deck are displayed in Figure 3.6 and 3.7. In the x-face it can be observed that high and concentrated stresses occur at the supports of the FM and the MLA's, which is where large loads are imposed. At all other positions, the stresses are considerably lower but vary somewhat in the plates supporting the MLA's. In the y-face, concentrated and large stresses are found in the points of the plates that are supported by the piles. This result can be expected, as the loads will be transferred to the piles, which are stiff and rigidly connected to the rib plates. The stresses at the position of the rib plates are somewhat smaller than the stresses in the spans between the rib plates. Very high concentrated stresses are again found in the supports of the FM and MLA's, which also holds for the xy-face. In the xy-face, no other considerably high stresses were found. The magnitudes of the extreme stresses are shown in Appendix C.3.1, the largest occurring stress is 14.2 MPa at the rib-parts and 6.0 MPa in the span between the rib-parts.



**(a)** Stress on negative face x

**(b)** Stress on positive face x

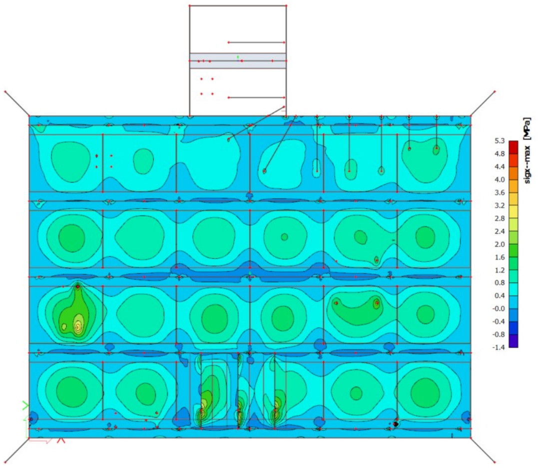
**(c)** Stress on negative face y

**(d)** Stress on positive face y

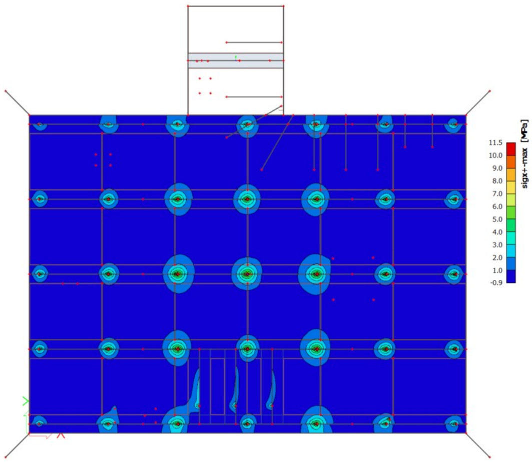
**(e)** Stress on negative face xy

**(f)** Stress on positive face xy

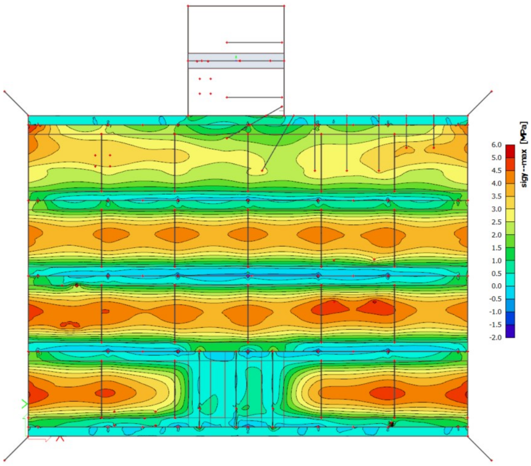
**Figure 3.6:** Extreme negative stresses in faces of reference jetty deck



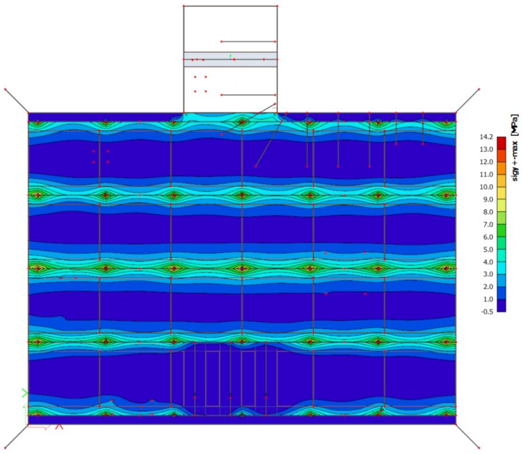
**(a)** Stress on negative face x



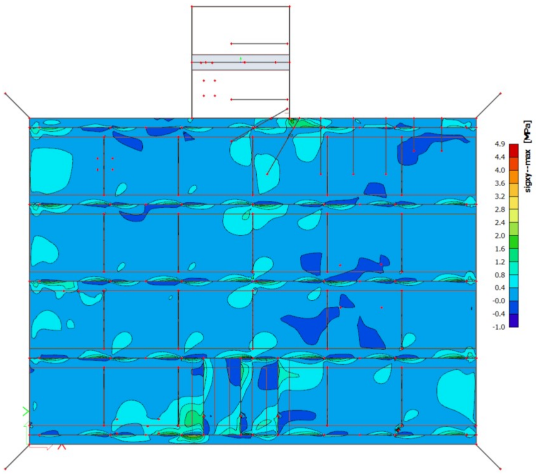
**(b)** Stress on positive face x



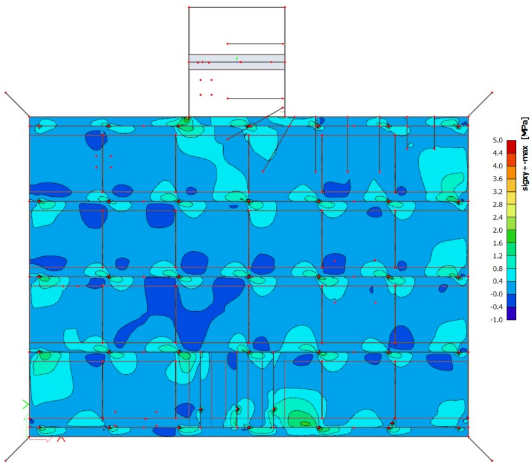
**(c)** Stress on negative face y



**(d)** Stress on positive face y



**(e)** Stress on negative face xy

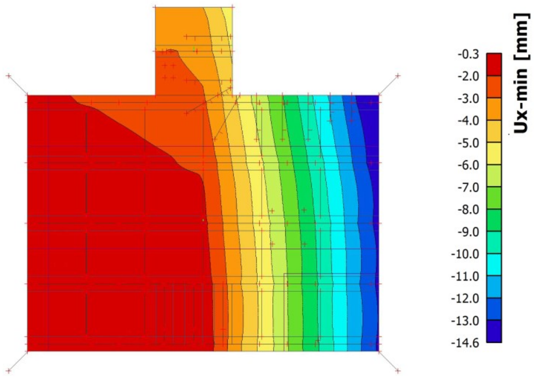


**(f)** Stress on positive face xy

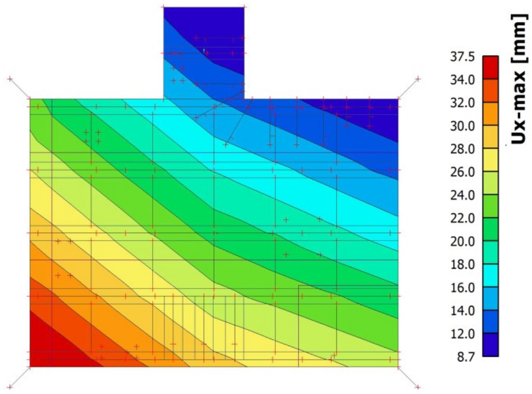
**Figure 3.7:** Extreme positive stress in faces of reference jetty deck

**Servicability limit state**

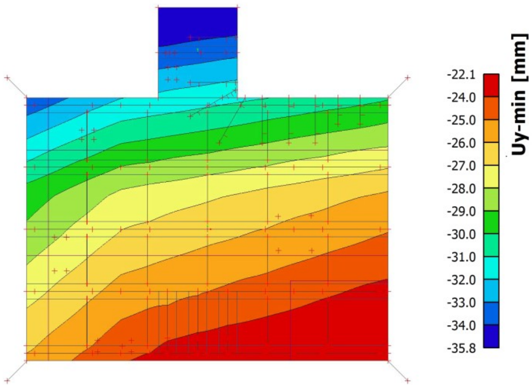
From the calculation results of the model in SLS can be observed that the structure is robust. As can be seen in Figure 3.8, the maximum horizontal displacement that is found is 35.8 mm, which is well within the given limit of 100 mm. Horizontal displacements are largest towards the edges of the deck, while vertical displacements are largest below the centre of the deck. Displacements in y- and z-direction are largest around the lower edge and to the right, which can be expected due to the large forces and moments imposed by the MLA's and FM. The maximum vertical displacement is 41.6 mm. As can be observed, there is no vertical displacement at the abutment, which agrees with the boundary conditions. Furthermore, no steps in the displacements are found, which also agrees with the condition that all elements are rigidly connected.



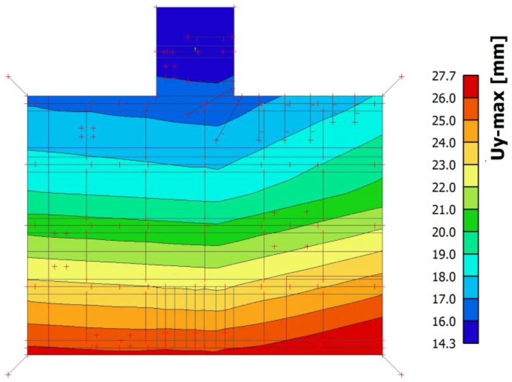

**(a)** Displacement in negative x-direction



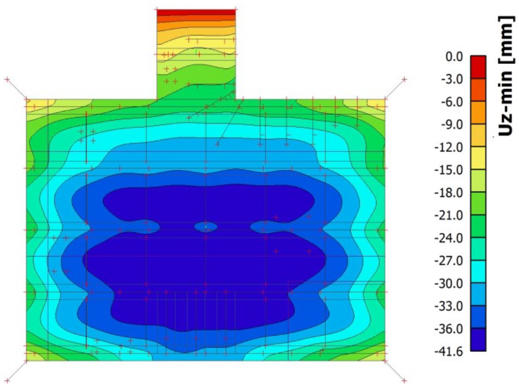

**(b)** Displacement in positive x-direction



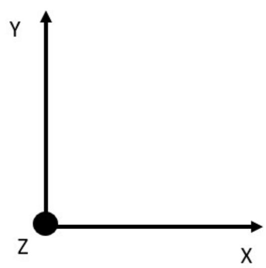

**(c)** Displacement in negative y-direction




**(d)** Displacement in positive y-direction




**(e)** Displacement in z-direction




**(f)** Directions of displacements

**Figure 3.8:** Extreme displacement of reference jetty deck

### 3.4.1. Assembly

In the factory, the prefab elements will be made. For the rib plates, a steel plate has to be made in the element as well. To do this, rods are welded onto the plate and together they can be placed in the casting. All prefab elements will be shipped to the site location of the jetty. The foundation piles under the deck can be vibrated until the beginning of a sand layer at a depth of NAP -21.0 m. For the last part, they will be hammered into the soil. The piles supporting the approach jetty will be hammered over the entire depth. The piles will be supplied and installed from the water.

After placing all foundation piles, the concrete rib plates can be lifted into place, which is also done from the water. When in place, the foundation piles will be welded to the steel plate in the concrete rib plate. The plate onto which the pile will be welded is larger than the pile diameter so a horizontal placement tolerance of 50 mm can be obtained. Also, the wet cast connections will be made to connect the smaller parts. When they are in place, the in situ beams can be constructed to support the MLA's.

On top of the rib plates, the prefab deck plates will be installed from the water. To avoid placement of concrete elements directly onto each other, rubber joint profiles are placed in between. The concrete elements are roughened on the sides that will touch the in situ compression layer to give additional shear strength. The deck plates have a horizontal placement tolerance of 50 mm, due to the large overlap with the rib plates. The plates can be placed from one side, so that the side of the plate can be placed against the side of the previously placed plate.

The in situ concrete for the compression layer can be supplied from land or water. This layer will make the deck one monolithic element and create a 1% slope to restrict the formation of puddles. Rising parts in the concrete will also be made in this stage.

The placement of the superstructure on the platform will be done from the water and is in the scope of the operator [31].

The total planned construction time for the platform is 188 days, which is including preparations and prefabrication, the construction of the platform and approach jetty, the construction of the slackening structure and a buffer time. The construction of the platform only (excluding the prefabrication) takes 121 days, which partly overlaps with other construction activities. Of these 121 days, 60 days are spent on the wet connections and the in situ pressure layer, which do not overlap with other activities within the platform construction [45].

### 3.4.2. Maintenance

The maintenance that will be applied to this jetty is similar to that of other jetties in the port of Rotterdam. According to Wormmeester (Appendix A), the maintenance of the steel foundation piles is most critical. The piles are protected by a coating, but this coating is effective for approximately ten years. After this, cathodic protection has to be installed and maintained. The steel piles are monitored during the entire lifetime of the structure.

With the help of a system called 'kade modellerings systeem' (KMS), the degradation of the concrete can be estimated based on the quality of the material. Samples are taken from the concrete of existing structures, or are taken during construction of new structures, which gives sufficient information to estimate the maintenance that is needed for the concrete. After 25 years, the first maintenance is approximately needed for the concrete elements, due to beginning corrosion of the reinforcement steel.

For other elements of the structure, only small maintenance is needed that is easily executed. This for example holds for the drainage in the concrete.

# 4

# Conceptual jetty design for reusability

In this chapter, a reusable design of the jetty under consideration is presented. In Section 4.1, the starting points of the design are stated and the different variants that are found are briefly explained, of which one variant is chosen to work with. Of this variant, the layout is described in Section 4.2. Lastly, the model and calculations are shown in Section 4.3 and are compared to those of the reference jetty.

## 4.1. Starting points and variants

As argued in Section 2.1, the structure should consist of prefabricated elements joint together with demountable connections to meet the Design for Disassembly (DfD) requirements. Next to the DfD requirements, Port of Rotterdam (PoR) also has defined requirements, as elaborated in Section 3.2. Obtaining a robust structure remains an important requirement, which PoR believes to achieve by using rigid connections. However, if it can be proven that a robust structure can also be obtained with simple connections, this is preferred. This preference is based on the DfD requirements mentioned in Section 2.1. So to realise the ambition to have more circular port structures, PoR possibly needs to change its requirements.

The starting points are stated below, which form the basis for exploring the possibilities of creating a reusable jetty structure. Those starting points are:

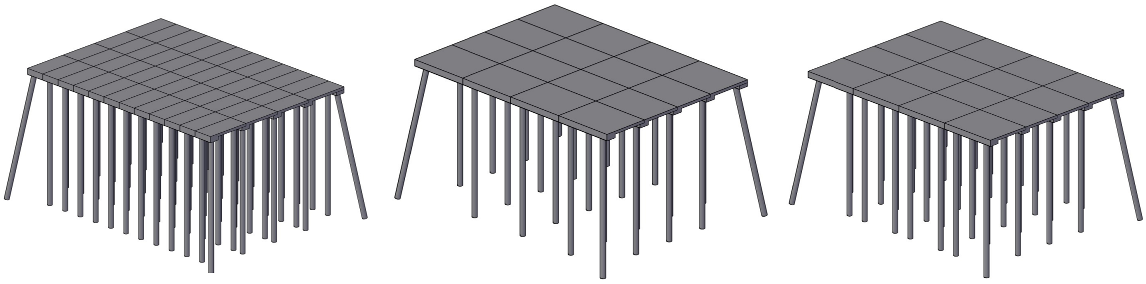
- All variants are modelled and calculated using the SCIA Engineer software. The SCIA models are based on the model that is used for the reference jetty and thus will use the boundary conditions as described in Section 3.2.3 and the load conditions as described in Section 3.2.2.
- The execution is assumed to be done using a crane operated from the water. This means that every element will be placed from above. Therefore it is not feasible to use any horizontal placement. Furthermore, one crane will be used, so the elements should be placed one by one and thus should be robust before they are connected to the element that is placed next.
- A regular crane that is normally used for the construction of jetties is assumed to have a loading capacity of 70 tonnes. This is the same as is used to build the reference jetty [45]. If this is insufficient a larger crane can be used with an assumed capacity of 200 tonnes. The larger crane can cause extra hindrance to the surrounding during construction and needs more fuel to run.

To make a reusable jetty design, the reference jetty is adapted according to the DfD requirements, while also complying with the PoR requirements and the above mentioned starting points. To arrive at a practical design, simple connection solutions are searched. In the process, multiple variants of a reusable design are made. The first design is a variant using separate rib plates and deck plates, which is similar to the reference jetty. The second variant is found that has the rib plates and deck plates already connected in the prefab element, creating T-shaped and n-shaped elements. Knowledge and understanding gained in the process lead to a final reusable design solution, in which elements are created that remind of roof tiles. For each variant, both a rigid connection and a simple connection solution are found. The variants are summarised in Table 4.1, along with a description of where more elaboration is provided. The roof tile variant with simple connections is chosen for further analysis. This decision is based on the simplicity of the design, the potential to create a modular system and the realistic placement tolerances of the elements. This choice is elaborated in Appendix E.5. The other design variants are described in Appendix E, in which the layouts are described and the behaviour of the structures is presented as well. In the further analysis of the roof tile variant with simple connections (also referred to as reusable design variant), the behaviour is described in detail and is compared to that of the reference jetty.

**Table 4.1:** Connection types in categories

| Reusable design | Solution | Connection position | Connection type | Dry | Semi-dry |
|---|---|---|---|---|---|
| Variant 1: Separate rib and deck plates (Figure E.3) | Rigid | Deck plate to deck plate | Rigid | Section E.3 | Section E.4 |
| | | Field rib plate to deck plate | Rigid | Section E.3 | Section E.4 |
| | | Edge rib plate to deck plate | Rigid | Section E.3 | Section E.4 |
| | | Rib plate to rib plate | Rigid | Section E.3 | Section E.4 |
| | Simple | Deck plate to deck plate | None | - | - |
| | | Field rib plate to deck plate | Hinged | - | Section 5.3 |
| | | Rib plate to rib plate | Shear | Section 5.2 | - |
| Variant 2: T-shaped and n-shaped elements (Figure E.11) | Rigid | n-shaped element to n-shaped element | Rigid | Section E.3 | Section E.4 |
| | | n-shaped element to T-shaped element | Rigid | Section E.3 | Section E.4 |
| | | T-shaped element to T-shaped element | Rigid | Section E.3 | Section E.4 |
| | Simple | n-shaped element to n-shaped element | Shear | Section 5.2 | - |
| | | n-shaped element to T-shaped element | Hinged | - | Section 5.3 |
| | | T-shaped element to T-shaped element | Shear | Section 5.2 | - |
| Variant 3: roof tile elements (Figure 4.4) | Rigid | Sides of elements | Rigid | Section E.3 | Section E.4 |
| | | Back side of element to front side or rib plate | Rigid | Section E.3 | Section E.4 |
| | Simple | Sides of elements | Shear | Section 5.2 | - |
| | | Back side of element to front side or rib plate | Hinged | - | Section 5.3 |

Within the roof tile variant, three sub variants can be distinguished, of which one is considered for further study. The three sub variants are: The regular crane variant with 65 foundation piles, the larger crane variant with 25 foundation piles and the larger crane variant with 40 foundation piles. The variants are shown in Figure 4.1. The layout and the assembly are similar for all variants and are further elaborated in Section 4.2. The calculation model is described in Section 4.3.



**(a)** Regular crane **(b)** Larger crane 25 piles **(c)** Larger crane 40 piles

**Figure 4.1:** Sub variants of the roof tile variant

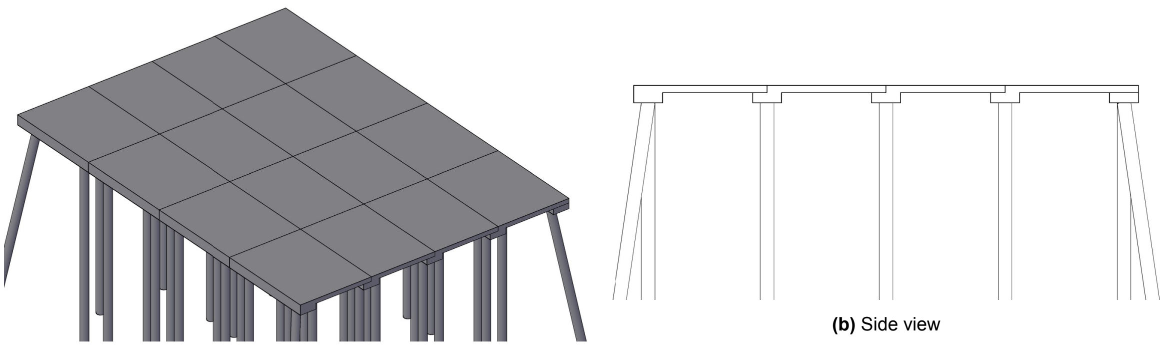
For the regular crane variant, the size of each element is small due to the weight limit set by the crane. Each element should be supported by the previously placed elements and by a pile, to obtain robustness during assembly. When placing the first five elements, no support can be given from a previously placed element, so two piles are needed. Due to the weight limitations, each element can have a length of up to 4.6 m. To arrive at a global length of 48 m, twelve elements of 4 m can be used. A total number of 60 elements is needed, of which the first five elements will be supported by two piles and the remaining elements by one pile. This leads to a total number of 65 piles needed. This is the minimum number to obtain robustness during construction. The robustness during use is proven in Appendix F.3. The number of piles is considered to increase significantly compared to the 35 piles that are needed for the reference jetty. Therefore, this variant is not further considered.

When using a larger crane, four elements of each 12 m can cover the total length of 48 m. The total number of elements that is needed becomes 20. When applying the same pile structure as with the regular crane variant that is discussed above, 25 piles are needed for robustness during construction. However, robustness during use cannot be proven for this amount of piles. As can be seen in Appendix F.2, a maximum displacement is found of 113.3 mm, which exceeds the maximum allowable 100 mm. Therefore, this variant is not further considered.

The larger crane variant with 40 foundation piles is elaborated in the remaining of this chapter.

## 4.2. Layout

The global dimensions of the jetty remain unchanged compared to that of the reference jetty. The roof tile variant layout consists of prefabricated concrete elements that are the roof tiles and a rib plate element at one edge of each tile. The concrete elements can be compared to a deck plate with a rib plate connected to it on one side. This is shown in Figure 4.2. The width and height of all rib-parts are 2 m and 0.7 m respectively. The plate-part differs in dimensions. For the edge elements, the plate-part is 9.25 m in width and 0.5 m in height and for the field elements, this is 8.25 m in width and 0.5 m in height. All elements can have a maximum length of 13.2 m, which is bound by the load capacity of the crane. To arrive at a global length of 48 m, as is the case for the reference jetty, it is chosen to work with four elements of each 12 m in the length direction. Four rib plates, four begin edge elements, eight field elements and four end edge elements will be needed to construct the jetty of 48m in length and 35 m in width. This is a total of 20 elements.



**(a)** 3D view

**(b)** Side view

**Figure 4.2:** Layout of variant 3: Roof tile concept

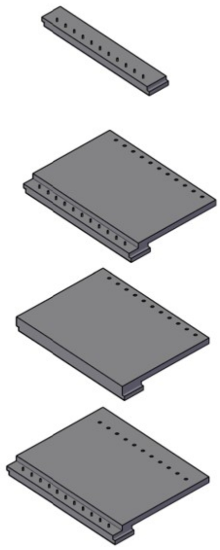



**Figure 4.3:** All prefab elements used in variant 3

**Assembly**
The construction of this variant begins with placing the piles. It is assumed that the piles can have the same placement tolerances as in the reference variant. When all piles are in place, the prefab rib plates can be placed on the beginning side. They will be connected to the piles and each other. On top of the rib plate, the begin edge element can be placed. Next, a field element can be placed and connected to the previous element. This is repeated for the next field element. Lastly, the end edge element can be placed and connected to the last field element. This completes the platform layout.

By only connecting the element to one side at once, the element can be fitted to this side. The next element that is placed can be fitted to the side of the previous element again and so on. Hereby, the construction tolerances can be realistic for this variant by avoiding the need to place the element on multiple other elements at the same time that can be placed with a tolerance already.

When considering robustness during construction, the elements should be supported on multiple points. For the rib plate, it is assumed to be sufficient if the element is placed on at least two points. Those points are the piles. The roof tile elements are resting on the previously placed elements along one full side. On the other side, two points are needed to create robustness during construction. The two points can be the piles, which is the case that is worked with in this variant. Per element two piles are thus needed. For the total number of 20 elements, this means that 40 piles are needed to ensure robustness during construction of the platform. Compared to the reference jetty, 5 additional piles are thus needed.

The construction time of the platform will be reduced by only using prefabricated elements and semi-dry and dry connections, as further elaborated in Chapter 5. The 60 days spent on the in situ concrete en wet connection is expected to reduce significantly. In this time, only some work on the hinged connections has to be done, which is installing the bolts, pouring the first grout layer, tightening the heads and pouring the second grout layer. The exact planning of this is not made, but it is estimated that of the 60 days initially required for the in situ concrete construction, only 10 will remain. This reduces the construction time of the platform to 71 days. The use of a large crane is a compromise that has to be made when compared to the construction of the reference variant. It has to be determined if it pays off in terms of environmental impact due to the shorter construction time and the possibility of reusing.

## 4.3. Model and calculation results

As for the reference jetty, the structure is calculated with a SCIA Engineer model, including the geotechnical conditions given in Section 3.2.3 and the load conditions as described in Section 3.2.2. It is chosen to perform a detailed analysis on the variant using a larger crane, as is explained in Section 4.2. If it is preferred to strictly use a regular crane, it will need further study. For the regular crane version, the displacements are given in Appendix F.3, in which it can be seen that the maximum displacement does not exceed the maximum allowable value.

The roof tile elements are working as plates that are stiffened by ribs. In each roof tile element, the plate-part is modelled as a separate 2D-plate element with a height of 500 mm and the rib-part as 1D rib element with a height of 700 mm. The rib plates at the beginning of the jetty are modelled as 1D-bar elements with a height of 700 mm and a width of 2000 mm. In the reference jetty model, the rib-plates are modelled as ribs. This is however not possible in the reusable jetty model, as the rib-parts and plate-parts are given different boundary conditions. The elements, cross-sections and layout of the model are given in Appendix D.3. This modelling change is not expected to raise large problems, because the rigidly connected variant shown in Appendix F.1 shows only little variation from the reference model.

Of each connection type, as shown in Figure 4.4, the simplest connection is searched while keeping the robustness of the structure. All connections are modelled, which are the rib-part to rib-part, plate-part to plate-part and back side to front side connections. The results are displayed in Appendix F.1, in which the influence of simplifying each connection is shown. In the final simplest solution, the rib-part is modelled as a shear connection with a hinge on the end of the ribs that is free in x- and y-direction and in all rotations. The deck-part to deck-part is modelled free from each other, by obtaining no connection between the plate elements. The back side to front side connection is modelled by a spring along the plate edge that allows all rotations and translations in x- and y-direction, creating a hinged connection. The model is displayed in Figure 4.5.

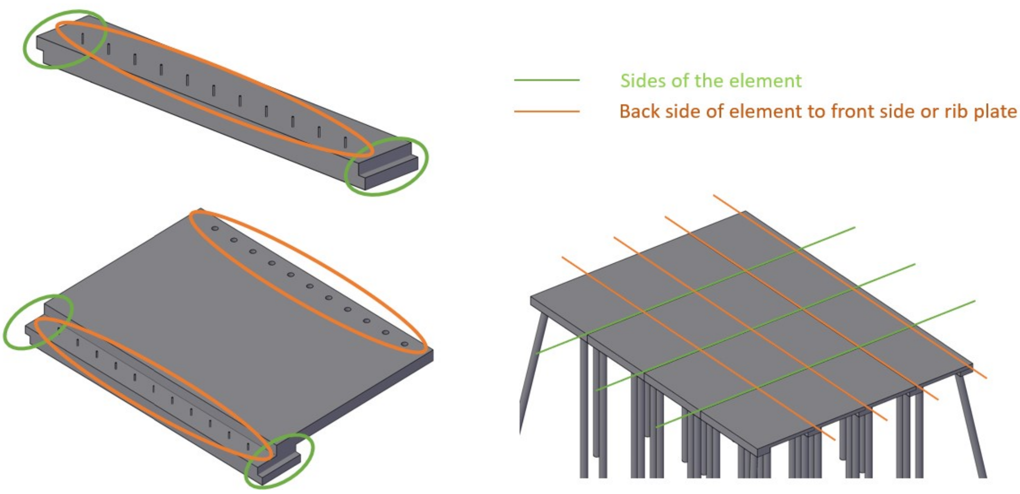



**Figure 4.4:** Connection types in variant 3

It is checked if the shear and hinged connections that are found can also be made without transferring a vertical upward force. This means that the force in the vertical direction could be carried by simply resting the edge on another piece. By doing this, the vertical movement of the element is restricted in the downward direction, while the upward direction is free. The most apparent method to check this is with a modelling configuration. However, due to restraints in the modelling software, this is a complicated modelling task. For simplicity, it is chosen to examine this possibility by hand calculations. As large moments occur in different parts of the structure, it is expected that tension resistance in the hinged connections is critical. The upward forces are compared to the weight of the roof tile element. If it is possible to not restrict upward movement, the upward forces should be lower than the weight of the element. As can be seen in Equation 4.1, this is not the case for the hinged connection, thus movements in the upward direction should be restricted in this connection. At the shear connection, this upward shear force can be compensated by the weight of the element. Therefore, no connectors are needed that resist the upward loads.

$$
\begin{aligned}
&V_{Rd,down} = mg = 1626.01\ kN \\
&V_{Ed,up,hinge} = 1698\ kN \\
&V_{Ed,up,shear} = 693\ kN \\
&UC_{hinge} = \frac{V_{Ed,up,hinge}}{V_{Rd,down}} = 1.04 \geq 1.0 \\
&UC_{shear} = \frac{V_{Ed,up,shear}}{V_{Rd,down}} = 0.43 \leq 1.0
\end{aligned}
\tag{4.1}
$$

In which,

$m$ mass of the roof tile element $m = V \cdot \gamma_c = 12(2 \cdot 0.7 + 8.25 \cdot 0.5) \cdot \gamma_c = 165.75 \cdot 10^3\ kg$;
$g$ gravitational acceleration $g = 9.81\ m/s^2$;
$\gamma_c$ Volumetric weight of concrete (Table C.1).

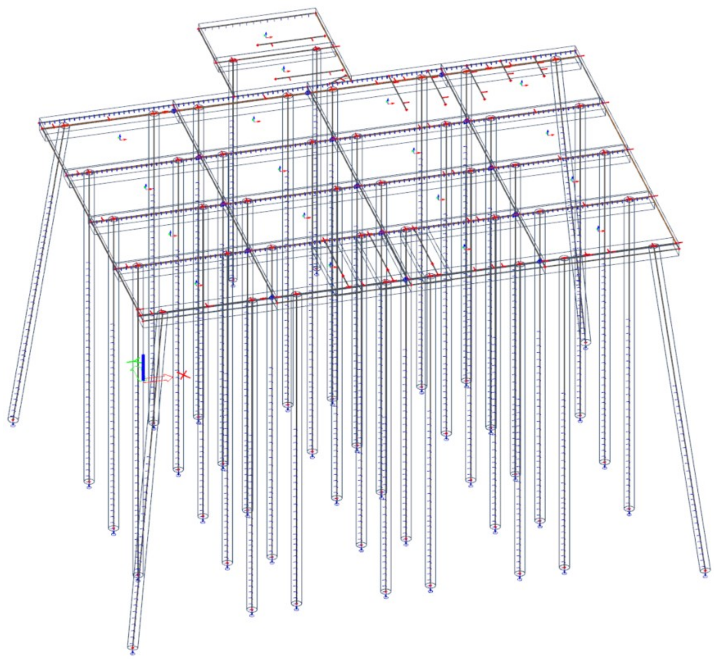
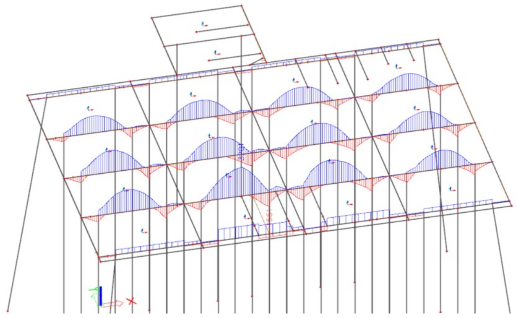


**Figure 4.5:** Overview of model reusable jetty

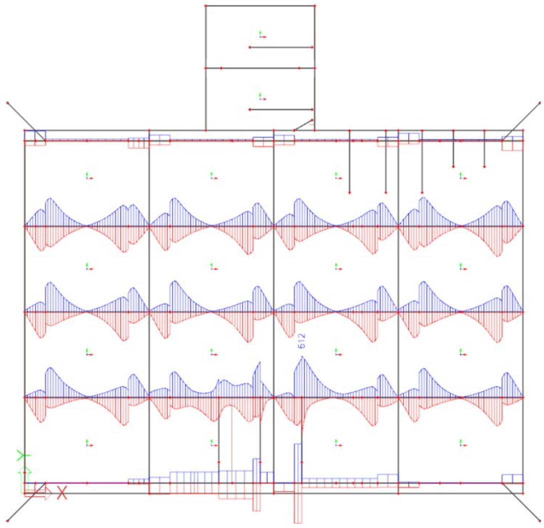
### 4.3.1. Ultimate limit state

The stresses and forces in the structure are found in the Ultimate Limit State (ULS). The internal forces that are found in the rib-parts of the reusable jetty are shown in Figure 4.6. As can be seen, all forces except the shear load in z-direction ($V_z$) are zero at the shear connections. The normal forces ($N$) are the largest in the middle of each span between the shear connections. The moments ($M_x$, $M_y$, $M_z$) are largest above the piles and in the middle of the span. In the shapes of the moment lines, clearly hogging and sagging bending moments can be seen. All forces and moments are largest at the places where the MLA support plates are connected to the rib-parts, due to the large loads that are implied by the MLA's.

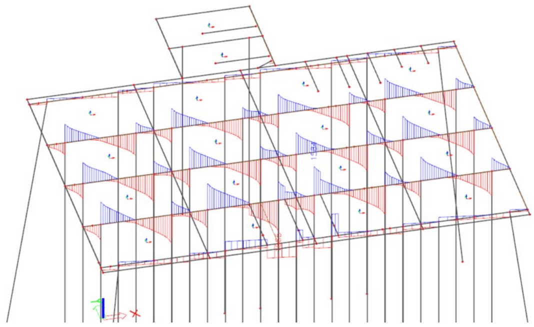
The forces in the rib-parts of the reusable jetty are comparable in shape and magnitude to those of the reference jetty given in Figure 3.4. They are compared in Figure 4.7. A considerable difference is that the maximum normal force has increased, leading to higher tension forces in the elements, which will require more reinforcement. Also, the maximum moment in y- and z-direction have decreased. The decrease in moments is found at the position of the MLA's, at which significantly smaller peak forces are found. The governing shear forces that are found in the rib plate to rib plate connections are given in Appendix F.5.



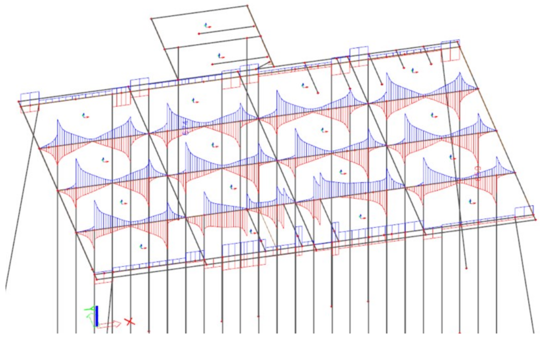
**(a)** Normal force



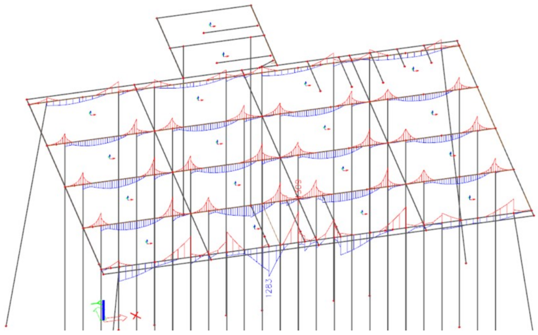
**(b)** Shear force in y-direction



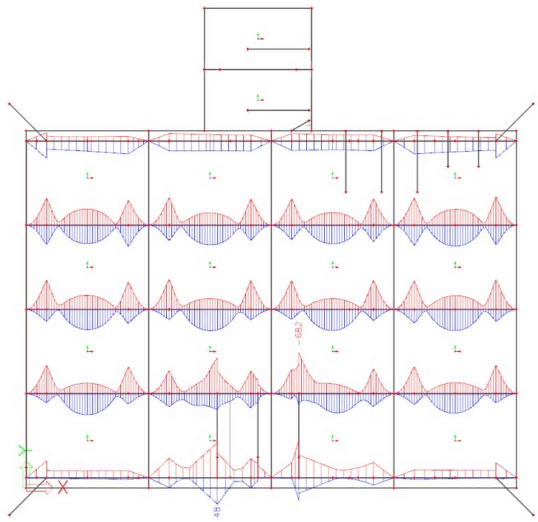
**(c)** Shear force in z-direction



**(d)** Moment in x-direction



**(e)** Moment in y-direction



**(f)** Moment in z-direction

**Figure 4.6:** Internal forces in rib plates of reusable jetty

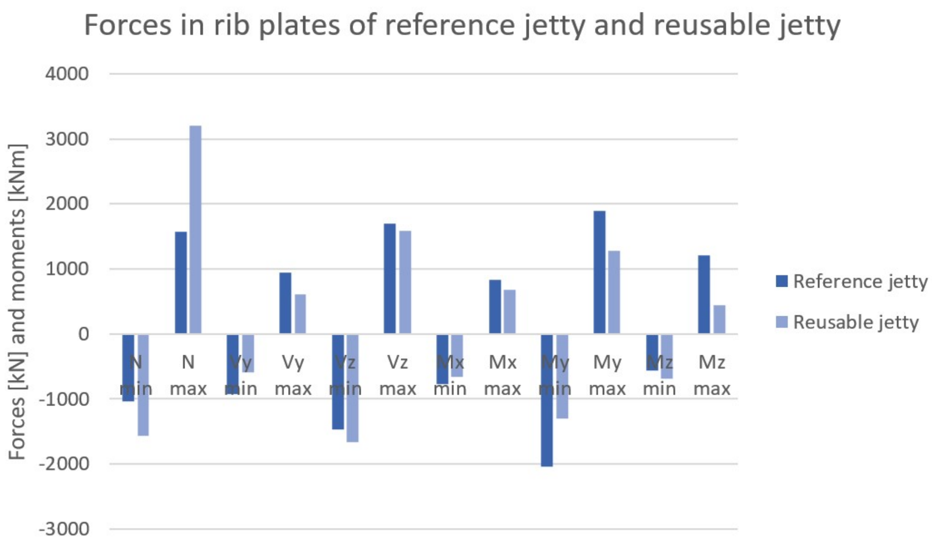
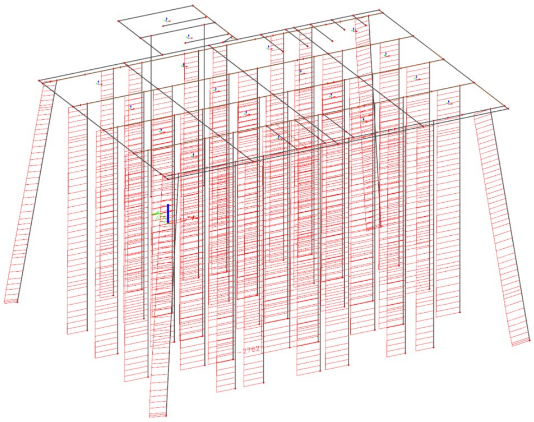


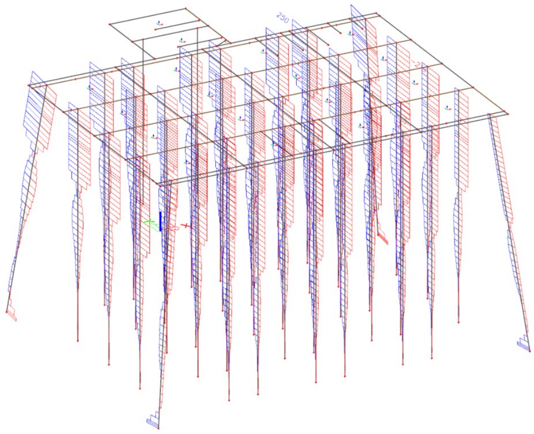

**Figure 4.7:** Forces in rib plates of reference jetty and reusable jetty

The results of the extreme internal forces in the piles are shown in Figure 4.8. The normal force is almost constant, as only the self-weight of the piles are contributing to this over the depth. All the loads from the deck are implied on the top of the piles. Due to this, the shear forces are highest at the top of the piles and are constant for the part above the soil. In the soil, that is modelled with springs, the shear forces start decreasing until zero at the bottom of the piles. Moments are also largest at the top and decrease to zero at the bottom of the piles.

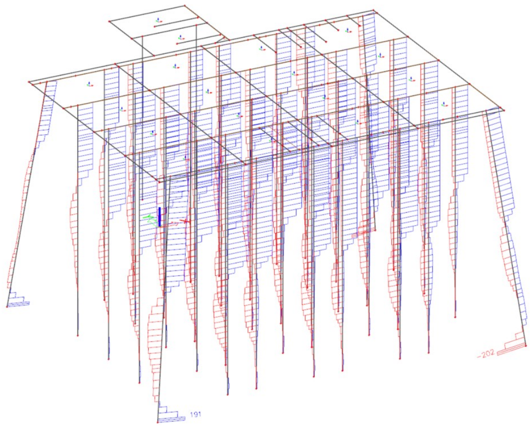
In shape and in magnitude, the results are highly comparable to that of the reference jetty as shown in Figure 4.9. It can be seen that the forces in the piles of the reusable jetty are a little smaller compared to the reference jetty, which is an expected result due to the row of piles that is added. Also, the governing forces in the rib plate to pile connections, shown in Appendix F.5, are similar.



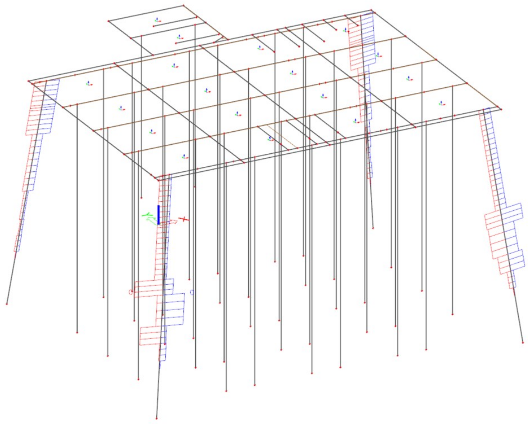
**(a)** Normal force



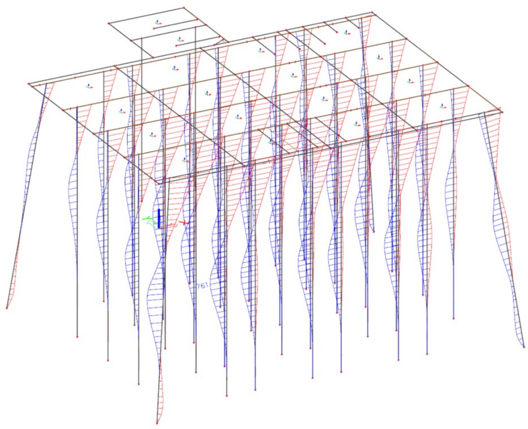
**(b)** Shear force in y-direction



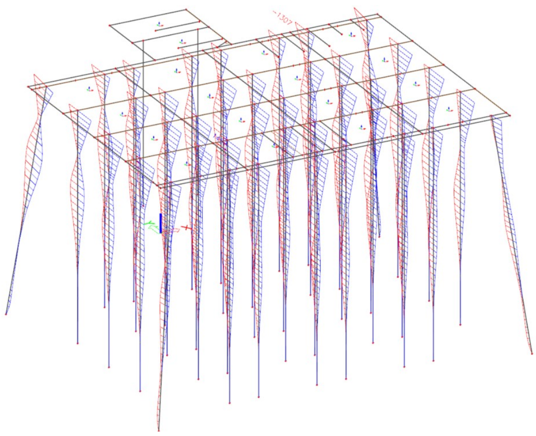
**(c)** Shear force in z-direction



**(d)** Moment in x-direction



**(e)** Moment in y-direction



**(f)** Moment in z-direction

**Figure 4.8:** Internal forces in piles of reusable jetty

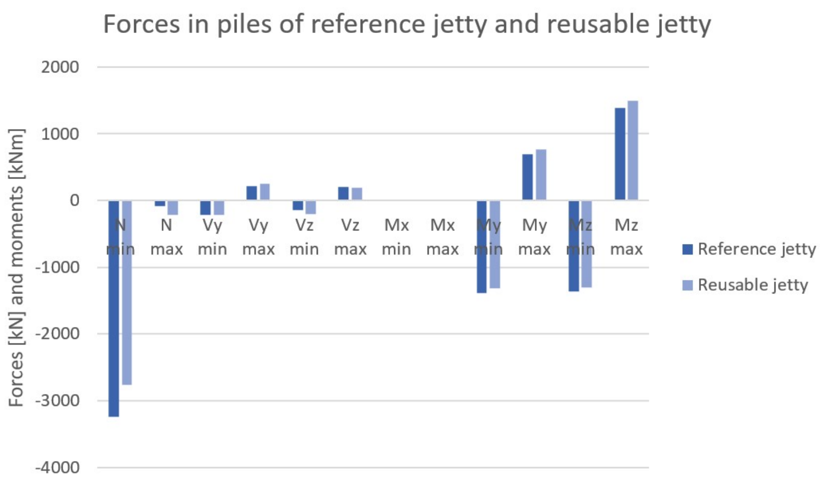
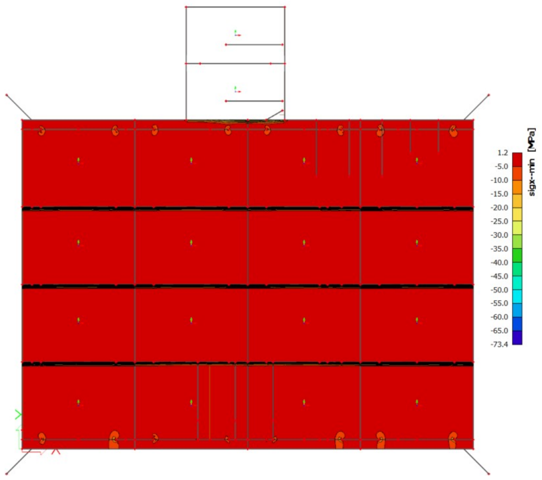
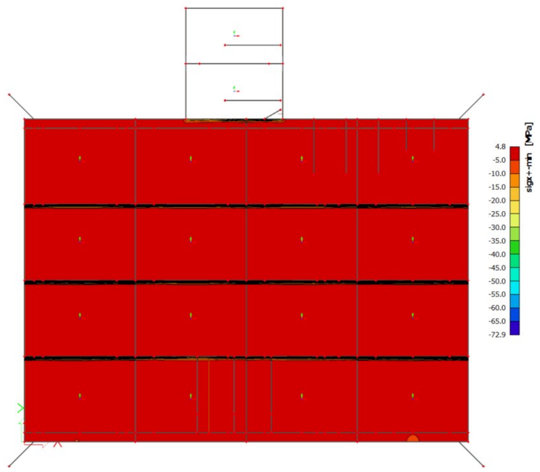



**Figure 4.9:** Forces in piles of reference jetty and reusable jetty

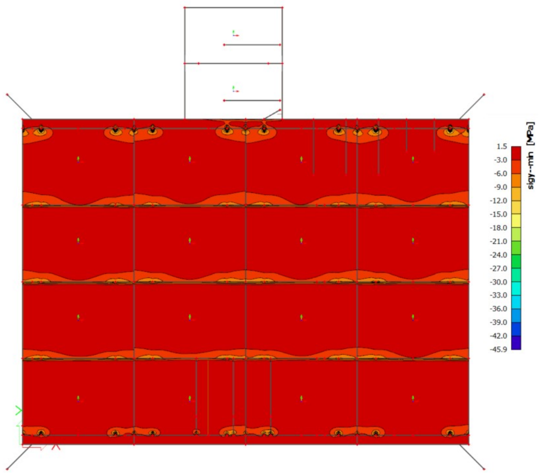
The stresses in the plate elements that are found are displayed in Figure 4.10 and 4.11. Large stresses are found in the connection with the piles and along the hinged connections. Only in the y-face, stresses are also found to be larger in the span between the rib plates. Overall, the stresses in the elements are larger than in the reference variant as can be seen in Figure 4.12. However, they are found in the same positions, which are in the rib-parts and where the piles are connected to the rib-parts. The larger stresses can be explained by the difference in modelling elements used for the rib-parts. In the reference jetty, this is modelled as a rib, which covers a width and thus increases the stiffness of the plate over a certain area of the plate. Here, a 1D-bar element is used, which does not cover a width and thus leads to a very sudden increase in stiffness. In reality, these stresses are expected to be lower. Furthermore, the increased stresses are only found in the connections. The connections are calculated in Chapter 5 and the forces that these calculations are based on are taken from this model, which are found to be realistic to transfer in DfD connections. The higher stresses in the elements should be considered in the final design, possibly leading to other detailing or element properties needed. In the plate-part of the elements, which is the span between the rib-parts, the stresses are highly comparable to that of the reference jetty. In the reference jetty, extreme stresses of 6.0 MPa were found in the span, for the reusable jetty this increases to 10.0 MPa.



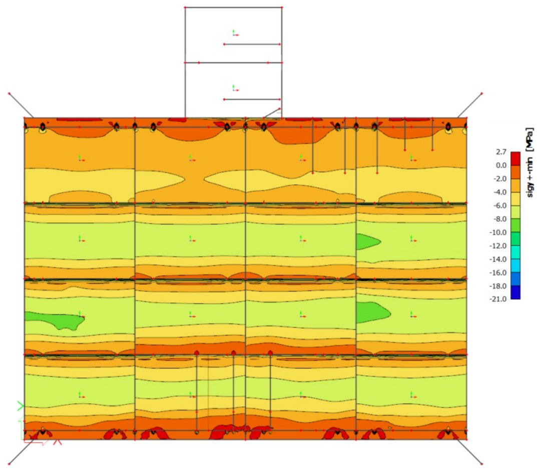
**(a)** Stress on negative face x



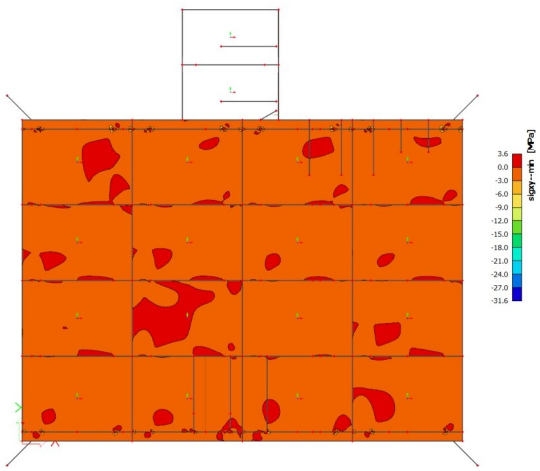
**(b)** Stress on positive face x



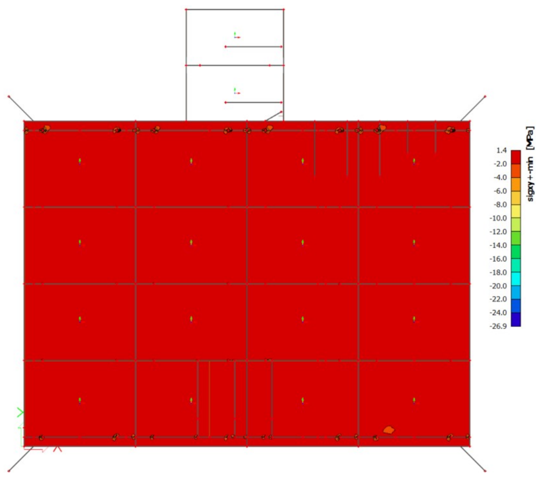
**(c)** Stress on negative face y



**(d)** Stress on positive face y

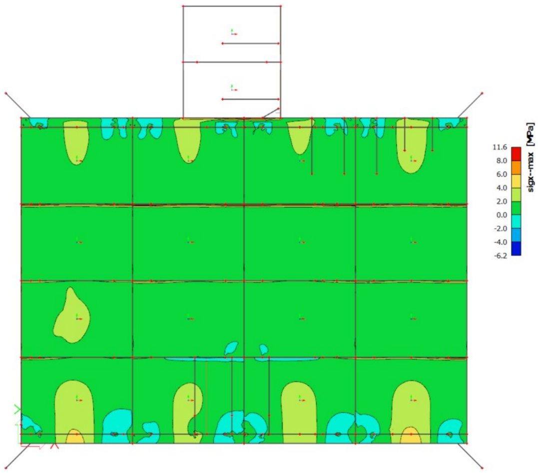


**(e)** Stress on negative face xy

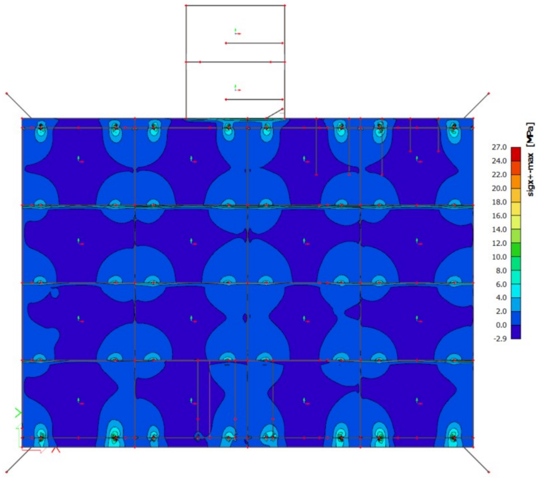


**(f)** Stress on positive face xy

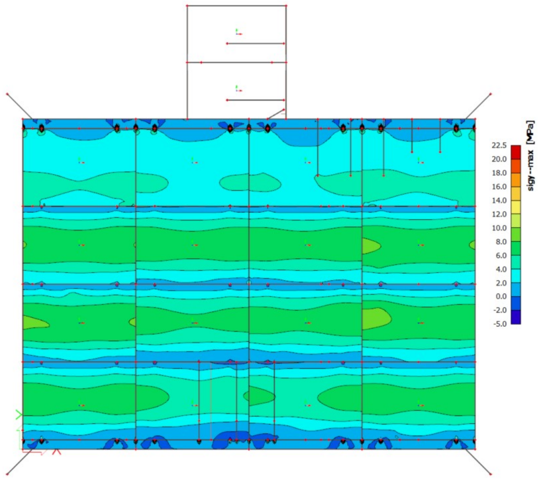
**Figure 4.10:** Extreme negative stresses in faces of reusable jetty deck



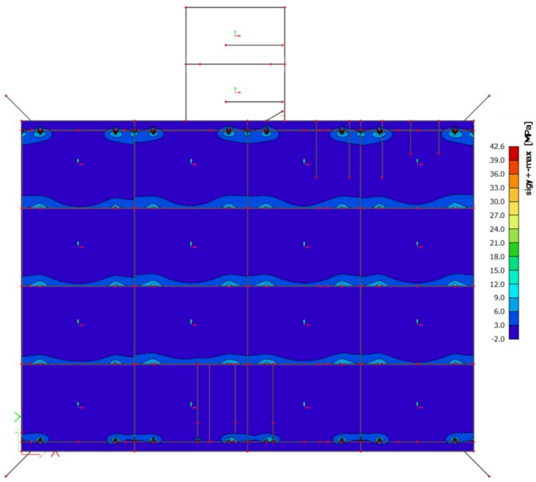
**(a)** Stress on negative face x



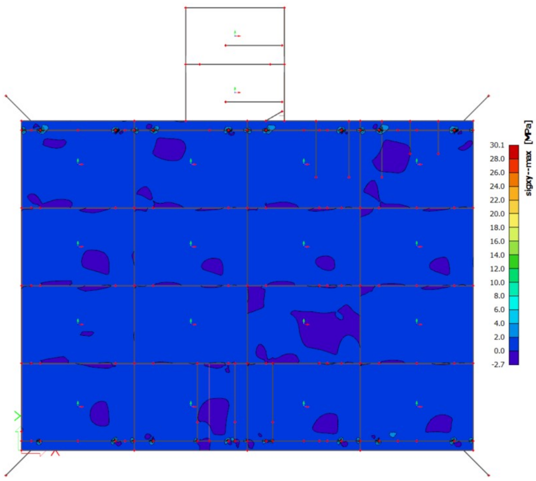
**(b)** Stress on positive face x



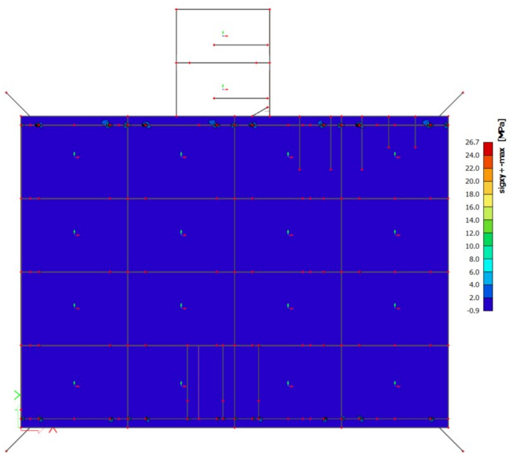
**(c)** Stress on negative face y



**(d)** Stress on positive face y



**(e)** Stress on negative face xy



**(f)** Stress on positive face xy

**Figure 4.11:** Extreme positive stress in faces of reusable jetty deck

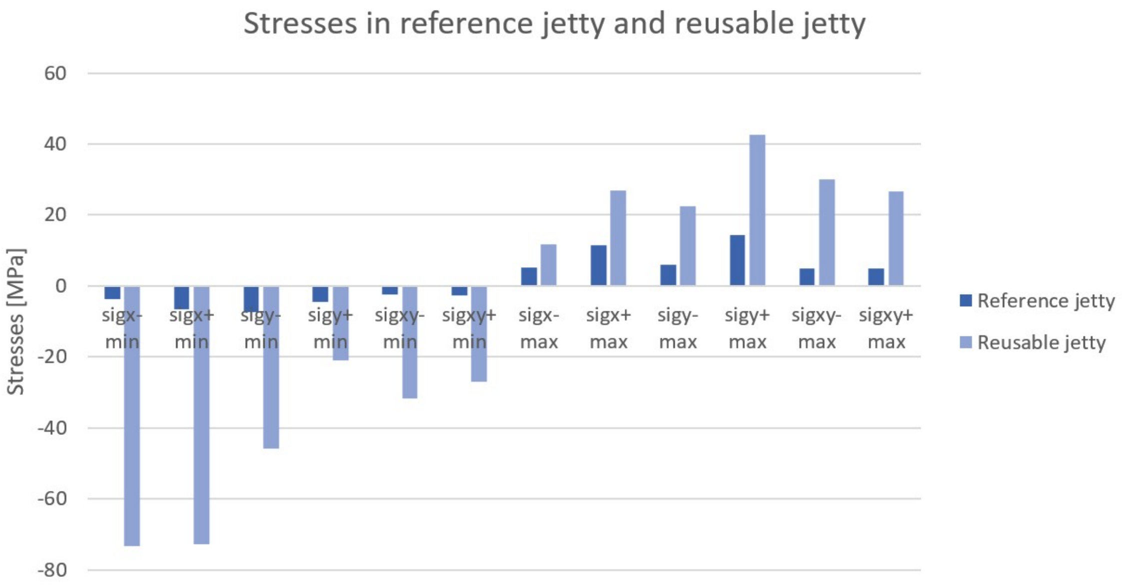
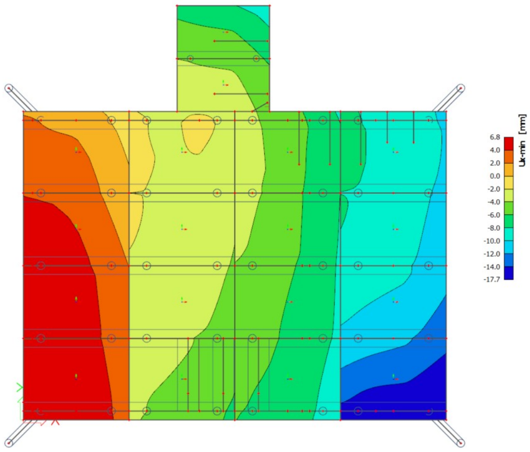


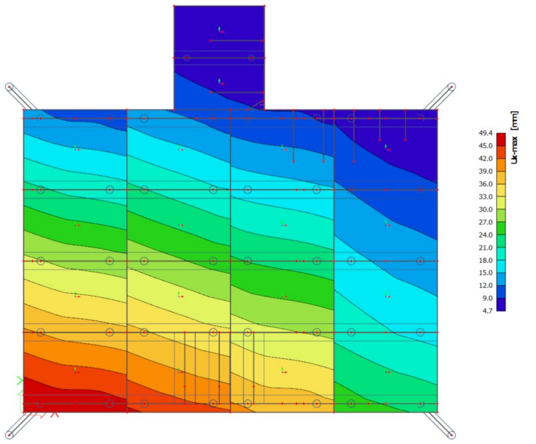

**Figure 4.12:** Stresses in reference jetty and reusable jetty

### 4.3.2. Serviceability limit state

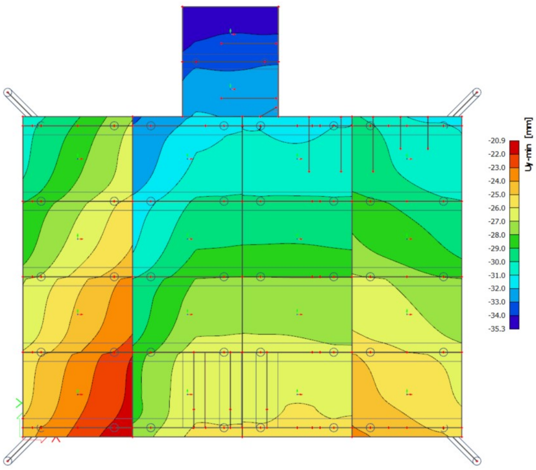
The maximum displacements that are found in the Serviceability Limit State (SLS) that are a result of the calculation of the model are shown in Figure 4.13. A maximum horizontal displacement of 49.4 mm is found, which is well within the limit given by PoR of 100 mm. This displacement is found in the positive x-direction. The magnitudes of the maximum displacements are comparable to that of the reference jetty, as can be seen in Figure 4.14. In the vertical direction, the shapes of the maximum displacements are comparable to the shapes of the maximum displacements in the reference jetty, given in Figure 3.8, which can be expected as all vertical movements are still restraint in the connections. Only between the plate-parts of the elements, there is no vertical restraint, as a shear connection is made here. For the horizontal displacements, a notable difference is that the displacement lines are curved, indicating rotations of the elements. The shear connections between the elements only transfer a vertical force. Due to this, in the displacements between those elements in x- and y-direction, discontinuities in displacement because of slip can be seen. Discontinuities up to 2.0 mm are found along all the vertical element edges. Larger discontinuities of maximally 11.0 mm occur rarely, but are found close to the Fire Monitor (FM) and left of the Marine Loading Arms (MLA's). The position of the FM and MLA's is shown in Appendix C.1. This is expected, as in Figure 4.6 it can be seen that the forces are very high in the elements where the MLA's are placed and are smaller in the other elements. In the horizontal lines between the elements, hinged connections are made, due to which no jumps in the displacements are seen. Due to this, the system displaces per four elements, which are connected by the hinged connections. The largest slip occurs in the displacements in the positive and negative y-direction, for which a zoomed-in analysis is done below.



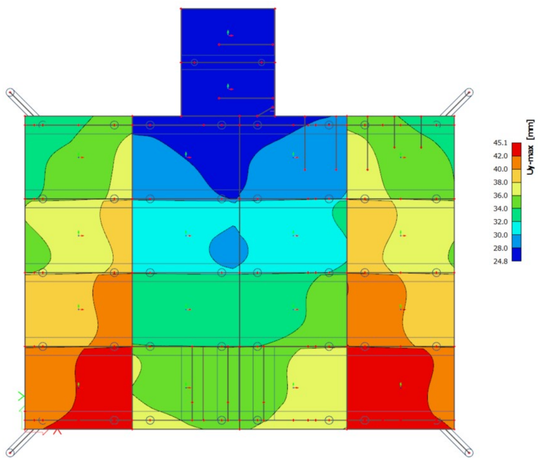
**(a)** Displacement in negative x-direction



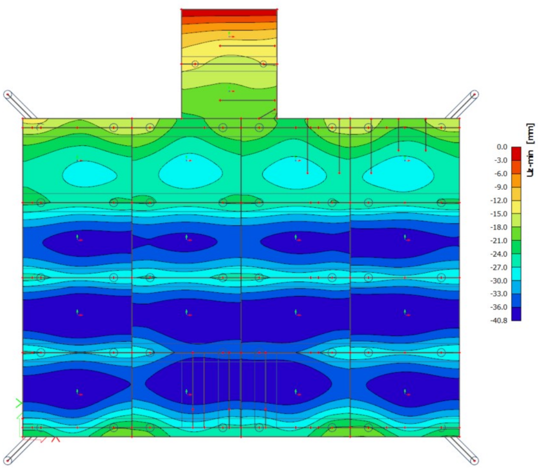
**(b)** Displacement in positive x-direction



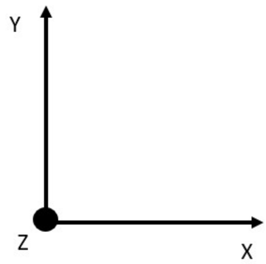
**(c)** Displacement in negative y-direction



**(d)** Displacement in positive y-direction



**(e)** Displacement in z-direction




**(f)** Directions of displacements

**Figure 4.13:** Extreme displacement of reusable jetty deck

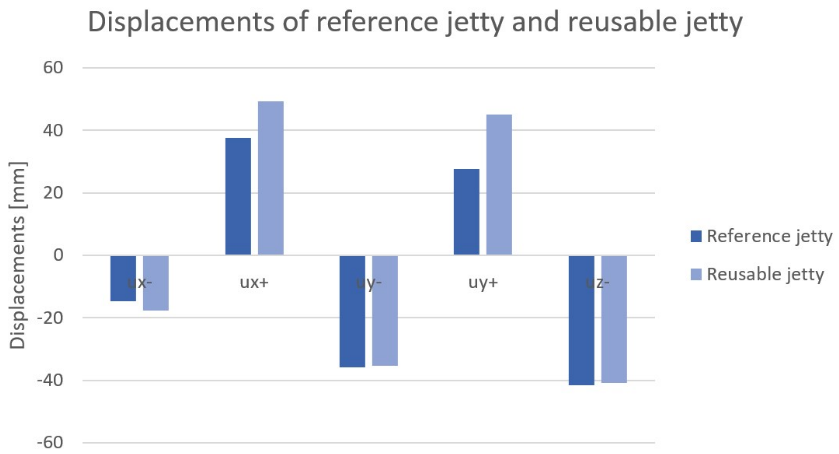
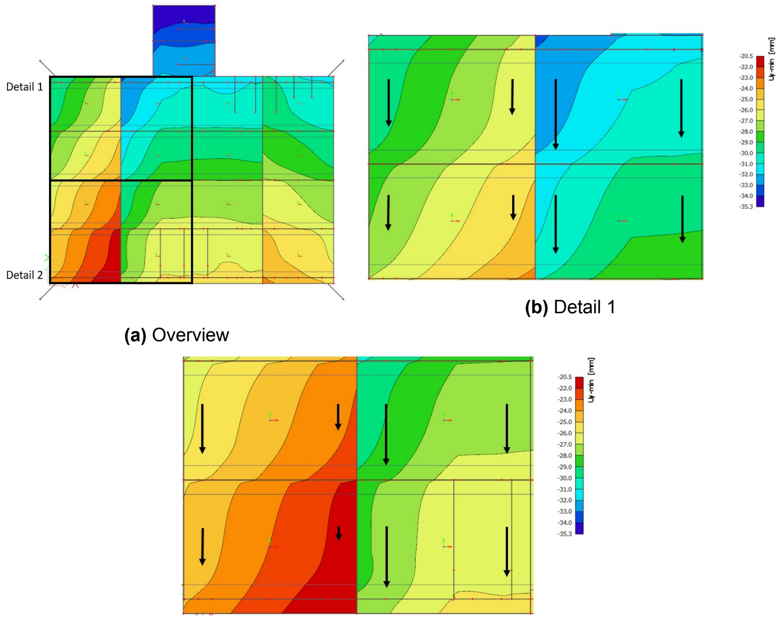



**Figure 4.14:** Extreme displacements of reference jetty and reusable jetty

In Figure 4.15, the detailed displacements in the negative y-direction are shown. The arrows indicate the displacement at the side of the element, in which a larger size arrow represents a larger displacement. As discussed above, there is movement between the elements at the shear connections, which is structurally acceptable. However, it may have consequences for the use of the structure and it makes the elements prone to wear and tear. Furthermore, gaps in the displacements between the elements raise additional challenges for making the deck liquid-tight. The horizontal slip in the shear connection that is seen in the structure limits possibilities for placing the superstructure. Equipment such as piperacks and cranes cannot overlap the discontinuities if those are large, as they will start acting as a structural element. This means they are bound to be placed between the discontinuities. In the reusable jetty, this is not yet causing problems, as non of the elements that are placed overlap multiple columns. However, flexibility in placing them is lost. Furthermore, pipelines are placed on top of piperacks and will inevitably cross discontinuities. It is expected that the pipelines can allow some deformations, as they are fixed and able to slide somewhat. However, their exact behaviour is unknown. This should be presented to the operator, so that more accurate estimations can be made. Further study should be done on the impact of the discontinuities in displacement on the superstructure, to find if this extra measure is needed. As initially it is not expected that this will cause significant problems, the simplest connection is considered further. A method to limit the discontinuities because of slip is discussed in Section 4.3.3.

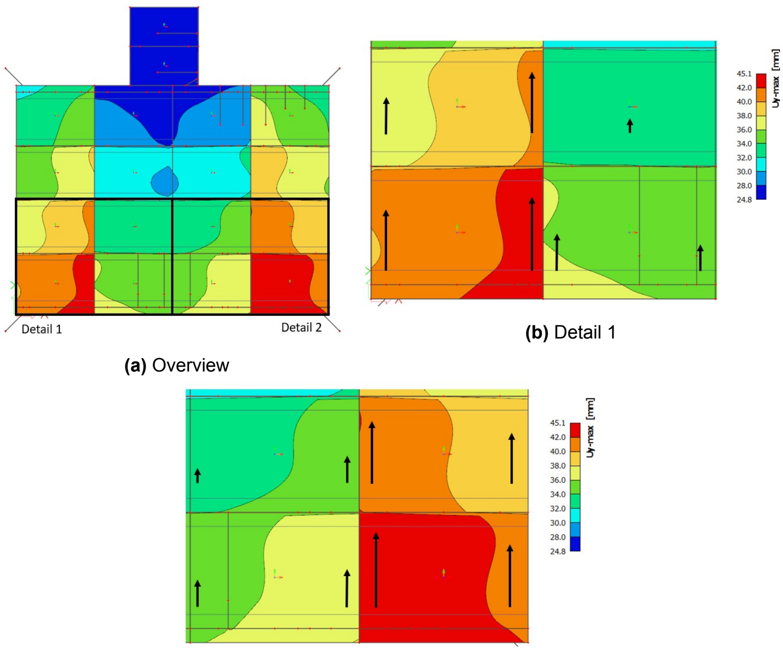
Along the hinged connection, the displacement line is suddenly very steep. This is a result of the rib-part of the plate that is modelled as a 1D bar element, locally increasing the stiffness of the element. In reality, the rib-part will cover a width, due to which is expected that this line will be less steep.

Both the phenomena of rotations and a steep displacement line can also be seen in the displacements in the positive y-direction, as displayed in Figure 4.16. The maximum discontinuity in displacements occurs in this direction and has a magnitude of 11.0 mm. This jump happens only in one part in Detail 1. More common are discontinuities up to 9.0 mm.




**(a)** Overview **(b)** Detail 1 **(c)** Detail 2

**Figure 4.15:** Displacement in negative y-direction of reusable jetty deck




**(a)** Overview **(b)** Detail 1 **(c)** Detail 2

**Figure 4.16:** Displacement in positive y-direction of reusable jetty deck

### 4.3.3. Mitigating discontinuities

By enabling horizontal displacements, the shear connection allows for discontinuity in the displacement. This has consequences for the superstructure, which might be unacceptable for the client. The slip can be mitigated by adding a horizontal connection in the shear connection, such as with an anchor bolt connection, as shown in Figure 5.3 and an overview is presented in Figure 4.17. What was previously a shear connection can now be classified as a hinged connection.

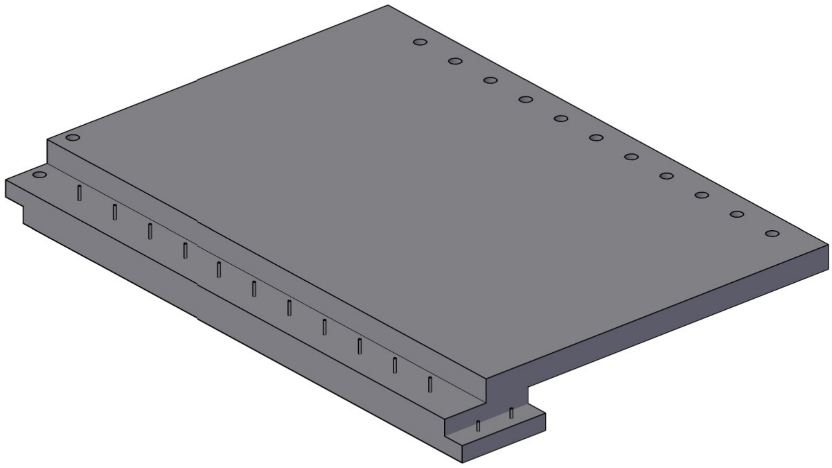


**Figure 4.17:** Example of anchor bolts in shear connection

This connection also implies placement tolerances in the shear connection, as the plate will have to connected at the back side and at the shear connection when placing, which both connect to a different previously placed element. This might cause the minimally acceptable tolerances of the connections to increase. To allow for this, the removable layer between the bolt and the concrete should not be a grout, but a reinforced resin. This material, as shown in Figure 4.18, can obtain very high strength and stiffness. The steel reinforcement particles transfer load through direct contact and reduce the amount of resin needed, which is economic. The resin fills the volume between the steel particles, prevents them from degradation and moving and provides initial stiffness. When using this as a filling material, the characteristics of the resin will not limit the possible gap size, so that large placement tolerances can be used [46]. This connection is not calculated in this configuration.

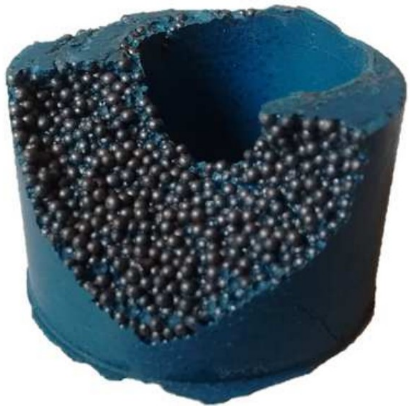
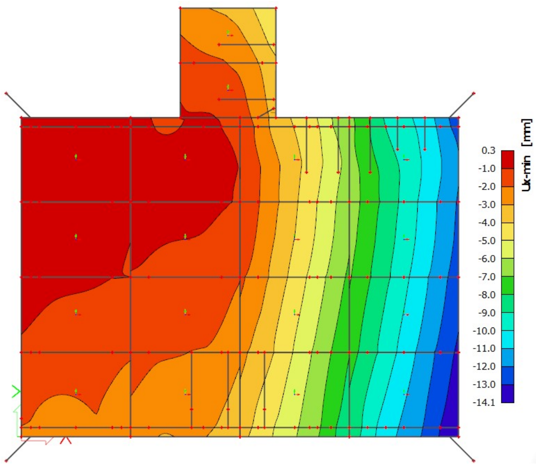
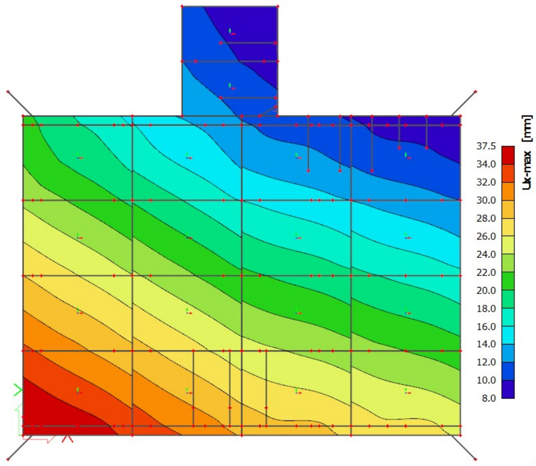


**Figure 4.18:** Reinforced resin

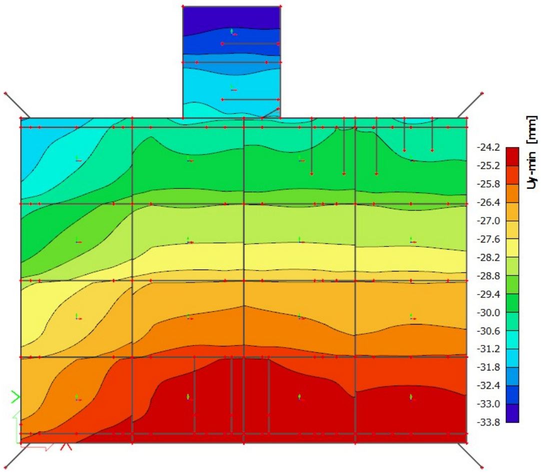
To create an overview of the result of adding connectors to the shear connection, the model that is discussed in Section 3.4 is used. In this model, only the interface conditions between the rib-parts of the elements, thus between the 1D bar elements, are changed. For this analysis, not only displacements in the z-direction are restrained, but also in x- and y-direction. The results are presented in Figure 4.19. The maximum displacement is 41.3 mm in this configuration. The locations of the minimum and maximum displacements and the shape of the displacement lines are similar to that of the variant with shear connections. It can be seen that in the location of the considered connection, namely in the corner of each element, no discontinuities are seen. This is in agreement with the interface conditions. Some discontinuities in displacements can still be found between elements in the span between the rib-parts, as in this place the plate-parts are not connected. However, those are mitigated and have a maximum magnitude of only 2.0 mm, which occur only in the positive x-direction and are rare. Discontinuities of 1.0 mm are also found in other directions and occur in more places.



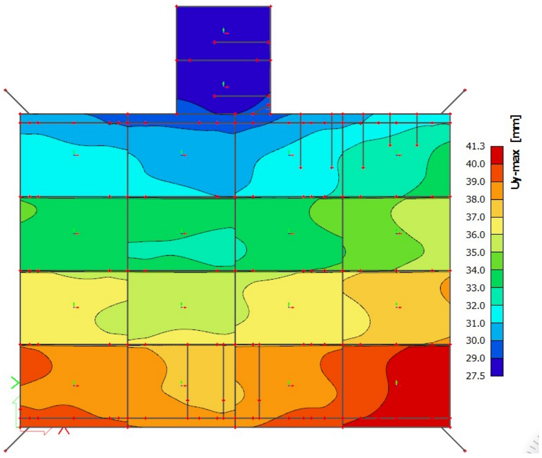

**(a)** Displacement in negative x-direction



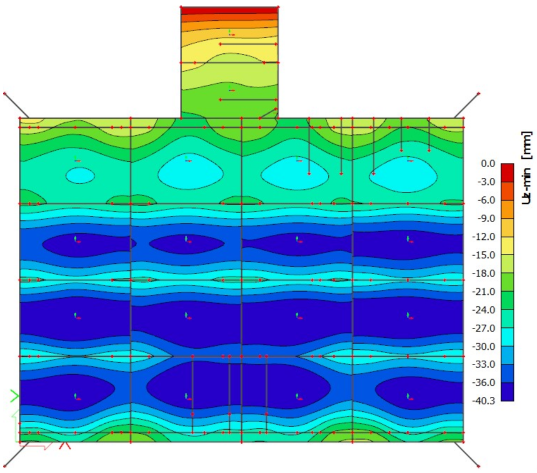

**(b)** Displacement in positive x-direction



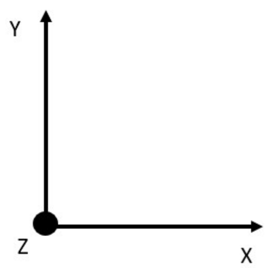

**(c)** Displacement in negative y-direction




**(d)** Displacement in positive y-direction




**(e)** Displacement in z-direction




**(f)** Directions of displacements

**Figure 4.19:** Extreme displacement of reusable jetty deck

# 5

# Design of demountable connections

In this chapter, the connections are elaborated. The approach is described in Section 5.1. The dry simple connection between the rib-parts of the elements is described in Section 5.2 and the semi-dry hinged connection between the plate-part and rib-part in Section 5.3. For the connections, their resistance is checked and the practical aspects of assembly and maintenance are considered.

## 5.1. Approach

The reusable jetty has two different connections in the concrete deck that have to be designed: The shear rib-part to rib-part connection and the hinged back side of the element to the front side of the element connection, as shown in Figure 4.4. The plate-part to plate-part connection is not designed, as no interaction exists between these parts. For each connection, it is proven if the concept is technically feasible for the forces that are found in Chapter 4. Preliminary calculations are included. Before implementing the connections, detailed calculations should be done.

Next to the technical feasibility, it is discussed in each category if the connection is practically feasible, considering the assembly procedure and maintenance. Knowledge of maintenance of structures is experience-based. Therefore, Marc Wormmeester is interviewed (Appendix A) on the maintenance challenges of the connections and the design variants. His expert judgement is taken into account when assessing the practical feasibility of the connections.

Next to the simple connections, also rigid connection solutions were proposed. Those are found to be unfeasible, as is elaborated in Appendix E.3 and E.4.

## 5.2. Dry simple connection

Dry simple connections can be made when concrete parts may support each other, by which displacements are restrained in either only a negative or positive vertical direction. This connection is applied in the rib-part to rib-part connection.

As shown in Section 4.3, the rib plate to rib plate connection is only subjected to a vertical shear force and as proven in Equation 4.1, this shear force only needs to be transferred in one vertical direction. Therefore, a familiar dry shear connection can be suggested for this. This connection is found in literature, as discussed in Section 2.1.2. The connection is made by creating dapped ends in the rib plates. This forms nibs so that they can rest on each other while the total height at the connection is similar to the height of the rib plates. This principle is shown in Figure 2.4 and 5.1. Between the nibs, bearing pads are used to enable movement and to avoid damage.

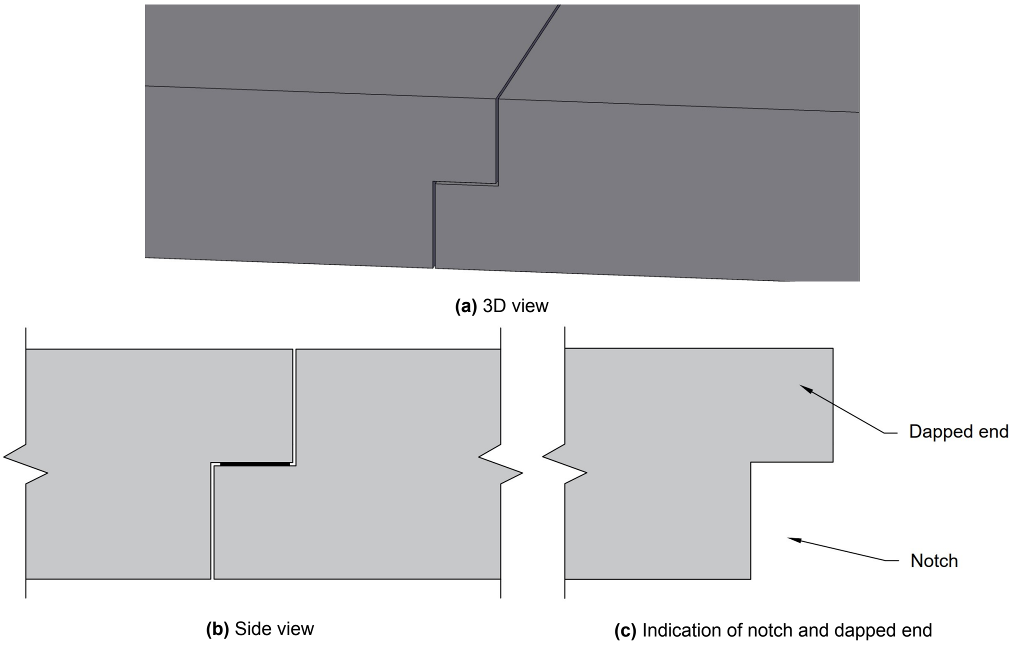



**Figure 5.1:** Shear rib plate to rib plate connection

By creating the notch in the rib plate end, the cross-section of the rib plate suddenly changes. This causes a non-uniform stress distribution in the end region of the rib plate, creating a higher stress intensity near the re-entrant corner and in the nib. Due to this higher stress, additional reinforcement should be placed in the nib and near the re-entrant corner [28].

Calculations of a dapped end rib plate are taken into account in the Eurocode EN 1992-1-1. With the use of a strut-and-tie model, the reinforcement needed in the nibs and end region of the rib plate can be calculated. This is a method that requires extensive calculations. A more conservative but simpler method is the shear friction method or Precast Concrete Institute (PCI) method. To investigate if this connection is realistic, the simple and conservative calculations are shown below.

### 5.2.1. Calculations

The maximum design load in the shear rib plate to rib plate connection is shown in Table F.1 as has a magnitude of $V_{z,d} = 693\ kN$. By calculating the reinforcement in the nib, as shown in Figure 5.2, it can be estimated if this is a realistic load to be carried by a nib of this size. The result of the calculation will be the minimal reinforcement, which should be divided over the number of bearing pads or a bearing strip that will be placed over the 2 m width of the rib plate. For this preliminary calculation, the reinforcement is calculated over four bearing pads. The checks of the reinforcement are done below and are based on the dimensions given in Table 5.1. The calculations are done according to the PCI method, based on the crack patterns as shown in Figure 5.2 [29].

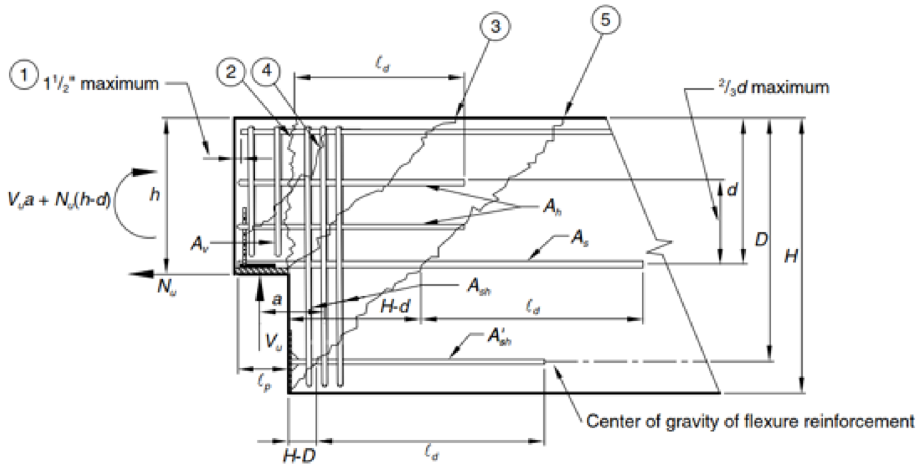



**Figure 5.2:** Reinforcement and crack formation in a dapped end connection [29]

**Table 5.1:** Dimensions of dapped end connection

| Description | Symbol | Relation | Value | Unit |
|---|---|---|---|---|
| Height of rib plate | $H$ | | 700 | $mm$ |
| Height of component above notch | $h$ | | 345 | $mm$ |
| Width of rib plate per bearing pad | $b$ | | 500 | $mm$ |
| Distance from top to center of reinforcement $A_s$ | $d$ | | 295 | $mm$ |
| Shear span | $a$ | | 252 | $mm$ |
| Characteristic strength of concrete | $f_{ck}$ | | 35 | $MPa$ |
| Characteristic yield strength of reinforcement | $f_{yk}$ | | 500 | $MPa$ |
| Number of longitudinal reinforcement bars | $n_s$ | | 1 | |
| Diameter of longitudinal reinforcement bars | $d_s$ | | 20 | $mm$ |
| Area of longitudinal reinforcement bars | $A_s$ | $\frac{1}{4}\pi d_s^2$ | 314.16 | $mm^2$ |
| Anchorage length longitudinal reinforcement bars | $l_{bd,s}$ | $H - d + 33d_s$ | 1065 | $mm$ |
| Number of shear friction reinforcement bars | $n_h$ | | 2 | |
| Diameter of shear friction reinforcement bars | $d_h$ | | 6 | $mm$ |
| Area of shear friction reinforcement bars | $A_h$ | $\frac{1}{4}\pi d_h^2$ | 28.27 | $mm^2$ |
| Anchorage length shear friction reinforcement bars | $l_{bd,h}$ | $33d_h$ | 198 | $mm$ |
| Number of hanger reinforcement bars | $n_{sh}$ | | 3 | |
| Diameter of hanger reinforcement bars | $d_{sh}$ | | 15 | $mm$ |
| Area of hanger reinforcement bars | $A_{sh}$ | $\frac{1}{4}\pi d_{sh}^2$ | 176.71 | $mm^2$ |
| Number of diagonal tension reinforcement bars | $n_v$ | | 2 | |
| Diameter of diagonal tension reinforcement bars | $d_v$ | | 15 | $mm$ |
| Area of diagonal tension reinforcement bars | $A_v$ | $\frac{1}{4}\pi d_v^2$ | 176.71 | $mm^2$ |

First, the sustained shear force portion ($V_u$) and normal force portion ($N_u$) are calculated. The sustained shear force portion is divided over the assumed number of bearings.

$$V_u = \frac{V_z}{4} = 173.25\ kN \qquad (5.1)$$
$$N_u = 0.2V_u = 34.65\ kN$$

The minimum required flexural reinforcement ($A_{s,min}$) is determined, in which $\phi = 0.75$ for flexure.

$$A_{s,min} = \frac{1}{\phi f_y}[V_u(\frac{a}{d}) + N_u(\frac{h}{d})] = 92.4\ mm^2 \qquad (5.2)$$

The required longitudinal reinforcement area due to direct shear ($A_{s,direct}$) is calculated. $\lambda$ is a material factor that is 1 for normal weight concrete, which leads to $\mu = 1.4\lambda = 1.4$

$$\mu_e = min\frac{\phi\lambda bh\mu}{V_u}; 3.4 = 3.4 \tag{5.3}$$

$$A_{s,direct} = \frac{2V_u}{3\phi f_y \mu_e} + \frac{N_u}{\phi f_{yk}} = 182.99\ mm^2 \tag{5.4}$$

This results in the total required longitudinal reinforcement area ($A_{s,req}$).

$$A_{s,req} = max(A_{s,min}; A_{s,direct}) = 182.99\ mm^2 \tag{5.5}$$

The required shear friction reinforcement area ($A_{h,req}$) and the required hanger reinforcement area ($A_{sh,req}$) are calculated.

$$A_{h,req} = 0.5(A_s - \frac{N_u}{\phi f_{yk}} = 45.29\ mm^2 \tag{5.6}$$

$$A_{sh,req} = \frac{V_u}{\phi f_{yk}} = 462.00\ mm^2 \tag{5.7}$$

The required diagonal tension reinforcement area ($A_{v,req}$) can be calculated based on the concrete capacity ($C$).

$$C = 2bd\lambda\sqrt{f_{ck}} = 1745.24\ N \tag{5.8}$$

$$A_{v,req} = \frac{1}{2f_{yk}}[\frac{V_u}{\phi} - C] = 229.26\ mm^2 \tag{5.9}$$

The unity checks are done below.

$$UC_s = \frac{A_{s,req}}{n_s A_s} = 0.58\ \leq\ 1.0 \tag{5.10}$$

$$UC_h = \frac{A_{h,req}}{n_h A_h} = 0.80\ \leq\ 1.0 \tag{5.11}$$

$$UC_{sh} = \frac{A_{sh,req}}{n_{sh} A_{sh}} = 0.87\ \leq\ 1.0 \tag{5.12}$$

$$UC_v = \frac{A_{v,req}}{n_v A_v} = 0.65\ \leq\ 1.0 \tag{5.13}$$

As can be seen, this connection type is realistic for the given loads and rib plate dimensions. More precise detailing and calculations on the bearing pad are needed before applying this connection type.

### 5.2.2. Assembly

The assembly of the dry simple connection is straightforward. In the prefabricated elements, the notches will be made and the additional reinforcement will be placed. The element with the dap on the bottom should be placed first, which should be taken into account when designing the elements. For all reusable design variants, this will mean that the rib plates or rib-parts of the elements will be put on the piles from one side and will be extended with elements until it covers the length. This would usually already be the case, as constructing from two sides towards the middle comes with additional challenges.

Between the elements, bearing pads should be placed. This is done before placing the second element, as they will cover some height and will be hard to reach in a later stage. A connection profile can be added to avoid damage caused by the elements moving relative to each other.

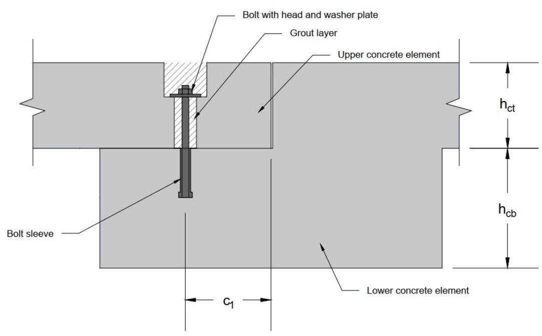
As this connection is very simple to execute, it is expected that no problems will arise in either of the reusable design variants.

### 5.2.3. Maintenance

The maintenance needed in this connection configuration is very similar to the maintenance that is usually done to concrete, as concluded by Wormmeester (Appendix A). Concrete is an easy to maintain material. This changes little with making a dry connection, as is suggested here, in the element. From experience with this type of connection, it is known that sometimes some concrete can break off of the corners of the daps. It is expected that this is due to design errors in the reinforcement, which should thus be carefully checked. A connection profile, for example made of rubber, will be needed to prevent the elements from clashing. This will need to be replaced approximately after ten years of use. There is abundant experience with the maintenance of connection profiles in marine structures.

## 5.3. Semi-dry hinged connection

For the connection between the back side of a roof tile element and the front side of the other element or of the rib plate, a hinged connection is made. This can be obtained with an anchor bolt, which can be made demountable and is included in the Eurocode [47]. The concept of this connection is shown in Figure 5.3, which is based on the suggestion found in literature given in Section 2.1.2. In the connection, an anchor bolt is used, which is anchored in a nut that is made in the bottom concrete element. This creates the possibility of post-installing the bolt, which will not be bonded to the concrete itself. A bolt sleeve is placed in the concrete, in which the bolt can be placed. This is chosen so that the anchor bolt can be replaced when this is needed in maintenance or when reusing the element. In the upper element, a shaft will be made through which the anchor bolt can go, after which a grout layer is poured that helps bear shear loads in the anchor bolt. On top, a nut connects the anchor bolt to the concrete element to withstand tensile forces and a washer plate can be added to allow a larger shaft width. This allows a larger placement tolerance. As the upper side of the top element has to be flat, the nut connection can be sunken to the desired depth. To protect the steel elements from the environment, a grout layer has to be applied. For the grout layer, it can be chosen to use cement or a reinforced epoxy resin [48]. In total, 11 anchor bolts will be placed on each side of the edge, due to which the bolts have a spacing of 1 m and an edge distance of 1 m on each side in x-direction. In the y-direction the bolts will be placed in the middle of the to be connected surface, resulting in an edge distance of 500 mm. This is indicated in Figure 5.3. The total amount of bolts that is used in the structure is 176, which is 11 per element.



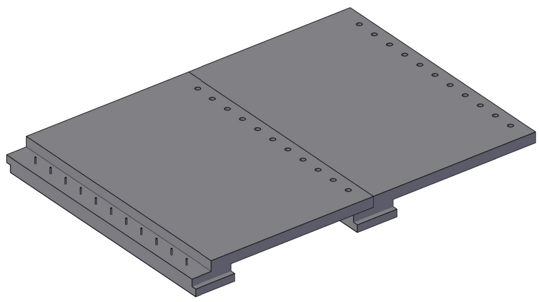



**Figure 5.3:** Anchor bolt concrete connection

### 5.3.1. Calculations

To see if this connection type is realistic to apply in this structure, it can be calculated according to the existing norms. The anchor bolts that are placed in the connection together take the tension force and shear force transferred by the connection. Those loads are given in Table 5.2. These loads are based on the extreme tensile forces in the connection. For these preliminary calculations, the possibility of using different bolts within one connection is not considered. Further detailed calculations will be needed to optimise the connection. The post-installed bolts that will be used are M39 10.9 bolts, of which the details are displayed in Appendix F.4. In total, 11 bolts will be placed on each element with a spacing of 1 m, as shown in Figure 5.3. Details of the design are given in Table 5.3.

**Table 5.2:** Governing loads on simple variant 3 hinged connections

| Load type | Symbol | Value | Unit |
|---|---|---|---|
| Design vertical tensile load | $n_{Ed}$ | $160$ | $kN/m$ |
| Design shear load | $v_{Ed}$ | $233.5$ | $kN/m$ |

**Table 5.3:** Details of hinged connection with anchor bolts

| Description | Symbol | Relation | Value | Unit |
|---|---|---|---|---|
| Bolt type | | | $M39\ 10.9$ | |
| Length of bolt | $l_b$ | | $600$ | $mm$ |
| Diameter of bolt | $d_b$ | | $39$ | $mm$ |
| Nominal diameter of the bolt over the length | $d_{nom}$ | $d_b$ (for uniform diameter) | $39$ | $mm$ |
| Yield strength of bolt | $f_{yk}$ | | $900$ | $N/mm^2$ |
| Ultimate strength of bolt | $f_{uk}$ | | $1000$ | $N/mm^2$ |
| Tensile stress area of bolt | $A_s$ | | $976$ | $mm^2$ |
| Diameter of nut | $d_{nut} = d_{head}$ | $\leq 6t_{nut} + d_b$ | $60$ | $mm$ |
| Thickness of nut | $t_{nut} = t_{head}$ | | $31$ | $mm$ |
| Diameter of washer plate | $d_{washer}$ | | $140$ | $mm$ |
| Thickness of washer plate | $t_{washer}$ | | $10$ | $mm$ |
| Effective embedment depth | $h_{ef}$ | | $300$ | $mm$ |
| Edge distance in y-direction | $c_1$ | | $500$ | $mm$ |
| Edge distance in x-direction | $c_2$ | | $1000$ | $mm$ |
| Spacing of bolts | $s_2$ | $\geq 4d_{nom}$ | $1000$ | $mm$ |
| Number of bolts per element | $n$ | | $11$ | |
| Characteristic edge distance | $c_{cr}$ | $1.5h_{ef}$ | $450$ | $mm$ |
| Characteristic spacing | $s_{cr}$ | $3h_{ef}$ | $900$ | $mm$ |
| Characteristic strength of concrete | $f_{ck}$ | | $35$ | $MPa$ |
| Height bottom element | $h_{cb}$ | | $700$ | $mm$ |
| Height top concrete element | $h_{ct}$ | | $500$ | $mm$ |

The anchor bolt has to be checked according to the norm EN1992-4 [49], which is done below. In the norm, nine failure mechanisms are distinguished to calculate, which are shown in Figure 5.4. Depending on the design, some failure mechanisms do not have to be checked, which are [49]:

- Combined pull-out failure and concrete failure of bonded fasteners does not need to be checked, as the fastener will not be bonded;
- Concrete splitting failure does not have to be taken into account, because $min(c_1; c_2) \geq c_c r$;
- Concrete blow-out failure will not need to be checked, because $c \leq 0.5h_{ef}$.

The remaining failure mechanisms are checked below. All calculations are done according to the Eurocode [49]. The safety factors that apply are the material factor for steel in tension ($\gamma_{Ms,tension} = 1.4$), steel in shear ($\gamma_{Ms,shear} = 1.5$), concrete in tension ($\gamma_{Mc,tension} = 1.5$) and concrete in shear ($\gamma_{Mc,shear} = 1.5$). Those are calculated in Appendix F.4.

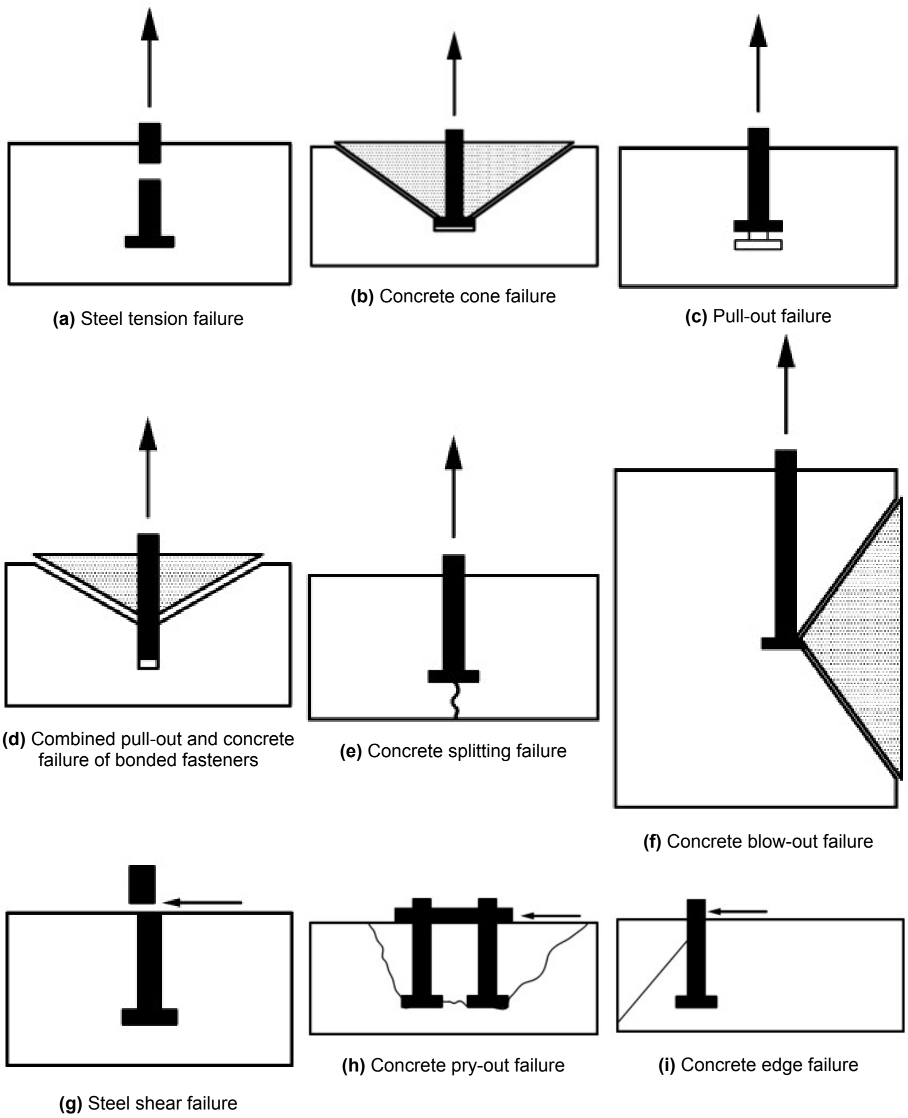



**Figure 5.4:** Failure mechanisms of anchor bolt [49]

**Tensile steel resistance**

The tensile steel resistance is calculated in Equation 5.14, in which $N_{Rk,s}$ is the characteristic tensile steel resistance and $N_{Rd,s}$ is the design tensile steel resistance of an individual bolt. All bolts are similar in properties, so only one is checked.

$$\begin{aligned} N_{Rk,s} &= A_s f_{uk} = 976.00\ kN \\ N_{Rd,s} &= \frac{N_{Rk,s}}{\gamma_{Ms,tension}} = 697.14\ kN \end{aligned} \tag{5.14}$$

**Concrete cone failure**

For the concrete cone failure, the characteristic resistance of a fastener is given by $N_{Rk,c}$, depending on the characteristic resistance of a fastener not influenced by adjacent fasteners or concrete edges ($N^0_{Rk,c}$), the geometry effect of axial spacing and edge distance ($A_{c,N}/A^0_{c,N}$) and the factors $\Psi_{s,N}$, $\Psi_{re,N}$, $\Psi_{ec,N}$, $\Psi_{M,N}$, taking into account the disturbance of the distribution of stresses in the concrete due to the proximity of an edge, the shell spalling, the group effect when different tension loads are acting on the fastener and effects of bending moments, respectively. Those are all calculated in Appendix F.4. With this, the design resistance of a fastener can be determined as given in Equation 5.15. For this failure mechanism, all fasteners can be considered individually because $s > s_{cr}$. As all fasteners are the same, only one has to be checked.

$$
\begin{aligned}
N_{Rk,c} &= N^0_{Rk,c} \frac{A_{c,N}}{A^0_{c,N}} \Psi_{s,N} \Psi_{re,N} \Psi_{ec,N} \Psi_{M,N} = 383.11\ kN \\
N_{Rd,c} &= \frac{N_{Rk,c}}{\gamma_{Mc,tension}} = 255.41\ kN
\end{aligned}
\tag{5.15}
$$

**Pull-out failure of fastener**

The pull-out failure is calculated in Equation 5.16, in which $A_h$ is the load bearing area of the head of the fastener, calculated in Appendix F.4, $N_{Rk,p}$ is the characteristic pull-out resistance of a single fastener and $N_{Rd,p}$ is the design pull-out resistance. This is calculated for one bolt, which can represent all bolts because their properties are the same.

$$
\begin{aligned}
N_{Rk,p} &= k_2 A_h f_{ck} = 428.62\ kN \\
N_{Rd,p} &= \frac{N_{Rk,p}}{\gamma_{Mc,tension}} = 285.75\ kN
\end{aligned}
\tag{5.16}
$$

**Steel shear failure**

The design steel shear resistance ($V_{Rd,s}$) is calculated in Equation 5.17. The characteristic steel shear resistance ($V_{Rk,s}$) is based on the characteristic resistance of a single fastener in case of steel shear failure ($V^0_{Rk,s}$), which is calculated in Appendix F.4. The fasteners in shear have to be considered as a group, because $s \leq 3c_1$. As for all bolts, the properties and spacing are the same, only one bolt has to be checked.

$$
\begin{aligned}
V_{Rk,s} &= k_7 A_s V^0_{Rk,s} = 488.00\ kN \\
V_{Rd,s} &= \frac{N_{Rk,p}}{\gamma_{Ms,shear}} = 325.33\ kN
\end{aligned}
\tag{5.17}
$$

**Concrete pry-out failure**

The design pry-out resistance of concrete ($V_{Rd,cp}$) is given in Equation 5.18, in which $V_{Rd,cp}$ is the characteristic concrete pry-out resistance and the factor $k_8 = 2.0$ for $h_{ef} \geq 60\ mm$. The pry-out has to be checked for the governing bolt, which in this case are all the bolts as they are similar in properties.

$$
\begin{aligned}
V_{Rk,cp} &= k_8 N_{Rk,c} = 766.22\ kN \\
V_{Rd,cp} &= \frac{N_{Rk,cp}}{\gamma_{Mc,shear}} = 510.81\ kN
\end{aligned}
\tag{5.18}
$$

**Concrete edge failure**

To calculate the design concrete edge resistance ($V_{Rd,c}$) in Equation 5.19, only the fasteners closest to the edge have to be checked, since those are governing. However, the fasteners will all act in a group for concrete edge failure, because $s_2 \geq 3c_1$. The characteristic resistance for the group of fasteners ($V_{Rk,c}$) is calculated with the initial value of the characteristic resistance of a fastener ($V^0_{Rk,c}$) and the ratio ($A_{c,V}/A^0_{c,V}$) taking into account the geometrical effect of spacing, edge distances and thickness of the concrete member. As the bolt acts in two members, the member with the smallest thickness is governing, which is the upper concrete member with $h_{ct}$. Furthermore, the characteristic resistance depends on the factors $\Psi_{s,V}$, $\Psi_{re,V}$, $\Psi_{ec,V}$, $\Psi_{h,V}$, $\Psi_{\alpha,V}$, taking into account the disturbance of the distribution of stresses in the concrete due to the further edges, the effect of the reinforcement located on the edge, the fact that the concrete edge resistance does not decrease proportionally to the member thickness and the influence of a shear load inclined to the edge, respectively. All those are calculated in Appendix F.4.

$$V_{Rk,c} = V^0_{Rk,c} \frac{A_{c,V}}{A^0_{c,V}} \Psi_{s,V} \Psi_{re,V} \Psi_{ec,V} \Psi_{\alpha,V} \Psi_{h,V} = 1214.35\ kN$$
$$V_{Rd,c} = \frac{N_{Rk,p}}{\gamma_{Mc,shear}} = 809.57\ kN \tag{5.19}$$

**Unity checks**
The unity checks are performed according to the norm. As can be seen in Equation 5.20, both the bolt and the concrete can take the loads, concluding that this connection is realistic in this application. As can be seen, the unity check for concrete in governing, in which the unity check for the tension force $(\frac{s_2 n_{Ed}}{min(N_{Rd,c};N_{Rd,cp})})^{1.5}$) is the largest.

$$UC_{steel} = (\frac{s_2 n_{Ed}}{N_{Rd,s}})^2 + (\frac{s_2 v_{Ed}}{V_{Rd,s}})^2 = 0.06 + 0.61 = 0.67 \leq 1.0$$
$$UC_{concrete} = (\frac{s_2 n_{Ed}}{min(N_{Rd,c};N_{Rd,cp})})^{1.5} + (\frac{s_2 v_{Ed}}{min(V_{Rd,c};V_{Rd,cp})})^{1.5} = 0.56 + 0.35 = 0.91 \leq 1.0 \tag{5.20}$$

## 5.3.2. Assembly

The simple semi-dry connection is mainly prefabricated, only a small part happens on site. In the prefabrication, the nuts have to be included in the rib-parts of the elements and in the rib plate and holes have to be made in the other connection parts. This is a familiar procedure and is thus not expected to be a challenge. When placing all elements in the correct sequence, each element can be connected to the previously placed one by fitting the holes over the bolts. It can also be chosen to first place the element and only install the bolts afterwards. When the elements are in place, the grout can be poured and a washer plate and nut can tighten the connection. Additional grout or plastic has to be added to close the top part of the steel in the connection off from the environment. There is no casting needed to put the grout in place, as this is simply filling a hole.

In this connection, an in situ grout layer is used to fill up the space between the shaft edge and the bolts, due to which the shaft can be made larger than the regularly used hole size. It is common to take around three times the regular hole diameter, which increases the placement tolerance [29]. The regular hole diameter for an M39 anchor bolt is 42 mm [49], which can now be increased to $42 \cdot 3 = 126\ mm$. The placement tolerance is the difference between the bolt diameter and the hole diameter, divided over 2 and over the number of elements that are connected. By using this hole size, the placement tolerance becomes $\frac{126-39}{2 \cdot 2} = 22\ mm$, which is a considerable tolerance compared to the other bolted solutions. It is still somewhat smaller than the tolerance of 50 mm that is used in the reference jetty, but it is expected that this tolerance is realistic.

## 5.3.3. Maintenance

As this connection closes the steel off from the environment, maintenance expert Wormmeester (Appendix A) does not expect any difficulties with the maintenance of this connection type. The maintenance will be as it is performed now, in which the concrete part needs little maintenance and the steel piles require more focus. Although steel is added to the design, this steel is completely protected and closed off from the environment, as is also the case with reinforcement steel in the concrete. Thereby, no additional maintenance is expected.

During the lifetime and when reusing, the anchor bolts should be inspected and if necessary replaced. This is possible due to the use of post-installed bolts. Also, the head and the washer plate can be replaced. Only the nut in the lower concrete element cannot be replaced, as it is bonded to the concrete. This raises no concerns, as this bolt will be entirely closed off from the environment by the use of a grout layer.

# 6 Applicability to other jetties

To make the design applicable to more jetties in the port, a generalisation is done in this chapter. In section 6.1, it is described how the design can be made modular and in Section 6.2 it is explained how the jetty would have to be adapted to different conditions.

## 6.1. Modularity

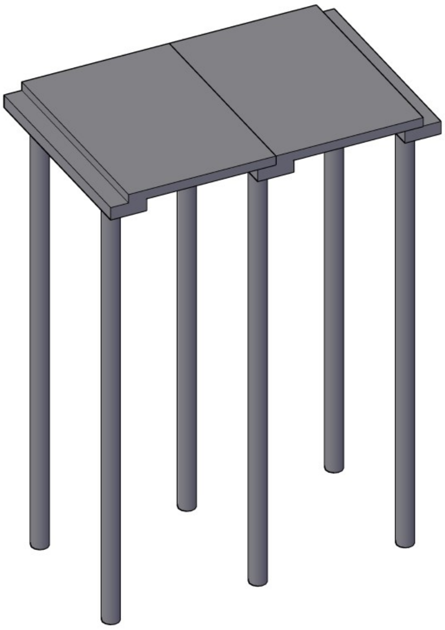
As described in Section 2.1, the reusability of this variant can be increased by making it modular. The structure can entirely be built up of similar modules. When making a structure entirely out of these modules, it can easily be expanded or changed during its lifetime. The reference platform is designed future-proof, as discussed in Section 1.4, meaning that it is made larger and heavier than is needed now, to allow for a possible change of use requirements in the future. However, a structure made of modules only needs to be made larger when these requirements apply. This is an advantage, as this means that the unused part of the jetty is not already worn out while it is not used, but also because the modules can be applied according to the new requirements. Due to this, the chance of a part of the structure being made but never used decreases.

### 6.1.1. Layout

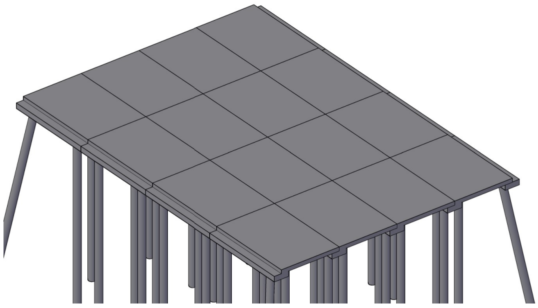
The module that can be used for this is given in Figure 6.1. In this, also the layout of the platform is displayed when build up of modules. The module consists of two roof tile elements, that together form a deck of 16.5 m in length and 12 m in width. This size is now based on the reference jetty. However, it should be researched what an optimised size of the modules is so that the system is applicable to all jetties, but material use is minimised. The separate rib plate that is shown in the figure is the beginning rib plate or the rib-part of the previously placed element. When aiming for a module that is robust on its own, this should be taken into account as a beginning rib.

A structure made of these modules can be expanded by 12 m in width direction and 16.5 m in length. The structure can be expanded to both sides, as from the empty side of the rib plate a new roof tile element can be placed. As jetties are sticking out into the water and are connected to the quay at one side, there is always a fixed starting point from which the jetty has to be made. The beginning rib plate can in some cases be left out if an abutment can take over its function.

When a structure is made with the modules, a rib-part of the last placed element will be sticking out. In this part, holes are present in which the post-installed anchor bolts can be placed. These holes should be closed off from the environment, so that the nut and the reinforcement steel are protected. This can be done by grout or a plastic protection layer, which should be removed before placing a new element.



**(a)** A single module



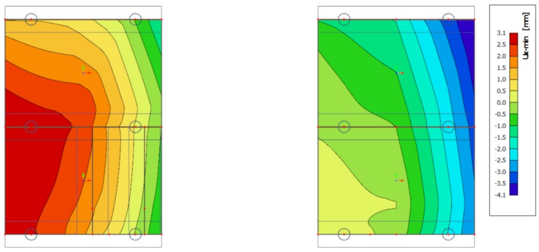
**(b)** Reusable jetty made of modules

**Figure 6.1:** Layout of modular reusable jetty structure

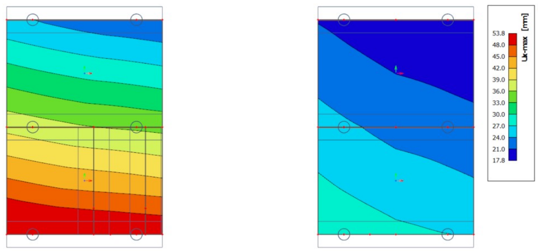
### 6.1.2. Calculations

To work with the modules, ideally each module would be robust on its own, so that all combinations and configurations of the structure will be robust as well. To investigate the feasibility of this, the place of two modules in which large displacements and stresses were found in Section 4.3 are modelled and calculated separately for the applying boundary conditions and load conditions as given in Section 3.2.2 and 3.2.3. The modules and their model are indicated in Appendix D.4

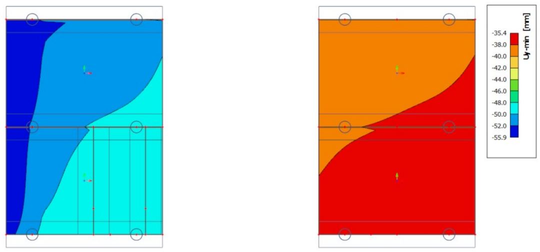
In Figure 6.2, the displacements of the two models are shown. In the calculation, no piles are placed at an angle. An optimised pile plan needs further investigation, so is not yet taken into account. The displacements are largest in the positive y-direction, with a maximum of 65.5 mm. Although the maximum displacements have increased, they are still within the maximum allowable 100 mm stated by Port of Rotterdam (PoR). The result was expected, as modules are not supported by other elements and the abutment. Also, the piles at an angle are not considered for simplicity. When multiple modules will be connected in a structure, the displacements are expected to decrease again. In Figure 6.3, the displacements of the separate modules are compared to the displacements of the corresponding elements in the reusable jetty. Especially the displacement in y-direction increase. The stresses are compared in Figure 6.4, in which can be seen that the stresses in x-direction increase significantly, whereas stresses in the other directions are comparable in magnitude.



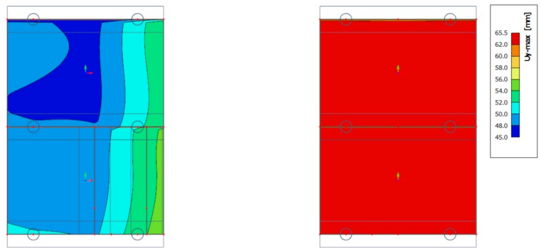
**(a)** Displacement in negative x-direction



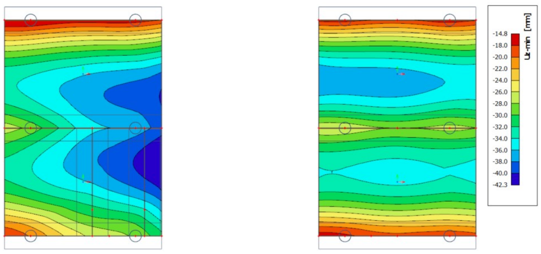
**(b)** Displacement in positive x-direction



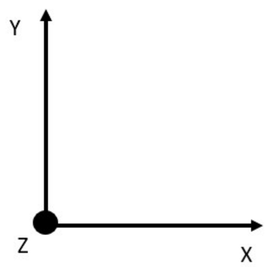
**(c)** Displacement in negative y-direction



**(d)** Displacement in positive y-direction



**(e)** Displacement in z-direction




**(f)** Directions of displacements

**Figure 6.2:** Displacement of reusable jetty modules

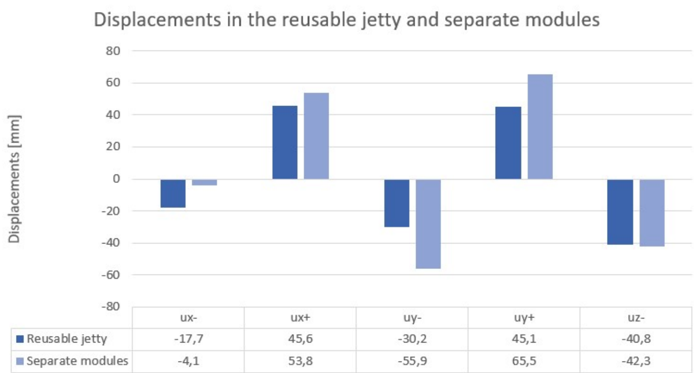
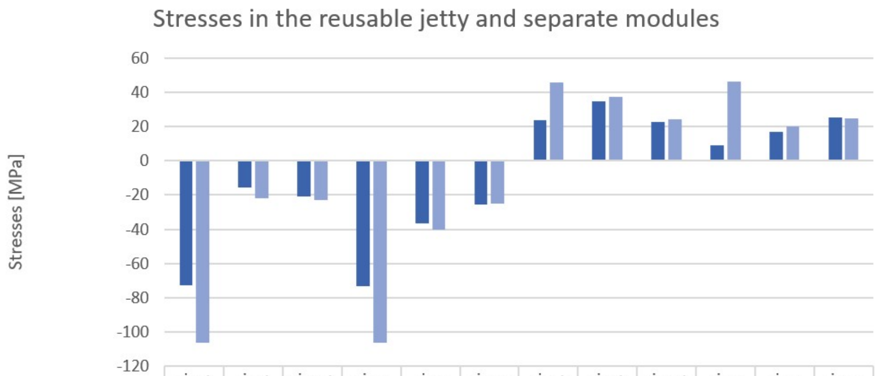



**Figure 6.3:** Comparison of displacements in reusable jetty and separate modules




| | sigx+ min | sigy+ min | sigxy+ min | sigx- min | sigy- min | sigxy- min | sigx+ max | sigy+ max | sigxy+ max | sigx- max | sigy- max | sigxy- max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reusable jetty | -72,9 | -15,5 | -20,6 | -73,4 | -36,8 | -25,4 | 23,7 | 34,9 | 22,6 | 8,8 | 16,8 | 25,4 |
| Separate modules | -106,3 | -21,8 | -23,1 | -106,6 | -40,3 | -25,1 | 45,8 | 37,2 | 24,3 | 46,1 | 20,2 | 25 |

**Figure 6.4:** Comparison of stresses in reusable jetty and separate modules

## 6.2. Varying conditions

The benefit of the modular structure is largest if it can be applied to all inland shipping jetties in the port of Rotterdam, so that the potential of finding an application for them to be reused structural elements is large. However, when moving more towards the eastern part of the port, the soil conditions change. In the first meters a clay layer is mostly found and the tight sand layer that can support the foundation can be found somewhat deeper [50]. Clay has a significantly lower penetration resistance ($q_c$) than sand and thus a lower stiffness, according to Equation 3.4. As robustness is governing for the jetty, the stiffness of the foundation should however remain approximately the same. For a weaker soil and a deeper tight sand layer, longer piles will be needed than is accounted for now to create a robust foundation. To arrive at the same stiffness, the longer piles should be made with a larger diameter and/or a larger thickness. When the same foundation stiffness is accomplished, no changes are expected in the behaviour of the concrete deck. The thickness of the piles can increase up to at least 30 mm and the diameter to 1420 mm. A change in diameter will however have consequences for the dimensions of the rib-part of the concrete elements, to which the pile is connected. A decrease in pile diameter leads to a decrease in the minimal width of the rib-part. To make the modular structure applicable to all inland jetties, it can thus be necessary to increase the width of the rib-part. Other solutions can be searched in changing the connection. This solution possibility will need more extensive research and is thus not further considered. It is assumed that the diameter of the pile can be increased up to 20%, due to which a 20% larger width of the rib-parts is needed. This scenario is taken into account in the environmental impact assessment.

Another change in conditions can come from the loads that apply to the jetty. Although this jetty is already designed for unknown future loads, the loads can increase. For the elements, this can have the consequence that they should increase in stiffness by adding more reinforcement and/or by increasing the height of the concrete. Although more calculations will be needed to determine this, this is not expected to raise any problems. The connections however, are the most critical part of the structure. In the hinged connection, the tension force is currently governing. However, with larger loading it can be the case that the shear force will become higher. This will especially be true in case of vibrations, for example imposed by large waves [21]. In the hinged connection, a larger shear force can be taken by using larger bolts. Another possibility of increasing the shear resistance of the connection is by applying ridges and notches, as is indicated in Figure 6.5. This is a common concrete connection solution and can thus be applied without further research [21].

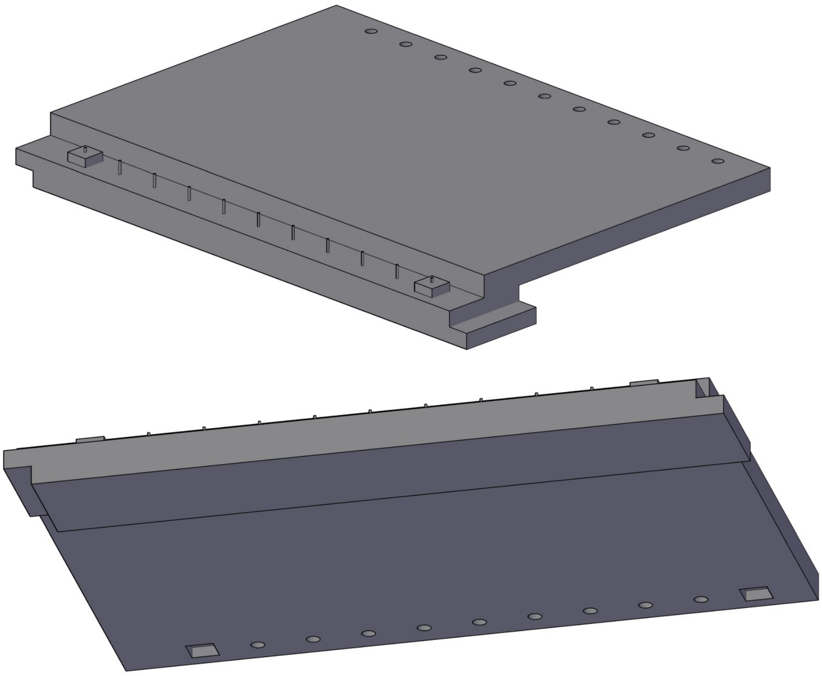


**Figure 6.5:** Example of element for connection with ridges and notches

# 7 Environmental impact quantification

In this chapter, the environmental impact of the reference variant and all reusable design variants are quantified. In Section 7.1, the input values of the different materials and the scenarios that are considered are given. In section 7.2, the results of the quantification are shown.

## 7.1. Input data and scenarios

The materials that are included in the assessment of the environmental impact of the jetty variants are: Concrete with reinforcement, steel piles with a coating, steel plates for the pile to rib plate connection and anchor bolts in the hinged connection. The impact of each of these materials per unit is given in Table 7.1. The numbers are based on assumptions and data as stated in Appendix G.1 and are expressed in ECI, as explained in Section 2.2.

**Table 7.1:** Impact of materials per life cycle substage as given in [51]

| | Unit | A1-A3 | A4 | A5 | B1-B7 | C1 | C2 | C3 | C4 | D |
|---|---|---|---|---|---|---|---|---|---|---|
| Concrete installed with regular crane | ECI/$m^3$ | 26.99 | 1.81 | 2.68 | 0 | 2.69 | 1.83 | 0.66 | 17e-3 | -1.24 |
| Concrete installed with large crane | ECI/$m^3$ | 26.99 | 1.81 | 7.12 | 0 | 7.16 | 1.83 | 0.66 | 17e-3 | -1.24 |
| Concrete installed with large crane using less clinker | ECI/$m^3$ | 20.72 | 1.82 | 6.26 | 0 | 7.16 | 1.84 | 0.67 | 17e-3 | -1.25 |
| Reinforcement | ECI/kg | 0.20 | 26e-4 | 0 | 0 | 0 | 17e-6 | 53e-5 | 0 | -0.11 |
| Steel piles | ECI/m | 3.94 | 31e-3 | 0.25 | 0 | 0.14 | 10e-3 | 57e-3 | 99e-6 | -2.02 |
| Coating | ECI/$m^2$ | 0.60 | 0.21 | 0 | 30e-4 | 0.33 | 0.14 | 56e-4 | 0.94 | 0 |
| Steel plate | ECI/piece | 5.00 | 20e-3 | 0 | 0 | 0.41 | 21e-3 | 0 | 32e-5 | -2.25 |
| Anchor bolt | ECI/piece | 50e-3 | 29e-5 | 11e-4 | 0 | 0 | 99e-6 | 21e-6 | 1e-7 | -17e-3 |

Initially, the environmental impact of the reference jetty structure and the reusable jetty structure are calculated for a functional lifetime of 50 years without reusing the structure. Separately, the impact of reusing the structure is calculated by calculating the impact of deconstruction, transport and reconstruction, as indicated in Figure 2.5. This can be added to the impact as many times as reuse is applied to obtain its final impact. When reusing the structure, deconstruction, transport and reconstruction can cause additional damage to the elements, causing a need for a partial replacement.

In the NMD, no distinction is made between in situ concrete and prefab concrete. Manually, the difference between the size of the cranes and the duration of the construction is accounted for, as described in Appendix G.1. However, the role of other differences is not accounted for. Effects of the higher quality and better production control in prefab elements may lead to a lower environmental impact in phase A1-A3. The environmental impact of each of the reusable variants that is presented in Section 7.2 is expected to be a slight overestimation, leading to conservative results.

In substage A5 for each material, already a 5% loss of material is taken into account. It is however assumed that additional loss of material will occur, as this can also happen during disassembly in substage C1. Based on estimations by NIBE, two scenarios can be taken into account for this. Those scenarios are 5 and 10% material loss [17], which thus additionally account for one to two times the 5% damage assumed during assembly. Two times a procedure is added in which this damage can take place. However, not all of the same problems, such as mistakes in orders, will occur. Therefore it is assumed to have a realistic additional material replacement during reuse of one to two times the loss during the initial construction. To account for this replacement in the reuse impact, the entire life cycle can be added again for the named percentage of material. Three variants of the jetty design are considered in the LCA, which are the reference jetty, the reusable jetty as designed in Chapter 4 and 5 and the modular reusable jetty as given in Chapter 6. In the modular jetty, an increased pile diameter and thus an increased rib-part width of 20% is assumed.

To research the impact of the choice of material, a second variant is included for the modular reusable jetty. In this variant, a different type of concrete is assumed to be used that has a lower environmental impact. A geopolymer concrete solution can be thought of. However, due to a lack of experience with this solution, it is not yet realistic to apply, thus this is disregarded. A solution that can be applied and has a highly comparable environmental impact to the geopolymer concrete is a type of concrete that partly uses CEMIII as a binder, containing little clinker. A disadvantage of this concrete is that the strength development during drying takes longer. This is however not a problem for the modular reusable jetty, as prefabricated elements are used [17].

The variants of which the environmental impact is calculated separately are stated below. After each variant, it is stated where the results can be found.

- Reference jetty (Appendix G.3.1)
- Reusable jetty (Appendix G.3.2)
  - Reuse of reusable jetty with 5% replacement
  - Reuse of reusable jetty with 10% replacement
- Modular reusable jetty (Appendix G.3.3)
  - Reuse of modular reusable jetty with 5% replacement
  - Reuse of modular reusable jetty with 10% replacement
- Modular reusable jetty with low clinker concrete (Appendix G.3.4)
  - Reuse of modular reusable jetty with low clinker concrete with 5% replacement
  - Reuse of modular reusable jetty with low clinker concrete with 10% replacement

## 7.2. Results

The results from the LCA are shown in Appendix G.3 and are summarized in Figure 7.1. From the figure, it can be seen that the environmental costs of one life cycle of all the reusable variants are 16-25% higher than that of the reference jetty. This and all further mentioned percentages depend on the functional unit. The aspect of scale should be recognised. When the design of the reusable jetty is based on a smaller reference jetty, the percentages are most likely also smaller and for a larger reference jetty, larger percentages are expected.

The environmental costs for reusing are significantly lower than the initial environmental costs, only 29-34% of the initial environmental costs of the corresponding structure remain. This can be expected as only a part of the life cycle substages is included in this. For all variants, the difference for reuse with a 10% replacement compared to a 5% replacement is within the range of 11-12%. When comparing this with the total environmental costs of the structure including one time reuse, this difference only accounts for 2.1 to 2.3% of the total ECI. The impact of the amount of replaced elements is thus small.

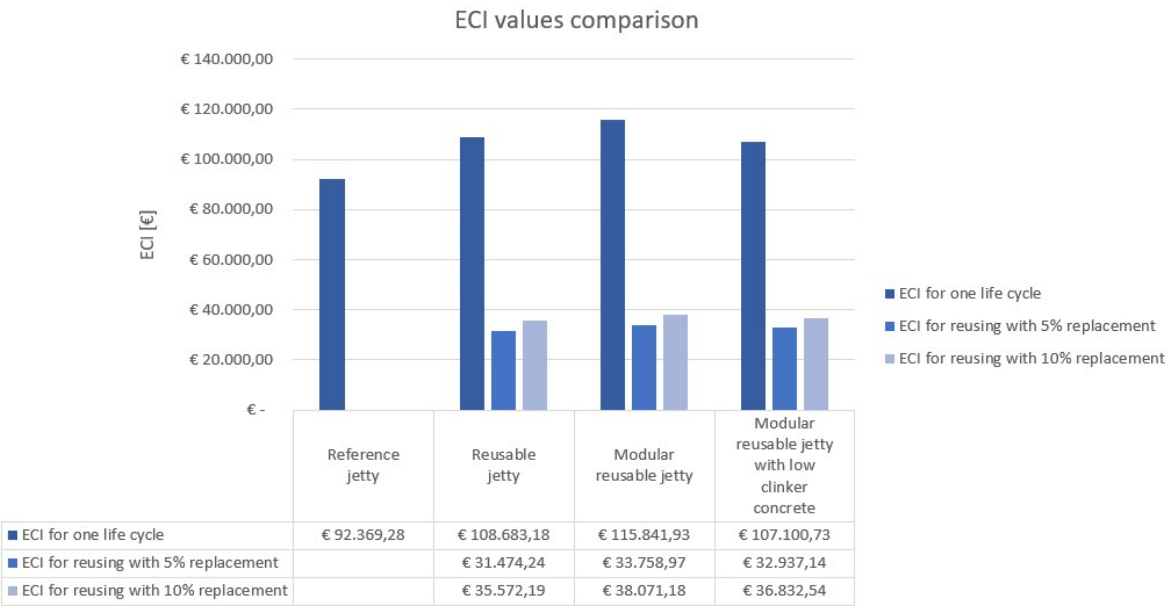


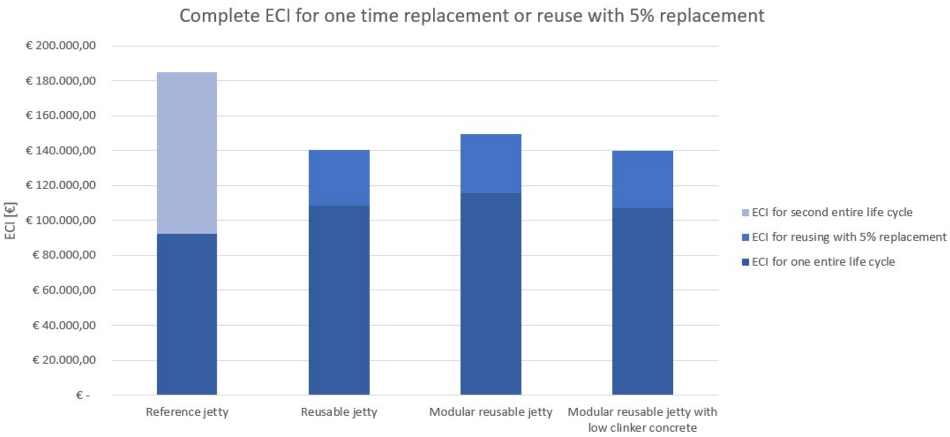

**Figure 7.1:** Overview of ECI for all variants

As the initial environmental costs of the reusable variants are higher than that of the reference jetty, this should be compensated during the lifetime of the structures. The environmental costs of reusing are considerably smaller than the environmental costs of an entirely new reference jetty, which is how this compensation can be made. The percentage of environmental costs that can be saved with one time reuse is shown per variant in Table 7.2. In Figure 7.2 it is shown that under the assumption of reuse once in the lifetime for the reusable variant or replacement for the reference jetty, the compensation is made.

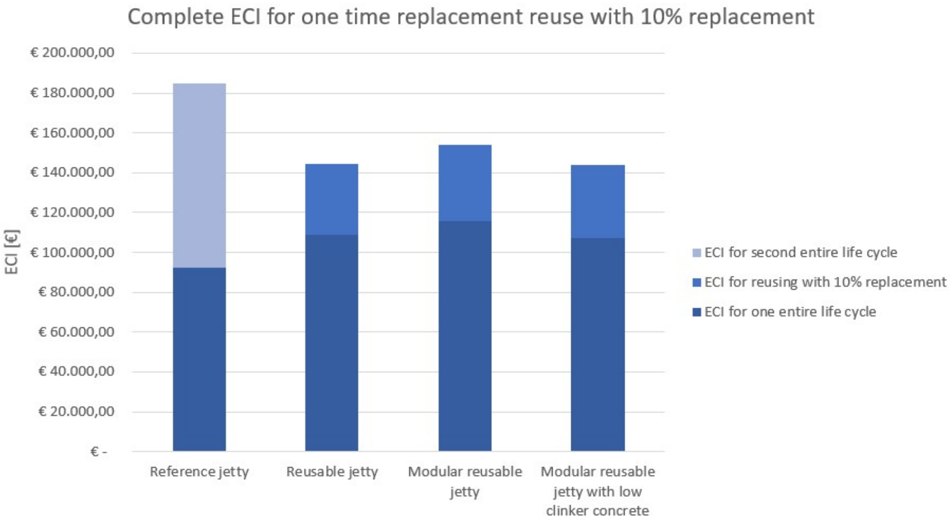
From Appendix G.3 it can be seen that the impact of the concrete contributes the most to the total environmental costs. This is expected, as concrete is the material that is used most in the jetty. From the results in Figure 7.1, it can be seen that using a low clinker concrete lowers the environmental impact. When compared to the modular variant with regular concrete, it decreases the impact by 8%. It is expected that this reduction can prosecute when choosing other types of concrete or materials that have an even lower environmental impact. The use of demountable connections on the other hand has very little impact on the total ECI. The anchor bolts and the grout that has to be replaced account for approximately 1% of the total ECI in all reusable variants.

**Table 7.2:** ECI comparison for one time reuse

| Jetty variant | ECI for two life cycles or one time reuse with 5% replacement [€] | Reduction of ECI [%] | ECI for two life cycles or one time reuse with 10% replacement [€] | Reduction of ECI [%] |
|---|---|---|---|---|
| Reference | 184738 | | 184738 | |
| Reusable | 140157 | 24 | 144255 | 22 |
| Modular reusable | 149601 | 19 | 153913 | 17 |
| Modular reusable with low clinker concrete | 140038 | 24 | 143933 | 22 |




**(a)** Reuse with 5% replacement




**(b)** Reuse with 10% replacement

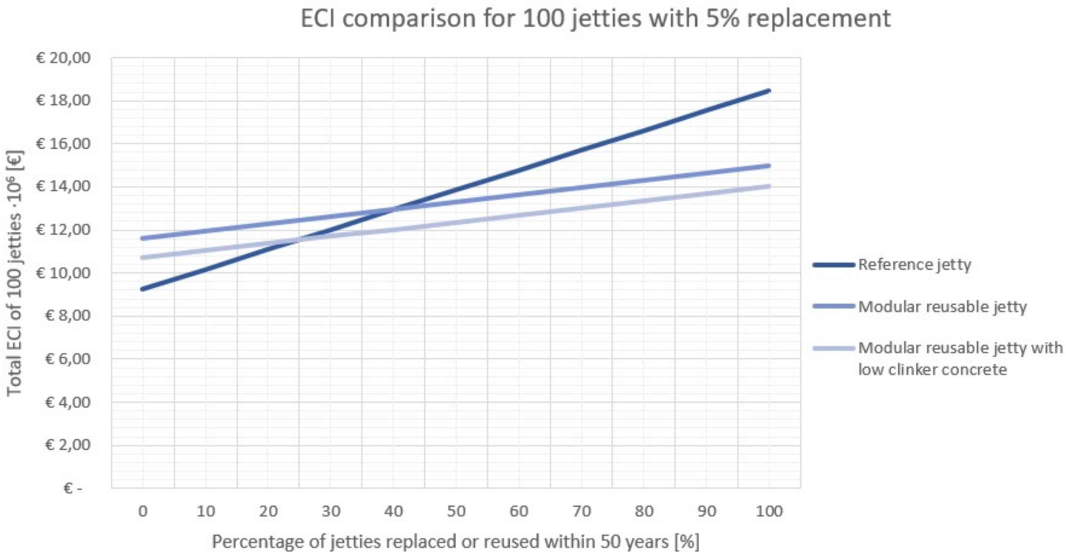
**Figure 7.2:** ECI comparison for one time reuse

### 7.2.1. Environmental costs for applying reusability to all jetties in port

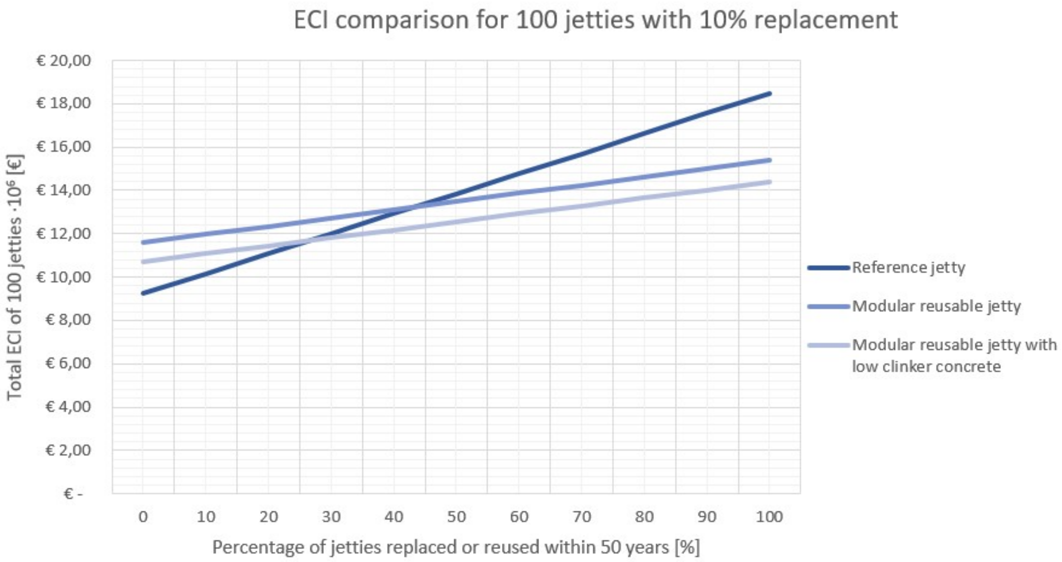
When implementing a modular system, all inland jetties in the port can eventually be made with the same elements. Currently, the port has a total of 100 jetties for inland shipping [1]. It is assumed that the modular system will be implemented in 100 jetties. This makes a difference for the environmental impact, as it is not anymore relevant how many times one jetty will be reused, but it becomes relevant what percentage of all jetties is being reused. For this analysis, the jetties are assumed to be reused maximally once in their lifetime of 50 years. The total environmental costs of 100 reference jetties ($TC_{ref}$) can be compared to the total environmental costs of 100 modular reusable jetties ($TC_{var}$). Based on this, a tipping point (TP) can be calculated at which the ECI for the conventional system is exactly as high as for the reusable system. This tipping point can be calculated with Equation 7.1, in which $p$ is the percentage of jetties that is being replaced in case of the reference variant or reused in case of the reusable variants. The results are given in Figure 7.3. The tipping point is found where the ECI for the reference jetty crosses the ECI for the reusable variants. For 5 to 10% replacement, these values lie at 40 and 43%, respectively for the modular reusable variant and at 25 and 27% for the modular reusable variant with low clinker concrete.

[1] https://www.portofrotterdam.com/sites/default/files/2021-05/feiten-en-cijfers-haven-rotterdam.pdf

$$
\begin{aligned}
TC_{ref} &= (100 + p)ECI_{ref} \\
TC_{var} &= 100ECI_{var} + p \cdot ECI_{reuse} \\
TP &= \frac{100ECI_{ref} - 100ECI_{var}}{ECI_{reuse} - ECI_{ref}}
\end{aligned}
\tag{7.1}
$$




**(a)** Reuse with 5% replacement




**(b)** Reuse with 10% replacement

**Figure 7.3:** ECI comparison for one time reuse of 100 jetties

### 7.2.2. Influence of avoiding construction for large uncertainties

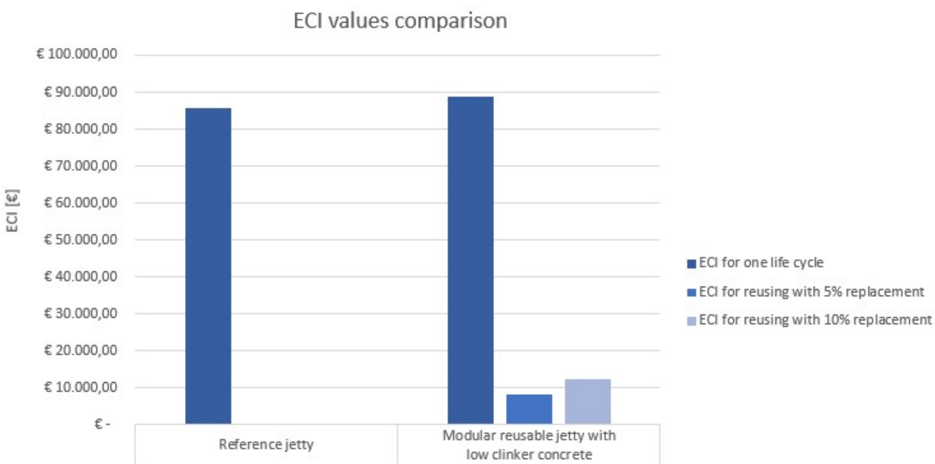
As is described in Section 1.1.2, the reference jetty is designed to be future-proof. A promising characteristic of the reusable jetty is that its layout can be easily adapted during the structure's lifetime. This makes it possible to only construct the parts of the structure of which the use is certain and prevents parts from wearing out during the period they are not needed or even from placing parts that will not be needed during the entire lifetime of the structure. When not taking possible future requirements into account, a size of the reference jetty of 10 m length and 10 m width would be sufficient [52]. This is 4.8

times smaller in length and 3.5 times smaller in length and a total of almost 17 times smaller in area. However, as the structure is under construction during this research and thus is not yet in use, no information is yet available on the future use of the platform. Nevertheless, from the previously presented results of the LCA it can be seen that if the given percentage is constructed unnecessarily in the reference jetty, this is already sufficient to avoid the need of an investment in environmental impact. This means that when 16-25% of the reference structure is not being used during its lifetime and this same amount is thus not constructed during the lifetime of the reusable variants, the environmental impact of the reusable variants will be equal to that of the reference variant, meaning that no investment has to be made. As the future-proof structure is currently made almost 17 times larger in platform area than what is needed for the initial use, it is expected that not needing a percentage of 16-25% of the platform during the lifetime is realistic. This percentage could be reduced, when accounting for the shorter use of the later placed elements, so that their residual value at the end of the structure's lifetime is higher than when they would have been exposed to the environment and load during the entire 50 years.

### 7.2.3. Influence of the energy transition

As mentioned in Section 1.2, it is Port of Rotterdam (PoR) policy to be $CO_2$-neutral in 2050, which includes an energy transition. If this policy is followed, by 2050 the cranes and other equipment that is used for construction in the port will be energy-neutral as well, which influences the environmental impact of construction and reuse procedures. When making the conservative assumption that only PoR will become energy-neutral, the impact of steps A5 and C1 in the life cycle of the structures decreases. Only the impact of material loss will remain in step A5 and in step C1, no impact will be made. In these calculations, it is assumed that the beginning of the lifetime of the jetty is no earlier than 2050, so that the transition has been completed. The reference jetty and the modular reusable jetty using lower clinker concrete are compared. In the calculations of the initial impact, the ECI in steps A5 and C1 will be set to zero and the material loss is accounted for by adding 5% to the amount of material used. For the reuse procedure, it is assumed that also step A4 can be set to zero, as this transport will take place within the port. The calculations are given in Appendix G.5.

The results are given in Figure 7.4. When comparing those to the results of the calculations that do not take any energy transition into account, as given in Figure 7.1, it can be seen that the environmental impact reduces in all cases. However, it is seen that for the modular reusable variant with low clinker concrete this reduction is larger. This difference is due to the larger crane that is used in the reusable variants. This initially has a larger impact than the crane used in the reference variant and will thus cause a larger impact reduction when not taken into account. The initial environmental impact of the modular reusable variant with low clinker concrete is 3.6% larger than that of the reference variant and the tipping point that is found using Equation 7.1 is 4.0 to 4.3% and is thus considerably lower than the tipping point that was originally found.




| | Reference jetty | Modular reusable jetty with low clinker concrete |
|---|---|---|
| ECI for one life cycle | € 85.544,91 | € 88.674,91 |
| ECI for reusing with 5% replacement | | € 8.229,93 |
| ECI for reusing with 10% replacement | | € 12.244,26 |

**Figure 7.4:** Overview of ECI for energy transition

# 8

# Conclusions and recommendations

## 8.1. Conclusions

This research aimed to identify how reusability can contribute to reducing the environmental impact of a jetty platform structure. To achieve this, a reference jetty was selected, which was adapted according to Design for Disassembly (DfD) requirements to arrive at a reusable design. Of this design, different variants were made. The environmental impact of the reference jetty and the reusable jetty variants were assessed and compared, based on which the main research question can be answered, which is repeated here.

*RQ. How can reusability contribute to reducing the environmental impact of a jetty platform structure?*

By stating the potential of the reuse principle for structures, it was expected that reusability can contribute to reducing the environmental impact of a jetty structure. However, due to the absence of solutions for reusable jetty structures in literature, it remained unclear if this would be technically feasible, as well as if the potential can be reached. By synthesising a reusable jetty design according to the DfD requirements, while fulfilling the same functions as the reference jetty, it was found that making a reusable jetty design is feasible. Both the structural behaviour and practical aspects as assembly and maintenance were proven to be realistic. As expected, the initial environmental impact of the reusable jetty variants is higher than that of the reference jetty. However, this can be compensated by reusing, which has a considerably lower impact than a new jetty. This is how reusability can contribute to reducing the environmental impact of a jetty platform structure, which can help Port of Rotterdam (PoR) to achieve their sustainability goals and to keep to the Paris Agreement.

The following general conclusions can be drawn:

- The use of prefab elements in a reusable jetty design has small consequences for the behaviour of the jetty. When comparing the calculation results of the reference jetty and the rigidly connected reusable jetty, only insignificantly small changes were found. There are however consequences for construction. The weight of the elements cannot be kept sufficiently low without increasing the number of piles from 35 in the reference platform to 65 in the reusable variant, which is assumed to be an unacceptable increase. Therefore, a larger crane must be used for construction than is conventionally used, increasing the maximum weight of the prefab elements from 70 tonnes to 200 tonnes. However, this larger crane can cause additional hindrance to the surroundings during construction and needs more fuel to run. Concurrently, the use of prefab elements causes a significant decrease in construction time. For the reference jetty platform, a duration of 121 days was planned, which can be reduced to 71 days for the reusable platform.
- The use of simple connections for the ease of (dis)assembly has consequences for the behaviour of the structure. The magnitude of the largest displacement increases from 41.6 to 49.4 mm. They are thus comparable in magnitude and are found in similar locations in the deck. However, the stresses increase from 14.2 to 73.4 MPa. The large stresses are found in the rib-parts of the elements are due to a modelling choice. In the span between the rib-parts, stresses are found

up to 10.0 MPa in the reusable variant, which is more comparable to those in the reference jetty. These large stresses are thus found close to the hinged connections, and are thus taken into account in the connection design. A considerable difference in behaviour is the discontinuities that are found in the displacements along the element edges, which are due to the slip that is allowed in the shear connections and due to the different loads imposed on the different elements. The discontinuities have a magnitude of up to 11.0 mm. This can have consequences for the superstructure. These consequences are limitations in the flexibility of placing the superstructure and possible deformations in the pipelines. If the limitations are unacceptable, the anchor bolt connection that is used in the hinged connection can also be added to the shear connection. To allow for realistic placement tolerances, a reinforced resin can be used as a filling material. This measure mitigates the discontinuities to a maximum magnitude of 2.0 mm.

- It is feasible to use connection methods that are familiar in other applications. Sufficient experience with those methods results in straightforward application. Furthermore, the methods are included in norm documents, due to which no further study is needed before using them. This makes it more attractive for PoR to implement the reusing principle in their jetty structures and enables them to do so in the near future. The placement tolerances for the demountable connections are 22 mm. Those are considered to be realistic, as the elements only have to be placed from one side and can thus fit the previously placed element.
- The initial environmental impact of all reusable design variants is higher than that of the reference jetty. The maximum difference is found between the reference jetty and the modular reusable jetty, which have an environmental cost indicator (ECI) of €92.369 and €115.842, respectively. However, the impact of reusing the structure is considerably lower than that of making a new structure similar to the reference jetty. Due to this, the initially higher environmental impact can be compensated. For reusing the structure once, this investment is already compensated and has 17 to 24% lower environmental costs compared to the conventional scenario of making a reference jetty twice.
- By generalising the design, it is expected that more jetties in the port of Rotterdam can be made into reusable jetty structures. When more structures are reusable, the potential environmental benefit increases. When assuming that a jetty is reused maximally once during a 50 year lifetime, a tipping point is found when 25 to 43% of the structures are being reused in case of the reusable structures or replaced in case of the reference structure. Based on these numbers, an estimation can be made by PoR if this tipping point is realistically reached.
- For reuse, the disassembly and reassembly procedures can cause additional damage to the elements, which can lead to replacement. This replacement can cause an increase in the environmental impact. However, when considering the number of damaged elements that need replacement to be between 5 and 10%, this impact is small. Only 2.1 to 2.3% of the total environmental costs are determined by this difference. It is therefore concluded that reduction of the chance of damage during dis- and reassembly is not particularly effective in further reducing the environmental impact of the reusable jetty.
- The concrete in the jetties contributes most to the total environmental costs, both initially and for reuse. This assessment takes the structural characteristics of this concrete into account. However, the use of a concrete type that has a lower environmental impact is an effective measure to decrease the total impact. By estimating that half of the concrete in the reusable jetty is a lower impact variant, the total ECI can be reduced by 8% compared to the variant using only regular concrete. Potentially, this impact can reduce further by applying a larger ratio of low impact concrete. It can potentially reduce to the point where no initial environmental impact investment has to be made when compared to the reference jetty with regular concrete. Even for the modular system, potentially the tipping point can be lowered.
- The initial investment that has to be made when comparing the reusable variants to the reference platform can be reduced by taking into account the possibility to avoid construction for large future uncertainties. The reference variant is made 17 times larger in area than initially needed, to account for future requirements that are very uncertain. The reusable variants allow for the option to construct additional parts of the jetty at a later stage, when requirements become more certain. When 16-25% of this total area is not needed during the entire lifetime, there is no initial investment that has to be made. This percentage can be reduced when the shorter exposure

time of the later placed elements is taken into account, which increases the residual value of the elements at the end of the structure's lifetime. A second way to reduce the initial investment is by taking the energy transition into account. The policy of PoR to be $CO_2$-neutral by 2050 also holds for the construction equipment that is used for the platform. When this is realised, only the materials and the energy that is consumed outside of the port have to be taken into account in the life cycle assessment (LCA), which leads to the result of a total ECI of €85.545 for the reference jetty and €88.675 for the modular reusable jetty with low clinker concrete. Due to which the investment is reduced to only 4.0 to 4.3% of the initial environmental impact of the reference jetty.

## 8.2. Discussion

The limitations and weaknesses that should be considered when interpreting the conclusions are stated below.

The design made in this research is only based on the design of a reference structure. This reference structure is designed and calculated with specific requirements and conditions. Although other jetties are also made for inland ships and in the port of Rotterdam, the requirements and conditions may vary. This can have an impact on the modular design variant, as this should be applicable to many jetties in the port. The LCA that is done for the modular variant currently only takes into account a larger pile diameter. However, other dimensions might also change. Although the ECI for the modular reusable jetty possibly increases further when taking into account a wider range of requirements and conditions, the potential benefit of modular reusable jetties for the port is stretched. It is not expected that this benefit will decrease to a point that it is not realistic.

The choice of jetty to use as a reference also impacts the results. Although it is expected that the roof tile concept can be applied to each inland jetty in the port of Rotterdam, details can be different. However, only very small changes are expected. A comparison based on a different reference jetty is expected to only lead to minor changes in the LCA. It is thus estimated that this will have no considerable effect on the conclusions.

By using solutions that are familiar in other practises, the ease with which this solution can be applied is considered. However, a large factor in the decision making process will be the costs, which are not considered in this research. It is expected that the largest increase in costs for PoR will be the disassembly of the structure when reuse will be applied, which is a process that differs from demolition. However, the ECI of the structure potentially has to be paid in the future according to the 'polluter-pays-principle'. When this is implemented, it is expected that costs can be saved. Until that point, the additional costs are an investment to reduce the environmental impact according to the Paris Agreement and the PoR policy.

Although the model used to calculate the reusable jetty variants is based on the reference jetty model, some notable changes were made. In the reference model, the deck is modelled as one large plate with ribs. In the reusable model, this is not possible, as the interface conditions between all the sides of the different element parts have to be defined separately. Due to this, the rib-part cannot be modelled as ribs, but has to be modelled as 1D-bar elements, thus not covering a width. This leads to a very sudden increase in stiffness of the plate element. In the calculation results, this is recognised in the sudden change in displacements and the high stresses near the 1D-bar elements. The resulting forces are used in the design and calculations of the connections. In reality, a better distribution of the forces is expected, due to which a slight overestimation of the connection is possibly made. This has no consequence on the feasibility of the connection. The impact of the overestimation on the LCA is expected to be very small. Only the number of anchor bolts and the amount of grout used will change, which together only account for around 1% of the total ECI.

For the LCA, numbers are taken from the Nationale Milieudatabase (NMD). However, those numbers remain an estimation. This can result in an unfair comparison between different materials, as the factors that are included can vary. The conclusion is based on the comparison between variants, in which the same materials are used. Therefore, the impact on the main conclusion is expected to be small. However, when comparing the impact of different materials, conclusions should be carefully interpreted.

The reference jetty consists of steel and concrete, based on which it is chosen to work with those materials only. However, in the LCA it was concluded that the impact of the materials is large and that the use of a different concrete type has great potential to lower the environmental impact. Changing concrete type can strongly influence the results and the location of tipping point.

The percentages that are mentioned in the LCA results are an depending on the scale of the reference jetty on which the design of the reusable variants is based. This functional unit is taken into account when interpreting the percentages. When the scale of the reference jetty and thus the functional unit are chosen differently, the percentages will change.

## 8.3. Recommendations

Although the potential of reusable jetties of PoR is stretched, the design is not yet ready for implementation. Recommendations are made to what should be studied further, so that an optimised and complete reusable jetty design can eventually be applied.

- Technical solutions for a modular structure were only briefly touched upon, whereas this increases the potential environmental benefit. To make the modular structure applicable to as many inland shipping jetties as possible, this should be worked out in further detail. Firstly, the dimensions of the rib plates and roof tile elements are not yet optimised for all relevant jetties. This can result in a slight change of dimensions, both in width and length. Also, the structural resistance of the modular system should be sufficient for all loads on the jetties. Furthermore, the Marine Loading Arm (MLA) support plates should be implemented in the modular design. The highest reuse potential can be reached when the number of MLA's can be varied. It can be considered to create a special roof tile element, in which a certain number of MLA's can be placed. When only changing this special piece or adding a special piece in the place of a regular roof tile element, the number of MLA's can easily be varied.
- To prevent spilt fluids from ending up in the water, the deck should be made liquid-tight. In the reference jetty, this is easily reached by the in situ compression layer that has no gaps over the entire deck. However, in the reusable variants, the elements are partly connected dry, so that liquids can run in between. A measure that can be thought of to prevent this is a rubber connection profile, which is already used between the elements. It was already stated by Wormmeester that those are realistic in terms of maintenance, but it should be found if this profile can make the connections liquid-tight. To prevent liquids from running off the sides of the element rising concrete edges are applied. It is yet to be determined how they can be applied in case of a modular system. When this is not feasible, it can be considered to make gutters instead along the sides of each element. Those gutters can be connected between the elements, so that only along the edges of the structure some drainage or catching system has to be made. It can also be a solution to only apply a catching system at critical positions, so for example small catchment tanks below the point where the pipelines are connected to other elements. Further study is needed to avoid liquids from spilling through and running off before the (modular) jetty can be applied.
- The only joint that is not yet considered in the reusable design is the pile to rib plate connection. It was found that this connection should be rigid for robustness of the structure. Currently, the connection is welded. This connection can be disassembled and reassembled. However, as the connection contains chemical bonding that should be cut and treated before reassembly, this cannot be considered easy to reuse. Further investigation can be dedicated to the question if it is realistic to reuse the structure with the welded connection or if the connection should be made easy to demount. In case of the latter, further study is needed on the layout and behaviour of the joint.
- By using simple connections, gaps in the displacements are found between elements. Those gaps can have consequences for the superstructure. The first consequence is a limitation of placement of elements, so that they do not overlap with the side of elements. This does not raise concerns for the reference jetty, as in the design this overlap is not found. However, this can be different when applying a modular system to more jetties. The impact of this limitation should be clear, so that it can be estimated if this is a significant restraint. If so, other solutions for the connections might be more suitable. The second consequence is that movement is expected in the pipelines, which are inevitably crossing multiple elements. Although it is expected that the movements can be taken by the pipelines, it should be investigated what the impact will be. Some adjustments in the pipelines or piperacks are possibly needed.

- The concrete in the jetty contributes most to the environmental impact. As is concluded, the use of a lower impact concrete can significantly lower the initial environmental impact. However, it is not yet researched what types of lower impact concrete exist or are currently being developed. Those should be examined for the application in a reusable jetty structure, considering structural resistance and practical challenges such as maintenance. If this is feasible, it will further decrease the environmental impact and thus help PoR reach their goals.

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# A

# Interview with Marc Wormmeester

Interviewee: Marc Wormmeester
Interviewer: Judith Kavelaars

Date: Wednesday, March 30, 2022

Meeting place: Online
Attendees: MW = Marc Wormmeester (interviewee), JK = Judith Kavelaars (interviewer)

JK: What is your role withing Port of Rotterdam and what is your experience with maintenance of marine structures?
MW: I have been working for 12.5 years within Port of Rotterdam and have been working as an asset manager within the department of asset management construction & dredging. This department is managing quay walls, jetties, engineering structures, pontoons, berthing facilities, so all of the marine structures that are owned by PoR. Within this, we are responsible for the maintenance, but we are also consulting in project teams regarding management and maintenance of the to be realized assets. If a project team is designing a jetty for example, we will be part of the team to consult about details that are influencing management and maintenance of the structure, so that we can make sure that the design and execution are such that we can also manage and maintain the structure in a cost efficient and durable way. Within the department I am also an expert in corrosion and corrosion control measures, so I am for example sometimes involved with cathodic protection measures in steel structures.

JK: Port of Rotterdam is known to be looking for opportunities to decrease their environmental impact. However, on the website they do not discuss this regarding their marine structures. What are they doing to decrease the environmental impact of this field?
MW: We are looking to make our structures more sustainable and since approximately two years this is something to which we are fully committed. Especially our quay walls, which have large amounts of steel and concrete in them, contribute significantly to the $CO_2$ emissions in our projects. We are trying to think of a more intelligent way to make structures like this, whether it is by making a smarter structure, smarter material use or smarter design.

JK: Do you think making reusable jetties fits in this wish to be more sustainable and that it would be realistic to expect the structures to be reused at some point?
MW: Your ideas are very interesting in this field. If we want to take the entire structure and place it at another client, we must be careful with their specifications and the regulations they have to comply with. Depending on the goods that are loaded and unloaded at the jetty, those might change.

JK: What do you do if you want to keep using structures that are at the end of their design lifetime?
MW: We usually make jetties for a lifetime of 25 to 50 years, but often we keep using it for way longer. We have marine structures that are way older than the design lifetime. We monitor all structures that we manage, both within the design lifetime and when the lifetime is exceeded. We don't want to keep

clients waiting while we have to construct a whole new jetty, while the old one can still be used. It should always keep meeting the specifications it was designed for, so we apply lifetime extending measures.

JK: If a client wishes to change the specifications of their jetty, how do you adapt the jetty?
MW: We get this wish regularly. Currently if we want to do this, we will make an entire new piece to add to it which takes a lot of time, while the structure should be always in operation. I see great opportunities to lower the construction time of this additional parts if we make use of modular pieces such as this. For changing jetties more easily, I would very much like to work with a system like this.

JK: What does the maintenance that you apply to jetty structures look like, when considering the platform part?
MW: The platform is a large concrete deck on steel piles. Because of the water depth the piles need to be very long, so because of the buckling length, we have to use steel piles. The piles are being conserved until 2 m in the soil and are being monitored. After approximately 10 years, depending on what we monitor, we put cathodic protection on them, because the conservation degrades. This cathodic protection itself will also be monitored once it is put in place.

For the concrete we don't need a lot of maintenance. We are monitoring the degradation of the concrete by using a special system. This system is called the KMS (kade modellerings systeem), by which we can monitor the degradation of the material based on the quality of the concrete. We do this by taking concrete samples out of the existing assets and examining them. Based on this we can predict the governing degradation system (such as carbonatation, chloride intrusion or chemical degradation) and with that we can predict the needed maintenance. In new structures we can take concrete sample in advance to examine them, so we can already predict the needed maintenance already during construction. The maintenance of concrete is simple. After 25 years there can be some corrosion of the reinforcement, so concrete repair projects need to take place. This is of course depending on the quality of the concrete.

The joint profiles that are placed between structural components have a lifetime of about 25 years, but the rubber joint profiles in between should be replaced approximately once every 10 years, which is due to chloride and UV radiation.

Also, the drainage in the concrete deck can need some maintenance, but that is very minimal.

JK: What is an example of a maintenance project in which a reusable structure would have made maintenance easier due to the possibility to replace only an element of the structure?
MW: The biggest challenges in the maintenance are with damages underneath the deck, because this is not easily accessible. In some parts of the port, we have a lot of space between the water and the deck, but if we go further in land this space becomes smaller, which is extra challenging. We are currently trying to solve a problem with a jetty in the Europoort that was made around the year 2000. The reinforcement can be seen from the outside of the concrete at the place where polluted water is captured. It looks like the concrete is being damaged from the inside out. We suspect a case of ASR (alkali silica reaction), which happens when the polluted water reacts with the cement and forms an expansive substance. This substance is crushing the concrete from within. This is a very complex maintenance job. We have to be underneath the jetty in this case, which creates challenges to make a safe working environment. The jetty is also always in operation, so we have to agree with the client on how to do this. In this case if we could replace the element, we could do this much faster. Or if we could take it out to repair on the side that would solve problems regarding creating a safe work environment.

JK: What are concerns that you might have regarding maintenance when considering the activity of disassembling, transporting, and assembling a jetty structure for reuse?
MW: Nothing comes to mind that would change the risk profile of the structure. As long as the requirements of the new jetty are met by the used jetty, there should be no additional maintenance challenges.

JK: What are concerns that you might have with maintenance to the connections that make use of steel plates and bolts on the surface?
MW: Connecting two steel plates to each other as a cold joint is not something we are able to maintain properly. Especially in the salty waters this is a source of corrosion, so if a project team would suggest this for a new jetty, we as asset managers would prevent this from being executed at all costs.

JK: Would the use of weathering steel be a solution?
MW: Weathering steel is still sensitive for chlorides, although the name suggests otherwise. There are very little kinds of weathering steel that are chloride resistant. You will need for example weathering steel with titanium alloy. That is very expensive, both in purchase and in maintenance, so although it exists, I would not see this as a realistic solution.

JK: When looking at the semi-dry connections solutions we see that there are bolts used, but they are protected by a grout. What are maintenance challenges that arise from using this solution?
MW: There aren't many challenges that come to mind. Also in the chloride environment, this is feasible. Whether you use a grout or a plastic to protect the bolts wouldn't matter. As long as the steel elements are completely closed off from the environment, then this solution would be good and realistic in terms of maintenance.

JK: The use of simple connections can allow some movement, which can cause the elements to displace relative from each other. What can be concerns for the maintenance when this can happen?
MW: We do have experience with this kind of connections. We sometimes see some concrete breaking off of the corners of the ridges. That is often due to a design mistake, because it has too little reinforcement in the corners. When there are temperature changes this can happen. Proper detailing should be able to solve this problem. I see no other problems with the simple connections that you suggest, as long as you use some joint profile in between, so that the concrete elements aren't touching each other cold. Also, the use of the bolt raises no concerns, as long as you close it off from the environment.

# B

# Design requirements

## B.1. Norms and guidelines

Norms

1. NEN-EN 1990+A1+C2/NB Eurocode 0: Basis of structural design [43].
2. NEN-EN 1991-1-1+A1+C2/NB Eurocode 1: Actions on structures - Part 1-1: General actions – Densities, self-weight, imposed loads for buildings [53].
3. NEN-EN 1991-1-4+A1+C2/NB Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions [41].
4. NEN-EN 1991-1-5+C1/NB Eurocode 1: Actions on structures - Part 1-5: General actions - Thermal actions [42].
5. NEN-EN 1991-1-6+C3/NB Eurocode 1: Actions on structures - Part 1-6: General actions - Actions during execution [40].
6. NEN-EN 1991-2+C1/NB Eurocode 1: Actions on structures – Part 2: Traffic loads on bridges [54].
7. NEN-EN 1992-1-1+C2/NB Eurocode 2: Design of concrete structures - Part 1-1: general rules and rules for buildings [39].
8. NEN-EN 1992-2 Eurocode 2: Design of concrete structures - Concrete bridges - Design and detailing rules [47].
9. NEN-EN 1993-1-1+C2/NB Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings [55].
10. NEN-EN 1993-1-8+C2/NB Eurocode 3: Design of steel structures - Part 1-8: Design of joints [56].
11. NEN-EN 1993-5+C1/NB Eurocode 3: Design of steel structures - Part 5: Piling [57].
12. NEN 9997-1+C2: Geotechnical design of structures - Part 1: General rules [58].

Guidelines

13 CUR Aanbeveling 65: Ontwerp, aanleg en herstel van vloeistofdichte voorzieningen van beton (2005, 2nd edition, revised version) [59].

14 SBRCURnet, 2013, Publication 211E, Quay Walls, second edition [60].

## B.2. Design requirements

**Table B.1:** Technical and operational requirements, product specific system requirements [38]

| Req. ID | Title | Requirement | Relevance for circular platform design |
|---|---|---|---|
| Design | | | |

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|---|---|---|---|
| 1.1 | Project scope | Contractor must realise a jetty suitable for the import of raw materials and the export of pre-treated raw materials, renewable propane and renewable n-paraffin from and to the design ships and all necessary actions. The products must regarded as flammable liquids in classes K0, K3 and K4. | This is the scope of the project and thus this should also be taken into account in the new design. |
| 1.1.1 | Berths | The system must be suitable for the safe accommodation of the design ships given in [38] and all the occurring loading/ballast conditions. | Out of scope |
| 1.2 | Top requirement | The contractor must realise a jetty that meets all of the following requirements. | Explained per below mentioned criterion. |
| 1.2.1 | Loading | The system must be able to absorb all combinations of occurring loads as those resulting from the dead weight, natural loads, ship loads, loads from the superstructure during its entire design lifetime. | These loads partly apply to the platform. These are taken into account in the load conditions that will be considered. |
| 1.2.2 | Permits | The system must comply with all preconditions and regulations arising from permits, decisions and exemptions. | Out of scope |
| 1.2.3 | Safety | The system must be safe for all intended users and those involved during construction, use, maintenance and demolition. | The phases should all be safe for users. This should be taken into account in the calculations and in the (de)constructability of the connections to be designed. |
| 1.2.3.1 | Nautical marking | (Temporary) objects in the water (such as installed pipe piles) have to be marked at all times to avoid collisions during execution. | Out of scope |
| 1.2.3.1 | ATEX | The system must comply with the ATEX zoning 137. | Out of scope |
| 1.2.3.2 | Escape routes | The system must have sufficient escape routes, in line with the ADN 2017 | Out of scope |
| 1.2.4 | Hydrometeo | The system must guarantee its function under all occurring hydro meteorological conditions during the design lifetime, including the water levels given in [38]. | Will be taken into account in the load conditions. |
| 1.2.5 | Taking uncertainties into account | The design and implementation of the system must take into account uncertainties in, among other things: the design and calculation methods, loads, quality, strength and weathering of materials (degradation), uncertainties and tolerances in the implementation. | Calculations of the design should account for uncertainties. |
| 1.2.6 | Maintainability | The system must be designed in such a way that maintenance work is minimally necessary and can be carried out safely, without hindrance, simply (e.g. no divers) in the use phase without making special requirements on the implementation. | This will be considered in the design of connections and elements. |

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| 1.2.6.1 | Replacement of parts (1) | The installations and components that require inspection, maintenance and/or replacement during the design life must be easily accessible on all sides where relevant, such that inspection, maintenance and replacement are safe and practicable without uncommon working methods , additional costs or measures, partly to minimize nuisance to the operator. | This will be considered in the design of connections and elements. |
| 1.2.6.2 | Replacement of parts (2) | The parts that have to be loosened during inspection, maintenance and/or replacement must be designed in such a way that they can still be practically loosened even after corrosion or damage. | This will be considered in the design of connections and elements. |
| 1.2.6.3 | Irreplaceable parts | Parts that are not accessible for inspection or that cannot be replaced must be maintenance-free for the entire design life. | This will be considered in the design of connections and elements. |
| 1.2.7 | Interfaces within the system | The contractor must take into account interfaces between the objects within the system during design and implementation. The integrity of the various objects and the operation of the system must be guaranteed. | This is important for the design of the structure and will be accounted for in this phase. |
| 1.2.9.1 | Constructability 01 | The work must be designed in such a way that it can be built smoothly and safely. | This will be considered in the design of connections and elements. |
| 1.2.9.2 | Constructability 02 | A pile driving analysis must be part of the design. | Out of scope |
| 1.3 | Design lifetime | The system must have a design life of at least 50 years without major preventive and corrective maintenance, unless stated otherwise for specific components. All components must provide the required functionality at the specified safety class throughout their design life. | This has relevance for the entire design and calculation phases. |
| 1.3.1 | Norms and guidelines | The system must comply with the binding documents that follow from the standards, guidelines, directives and manuals that are common and / or applicable in the Netherlands. | Has to be taken into account in the calculation of the platform design. |
| 1.3.2 | Safetyclasses | The system must comply with Eurocode Reliability Class 2. | Has to be taken into account in the calculation of the platform design. |
| 1.3.3 | Design methodology | Mooring structures such as braking works, dolphins and truss piles must be designed in accordance with the guideline for calculating (truss) piles. | Out of scope |
| External interface requirements | | | |

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| 1.5 | Environmental disturbance | The system should not hinder existing infrastructure (including ports, cables and pipelines, shipping routes, dyke bodies, quays, sea walls, etc.) and should not cause existing infrastructure to be functionally negatively affected. If this is not possible, the Contractor (in consultation with the relevant manager) must take appropriate measures so that the nuisance is minimal during implementation and all functionality is restored from completion at the latest. | Has to be taken into account to achieve a realistic platform design |
| 1.5.4 | Interface adjacent terminals | The activities must not hinder the adjacent terminals or jetties. | Out of scope |
| 1.5.5 | Cables and pipes | The work must not affect the surrounding infrastructure. | Out of scope |

**Table B.2:** Technical and operational requirements, jetty [38]

| Req. ID | Title | Requirement | Relevance for circular platform design |
|---|---|---|---|
| Jetty deck and loading zones | | | |
| 3.1 | Layout | The jetty must be designed in accordance with the floor plan as indicated in [38]. | The layout should be kept to as much as possible |
| 3.1.1 | Pile plan | The foundation of the Jetty must be realized in accordance with the pile plan in accordance with drawing 3005 [38]. | The layout will be kept to. |

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| 3.1.2 | Loads | An overview of the loads is given by Technip. They are summarized below.<br><br>General loads platform<br>- Vertical: 15 $kN/m^2$;<br>- Horizontal: 1.5 $kN/m^2$.<br>*Above mentioned loads are including the superstructure of Neste with the exception of the MLA's, fire monitor and JIP cranes*<br><br>MLA (three pieces), loads per MLA<br>- Vertical: 250 kN;<br>- Horizontal: 60 kN;<br>- Moment bottom plate: 750 kNm.<br><br>JIB Crane No 1 and 2, including weight of steel frame, excluding wind<br>- Maximum lifting weight: 2t on 20 m;<br>- On steel frame with 4 legs c.t.c. 2.6 m;<br>- Downward vertical load (compression) per bottom plate: 200 kN;<br>- Upward vertical load (tension) per bottom plate: 100 kN;<br>- Horizontal load: 60 kN.<br><br>JIB Crane No 3, including weight of steel frame, excluding wind<br>- Maximum lifting weight: 1t on 10 m;<br>- On steel frame with 4 legs c.t.c. 2.6 m;<br>- Downward vertical load (compression) per bottom plate: 90 kN;<br>- Upward vertical load (tension) per bottom plate: 30 kN;<br>- Horizontal load: 60 kN.<br><br>Fire monitor<br>- Vertical: 20 kN;<br>- Horizontal: 12 kN;<br>Moment bottom plate: 100 kNm.<br><br>Stripping pump<br>- Vertical: 15 kN/m.<br><br>Loads on concrete pipeline supports<br>- Vertical: 120 kN (=20 kN/m x 6m support);<br>- Horizontal in longitudinal direction (on upper side of support): 12 kN;<br>- Horizontal in transverse direction (on upper side of support): 8 kN;<br>- Moment (longitudinal direction) on lower side support: 19 kNm.<br>Pipe supports have a centre to centre distance of 4.5 m.<br><br>Load on pipes on piperack<br>- Vertical 1.8 $kN/m^2$, for pipes that are not supported by concrete.<br><br>Approach jetty<br>- 5 $kN/m^2$ on walking area. | These loads partly apply to the platform. These are taken into account in the load conditions that will be considered. |

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|---|---|---|---|
| | | Forklift<br>- Load front axle 6500 kg, rear axle 900 kg. Load is applied to the approach jetty and the driveable part of the platform.<br><br>Escaping routes<br>- Loads according to NEN-EN 1991-2. | |
| 3.1.3 | Dimensions loading zone | Dimensions of the deck within the loading zone are a minimum of 45 x 28m minus a 13 x 10.5m rectangle in the southeast corner. | Dimensions of loading zones on the deck will be taken into account in the platform design. |
| 3.1.3.1 | Width loading zone | Width of the deck at the loading zone is at least 45 m. | Dimensions of loading zones on the deck will be taken into account in the platform design. |
| 3.1.4 | Height top of jetty deck | Top side of jetty deck at least NAP +6.0 m. (Excluding casting and gutter). | Height of the deck is relevant for the platform design. |
| 3.1.4.1 | Top of deck | Upon delivery, the deck must have a non-slip concrete surface, with a value of the Leroux number of 70 or higher, in accordance with NEN 2873+w99. | The requirements of the concrete deck are relevant for the platform design. |
| 3.1.4.2 | Slope | The deck has a slope of 1% in the direction of a linear gutter. | The requirements of the concrete deck are relevant for the platform design. |
| 3.1.5 | Bottom of concrete construction | Bottom of concrete construction above NAP +4.0 m. | The minimum height is relevant for the platform design. |
| 3.1.6 | Width roadway | A roadway with a net width of at least 3.5 m must be realized over the entire concourse jetty for the purpose of driving on and off a forklift truck. | Approach jetty dimensions are relevant for the platform design. |
| 3.1.6.1 | Fences and guardrail | Jetty deck must be suitable for the attachment of fencing/railings of and by the operator. | Deck requirements are taken into account in the platform design. |
| 3.1.7 | Pipeline streets | The jetty must be suitable for placing and fixing pipe lines of and by the operator. | Relevant for the platform design. |
| 3.1.8 | Fire fighting facilities | A facility for the mounting of firefighting must be realized in the jetty deck in accordance with Appendix IV (Pump, fire monitor, pipes and connections by third parties). | Deck requirements are taken into account in the platform design. |
| 3.1.9 | Casting | The entire deck is surrounded by a raised concrete edge for the purpose of collecting (extinguishing) water and spill.<br>The liquid-tight loading zone is also surrounded by a concrete edge.<br>In addition, casting facilities are provided for the MLA, JIB Cranes and the Fire monitor. | Deck requirements are taken into account in the platform design. |

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| 3.1.11 | Drainage | Lead-throughs for a rainwater drainage pipe are provided at the lowest point of the deck. Penetrations at the loading zones must be made of stainless steel. Provision for the discharge of waste water from the stainless steel lead-throughs to the terminal sewer is the operator's scope. | Deck requirements are taken into account in the platform design. |
| 3.1.12 | To be concreted anchors | The anchors for the MLA, JIB Crane and the Fire monitor must be placed in the jetty deck. Positioning of MLAs in accordance with the operator's statement, see [ref. 6] | Deck requirements are taken into account in the platform design. |
| 3.1.13 | Grounding points | The grounding of the loading arms, JIB cranes and the extinguishing monitors must be carried out with a smooth reinforcing bar with a resistance <1.0 Ohm that is directly connected to the foundation piles. Two earthing points must be provided per landfill. The grounding network of the jetty must be connected to the grounding network on the shore in order to eliminate voltage differences. Handrails must be provided with earthing. The Contractor must ensure the correct connection to the construction and "discharge" to the substrate. The top of the earthing points must be slightly below or level with the top of the concrete to prevent damage. | Deck requirements are taken into account in the platform design. |
| 3.1.15 | Liquid-thightness | Loading zones suitable for the storage and transfer of chemical products must be liquid-tight.<br>The loading zones are the zones within the raised edges. | Deck requirements are taken into account in the platform design. |
| 3.1.15.1 | Liquid-tight declaration certificate | The construction of the jetty deck must be carried out under a certificate of liquid-tightness. This certificate must be a Liquid-Tight Facility in accordance with AS 6700. | Deck requirements are taken into account in the platform design. |
| 3.1.15.2 | Crack-width reinforced concrete | The design criterion crack width according to CUR recommendation 65 is:<br>situation 1:<br>$h_{liquid} \leq \frac{1}{2} h_{floor}$<br>$crackwidth_{max} = 0.15mm$<br>$h_{floor} \geq 160mm$<br><br>situation 2:<br>$h_{liquid} > \frac{1}{2} h_{floor}$<br>$crackwidth_{max} = 0.07mm$<br>$h_{floor} \geq 250mm$ | Deck requirements are taken into account in the platform design. |
| Deformations and tolerances | | | |
| Req. ID | Title | On the slackening structure bollards should | Relevance for circular platform design |
| 3.2 | Deformations and tolerances | The following deformation and tolerance requirements apply. | Elaborated per requirement |

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| 3.2.3 | Deflection prefab concrete parts | When building a deck from prefabricated parts, the underside of the deck (also during pouring of the pressure layer) must remain flat | |
| 3.2.4 | Steel plates to be casted in precast concrete | When casting in steel plates as a connection between concrete beam and tubular pile, injection holes and expansion space by means of densotape should be applied. See also drawing 3007. | Out of scope |
| 3.2.5 | Displacements | Allowable horizontal displacement of the jetty is 1: 300 of the height of the jetty with a maximum of 100 mm (height of the jetty = distance from the zero moment of the foundation to the top of the jetty deck). | The maximum horizontal displacement is checked in ULS |
| Facilities | | | |
| 3.3 | Rainwater drainage | The deck must be able to drain rainwater in such a way that no puddles remain. | Deck requirements are taken into account in the platform design. |
| 3.3.1 | Chemical products in rainwater | At the location of the impermeable zones, rainwater discharge must be collected in a waste water gutter. (Discharge from gutter to land by Neste). | Deck requirements are taken into account in the platform design. |
| 3.3.2 | Rainwater drainage at liquid-tight zones | Parts of the rainwater drainage system must be suitable for the chemical products that are handled. | Out of scope |
| 3.3.3 | Gutter | The gutter, dimensions 160 x 100 mm, in the deck must be provided with a removable grid suitable for local loads according to 3.1.2. | Deck requirements are taken into account in the platform design. |
| 3.3.5 | Buffer capacity of liquid-tight zones | For the temporary collection of (fire extinguishing) water and spill from products, the liquid-tight zones must have a buffer of 250 $m^3$. | Deck requirements are taken into account in the platform design. |
| 3.3.5.1 | Height thresholds and edge beams | Edge beams and thresholds must have a minimum height of 200 mm. | Deck requirements are taken into account in the platform design. |

**Table B.3:** Technical and operational requirements, pile configuration and piles

| Req. ID | Title | Requirement | Relevance for circular platform design |
|---|---|---|---|
| General | | | |
| 4.1 | Straight mooring line | The berths must have a straight mooring line and be suitable for the safe accommodation of the range of ships as specified in [38]. | Out of scope |
| 4.1.1 | Protection of other structures | In the design of a fender system it must be demonstrated that the smallest and largest design vessel cannot touch the structures under all tidal conditions and loading degrees, taking into account heel, mooring angle and bow radius. | Out of scope |

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| 4.1.2 | Stuck hawsers | In the design it should be avoided that hawsers get stuck during attaching and detaching ships. | Out of scope |
| 4.1.3 | Bed levels berth | NGD: NAP –7.2 m<br>Construction depth: NAP –8.2 m<br>No deepening may take place. | Out of scope |
| 4.1.4 | Berthing configuration | See [38]. | Out of scope |
| 4.1.5 | Bollards | On the slackening structure bollards should be placed at the location as in [38]. | Out of scope |
| 4.1.5.1 | Types of bollards | Types of bollards according to PoR standard dolphins SWL600 kN. | Out of scope |
| 4.1.5.2 | Loaddirection | The bollard loads act in a hawser angle of maximal + and minimal - 45 degrees relative to the horizontal surface and maximal 0-180 degrees relative to the berthing surface. | Out of scope |
| 4.1.7 | Closed upside of open tubular piles | Open tubular piles that are part of the berthing and hawser facilities should be closed and watertight on the upper side. | Out of scope |
| Detached slackening structure/dolphins | | | |
| 4.2.1 | Structurally independent | The slackening structure/dolphins should be robust independent of other structures, and thus should have no load transfer to other structures. | Out of scope |
| 4.2.1.1 | Deformations | The deformed structure may not touch other structures. With a minimal distance of 100 mm in ALS. | Out of scope |
| 4.2.1.2 | Design | The design of the slackening structure should be according to PoR standards. | Out of scope |
| 4.2.2 | Escape routes inland shipping | The berth should have sufficient escape routes by having standard ladders, at the place of the front and back of the inland ship according to ADN. | Out of scope |
| 4.2.3 | Bollards inland shipping | Bollards on NAP +1.5m and NAP +3.5 m and NAP +6.2m (height bollard pin). | Out of scope |
| 4.2.3.1 | Deviation levels | The levels of the bollards can maximally deviate +/- 0.25m from the above mentioned levels. | Out of scope |
| 4.2.3.2 | Accessibility bollards | The distance from the front of the bollards to the mooring line of the bollards in the slackening structure should be minimally 0.15m. The distance between the upper side of the bollard and waling should be minimally 0.35m. | Out of scope |
| 4.2.3.3 | Loaddirection on bollards | The bollard loads act in a hawser angle of maximal + and minimal - 45 degrees relative to the horizontal surface and maximal 0-180 degrees relative to the berthing surface. | Out of scope |
| 4.2.4.1 | Bollard pattern | At the place of the ladders, bollards will be place twice. | Out of scope |

| | | | |
|---|---|---|---|
| 4.2.5 | Hawserguider | Slackening structure at the upper side at the place of bollards is facilitated with a hawserguider over the entire length. | Out of scope |
| 4.2.7 | Sliding fenders and waling | Over the entire length, sliding fenders should be applied. The maximal centre to centre distance is 5m. | Out of scope |
| 4.2.7.1 | Sliding fender length | Sliding fenders of slackening structure should minimally range from NAP +5.00m to NAP -1.80 m. At doplhins the sliding fenders will be extended to be able to place the ladders. | Out of scope |
| 4.2.7.2 | Chamfer sliding fenders | The upper and lower side of the sliding fenders should be chamfered. | Out of scope |
| 4.2.7.3 | Levels support sliding fenders | The lower side of the support will not be lower than NAP 0m and the upper side of the support is maximally 300 mm below the upper side of the sliding fender. | Out of scope |
| 4.2.8 | Mooring line | The front of the sliding fender support = mooring line | Out of scope |
| 4.2.8.1 | Bolt head | The front of the bolt head should be at least 50 mm countersunk relative to the front of the sliding fender. | Out of scope |
| 4.2.9 | Walkway on slackening structure | The entire length of the walkway should have sufficient space for rowers, according to richtlijnen afmeervoorzieningen Rotterdam (versie 5 september 2011). The walkway has a uniformly distributed load: 5 kPa (usecategory C-C4). | Out of scope |
| 4.2.9.1 | Level upper side | Level of upper side of the walkway is NAP +6.3m. | Out of scope |
| 4.2.9.2 | Walkway safety | On the longitudinal side the walkway should have fences (except at the loading zones, edge protection, antislip grid and entrance to jetty). | Out of scope |
| 4.2.10 | Ladders (drowning men and skippers) | Standard PoR ladder, center to center distance 20 m from upper side of slackening structure and at least until NAP -2.30 m. | Out of scope |
| 4.2.11 | Laboratory stairs | The slackening structure has one laboratory stairs according to standard detail. | Out of scope |
| 4.2.12 | Bollard numbering | Numbering according to standard. Start west with number 01. | Out of scope |

**Table B.4:** Technical and operational requirements, nautical facilities [38]

| Req. ID | Title | Requirement | Relevance for circular platform design |
|---|---|---|---|
| Collision security/head slackening structure | | | |
| 5.1.1 | Velocity during collision | The boat velocity during impact of inland ship: 0.75 m/s at level NAP+2.5 m perpendicular to the collision protection. | Out of scope |
| 5.1.2 | Plastic deformations | Collision protection may deform plastically at collision, if other structures are not touched. | Out of scope |
| 5.1.3 | Visibility | Collision protection should have straps of yellow coating, applied according to specification of supplier. | Out of scope |

| | | | |
|---|---|---|---|
| 5.1.4 | Not floating | Do not use floating sleepers, but a rigid construction. | Connections will be changed in the design, but still rib plates will be non floating. |
| Signage | | | |
| 5.2.1 | BPR signs | Within the project, BPR signs need to be placed of 1000 mm x 1000 mm (inland shipping) with the following characteristics: A5. To be attached at the front of the concrete deck. | Out of scope |
| 5.2.3 | Bank front number signs | The berthing structure should have bank front number signs at circa 1 m below the upper side of the jetty. | Out of scope |
| Visibility measures | | | |
| 5.4.4 | Tubular pile covers | To apply to tubular pile, according to Appendix A paragraph 10.5 of the Standaard Maritieme Infra 2018. | Out of scope |

**Table B.5:** Technical and operational requirements, excavations, dredging, bank and shore works [38]

| Req. ID | Title | Requirement | Relevance for circular platform design |
|---|---|---|---|
| Bank and shore works | | | |
| 6.4.1 | Bank and shore works | Realisation of the bank and shore works should be executed within the work area. | Out of scope |
| 6.4.3 | Geometrically closed | All granular structures should be geometrically closed. | Out of scope |
| 6.4.4 | Complement slope | Slopes that are damaged during the work should be complemented according to the original design. | Out of scope |

# C
# Reference jetty analysis

## C.1. Outline of complete jetty

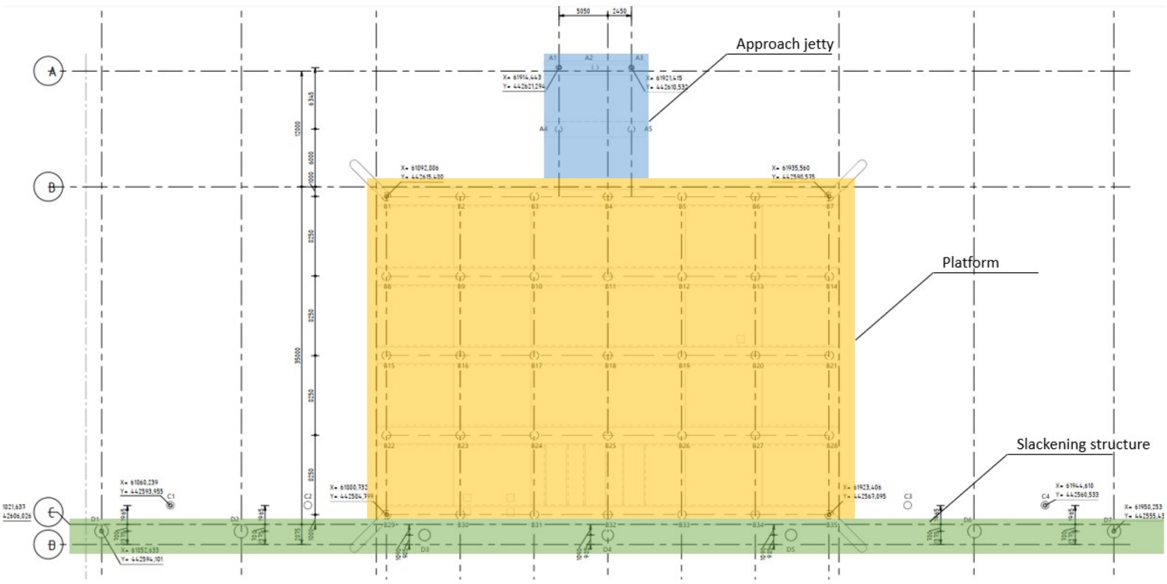



**Figure C.1:** Overview of reference jetty parts

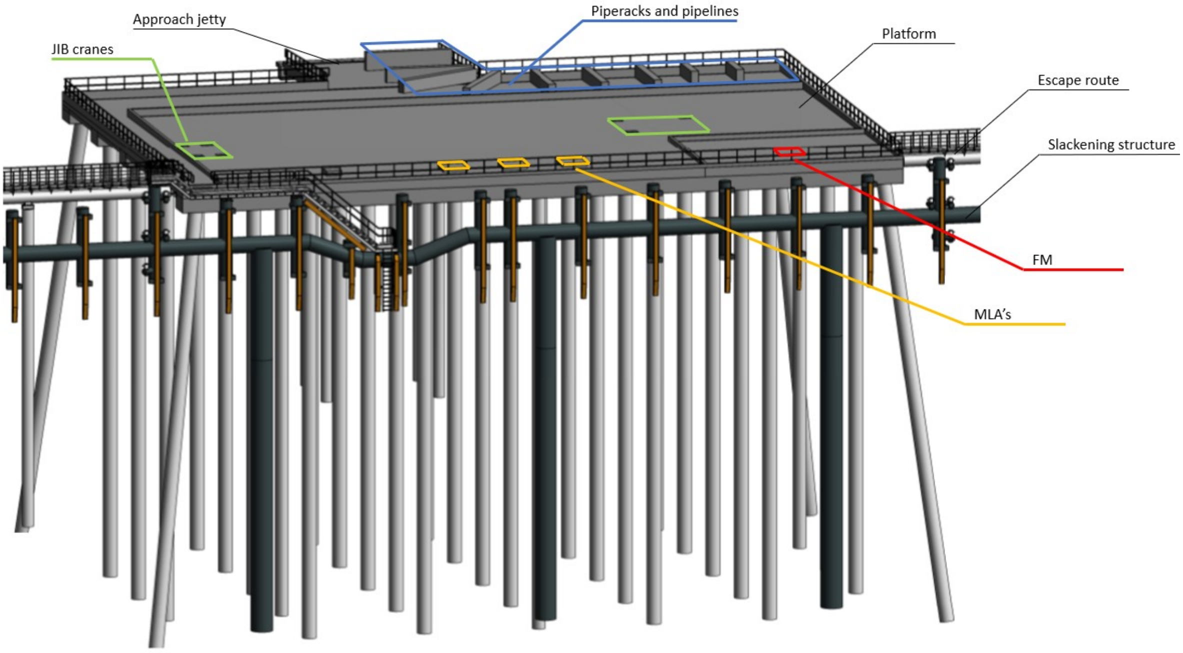



**Figure C.2:** Overview of reference jetty parts, MLA's, piperacks and pipelines

# C.2. Material specifications

**Table C.1:** Material properties of concrete [31]

| | |
|---|---|
| Strength class | C35/45 |
| Characteristic cylinder compression strength ($f_{ck}$) | 35 $N/mm^2$ |
| E-modulus uncracked ($E_{cm}$) | 34000 $N/mm^2$ |
| E_modulus cracked | 11333 $N/mm^2$ |
| Volumetric weight ($\gamma_c$) | 2500 $kg/m^3$ |

**Table C.2:** Material properties of reinforcement steel [31]

| | |
|---|---|
| Strength class | B500B |
| Characteristic tension strength ($f_{tk}$) | 540 $N/mm^2$ |
| Characteristic yield strength ($f_{yk}$) | 500 $N/mm^2$ |
| Design value yield strength ($f_{yd}$) | 435 $N/mm^2$ |
| E-modulus | $2.0 \cdot 10^5$ $N/mm^2$ |

**Table C.3:** Material properties of steel [31]

| | |
|---|---|
| Steel grade | S355 |
| Yield strength | 355 $N/mm^2$ |
| E-modulus | $2.1 \cdot 10^5$ $N/mm^2$ |

**Table C.4:** Concrete cover per concrete element [31]

| Location | Concrete strength | Environment class | Construction class | Minimum concrete cover $c_{min}$ [mm] | Execution tolerance $\Delta c_{dev}$ [mm] | Nominal concrete cover $c_{nom}$ [mm] | Applied cover $c_{toep}$ [mm] |
|---|---|---|---|---|---|---|---|
| Deck upper side | C35/45 | XC4, XD3, XS3, XF4, XA2 | S3 | 35 | 5 | 40 | 50 |
| Deck lower side | C35/45 | XC4, XS3, XF4 | S3 | 35 | 5 | 40 | 50 |
| Prefab rib plates lower side | C35/45 | XC4, XS3, XF4 | S3 | 35 | 5 | 40 | 75 |
| Prefab rib plates sides | C35/45 | XC4, XS3, XF4 | S3 | 35 | 5 | 40 | 50 |
| Prefab rib plates rising edge | C35/45 | XC4, XD3, XS3, XF4, XA2 | S4 | 40 | 5 | 45 | 50 |
| Abutment | C35/45 | XC4, XD3, XS1, XF4 | S4 | 40 | 5 | 45 | 50 |

**Table C.5:** Steel corrosion per zone

| Zone | Zone bottom level [m NAP] | Corrosion [mm/year] |
|---|---|---|
| Atmospheric zone | 6 | 0.05 |
| Splash zone | 1.11 | 0.15 |
| Tide zone | -1.85 | 0.1 |
| Permanent underwater zone | -9.7 | 0.02 |
| In soil zone | bottom of pile | 0.02 |

## C.3. Element connections

**Steel foundation to prefab rib plate**

The connection between the foundation piles and the prefab concrete rib plates is rigid. A steel plate is connected to the concrete with anchor rods and is placed before pouring the concrete. The rods are welded onto the steel plate. The finished prefab concrete rib plate has the rods sticking out on the top side, so that the in situ concrete will also attach to this. On the lower side of the rib plate, the steel plate is at the same level as the surrounding concrete. The steel plate is welded onto the tubular foundation pile in situ [31]. The detail is displayed in Figure C.3.

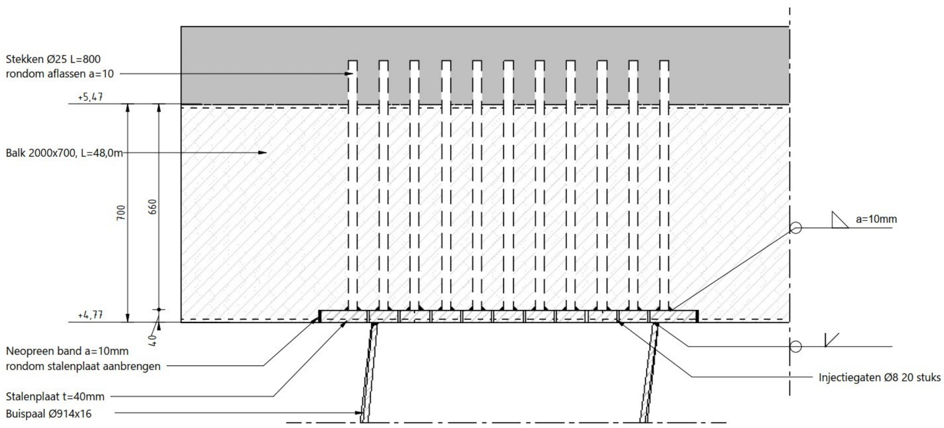



**Figure C.3:** Detail of fixed pile to beam connection [61]

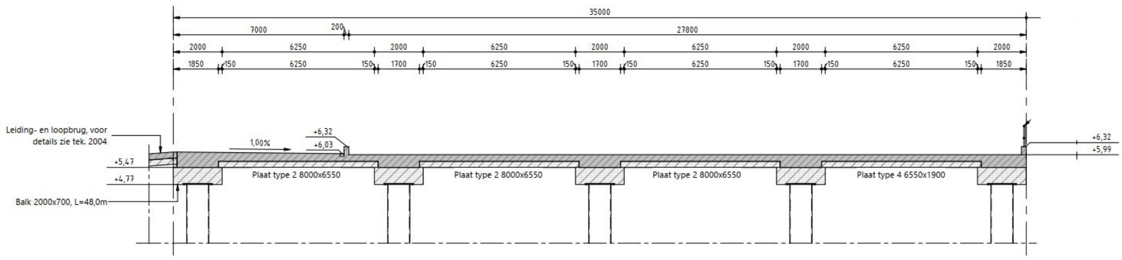
**Prefab rib plate to prefab rib plate**

With the help of a large floating crane, it is possible to place the large prefab rib plates at once. However, this requires a lot of space on the ground. In this project, this means that other jetties temporarily have to be taken out of use. This is unwanted, as stated in requirement 1.5 in Appendix B. Therefore it is decided to divide the rib plates into shorter elements and connect them in situ. The length of the rib plates is chosen so that they have to be connected between piles. A wet cast connection is made to obtain full continuity of the rib plate. This makes the connections in the rib plate rigid. To make this connection, reinforcement will stick out of the rib plate in the longitudinal direction and additional reinforcement is added in situ before pouring the concrete [31].

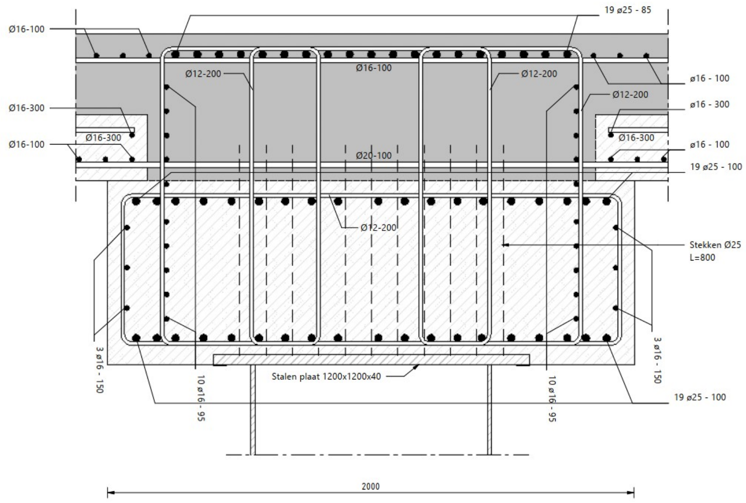
**Prefab rib plate to prefab deck plates**

The prefab deck plates are placed on top of the sides of the prefab rib plates. Those are also joined by a wet cast connection. Reinforcement and rods stick out from the upper side of the rib plate and from the sides of the deck plate. The space between the deck plates is filled with concrete. To obtain a liquid-tight floor, also a layer of concrete is poured on top of the deck plates. This compression layer creates a monolith deck. The connections between the rib plate and deck plates are fixed [31]. A side view of the concrete deck and the details of a wet cast connection are shown in Figure C.4.

At the side edges perpendicular to the rib plates, the deck plates touch each other. At these locations, the sides of the deck plates are not fully horizontal. This allows the poured concrete to flow in between the deck plates, which connects them to each other [31]. These details are shown in Figure C.5.




**(a)** Side view




**(b)** Detail

**Figure C.4:** Overview of rib plate to deck plate connections [61]

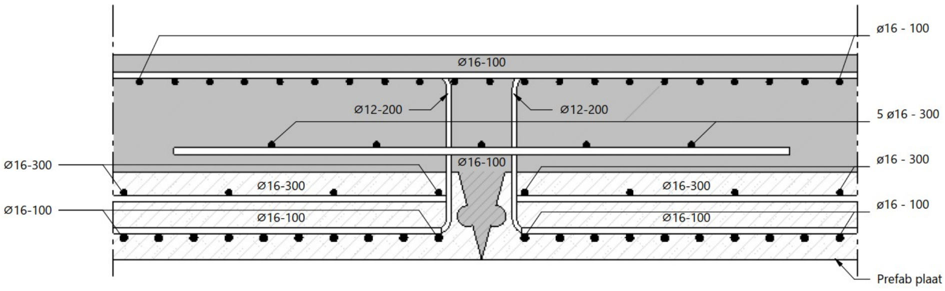



**Figure C.5:** Details of deck plate edges [61]

## C.3.1. Magnitude of calculation results

| Staaf | Belasting | elem | sigx+ [MPa] | sigy+ [MPa] | sigxy+ [MPa] |
|---|---|---|---|---|---|
| | | | sigx- [MPa] | sigy- [MPa] | sigxy- [MPa] |
| E1 | UGT | 3510 | **-7,7** | -3,9 | -0,2 |
| | | | -1,2 | -0,6 | -1,4 |
| E1 | UGT | 4674 | **11,5** | 12,6 | 1,5 |
| | | | 1,6 | -1,5 | 0,8 |
| E1 | UGT | 26030 | -7,5 | **-6,9** | -0,6 |
| | | | -0,2 | -1,8 | -0,8 |
| E1 | UGT | 10975 | 9,1 | **14,2** | 2,6 |
| | | | 0,3 | -2,0 | 0,9 |
| E1 | UGT | 1222 | 0,2 | -0,7 | **-5,1** |
| | | | **-5,5** | -7,7 | -0,1 |
| E1 | UGT | 10660 | 9,6 | 13,1 | **5,0** |
| | | | 1,3 | 0,3 | 0,8 |
| E1 | UGT | 1220 | 1,9 | 4,4 | 4,8 |
| | | | **5,3** | 4,3 | 0,4 |
| E1 | UGT | 10976 | 2,0 | -1,3 | -3,3 |
| | | | -1,3 | **-11,1** | -1,1 |
| E1 | UGT | 4773 | -0,4 | 0,8 | 0,2 |
| | | | 4,5 | **6,2** | 0,3 |
| E1 | UGT | 1220 | -5,4 | -4,6 | -0,6 |
| | | | -1,2 | -4,0 | **-4,8** |
| E1 | UGT | 1222 | 6,1 | 8,5 | 0,2 |
| | | | 0,1 | 0,6 | **4,9** |

**Figure C.6:** Extreme stresses in the deck

| Naam | dx [m] | Belasting | N [kN] | $V_y$ [kN] | $V_z$ [kN] | $M_x$ [kNm] | $M_y$ [kNm] | $M_z$ [kNm] |
|---|---|---|---|---|---|---|---|---|
| S121 | 31,650+ | UGT-4a/1 | **-1044** | -23 | 643 | -78 | -1219 | 39 |
| S121 | 42,755- | UGT-3a/2 | **1566** | -6 | 65 | -87 | 1620 | -4 |
| S137 | 29,300+ | UGT-3b/3 | 353 | **-924** | -943 | -314 | 1318 | 1074 |
| S137 | 21,300- | UGT-3b/4 | 482 | **949** | 225 | 264 | 1548 | 1210 |
| S129 | 31,389- | UGT-3b/5 | 96 | 53 | **-1476** | -116 | -1227 | -70 |
| S129 | 24,260- | UGT-3b/6 | 223 | -135 | **1698** | 12 | -1420 | 34 |
| S121 | 1,050+ | UGT-7b/7 | 71 | -168 | 924 | **-777** | -588 | 185 |
| S129 | 46,950- | UGT-7b/8 | 87 | 174 | -924 | **831** | -524 | 193 |
| S129 | 16,350+ | UGT-3b/9 | -180 | 53 | 1608 | -91 | **-2047** | 92 |
| S137 | 21,300- | UGT-5a/10 | 876 | 690 | 288 | 208 | **1892** | 908 |
| S129 | 29,300+ | UGT-3b/11 | 351 | 687 | -656 | 155 | 724 | **-556** |
| S137 | 21,300- | UGT-3b/12 | 423 | 936 | 189 | 255 | 1540 | **1211** |

**Figure C.7:** Extreme internal forces in rib plates in reference jetty

| Naam | dx [m] | Belasting | N [kN] | $V_y$ [kN] | $V_z$ [kN] | $M_x$ [kNm] | $M_y$ [kNm] | $M_z$ [kNm] |
|---|---|---|---|---|---|---|---|---|
| S133 | 30,250+ | UGT-3b/1 | **-3246** | 2 | 0 | 0 | 0 | -1 |
| S6 | 0,000 | UGT-8b/2 | **-81** | 4 | -134 | **0** | 631 | 92 |
| S109 | 0,000 | UGT-8b/3 | -980 | **-220** | -18 | 0 | 125 | 1191 |
| S6 | 7,600- | UGT-8a/4 | -113 | 5 | **-145** | 0 | -392 | 104 |
| S7 | 0,000 | UGT-3a/5 | -1081 | -26 | **207** | 0 | **-1393** | 160 |
| S6 | 0,000 | UGT-8a/6 | -90 | 5 | -141 | 0 | **696** | 68 |
| S110 | 0,000 | UGT-3b/7 | -1465 | **210** | 7 | 0 | -19 | **-1362** |
| S126 | 0,000 | UGT-8b/8 | -1589 | -176 | -4 | 0 | 36 | **1382** |

**Figure C.8:** Extreme internal forces in piles in reference jetty

**Table C.6:** Governing forces in pile to rib plate connections in reference jetty

| Staaf | css | dx [m] | Belasting | N [kN] | Vy [kN] | Vz [kN] | My [kNm] | Mz [kNm] |
|---|---|---|---|---|---|---|---|---|
| S123 | CS10 - Buis | 0 | UGT-3a/231 | **-2660** | 21 | 134 | -1070 | -164 |
| S109 | CS10 - Buis | 0 | UGT-8b/15 | -980 | **-220** | -18 | 125 | 1191 |
| S111 | CS10 - Buis | 0 | UGT-3b/16 | -1278 | **210** | -6 | 93 | -1355 |
| S6 | CS10 - Buis | 0 | UGT-8a/21 | -90 | 5 | **-141** | **696** | 68 |
| S7 | CS10 - Buis | 0 | UGT-3a/18 | -1081 | -26 | **207** | **-1393** | 160 |
| S110 | CS10 - Buis | 0 | UGT-3b/16 | -1465 | 210 | 7 | -19 | **-1362** |
| S126 | CS10 - Buis | 0 | UGT-8b/22 | -1589 | -176 | -4 | 36 | **1382** |

# D

# Design conditions and models

## D.1. Load conditions

# Loads

## Load cases

| Name | Action type | Load group | Duration |
|---|---|---|---|
| PB.1 - Eigen gewicht | Permanent | LG1 | |
| PB.2 - Krimp | Permanent | LG1 | |
| PB.3.1 - BGT oplegreactie vluchtweg | Permanent | LG1 | |
| PB.3.2 - UGT oplegreactie vluchtweg | Permanent | LG1 | |
| VB.0.1 piperacks | Variable | VB.0 piperacks | Short |
| VB.0.2 piperacks | Variable | VB.0 piperacks | Short |
| VB.1.1 - Variabele belasting X.1 - Verticaal | Variable | VB.1 - VB - Verticaal | Short |
| VB.1.2 - Variabele belasting X.2 - Verticaal | Variable | VB.1 - VB - Verticaal | Short |
| VB.1.3 - Variabele belasting Y.1 - Verticaal | Variable | VB.1 - VB - Verticaal | Short |
| VB.1.4 - Variabele belasting Y.2 - Verticaal | Variable | VB.1 - VB - Verticaal | Short |
| VB.1.5 - Variabele belasting Y.3 - Verticaal | Variable | VB.1 - VB - Verticaal | Short |
| VB.1.6 - Variabele belasting Y.4 - Verticaal | Variable | VB.1 - VB - Verticaal | Short |
| VB.2.1 - Variabele belasting horizontaal x-richting | Variable | VB.2 - VB- horizontaal | Short |
| VB.2.2 - Variabele belasting horizontaal y-richting | Variable | VB.2 - VB- horizontaal | Short |
| VB.2.3 - Variabele belasting horizontaal y-richting land | Variable | VB.2 - VB- horizontaal | Short |
| VB.3.1 - MLA and JIB crane- X-richting | Variable | VB.3 - MLA | Short |
| VB.3.2 - MLA and JIB crane - Y-richting | Variable | VB.3 - MLA | Short |
| VB.3.3 - MLA and JIB crane - 45gr | Variable | VB.3 - MLA | Short |
| VB.4.1 - Wind -x-richting | Variable | VB.4 - wind | Short |
| VB.4.2 - Wind -y-richting | Variable | VB.4 - wind | Short |
| VB.5.1 - Temperatuur - comb.1 | Variable | VB.5 - Temperatuur | Short |
| VB.5.2 - Temperatuur - comb.2 | Variable | VB.5 - Temperatuur | Short |
| VB.5.3 - Temperatuur - comb.3 | Variable | VB.5 - Temperatuur | Short |
| VB.5.4 - Temperatuur - comb.4 | Variable | VB.5 - Temperatuur | Short |
| VB.6.1 - FM - X richting | Variable | VB.6 - FM | Short |
| VB.6.2 - FM - y richting | Variable | VB.6 - FM | Short |
| VB.6.3 - FM - 45 gr | Variable | VB.6 - FM | Short |
| VB.7.1- VB -wal - variabel | Variable | VB.7 - VB wal | Short |
| VB.7.2 -VB - wal + hef midden | Variable | VB.7 - VB wal | Short |
| VB.7.3 -VB - wal + hef ligger | Variable | VB.7 - VB wal | Short |
| VB.8 heftruck op platform + geen piperacks | Variable | VB.8 - heftruck | Short |

## Combinations

| Name | Type | Load cases | Coeff. [-] |
|---|---|---|---|
| UGT-1a | Envelope - ultimate | PB.1 - Eigen gewicht | 1,35 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,20 |
| | | VB.0.2 piperacks | 1,20 |
| | | VB.1.1 - Variabele belasting X.1 - Verticaal | 1,20 |
| | | VB.1.2 - Variabele belasting X.2 - Verticaal | 1,20 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,20 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,20 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,20 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,20 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,20 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,20 |
| | | VB.4.1 - Wind -x-richting | 0,45 |
| | | VB.4.2 - Wind -y-richting | 0,45 |
| | | VB.6.1 - FM - X richting | 1,20 |
| | | VB.6.2 - FM - y richting | 1,20 |
| | | VB.6.3 - FM - 45 gr | 1,20 |
| | | VB.7.1- VB -wal - variabel | 0,60 |
| | | VB.7.2 -VB - wal + hef midden | 0,60 |
| | | VB.7.3 -VB - wal + hef ligger | 0,60 |
| UGT-2a | Envelope - ultimate | PB.1 - Eigen gewicht | 0,90 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,20 |
| | | VB.0.2 piperacks | 1,20 |
| | | VB.1.1 - Variabele belasting X.1 - Verticaal | 1,20 |
| | | VB.1.2 - Variabele belasting X.2 - Verticaal | 1,20 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,20 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,20 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,20 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,20 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,20 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,20 |
| | | VB.4.1 - Wind -x-richting | 0,45 |
| | | VB.4.2 - Wind -y-richting | 0,45 |
| | | VB.6.1 - FM - X richting | 1,20 |
| | | VB.6.2 - FM - y richting | 1,20 |
| | | VB.6.3 - FM - 45 gr | 1,20 |
| | | VB.7.1- VB -wal - variabel | 0,60 |

| Name | Type | Load cases | Coeff. [-] |
|---|---|---|---|
| | | VB.7.2 -VB - wal + hef midden | 0,60 |
| | | VB.7.3 -VB - wal + hef ligger | 0,60 |
| UGT-3a | Envelope - ultimate | PB.1 - Eigen gewicht | 1,20 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,50 |
| | | VB.0.2 piperacks | 1,50 |
| | | VB.1.1 - Variabele belasting X.1 - Verticaal | 1,50 |
| | | VB.1.2 - Variabele belasting X.2 - Verticaal | 1,50 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,50 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,50 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,50 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,20 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,20 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,20 |
| | | VB.4.1 - Wind -x-richting | 0,45 |
| | | VB.4.2 - Wind -y-richting | 0,45 |
| | | VB.6.1 - FM - X richting | 1,20 |
| | | VB.6.2 - FM - y richting | 1,20 |
| | | VB.6.3 - FM - 45 gr | 1,20 |
| | | VB.7.1- VB -wal - variabel | 0,60 |
| | | VB.7.2 -VB - wal + hef midden | 0,60 |
| | | VB.7.3 -VB - wal + hef ligger | 0,60 |
| UGT-4a | Envelope - ultimate | PB.1 - Eigen gewicht | 0,90 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,50 |
| | | VB.0.2 piperacks | 1,50 |
| | | VB.1.1 - Variabele belasting X.1 - Verticaal | 1,50 |
| | | VB.1.2 - Variabele belasting X.2 - Verticaal | 1,50 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,50 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,50 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,50 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,20 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,20 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,20 |
| | | VB.4.1 - Wind -x-richting | 0,45 |
| | | VB.4.2 - Wind -y-richting | 0,45 |
| | | VB.6.1 - FM - X richting | 1,20 |
| | | VB.6.2 - FM - y richting | 1,20 |
| | | VB.6.3 - FM - 45 gr | 1,20 |
| | | VB.7.1- VB -wal - variabel | 0,60 |
| | | VB.7.2 -VB - wal + hef midden | 0,60 |
| | | VB.7.3 -VB - wal + hef ligger | 0,60 |
| UGT-5a | Envelope - ultimate | PB.1 - Eigen gewicht | 1,20 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,50 |
| | | VB.0.2 piperacks | 1,50 |
| | | VB.1.1 - Variabele belasting X.1 - Verticaal | 1,20 |
| | | VB.1.2 - Variabele belasting X.2 - Verticaal | 1,20 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,20 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,20 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,20 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,50 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,50 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,50 |
| | | VB.4.1 - Wind -x-richting | 0,45 |
| | | VB.4.2 - Wind -y-richting | 0,45 |
| | | VB.6.1 - FM - X richting | 1,20 |
| | | VB.6.2 - FM - y richting | 1,20 |
| | | VB.6.3 - FM - 45 gr | 1,20 |
| | | VB.7.1- VB -wal - variabel | 0,60 |
| | | VB.7.2 -VB - wal + hef midden | 0,60 |
| | | VB.7.3 -VB - wal + hef ligger | 0,60 |
| UGT-6a | Envelope - ultimate | PB.1 - Eigen gewicht | 0,90 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,50 |
| | | VB.0.2 piperacks | 1,50 |
| | | VB.1.1 - Variabele belasting X.1 - Verticaal | 1,20 |
| | | VB.1.2 - Variabele belasting X.2 - Verticaal | 1,20 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,20 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,20 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,20 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,50 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,50 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,50 |
| | | VB.4.1 - Wind -x-richting | 0,45 |
| | | VB.4.2 - Wind -y-richting | 0,45 |

| Name | Type | Load cases | Coeff. [-] |
|---|---|---|---|
| | | VB.6.1 - FM - X richting | 1,20 |
| | | VB.6.2 - FM - y richting | 1,20 |
| | | VB.6.3 - FM - 45 gr | 1,20 |
| | | VB.7.1- VB -wal - variabel | 0,60 |
| | | VB.7.2 -VB - wal + hef midden | 0,60 |
| | | VB.7.3 -VB - wal + hef ligger | 0,60 |
| UGT-7a | Envelope - ultimate | PB.1 - Eigen gewicht | 1,20 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,50 |
| | | VB.0.2 piperacks | 1,50 |
| | | VB.1.1 - Variabele belasting X.1 - Verticaal | 1,20 |
| | | VB.1.2 - Variabele belasting X.2 - Verticaal | 1,20 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,20 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,20 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,20 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,20 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,20 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,20 |
| | | VB.4.1 - Wind -x-richting | 1,50 |
| | | VB.4.2 - Wind -y-richting | 1,50 |
| | | VB.6.1 - FM - X richting | 1,20 |
| | | VB.6.2 - FM - y richting | 1,20 |
| | | VB.6.3 - FM - 45 gr | 1,20 |
| | | VB.7.1- VB -wal - variabel | 0,60 |
| | | VB.7.2 -VB - wal + hef midden | 0,60 |
| | | VB.7.3 -VB - wal + hef ligger | 0,60 |
| UGT-8a | Envelope - ultimate | PB.1 - Eigen gewicht | 0,90 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,50 |
| | | VB.0.2 piperacks | 1,50 |
| | | VB.1.1 - Variabele belasting X.1 - Verticaal | 1,20 |
| | | VB.1.2 - Variabele belasting X.2 - Verticaal | 1,20 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,20 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,20 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,20 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,20 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,20 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,20 |
| | | VB.4.1 - Wind -x-richting | 1,50 |
| | | VB.4.2 - Wind -y-richting | 1,50 |
| | | VB.6.1 - FM - X richting | 1,20 |
| | | VB.6.2 - FM - y richting | 1,20 |
| | | VB.6.3 - FM - 45 gr | 1,20 |
| | | VB.7.1- VB -wal - variabel | 0,60 |
| | | VB.7.2 -VB - wal + hef midden | 0,60 |
| | | VB.7.3 -VB - wal + hef ligger | 0,60 |
| UGT-9a | Envelope - ultimate | PB.1 - Eigen gewicht | 1,20 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,50 |
| | | VB.0.2 piperacks | 1,50 |
| | | VB.1.1 - Variabele belasting X.1 - Verticaal | 1,20 |
| | | VB.1.2 - Variabele belasting X.2 - Verticaal | 1,20 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,20 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,20 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,20 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,20 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,20 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,20 |
| | | VB.4.1 - Wind -x-richting | 0,45 |
| | | VB.4.2 - Wind -y-richting | 0,45 |
| | | VB.6.1 - FM - X richting | 1,50 |
| | | VB.6.2 - FM - y richting | 1,50 |
| | | VB.6.3 - FM - 45 gr | 1,50 |
| | | VB.7.1- VB -wal - variabel | 0,60 |
| | | VB.7.2 -VB - wal + hef midden | 0,60 |
| | | VB.7.3 -VB - wal + hef ligger | 0,60 |
| UGT-10a | Envelope - ultimate | PB.1 - Eigen gewicht | 0,90 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,50 |
| | | VB.0.2 piperacks | 1,50 |
| | | VB.1.1 - Variabele belasting X.1 - Verticaal | 1,20 |
| | | VB.1.2 - Variabele belasting X.2 - Verticaal | 1,20 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,20 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,20 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,20 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,20 |

| Name | Type | Load cases | Coeff. [-] |
|---|---|---|---|
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,20 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,20 |
| | | VB.4.1 - Wind -x-richting | 0,45 |
| | | VB.4.2 - Wind -y-richting | 0,45 |
| | | VB.6.1 - FM - X richting | 1,50 |
| | | VB.6.2 - FM - y richting | 1,50 |
| | | VB.6.3 - FM - 45 gr | 1,50 |
| | | VB.7.1- VB -wal - variabel | 0,60 |
| | | VB.7.2 -VB - wal + hef midden | 0,60 |
| | | VB.7.3 -VB - wal + hef ligger | 0,60 |
| UGT-11a | Envelope - ultimate | PB.1 - Eigen gewicht | 1,20 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,50 |
| | | VB.0.2 piperacks | 1,50 |
| | | VB.1.1 - Variabele belasting X.1 - Verticaal | 1,20 |
| | | VB.1.2 - Variabele belasting X.2 - Verticaal | 1,20 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,20 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,20 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,20 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,20 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,20 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,20 |
| | | VB.4.1 - Wind -x-richting | 0,45 |
| | | VB.4.2 - Wind -y-richting | 0,45 |
| | | VB.6.1 - FM - X richting | 1,20 |
| | | VB.6.2 - FM - y richting | 1,20 |
| | | VB.6.3 - FM - 45 gr | 1,20 |
| | | VB.7.1- VB -wal - variabel | 1,35 |
| | | VB.7.2 -VB - wal + hef midden | 1,35 |
| | | VB.7.3 -VB - wal + hef ligger | 1,35 |
| UGT-12a | Envelope - ultimate | PB.1 - Eigen gewicht | 0,90 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,50 |
| | | VB.0.2 piperacks | 1,50 |
| | | VB.1.1 - Variabele belasting X.1 - Verticaal | 1,20 |
| | | VB.1.2 - Variabele belasting X.2 - Verticaal | 1,20 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,20 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,20 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,20 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,20 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,20 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,20 |
| | | VB.4.1 - Wind -x-richting | 0,45 |
| | | VB.4.2 - Wind -y-richting | 0,45 |
| | | VB.6.1 - FM - X richting | 1,20 |
| | | VB.6.2 - FM - y richting | 1,20 |
| | | VB.6.3 - FM - 45 gr | 1,20 |
| | | VB.7.1- VB -wal - variabel | 1,35 |
| | | VB.7.2 -VB - wal + hef midden | 1,35 |
| | | VB.7.3 -VB - wal + hef ligger | 1,35 |
| UGT-1b | Envelope - ultimate | PB.1 - Eigen gewicht | 1,35 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,20 |
| | | VB.0.2 piperacks | 1,20 |
| | | VB.1.3 - Variabele belasting Y.1 - Verticaal | 1,20 |
| | | VB.1.4 - Variabele belasting Y.2 - Verticaal | 1,20 |
| | | VB.1.5 - Variabele belasting Y.3 - Verticaal | 1,20 |
| | | VB.1.6 - Variabele belasting Y.4 - Verticaal | 1,20 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,20 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,20 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,20 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,20 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,20 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,20 |
| | | VB.4.1 - Wind -x-richting | 0,45 |
| | | VB.4.2 - Wind -y-richting | 0,45 |
| | | VB.6.1 - FM - X richting | 1,20 |
| | | VB.6.2 - FM - y richting | 1,20 |
| | | VB.6.3 - FM - 45 gr | 1,20 |
| | | VB.7.1- VB -wal - variabel | 0,60 |
| | | VB.7.2 -VB - wal + hef midden | 0,60 |
| | | VB.7.3 -VB - wal + hef ligger | 0,60 |
| UGT-2b | Envelope - ultimate | PB.1 - Eigen gewicht | 0,90 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,20 |
| | | VB.0.2 piperacks | 1,20 |

| Name | Type | Load cases | Coeff. [-] |
|---|---|---|---|
| | | VB.1.3 - Variabele belasting Y.1 - Verticaal | 1,20 |
| | | VB.1.4 - Variabele belasting Y.2 - Verticaal | 1,20 |
| | | VB.1.5 - Variabele belasting Y.3 - Verticaal | 1,20 |
| | | VB.1.6 - Variabele belasting Y.4 - Verticaal | 1,20 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,20 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,20 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,20 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,20 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,20 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,20 |
| | | VB.4.1 - Wind -x-richting | 0,45 |
| | | VB.4.2 - Wind -y-richting | 0,45 |
| | | VB.6.1 - FM - X richting | 1,20 |
| | | VB.6.2 - FM - y richting | 1,20 |
| | | VB.6.3 - FM - 45 gr | 1,20 |
| | | VB.7.1- VB -wal - variabel | 0,60 |
| | | VB.7.2 -VB - wal + hef midden | 0,60 |
| | | VB.7.3 -VB - wal + hef ligger | 0,60 |
| UGT-3b | Envelope - ultimate | PB.1 - Eigen gewicht | 1,20 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,50 |
| | | VB.0.2 piperacks | 1,50 |
| | | VB.1.3 - Variabele belasting Y.1 - Verticaal | 1,50 |
| | | VB.1.4 - Variabele belasting Y.2 - Verticaal | 1,50 |
| | | VB.1.5 - Variabele belasting Y.3 - Verticaal | 1,50 |
| | | VB.1.6 - Variabele belasting Y.4 - Verticaal | 1,50 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,50 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,50 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,50 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,20 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,20 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,20 |
| | | VB.4.1 - Wind -x-richting | 0,45 |
| | | VB.4.2 - Wind -y-richting | 0,45 |
| | | VB.6.1 - FM - X richting | 1,20 |
| | | VB.6.2 - FM - y richting | 1,20 |
| | | VB.6.3 - FM - 45 gr | 1,20 |
| | | VB.7.1- VB -wal - variabel | 0,60 |
| | | VB.7.2 -VB - wal + hef midden | 0,60 |
| | | VB.7.3 -VB - wal + hef ligger | 0,60 |
| UGT-4b | Envelope - ultimate | PB.1 - Eigen gewicht | 0,90 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,50 |
| | | VB.0.2 piperacks | 1,50 |
| | | VB.1.3 - Variabele belasting Y.1 - Verticaal | 1,50 |
| | | VB.1.4 - Variabele belasting Y.2 - Verticaal | 1,50 |
| | | VB.1.5 - Variabele belasting Y.3 - Verticaal | 1,50 |
| | | VB.1.6 - Variabele belasting Y.4 - Verticaal | 1,50 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,50 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,50 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,50 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,20 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,20 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,20 |
| | | VB.4.1 - Wind -x-richting | 0,45 |
| | | VB.4.2 - Wind -y-richting | 0,45 |
| | | VB.6.1 - FM - X richting | 1,20 |
| | | VB.6.2 - FM - y richting | 1,20 |
| | | VB.6.3 - FM - 45 gr | 1,20 |
| | | VB.7.1- VB -wal - variabel | 0,60 |
| | | VB.7.2 -VB - wal + hef midden | 0,60 |
| | | VB.7.3 -VB - wal + hef ligger | 0,60 |
| UGT-5b | Envelope - ultimate | PB.1 - Eigen gewicht | 1,20 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,50 |
| | | VB.0.2 piperacks | 1,50 |
| | | VB.1.3 - Variabele belasting Y.1 - Verticaal | 1,20 |
| | | VB.1.4 - Variabele belasting Y.2 - Verticaal | 1,20 |
| | | VB.1.5 - Variabele belasting Y.3 - Verticaal | 1,20 |
| | | VB.1.6 - Variabele belasting Y.4 - Verticaal | 1,20 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,20 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,20 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,20 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,50 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,50 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,50 |

| Name | Type | Load cases | Coeff. [-] |
|---|---|---|---|
| | | VB.4.1 - Wind -x-richting | 0,45 |
| | | VB.4.2 - Wind -y-richting | 0,45 |
| | | VB.6.1 - FM - X richting | 1,20 |
| | | VB.6.2 - FM - y richting | 1,20 |
| | | VB.6.3 - FM - 45 gr | 1,20 |
| | | VB.7.1- VB -wal - variabel | 0,60 |
| | | VB.7.2 -VB - wal + hef midden | 0,60 |
| | | VB.7.3 -VB - wal + hef ligger | 0,60 |
| UGT-6b | Envelope - ultimate | PB.1 - Eigen gewicht | 0,90 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,50 |
| | | VB.0.2 piperacks | 1,50 |
| | | VB.1.3 - Variabele belasting Y.1 - Verticaal | 1,20 |
| | | VB.1.4 - Variabele belasting Y.2 - Verticaal | 1,20 |
| | | VB.1.5 - Variabele belasting Y.3 - Verticaal | 1,20 |
| | | VB.1.6 - Variabele belasting Y.4 - Verticaal | 1,20 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,20 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,20 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,20 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,50 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,50 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,50 |
| | | VB.4.1 - Wind -x-richting | 0,45 |
| | | VB.4.2 - Wind -y-richting | 0,45 |
| | | VB.6.1 - FM - X richting | 1,20 |
| | | VB.6.2 - FM - y richting | 1,20 |
| | | VB.6.3 - FM - 45 gr | 1,20 |
| | | VB.7.1- VB -wal - variabel | 0,60 |
| | | VB.7.2 -VB - wal + hef midden | 0,60 |
| | | VB.7.3 -VB - wal + hef ligger | 0,60 |
| UGT-7b | Envelope - ultimate | PB.1 - Eigen gewicht | 1,20 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,50 |
| | | VB.0.2 piperacks | 1,50 |
| | | VB.1.3 - Variabele belasting Y.1 - Verticaal | 1,20 |
| | | VB.1.4 - Variabele belasting Y.2 - Verticaal | 1,20 |
| | | VB.1.5 - Variabele belasting Y.3 - Verticaal | 1,20 |
| | | VB.1.6 - Variabele belasting Y.4 - Verticaal | 1,20 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,20 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,20 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,20 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,20 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,20 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,20 |
| | | VB.4.1 - Wind -x-richting | 1,50 |
| | | VB.4.2 - Wind -y-richting | 1,50 |
| | | VB.6.1 - FM - X richting | 1,20 |
| | | VB.6.2 - FM - y richting | 1,20 |
| | | VB.6.3 - FM - 45 gr | 1,20 |
| | | VB.7.1- VB -wal - variabel | 0,60 |
| | | VB.7.2 -VB - wal + hef midden | 0,60 |
| | | VB.7.3 -VB - wal + hef ligger | 0,60 |
| UGT-8b | Envelope - ultimate | PB.1 - Eigen gewicht | 0,90 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,50 |
| | | VB.0.2 piperacks | 1,50 |
| | | VB.1.3 - Variabele belasting Y.1 - Verticaal | 1,20 |
| | | VB.1.4 - Variabele belasting Y.2 - Verticaal | 1,20 |
| | | VB.1.5 - Variabele belasting Y.3 - Verticaal | 1,20 |
| | | VB.1.6 - Variabele belasting Y.4 - Verticaal | 1,20 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,20 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,20 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,20 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,20 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,20 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,20 |
| | | VB.4.1 - Wind -x-richting | 1,50 |
| | | VB.4.2 - Wind -y-richting | 1,50 |
| | | VB.6.1 - FM - X richting | 1,20 |
| | | VB.6.2 - FM - y richting | 1,20 |
| | | VB.6.3 - FM - 45 gr | 1,20 |
| | | VB.7.1- VB -wal - variabel | 0,60 |
| | | VB.7.2 -VB - wal + hef midden | 0,60 |
| | | VB.7.3 -VB - wal + hef ligger | 0,60 |
| UGT-9b | Envelope - ultimate | PB.1 - Eigen gewicht | 1,20 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |

| Name | Type | Load cases | Coeff. [-] |
|---|---|---|---|
| | | VB.0.1 piperacks | 1,50 |
| | | VB.0.2 piperacks | 1,50 |
| | | VB.1.3 - Variabele belasting Y.1 - Verticaal | 1,20 |
| | | VB.1.4 - Variabele belasting Y.2 - Verticaal | 1,20 |
| | | VB.1.5 - Variabele belasting Y.3 - Verticaal | 1,20 |
| | | VB.1.6 - Variabele belasting Y.4 - Verticaal | 1,20 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,20 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,20 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,20 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,20 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,20 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,20 |
| | | VB.4.1 - Wind -x-richting | 0,45 |
| | | VB.4.2 - Wind -y-richting | 0,45 |
| | | VB.6.1 - FM - X richting | 1,50 |
| | | VB.6.2 - FM - y richting | 1,50 |
| | | VB.6.3 - FM - 45 gr | 1,50 |
| | | VB.7.1- VB -wal - variabel | 0,60 |
| | | VB.7.2 -VB - wal + hef midden | 0,60 |
| | | VB.7.3 -VB - wal + hef ligger | 0,60 |
| UGT-10b | Envelope - ultimate | PB.1 - Eigen gewicht | 0,90 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,50 |
| | | VB.0.2 piperacks | 1,50 |
| | | VB.1.3 - Variabele belasting Y.1 - Verticaal | 1,20 |
| | | VB.1.4 - Variabele belasting Y.2 - Verticaal | 1,20 |
| | | VB.1.5 - Variabele belasting Y.3 - Verticaal | 1,20 |
| | | VB.1.6 - Variabele belasting Y.4 - Verticaal | 1,20 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,20 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,20 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,20 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,20 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,20 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,20 |
| | | VB.4.1 - Wind -x-richting | 0,45 |
| | | VB.4.2 - Wind -y-richting | 0,45 |
| | | VB.6.1 - FM - X richting | 1,50 |
| | | VB.6.2 - FM - y richting | 1,50 |
| | | VB.6.3 - FM - 45 gr | 1,50 |
| | | VB.7.1- VB -wal - variabel | 0,60 |
| | | VB.7.2 -VB - wal + hef midden | 0,60 |
| | | VB.7.3 -VB - wal + hef ligger | 0,60 |
| UGT-11b | Envelope - ultimate | PB.1 - Eigen gewicht | 1,20 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,50 |
| | | VB.0.2 piperacks | 1,50 |
| | | VB.1.3 - Variabele belasting Y.1 - Verticaal | 1,20 |
| | | VB.1.4 - Variabele belasting Y.2 - Verticaal | 1,20 |
| | | VB.1.5 - Variabele belasting Y.3 - Verticaal | 1,20 |
| | | VB.1.6 - Variabele belasting Y.4 - Verticaal | 1,20 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,20 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,20 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,20 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,20 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,20 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,20 |
| | | VB.4.1 - Wind -x-richting | 0,45 |
| | | VB.4.2 - Wind -y-richting | 0,45 |
| | | VB.6.1 - FM - X richting | 1,20 |
| | | VB.6.2 - FM - y richting | 1,20 |
| | | VB.6.3 - FM - 45 gr | 1,20 |
| | | VB.7.1- VB -wal - variabel | 1,35 |
| | | VB.7.2 -VB - wal + hef midden | 1,35 |
| | | VB.7.3 -VB - wal + hef ligger | 1,35 |
| UGT-12b | Envelope - ultimate | PB.1 - Eigen gewicht | 0,90 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,50 |
| | | VB.0.2 piperacks | 1,50 |
| | | VB.1.3 - Variabele belasting Y.1 - Verticaal | 1,20 |
| | | VB.1.4 - Variabele belasting Y.2 - Verticaal | 1,20 |
| | | VB.1.5 - Variabele belasting Y.3 - Verticaal | 1,20 |
| | | VB.1.6 - Variabele belasting Y.4 - Verticaal | 1,20 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,20 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,20 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,20 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,20 |

| Name | Type | Load cases | Coeff. [-] |
|---|---|---|---|
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,20 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,20 |
| | | VB.4.1 - Wind -x-richting | 0,45 |
| | | VB.4.2 - Wind -y-richting | 0,45 |
| | | VB.6.1 - FM - X richting | 1,20 |
| | | VB.6.2 - FM - y richting | 1,20 |
| | | VB.6.3 - FM - 45 gr | 1,20 |
| | | VB.7.1- VB -wal - variabel | 1,35 |
| | | VB.7.2 -VB - wal + hef midden | 1,35 |
| | | VB.7.3 -VB - wal + hef ligger | 1,35 |
| UGT-13 | Envelope - ultimate | PB.1 - Eigen gewicht | 1,20 |
| | | PB.3.2 - UGT oplegreactie vluchtweg | 1,00 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 1,50 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 1,50 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 1,50 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 1,20 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 1,20 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 1,20 |
| | | VB.4.1 - Wind -x-richting | 0,45 |
| | | VB.4.2 - Wind -y-richting | 0,45 |
| | | VB.6.1 - FM - X richting | 1,20 |
| | | VB.6.2 - FM - y richting | 1,20 |
| | | VB.6.3 - FM - 45 gr | 1,20 |
| | | VB.8 heftruck op platform + geen piperacks | 1,35 |
| BGT-1a | Envelope - serviceability | PB.1 - Eigen gewicht | 1,00 |
| | | PB.2 - Krimp | 1,00 |
| | | PB.3.1 - BGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,00 |
| | | VB.0.2 piperacks | 1,00 |
| | | VB.1.1 - Variabele belasting X.1 - Verticaal | 0,80 |
| | | VB.1.2 - Variabele belasting X.2 - Verticaal | 0,80 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 0,80 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 0,80 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 0,80 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 0,60 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 0,60 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 0,60 |
| | | VB.5.1 - Temperatuur - comb.1 | 0,30 |
| | | VB.5.2 - Temperatuur - comb.2 | 0,30 |
| | | VB.5.3 - Temperatuur - comb.3 | 0,30 |
| | | VB.5.4 - Temperatuur - comb.4 | 0,30 |
| | | VB.6.1 - FM - X richting | 0,60 |
| | | VB.6.2 - FM - y richting | 0,60 |
| | | VB.6.3 - FM - 45 gr | 0,60 |
| | | VB.7.1- VB -wal - variabel | 0,40 |
| | | VB.7.2 -VB - wal + hef midden | 0,40 |
| | | VB.7.3 -VB - wal + hef ligger | 0,40 |
| BGT-2a | Envelope - serviceability | PB.1 - Eigen gewicht | 1,00 |
| | | PB.2 - Krimp | 1,00 |
| | | PB.3.1 - BGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,00 |
| | | VB.0.2 piperacks | 1,00 |
| | | VB.1.1 - Variabele belasting X.1 - Verticaal | 0,60 |
| | | VB.1.2 - Variabele belasting X.2 - Verticaal | 0,60 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 0,60 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 0,60 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 0,60 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 0,80 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 0,80 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 0,80 |
| | | VB.5.1 - Temperatuur - comb.1 | 0,30 |
| | | VB.5.2 - Temperatuur - comb.2 | 0,30 |
| | | VB.5.3 - Temperatuur - comb.3 | 0,30 |
| | | VB.5.4 - Temperatuur - comb.4 | 0,30 |
| | | VB.6.1 - FM - X richting | 0,60 |
| | | VB.6.2 - FM - y richting | 0,60 |
| | | VB.6.3 - FM - 45 gr | 0,60 |
| | | VB.7.1- VB -wal - variabel | 0,40 |
| | | VB.7.2 -VB - wal + hef midden | 0,40 |
| | | VB.7.3 -VB - wal + hef ligger | 0,40 |
| BGT-3a | Envelope - serviceability | PB.1 - Eigen gewicht | 1,00 |
| | | PB.2 - Krimp | 1,00 |
| | | PB.3.1 - BGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,00 |
| | | VB.0.2 piperacks | 1,00 |
| | | VB.1.1 - Variabele belasting X.1 - Verticaal | 0,60 |

| Name | Type | Load cases | Coeff. [-] |
|---|---|---|---|
| | | VB.1.2 - Variabele belasting X.2 - Verticaal | 0,60 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 0,60 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 0,60 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 0,60 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 0,80 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 0,80 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 0,80 |
| | | VB.4.1 - Wind -x-richting | 0,60 |
| | | VB.4.2 - Wind -y-richting | 0,60 |
| | | VB.5.1 - Temperatuur - comb.1 | 0,30 |
| | | VB.5.2 - Temperatuur - comb.2 | 0,30 |
| | | VB.5.3 - Temperatuur - comb.3 | 0,30 |
| | | VB.5.4 - Temperatuur - comb.4 | 0,30 |
| | | VB.6.1 - FM - X richting | 0,60 |
| | | VB.6.2 - FM - y richting | 0,60 |
| | | VB.6.3 - FM - 45 gr | 0,60 |
| | | VB.7.1- VB -wal - variabel | 0,40 |
| | | VB.7.2 -VB - wal + hef midden | 0,40 |
| | | VB.7.3 -VB - wal + hef ligger | 0,40 |
| BGT-4a | Envelope - serviceability | PB.1 - Eigen gewicht | 1,00 |
| | | PB.2 - Krimp | 1,00 |
| | | PB.3.1 - BGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,00 |
| | | VB.0.2 piperacks | 1,00 |
| | | VB.1.1 - Variabele belasting X.1 - Verticaal | 0,60 |
| | | VB.1.2 - Variabele belasting X.2 - Verticaal | 0,60 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 0,60 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 0,60 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 0,60 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 0,60 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 0,60 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 0,60 |
| | | VB.5.1 - Temperatuur - comb.1 | 0,80 |
| | | VB.5.2 - Temperatuur - comb.2 | 0,80 |
| | | VB.5.3 - Temperatuur - comb.3 | 0,80 |
| | | VB.5.4 - Temperatuur - comb.4 | 0,80 |
| | | VB.6.1 - FM - X richting | 0,60 |
| | | VB.6.2 - FM - y richting | 0,60 |
| | | VB.6.3 - FM - 45 gr | 0,60 |
| | | VB.7.1- VB -wal - variabel | 0,40 |
| | | VB.7.2 -VB - wal + hef midden | 0,40 |
| | | VB.7.3 -VB - wal + hef ligger | 0,40 |
| BGT-5a | Envelope - serviceability | PB.1 - Eigen gewicht | 1,00 |
| | | PB.2 - Krimp | 1,00 |
| | | PB.3.1 - BGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,00 |
| | | VB.0.2 piperacks | 1,00 |
| | | VB.1.1 - Variabele belasting X.1 - Verticaal | 0,60 |
| | | VB.1.2 - Variabele belasting X.2 - Verticaal | 0,60 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 0,60 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 0,60 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 0,60 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 0,80 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 0,80 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 0,80 |
| | | VB.5.1 - Temperatuur - comb.1 | 0,60 |
| | | VB.5.2 - Temperatuur - comb.2 | 0,60 |
| | | VB.5.3 - Temperatuur - comb.3 | 0,60 |
| | | VB.5.4 - Temperatuur - comb.4 | 0,60 |
| | | VB.6.1 - FM - X richting | 0,80 |
| | | VB.6.2 - FM - y richting | 0,80 |
| | | VB.6.3 - FM - 45 gr | 0,80 |
| | | VB.7.1- VB -wal - variabel | 0,40 |
| | | VB.7.2 -VB - wal + hef midden | 0,40 |
| | | VB.7.3 -VB - wal + hef ligger | 0,40 |
| BGT-6a | Envelope - serviceability | PB.1 - Eigen gewicht | 1,00 |
| | | PB.2 - Krimp | 1,00 |
| | | PB.3.1 - BGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,00 |
| | | VB.0.2 piperacks | 1,00 |
| | | VB.1.1 - Variabele belasting X.1 - Verticaal | 0,60 |
| | | VB.1.2 - Variabele belasting X.2 - Verticaal | 0,60 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 0,60 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 0,60 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 0,60 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 0,80 |

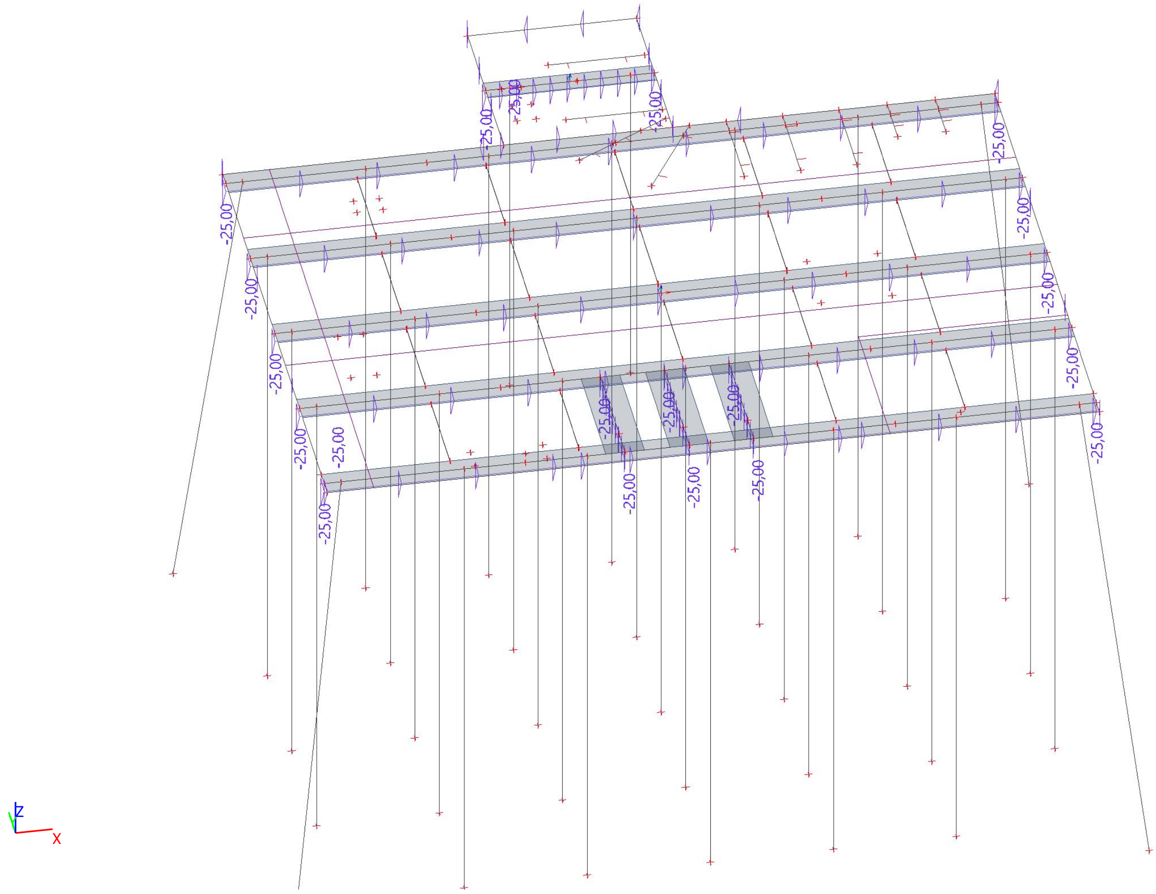
| Name | Type | Load cases | Coeff. [-] |
|---|---|---|---|
| | | VB.3.2 - MLA and JIB crane - Y-richting | 0,80 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 0,80 |
| | | VB.5.1 - Temperatuur - comb.1 | 0,60 |
| | | VB.5.2 - Temperatuur - comb.2 | 0,60 |
| | | VB.5.3 - Temperatuur - comb.3 | 0,60 |
| | | VB.5.4 - Temperatuur - comb.4 | 0,60 |
| | | VB.6.1 - FM - X richting | 0,60 |
| | | VB.6.2 - FM - y richting | 0,60 |
| | | VB.6.3 - FM - 45 gr | 0,60 |
| | | VB.7.1- VB -wal - variabel | 0,80 |
| | | VB.7.2 -VB - wal + hef midden | 0,80 |
| | | VB.7.3 -VB - wal + hef ligger | 0,80 |
| BGT-1b | Envelope - serviceability | PB.1 - Eigen gewicht | 1,00 |
| | | PB.2 - Krimp | 1,00 |
| | | PB.3.1 - BGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,00 |
| | | VB.0.2 piperacks | 1,00 |
| | | VB.1.3 - Variabele belasting Y.1 - Verticaal | 0,80 |
| | | VB.1.4 - Variabele belasting Y.2 - Verticaal | 0,80 |
| | | VB.1.5 - Variabele belasting Y.3 - Verticaal | 0,80 |
| | | VB.1.6 - Variabele belasting Y.4 - Verticaal | 0,80 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 0,80 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 0,80 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 0,80 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 0,60 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 0,60 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 0,60 |
| | | VB.5.1 - Temperatuur - comb.1 | 0,30 |
| | | VB.5.2 - Temperatuur - comb.2 | 0,30 |
| | | VB.5.3 - Temperatuur - comb.3 | 0,30 |
| | | VB.5.4 - Temperatuur - comb.4 | 0,30 |
| | | VB.6.1 - FM - X richting | 0,60 |
| | | VB.6.2 - FM - y richting | 0,60 |
| | | VB.6.3 - FM - 45 gr | 0,60 |
| | | VB.7.1- VB -wal - variabel | 0,40 |
| | | VB.7.2 -VB - wal + hef midden | 0,40 |
| | | VB.7.3 -VB - wal + hef ligger | 0,40 |
| BGT-2b | Envelope - serviceability | PB.1 - Eigen gewicht | 1,00 |
| | | PB.2 - Krimp | 1,00 |
| | | PB.3.1 - BGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,00 |
| | | VB.0.2 piperacks | 1,00 |
| | | VB.1.3 - Variabele belasting Y.1 - Verticaal | 0,60 |
| | | VB.1.4 - Variabele belasting Y.2 - Verticaal | 0,60 |
| | | VB.1.5 - Variabele belasting Y.3 - Verticaal | 0,60 |
| | | VB.1.6 - Variabele belasting Y.4 - Verticaal | 0,60 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 0,60 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 0,60 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 0,60 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 0,80 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 0,80 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 0,80 |
| | | VB.5.1 - Temperatuur - comb.1 | 0,30 |
| | | VB.5.2 - Temperatuur - comb.2 | 0,30 |
| | | VB.5.3 - Temperatuur - comb.3 | 0,30 |
| | | VB.5.4 - Temperatuur - comb.4 | 0,30 |
| | | VB.6.1 - FM - X richting | 0,60 |
| | | VB.6.2 - FM - y richting | 0,60 |
| | | VB.6.3 - FM - 45 gr | 0,60 |
| | | VB.7.1- VB -wal - variabel | 0,40 |
| | | VB.7.2 -VB - wal + hef midden | 0,40 |
| | | VB.7.3 -VB - wal + hef ligger | 0,40 |
| BGT-3b | Envelope - serviceability | PB.1 - Eigen gewicht | 1,00 |
| | | PB.2 - Krimp | 1,00 |
| | | PB.3.1 - BGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,00 |
| | | VB.0.2 piperacks | 1,00 |
| | | VB.1.3 - Variabele belasting Y.1 - Verticaal | 0,60 |
| | | VB.1.4 - Variabele belasting Y.2 - Verticaal | 0,60 |
| | | VB.1.5 - Variabele belasting Y.3 - Verticaal | 0,60 |
| | | VB.1.6 - Variabele belasting Y.4 - Verticaal | 0,60 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 0,60 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 0,60 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 0,60 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 0,80 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 0,80 |

| Name | Type | Load cases | Coeff. [-] |
|---|---|---|---|
| | | VB.3.3 - MLA and JIB crane - 45gr | 0,80 |
| | | VB.4.1 - Wind -x-richting | 0,60 |
| | | VB.4.2 - Wind -y-richting | 0,60 |
| | | VB.5.1 - Temperatuur - comb.1 | 0,30 |
| | | VB.5.2 - Temperatuur - comb.2 | 0,30 |
| | | VB.5.3 - Temperatuur - comb.3 | 0,30 |
| | | VB.5.4 - Temperatuur - comb.4 | 0,30 |
| | | VB.6.1 - FM - X richting | 0,60 |
| | | VB.6.2 - FM - y richting | 0,60 |
| | | VB.6.3 - FM - 45 gr | 0,60 |
| | | VB.7.1- VB -wal - variabel | 0,40 |
| | | VB.7.2 -VB - wal + hef midden | 0,40 |
| | | VB.7.3 -VB - wal + hef ligger | 0,40 |
| BGT-4b | Envelope - serviceability | PB.1 - Eigen gewicht | 1,00 |
| | | PB.2 - Krimp | 1,00 |
| | | PB.3.1 - BGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,00 |
| | | VB.0.2 piperacks | 1,00 |
| | | VB.1.3 - Variabele belasting Y.1 - Verticaal | 0,60 |
| | | VB.1.4 - Variabele belasting Y.2 - Verticaal | 0,60 |
| | | VB.1.5 - Variabele belasting Y.3 - Verticaal | 0,60 |
| | | VB.1.6 - Variabele belasting Y.4 - Verticaal | 0,60 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 0,60 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 0,60 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 0,60 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 0,60 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 0,60 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 0,60 |
| | | VB.5.1 - Temperatuur - comb.1 | 0,80 |
| | | VB.5.2 - Temperatuur - comb.2 | 0,80 |
| | | VB.5.3 - Temperatuur - comb.3 | 0,80 |
| | | VB.5.4 - Temperatuur - comb.4 | 0,80 |
| | | VB.6.1 - FM - X richting | 0,60 |
| | | VB.6.2 - FM - y richting | 0,60 |
| | | VB.6.3 - FM - 45 gr | 0,60 |
| | | VB.7.1- VB -wal - variabel | 0,40 |
| | | VB.7.2 -VB - wal + hef midden | 0,40 |
| | | VB.7.3 -VB - wal + hef ligger | 0,40 |
| BGT-5b | Envelope - serviceability | PB.1 - Eigen gewicht | 1,00 |
| | | PB.2 - Krimp | 1,00 |
| | | PB.3.1 - BGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,00 |
| | | VB.0.2 piperacks | 1,00 |
| | | VB.1.3 - Variabele belasting Y.1 - Verticaal | 0,60 |
| | | VB.1.4 - Variabele belasting Y.2 - Verticaal | 0,60 |
| | | VB.1.5 - Variabele belasting Y.3 - Verticaal | 0,60 |
| | | VB.1.6 - Variabele belasting Y.4 - Verticaal | 0,60 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 0,60 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 0,60 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 0,60 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 0,80 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 0,80 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 0,80 |
| | | VB.5.1 - Temperatuur - comb.1 | 0,60 |
| | | VB.5.2 - Temperatuur - comb.2 | 0,60 |
| | | VB.5.3 - Temperatuur - comb.3 | 0,60 |
| | | VB.5.4 - Temperatuur - comb.4 | 0,60 |
| | | VB.6.1 - FM - X richting | 0,80 |
| | | VB.6.2 - FM - y richting | 0,80 |
| | | VB.6.3 - FM - 45 gr | 0,80 |
| | | VB.7.1- VB -wal - variabel | 0,40 |
| | | VB.7.2 -VB - wal + hef midden | 0,40 |
| | | VB.7.3 -VB - wal + hef ligger | 0,40 |
| BGT-6b | Envelope - serviceability | PB.1 - Eigen gewicht | 1,00 |
| | | PB.2 - Krimp | 1,00 |
| | | PB.3.1 - BGT oplegreactie vluchtweg | 1,00 |
| | | VB.0.1 piperacks | 1,00 |
| | | VB.0.2 piperacks | 1,00 |
| | | VB.1.3 - Variabele belasting Y.1 - Verticaal | 0,60 |
| | | VB.1.4 - Variabele belasting Y.2 - Verticaal | 0,60 |
| | | VB.1.5 - Variabele belasting Y.3 - Verticaal | 0,60 |
| | | VB.1.6 - Variabele belasting Y.4 - Verticaal | 0,60 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 0,60 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 0,60 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 0,60 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 0,80 |

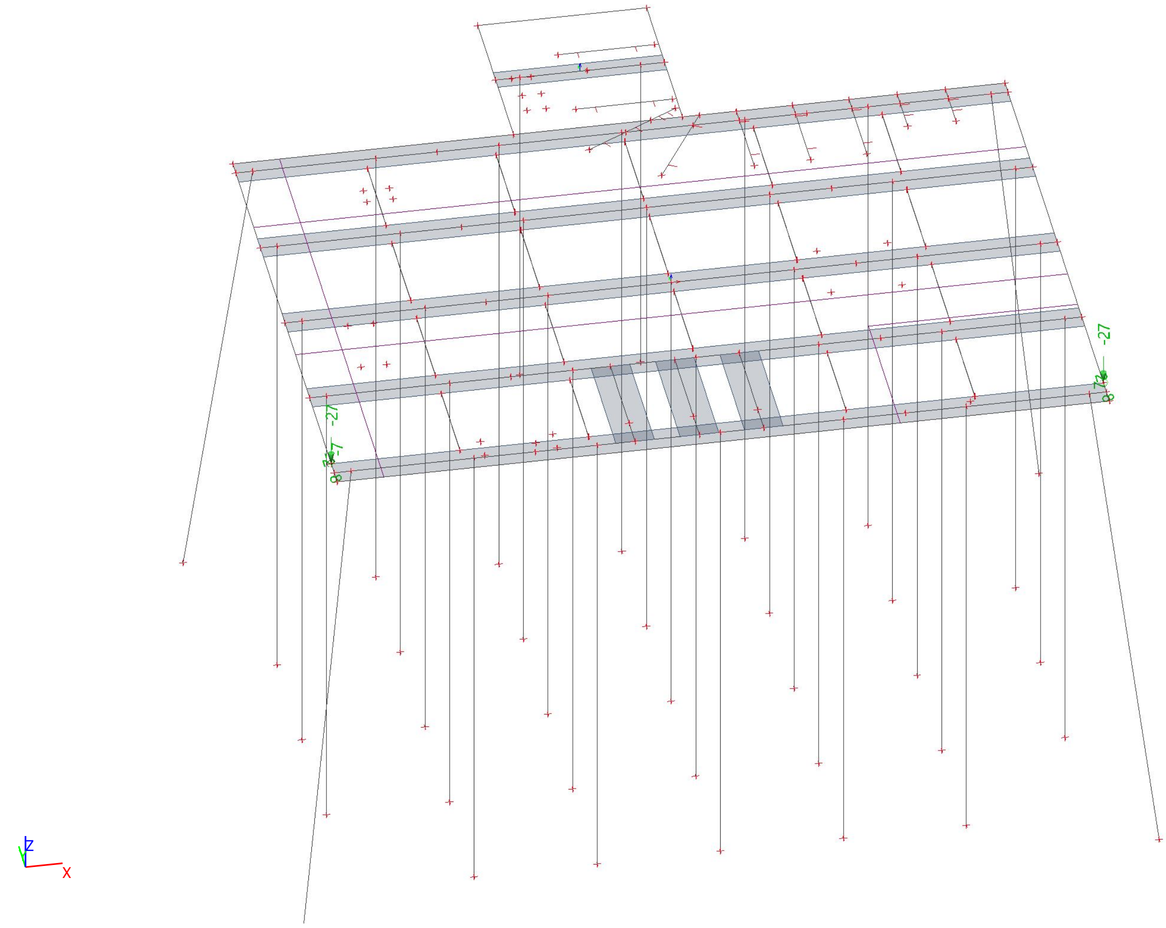
| Name | Type | Load cases | Coeff. [-] |
|---|---|---|---|
| | | VB.3.2 - MLA and JIB crane - Y-richting | 0,80 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 0,80 |
| | | VB.5.1 - Temperatuur - comb.1 | 0,60 |
| | | VB.5.2 - Temperatuur - comb.2 | 0,60 |
| | | VB.5.3 - Temperatuur - comb.3 | 0,60 |
| | | VB.5.4 - Temperatuur - comb.4 | 0,60 |
| | | VB.6.1 - FM - X richting | 0,60 |
| | | VB.6.2 - FM - y richting | 0,60 |
| | | VB.6.3 - FM - 45 gr | 0,60 |
| | | VB.7.1- VB -wal - variabel | 0,80 |
| | | VB.7.2 -VB - wal + hef midden | 0,80 |
| | | VB.7.3 -VB - wal + hef ligger | 0,80 |
| BGT-7 | Envelope - serviceability | PB.1 - Eigen gewicht | 1,00 |
| | | PB.2 - Krimp | 1,00 |
| | | PB.3.1 - BGT oplegreactie vluchtweg | 1,00 |
| | | VB.2.1 - Variabele belasting horizontaal x-richting | 0,80 |
| | | VB.2.2 - Variabele belasting horizontaal y-richting | 0,80 |
| | | VB.2.3 - Variabele belasting horizontaal y-richting land | 0,80 |
| | | VB.3.1 - MLA and JIB crane- X-richting | 0,60 |
| | | VB.3.2 - MLA and JIB crane - Y-richting | 0,60 |
| | | VB.3.3 - MLA and JIB crane - 45gr | 0,60 |
| | | VB.5.1 - Temperatuur - comb.1 | 0,30 |
| | | VB.5.2 - Temperatuur - comb.2 | 0,30 |
| | | VB.5.3 - Temperatuur - comb.3 | 0,30 |
| | | VB.5.4 - Temperatuur - comb.4 | 0,30 |
| | | VB.6.1 - FM - X richting | 0,60 |
| | | VB.6.2 - FM - y richting | 0,60 |
| | | VB.6.3 - FM - 45 gr | 0,60 |
| | | VB.8 heftruck op platform + geen piperacks | 0,80 |

# Load conditions

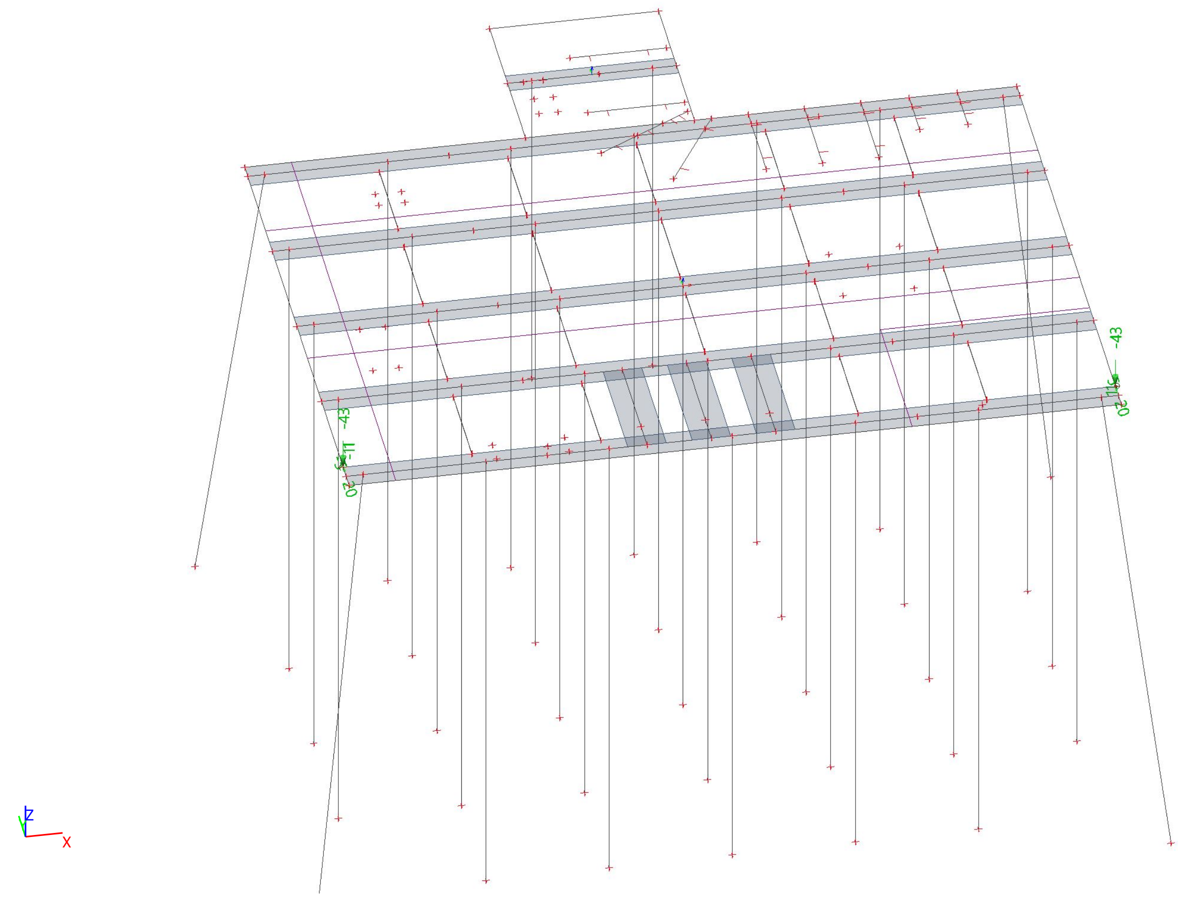
## PB.2 - Krimp



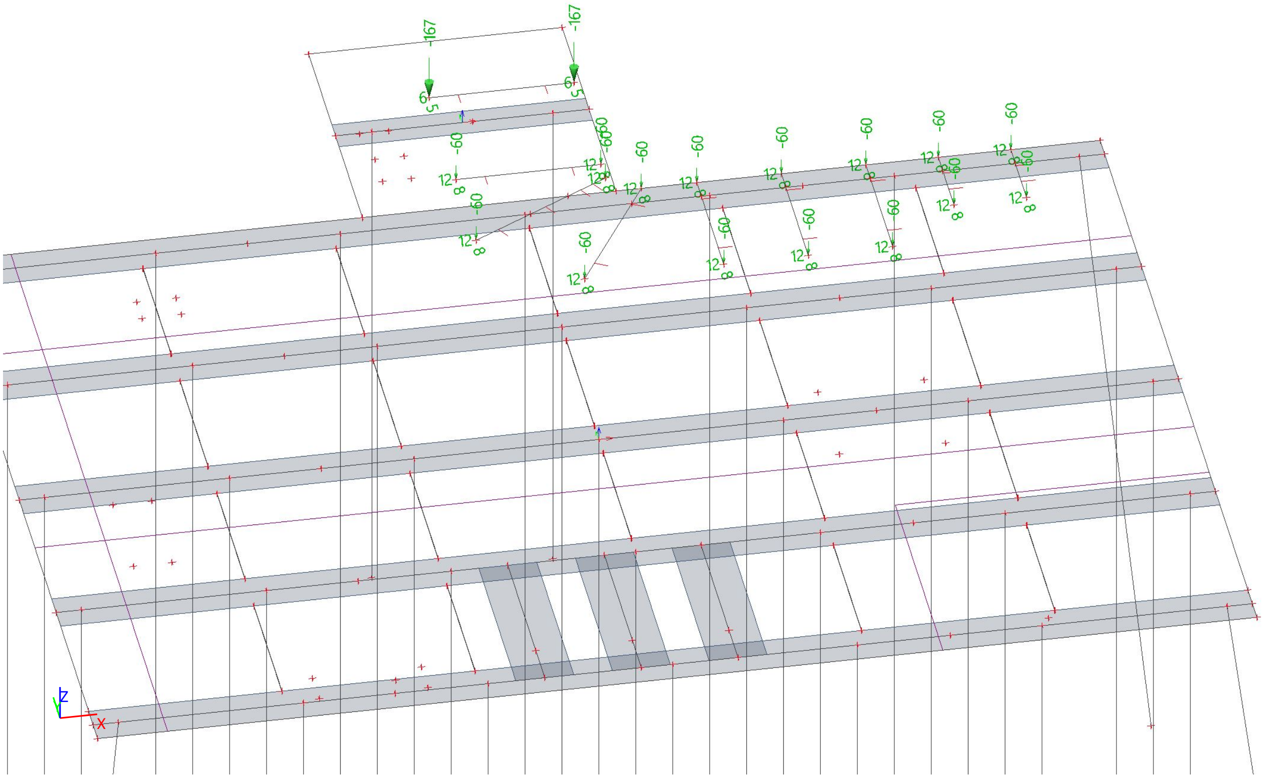
## PB.3.1 - BGT oplegreactie vluchtweg



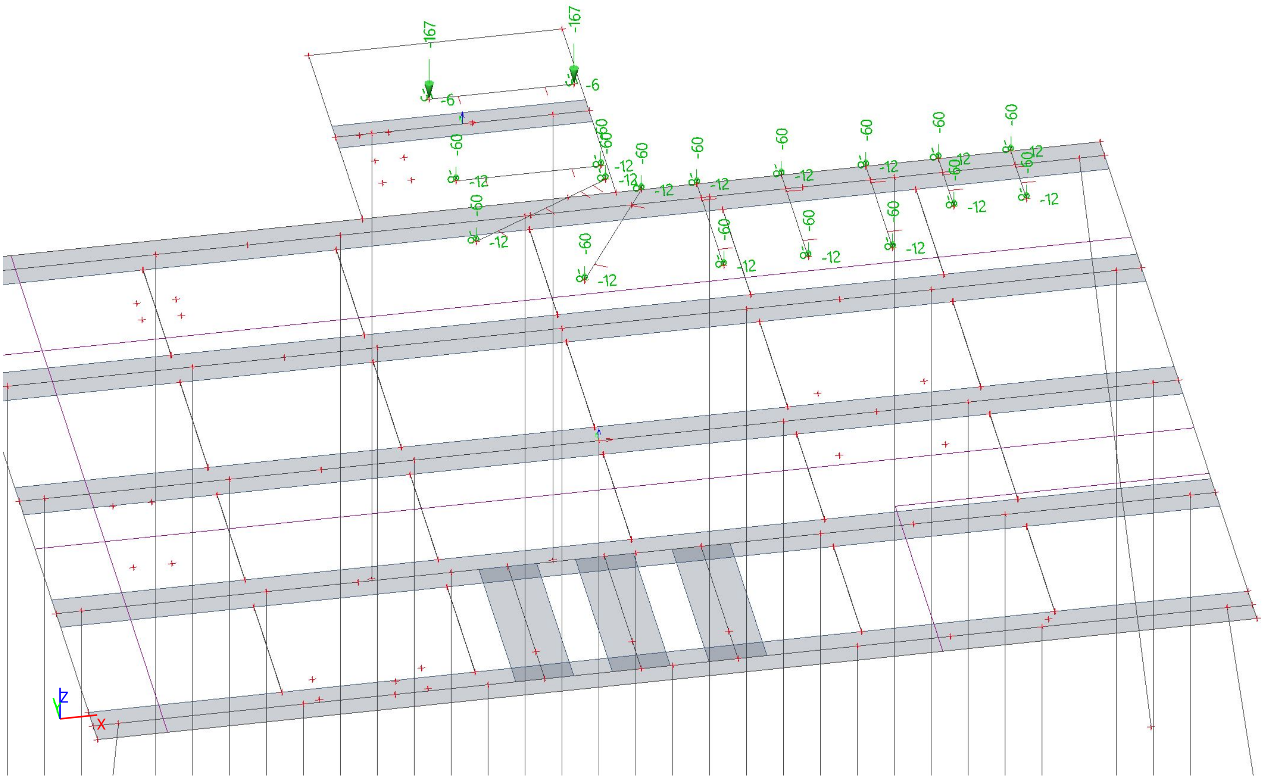

## PB.3.2 - UGT oplegreactie vluchtweg



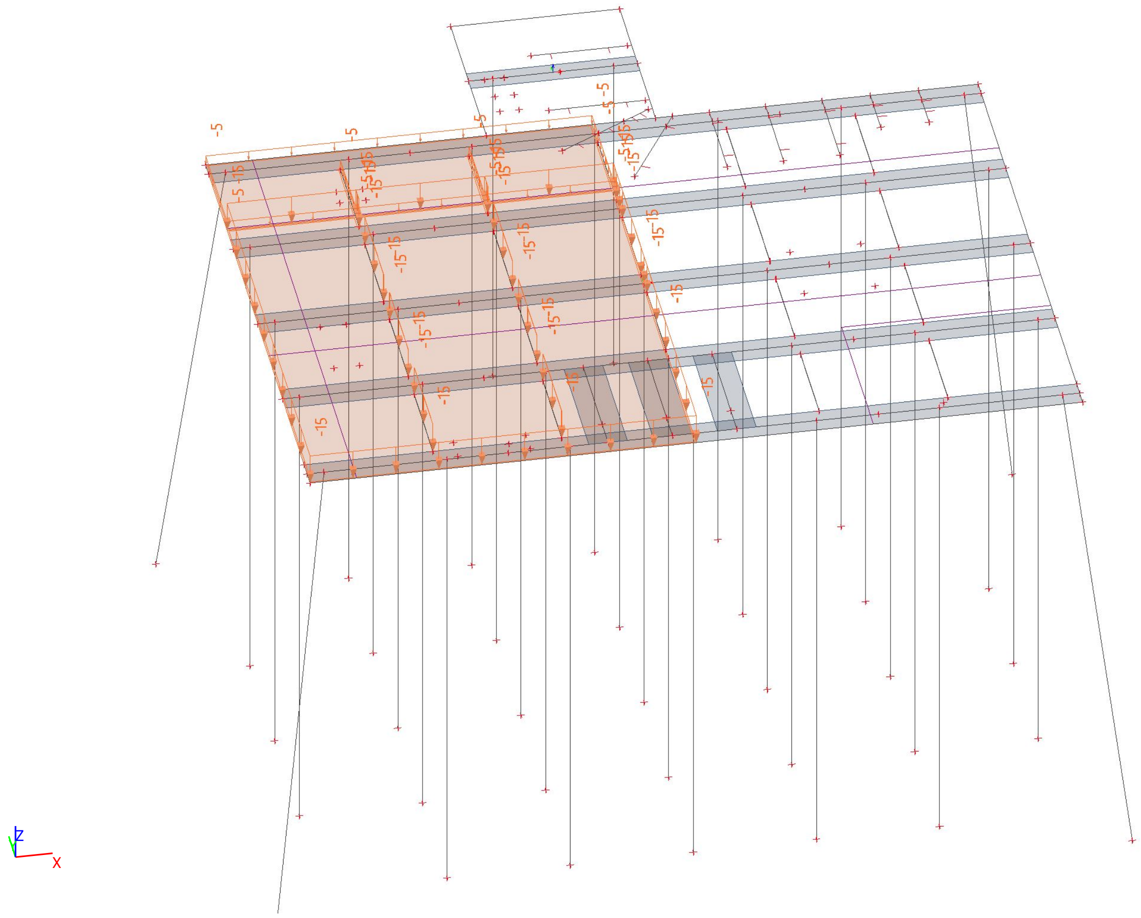
## VB.0.1 piperacks



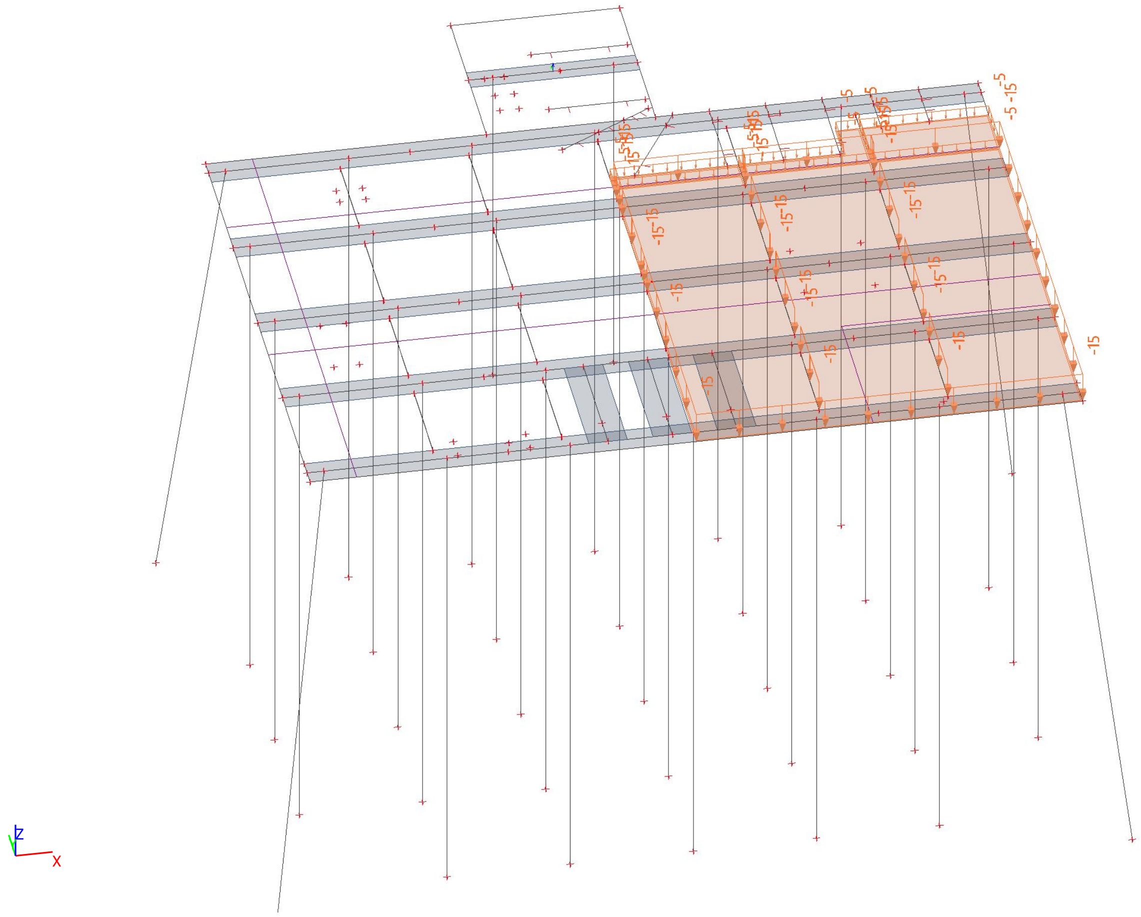

## VB.0.2 piperacks



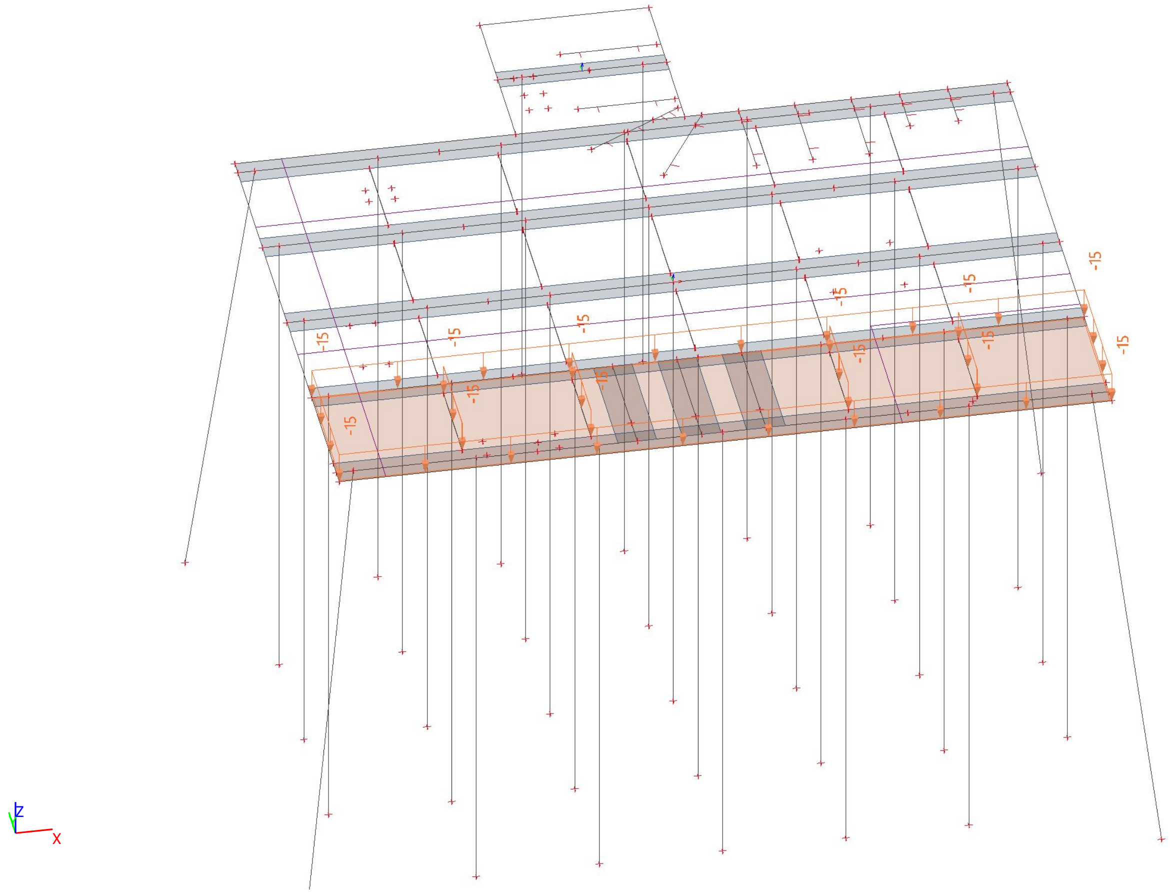
**VB.1.1 - Variabele belasting X.1 - Verticaal**



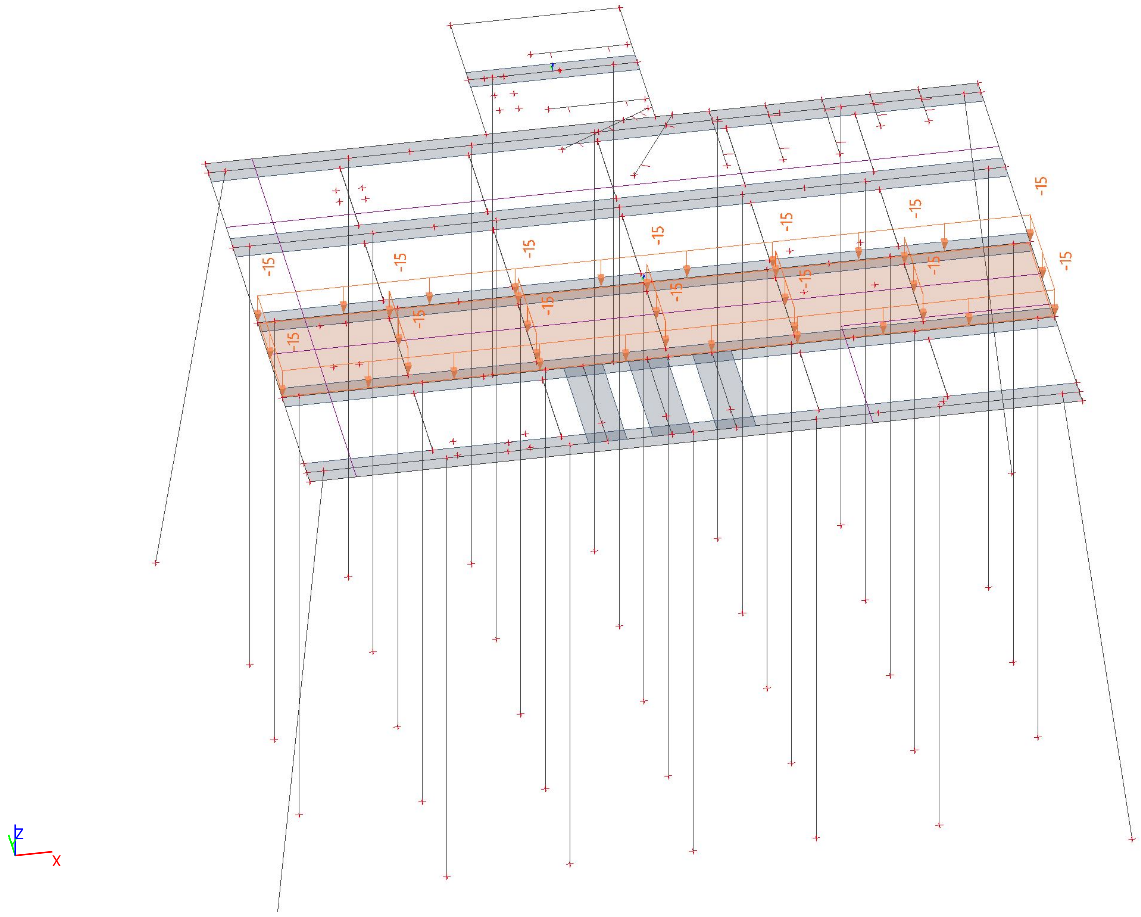

**VB.1.2 - Variabele belasting X.2 - Verticaal**



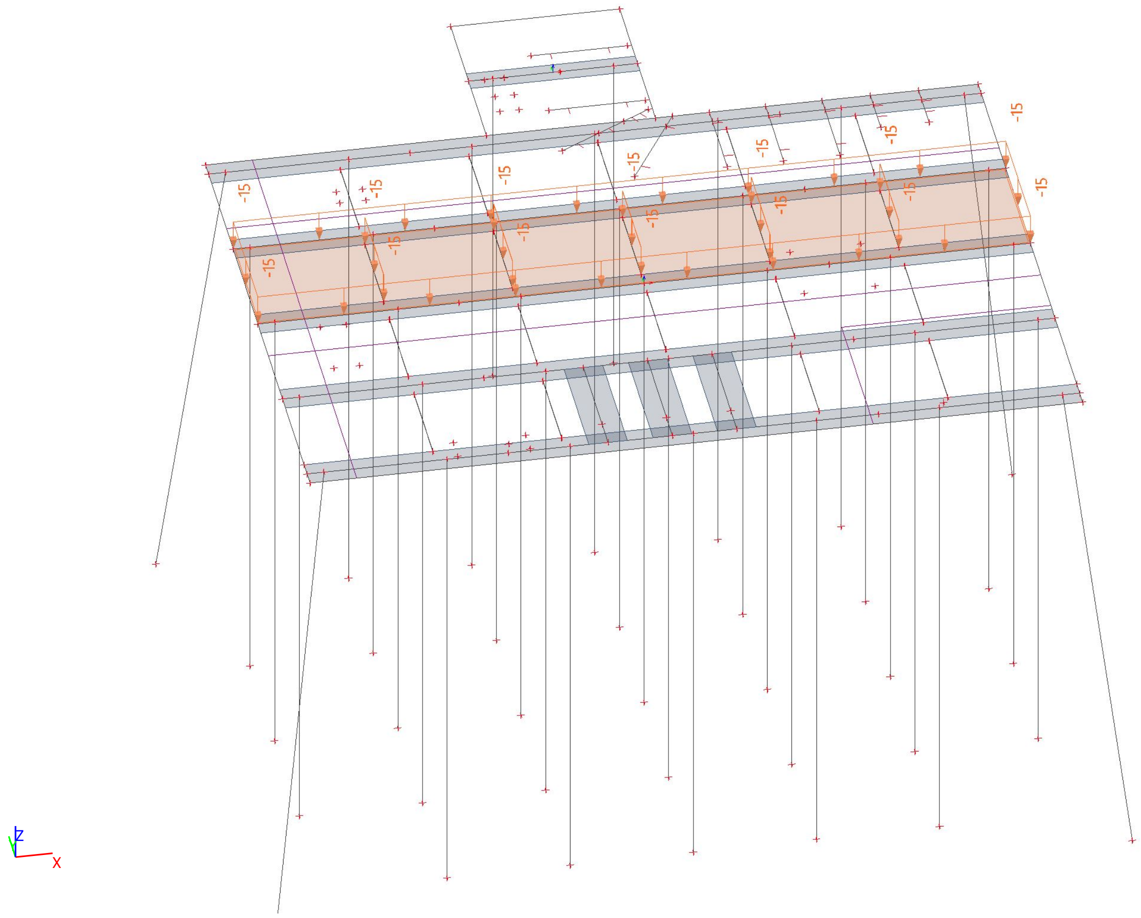
## VB.1.3 - Variabele belasting Y.1 - Verticaal



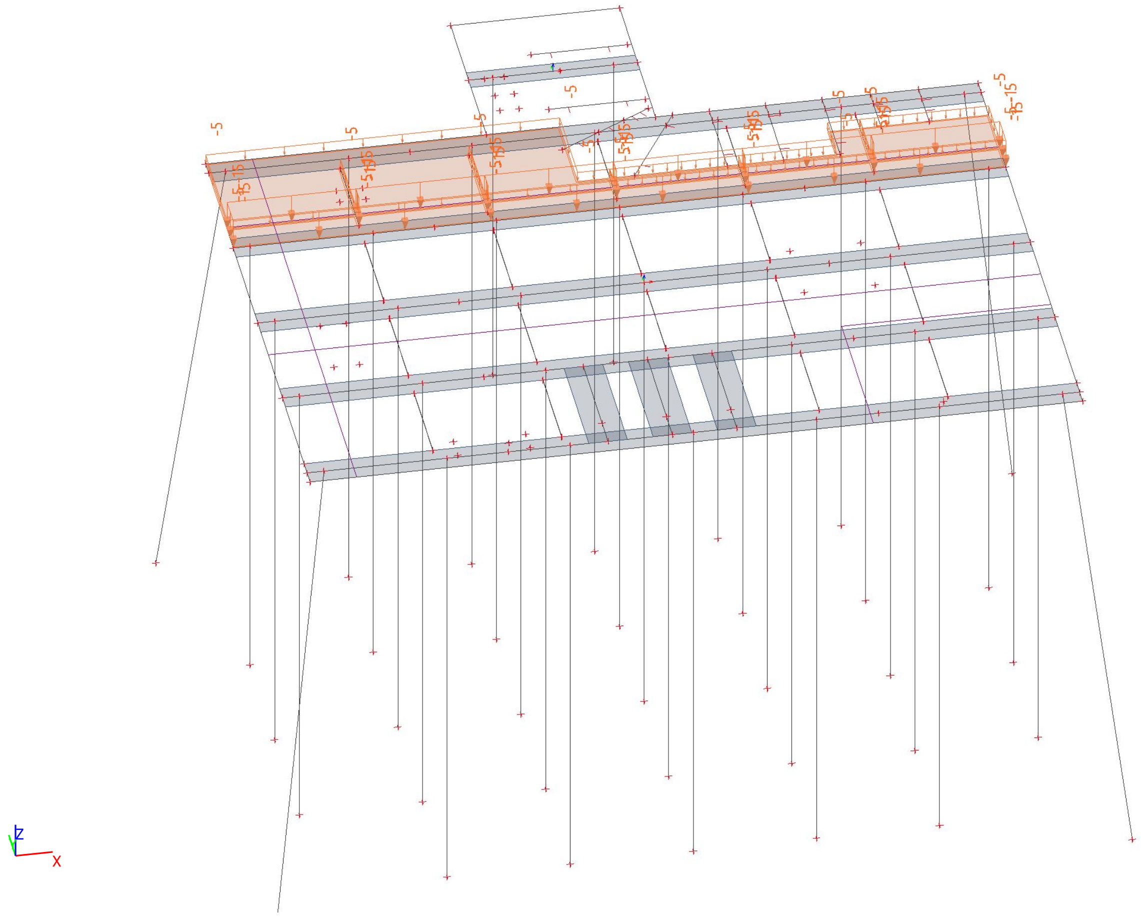

## VB.1.4 - Variabele belasting Y.2 - Verticaal



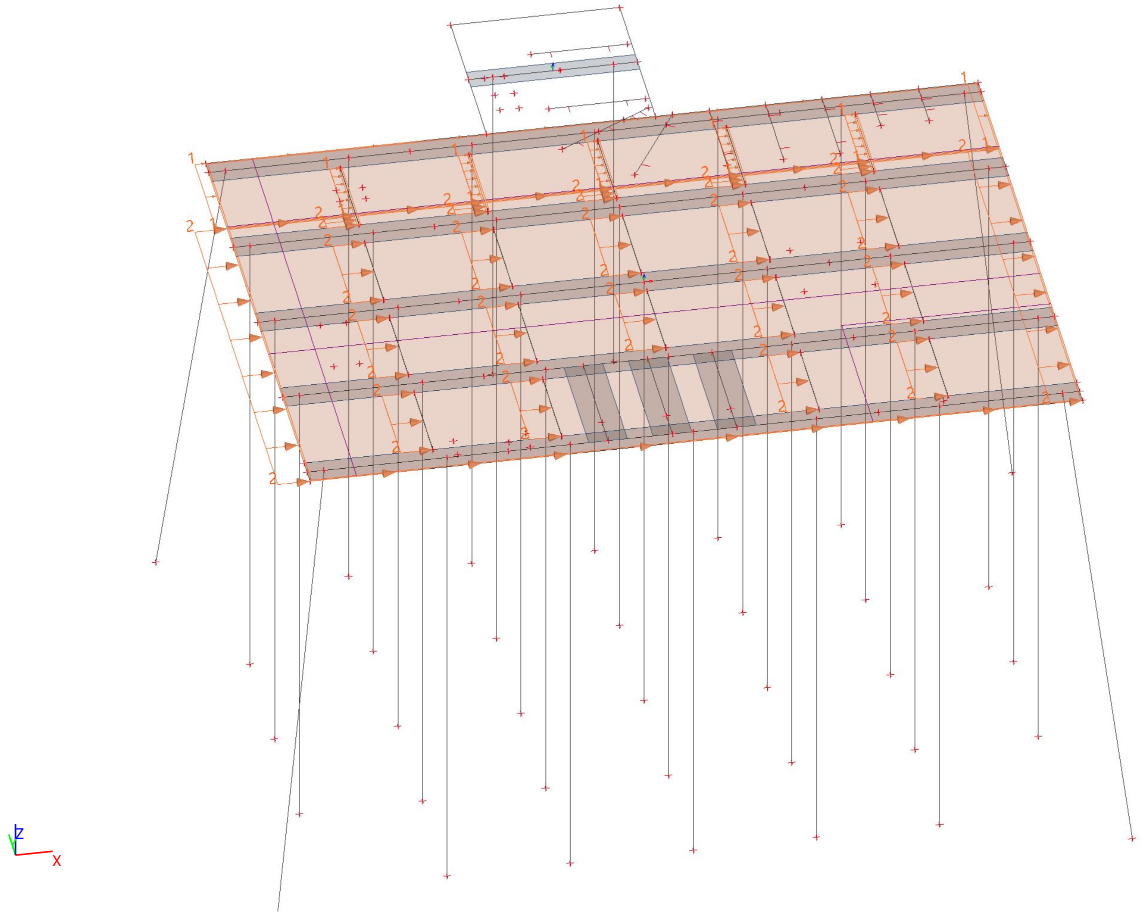
**VB.1.5 - Variabele belasting Y.3 - Verticaal**



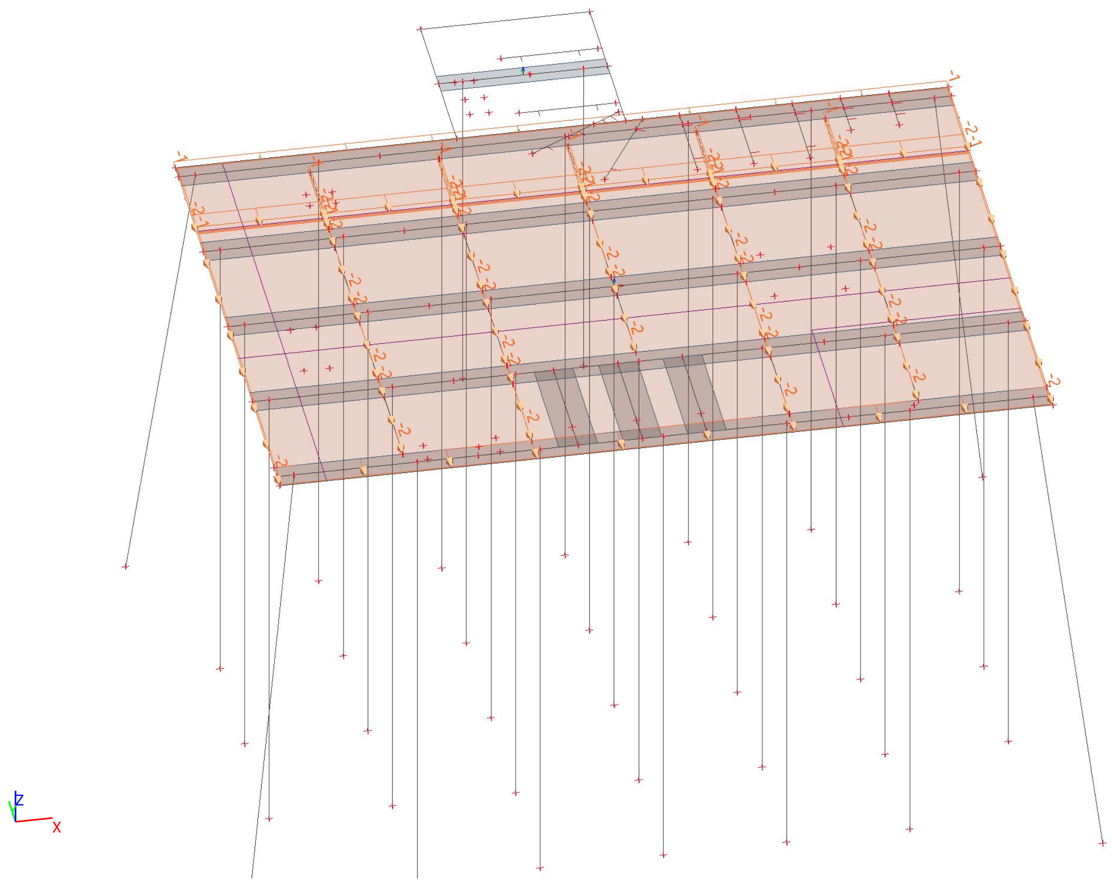

**VB.1.6 - Variabele belasting Y.4 - Verticaal**



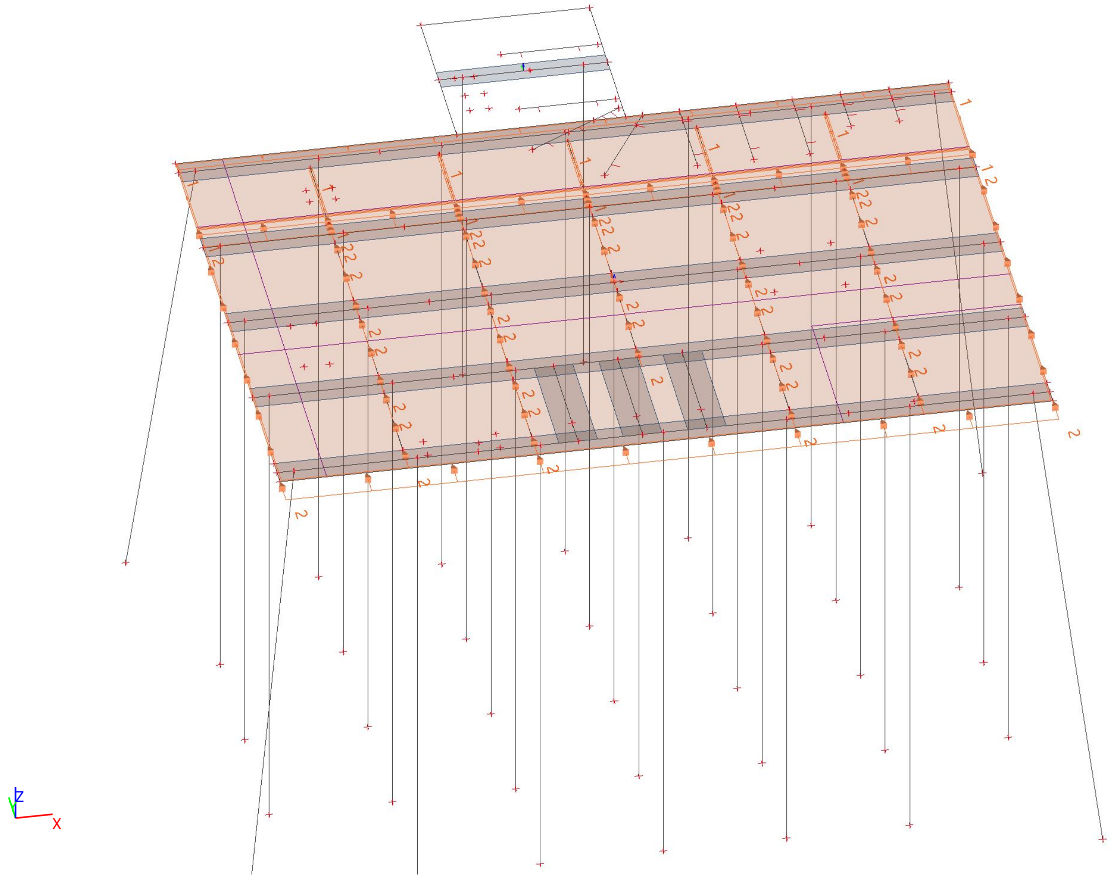
**VB.2.1 - Variabele belasting horizontaal x-richting**



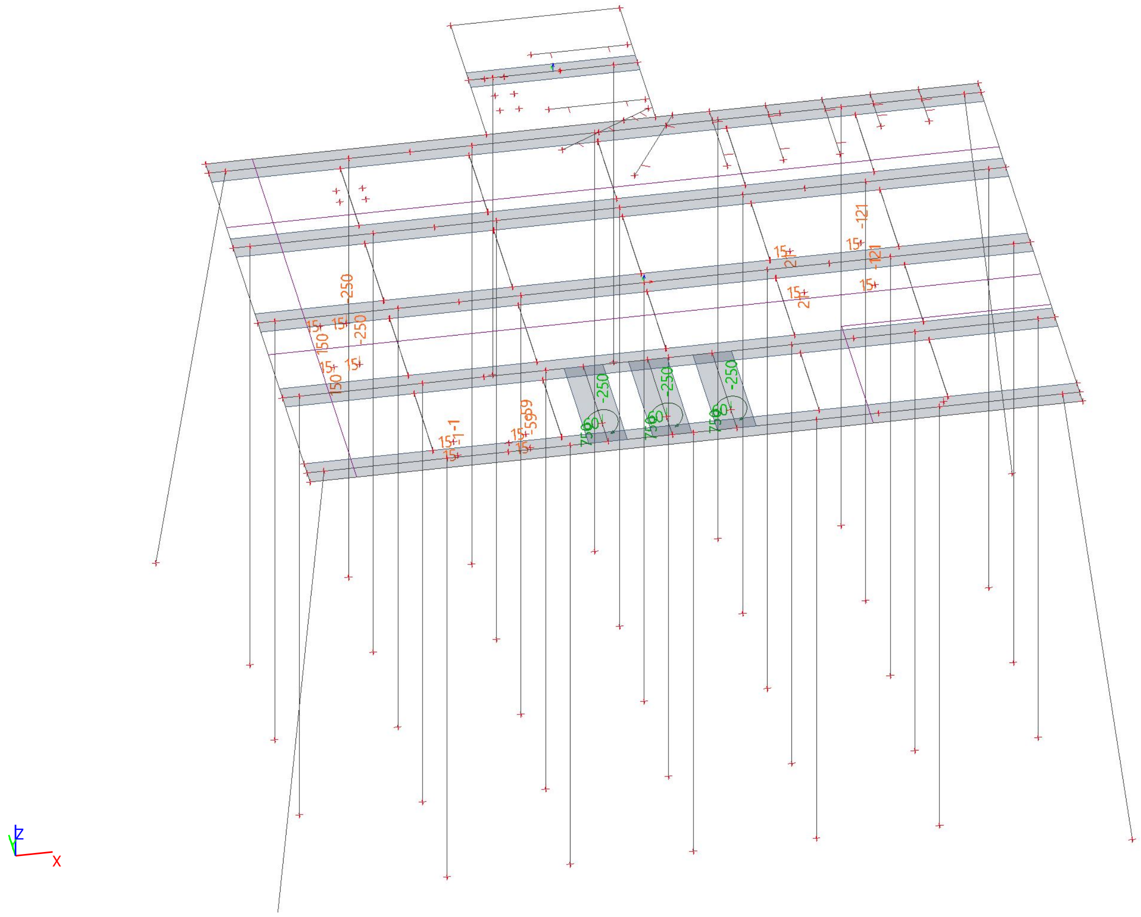
**VB.2.2 - Variabele belasting horizontaal y-richting**



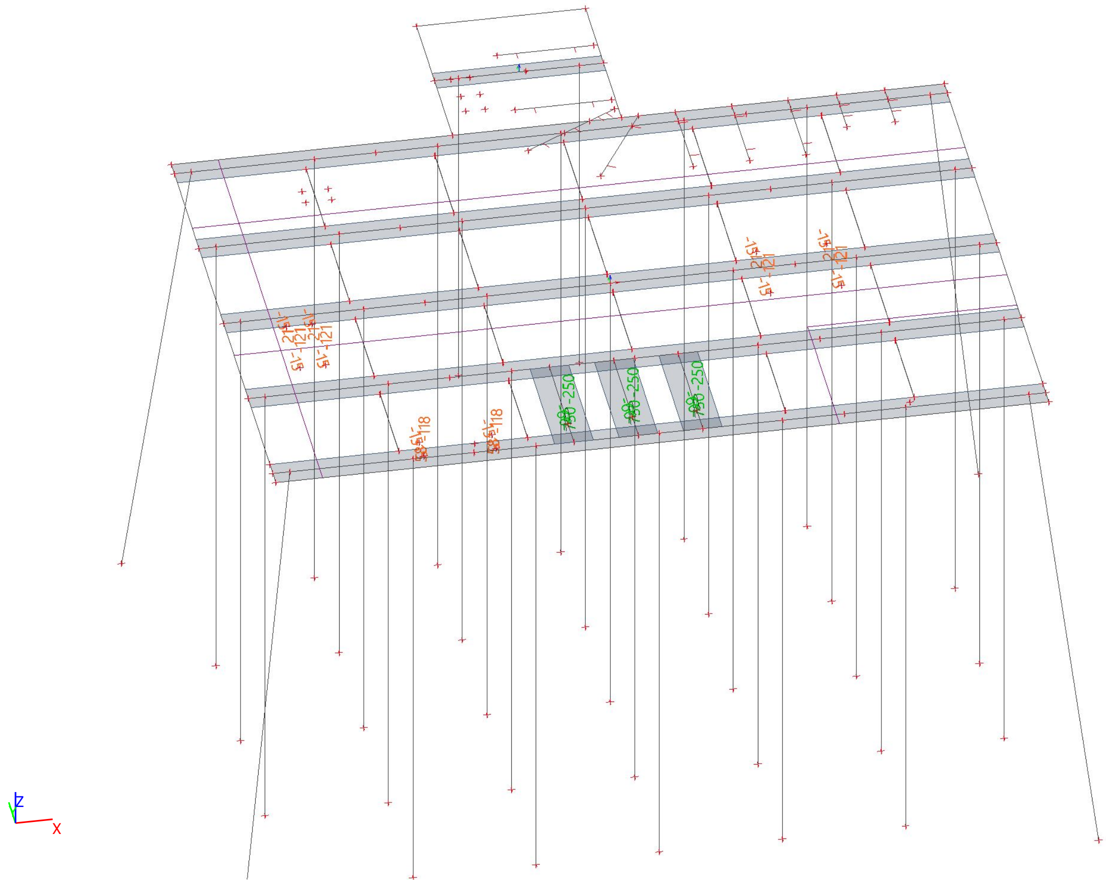
## VB.2.3 - Variabele belasting horizontaal y-richting land



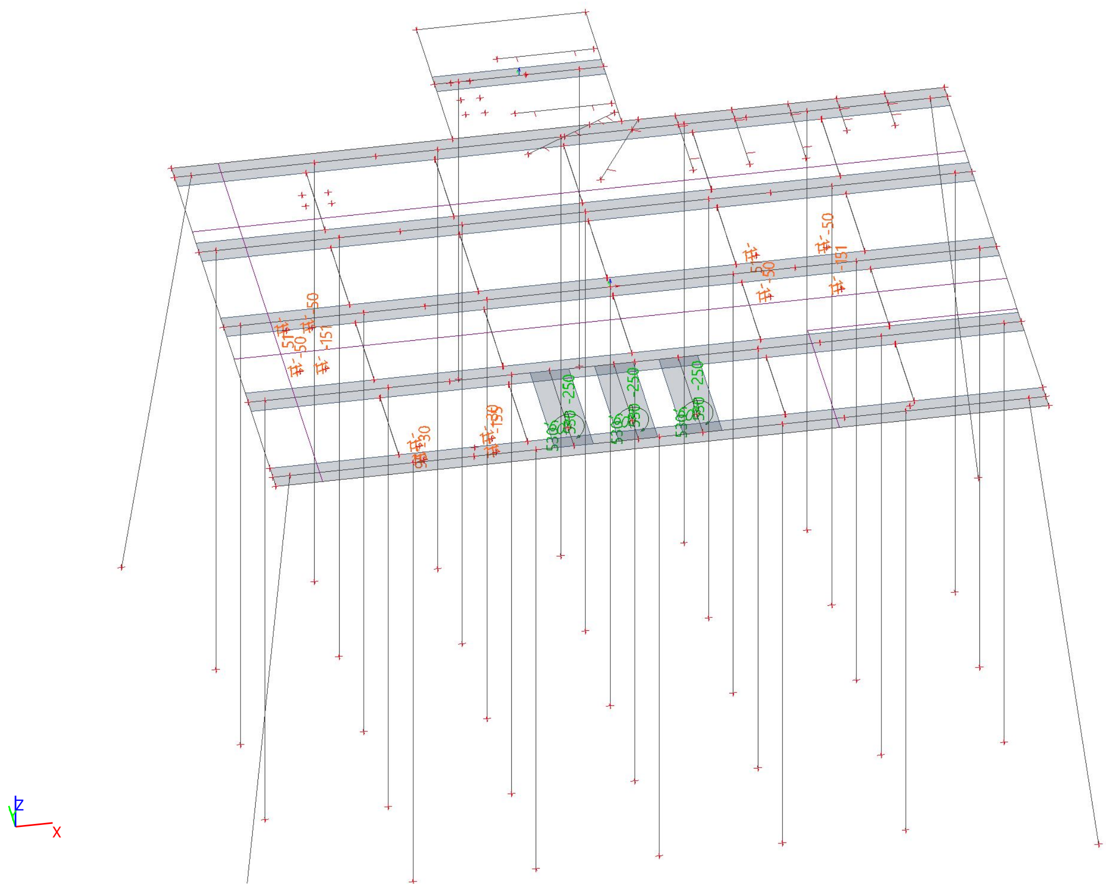
## VB.3.1 - MLA and JIB crane- X-richting



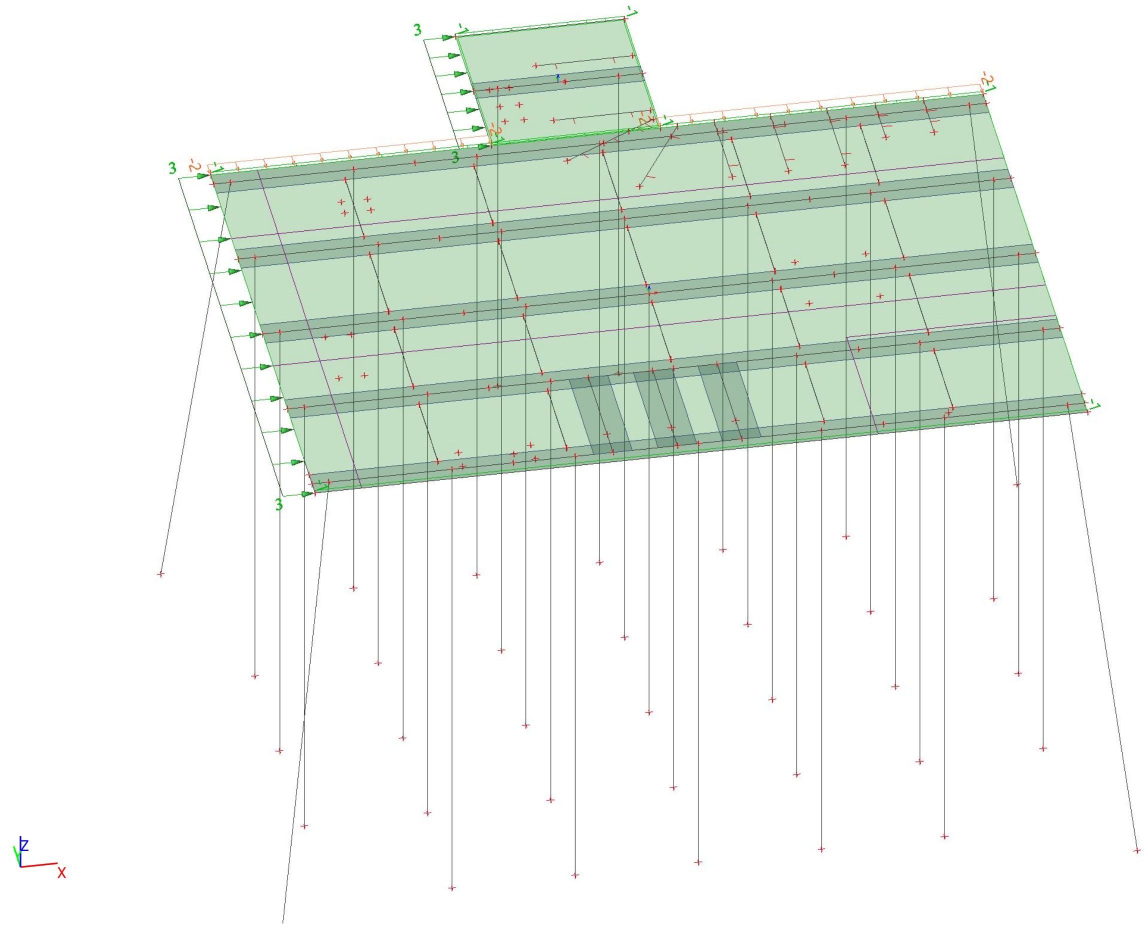
**VB.3.2 - MLA and JIB crane - Y-richting**



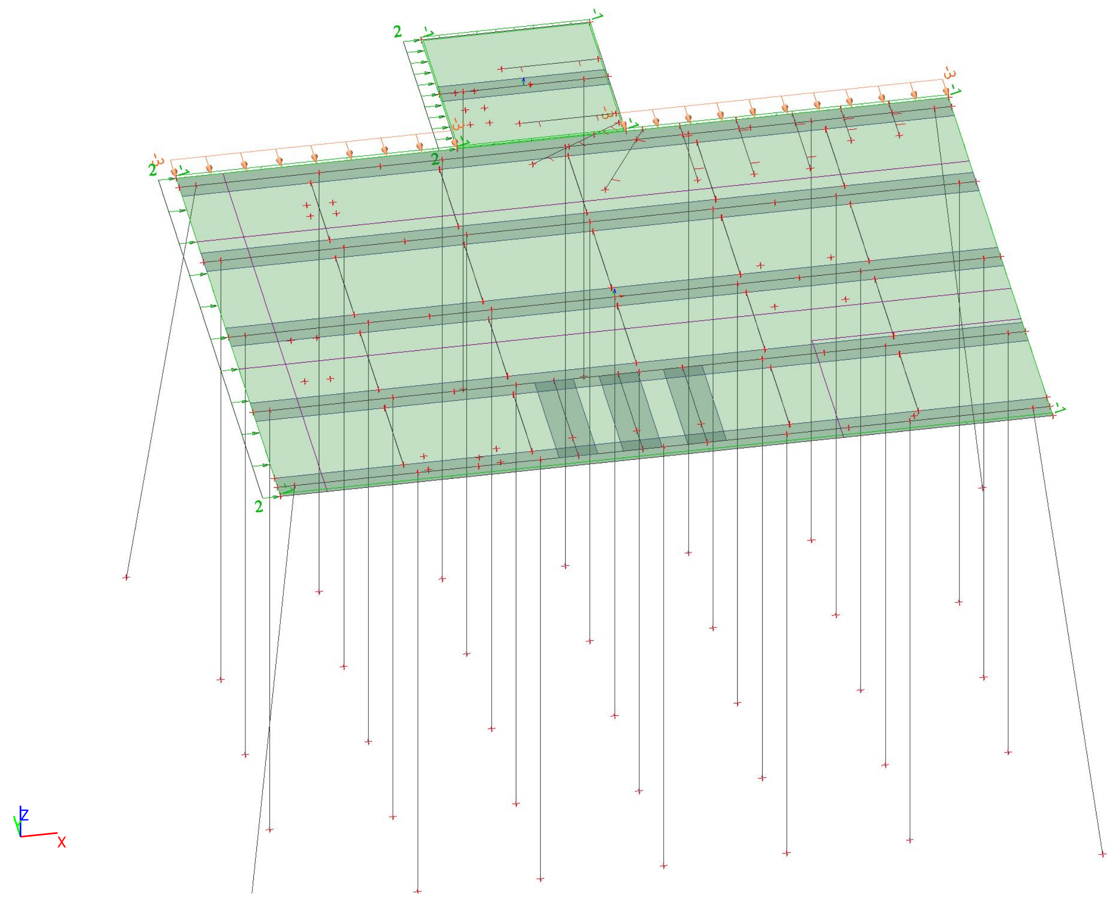
**VB.3.3 - MLA and JIB crane - 45gr**



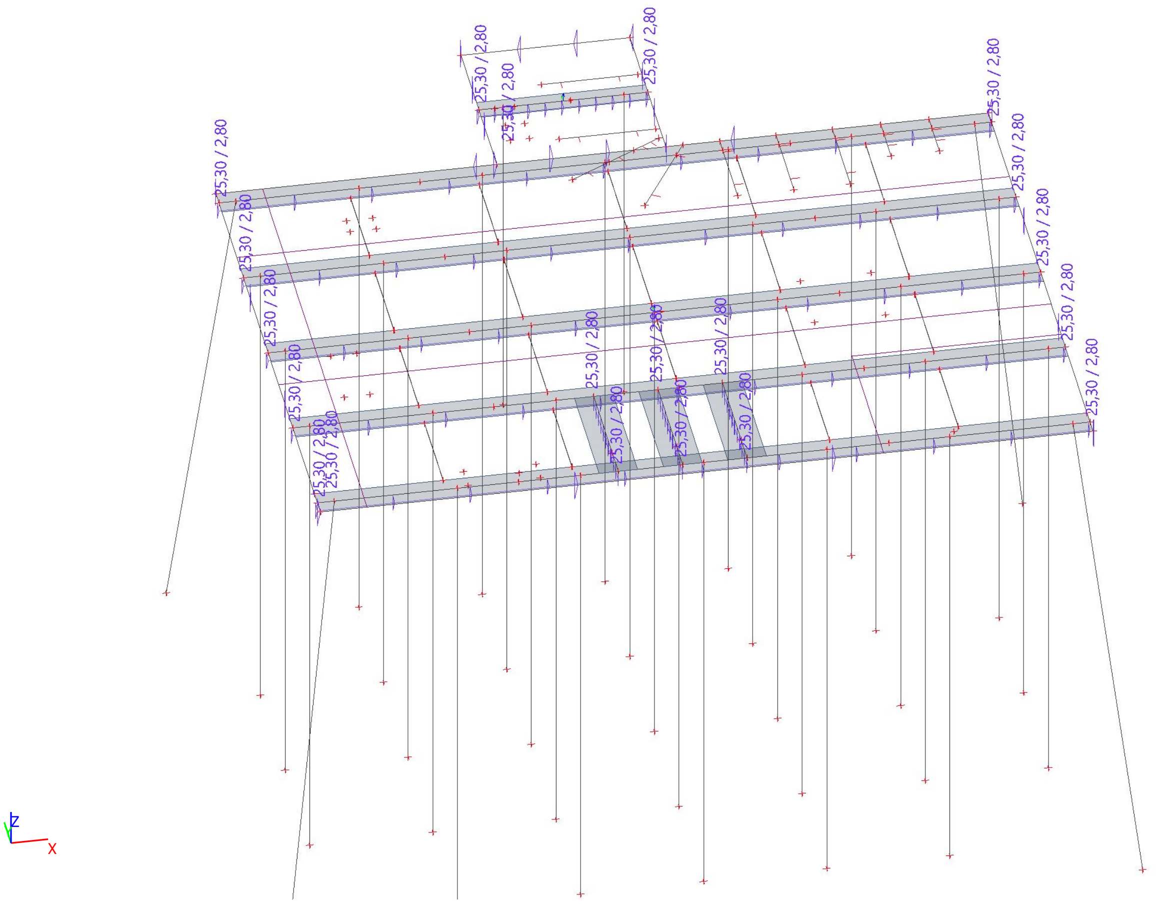
## VB.4.1 - Wind -x-richting



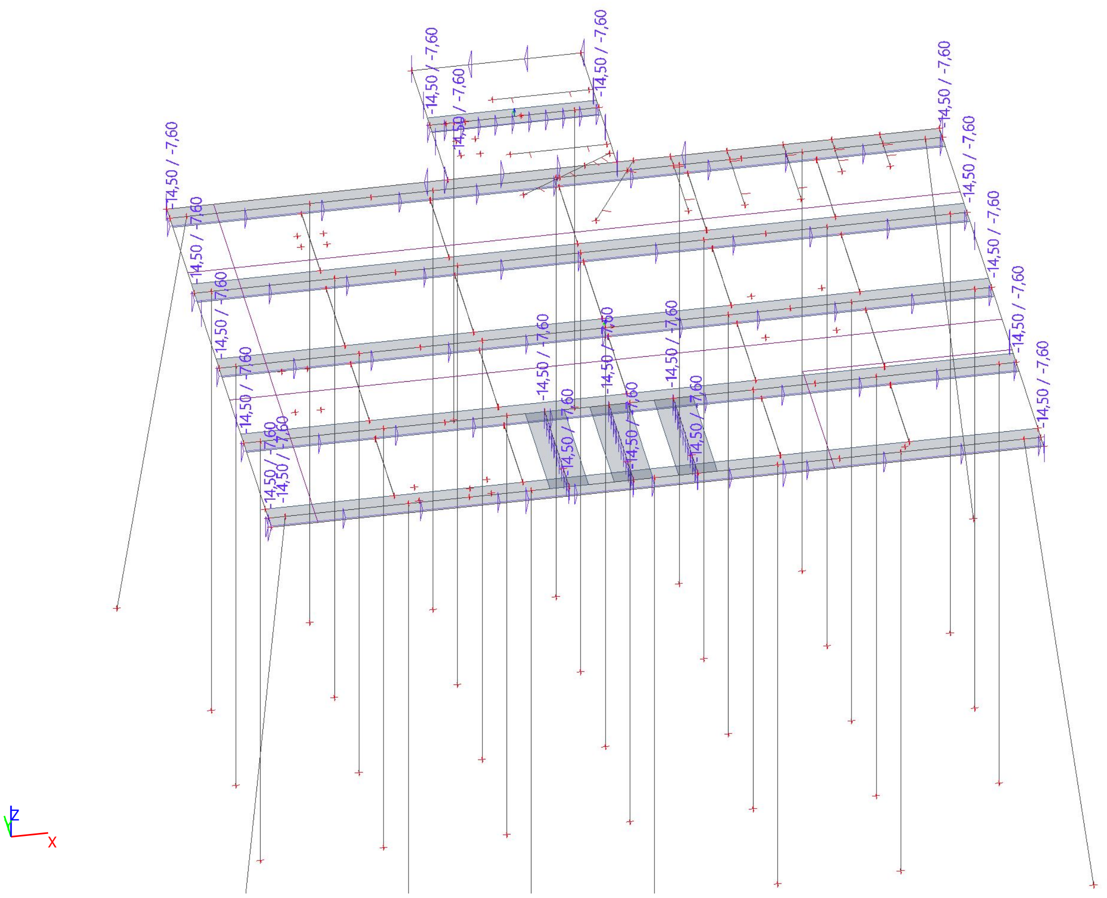
## VB.4.2 - Wind -y-richting



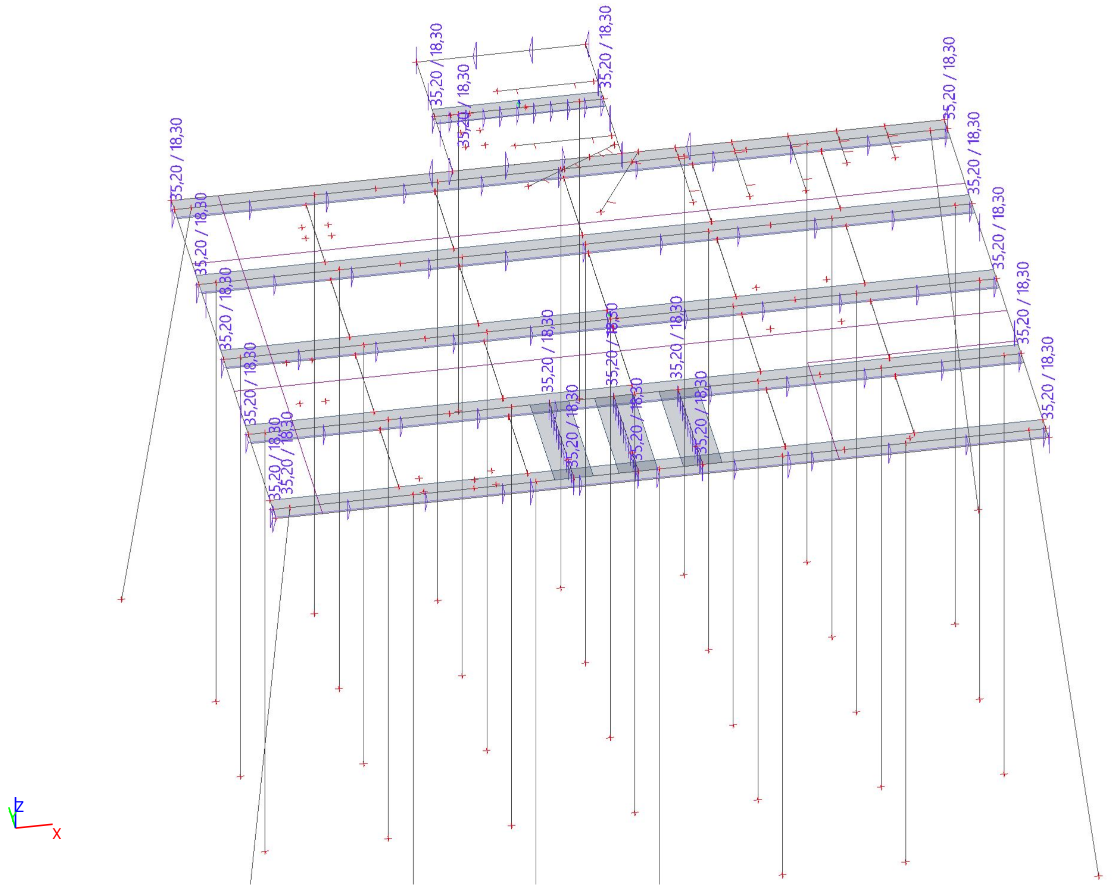
**VB.5.1 - Temperatuur - comb.1**



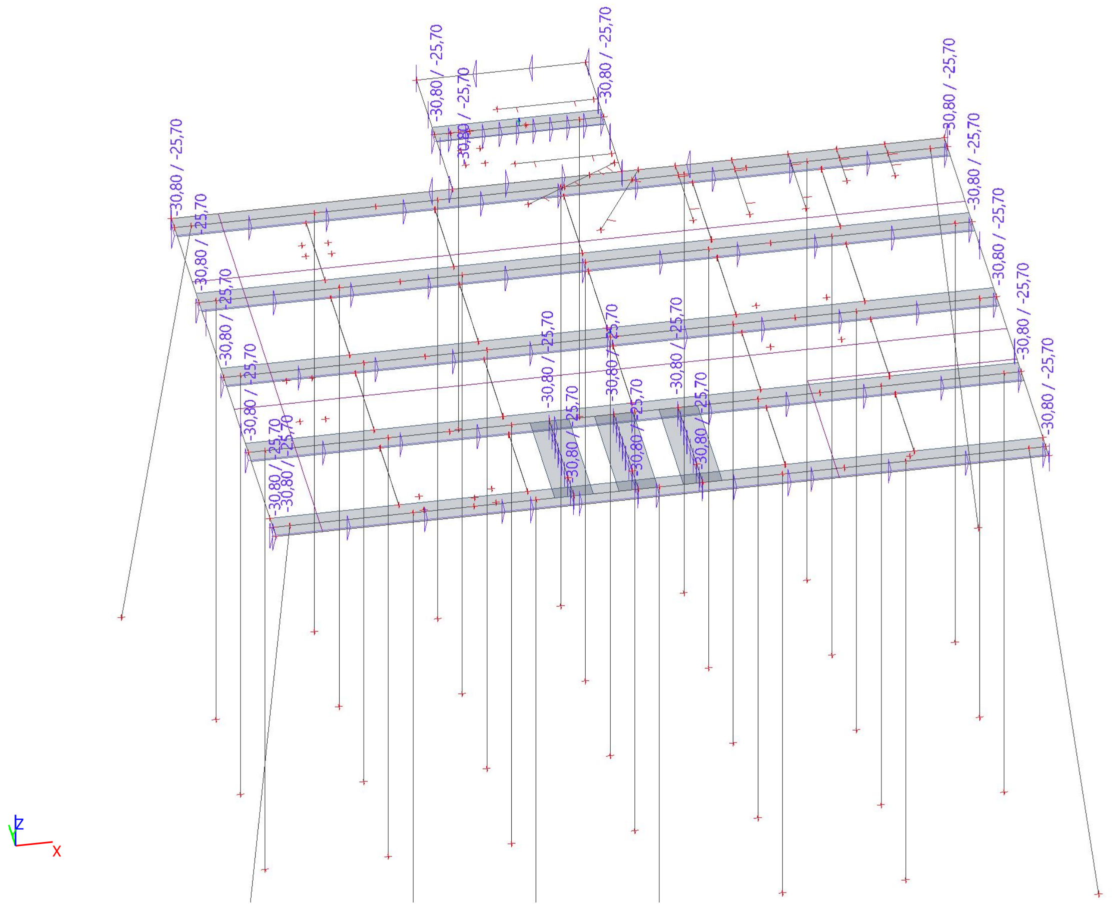

**VB.5.2 - Temperatuur - comb.2**



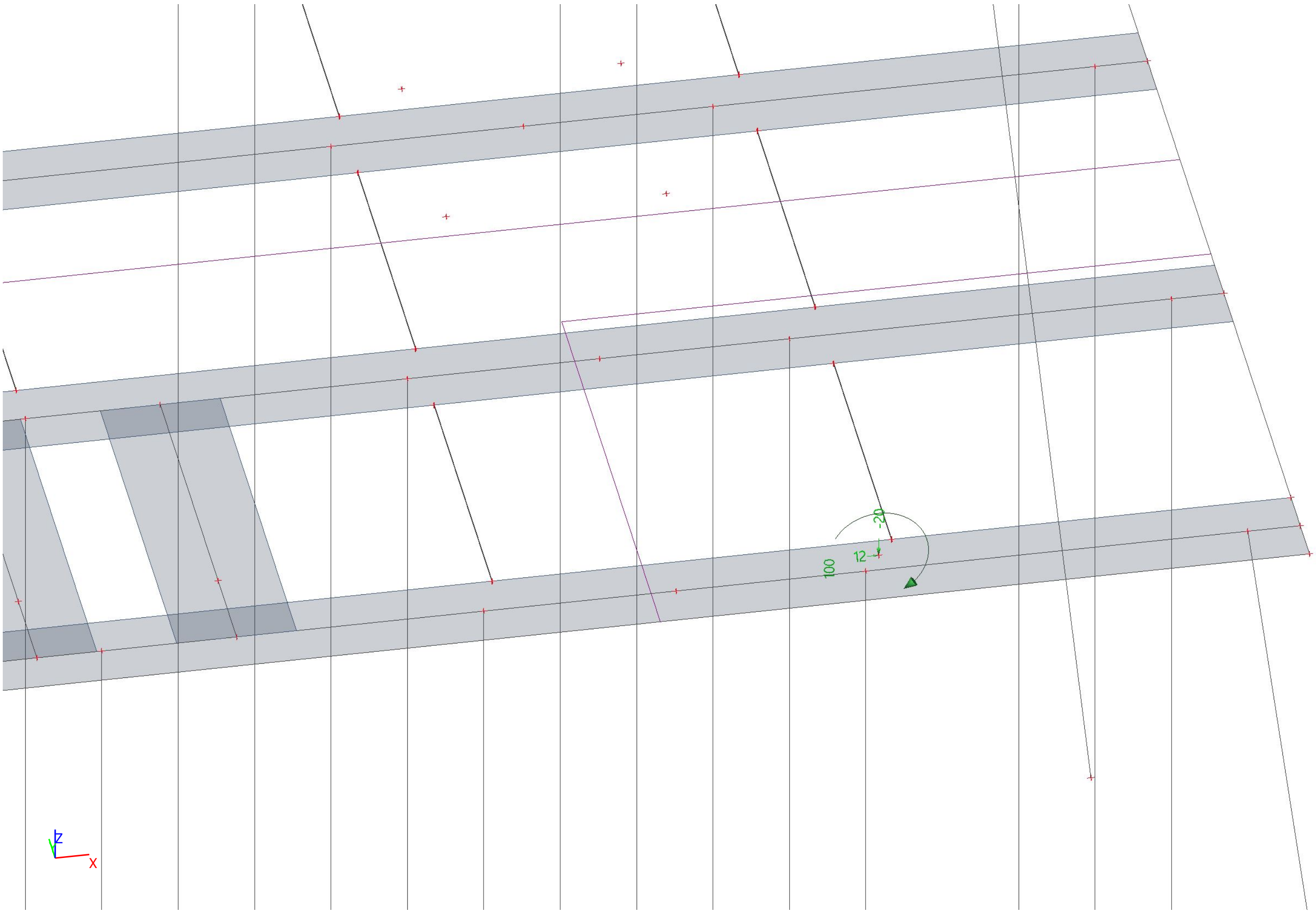
## VB.5.3 - Temperatuur - comb.3



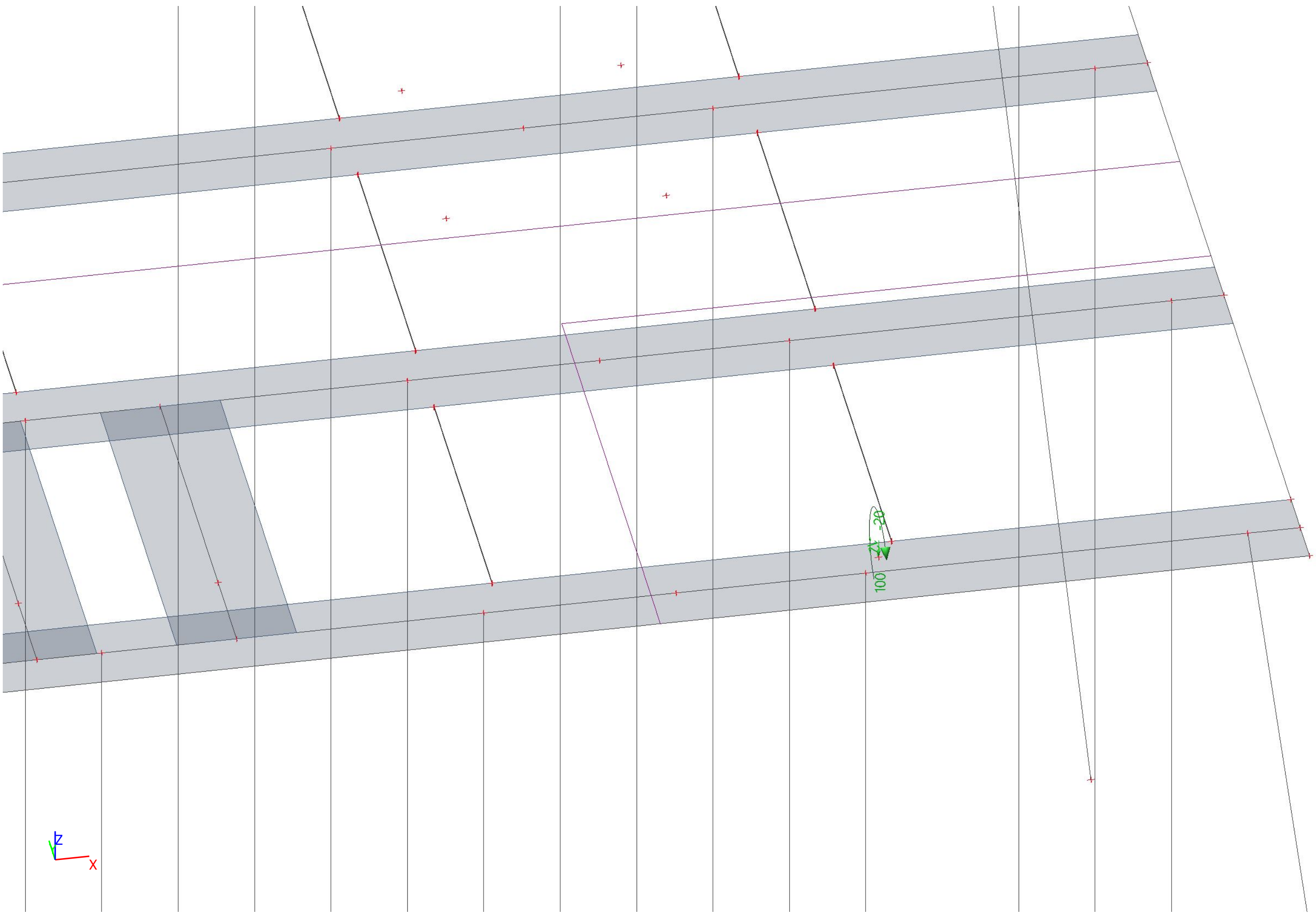

## VB.5.4 - Temperatuur - comb.4



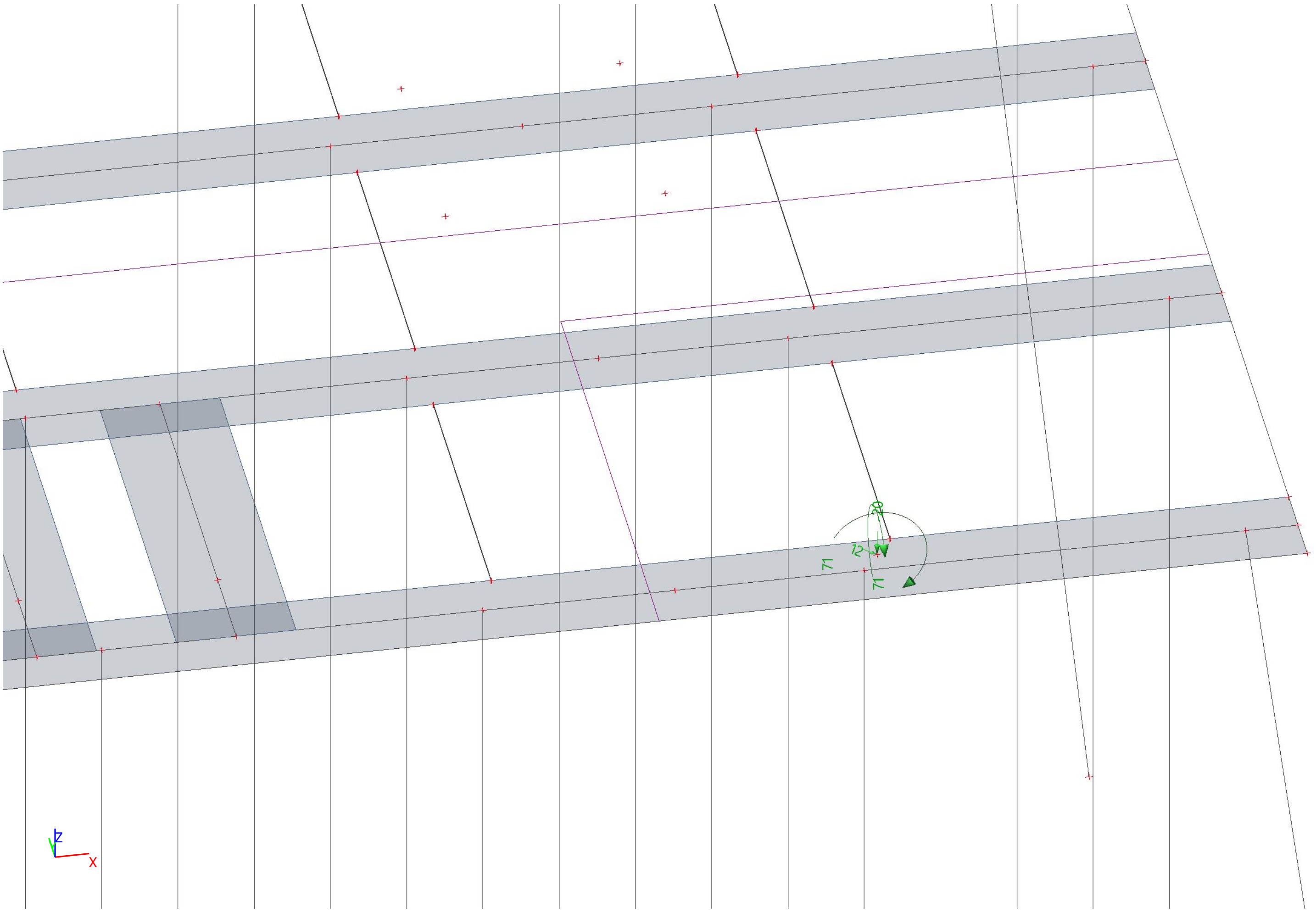
**VB.6.1 - FM - X richting**



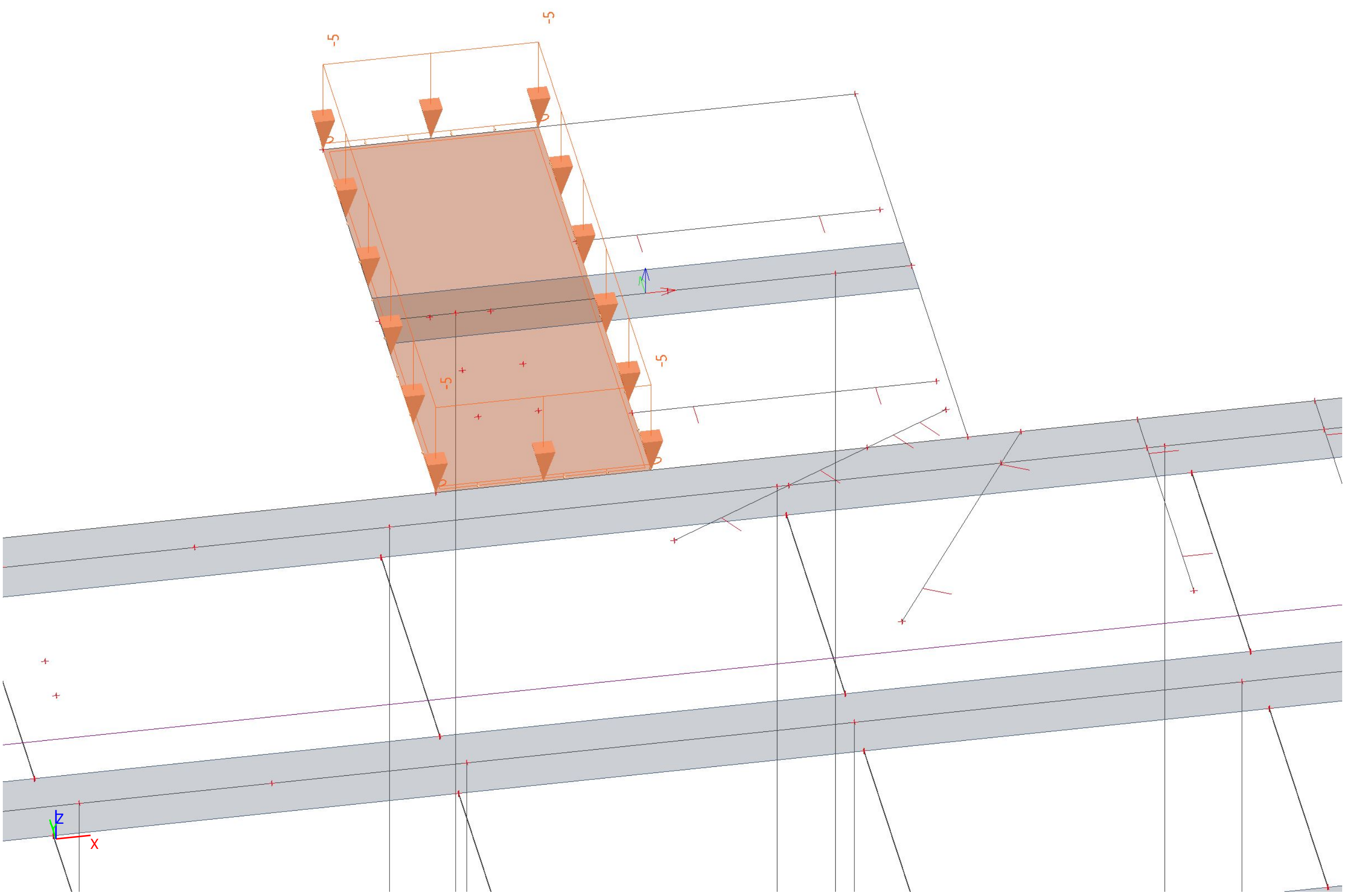

**VB.6.2 - FM - y richting**



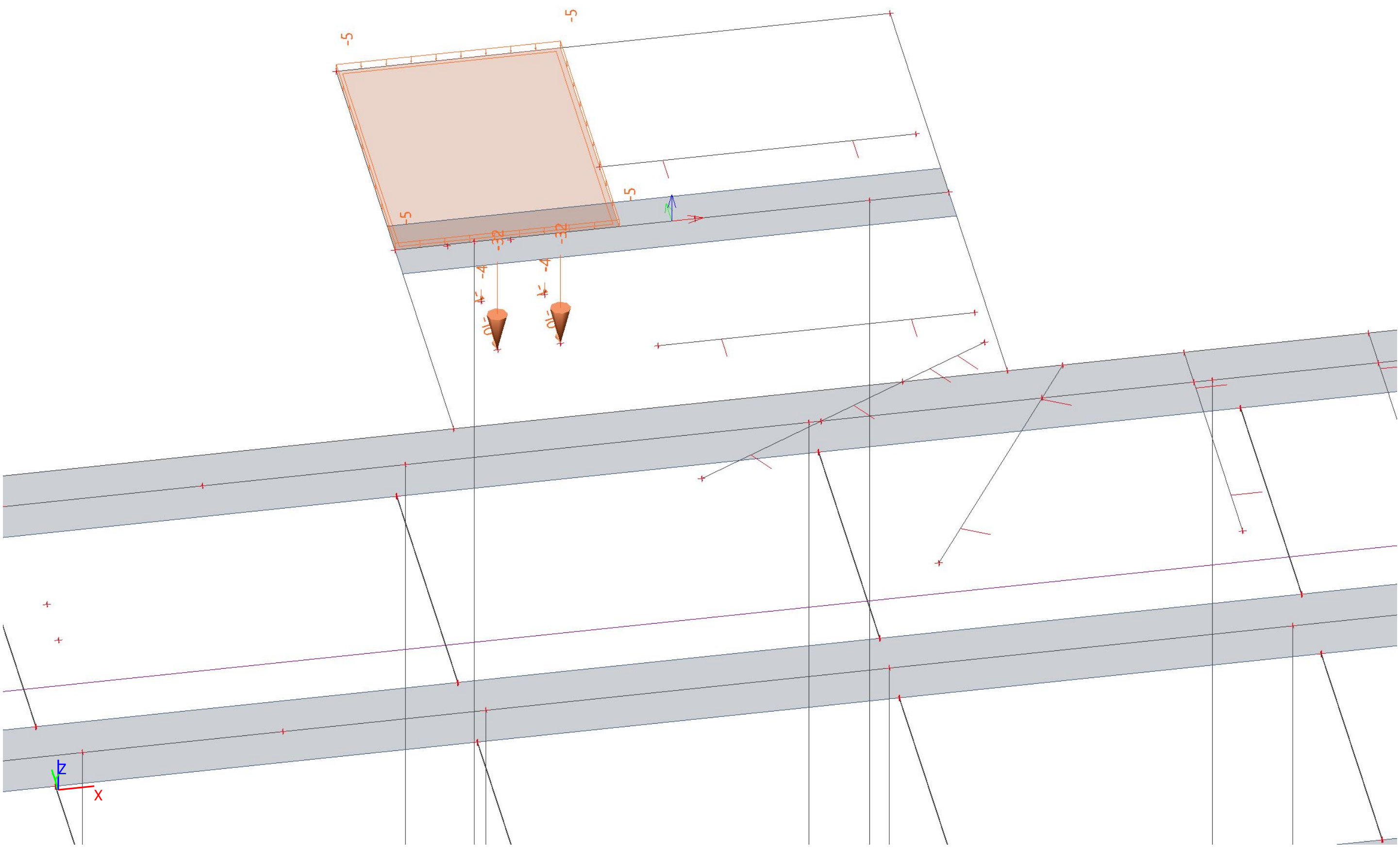
**VB.6.3 - FM - 45 gr**



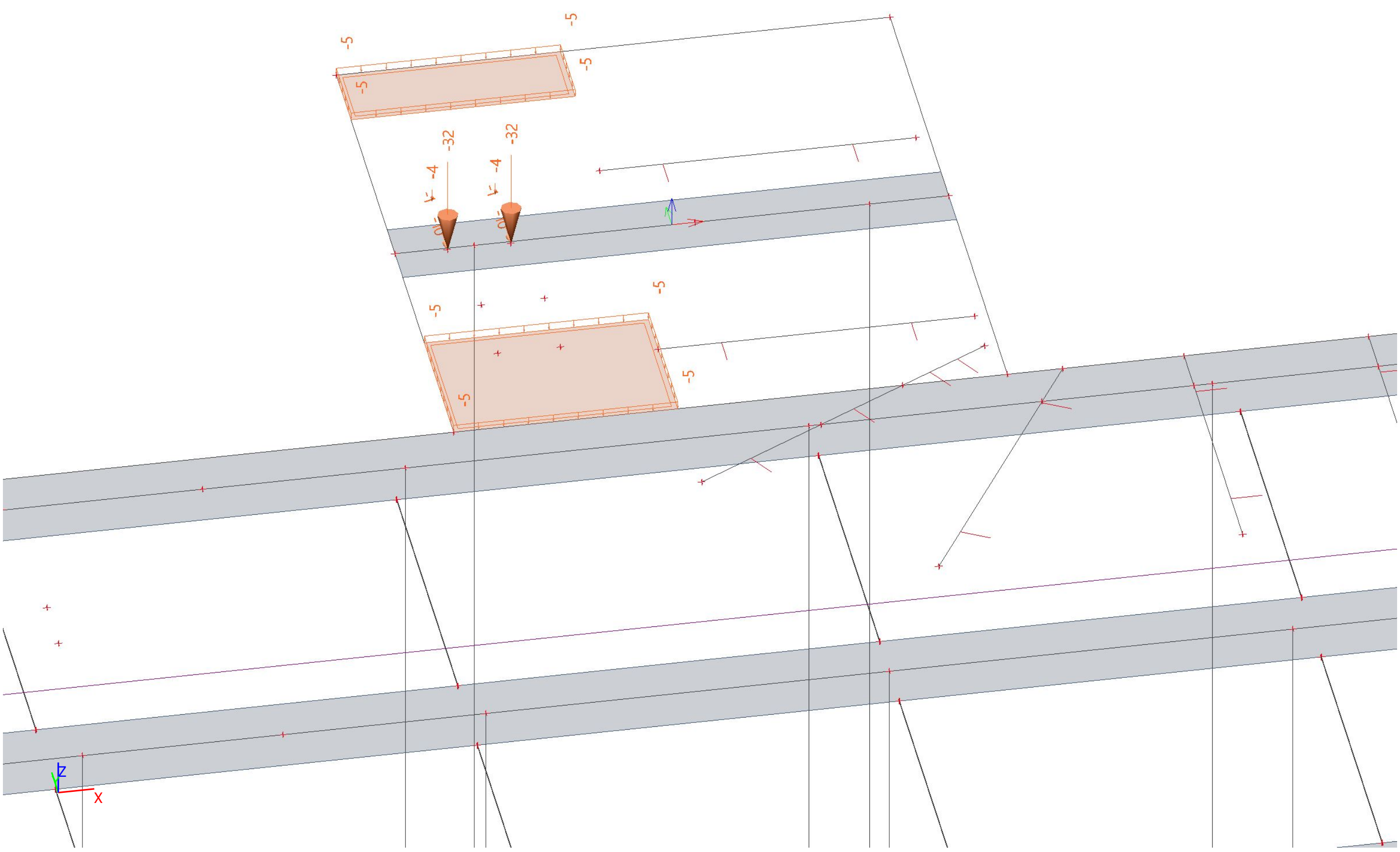
**VB.7.1- VB -wal - variabel**



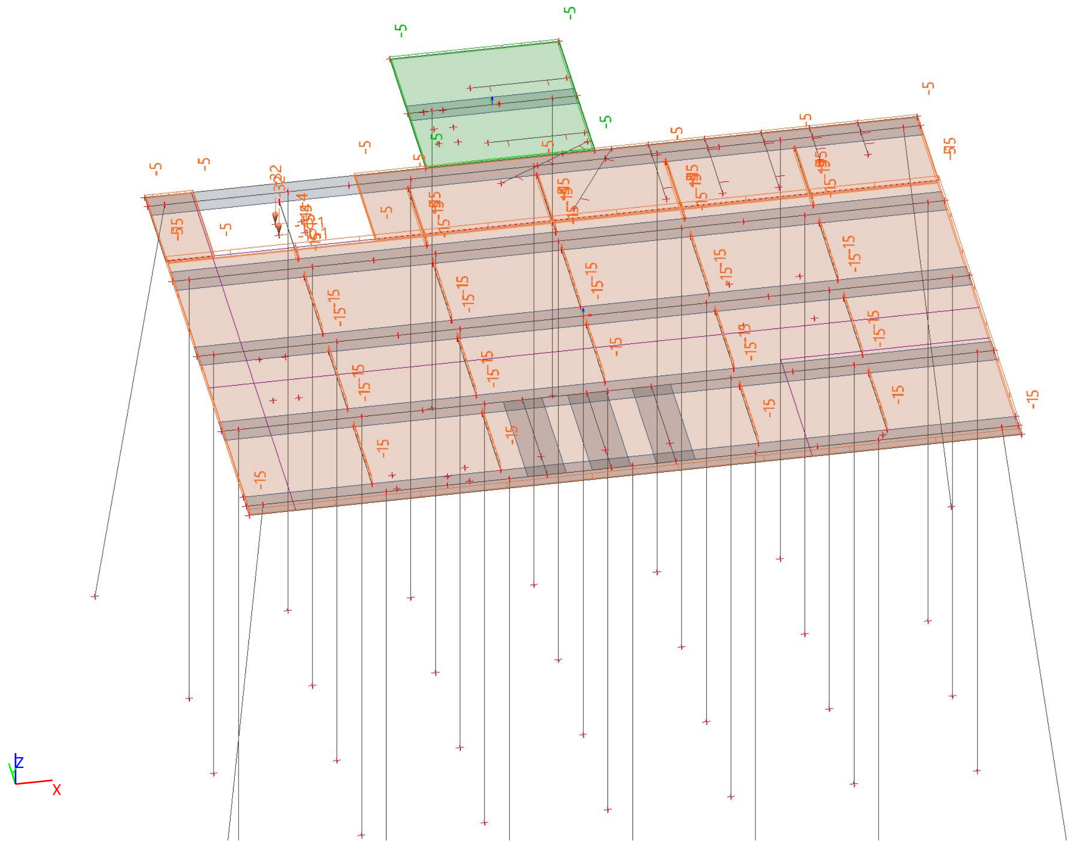
**VB.7.2 -VB - wal + hef midden**




**VB.7.3 -VB - wal + hef ligger**



**VB.8 heftruck op platform + geen piperacks**



## D.2. Boundary conditions

The line support that represents the abutment is shown in Figure D.1 and D.2.

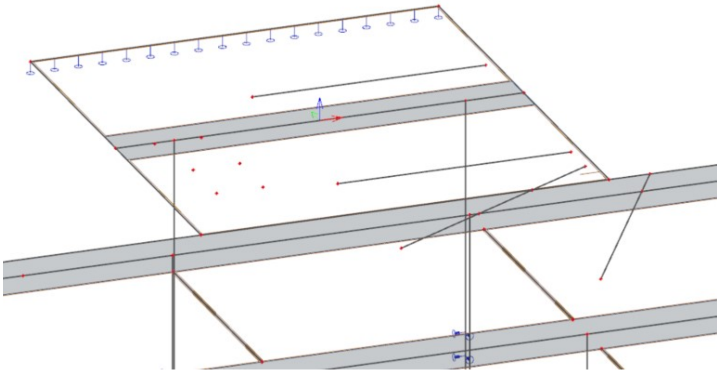


**Figure D.1:** Line support abutment

The supports from the soil are given in Figure D.3. The cone penetration tests on which they were based are given below, of which the first is the governing test for the platform (DKMP004) and the second is the governing test for the approach jetty (DKMP008).

**1. Line support at the abutment**

| Naam | 2D-element<br>Rand | Pos $x_1$<br>Pos $x_2$ | X | Y | Z | Rx | Ry | Rz |
|---|---|---|---|---|---|---|---|---|
| Sle1 | E2<br>3 | 0.000<br>1.000 | Vrij | Vrij | Vast | Vrij | Vrij | Vrij |

**Figure D.2:** Properties of line support abutment

## 1. Vertical support piles

| Naam | Knoop | Systeem | Type | X | Y | Z | Rx | Ry | Rz | Stijfheid Z [MN/m] |
|---|---|---|---|---|---|---|---|---|---|---|
| Sn80 | K696 | GCS | Standaard | Vrij | Vrij | Verend | Vrij | Vrij | Vrij | 7,0700e+01 |

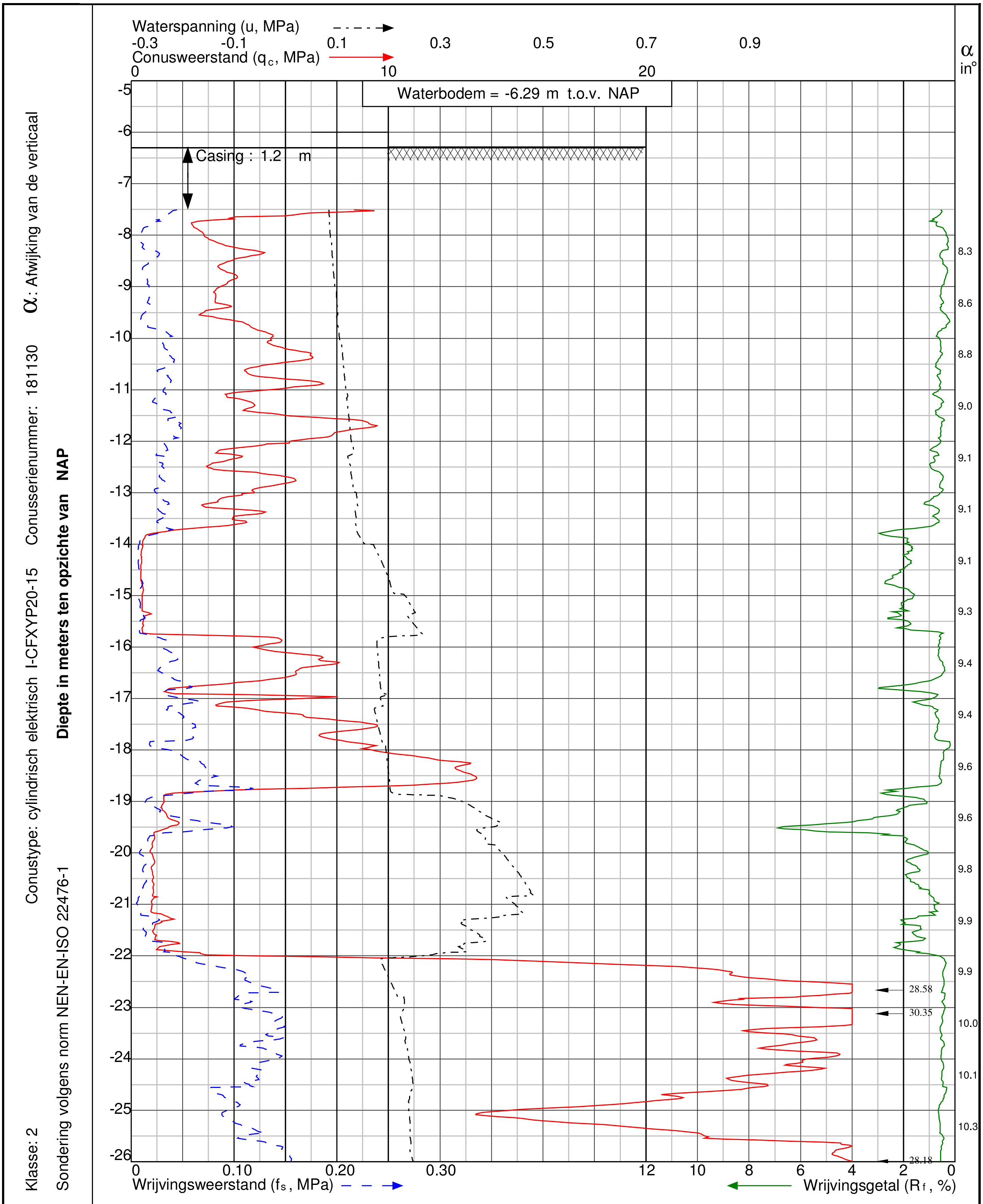
## 2. Line support on pile platform

| Naam | Type | Staaf | Pos $x_1$ [m] | X | Y | Z | Rx | Ry | Rz | Stijfheid X [MN/m²] | Stijfheid Y [MN/m²] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Systeem | Pos $x_2$ [m] | | | | | | | | |
| Slb473 | Lijn | S111 | 7,500 | Verend | Verend | Vrij | Vrij | Vrij | Vrij | 7,0000e+00 | 7,0000e+00 |
| | | GCS | 15,500 | | | | | | | | |
| Slb474 | Lijn | S111 | 19,500 | Verend | Verend | Vrij | Vrij | Vrij | Vrij | 1,5000e+00 | 1,5000e+00 |
| | | GCS | 21,750 | | | | | | | | |
| Slb475 | Lijn | S111 | 21,750 | Verend | Verend | Vrij | Vrij | Vrij | Vrij | 1,0500e+01 | 1,0500e+01 |
| | | GCS | 24,000 | | | | | | | | |
| Slb476 | Lijn | S111 | 24,000 | Verend | Verend | Vrij | Vrij | Vrij | Vrij | 1,9300e+01 | 1,9300e+01 |
| | | GCS | 25,000 | | | | | | | | |
| Slb477 | Lijn | S111 | 25,000 | Verend | Verend | Vrij | Vrij | Vrij | Vrij | 3,0000e+00 | 3,0000e+00 |
| | | GCS | 28,000 | | | | | | | | |
| Slb478 | Lijn | S111 | 28,000 | Verend | Verend | Vrij | Vrij | Vrij | Vrij | 4,3900e+01 | 4,3900e+01 |
| | | GCS | 31,000 | | | | | | | | |
| Slb876 | Lijn | S111 | 15,500 | Verend | Verend | Vrij | Vrij | Vrij | Vrij | 8,8000e+00 | 8,8000e+00 |
| | | GCS | 19,500 | | | | | | | | |

## 3. Line support on pile approach jetty

| Naam | Type | Staaf | Pos $x_1$ [m] | X | Y | Z | Rx | Ry | Rz | Stijfheid Y [MN/m²] | Stijfheid Z [MN/m²] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Systeem | Pos $x_2$ [m] | | | | | | | | |
| Slb651 | Lijn | S147 | 6,000 | Vrij | Verend | Verend | Vrij | Vrij | Vrij | 6,1000e+00 | 6,1000e+00 |
| | | LCS | 14,000 | | | | | | | | |
| Slb652 | Lijn | S147 | 14,000 | Vrij | Verend | Verend | Vrij | Vrij | Vrij | 7,7000e+00 | 7,7000e+00 |
| | | LCS | 20,500 | | | | | | | | |
| Slb653 | Lijn | S147 | 20,500 | Vrij | Verend | Verend | Vrij | Vrij | Vrij | 2,8000e+00 | 2,8000e+00 |
| | | LCS | 21,500 | | | | | | | | |
| Slb654 | Lijn | S147 | 21,500 | Vrij | Verend | Verend | Vrij | Vrij | Vrij | 1,8400e+01 | 1,8400e+01 |
| | | LCS | 22,000 | | | | | | | | |

**Figure D.3:** Springs in SCIA Engineer model



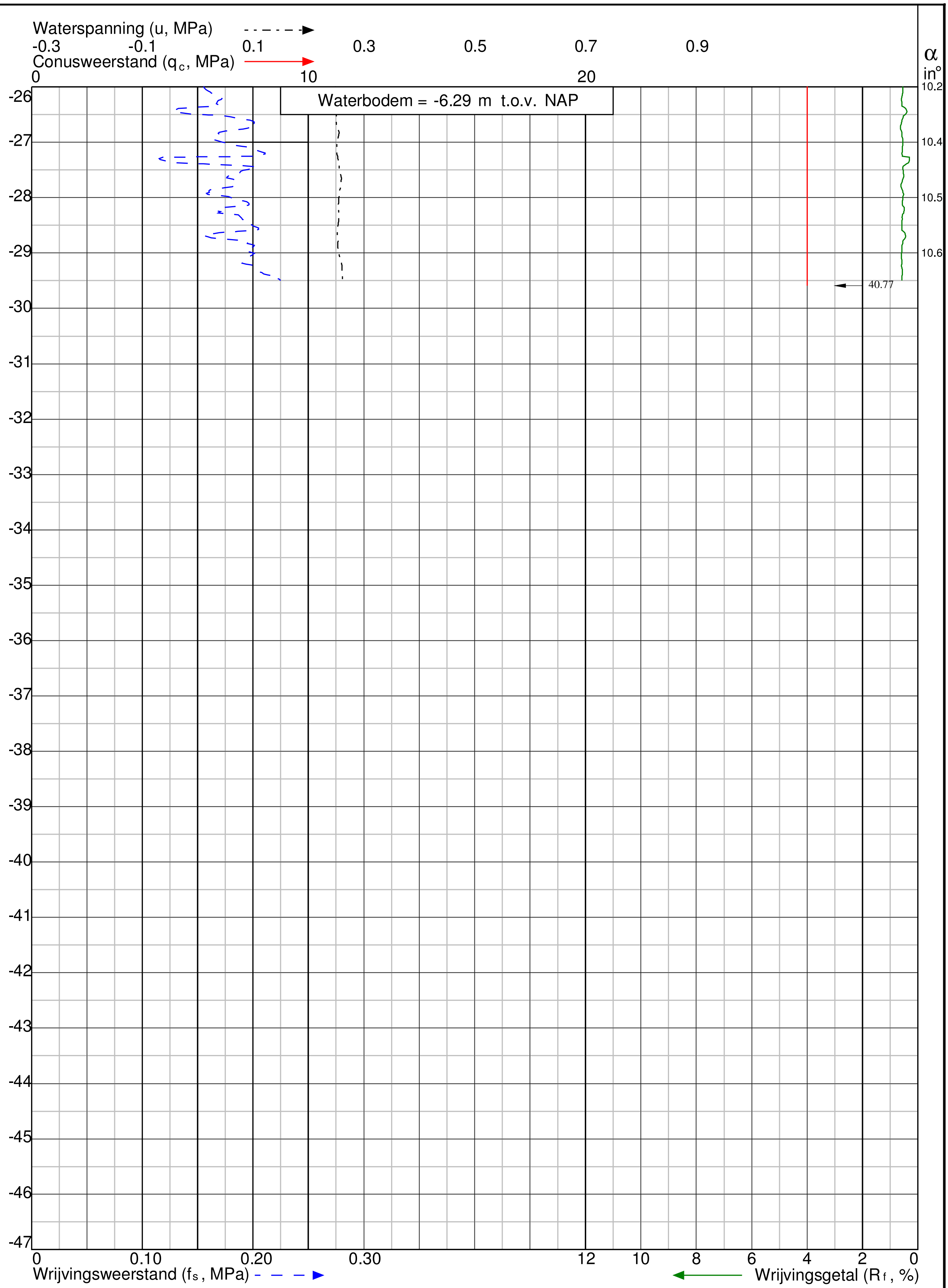

| | |
|---|---|
| Project: Extra binnenvaartligplaats in de Europahaven bij Neste Biofuels<br>te **Europoort** | Sondering:<br>DKMP004 |
| Wiertsema & Partners<br>RAADGEVEND INGENIEURS | x = 61926<br>y = 442564 |
| | Opdr.nr: VN-74461-1 |
| Blad: 1 van 2 | Datum: 16-9-2019 |

AKKOORD UITV

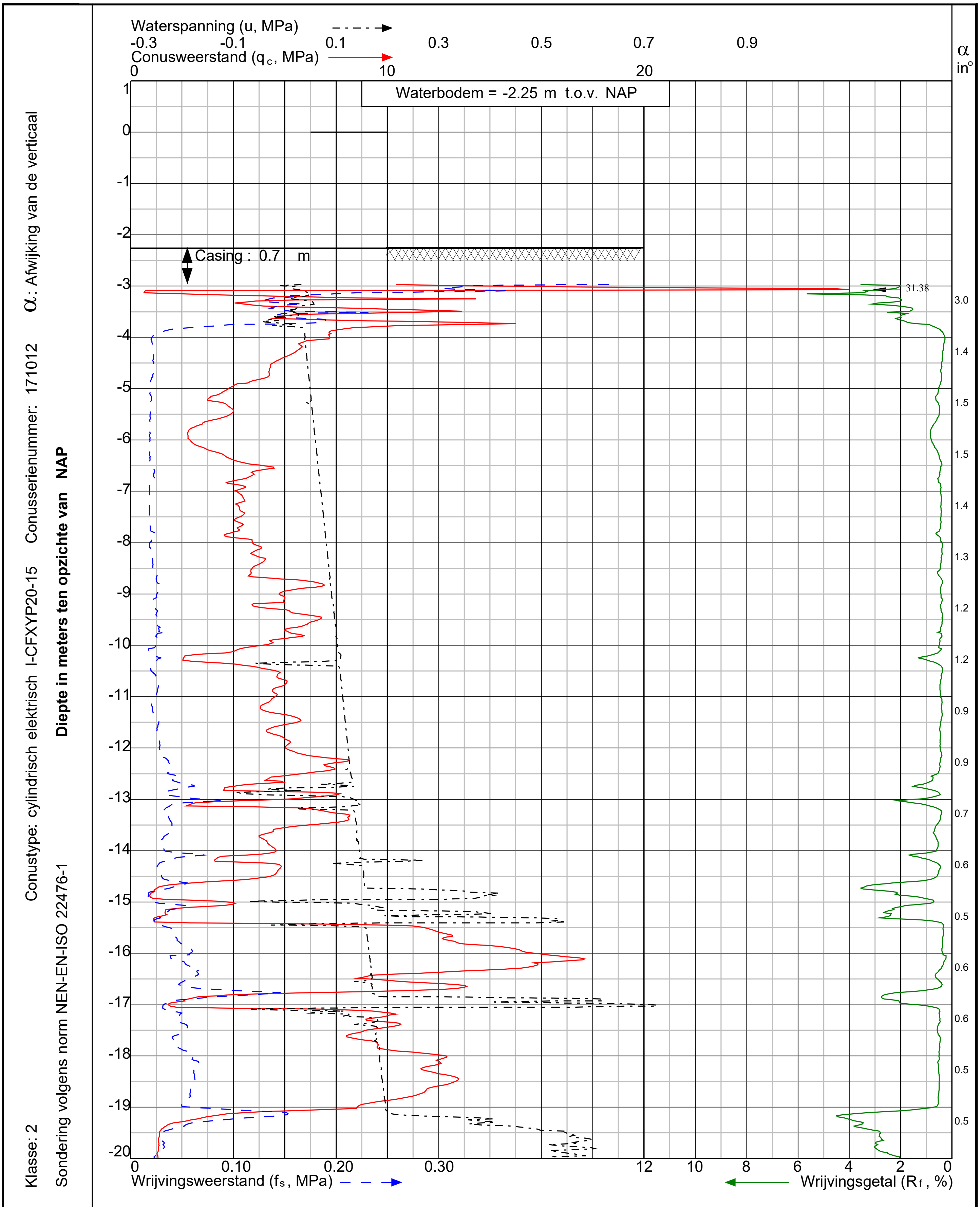
Klasse: 2

Conustype: cylindrisch elektrisch I-CFXYP20-15 Conusserienummer: 181130 α: Afwijking van de verticaal

Sondering volgens norm NEN-EN-ISO 22476-1 **Diepte in meters ten opzichte van NAP**




| | |
|---|---|
| Project: Extra binnenvaartligplaats in de Europahaven bij Neste Biofuels te **Europoort** | Sondering: DKMP004 |
| Wiertsema & Partners RAADGEVEND INGENIEURS | x = 61926<br>y = 442564 |
| Blad: 2 van 2 | Opdr.nr: VN-74461-1 |
| | Datum: 16-9-2019 |
| | AKKOORD UITV |




Project: Extra binnenvaartligplaats in de Europahaven bij Neste Biofuels te **Europoort**

Sondering: DKMP008

Wiertsema & Partners
RAADGEVEND INGENIEURS

x = 61904

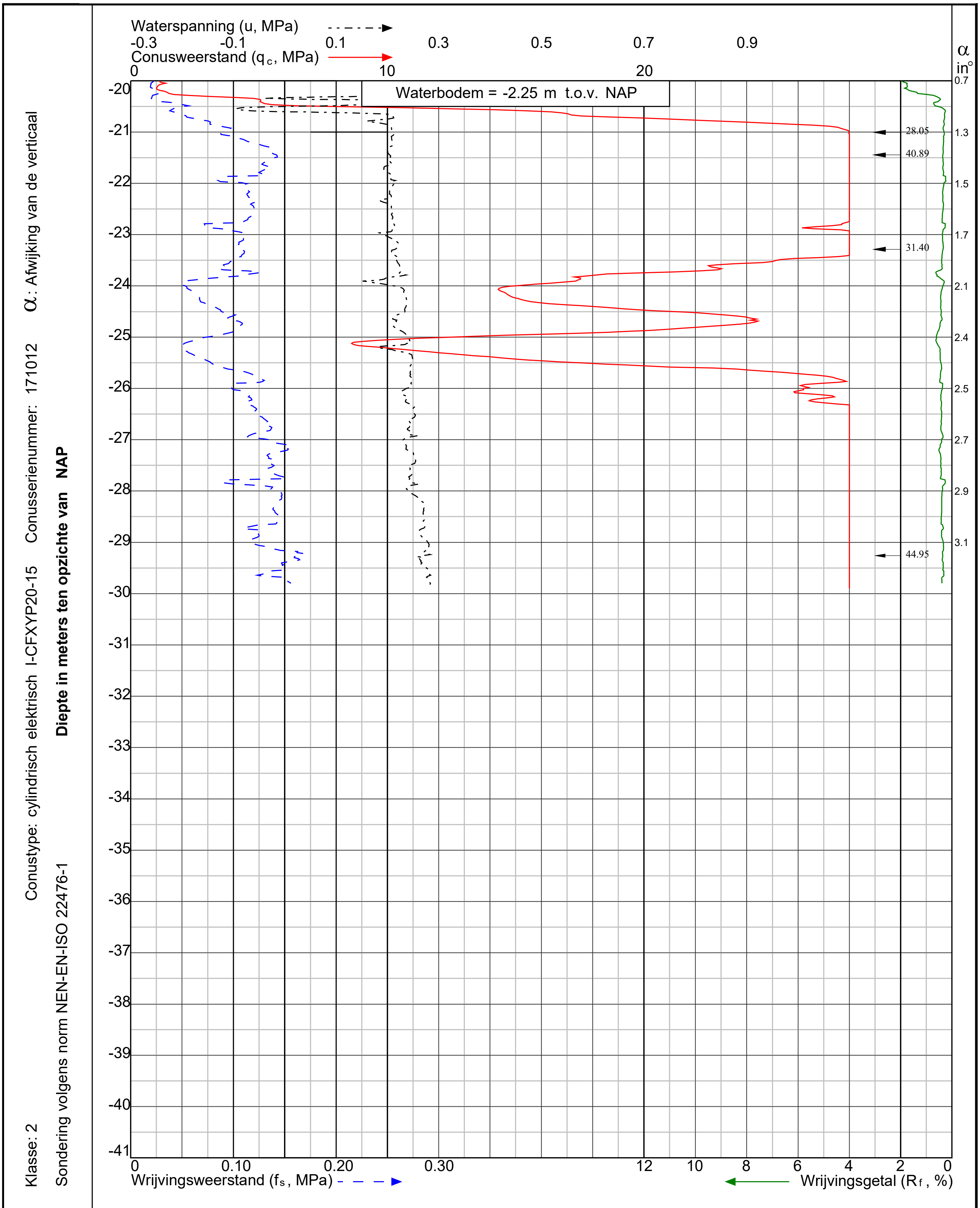
y = 442594

Opdr.nr: VN-74461-1

Blad: 1 van 2

Datum: 19-9-2019

AKKOORD UITV




Project: Extra binnenvaartligplaats in de Europahaven bij Neste Biofuels
te **Europoort**

Sondering:
DKMP008

x = 61904
y = 442594

Wiertsema & Partners
RAADGEVEND INGENIEURS

Opdr.nr: VN-74461-1

Blad: 2 van 2

Datum: 19-9-2019

AKKOORD UITV

# D.3. Elements and layout of models

## D.3.1. Reference jetty model

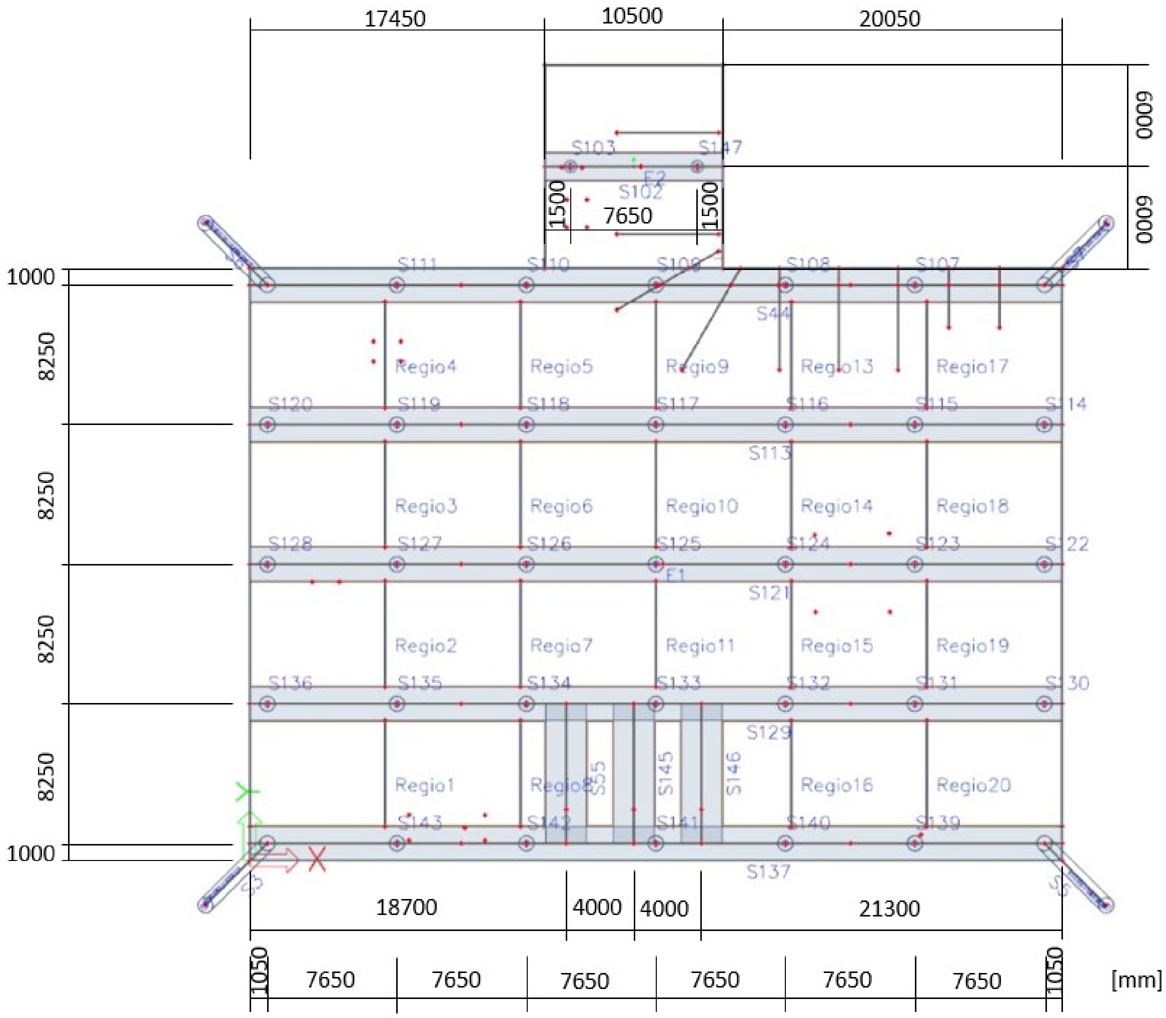



**Figure D.4:** Layout of reference jetty model

# 1. Elements and cross-sections of reference jetty model

## 1.1. Foundation piles

| Naam | Doorsnede | Materiaal | Lengte [m] | Beginknoop | Eindknoop | Type |
|---|---|---|---|---|---|---|
| S3 | CS10 - Buis (914; 16) | S 355 | 31,428 | K646 | K10 | Balk (80) |
| S5 | CS10 - Buis (914; 16) | S 355 | 31,428 | K647 | K14 | Balk (80) |
| S6 | CS10 - Buis (914; 16) | S 355 | 31,428 | K690 | K16 | Balk (80) |
| S7 | CS10 - Buis (914; 16) | S 355 | 31,428 | K684 | K20 | Balk (80) |
| S107 | CS10 - Buis (914; 16) | S 355 | 31,000 | K685 | K692 | Balk (80) |
| S108 | CS10 - Buis (914; 16) | S 355 | 31,000 | K686 | K693 | Balk (80) |
| S109 | CS10 - Buis (914; 16) | S 355 | 31,000 | K687 | K694 | Balk (80) |
| S110 | CS10 - Buis (914; 16) | S 355 | 31,000 | K688 | K695 | Balk (80) |
| S111 | CS10 - Buis (914; 16) | S 355 | 31,000 | K689 | K696 | Balk (80) |
| S114 | CS10 - Buis (914; 16) | S 355 | 31,000 | K707 | K698 | Balk (80) |
| S115 | CS10 - Buis (914; 16) | S 355 | 31,000 | K708 | K699 | Balk (80) |
| S116 | CS10 - Buis (914; 16) | S 355 | 31,000 | K709 | K700 | Balk (80) |
| S117 | CS10 - Buis (914; 16) | S 355 | 31,000 | K710 | K701 | Balk (80) |
| S118 | CS10 - Buis (914; 16) | S 355 | 31,000 | K711 | K702 | Balk (80) |
| S119 | CS10 - Buis (914; 16) | S 355 | 31,000 | K712 | K703 | Balk (80) |
| S120 | CS10 - Buis (914; 16) | S 355 | 31,000 | K713 | K704 | Balk (80) |
| S122 | CS10 - Buis (914; 16) | S 355 | 31,000 | K723 | K714 | Balk (80) |
| S123 | CS10 - Buis (914; 16) | S 355 | 31,000 | K724 | K715 | Balk (80) |
| S124 | CS10 - Buis (914; 16) | S 355 | 31,000 | K725 | K716 | Balk (80) |
| S125 | CS10 - Buis (914; 16) | S 355 | 31,000 | K726 | K717 | Balk (80) |
| S126 | CS10 - Buis (914; 16) | S 355 | 31,000 | K727 | K718 | Balk (80) |
| S127 | CS10 - Buis (914; 16) | S 355 | 31,000 | K728 | K719 | Balk (80) |
| S128 | CS10 - Buis (914; 16) | S 355 | 31,000 | K729 | K720 | Balk (80) |
| S130 | CS10 - Buis (914; 16) | S 355 | 31,000 | K739 | K730 | Balk (80) |
| S131 | CS10 - Buis (914; 16) | S 355 | 31,000 | K740 | K731 | Balk (80) |
| S132 | CS10 - Buis (914; 16) | S 355 | 31,000 | K741 | K732 | Balk (80) |
| S133 | CS10 - Buis (914; 16) | S 355 | 31,000 | K742 | K733 | Balk (80) |
| S134 | CS10 - Buis (914; 16) | S 355 | 31,000 | K743 | K734 | Balk (80) |
| S135 | CS10 - Buis (914; 16) | S 355 | 31,000 | K744 | K735 | Balk (80) |
| S136 | CS10 - Buis (914; 16) | S 355 | 31,000 | K745 | K736 | Balk (80) |
| S139 | CS10 - Buis (914; 16) | S 355 | 31,000 | K756 | K747 | Balk (80) |
| S140 | CS10 - Buis (914; 16) | S 355 | 31,000 | K757 | K748 | Balk (80) |
| S141 | CS10 - Buis (914; 16) | S 355 | 31,000 | K758 | K749 | Balk (80) |
| S142 | CS10 - Buis (914; 16) | S 355 | 31,000 | K759 | K750 | Balk (80) |
| S143 | CS10 - Buis (914; 16) | S 355 | 31,000 | K760 | K751 | Balk (80) |
| S103 | CS11 - Buis (711; 12) | S 355 | 22,000 | K857 | K858 | Balk (80) |
| S147 | CS11 - Buis (711; 12) | S 355 | 22,000 | K856 | K859 | Balk (80) |

## 1.2. Rib plates

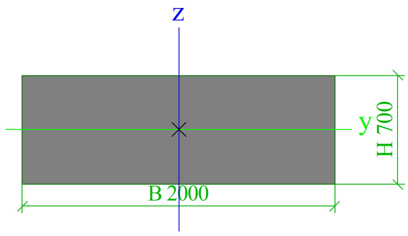
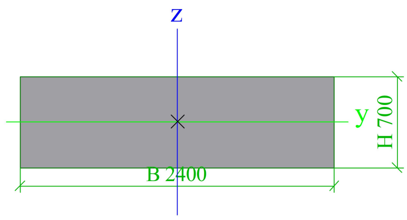
| Naam | Doorsnede | Materiaal | Lengte [m] | Beginknoop | Eindknoop | Type |
|---|---|---|---|---|---|---|
| S44 | CS1 - Rechthoek (700; 2000) | C35/45 * | 48,000 | K290 | K291 | Plaatrib (92) |
| S55 | CS6 - Rechthoek (700; 2400) | C35/45 * | 8,250 | K765 | K762 | Plaatrib (92) |
| S102 | CS7 - Rechthoek (500; 1600) | C35/45 * | 10,500 | K294 | K570 | Plaatrib (92) |
| S113 | CS1 - Rechthoek (700; 2000) | C35/45 * | 48,000 | K705 | K706 | Plaatrib (92) |
| S121 | CS1 - Rechthoek (700; 2000) | C35/45 * | 48,000 | K721 | K722 | Plaatrib (92) |
| S129 | CS1 - Rechthoek (700; 2000) | C35/45 * | 48,000 | K737 | K738 | Plaatrib (92) |
| S137 | CS1 - Rechthoek (700; 2000) | C35/45 * | 48,000 | K753 | K754 | Plaatrib (92) |
| S145 | CS6 - Rechthoek (700; 2400) | C35/45 * | 8,250 | K766 | K763 | Plaatrib (92) |
| S146 | CS6 - Rechthoek (700; 2400) | C35/45 * | 8,250 | K767 | K764 | Plaatrib (92) |

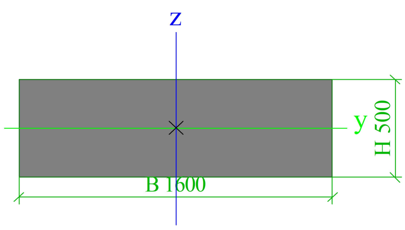
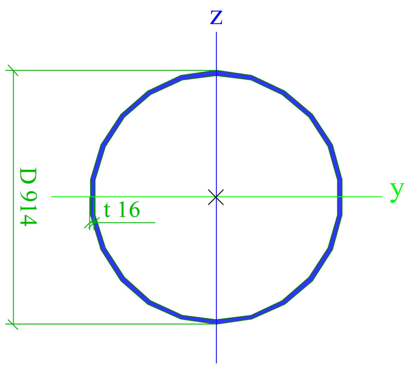
## 1.3. Plates

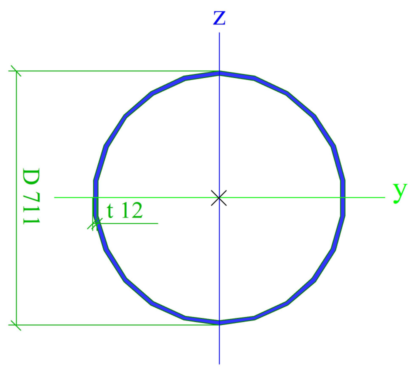
| Naam | Laag | Type | Element type | Materiaal | Dikte type | D. [mm] |
|---|---|---|---|---|---|---|
| E1 | Laag1 | vloer (90) | Standaard | C35/45 * | constant | 500 |
| E2 | Laag1 | vloer (90) | Standaard | C35/45 * | constant | 500 |

## 1.4. All cross sections

| CS1 | | |
|---|---|---|
| Type | Rechthoek | |
| Uitgebreid | 700; 2000 | |
| Vorm type | Dikke wanden | |
| Onderdeelmateriaal | C35/45 * | |
| Bouwwijze | beton | |
| Kleur | | |
| A [m$^2$] | 1,4000e+00 | |
| $A_y$ [m$^2$], $A_z$ [m$^2$] | 1,1671e+00 | 1,1704e+00 |
| $A_L$ [m$^2$/m], $A_D$ [m$^2$/m] | 5,4000e+00 | 5,4000e+00 |
| $c_{Y.UCS}$ [mm], $c_{Z.UCS}$ [mm] | 1000 | 350 |
| α [deg] | 0,00 | |

| | | |
|---|---|---|
| $I_y$ [$m^4$], $I_z$ [$m^4$] | 5,7167e-02 | 4,6667e-01 |
| $i_y$ [mm], $i_z$ [mm] | 202 | 577 |
| $W_{el.y}$ [$m^3$], $W_{el.z}$ [$m^3$] | 1,6333e-01 | 4,6667e-01 |
| $W_{pl.y}$ [$m^3$], $W_{pl.z}$ [$m^3$] | 0,0000e+00 | 0,0000e+00 |
| $M_{pl.y.+}$ [Nm], $M_{pl.y.-}$ [Nm] | 0,00e+00 | 0,00e+00 |
| $M_{pl.z.+}$ [Nm], $M_{pl.z.-}$ [Nm] | 0,00e+00 | 0,00e+00 |
| $d_y$ [mm], $d_z$ [mm] | 0 | 0 |
| $I_t$ [$m^4$], $I_w$ [$m^6$] | 1,7783e-01 | 1,1423e-02 |
| $β_y$ [mm], $β_z$ [mm] | 0 | 0 |
| Afbeelding |   | |
| **CS6** | | |
| Type | Rechthoek | |
| Uitgebreid | 700; 2400 | |
| Vorm type | Dikke wanden | |
| Onderdeelmateriaal | C35/45 * | |
| Bouwwijze | beton | |
| Kleur | | |
| A [$m^2$] | 1,6800e+00 | |
| $A_y$ [$m^2$], $A_z$ [$m^2$] | 1,4004e+00 | 1,4052e+00 |
| $A_L$ [$m^2$/m], $A_D$ [$m^2$/m] | 6,2000e+00 | 6,2000e+00 |
| $c_{Y.UCS}$ [mm], $c_{Z.UCS}$ [mm] | 1200 | 350 |
| α [deg] | 0,00 | |
| $I_y$ [$m^4$], $I_z$ [$m^4$] | 6,8600e-02 | 8,0640e-01 |
| $i_y$ [mm], $i_z$ [mm] | 202 | 693 |
| $W_{el.y}$ [$m^3$], $W_{el.z}$ [$m^3$] | 1,9600e-01 | 6,7200e-01 |
| $W_{pl.y}$ [$m^3$], $W_{pl.z}$ [$m^3$] | 0,0000e+00 | 0,0000e+00 |
| $M_{pl.y.+}$ [Nm], $M_{pl.y.-}$ [Nm] | 0,00e+00 | 0,00e+00 |
| $M_{pl.z.+}$ [Nm], $M_{pl.z.-}$ [Nm] | 0,00e+00 | 0,00e+00 |
| $d_y$ [mm], $d_z$ [mm] | 0 | 0 |
| $I_t$ [$m^4$], $I_w$ [$m^6$] | 2,2344e-01 | 2,2890e-02 |
| $β_y$ [mm], $β_z$ [mm] | 0 | 0 |
| Afbeelding |   | |
| **CS7** | | |
| Type | Rechthoek | |
| Uitgebreid | 500; 1600 | |
| Vorm type | Dikke wanden | |
| Onderdeelmateriaal | C35/45 * | |
| Bouwwijze | beton | |
| Kleur | | |
| A [$m^2$] | 8,0000e-01 | |
| $A_y$ [$m^2$], $A_z$ [$m^2$] | 6,6689e-01 | 6,6896e-01 |
| $A_L$ [$m^2$/m], $A_D$ [$m^2$/m] | 4,2000e+00 | 4,2000e+00 |
| $c_{Y.UCS}$ [mm], $c_{Z.UCS}$ [mm] | 800 | 250 |
| α [deg] | 0,00 | |
| $I_y$ [$m^4$], $I_z$ [$m^4$] | 1,6667e-02 | 1,7067e-01 |
| $i_y$ [mm], $i_z$ [mm] | 144 | 462 |
| $W_{el.y}$ [$m^3$], $W_{el.z}$ [$m^3$] | 6,6667e-02 | 2,1333e-01 |
| $W_{pl.y}$ [$m^3$], $W_{pl.z}$ [$m^3$] | 0,0000e+00 | 0,0000e+00 |
| $M_{pl.y.+}$ [Nm], $M_{pl.y.-}$ [Nm] | 0,00e+00 | 0,00e+00 |
| $M_{pl.z.+}$ [Nm], $M_{pl.z.-}$ [Nm] | 0,00e+00 | 0,00e+00 |
| $d_y$ [mm], $d_z$ [mm] | 0 | 0 |
| $I_t$ [$m^4$], $I_w$ [$m^6$] | 5,3415e-02 | 2,3515e-03 |
| $β_y$ [mm], $β_z$ [mm] | 0 | 0 |

| | | |
|---|---|---|
| Afbeelding |   | |
| **CS10** | | |
| Type | Buis | |
| Uitgebreid | 914; 16 | |
| Vorm type | Dikke wanden | |
| Onderdeelmateriaal | S 355 | |
| Bouwwijze | Algemeen | |
| Kleur | ■ | |
| Knik y-y, Knik z-z | d | d |
| A [m$^2$] | 4,5138e-02 | |
| $A_y$ [m$^2$], $A_z$ [m$^2$] | 3,0000e-02 | 3,0000e-02 |
| $A_L$ [m$^2$/m], $A_D$ [m$^2$/m] | 2,8713e+00 | 5,6420e+00 |
| $c_{Y.UCS}$ [mm], $c_{Z.UCS}$ [mm] | 457 | 457 |
| α [deg] | 0,00 | |
| $I_y$ [m$^4$], $I_z$ [m$^4$] | 4,5514e-03 | 4,5514e-03 |
| $i_y$ [mm], $i_z$ [mm] | 318 | 318 |
| $W_{el.y}$ [m$^3$], $W_{el.z}$ [m$^3$] | 9,9593e-03 | 9,9593e-03 |
| $W_{pl.y}$ [m$^3$], $W_{pl.z}$ [m$^3$] | 1,2904e-02 | 1,2904e-02 |
| $M_{pl.y.+}$ [Nm], $M_{pl.y.-}$ [Nm] | 4,58e+06 | 4,58e+06 |
| $M_{pl.z.+}$ [Nm], $M_{pl.z.-}$ [Nm] | 4,58e+06 | 4,58e+06 |
| $d_y$ [mm], $d_z$ [mm] | 0 | 0 |
| $I_t$ [m$^4$], $I_w$ [m$^6$] | 8,8332e-03 | 2,2214e-18 |
| $β_y$ [mm], $β_z$ [mm] | 0 | 0 |
| Afbeelding |   | |
| **CS11** | | |
| Type | Buis | |
| Uitgebreid | 711; 12 | |
| Vorm type | Dikke wanden | |
| Onderdeelmateriaal | S 355 | |
| Bouwwijze | Algemeen | |
| Kleur | ■ | |
| Knik y-y, Knik z-z | d | d |
| A [m$^2$] | 2,6352e-02 | |
| $A_y$ [m$^2$], $A_z$ [m$^2$] | 1,7531e-02 | 1,7531e-02 |
| $A_L$ [m$^2$/m], $A_D$ [m$^2$/m] | 2,2336e+00 | 4,3917e+00 |
| $c_{Y.UCS}$ [mm], $c_{Z.UCS}$ [mm] | 356 | 356 |
| α [deg] | 0,00 | |
| $I_y$ [m$^4$], $I_z$ [m$^4$] | 1,6099e-03 | 1,6099e-03 |
| $i_y$ [mm], $i_z$ [mm] | 247 | 247 |
| $W_{el.y}$ [m$^3$], $W_{el.z}$ [m$^3$] | 4,5286e-03 | 4,5286e-03 |
| $W_{pl.y}$ [m$^3$], $W_{pl.z}$ [m$^3$] | 5,8638e-03 | 5,8638e-03 |
| $M_{pl.y.+}$ [Nm], $M_{pl.y.-}$ [Nm] | 2,08e+06 | 2,08e+06 |
| $M_{pl.z.+}$ [Nm], $M_{pl.z.-}$ [Nm] | 2,08e+06 | 2,08e+06 |
| $d_y$ [mm], $d_z$ [mm] | 0 | 0 |
| $I_t$ [m$^4$], $I_w$ [m$^6$] | 3,1234e-03 | 3,6114e-19 |
| $β_y$ [mm], $β_z$ [mm] | 0 | 0 |

| Afbeelding |  | |
|---|---|---|

| Verklaring van symbolen | |
|---|---|
| $A$ | Gebied |
| $A_y$ | Afschuifoppervlak in hoofd y-richting - Berekend door 2D EEM analyse |
| $A_z$ | Afschuifoppervlak in hoofd z-richting - Berekend door 2D EEM analyse |
| $A_L$ | Omtrek per eenheidslengte |
| $A_D$ | Uithardingsoppervlakte per eenheidslengte |
| $c_{Y.UCS}$ | Zwaartepunt coordinaten in Y-richting van het invoer assen systeem |
| $c_{Z.UCS}$ | Zwaartepunt coordinaten in Z-richting van het invoer assen systeem |
| $I_{Y.LCS}$ | Tweede moment van het gebied rond de YLCS as |
| $I_{Z.LCS}$ | Tweede moment van het gebied rond de ZLCS as |
| $I_{YZ.LCS}$ | Product moment van het gebied in het LCS systeem |
| $\alpha$ | Rotatiehoek van het hoofd assen systeem |
| $I_y$ | Tweede moment van het gebied rond de hoofd y-as |
| $I_z$ | Tweede moment van het gebied rond de hoofd z-as |
| $i_y$ | Traagheidsstraal rond de hoofd y-as |
| $i_z$ | Traagheidsstraal rond de hoofd z-as |

| Verklaring van symbolen | |
|---|---|
| $W_{el.y}$ | Elastische doorsnede modulus rond de hoofd y-as |
| $W_{el.z}$ | Elastische doorsnede modulus rond de hoofd z-as |
| $W_{pl.y}$ | Plastische doorsnede modulus rond de hoofd y-as |
| $W_{pl.z}$ | Plastische doorsnede modulus rond de hoofd z-as |
| $M_{pl.y.+}$ | Plastisch moment rond de hoofd y-as voor een positief My moment |
| $M_{pl.y.-}$ | Plastisch moment rond de hoofd y-as voor een negatief My moment |
| $M_{pl.z.+}$ | Plastisch moment rond de hoofd z-as voor een positief Mz moment |
| $M_{pl.z.-}$ | Plastisch moment rond de hoofd z-as voor een negatief Mz moment |
| $d_y$ | Afschuif middencoordinaat in hoofd y-richting gemeten vanaf het zwaartepunt - Berekend door 2D EEM analyse |
| $d_z$ | Afschuif middencoordinaat in hoofd z-richting gemeten vanaf het zwaartepunt - Berekend door 2D EEM analyse |
| $I_t$ | Torsie constante - Berekend door 2D EEM analyse |
| $I_w$ | Welvings constante - Berekend door 2D EEM analyse |
| $\beta_y$ | Mono-symmetrische constante rond de hoofd y-as |
| $\beta_z$ | Mono-symmetrische constante rond de hoofd z-as |

## D.3.2. Reusable jetty model

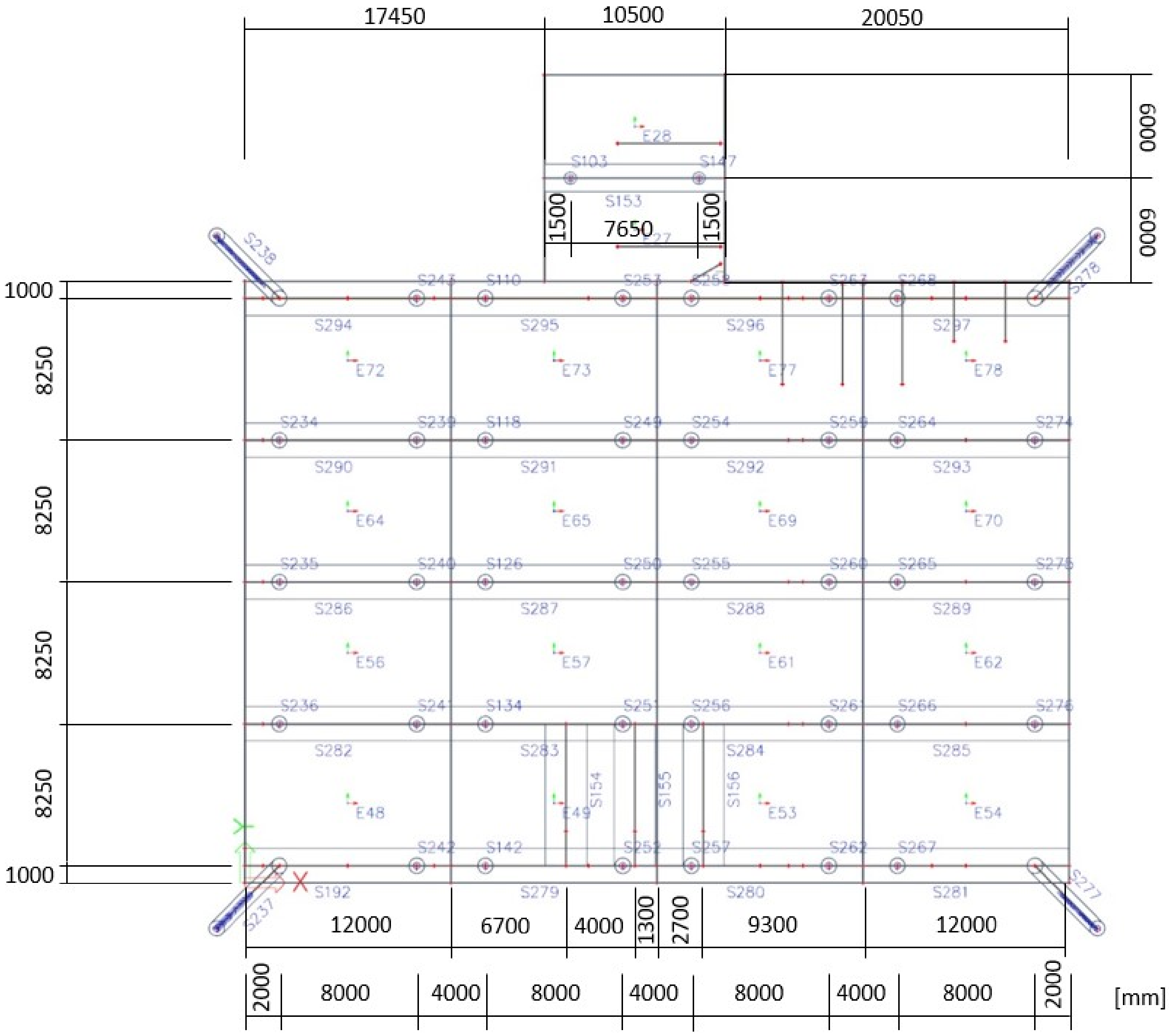



**Figure D.5:** Layout of reference jetty model

# 1. Elements and cross-section of reusable jetty model

## 1.1. Foundation piles

| Naam | Doorsnede | Materiaal | Lengte [m] | Beginknoop | Eindknoop | Type |
|---|---|---|---|---|---|---|
| S110 | CS10 - Buis (914; 16) | S 355 | 31,000 | K688 | K695 | Balk (80) |
| S118 | CS10 - Buis (914; 16) | S 355 | 31,000 | K711 | K702 | Balk (80) |
| S126 | CS10 - Buis (914; 16) | S 355 | 31,000 | K727 | K718 | Balk (80) |
| S134 | CS10 - Buis (914; 16) | S 355 | 31,000 | K743 | K734 | Balk (80) |
| S142 | CS10 - Buis (914; 16) | S 355 | 31,000 | K759 | K750 | Balk (80) |
| S103 | CS11 - Buis (711; 12) | S 355 | 22,000 | K857 | K858 | Balk (80) |
| S147 | CS11 - Buis (711; 12) | S 355 | 22,000 | K856 | K859 | Balk (80) |
| S234 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1488 | K1483 | Balk (80) |
| S235 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1489 | K1484 | Balk (80) |
| S236 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1490 | K1485 | Balk (80) |
| S237 | CS10 - Buis (914; 16) | S 355 | 31,428 | K1491 | K1486 | Balk (80) |
| S238 | CS10 - Buis (914; 16) | S 355 | 31,428 | K1492 | K1487 | Balk (80) |
| S239 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1498 | K1493 | Balk (80) |
| S240 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1499 | K1494 | Balk (80) |
| S241 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1500 | K1495 | Balk (80) |
| S242 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1501 | K1496 | Balk (80) |
| S243 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1502 | K1497 | Balk (80) |
| S249 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1518 | K1513 | Balk (80) |
| S250 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1519 | K1514 | Balk (80) |
| S251 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1520 | K1515 | Balk (80) |
| S252 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1521 | K1516 | Balk (80) |
| S253 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1522 | K1517 | Balk (80) |
| S254 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1528 | K1523 | Balk (80) |
| S255 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1529 | K1524 | Balk (80) |
| S256 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1530 | K1525 | Balk (80) |
| S257 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1531 | K1526 | Balk (80) |
| S258 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1532 | K1527 | Balk (80) |
| S259 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1538 | K1533 | Balk (80) |
| S260 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1539 | K1534 | Balk (80) |
| S261 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1540 | K1535 | Balk (80) |
| S262 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1541 | K1536 | Balk (80) |
| S263 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1542 | K1537 | Balk (80) |
| S264 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1548 | K1543 | Balk (80) |
| S265 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1549 | K1544 | Balk (80) |
| S266 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1550 | K1545 | Balk (80) |
| S267 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1551 | K1546 | Balk (80) |
| S268 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1552 | K1547 | Balk (80) |
| S274 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1568 | K1563 | Balk (80) |
| S275 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1569 | K1564 | Balk (80) |
| S276 | CS10 - Buis (914; 16) | S 355 | 31,000 | K1570 | K1565 | Balk (80) |
| S277 | CS10 - Buis (914; 16) | S 355 | 31,428 | K1603 | K1566 | Balk (80) |
| S278 | CS10 - Buis (914; 16) | S 355 | 31,428 | K1604 | K1567 | Balk (80) |

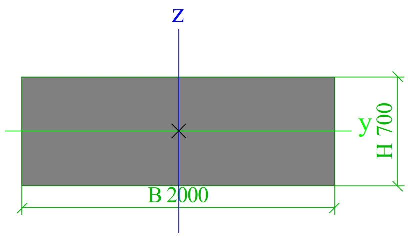
## 1.2. Rib plates

| Naam | Doorsnede | Materiaal | Lengte [m] | Beginknoop | Eindknoop | Type |
|---|---|---|---|---|---|---|
| S153 | CS7 - Rechthoek (500; 1600) | C35/45 * | 10,500 | K1152 | K1153 | Balk (80) |
| S192 | CS1 - Rechthoek (700; 2000) | C35/45 * | 12,000 | K1107 | K1481 | Balk (80) |
| S279 | CS1 - Rechthoek (700; 2000) | C35/45 * | 12,000 | K1481 | K1593 | Balk (80) |
| S280 | CS1 - Rechthoek (700; 2000) | C35/45 * | 12,000 | K1593 | K1594 | Balk (80) |
| S281 | CS1 - Rechthoek (700; 2000) | C35/45 * | 12,000 | K1594 | K1571 | Balk (80) |
| S282 | CS1 - Rechthoek (700; 2000) | C35/45 * | 12,000 | K1109 | K1480 | Balk (80) |
| S283 | CS1 - Rechthoek (700; 2000) | C35/45 * | 12,000 | K1480 | K1595 | Balk (80) |
| S284 | CS1 - Rechthoek (700; 2000) | C35/45 * | 12,000 | K1595 | K1596 | Balk (80) |
| S285 | CS1 - Rechthoek (700; 2000) | C35/45 * | 12,000 | K1596 | K1332 | Balk (80) |
| S286 | CS1 - Rechthoek (700; 2000) | C35/45 * | 12,000 | K1111 | K1479 | Balk (80) |
| S287 | CS1 - Rechthoek (700; 2000) | C35/45 * | 12,000 | K1479 | K1597 | Balk (80) |
| S288 | CS1 - Rechthoek (700; 2000) | C35/45 * | 12,000 | K1597 | K1598 | Balk (80) |
| S289 | CS1 - Rechthoek (700; 2000) | C35/45 * | 12,000 | K1598 | K1363 | Balk (80) |
| S290 | CS1 - Rechthoek (700; 2000) | C35/45 * | 12,000 | K1113 | K1478 | Balk (80) |
| S291 | CS1 - Rechthoek (700; 2000) | C35/45 * | 12,000 | K1478 | K1599 | Balk (80) |
| S292 | CS1 - Rechthoek (700; 2000) | C35/45 * | 12,000 | K1599 | K1600 | Balk (80) |
| S293 | CS1 - Rechthoek (700; 2000) | C35/45 * | 12,000 | K1600 | K1379 | Balk (80) |
| S294 | CS1 - Rechthoek (700; 2000) | C35/45 * | 12,000 | K1115 | K1482 | Balk (80) |
| S295 | CS1 - Rechthoek (700; 2000) | C35/45 * | 12,000 | K1482 | K1601 | Balk (80) |
| S296 | CS1 - Rechthoek (700; 2000) | C35/45 * | 12,000 | K1601 | K1602 | Balk (80) |
| S297 | CS1 - Rechthoek (700; 2000) | C35/45 * | 12,000 | K1602 | K1572 | Balk (80) |

## 1.3. 2D-elementen

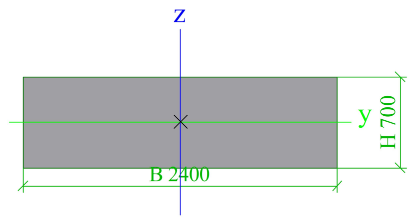
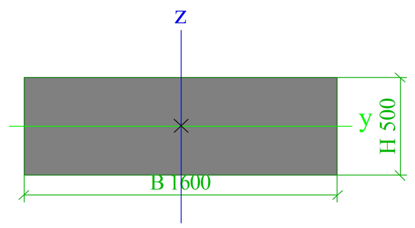
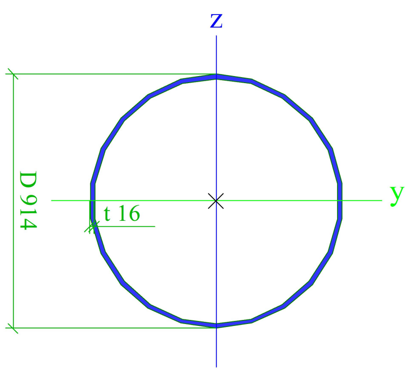
| Naam | Laag | Type | Element type | Materiaal | Dikte type | D. [mm] |
|---|---|---|---|---|---|---|
| E27 | Laag1 | vloer (90) | Standaard | C35/45 * | constant | 500 |
| E28 | Laag1 | vloer (90) | Standaard | C35/45 * | constant | 500 |
| E48 | Laag1 | vloer (90) | Standaard | C35/45 * | constant | 500 |
| E49 | Laag1 | vloer (90) | Standaard | C35/45 * | constant | 500 |
| E53 | Laag1 | vloer (90) | Standaard | C35/45 * | constant | 500 |
| E54 | Laag1 | vloer (90) | Standaard | C35/45 * | constant | 500 |
| E56 | Laag1 | vloer (90) | Standaard | C35/45 * | constant | 500 |
| E57 | Laag1 | vloer (90) | Standaard | C35/45 * | constant | 500 |
| E61 | Laag1 | vloer (90) | Standaard | C35/45 * | constant | 500 |
| E62 | Laag1 | vloer (90) | Standaard | C35/45 * | constant | 500 |
| E64 | Laag1 | vloer (90) | Standaard | C35/45 * | constant | 500 |
| E65 | Laag1 | vloer (90) | Standaard | C35/45 * | constant | 500 |
| E69 | Laag1 | vloer (90) | Standaard | C35/45 * | constant | 500 |
| E70 | Laag1 | vloer (90) | Standaard | C35/45 * | constant | 500 |
| E72 | Laag1 | vloer (90) | Standaard | C35/45 * | constant | 500 |
| E73 | Laag1 | vloer (90) | Standaard | C35/45 * | constant | 500 |
| E77 | Laag1 | vloer (90) | Standaard | C35/45 * | constant | 500 |
| E78 | Laag1 | vloer (90) | Standaard | C35/45 * | constant | 500 |

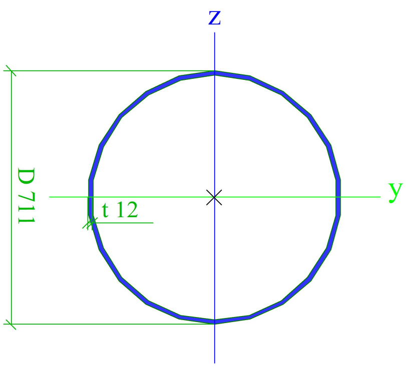
## 1.4. All cross sections

| CS1 | | |
|---|---|---|
| Type | Rechthoek | |
| Uitgebreid | 700; 2000 | |
| Vorm type | Dikke wanden | |
| Onderdeelmateriaal | C35/45 * | |
| Bouwwijze | beton | |
| Kleur | | |
| A [$m^2$] | 1,4000e+00 | |
| $A_y$ [$m^2$], $A_z$ [$m^2$] | 1,1671e+00 | 1,1704e+00 |
| $A_L$ [$m^2/m$], $A_D$ [$m^2/m$] | 5,4000e+00 | 5,4000e+00 |
| $c_{Y.UCS}$ [mm], $c_{Z.UCS}$ [mm] | 1000 | 350 |
| α [deg] | 0,00 | |
| $I_y$ [$m^4$], $I_z$ [$m^4$] | 5,7167e-02 | 4,6667e-01 |
| $i_y$ [mm], $i_z$ [mm] | 202 | 577 |
| $W_{el.y}$ [$m^3$], $W_{el.z}$ [$m^3$] | 1,6333e-01 | 4,6667e-01 |
| $W_{pl.y}$ [$m^3$], $W_{pl.z}$ [$m^3$] | 0,0000e+00 | 0,0000e+00 |
| $M_{pl.y.+}$ [Nm], $M_{pl.y.-}$ [Nm] | 0,00e+00 | 0,00e+00 |
| $M_{pl.z.+}$ [Nm], $M_{pl.z.-}$ [Nm] | 0,00e+00 | 0,00e+00 |
| $d_y$ [mm], $d_z$ [mm] | 0 | 0 |
| $I_t$ [$m^4$], $I_w$ [$m^6$] | 1,7783e-01 | 1,1423e-02 |
| $β_y$ [mm], $β_z$ [mm] | 0 | 0 |
| Afbeelding |  | |



| CS6 | | |
|---|---|---|
| Type | Rechthoek | |
| Uitgebreid | 700; 2400 | |
| Vorm type | Dikke wanden | |
| Onderdeelmateriaal | C35/45 * | |
| Bouwwijze | beton | |
| Kleur | | |
| A [$m^2$] | 1,6800e+00 | |
| $A_y$ [$m^2$], $A_z$ [$m^2$] | 1,4004e+00 | 1,4052e+00 |
| $A_L$ [$m^2/m$], $A_D$ [$m^2/m$] | 6,2000e+00 | 6,2000e+00 |
| $c_{Y.UCS}$ [mm], $c_{Z.UCS}$ [mm] | 1200 | 350 |
| α [deg] | 0,00 | |
| $I_y$ [$m^4$], $I_z$ [$m^4$] | 6,8600e-02 | 8,0640e-01 |
| $i_y$ [mm], $i_z$ [mm] | 202 | 693 |
| $W_{el.y}$ [$m^3$], $W_{el.z}$ [$m^3$] | 1,9600e-01 | 6,7200e-01 |
| $W_{pl.y}$ [$m^3$], $W_{pl.z}$ [$m^3$] | 0,0000e+00 | 0,0000e+00 |
| $M_{pl.y.+}$ [Nm], $M_{pl.y.-}$ [Nm] | 0,00e+00 | 0,00e+00 |
| $M_{pl.z.+}$ [Nm], $M_{pl.z.-}$ [Nm] | 0,00e+00 | 0,00e+00 |
| $d_y$ [mm], $d_z$ [mm] | 0 | 0 |
| $I_t$ [$m^4$], $I_w$ [$m^6$] | 2,2344e-01 | 2,2890e-02 |
| $β_y$ [mm], $β_z$ [mm] | 0 | 0 |

| | | |
|---|---|---|
| Afbeelding |  | |
| **CS7** | | |
| Type | Rechthoek | |
| Uitgebreid | 500; 1600 | |
| Vorm type | Dikke wanden | |
| Onderdeelmateriaal | C35/45 * | |
| Bouwwijze | beton | |
| Kleur | ■ | |
| A [m$^2$] | 8,0000e-01 | |
| $A_y$ [m$^2$], $A_z$ [m$^2$] | 6,6689e-01 | 6,6896e-01 |
| $A_L$ [m$^2$/m], $A_D$ [m$^2$/m] | 4,2000e+00 | 4,2000e+00 |
| $c_{Y.UCS}$ [mm], $c_{Z.UCS}$ [mm] | 800 | 250 |
| α [deg] | 0,00 | |
| $I_y$ [m$^4$], $I_z$ [m$^4$] | 1,6667e-02 | 1,7067e-01 |
| $i_y$ [mm], $i_z$ [mm] | 144 | 462 |
| $W_{el.y}$ [m$^3$], $W_{el.z}$ [m$^3$] | 6,6667e-02 | 2,1333e-01 |
| $W_{pl.y}$ [m$^3$], $W_{pl.z}$ [m$^3$] | 0,0000e+00 | 0,0000e+00 |
| $M_{pl.y.+}$ [Nm], $M_{pl.y.-}$ [Nm] | 0,00e+00 | 0,00e+00 |
| $M_{pl.z.+}$ [Nm], $M_{pl.z.-}$ [Nm] | 0,00e+00 | 0,00e+00 |
| $d_y$ [mm], $d_z$ [mm] | 0 | 0 |
| $I_t$ [m$^4$], $I_w$ [m$^6$] | 5,3415e-02 | 2,3515e-03 |
| $β_y$ [mm], $β_z$ [mm] | 0 | 0 |
| Afbeelding |  | |
| **CS10** | | |
| Type | Buis | |
| Uitgebreid | 914; 16 | |
| Vorm type | Dikke wanden | |
| Onderdeelmateriaal | S 355 | |
| Bouwwijze | Algemeen | |
| Kleur | ■ | |
| Knik y-y, Knik z-z | d | d |
| A [m$^2$] | 4,5138e-02 | |
| $A_y$ [m$^2$], $A_z$ [m$^2$] | 3,0000e-02 | 3,0000e-02 |
| $A_L$ [m$^2$/m], $A_D$ [m$^2$/m] | 2,8713e+00 | 5,6420e+00 |
| $c_{Y.UCS}$ [mm], $c_{Z.UCS}$ [mm] | 457 | 457 |
| α [deg] | 0,00 | |
| $I_y$ [m$^4$], $I_z$ [m$^4$] | 4,5514e-03 | 4,5514e-03 |
| $i_y$ [mm], $i_z$ [mm] | 318 | 318 |
| $W_{el.y}$ [m$^3$], $W_{el.z}$ [m$^3$] | 9,9593e-03 | 9,9593e-03 |
| $W_{pl.y}$ [m$^3$], $W_{pl.z}$ [m$^3$] | 1,2904e-02 | 1,2904e-02 |
| $M_{pl.y.+}$ [Nm], $M_{pl.y.-}$ [Nm] | 4,58e+06 | 4,58e+06 |
| $M_{pl.z.+}$ [Nm], $M_{pl.z.-}$ [Nm] | 4,58e+06 | 4,58e+06 |
| $d_y$ [mm], $d_z$ [mm] | 0 | 0 |
| $I_t$ [m$^4$], $I_w$ [m$^6$] | 8,8332e-03 | 2,2214e-18 |
| $β_y$ [mm], $β_z$ [mm] | 0 | 0 |
| Afbeelding |  | |
| **CS11** | | |
| Type | Buis | |

| | | |
|---|---|---|
| Uitgebreid | 711; 12 | |
| Vorm type | Dikke wanden | |
| Onderdeelmateriaal | S 355 | |
| Bouwwijze | Algemeen | |
| Kleur | | |
| Knik y-y, Knik z-z | d | d |
| A [$m^2$] | 2,6352e-02 | |
| $A_y$ [$m^2$], $A_z$ [$m^2$] | 1,7531e-02 | 1,7531e-02 |
| $A_L$ [$m^2/m$], $A_D$ [$m^2/m$] | 2,2336e+00 | 4,3917e+00 |
| $c_{Y.UCS}$ [mm], $c_{Z.UCS}$ [mm] | 356 | 356 |
| α [deg] | 0,00 | |
| $I_y$ [$m^4$], $I_z$ [$m^4$] | 1,6099e-03 | 1,6099e-03 |
| $i_y$ [mm], $i_z$ [mm] | 247 | 247 |
| $W_{el.y}$ [$m^3$], $W_{el.z}$ [$m^3$] | 4,5286e-03 | 4,5286e-03 |
| $W_{pl.y}$ [$m^3$], $W_{pl.z}$ [$m^3$] | 5,8638e-03 | 5,8638e-03 |
| $M_{pl.y.+}$ [Nm], $M_{pl.y.-}$ [Nm] | 2,08e+06 | 2,08e+06 |
| $M_{pl.z.+}$ [Nm], $M_{pl.z.-}$ [Nm] | 2,08e+06 | 2,08e+06 |
| $d_y$ [mm], $d_z$ [mm] | 0 | 0 |
| $I_t$ [$m^4$], $I_w$ [$m^6$] | 3,1234e-03 | 3,6114e-19 |
| $β_y$ [mm], $β_z$ [mm] | 0 | 0 |
| Afbeelding |  | |

| Verklaring van symbolen | |
|---|---|
| A | Gebied |
| $A_y$ | Afschuifoppervlak in hoofd y-richting - Berekend door 2D EEM analyse |
| $A_z$ | Afschuifoppervlak in hoofd z-richting - Berekend door 2D EEM analyse |
| $A_L$ | Omtrek per eenheidslengte |
| $A_D$ | Uithardingsoppervlakte per eenheidslengte |
| $c_{Y.UCS}$ | Zwaartepunt coordinaten in Y-richting van het invoer assen systeem |
| $c_{Z.UCS}$ | Zwaartepunt coordinaten in Z-richting van het invoer assen systeem |
| $I_{Y.LCS}$ | Tweede moment van het gebied rond de YLCS as |
| $I_{Z.LCS}$ | Tweede moment van het gebied rond de ZLCS as |
| $I_{YZ.LCS}$ | Product moment van het gebied in het LCS systeem |
| α | Rotatiehoek van het hoofd assen systeem |
| $I_y$ | Tweede moment van het gebied rond de hoofd y-as |
| $I_z$ | Tweede moment van het gebied rond de hoofd z-as |
| $i_y$ | Traagheidsstraal rond de hoofd y-as |
| $i_z$ | Traagheidsstraal rond de hoofd z-as |

| Verklaring van symbolen | |
|---|---|
| $W_{el.y}$ | Elastische doorsnede modulus rond de hoofd y-as |
| $W_{el.z}$ | Elastische doorsnede modulus rond de hoofd z-as |
| $W_{pl.y}$ | Plastische doorsnede modulus rond de hoofd y-as |
| $W_{pl.z}$ | Plastische doorsnede modulus rond de hoofd z-as |
| $M_{pl.y.+}$ | Plastisch moment rond de hoofd y-as voor een positief My moment |
| $M_{pl.y.-}$ | Plastisch moment rond de hoofd y-as voor een negatief My moment |
| $M_{pl.z.+}$ | Plastisch moment rond de hoofd z-as voor een positief Mz moment |
| $M_{pl.z.-}$ | Plastisch moment rond de hoofd z-as voor een negatief Mz moment |
| $d_y$ | Afschuif middencoordinaat in hoofd y-richting gemeten vanaf het zwaartepunt - Berekend door 2D EEM analyse |
| $d_z$ | Afschuif middencoordinaat in hoofd z-richting gemeten vanaf het zwaartepunt - Berekend door 2D EEM analyse |
| $I_t$ | Torsie constante - Berekend door 2D EEM analyse |
| $I_w$ | Welvings constante - Berekend door 2D EEM analyse |
| $β_y$ | Mono-symmetrische constante rond de hoofd y-as |
| $β_z$ | Mono-symmetrische constante rond de hoofd z-as |

# D.4. Modular reusable jetty model

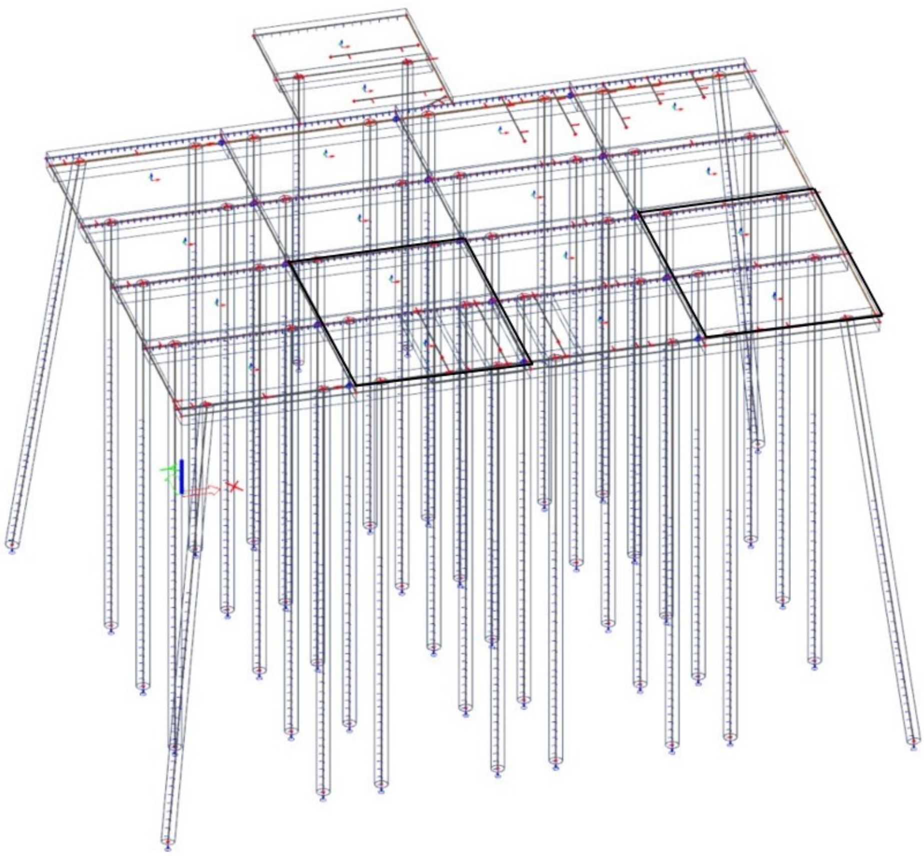


**Figure D.6:** The modules that are calculated

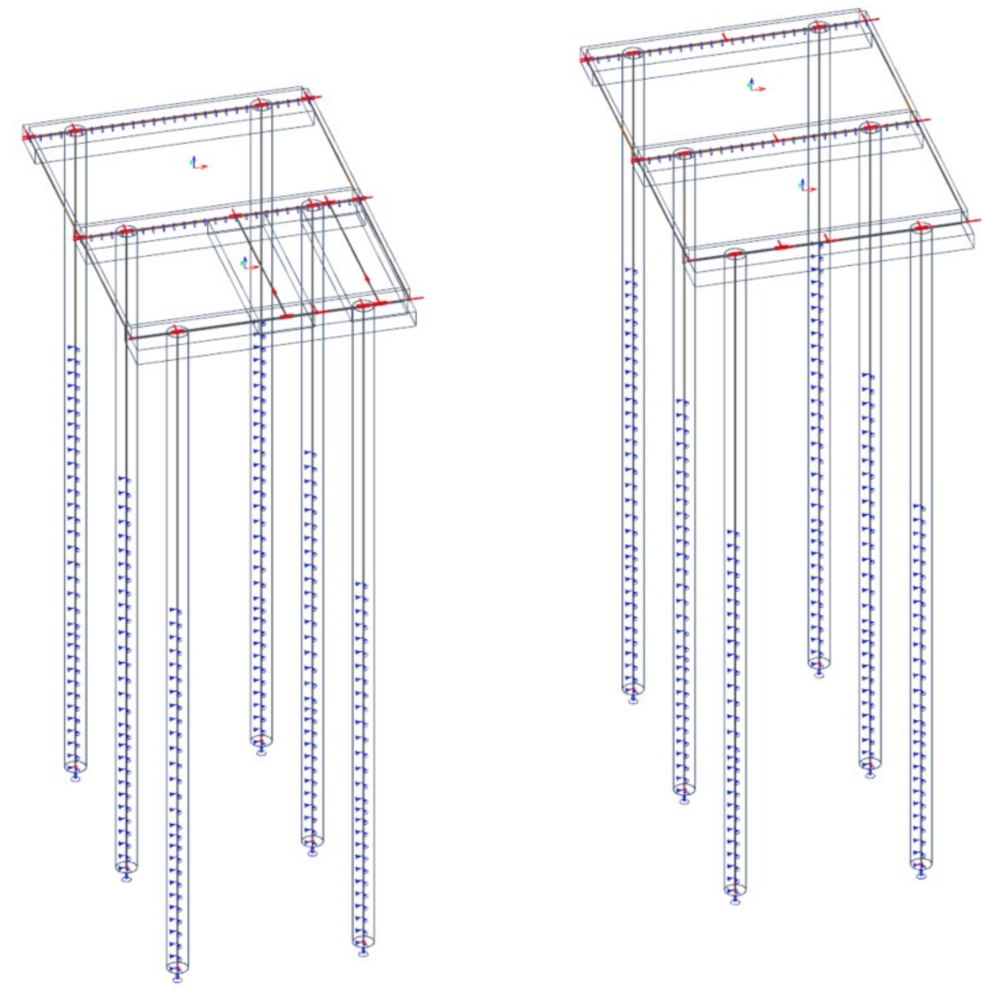


**Figure D.7:** Model of two separate modules

# E
# Considered design and connection variants

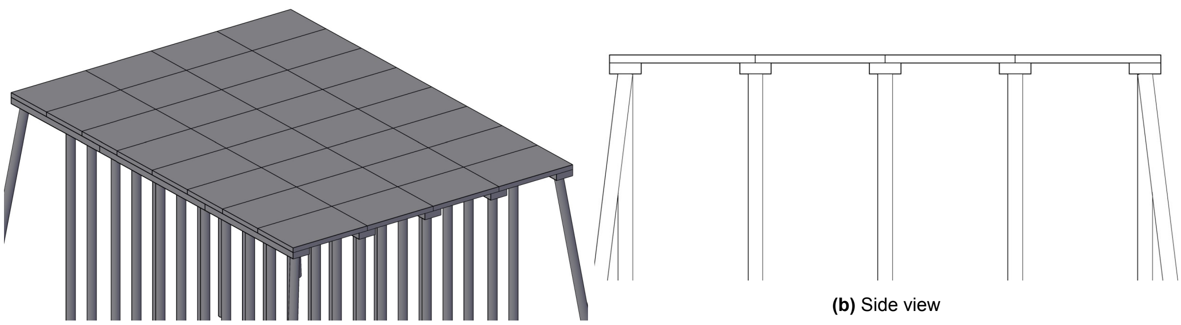
## E.1. Variant 1: Separate rib plates and deck plates

The design of variant 1 is kept as close to the reference design as possible. However, to create a DfD structure, changes will be made. Those are elaborated below.

### E.1.1. Layout

The layout of this variant is similar to that of the reference structure, which is described in Section 3.3 and shown in Figure 3.2. The structure will consist of separate rib plates and deck plates, which will all be prefabricated elements, as is prescribed in DfD requirement 4 in Section 2.1.

To arrive at the wanted global dimensions, the dimensions of the deck plates will have to change slightly, as currently in situ concrete is used for this. Therefore, the deck plates will have a height of 0.5 m and a width of 8.25 m for the middle deck plates and 9.25 m for the edge deck plates (compared to a height of 0.25 m and a width of 6.55 m for the reference jetty). However, when assuming the use of a regular crane, the elements should not weigh over 70 tonnes. When taking this into account and assuming a weight of the concrete of $2.5\ tonnes/m^3$, the deck plate dimensions arrive at 6x9.25x0.5m for the edge deck plates and 6x8.25x0.5m for the middle deck plates. As is described in Section 3.3.2, the rib plates will have to be divided into smaller parts as well when using a regular crane. To have the rib plate rest on at least two piles during construction, which offers robustness before connecting the rib plates, and to prevent the rib plate to rib plate connections to intersect with the pile to rib plate connection, there will be a rib plate element of 15 m in the middle and a rib plate element of 18 m on each side. The layout of this variant is shown in Figure E.1.



**(a)** 3D view

**(b)** Side view

**Figure E.1:** Layout of variant 1: Separate rib plates and deck plates

A total of 47 prefab concrete elements of four different sizes will be used in this variant using a regular crane and there are no changes to the current pile plan. The elements are shown in Figure E.2.

The use of a larger crane is not considered for this variant. By using a larger crane, fewer connections between the deck plates and no connections between the rib plates are needed. However, the deck plate to deck plate and rib plate to rib plate connections are not critical in this design, as is further elaborated in Section E.1.2. Due to this, it is assumed that there will be little to no gains from using larger deck plates and rib plates, which will thus be assumed to not outweigh the disadvantages of using a larger crane.

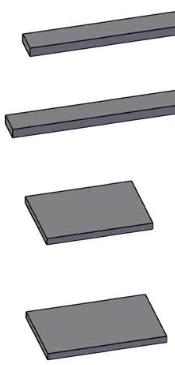



**Figure E.2:** All prefab elements used in variant 1

**Construction**

The construction of this variant is similar to the construction of the reference variant, except for the last stage in which the prefab elements are being connected. The execution of the structure will start with placing all steel piles, which have to be precisely placed in height but can have placing tolerance in the horizontal plane depending on the connection methods. Placing all piles first is wanted, as this requires special equipment that should not need to stay on site unnecessarily long or should not be transported from and to site unnecessarily often. After placing all piles, the rib plates can be laid on top and connected to each other and the piles. Connecting the rib plates together can be done before placing the deck plates, so that the connections are easily accessible.

After this, the deck plates can be placed on top of the rib plates and connected to the rib plates and each other, depending on the connection types discussed in the section below. During construction the deck plates are robust, as they are supported by the rib plates on two sides over the full length. This will form the final version of the platform as displayed in Figure E.1.

This construction sequence can create low placement tolerances. This is because the rib plates have to be placed before placing the deck plates. When placing the deck plates, they should be connected to a rib plate on each side. If those rib plates are not placed precisely, the connection points to the deck plate can have a different distance than those same points on the deck plate. This creates irrealistically small placement tolerances for the elements. This can influence the structural behaviour of the platform, which is unwanted.

During construction, the jetty will not be loaded fully. However, loads such as self-weight, construction loads and wind loads will occur. Before connecting all elements so that the jetty is made into its final form, the elements should still be robust to avoid any additional risks. It is assumed that this robustness is achieved when the rib plate elements rest on at least 2 piles. For the deck plates, this robustness can be guaranteed, as two of the opposite edges are supported by rib plates over the full length.

## E.1.2. Global calculations

As described in Section 2.1, the structure should consist of demountable connections. Currently, the concrete elements are rigidly connected using in situ concrete, meaning that normal forces, shear forces and bending moments are transferred through the connection. With this, a monolithic concrete deck is created. However, to make the variant easy to reuse, the possibilities of using simpler connection types are explored, influencing the structural behaviour of the structure. The robustness of the structure should however remain to be ensured, for which reason the global robustness of the structure is examined for different connection types and different combinations of them, with the goal to arrive at a variant that needs as few rigid connections as possible. By changing the connection characteristics, the possibilities of using simpler connections can be explored.

The different connection types that are explored are the pile to rib plate, rib plate to rib plate, rib plate to deck plate and deck plate to deck plate connections, of which the rib plate to deck plate connections can be distinguished between field rib plate to deck plate and edge rib plate to deck plate. The different connection types are displayed in Figure E.3.

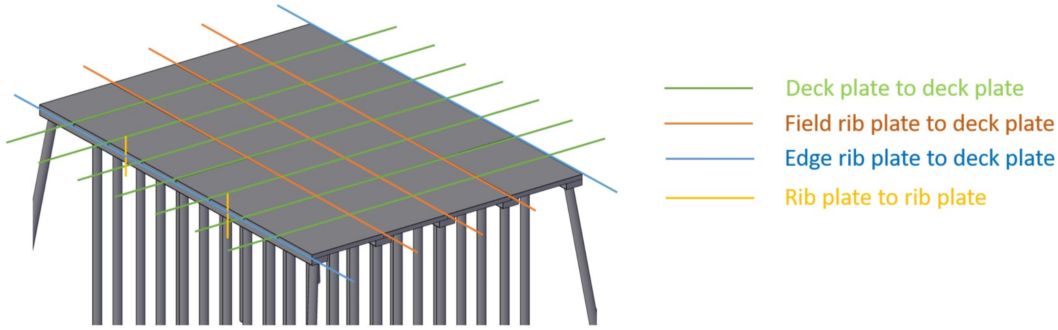



**Figure E.3:** Connection types in variant 1

A fully rigid variant is made by connecting all elements to all adjacent elements with full continuity of all forces. The fully rigid variant is found to be robust, which was expected as this is the same for the reference jetty, and has a maximum displacement of 42.5 mm, shown in Figure E.4.

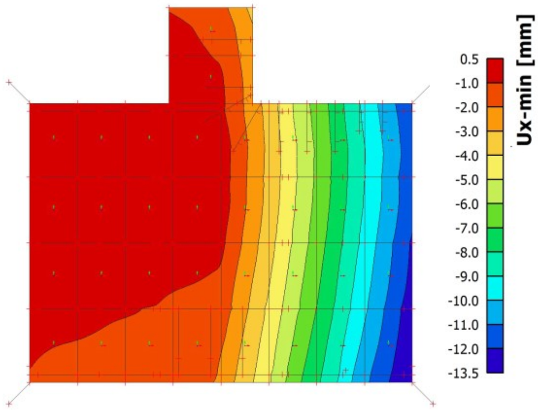
The piles are supported in the soil and are connected to the rib plates on the other side. The connection between the piles and rib plates cannot be made simpler than rigid. When allowing rotations around the pile axes, the structure loses it robustness. This is because each pile can separately rotate around its axis in this case, as the pile is only supported in the soil. When allowing rotations in the other directions, displacements in the structure become very large. Rotations around the pile axis should always be avoided.

For the deck plate to deck plate connection, the structure is still robust when this connection is not made at all. The maximum displacement even decreases to 42.4 mm, as shown in Figure E.5. For the rib plate to rib plate connections, the simplest connection form that can be found is a shear connection, meaning that one rib plate end supports the other rib plate end in the z-direction, while rotations and displacements in x- and y-direction are allowed. This solution does not influence the robustness of the structure and only a very small increase in displacements is found. This option gives a maximum displacement of 42.8 mm, as shown in Figure E.6. However, as the deck plates are not connected, jumps in displacements can be observed.

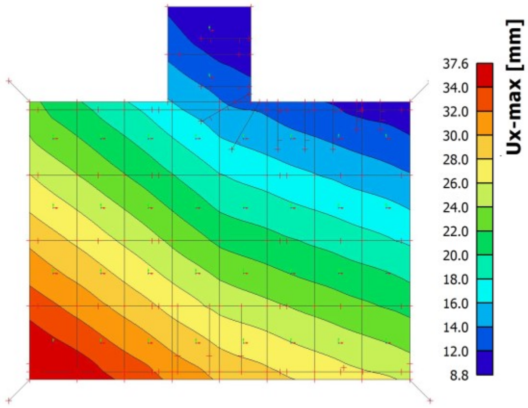
For the rib plate to deck plate connections, finding the simplest solution is more difficult, as it is not feasible to make all of them simple. The option that is considered is a combination of rigid and hinged rib plate to deck plate connections. When the edge rib plates are rigidly connected to the deck plates, a hinged connection is sufficient for the field rib plates. Unfortunately, the use of rigid connections is inevitable for the connection between these elements. It is expected that this is due to a low stiffness of the deck plates.

When taking the hinged field rib plate to deck plate connections with rigid edge rib plate to deck plate connections, the global robustness of the structure can be ensured. Furthermore, when combining this with the shear rib plate to rib plate and no deck plate to deck plate connections, the robustness and displacements stay the same. The maximum displacement is 68.2 mm, as is shown in Figure E.7. The jumps in displacements, that can occur because of the simple connections, have a maximum magnitude of 4 mm.

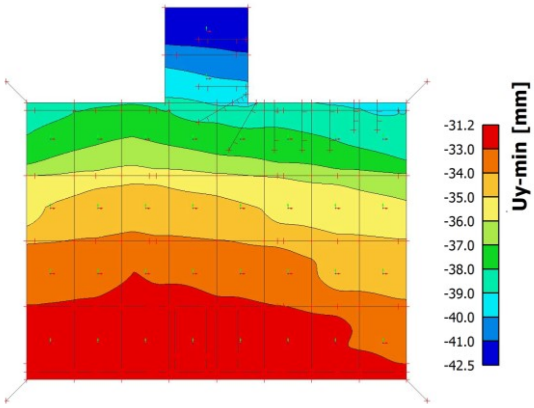
From the calculations, it can be concluded that the connections between the rib plates and deck plates are affecting the robustness of the structure significantly, where the connection between the deck plates and the connection between the rib plates are influencing the structural behaviour to an insignificant extent.



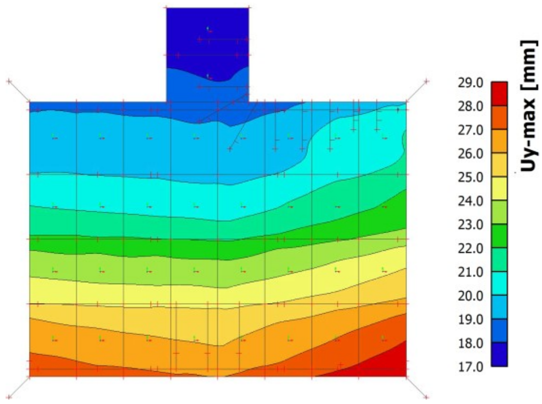

**(a)** Displacement in negative x-direction



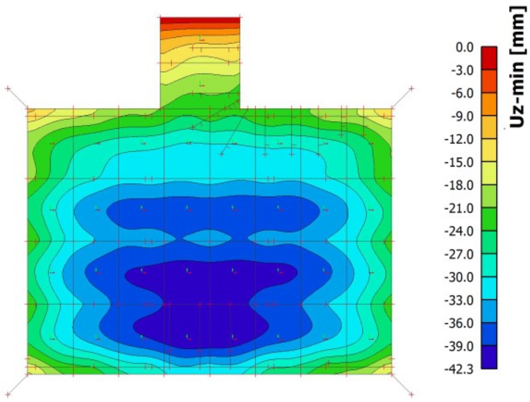

**(b)** Displacement in positive x-direction




**(c)** Displacement in negative y-direction

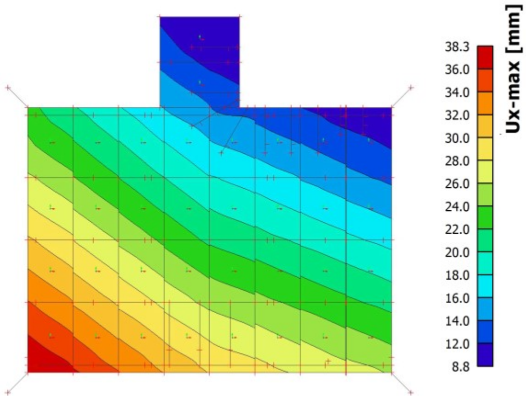



**(d)** Displacement in positive y-direction

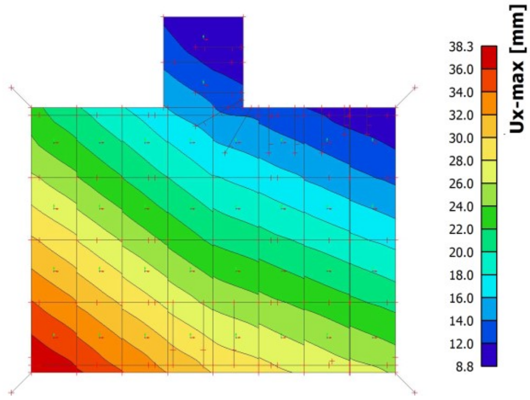



**(e)** Displacement in z-direction

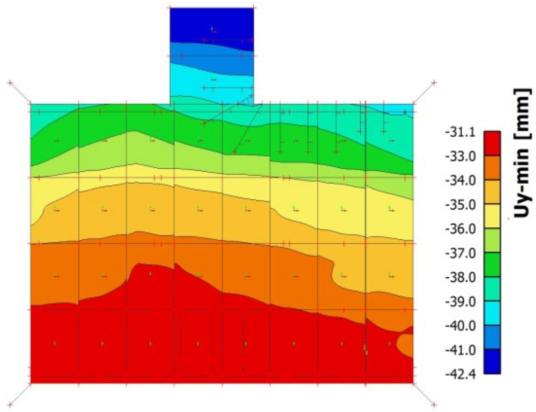
**Figure E.4:** Displacement of rigid solution for variant 1



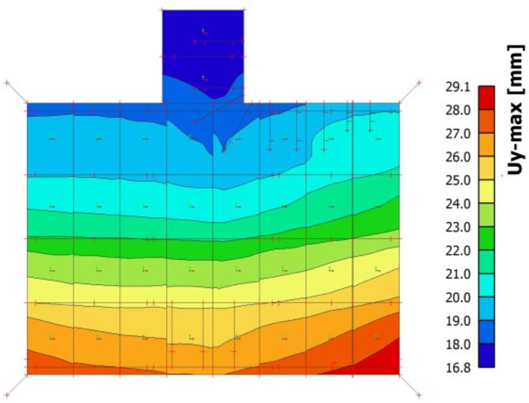

**(a)** Displacement in negative x-direction



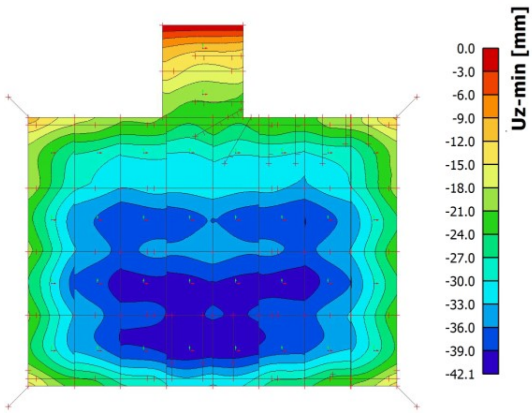

**(b)** Displacement in positive x-direction




**(c)** Displacement in negative y-direction

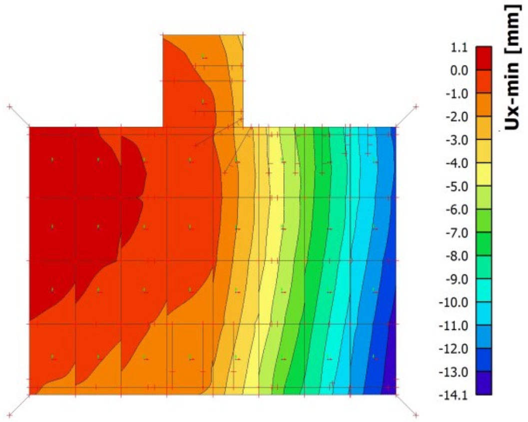



**(d)** Displacement in positive y-direction

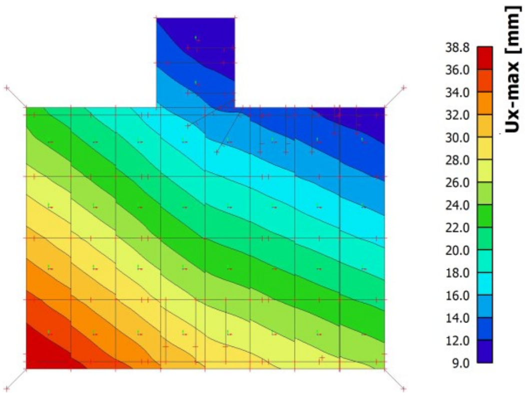



**(e)** Displacement in z-direction

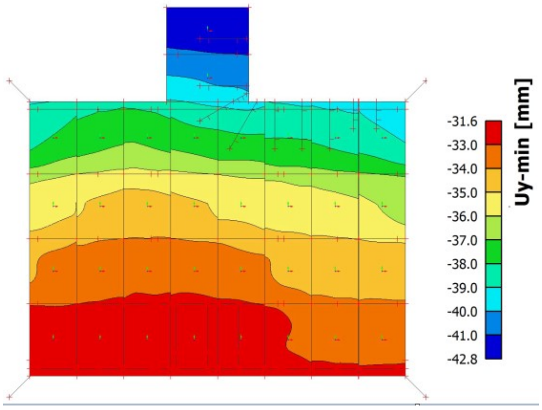
**Figure E.5:** Displacement with no deck plate to deck plate connection variant 1



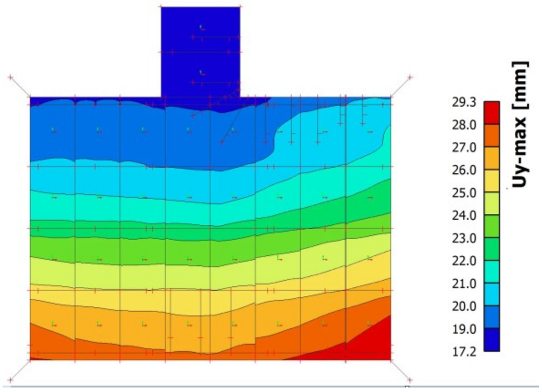

**(a)** Displacement in negative x-direction



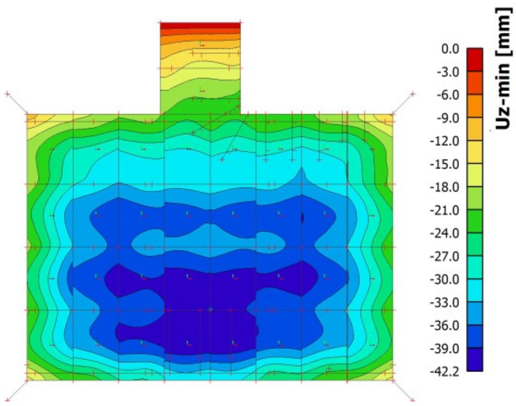

**(b)** Displacement in positive x-direction




**(c)** Displacement in negative y-direction

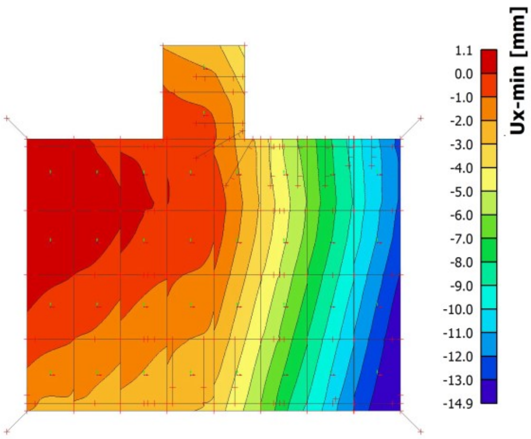



**(d)** Displacement in positive y-direction

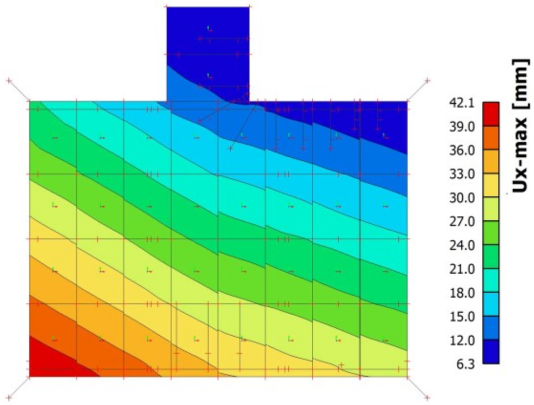



**(e)** Displacement in z-direction

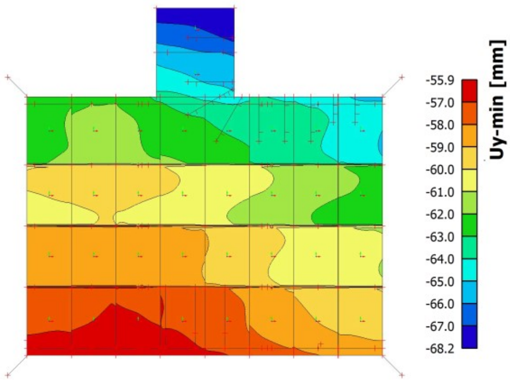
**Figure E.6:** Displacement of no deck plate to deck plate and shear rib plate to rib plate connection variant 1



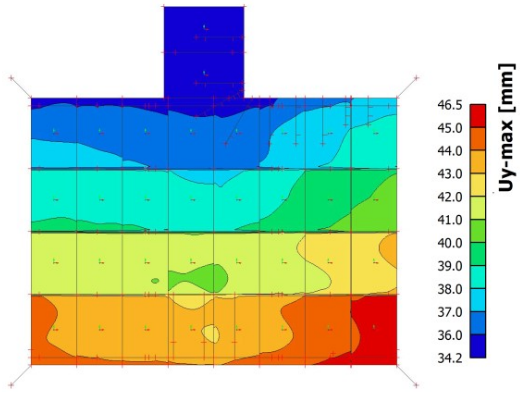

**(a)** Displacement in negative x-direction



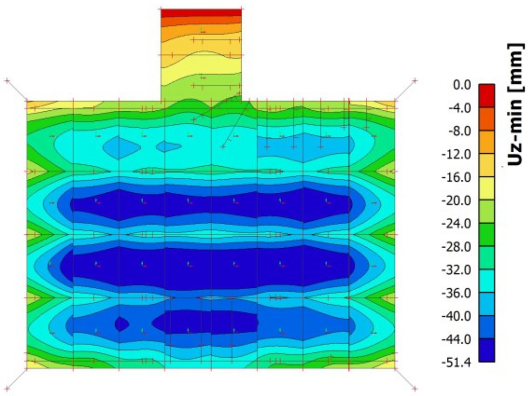

**(b)** Displacement in positive x-direction




**(c)** Displacement in negative y-direction




**(d)** Displacement in positive y-direction




**(e)** Displacement in z-direction

**Figure E.7:** Displacement of simplest solution for variant 1

### E.1.3. Modularity

As stated in DfD requirement 3, mentioned in Section 2.1, a standard structural grid should be used to obtain components in standard sizes. For the jetty structure, it is assumed that the future application will be also a jetty structure. Therefore, this requirement is interpreted as using a structural grid for modularity. By changing the design slightly, the structure can be made modular. A modular structure is built up of standard modules and can be extended or changed in shape easily by placing these modules differently. By making the structure modular, reusing can be more easily done. This would be made feasible by making each module robust on its own and for each load that can occur, so that it can be ensured that the structure as a whole is robust as well.

For this variant, a module can exist of four deck plates and two rib plates as is shown in Figure E.8. The third rib plate in the figure is from the previously placed module or had to be added to the first module that is placed in a row and should be taken into account when determining the robustness of the module individually. As can be seen, the deck plates do not overlap fully with the rib plates. This is so that the deck plates of the next module can rest on the rib plate as well, which is similar to the regular design of this variant. In the modular design, there will be no deck plates overlapping the entire width of the rib plate, as is the case for the edges of the regular design, so that when requirements change, modules can be added to the structure at all sides, without needing to replace the deck plate elements of the modules on the edge of the structure. The modular structure will be expandable per module, which is 16.5 m for the deck length and 12 m for the deck width. From looking at the dimensions of other jetties it should be found if these dimensions will fit well in other designs or if changes should be made to the size of a module.

To allow easy extension of the modular structure, also the connections need to be prepared on each side of the module. While the structure is in use, it can give the impressions that it is not entirely finished, as concrete parts can be sticking out and not finished connections can be seen. This is no problem, as aesthetics is not a requirement for jetty structures in the port of Rotterdam.

The separate deck plates and rib plates make this variant suitable for modularity. It can be expanded in each direction and the construction is similar to that of the regular version. Still, challenges have to be overcome to optimise this design for modularity.

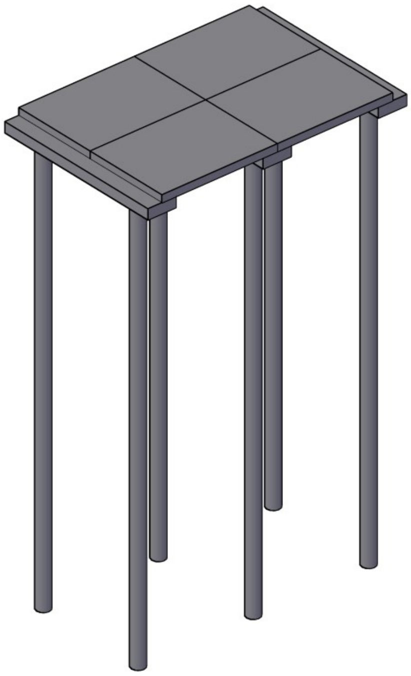


**Figure E.8:** Module variant 1

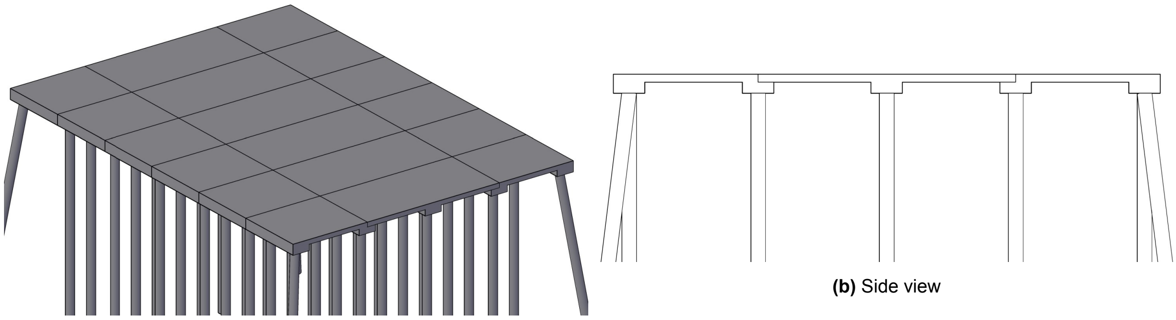
## E.2. Variant 2: T- and n-shaped elements

As mentioned in Section E.1.2, variant 1 is not an optimal solution due to the need of rigid connections. To try to avoid the use of rigid DfD connections, a second variant is explored in which the deck plates and rib plates are already rigidly connected in a prefabricated element. Below, the layout is explained in further detail and the opportunities of this variant are explored.

### E.2.1. Layout

The global dimensions of the jetty will remain unchanged. However, the initial way of using separate rib plate and deck plate elements is dismissed. From the calculations of variant 1 it appeared that the edge rib plates should be rigidly connected to the deck plates. Due to this, for variant 2 it is chosen to connect the edge deck plates to the two rib plates they were initially resting. The middle deck plates will be connected to the middle rib plate. By doing this, two types of elements are formed: T-shaped elements will be in the middle, resting on piles and n-shaped elements on the edges. The element consists of a plate-part with a width of 16.5 m and a height of 0.5 m and a rib-part with a 2 m width and a 0.5 m height. The n-shaped element has a plate-part of 9.25 m width and 0.5 m height with on each side a rib-part of 2 m width and 0.7 m height. The concept is shown in Figure E.9. The T-shaped elements will be governing in terms of weight. When using a regular crane, the length can be maximally 2.9 m, but to arrive at a total length of 48 m, a length of 2.4 m per element should be used. This would lead to a total amount of 60 prefabricated concrete elements in two shapes.

As the prefabricated elements are heavy, the use of a large crane with an assumed maximum capacity of 200 tonnes can be considered. When accounting for this larger crane, the elements can be 8 m in length. This variant would need 18 prefab elements in two shapes. Those elements are shown in Figure E.10.



**(a)** 3D view

**(b)** Side view

**Figure E.9:** Layout of variant 2: T and n-shaped elements

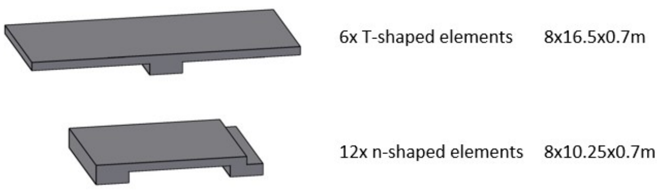



**Figure E.10:** All prefab elements used in variant 2

**Construction**

For the construction of this variant, the piles have to be placed first. Placement tolerances for the piles can stay the same, as the connection between the rib plates and piles is assumed to remain unchanged in this research. When all piles are positioned, the n-shaped elements have to be placed and connected to the rib plates. Each rib-part of the elements rests on piles. However, two piles per rib-part should be available, so that the elements are robust during construction by resting on four piles. This can cause changes in the number of piles that are needed for this variant. Otherwise, the crane should be holding the elements while they are being connected, which is impossible with using one crane and also implements risks. The possibility of needing additional piles in the design is considered in the global calculations in Section E.2.2.

When the n-shaped elements are in place, the T-shaped elements can be put in the middle. The T-shaped elements rest on an n-shaped element on each side, so both n-shaped elements should be in place. Whether all n-shaped elements are placed first or after placing two n-shaped elements, the T-shaped elements are put in between immediately can be decided by the executor. After placing the T-shaped elements, they can be connected to the n-shaped elements and the deck construction will be finished.

Similar to variant 1, this construction sequence can cause small placement tolerances. As explained in Section E.1.1, the structural behaviour can be influenced by needing force to place the elements properly between several connection points.

## E.2.2. Global calculations

As is the case for variant 1, it is investigated if simpler connections can be used instead of rigidly connecting all elements. However, first a rigid variant will be modelled, which is following the requirement given by PoR to have rigid connections.

As is explained in the previous section, the n-shaped elements should be resting on four piles to be robust during construction. To make sure each element is supported by enough piles, extra piles should be added to the design. The small crane solution has elements with a length of 2.4 m, needing 20 elements over the length. With 20 elements over the length and 5 rib-parts over the width, a total amount of piles of 200 piles will be needed. This is a significantly high number of piles compared to the original number of 35. Furthermore, by placing a pile with a diameter of 0.914 m each 1.2 m over the length, the piles would be standing so close to each other that their behaviour in the ground is expected to change. It is outside the scope of this research to change the entire pile plan. Therefore, the small crane variant will not be further considered.

When using the larger crane, the elements can become 8 m in length, needing 6 elements over the length. For placing two piles underneath each rib-part of the elements over the length, a total of 60 piles is needed. This is already a high number compared to the original 35. However, this variant is still being worked out further to see possibilities and challenges that arise.

This variant has three different connections between the concrete elements. Those are the n-shaped element to n-shaped element, the T-shaped element to T-shaped element and the n-shaped element to T-shaped element. The position of those connections is shown in Figure E.11.

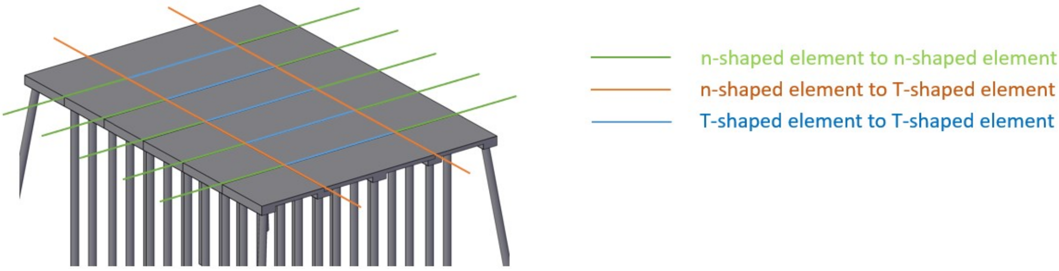
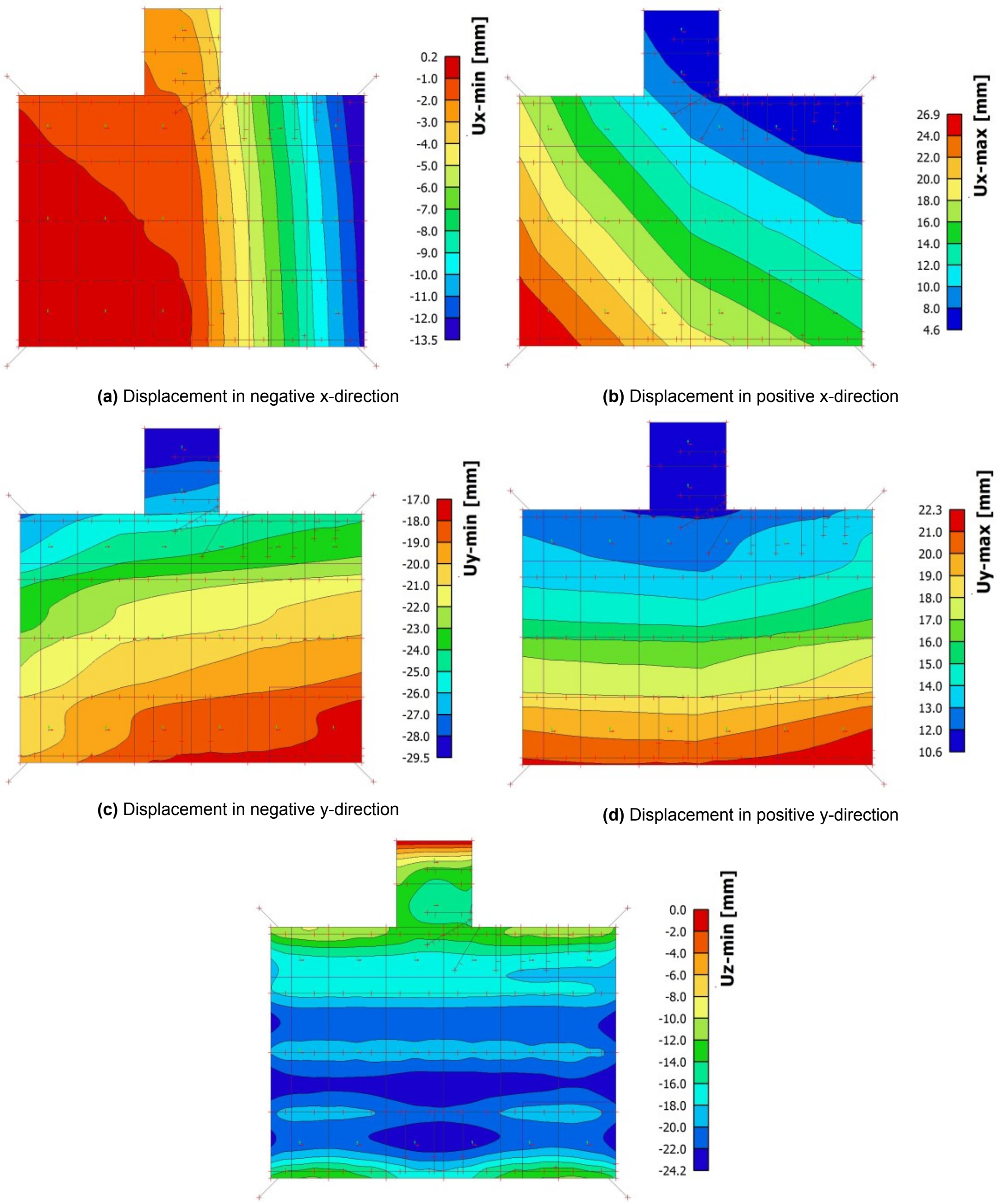



**Figure E.11:** Connection types in variant 2

When applying rigid connections to the large crane variant everywhere, the structure is robust. The maximum displacement becomes 29.5 mm, as shown in Figure E.12, which is smaller than for the reference variant. This result can be expected, as the amount of piles is increased considerably.

From variant 1 was learned that the rib plate to rib plate and deck plate to deck plate connections are not as critical as the rib plate to deck plate connections. It is expected that this still holds for this variant. By modelling a shear connection between the rib-parts of the elements and no connection between the plate-parts of the elements, a maximum displacement of 37 mm is found, shown in Figure E.13. It is found that these connections have a larger influence on the structural behaviour than in variant 1. However, displacements remain well within the acceptable range and are even smaller than that of the reference jetty. Therefore, the connection between the n-shaped element and the T-shaped element is made simpler. The simplest form of connection for these parts is hinged, meaning that moments cannot be transferred, but forces in all directions can be. This results in a robust structure with a maximum displacement of 37.3 mm, displayed in Figure E.14, only increasing a little compared to the variant with rigid n-shaped element to T-shaped element connections. A maximum jump between the elements that are not connected is observed of 9 mm.

Connecting the rib plates to the deck plates in prefab elements is found to be an effective measure to avoid the use of rigid connections in the structure. However, from the execution of variant 2 challenges arise that are difficult to overcome. For the variant using the larger crane, the number of piles increases significantly. The option to minimize the pile use is limited by the length of the elements, which is in its place limited by the loading capacity of the crane. A new variant will be made, in which the idea of prefabricated deck plate elements that are stiffer is explored together with trying to limit the weight of the individual elements to reduce pile use.




**(a)** Displacement in negative x-direction

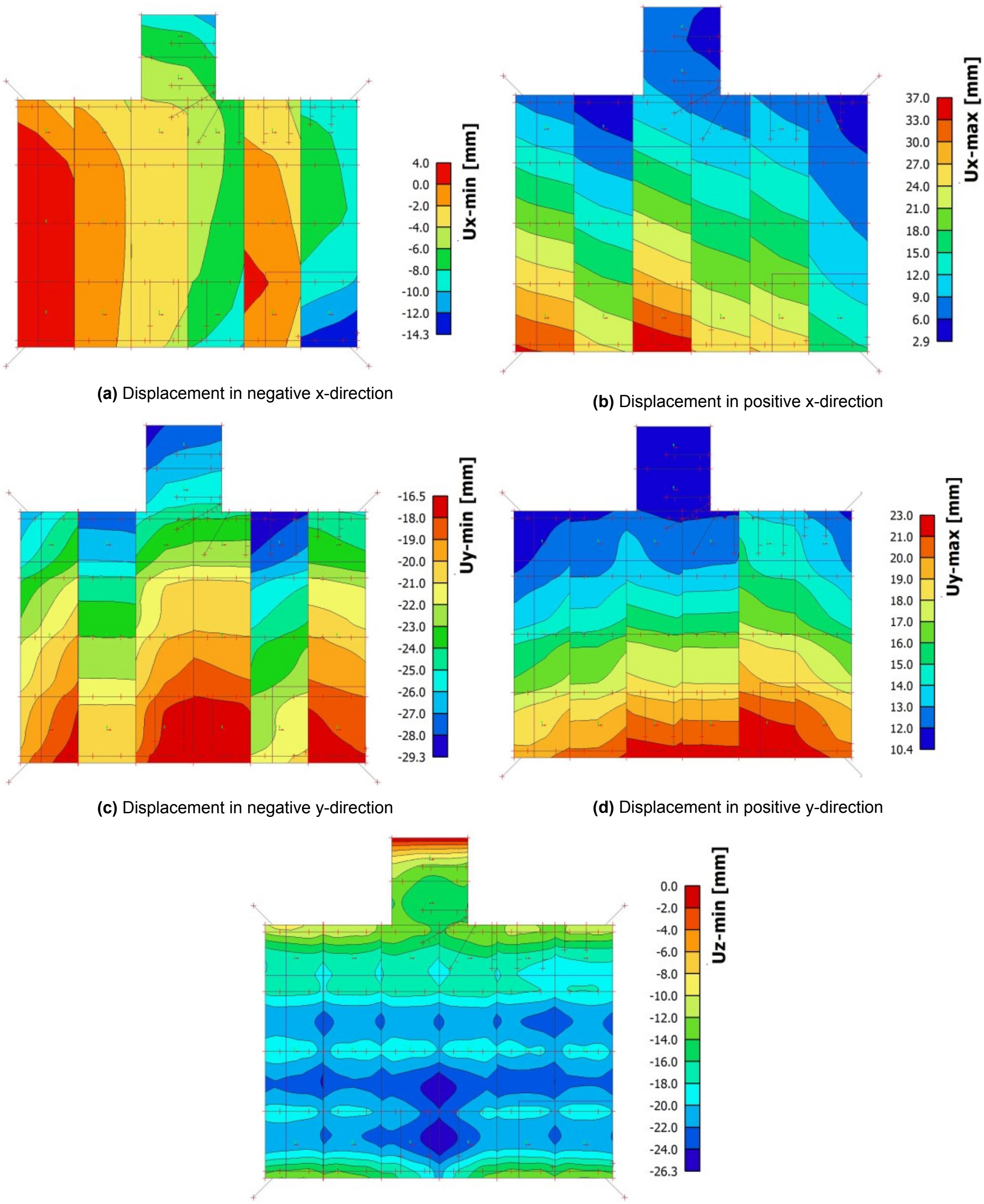
**(b)** Displacement in positive x-direction

**(c)** Displacement in negative y-direction

**(d)** Displacement in positive y-direction

**(e)** Displacement in z-direction

**Figure E.12:** Displacement of rigid solution for variant 2




**(a)** Displacement in negative x-direction

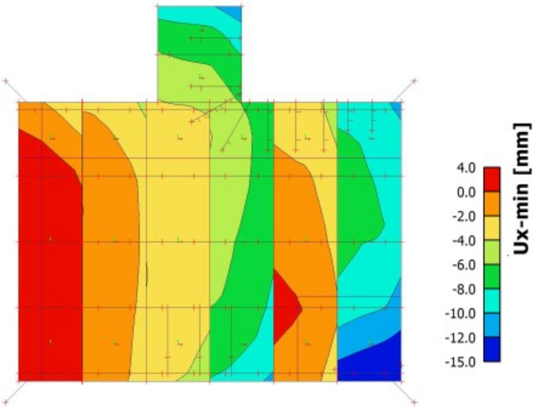
**(b)** Displacement in positive x-direction

**(c)** Displacement in negative y-direction

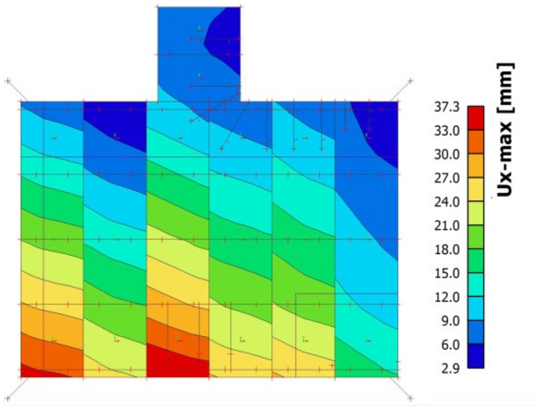
**(d)** Displacement in positive y-direction

**(e)** Displacement in z-direction

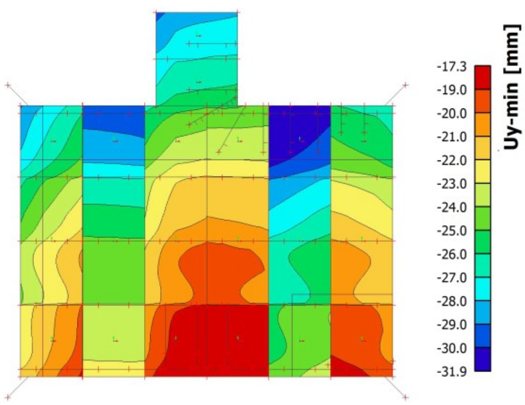
**Figure E.13:** Displacement of no plate-part to plate-part and shear rib plate to rib plate connection variant 2



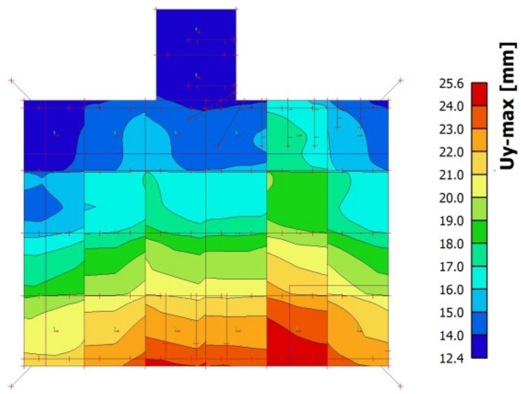

**(a)** Displacement in negative x-direction



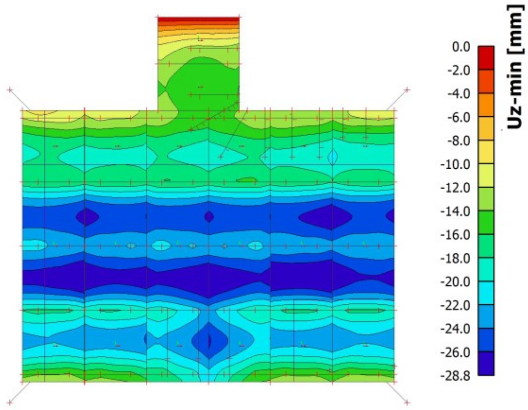

**(b)** Displacement in positive x-direction




**(c)** Displacement in negative y-direction




**(d)** Displacement in positive y-direction




**(e)** Displacement in z-direction

**Figure E.14:** Displacement of simplest solution for variant 2

## E.2.3. Modularity

As explained in Section 2.1, the reusability of the structure can be increased by making it modular. The module that can be used to make this variant is displayed in Figure E.15. A module consists of one T-shaped element and one n-shaped element, supported by eight piles. The additional n-shaped element that is seen in the figure can be the n-shaped element from a previously placed module or an extra n-shaped element at the beginning of the structure. When considering the robustness of a single module, this additional element should be taken into account.

The deck size of this module including an n-shaped element at the beginning is 33 m in length and 8 m in width. In the length direction, it is expendable to each side per one T-shaped and one n-shaped element. This increases the deck length by 24.75 m per step. In the width direction, it is expendable per 8 m. The exact dimensions of the modules can change according to the global dimensions of other jetties, but the step size will remain approximately the same.

This variant is suitable to make modular, as it is expendable in each direction and easy to construct. Only the step size of adding modules in the length direction is rather large. If this is an unrealistic length for the module has to be researched further based on existing jetty and wanted expansions.

**Figure E.15:** Module variant 2

## E.3. Dry rigid connections

For the dry rigid connection, it is chosen to work out a configuration both for the rib plate to rib plate and the rib plate to deck plate connections of reusable design variant 1, as presented in Section E.1. They are based on the layout of the successfully tested moment resistant connection shown in Figure 2.3. The connection elements, namely the steel plates welded to rods and bolts connecting the steel plates, are the main components of the dry demountable connections in the jetty. Calculations on the connections are done based on a combination of the Eurocode for steel and the Eurocode for concrete. However, as this connection is not yet implemented in the norms, it cannot be seen as a final version. The calculations serve as a method to explore the approximate dimensions and possibilities of the configuration. Expert judgement and further studies like testing or advanced modelling should lead to an optimized and verified connection design that can be applied in practice. This is out of scope for this research. The connection is presented on a conceptual level and it is expected that for the other dry rigid connections in the different variants, a comparable method based on this concept can be used.

As this connection uses added steel elements to obtain continuity, it is expected that this connection form can be applied to all rigid connections that were made in each DfD design variant.

### E.3.1. Rib plate to rib plate connections

The rib plate to rib plate connection should transfer a tensile load, a shear load and a bending moment in y-direction and z-direction. The loads are based on the prefabricated element design as in Section E.1.1 and the governing loads are given in Table E.4. The connection consists of two similar end plates of steel grade S235 that have the same height as the rib plate and stick out on the sides where the bolts will be placed. The end plates have a total width of 2180 mm and a thickness of 26 mm. On each side of the rib plate, the end plates will be connected with six M36 10.9 bolts. Oversized bolts holes are used to increase the placement tolerances. The end plates will be connected to steel rods in the concrete using welds. In total, sixteen B500B steel rods will create the connection between the plates and the concrete. The concept of the connection is shown in Figure E.16.

Calculations on the joint are performed according to a combination of existing norms. The structural behaviour of the joint is divided into failure mechanisms, which are checked separately according to the norms. The bolted end plate to end plate connection is checked with EN 1993-1-8, which is the Eurocode for steel joints. The rods welded to the end plate and bonded to the concrete are checked with EN 1992-1-1, the European standard for general concrete design. While both of the connection parts separately are familiar in the norms and can thus be calculated, the behaviour of the combination of these parts is not yet implemented in a standard. Nevertheless, an estimation of the rigidity of the connection is made. From the calculations it can be seen that the joint is estimated to be semi-rigid. This is in line with the expectation when looking at similar configurations in the steel industry. However, the elasticity of the concrete that is connected by the joint is considerably lower than that of steel. Therefore, for simplicity, the joint is assumed to be very close to the rigid boundary, which is why it is modelled as a rigid connection and full continuity is assumed.

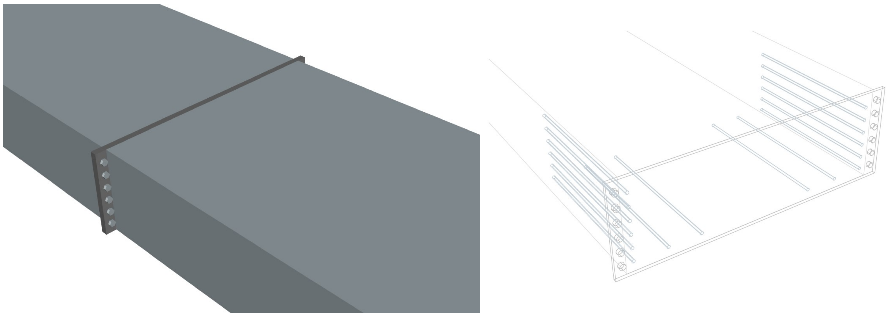
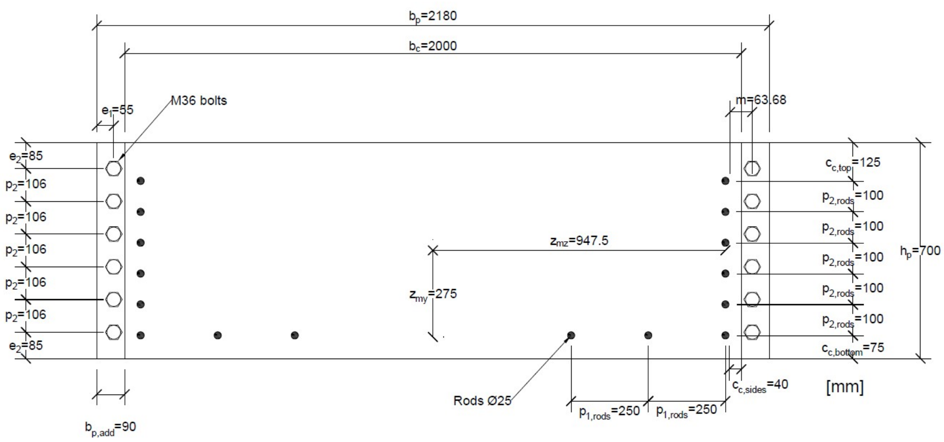
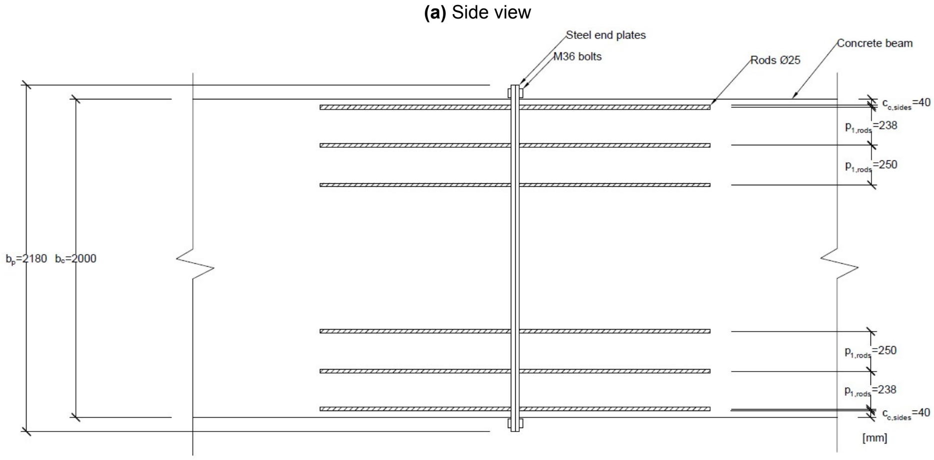


**Figure E.16:** 3D view of rigid beam to beam connection

### Calculations




**(a)** Side view




**(b)** Top view

**Figure E.17:** Layout of rigid rib plate to rib plate connection

**Table E.1:** Dimensions and material properties of concrete

| Description | Symbol | Relation | Value | Unit | Source |
|---|---|---|---|---|---|
| deck plate dimensions | | | | | |
| Height of concrete deck plate | $h_{cb}$ | | $700$ | $mm$ | [44] |
| Width of concrete deck plate | $b_{cb}$ | | $2000$ | $mm$ | [44] |
| Concrete material properties | | | | | |
| Concrete class | | | $C35/45$ | | [44] |
| Partial factor for concrete | $\gamma_c$ | | $1.15$ | | [39] |
| Elastic modulus | $E_c$ | | $11000$ | $MPa$ | [39] |
| Characteristic cylinder compressive strength | $f_{ck}$ | | $35$ | $MPa$ | [39] |
| Design cylinder compressive strength | $f_{cd}$ | $\frac{f_{ck}}{\gamma_c}$ | $23.33$ | $MPa$ | [39] |
| Lower characteristic tensile strength | $f_{ctk,0.05}$ | | $2.2$ | $MPa$ | [39] |
| Layout of steel rods | | | | | |
| Concrete cover top and sides | $c_{c,sides}$ | | $40$ | $mm$ | [44] |
| Concrete cover bottom | $c_{c,bottom}$ | | $75$ | $mm$ | [44] |
| Concrete cover top | $c_{c,top}$ | | $125$ | $mm$ | |
| Horizontal spacing | $p_{1,rods}$ | | $250$ | $mm$ | |
| Vertical spacing | $p_{2,rods}$ | | $100$ | $mm$ | |
| Steel rods material properties | | | | | |
| Steel grade | | | $B500B$ | | [44] |
| Partial factor for steel rods | $\gamma_{sr}$ | | $1.15$ | | [39] |
| Characteristic yield strength | $f_{yk,r}$ | | $500$ | $MPa$ | [39] |
| Design yield strength | $f_{yd,r}$ | $\frac{f_{ck,r}}{\gamma_{sr}}$ | $435$ | $MPa$ | [39] |
| Diameter of rods | $d_r$ | | $25$ | $mm$ | |
| Rod area | $A_{sr}$ | $\frac{1}{4}\pi d_r^2$ | $490.87$ | $mm^2$ | |
| Throat thickness of weld | $a$ | | $10$ | $mm$ | |
| Length of rods | $L_{br}$ | | $1200$ | $mm$ | |

**Table E.2:** Dimensions and material properties of end plate

| Description | Symbol | Relation | Value | Unit | Source |
|---|---|---|---|---|---|
| Dimensions | | | | | |
| Height of plate | $h_p$ | | $700$ | $mm$ | |
| Additional width of plate per connection side | $b_{p,add}$ | | $90$ | $mm$ | |
| Total width of plate | $b_p$ | | $2180$ | | |
| Plate thickness | $t_p$ | | $26$ | $mm$ | |
| Horizontal edge distance | $e_1$ or $n$ | | $55$ | $mm$ | |
| Vertical edge distance | $e_2$ | | $85$ | $mm$ | |
| Vertical spacing | $p_2$ | | $106$ | $mm$ | |
| Distance between plastic hinges at bolt and rods | $m$ | $b_{p,add} - e_1 - 0.8\sqrt{2}a$ | $63.69$ | $mm$ | |
| Material properties | | | | | |
| Steel grade | | | $S235$ | | |
| Yield strength | $f_y$ | | $235$ | $MPa$ | [55] |
| Ultimate strength | $f_u$ | | $360$ | $MPa$ | [55] |
| Elastic modulus | $E_s$ | | $210000$ | $MPa$ | [55] |

**Table E.3:** Dimensions and material properties of bolts

| Description | Symbol | Relation | Value | Unit | Source |
|---|---|---|---|---|---|
| Bolt type | | | $M36$ 10.9 | | |
| Nominal bolt diameter | $d_b$ | | 36 | $mm$ | [56] |
| Diameter of bolt hole | $d_0$ | | 44 | $mm$ | [56] |
| Diameter of head and nut | $d_{head}$ | | 55 | $mm$ | [56] |
| Diameter of washer plate | $d_{washer}$ | | 55 | $mm$ | [56] |
| Thickness of head and nut | $t_{head}$ | | 21 | $mm$ | [56] |
| Thickness of washer plate | $t_{washer}$ | | 5 | $mm$ | [56] |
| Tensile stress area | $A_s$ | | 817 | $mm^2$ | [56] |
| Amount of bolts per side | $n_b$ | | 6 | | |
| Yield strength of bolt | $f_{yb}$ | | 900 | $N/mm^2$ | [56] |
| Ultimate strength of bolt | $f_{ub}$ | | 1000 | $N/mm^2$ | [56] |
| Factor for tensile resistance | $k_2$ | | 0.9 | | [56] |
| Tensile resistance | $F_{t,Rd}$ | $k_2 f_{ub} A_s/\gamma_{M2}$ | 588.24 | $kN$ | [56] |
| Factor for shear resistance | $\alpha_v$ | | 0.5 | | [56] |

The connection should transfer the loads given in Table E.4. For the calculation of the connection resistance, the connection is calculated per failure mechanism. For the connection, the following four failure mechanisms can be identified. The failure mechanisms 1 to 3 are based on the standards for steel connections from EN 1993-1-8 [56]. Failure mechanism 4 is based on the calculations of the rods in the pile to rib plate connection as described in Appendix C.3 and on the standards for reinforced concrete from EN 1992-1-1 [39].

- Failure mechanism 1: Resistance of bolts in tension
- Failure mechanism 2: Bending moment resistance
- Failure mechanism 3: Resistance of bolts in shear
- Failure mechanism 4: Resistance of rods in tension

The four failure mechanisms are explained below per mechanism and are calculated and checked.

**Table E.4:** Governing loads on rib plate to rib plate connection

| Load type | Symbol | Value | Unit |
|---|---|---|---|
| Design normal force | $N_{Ed}$ | 1376 | $kN$ |
| Design shear force | $V_{Ed}$ | 101 | $kN$ |
| Design bending moment in y-direction | $M_{y,Ed}$ | 334 | $kNm$ |
| Design bending moment in z-direction | $M_{z,Ed}$ | 160 | $kNm$ |

The applied material safety factors $\gamma_{M0}$ and $\gamma_{M2}$ are:

$$\begin{aligned} \gamma_{M0} &= 1.0 \\ \gamma_{M2} &= 1.25 \end{aligned} \tag{E.1}$$

**Eurocode applicability checks**
To be able to apply the EN 1993-1-8 calculations, the spacing of the bolts, plate thickness and elongation length of the bolts should be checked. The position of the bolt holes have a minimum spacing from the edge of the end plate and from other bolt holes. Those are checked below.

$$\begin{aligned} e_1 &= 55\ mm \geq 1.2d_0 = 52.8\ mm \\ e_2 &= 50\ mm \geq 1.2d_0 = 52.8\ mm \\ p_2 &= 120\ mm \geq 2.4d_0 = 105.6\ mm \end{aligned} \tag{E.2}$$

The joint should have sufficient rotation capacity, so that plastic distribution can be assumed. This is checked with the following equation.

$$t_p = 26\ mm \leq 0.36d\sqrt{f_{ub}/f_y} = 26.73\ mm \tag{E.3}$$

To see if prying forces may develop between the end plates, depends on the elongation length of the bolt $L_b$ and a factor based on plate and bolt properties. This check is done below, in which $l_{eff,1}$ is the effective length of the equivalent T-stub as explained in the section below.

$$\begin{aligned} L_b &= 2t_p + t_{washer} + \frac{t_{head} + t_{nut}}{2} = 78\ mm \\ L_b &\leq \frac{8.8m^3 A_s}{\sum l_{eff,1} t_p^3} = 230.33\ mm, \text{ so prying forces may develop} \end{aligned} \tag{E.4}$$

**Failure mechanism 1: Resistance of bolts in tension**
The connection is loaded with a tension force ($N_{Ed}$), as can be seen in Table E.4. This causes the bolts to be loaded in tension. The failure mechanism of bolts in tension can be identified and calculated according to EN 1993-1-8 [56]. The mechanism can be checked by identifying the equivalent T-stub. For this connection, the T-stub flanges are the end plates, as can be seen in Figure E.18. The modes of failure from the T-stub are assumed to be the same as the expected modes of failure of the end plate in bending. The T-stub can fail in three modes: Mode 1: Complete yielding of the flange, mode 2: Bolt failure with yielding of the flange, mode 3: Bolt failure. The three failure modes are calculated and checked.

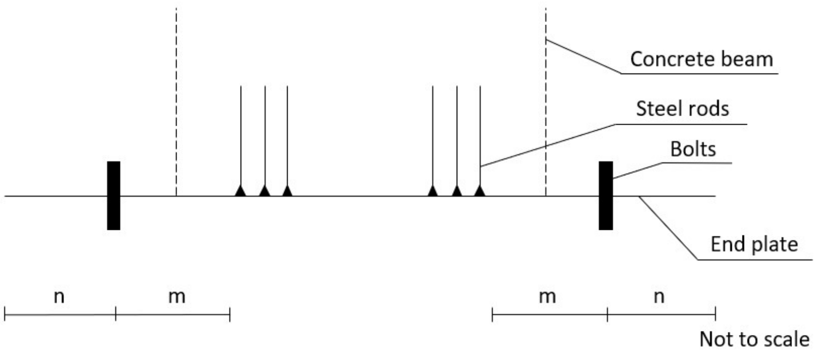
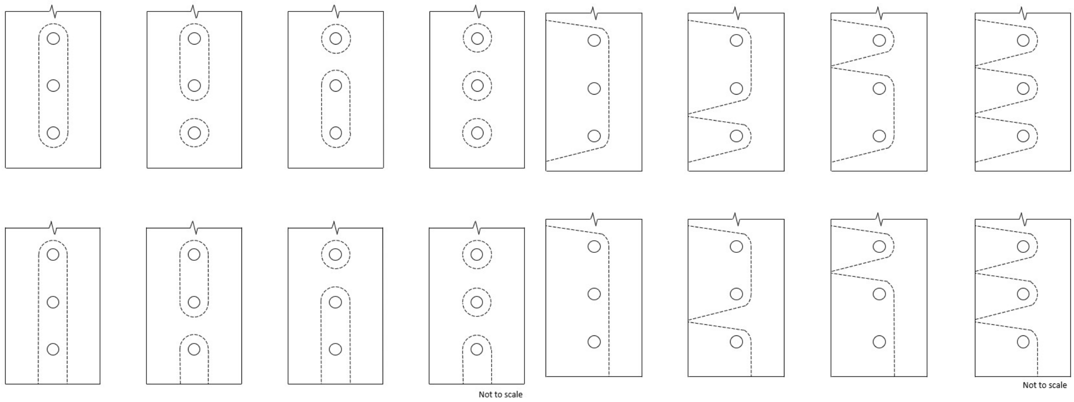



**Figure E.18:** Equivalent T-stub

In Mode 1, plastic hinges form in the equivalent T-stub flange as indicated in Figure E.20. The calculation of the design tensile resistance of the end plate ($F_{T,1,Rd}$) can be found below. For the T-stub flange in bending, the effective lengths ($l_{eff}$) should be determined. This is done with the method used in NEN-EN 1993-1-8, which is divided in a effective length for a circular pattern and a non-circular pattern, as shown in Figure E.19. The effective length is taken over three bolts, as there are three bolts in tension. This is explained in the calculation of failure mechanism 2.




**(a)** Circular pattern **(b)** Non-circular pattern

**Figure E.19:** Effective lengths for bolts in tension

$$\sum l_{eff,cp} = min(2\pi m + 4p_2; \pi m + 4p_2 + 2e_2; 4\pi m + 2p_2; 3\pi m + 2p_2 + 2e_2 \\ 6\pi m; 5\pi m + 2e_2) = 794.08\ mm \tag{E.5}$$

$$\sum l_{eff,nc} = min(4m + 1.25e_1 + 2p_2; 2m + 0.625e_1 + 2p_2 + e_2; \\ 8m + 2.5e_1 + p_2; 6m + 1.875e_1 + p_2 + e_2; 12m + 3.75e_1; \\ 10m + 3.125e_1 + e_2) = 458.75\ mm \tag{E.6}$$

$$\sum l_{eff,1} = min(\sum l_{eff,cp}; \sum l_{eff,nc}) = 458.75\ mm \\ \sum l_{eff,2} = \sum l_{eff,nc} = 458.75\ mm \tag{E.7}$$

Based on the effective lengths determined here, the plastic moment resistance of mode 1 ($M_{pl,1,Rd}$) is calculated, which is done below.

$$M_{pl,1,Rd} = 0.25 \sum l_{eff,1}\ t_p^2 f_{yp}/\gamma_{M0} = 18.22\ kNm \tag{E.8}$$

The distance between the centre of the bolt and the plastic hinge ($e_w$) is can be determined based on the washer plate diameter.

$$e_w = \frac{d_{washer}}{4} = 13.75\ mm \tag{E.9}$$

$$F_{T,1,Rd} = \frac{(8n - 2e_w)M_{pl,1,Rd}}{2nm - e_w(m+n)} = 1398.59\ kN \tag{E.10}$$

$$U.C._1 = \frac{N_{Ed}}{F_{T,1,Rd}} = 0.98 \tag{E.11}$$

Mode 2 is a combination of flange yielding and bolt failure. This is illustrated in Figure E.21. The design tensile resistance of the end plate and bolts ($F_{T,2,Rd}$) is and the unity check are shown below.

$$M_{pl,2,Rd} = 0.25 \sum l_{eff,2}\ t_p^2 f_{yp}/\gamma_{M0} = 18.22\ kNm \tag{E.12}$$

$$F_{T,2,Rd} = \frac{2M_{pl,2,Rd} + n\sum F_{t,Rd}}{m+n} = 1942.58\ kN \tag{E.13}$$

$$U.C._2 = \frac{N_{Ed}}{F_{T,2,Rd}} = 0.71 \tag{E.14}$$

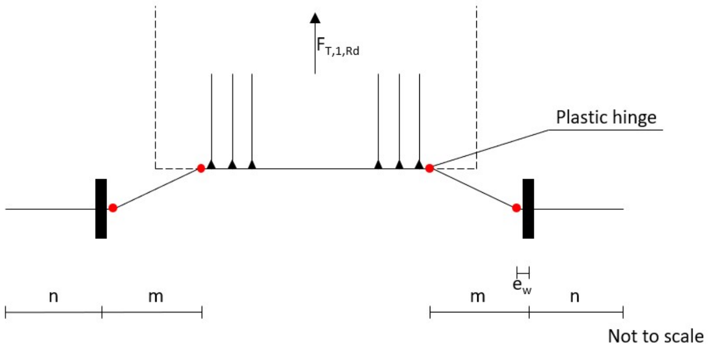



**Figure E.20:** Mode 1: Complete yielding of the flange

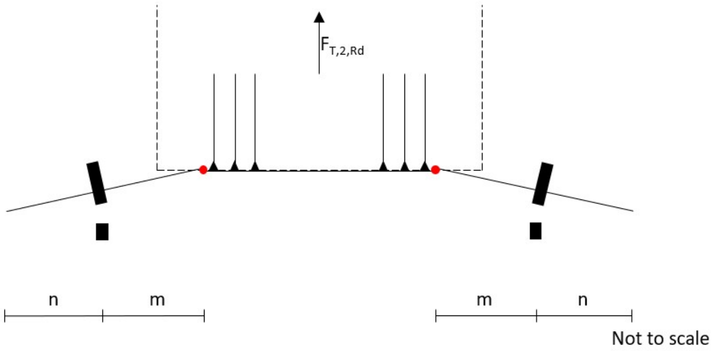



**Figure E.21:** Mode 2: Bolt failure with yielding of the flange

In the third failure mode, bolt failure is governing. This is shown in Figure E.22. The design tensile resistance of the bolts $F_{T,3,Rd}$ and the unity check are calculated below.

$$F_{T,3,Rd} = \sum F_{t,Rd} = 1764.72\ kN \tag{E.15}$$

$$U.C._3 = \frac{N_{Ed}}{F_{T,3,Rd}} = 0.78 \tag{E.16}$$

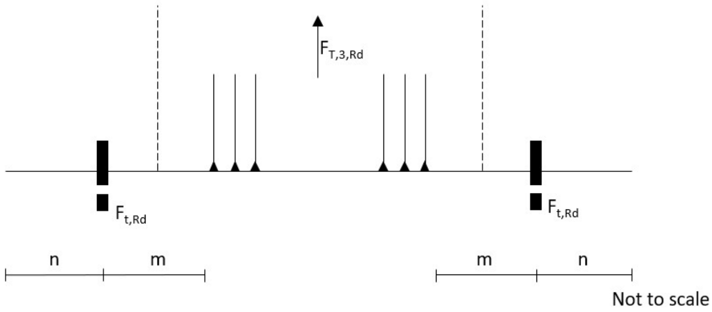



**Figure E.22:** Mode 3: Bolt failure

**Failure mechanism 2: Bending moment resistance**
As shown in Table E.4, the connection is loaded with bending moments in y- and z-direction ($M_{y,Ed}$, $M_{z,Ed}$). The bending moment resistance of the joint should be checked in both directions ($M_{y,Rd}$, $M_{z,Rd}$). The calculation and checking of the bending moment resistance can be done according to EN 1993-1-8 [56]. The bending moment resistance is given by the tensile resistance of the bolts in tension around the centre of compression ($C_c$), as indicated in Figure E.23.

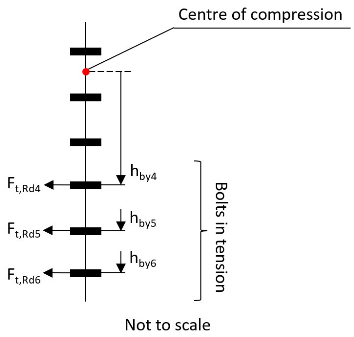



**Figure E.23:** Bending moment resistance of connection

The centre of compression from the top of the concrete rib plate in y-direction ($C_{cy}$) is calculated below. This is done based on the compressive strain ($\epsilon_{c3}$) and the ultimate compressive strain in the concrete ($\epsilon_{cu3}$). Also, the distances of each bolt row from the centre of compression is given. The distances can are visualised in Figure E.24.

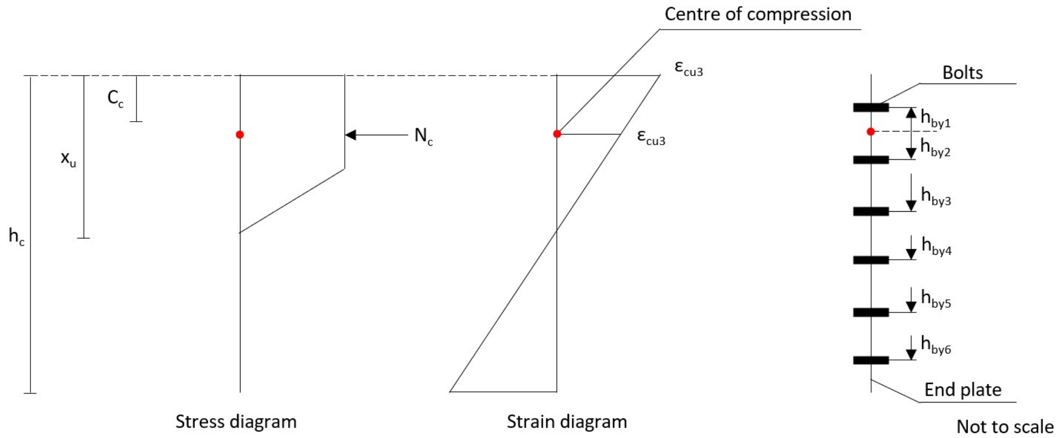



**Figure E.24:** Determination of centre of compression

$$\begin{aligned} \epsilon_{c3} &= 1.75 \text{ ‰} \\ \epsilon_{cu3} &= 3.5 \text{ ‰} \end{aligned} \tag{E.17}$$

The height of the concrete compressive zone ($x_{uy}$) is calculated below.

$$x_{uy} = (1 - \frac{\epsilon_{c3}}{\epsilon_{cu3}})h_{cb} = 350\ mm \tag{E.18}$$

$$\beta = \frac{7}{18} \tag{E.19}$$

$$C_{cy} = \beta x_{uy} = 136.11\ mm \tag{E.20}$$

$$\begin{aligned} h_{by1} &= e_2 - x_{uy} = 51.11\ mm \\ h_{by2} &= e_2 + p_2 - x_{uy} = 54.89\ mm \\ h_{by3} &= e_2 + 2p_2 - x_{uy} = 160.89\ mm \\ h_{by4} &= e_2 + 3p_2 - x_{uy} = 266.89\ mm \\ h_{by5} &= e_2 + 4p_2 - x_{uy} = 372.89\ mm \\ h_{by6} &= e_2 + 5p_2 - x_{uy} = 478.89\ mm \end{aligned} \tag{E.21}$$

Based on the distances of each bolt row to the centre of compression, the bending moment resistance in y-direction can be calculated.

$$M_{y,Rd} = \sum_{i=4,5,6} F_{t,Rdi} h_{byi} = 1316.09\ kNm \tag{E.22}$$

$$U.C._{My} = \frac{M_{y,Ed}}{M_{y,Rd}} = 0.25 \tag{E.23}$$

The width of the concrete compressive zone in z-direction ($x_{uz}$) and the centre of compression in z-direction from the side of the concrete rib plate ($C_{cz}$) is calculated below.

$$x_{uz} = (1 - \frac{\epsilon_{c3}}{\epsilon_{cu3}}) b_{cb} = 1000\ mm \tag{E.24}$$

$$C_{cz} = \beta x_{uz} = 388.89\ mm \tag{E.25}$$

$$h_{bz} = b_{cb} - C_{cz} + (b_{p,add} - e_1) = 1646.11\ mm \tag{E.26}$$

Based on $h_{bz}$, the bending moment resistance in z-direction is calculated below.

$$M_{z,Rd} = \sum_{i=1,2,..,6} F_{t,Rdi} h_{bz} = 5809.85\ kNm \tag{E.27}$$

$$U.C._{Mz} = \frac{M_{z,Ed}}{M_{z,Rd}} = 0.03 \tag{E.28}$$

**Failure mechanism 3: Resistance of bolts in shear**

The connection is subjected to a shear force ($V_{Ed}$) given in Table E.4. Therefore, the shear resistance of the bolts and end plates ($F_{v,Rd}$) is checked. This is done according to EN 1993-1-8 [56] and can be divided into two failure modes: bolts in shear and bolts in bearing.

At first, the shear force will be taken by the bolts that are loaded in compression. Any remaining shear can be taken by the bolts loaded in tension. However, because of this interaction, the shear resistance of the tension bolts will be lower. As can be seen in the unity check below, all bolts in compression are able to take the shear force and thus no interaction of the tension bolts has to be taken into account.

The bearing resistance of the bolts is determined by the end plate properties and the spacing and edge distances of the bolts. The bearing resistance should be calculated per end plate for the bolts as a group ($F_{b,Rd,total}$). However, as both end plates are similar in dimensions and properties, only one has to be checked.

Shear resistance of an individual bolt is given below.

$$F_{v,Rd} = \alpha_v f_{Ub} A_s / \gamma_{M2} = 326.80\ kN \tag{E.29}$$

$$U.C._{shear} = \frac{V_{Ed}}{n_b F_{v,Rd}} = 0.10 \tag{E.30}$$

The bearing resistance of an individual bolt (($F_{b,Rd}$) and their interaction is calculated below. As the bearing resistance of a bolt is dependent on the spacing and edge distances of the bolts, the bearing resistance for inner bolts is different than for outer bolts. This difference in factors $\alpha_d$ and $\alpha_b$. To calculate the bearing resistance of the bolts, also factor $k_1$ is taken into account. In the load direction, five of the six bolts are inner bolts and one is an outer bolt, as is shown in Figure E.25.

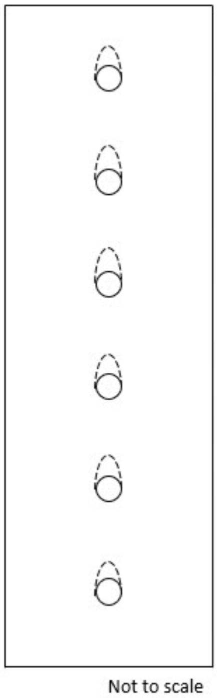



**Figure E.25:** Direction of bolts in bearing

$$k_1 = min(\frac{2.8e_2}{d_0} - 1.7; 2.5) = 2.5 \tag{E.31}$$

$$\alpha_{d,inner} = \frac{p_1}{3d_0} - \frac{1}{4} = 0.23 \tag{E.32}$$

In which $p_1$ is the spacing between bolt columns. As there is only one column, so no $p_1$ is present. Therefore, the conservative value of $m$ is used for this.

$$\alpha_{d,end} = \frac{e_1}{3d_0} = 0.42 \tag{E.33}$$

$$\alpha_{b,inner} = min(\alpha_{d,inner}; \frac{f_{ub}}{f_{yp}}; 1.0) = 0.23 \tag{E.34}$$

$$\alpha_{b,end} = min(\alpha_{d,end}; \frac{f_{ub}}{f_{yp}}; 1.0) = 0.42 \tag{E.35}$$

$$F_{b,Rd,inner} = k_1 \alpha_{b,inner} f_u d_b t_p / \gamma_{M2} = 156.67\ kN \tag{E.36}$$

$$F_{b,Rd,end} = k_1 \alpha_{b,end} f_u d_b t_p / \gamma_{M2} = 280.80\ kN \tag{E.37}$$

$$F_{b,Rd,total} = 2(n_b - 1) F_{b,Rd,inner} + 2F_{b,Rd,outer} = 1847.75\ kN \tag{E.38}$$

$$U.C._{bearing} = \frac{V_{Ed}}{F_{b,Rd,total}} = 0.05 \tag{E.39}$$

**Failure mechanism 4: Resistance of rods in tension**
On the rib plate side of the joint, the end plates are connected to steel rods in the concrete. Those are subjected to tension, resulting in three possible modes of failure: Yielding of rods, bond strength of rods to concrete, welds.

The yielding of the rods has to be checked according to EN 1992-1-1 [39]. Tension in the rods is caused by the tensile force ($N_Ed$), the bending moment in y-direction ($M_{y,Ed}$) and the bending moment in z-direction ($M_{z,Ed}$). The failure mode is visualised in Figure E.26. The tensile force causes tension in the entire cross-section of the rib plate, so the rods can be placed anywhere within the section. The moment in y-direction causes tension in the bottom part of the cross-section, so rods should be placed in the bottom. For the moment in z-direction, they should be placed on the sides of the rib plate, as it causes tension in the sides. The placement and the amount of rods ($n_{rods,tot}$) can be found in Figure E.17. The calculations of the required rod area ($A_{sr,rqd,total}$) are shown below.

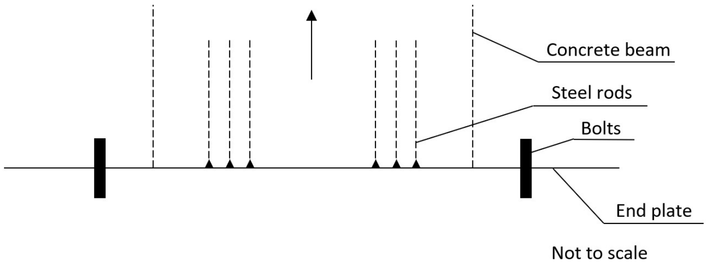



**Figure E.26:** Failure mode 1: Yielding of rods

For the yielding of the rods, the required total rod area is calculated below, leading to a required amount of rods. This is done per load ($N_{Ed}$, $M_{y,Ed}$, $M_{z,Ed}$), so that the rods can be properly placed. The placement of the rods can be seen in Figure E.17. The calculations are shown below.

$$A_{sr,rqd,N} = \frac{N_{Ed}}{f_{yd,r}} = 3164.80\ mm^2 \quad \text{(E.40)}$$

$$n_{rods,rqd,N} = \frac{A_{s,rqd,N}}{A_{sr}} = 7 \quad \text{(E.41)}$$

$$z_{My} = \frac{h_{cb}}{2} - p_{2,rods} = 250\ mm \quad \text{(E.42)}$$

$$A_{sr,rqd,My} = \frac{M_{y,Ed}}{f_{yd,r} z_{My}} = 2793.46\ mm^2 \quad \text{(E.43)}$$

$$n_{rods,rqd,My} = \frac{A_{sr,rqd,My}}{A_{sr}} = 6 \quad \text{(E.44)}$$

$$z_{Mz} = \frac{b_{cb}}{2} - c_{c,sides} - \frac{d_r}{2} = 948\ mm \quad \text{(E.45)}$$

$$A_{sr,rqd,Mz} = \frac{M_{z,Ed}}{f_{yd,r} z_{Mz}} = 766.67\ mm^2 \quad \text{(E.46)}$$

$$n_{rods,rqd,Mz} = \frac{A_{sr,rqd,Mz}}{A_{sr}} = 2 \quad \text{(E.47)}$$

$$A_{sr,rqd,total} = A_{sr,rqd,N} + A_{sr,rqd,My} + A_{sr,rqd,Mz} = 7491.59\ mm^2 \quad \text{(E.48)}$$

$$n_{rods,tot} = n_{rods,rqd,N} + n_{rods,rqd,My} + n_{rods,rqd,Mz} = 15 \quad \text{(E.49)}$$

$$U.C. = \frac{A_{sr,rqd,total}}{n_{rods,tot} A_{sr}} = 0.95 \quad \text{(E.50)}$$

For the second failure mode, the bond strength between the concrete and the rod should be checked. This is to ensure that the rods in tension are not pulled out of the concrete as can be seen in Figure E.27. According to EN 1992-1-1, the required bond length of the rods ($l_{b,rqd}$) should be checked for this [39]. Furthermore, the spacing of the rods should be checked. The minimal spacing ($s_{rods,min}$) is calculated according to EN-ISO 17660-1 [62].

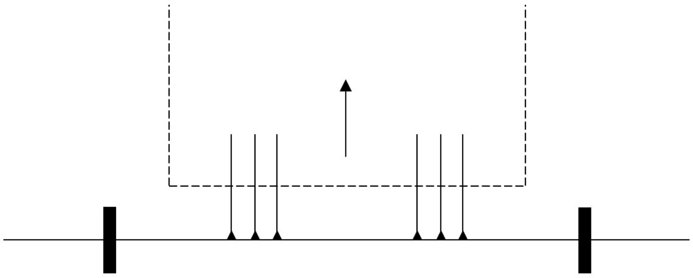



**Figure E.27:** Failure mode 2: Bond strength

The design axial tensile strength of the concrete ($f_{ctd}$) is calculated below, based on the factor ($\alpha_{ct}$).With this, the ultimate bond stress ($f_{bd}$) is calculated, which is dependent on the $\eta$ factors. The factor $\eta_1$, depends of the conditions of the bond. As there are rods in the upper 300 mm of the rib plate, the bond conditions cannot be seen as good. $\eta_2$ is a factor related to the diameter of the rod.

$$\alpha_{ct} = 1 \tag{E.51}$$

$$f_{ctd} = \alpha_{ct} f_{ctk,0.05}/\gamma_c = 1.47\ MPa \tag{E.52}$$

$$\begin{aligned} &\eta_1 = 0.7 \text{ for all other than good bond conditions} \\ &\eta_2 = 1 \text{ for } d_r < 32mm \end{aligned} \tag{E.53}$$

$$f_{bd} = 2.25\eta_1\eta_2 f_{ctd} = 2.31\ MPa \tag{E.54}$$

This gives the following required bond length.

$$l_{b,rqd} = \frac{d_{rod}}{4}\frac{f_{yd,r}}{f_{bd}} = 1176.36\ mm \tag{E.55}$$

$$l_{b,applied} = 1200\ mm \tag{E.56}$$

The minimal spacing of the rods is calculated.

$$s_{rods,min} = 3d_{rod} = 75\ mm \tag{E.57}$$

$$U.C._{bondlength} = \frac{l_{b,rqd}}{l_{br}} = 0.98 \tag{E.58}$$

$$U.C._{horizontalspacing} = \frac{s_{rods,min}}{p_{1,rods}} = 0.75 \tag{E.59}$$

$$U.C._{verticalspacing} = \frac{s_{rods,min}}{p_{2,rods}} = 0.30 \tag{E.60}$$

The third failure mode, failure of the welds, should be checked according to EN-ISO 17660-1 [62]. Weld failure is illustrated in Figure E.28. By calculating full strength welds, the load transfer from the end plates to the rods is ensured. This is done below.

Because the rod diameter is within the range of $6 \leq d_{rod} \leq 50mm$ and the end plate thickness agrees with $t_p \geq 4mm$, the throat thickness of the butt weld ($a$), as indicated in Figure E.29, connecting the rods to the end plate that is determined below will give full load-bearing capacity of the bar.

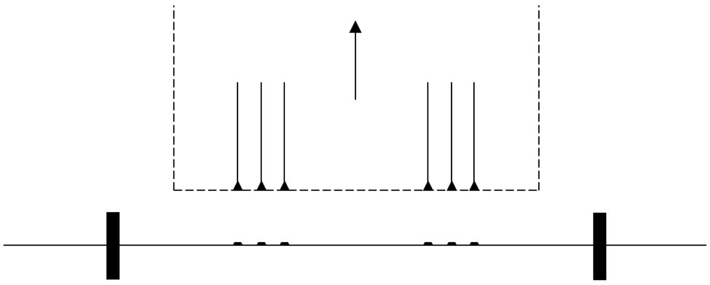



**Figure E.28:** Failure mode 3: Welds

$$a = 0.4d = 10mm \leq t_p \tag{E.61}$$

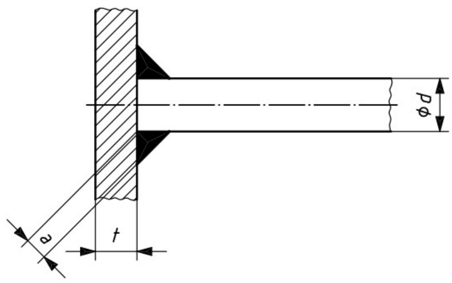



**Figure E.29:** Dimensions of weld [62]

**Calculation verification**

To verify the above performed calculations, the component method is used according to EN 1993-1-8 [56]. In this method, the components of the connection are modelled as springs with a certain stiffness. Based on the effective stiffness of the components together, it can be determined if the joint is rigid, semi-rigid or nominally pinned. To do this, the initial rotational stiffness ($S_{j,ini}$) of the connection is compared to the classification boundary, as in Equation E.78.

According to NEN-EN 1993-1-8, the stiffnesses that have to be taken into account for rib plate splices are the end plates in bending ($k_5$) and the bolts in tension ($k_{10}$). However, for this connection, also the rods in tension have to be taken into account. This can be done by the component of anchor bolts in tension ($k_{16}$), in which the anchor bolts represent the rods. They can be compared, as anchor bolts are also connecting a steel plate to a concrete element. The stiffness of bolts and rods that are not in tension can be assumed to be infinitely large, so they do not have to be taken into account in the stiffness calculations. The stiffness of the connection in visualised in Figure E.30. The stiffness of each component is calculated below.

$$k_5 = \frac{0.9 l_{eff} t_p^3}{m^3} = 27.66\ mm \tag{E.62}$$

$$k_{10} = \frac{1.6 A_s}{L_b} = 16.76\ mm \tag{E.63}$$

$$k_{16} = \frac{2A_s}{L_{b,rod}} = \frac{2A_s}{8d_r} = 4.91\ mm \tag{E.64}$$

The interaction of the different components, as shown in Figure E.30, is determined by the effective stiffness ($k_{eff}$) of each bolt and rod row. The distance from each rod to the centre of compression ($h_{ri}$),is calculated as well. Also the equivalent lever arm ($z_{eq}$) and the equivalent stiffness coefficient ($k_{eq}$) are calculated. Based on those values, the initial rotational stiffness of the connection is determined.

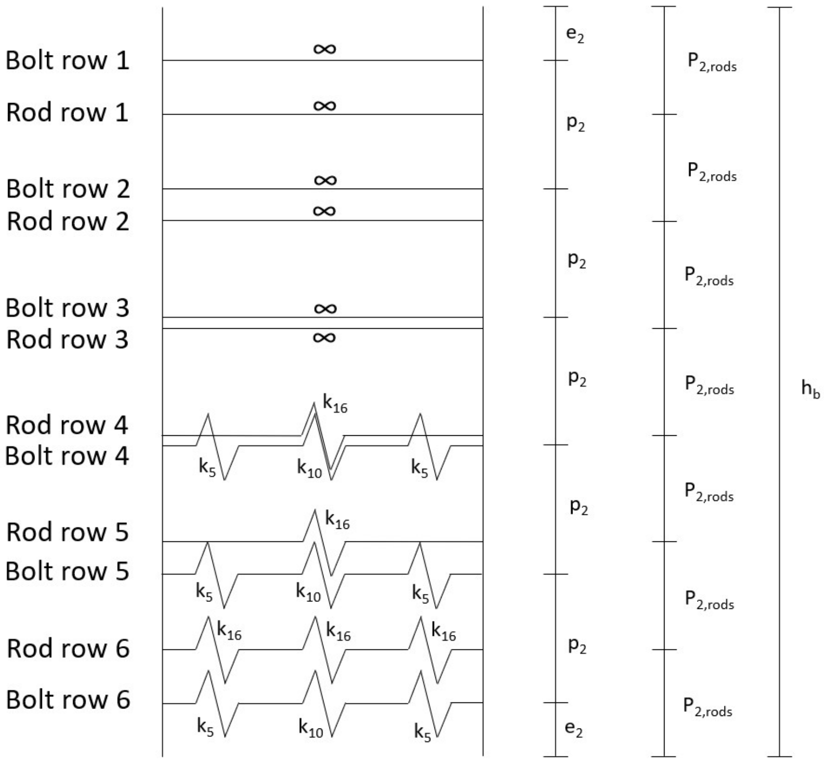



**Figure E.30:** Stiffness of the connection

$$k_{eff,b1} = k_{eff,b2} = k_{eff,b3} = \infty \tag{E.65}$$

$$k_{eff,b4} = k_{eff,b5} = k_{eff,b6} = \frac{1}{\frac{1}{k_5} + \frac{1}{k_{10}} + \frac{1}{k_5}} = 7.58\ mm \tag{E.66}$$

$$k_{eff,r1} = k_{eff,r2} = k_{eff,r3} = \infty \tag{E.67}$$

$$k_{eff,r4} = k_{eff,r5} == \frac{1}{\frac{1}{k_{16}}} = 4.91\ mm \tag{E.68}$$

$$k_{eff,r6} = \frac{1}{\frac{1}{k_{16}} + \frac{1}{k_{16}} + \frac{1}{k_{16}}} = 1.64\ mm \tag{E.69}$$

$$\begin{aligned} h_{by1} &= -c_{c,top} + x_{uy} = 11.11\ mm \\ h_{by2} &= c_{c,top} + p_{2,rods} - x_{uy} = 88.89\ mm \\ h_{by3} &= c_{c,top} + 2p_{2,rods} - x_{uy} = 188.89\ mm \\ h_{by4} &= c_{c,top} + 3p_{2,rods} - x_{uy} = 288.89\ mm \\ h_{by5} &= c_{c,top} + 4p_{2,rods} - x_{uy} = 388.89\ mm \\ h_{by6} &= c_{c,top} + 5p_{2,rods} - x_{uy} = 488.89\ mm \end{aligned} \tag{E.70}$$

$$z_{eq} = \frac{\sum k_{eff,bi} h_{byi}^2 + \sum k_{eff,ri} h_{ri}^2}{\sum k_{eff,bi} h_{byi} + \sum k_{eff,ri} h_{ri}} = 386.77\ mm^2 \tag{E.71}$$

$$k_{eq} = \frac{\sum k_{eff,bi} h_{byi} + \sum k_{eff,ri} h_{ri}}{z_{eq}} = 32.77\ mm \tag{E.72}$$

$$S_{j,ini} = \frac{E_s z_{eq}^2}{\frac{1}{k_{eq}}} = 1030.52\ MNm/rad \tag{E.73}$$

For the comparison of the connection stiffness and the classification boundary, a factor taking into account possible bracing of the frame ($k_b$), the second moment of area of the rib plate ($I_b$) and the span of the rib plate ($L_b$) are determined below. If the initial stiffness ($S_{j,ini}$) is greater than the boundary of $\frac{k_b E_c I_b}{L_{ribplate}}$, the connection is considered rigid. If the initial stiffness is smaller than the boundary $\frac{0.5 E_c I_b}{L_{ribplate}}$, the connection can be considered hinged. For results in between these boundaries, the connection is semi-rigid.

$$k_b = 25 \text{ for unbraced frames} \tag{E.74}$$

$$I_b = \frac{1}{12} b h^3 = 5.72 \cdot 10^1 0\ mm^4 \tag{E.75}$$

$$L_{ribplate,short} = min(12500; 23000) = 12500\ mm \tag{E.76}$$

$$L_{ribplate,long} = max(12500; 23000) = 23000\ mm \tag{E.77}$$

$$\frac{0.5 E_c I_b}{L_{ribplate,long}} = 14.08\ MNm/rad \leq S_{j,ini} = 1030.52\ MNm/rad \leq \frac{k_b E_c I_b}{L_{ribplate,short}} = 1295.74\ MNm/rad \tag{E.78}$$

As can be seen in Equation E.78, the stiffness of the connection lies between the boundary for hinged connections and for rigid connections. This means that the connection is semi-rigid.

### E.3.2. Rib plate to deck plate connections

The rib plate to deck plate connection has to transfer a normal force, shear force and a bending moment. For this connection, a similar approach is suggested as that of the dry rib plate to rib plate connection. In this case, a haunch is suggested that can be placed per a certain distance over the length of the rib plate. This concept is shown in Figure E.31. The proposed variant can be placed each meter. The haunch consists of steel plates with a thickness of 15 mm. The legs of the haunch are 300 mm wide and 500 mm long. One leg of the haunch will be welded onto rods that will be placed in the deck plate. The other leg will be connected to a plate of the same size with six M27 10.9 bolts with oversized bolt holes. The plate is welded to rods in the rib plate. Seventeen rods of 8 mm diameter and B500B steel will be placed in the deck plate and five rods of 20 mm diameter in the rib plate.

The calculation of the joint is based on the same principle as the dry rigid rib plate to rib plate connection. An additional failure mechanism is buckling of the haunch. If necessary, the buckling resistance of the haunch can be increased by welding an additional steel plate onto the hypotenuse of the haunch, functioning as a flange. As holds for the rib plate to rib plate variant as well, these connections are done to provide an estimation of the possibilities of the connection type. More knowledge should be gained before applying this type. This connection is assumed to be rigid and thus to provide full continuity.

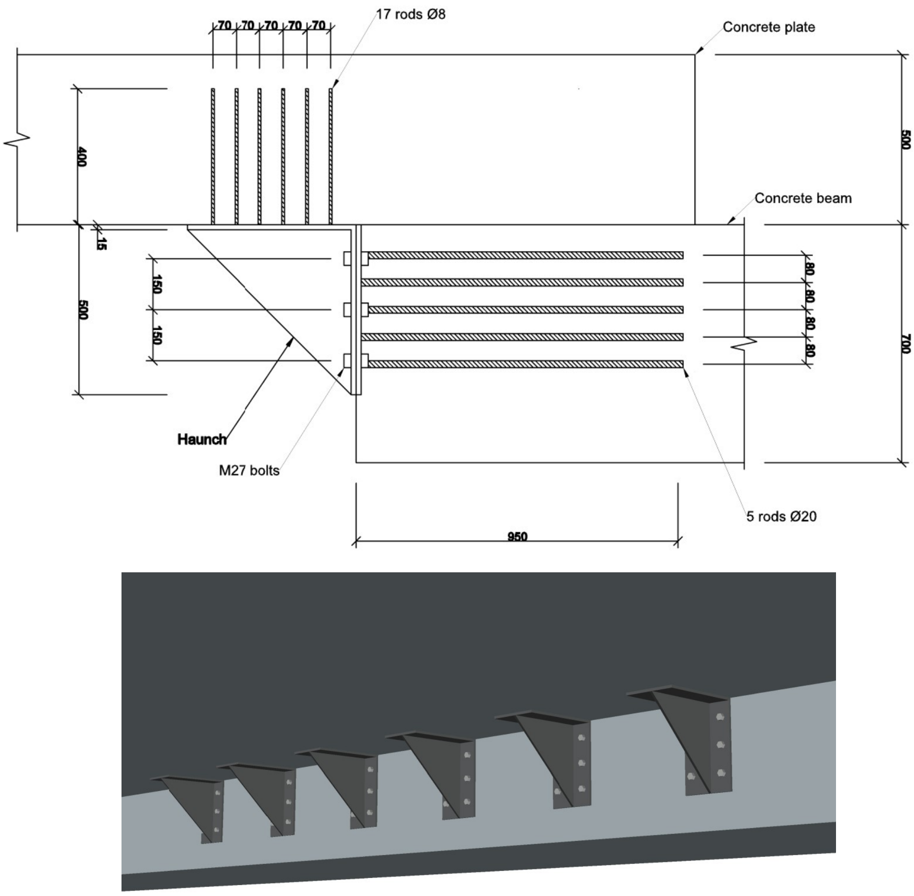



**Figure E.31:** Rigid beam to plate connection

**Calculations**

For the rigid dry connection between the rib plate and the deck plate, a steel haunch is used, as is also used in the steel industry. The steel and concrete properties are similar to the ones used in the rib plate to rib plate dry connection and are stated in Table E.1 and E.2. For the connectors, M27 10.9 bolts are used with oversized boltholes.

The connection should transfer the loads per meter given in Table E.5. The calculations are performed similar to the calculation of the rigid rib plate to rib plate dry connection. The results are given below.

**Table E.5:** Governing loads on rib plate to deck plate connection per meter

| Load type | Symbol | Value | Unit |
|---|---|---|---|
| Design normal force | $N_{Ed}$ | 76 | $kN$ |
| Design shear force | $V_{Ed}$ | 161 | $kN$ |
| Design bending moment in y-direction | $M_{Ed}$ | 77 | $kNm$ |

**Eurocode applicability checks**

$$\begin{aligned} e_1 &= 50\ mm \geq 1.2d_0 = 42\ mm \\ e_2 &= 100\ mm \geq 1.2d_0 = 42\ mm \\ p_2 &= 150\ mm \geq 2.4d_0 = 84\ mm \end{aligned} \tag{E.79}$$

$$t_p = 15\ mm \leq 0.36d\sqrt{f_{ub}/f_y} = 20.05\ mm \tag{E.80}$$

$$L_b = 2t_p + t_{washer} + \frac{t_{head} + t_{nut}}{2} = 49.50\ mm$$
$$L_b \leq \frac{8.8m^3 A_s}{\sum l_{eff,1} t_p^3} = 1468.42\ mm \text{, so prying forces may develop} \tag{E.81}$$

**Failure mechanism 1: Resistance of bolts in tension**

$$\sum l_{eff,cp} = min(2\pi m + 4p_2; \pi m + 4p_2 + 2e_2; 4\pi m + 2p_2; 3\pi m + 2p_2 + 2e_2$$
$$6\pi m; 5\pi m + 2e_2) = 1085.72\ mm \tag{E.82}$$

$$\sum l_{eff,nc} = min(4m + 1.25e_1 + 2p_2; 2m + 0.625e_1 + 2p_2 + e_2;$$
$$8m + 2.5e_1 + p_2; 6m + 1.875e_1 + p_2 + e_2; 12m + 3.75e_1;$$
$$10m + 3.125e_1 + e_2) = 613.15\ mm \tag{E.83}$$

$$\sum l_{eff,1} = min(\sum l_{eff,cp}; \sum l_{eff,nc}) = 613.15\ mm$$
$$\sum l_{eff,2} = \sum l_{eff,nc} = 613.15\ mm \tag{E.84}$$

$$M_{pl,1,Rd} = 0.25 \sum l_{eff,1}\ t_p^2 f_{yp}/\gamma_{M0} = 8.11\ kNm \tag{E.85}$$

$$e_w = \frac{d_{washer}}{4} = 10.25\ mm \tag{E.86}$$

$$F_{T,1,Rd} = \frac{(8n - 2e_w)M_{pl,1,Rd}}{2nm - e_w(m+n)} = 402.06\ kN \tag{E.87}$$

$$U.C._1 = \frac{N_{Ed}}{F_{T,1,Rd}} = 0.19 \tag{E.88}$$

$$M_{pl,2,Rd} = 0.25 \sum l_{eff,2}\ t_p^2 f_{yp}/\gamma_{M0} = 8105.05\ kNm \tag{E.89}$$

$$F_{T,2,Rd} = \frac{2M_{pl,2,Rd} + n \sum F_{t,Rd}}{m+n} = 532.35\ kN \tag{E.90}$$

$$U.C._2 = \frac{N_{Ed}}{F_{T,2,Rd}} = 0.15 \tag{E.91}$$

$$F_{T,3,Rd} = \sum F_{t,Rd} = 3529.44\ kN \tag{E.92}$$

$$U.C._3 = \frac{N_{Ed}}{F_{T,3,Rd}} = 0.02 \tag{E.93}$$

**Failure mechanism 2: Bending moment resistance**

$$\epsilon_{c3} = 1.75\ \text{‰}$$
$$\epsilon_{cu3} = 3.5\ \text{‰} \tag{E.94}$$

$$x_{uy} = (1 - \frac{\epsilon_{c3}}{\epsilon_{cu3}})h_{cb} = 250\ mm \tag{E.95}$$

$$\beta = \frac{7}{18} \tag{E.96}$$

$$C_{cy} = \beta x_{uy} = 97.22\ mm \tag{E.97}$$

$$h_{by1} = h_{cp} - x_{uy} + e_2 = 517.78\ mm$$
$$h_{by2} = h_{cp} - x_{uy} + e_2 + p_2 = 667.78\ mm \tag{E.98}$$
$$h_{by3} = h_{cp} - x_{uy} + e_2 + 2p_2 = 817.78\ mm$$

$$M_{y,Rd} = \sum_{i=1,2,3} F_{t,Rdi} h_{byi} = 2356.88\ kNm \tag{E.99}$$

$$U.C._{My} = \frac{M_{y,Ed}}{M_{y,Rd}} = 0.03 \tag{E.100}$$

**Failure mechanism 3: Resistance of bolts in shear**

$$F_{v,Rd} = \alpha_v f_{Ub} A_s / \gamma_{M2} = 183.6\ kN \tag{E.101}$$

$$U.C._{shear} = \frac{F_{v,Ed}}{F_{v,Rd}} + \frac{F_t, Ed}{1.4F_t, Rd} = 0.89 \tag{E.102}$$

$$k_1 = min(\frac{2.8e_2}{d_0} - 1.7; 2.5) = 2.5 \tag{E.103}$$

$$\alpha_{d,inner} = \frac{p_1}{3d_0} - \frac{1}{4} = 1.65 \tag{E.104}$$

$$\alpha_{d,end} = \frac{e_1}{3d_0} = 0.48 \tag{E.105}$$

$$\alpha_{b,inner} = min(\alpha_{d,inner}; \frac{f_{ub}}{f_{yp}}; 1.0) = 1 \tag{E.106}$$

$$\alpha_{b,end} = min(\alpha_{d,end}; \frac{f_{ub}}{f_{yp}}; 1.0) = 0.48 \tag{E.107}$$

$$F_{b,Rd,inner} = k_1 \alpha_{b,inner} f_u d_b t_p / \gamma_{M2} = 673.92\ kN \tag{E.108}$$

$$F_{b,Rd,end} = k_1 \alpha_{b,end} f_u d_b t_p / \gamma_{M2} = 320.91\ kN \tag{E.109}$$

$$F_{b,Rd,total} = 2(n_b - 1) F_{b,Rd,inner} + 2F_{b,Rd,outer} = 1668.75\ kN \tag{E.110}$$

$$U.C._{bearing} = \frac{V_{Ed}}{F_{b,Rd,total}} = 0.10 \tag{E.111}$$

**Failure mechanism 4: Resistance of rods in tension**

In the rib plate the following amount of rods is required.

$$A_{sr,rqd,N} = \frac{N_{Ed}}{f_{yd,r}} = 174.8\ mm^2 \tag{E.112}$$

$$n_{rods,rqd,N} = \frac{A_{s,rqd,N}}{A_{sr}} = 1 \tag{E.113}$$

$$z_{My} = h_{cp} - C_c + \frac{h_{bp}}{2} = 652.78\ mm \tag{E.114}$$

$$A_{sr,rqd,My} = \frac{M_{y,Ed}}{f_{yd,r} z_{My}} = 217.30\ mm^2 \tag{E.115}$$

$$n_{rods,rqd,My} = \frac{A_{sr,rqd,My}}{A_{sr}} = 1 \tag{E.116}$$

$$A_{sr,rqd,V} = \frac{V_{Ed}}{f_{yd,r}/\sqrt(3)} = 641.38\ mm^2 \tag{E.117}$$

$$n_{rods,rqd,V} = \frac{A_{sr,rqd,V}}{A_{sr}} = 3 \tag{E.118}$$

$$A_{sr,rqd,total} = A_{sr,rqd,N} + A_{sr,rqd,My} + A_{sr,rqd,V} = 1087.48\ mm^2 \tag{E.119}$$

$$n_{rods,tot} = n_{rods,rqd,N} + n_{rods,rqd,My} + n_{rods,rqd,V} = 5 \tag{E.120}$$

$$U.C. = \frac{A_{sr,rqd,total}}{n_{rods,tot}A_{sr}} = 0.69 \tag{E.121}$$

The checks for the rods in the deck plate are done below.

$$A_{sr,rqd,N} = \frac{N_{Ed}}{f_{yd,r}} = 174.8\ mm^2 \tag{E.122}$$

$$n_{rods,rqd,N} = \frac{A_{s,rqd,N}}{A_{sr}} = 4 \tag{E.123}$$

$$z_{My} = h_{cp} - C_c + \frac{h_{bp}}{2} = 652.78\ mm \tag{E.124}$$

$$A_{sr,rqd,V} = \frac{V_{Ed}}{f_{yd,r}/\sqrt(3)} = 641.38\ mm^2 \tag{E.125}$$

$$n_{rods,rqd,V} = \frac{A_{sr,rqd,V}}{A_{sr}} = 13 \tag{E.126}$$

$$A_{sr,rqd,total} = A_{sr,rqd,N} + A_{sr,rqd,V} = 816.18\ mm^2 \tag{E.127}$$

$$n_{rods,tot} = n_{rods,rqd,N} + n_{rods,rqd,V} = 17 \tag{E.128}$$

$$U.C. = \frac{A_{sr,rqd,total}}{n_{rods,tot}A_{sr}} = 0.96 \tag{E.129}$$

$$\alpha_{ct} = 1 \tag{E.130}$$

$$f_{ctd} = \alpha_{ct} f_{ctk,0.05}/\gamma_c = 1.47\ MPa \tag{E.131}$$

$\eta_1 = 0.7$ for all other than good bond conditions
$\eta_2 = 1$ for $d_r < 32mm$ (E.132)

$$f_{bd} = 2.25\eta_1\eta_2 f_{ctd} = 2.31\ MPa \tag{E.133}$$

The bond length for the rods in the rib plate is given below.

$$l_{b,rqd} = \frac{d_{rod}}{4}\frac{f_{yd,r}}{f_{bd}} = 941.09\ mm \tag{E.134}$$

$$l_{b,applied} = 950\ mm \tag{E.135}$$

$$s_{rods,min} = 3d_{rod} = 60\ mm \tag{E.136}$$

$$U.C._{bondlength} = \frac{l_{b,rqd}}{l_{br}} = 0.94 \tag{E.137}$$

$$U.C._{horizontalspacing} = \frac{s_{rods,min}}{p_{1,rods}} = 0.80 \tag{E.138}$$

$$U.C._{verticalspacing} = \frac{s_{rods,min}}{p_{2,rods}} = 0.40 \tag{E.139}$$

The bond length for the rods in the deck plate is given below.

$$l_{b,rqd} = \frac{d_{rod}}{4}\frac{f_{yd,r}}{f_{bd}} = 376.44\ mm \tag{E.140}$$

$$l_{b,applied} = 400\ mm \tag{E.141}$$

$$s_{rods,min} = 3d_{rod} = 24\ mm \tag{E.142}$$

$$U.C._{bondlength} = \frac{l_{b,rqd}}{l_{br}} = 0.94 \tag{E.143}$$

$$U.C._{horizontalspacing} = \frac{s_{rods,min}}{p_{1,rods}} = 1.00 \tag{E.144}$$

$$U.C._{verticalspacing} = \frac{s_{rods,min}}{p_{2,rods}} = 0.16 \tag{E.145}$$

The weld size of the rods in the rib plate is given here.

$$a = 0.4d = 8mm \leq t_p \tag{E.146}$$

The weld size of the rods in the deck plate is given below.

$$a = 0.4d = 3.2mm \leq t_p \tag{E.147}$$

## E.3.3. Assembly

The construction of the dry rigid connections consists of two parts, of which the first part is to make the prefabricated elements and the second part is the assembly of the elements on site. For the construction of the prefab rib plates, the steel end plates should be prepared before casting the concrete. Onto the end plates, all the rods should be welded. According to EN 10080, the chosen rods are suitable for welding. The same holds for the haunch that is connected to the deck plate. The weldability of reinforcement steel or rods depends on its chemical composition, in which the carbon equivalent and limitation on the content of certain elements are important [63]. The welding process should be executed according to EN-ISO 17660-1 [62]. This method is also applied in the execution of the reference jetty for the steel foundation to prefab rib plate connection, as described in Appendix C.3. When casting the prefab rib plate, the end plate and connected steel rods have to be placed. This is a familiar procedure, which was also applied in the reference jetty steel foundation to prefab rib plate connection.

The placement tolerance of the elements becomes smaller for the rigid connection variants than for the reference jetty. For the reference jetty, a horizontal placement tolerance of 50 mm was taken into account. However, in the DfD connection, the bolts should be placed, connecting two elements. To create a placement tolerance as large as possible, oversized boltholes are applied. The diameter of the bolt hole is 8 mm larger than the nominal bolt diameter. As the holes should be aligned from two sides, the placement tolerance of this connection is $\frac{8}{2} = 4\ mm$, which is considerably smaller than the current tolerance of 50 mm. As already discussed in Section E.1.1, this can creates a problem. These small tolerances can be realistic if the elements can be placed and connected to one side before the element on the other side is placed. However, for variant 1 the deck plates are supported by the rib plates on two sides, due to which the rib plates are both placed before placing the deck plate. For variant two the n-shaped elements are placed on both sides before the T-shaped element can be placed in between. Aligning the boltholes on two sides of the deck plate will be a challenge, as the rib plates and n-shaped elements are not realistically placed with this precision. The deck plate will have to be forced into place, creating initial stresses in the element. For variant 3, this is not expected to create a significant challenge, as the elements can be placed and connected on one side, before the to be connected element on the other side is placed. If the rib plate at the beginning is placed a few millimetres to one side, the entire row of elements will follow this and no initial stresses form in the elements.

### E.3.4. Maintenance

According to Wormmeester (Appendix A), this connection configuration is impractical in terms of maintenance. In the jetties that are currently part of the PoR asset, steel is protected for around ten years by the coating, while it is being monitored during this period as well. After approximately ten years, cathodic protection is used to minimise the corrosion of the steel. The cold connection between two steel plates that is suggested, is very hard to maintain, especially the part where the plates touch is not accessible to maintain but will corrode. In the chloride environment of the port, the steel will corrode easily. Using a coating as is applied to the steel foundation piles is only a solution that works for a limited amount of time.

The use of weathering steel was considered a solution. However, Wormmeester mentions that weathering steel is still sensitive to chloride. Only very expensive weathering steel types, such as a type with titanium alloy, will be suitable. However, those types of steel are extremely expensive, also to maintain.

A significant part of the steel connections will be below the deck, which is already hard to reach. Therefore, maintaining this connection solution in each of the design variants is not feasible and this connection type will not be accepted by PoR when it is proposed in a marine structure design. In agreement with Wormmeester, this connection solution is thus not considered to be realistic to apply in terms of maintenance.

## E.4. Semi-dry rigid connections

For the design of semi-dry rigid connections, the rib plate to rib plate and rib plate to deck plate connections of variant 1 are taken as a reference. As mentioned in Section 2.1.2, a tested product is available that allows for the connection of prefabricated elements and is demountable. This connection, made by Peikko, is a semi-dry connection that makes use of a shoe, anchor bolts and a grout protection layer [35][64]. An element, as shown in Figure 2.2, can be used to connect prefabricated concrete elements. In Figure E.32, the execution of this connection is shown. In each corner of the to be connected surfaces, a shoe will be placed in one element and an anchor bolt at the corresponding position of the other element. Shoes can also be placed on the surface edge of the first element and the anchor bolt can be placed anywhere in the corresponding surface of the second element [35]. The shoe and anchor bolts are placed in the casting of the concrete before pouring, whereby it forms a bond with the concrete when it hardens. The grout layer of concrete has to be added in situ to protect the steel elements. This layer also fills the corner notches that are left open for assembly [64].

As the shoes can be placed anywhere on element edges and the anchor bolt anywhere on the corresponding surface, this connection can be made in all rigid connections that were made in the three reusable design variants.

To estimate if the connections are applicable on the scale of the jetty elements and to estimate the number of connectors needed, basic calculations are made based on the resistance of the connection product given by Peikko [35]. This is done for the rib plate to rib plate and rib plate to deck plate connections of variant 1. It can be seen that the configuration is designed to take loads in the right order of magnitude. To be able to use this connection, it should be calculated using the Peikko Designer software. The configuration is tested for moment resistant connections and thus this connection type can be assumed to be rigid. In total, four connectors will be used in each rib plate to rib plate connection, and each 0.9 m a connector will be placed on each side of the rib plate for the rib plate to deck plate connection, which leads to a total number of $\frac{48}{0.9} = 54\ connectors$ needed on each long side of the rib plate.

### E.4.1. Calculation

The loads that work on the connection are given in Table E.4. In each corner of the to be connected surfaces, a shoe and anchor bolt will be placed. The tensile force is taken by the tensile resistance of the four applied shoes and anchor bolts together, which also holds for the shear force. The moments create a tensile force in two of the shoes and bolts, which should be added to the tensile force that is taken by these. This creates the governing tension load ($N_{Ed,governing}$). The calculations are done below.

$$N_{Ed,governing} = \frac{N_{Ed}}{4} + \frac{\frac{h_{cb}}{2} M_{y,Ed}}{2} + \frac{\frac{b_{cb}}{2} M_{z,Ed}}{2} = 797.23kN \quad \text{(E.148)}$$

The beam shoe that is chosen is the BECO 52, with which anchor bolts COPRA 52 are used. Those have a design tensile resistance of $N_{Rd} = 938\ kN$ and a design shear resistance of $V_{Rd} = 219\ kN$ [65]. This leads to the following unity checks.

$$UC_N = \frac{N_{Ed,governing}}{N_{Rd}} = 0.95 \quad \text{(E.149)}$$

$$UC_V = \frac{V_{Ed}}{V_{Rd}} = 0.46 \quad \text{(E.150)}$$

A similar approach is applied for calculating the amount of connectors needed per meter for the rib plate to deck plate connections. The loads are given in Table E.5.

$$N_{Ed,governing} = 1M_{Ed} = 77\ kN/m \quad \text{(E.151)}$$

$$V_{Ed,governing} = V_{Ed} + N_{Ed} = 237\ kN/m \quad \text{(E.152)}$$

With the BECO52 shoe and COPRA 52 anchor bolts, the amount of connectors per meter becomes the following.

$$n_{connectors,req} = max(\frac{V_{Ed,governing}}{V_{Rd}}; \frac{N_{Ed,governing}}{N_{Rd}} = 1.08 \text{ connectors per meter} \quad \text{(E.153)}$$

This means that each 0.9 m, a connector should be placed. As a result, a total amount of 54 connectors will be placed per side of the each deck plate.

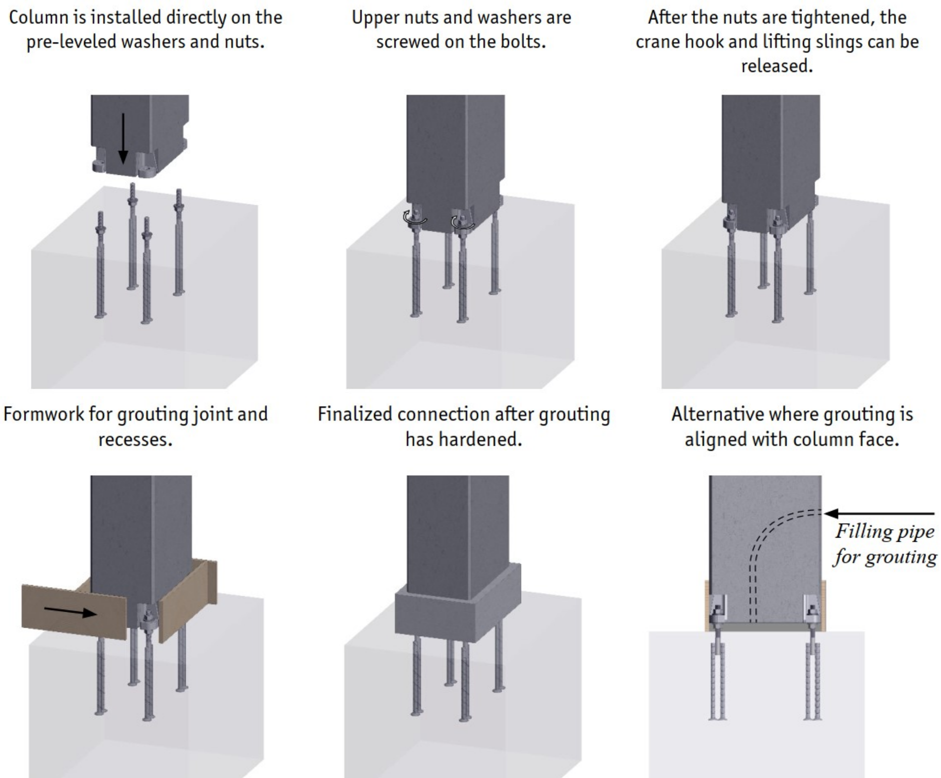



**Figure E.32:** Execution semi-dry connection [35]

### E.4.2. Assembly

The assembly of the semi-dry rigid connections is very similar to that of the dry rigid connections as discussed in Section E.3.3. As for the dry rigid connection, the steel elements should be placed in the mold before the concrete is poured. On site, the steel elements are connected. However, as the bolt is already a part of the prefabricated element, the elements should be placed in the direction of the bolts to allow the boltholes to fit over the bolts, so that a nut can connect the elements. However, this is expected to cause a problem for the shear connections that are discussed in each design variant, as the placement of the concrete elements should be done from above, as is discussed in Section 4.1, and the bolts are placed horizontally in the ribs. To solve this, a combination of the dry connection discussed in Section 5.2 and the Peikko solution is suggested. By combining the dapped end of the simple dry connection and using this to create room to place the shoe and anchor bolts vertically, a rigid semi-dry connection is created that allows for vertical placement of the elements. This solution requires further calculations, but is expected to be a realistic approach in terms of load transfer and assembly.

After connecting the elements with the nuts, a casting should be made and the grout should be poured. This grout should dry before it can take loads. During this drying time, the connections should thus be unloaded, which can delay the further assembly procedure.

For the semi-dry rigid connection, the placement tolerances are 2 mm [35]. This is smaller than the originally used 50 mm. As is explained in Section E.3.3, this is likely to cause problems for variants 1 and 2, as one element will have to be connected to two elements that are already placed on the opposite sides. This creates a placement tolerance of the two previously places elements of $\frac{2}{2} = 1\ mm$, which is expected to be a problematic small tolerance. For variant 3, this can be a realistic tolerance, due to the placement order of the elements.

### E.4.3. Maintenance

Although this connection also uses a significant amount of steel, Wormmeester (Appendix A) can not think of problems that would arise when maintaining a structure with this type of connection. The material that is used as a protection in this configuration is grout, which is also taking forces. However, with an eye on maintenance, the material that is used can be different. Either a grout or a plastic material is applicable.

## E.5. Variant comparison

Each of the design variants can be made with only rigid connections and in a simpler configuration. Each of those connection types was worked out in Chapter 5, in which both dry and semi-dry connections were explored. Not each connection type was possible in a dry or semi-dry configuration, as is shown in Table 4.1. For the variant comparison, it is chosen to not include the rigid dry connection configuration as is described in Section E.3, as this is already stated to be practically unfeasible to maintain and will thus not be considered a realistic solution. The other solutions presented in Chapter 5 will be considered in each variant, from which a most realistic solution is chosen for further study.

When considering the semi-dry rigid, dry shear and semi-dry hinged connections, each variant has two solutions. A is shown in Table E.6, this is a rigid and simple solution, of which the simple solution of variant 1 does require one connection type to be rigid.

**Table E.6:** Variants for comparison

| | Deck plate to deck plate | Field rib plate to deck 7plate | Edge rib plate to deck plate | Rib plate to rib plate |
|---|---|---|---|---|
| Variant 1 rigid | Semi-dry rigid | Semi-dry rigid | Semi-dry rigid | Semi-dry rigid |
| Variant 1 simple | None | Semi-dry hinged | Semi-dry rigid | Dry shear |

| | n-shaped element to n-shaped element | T-shaped element to T-shaped element | T-shaped element to n-shaped element |
|---|---|---|---|
| Variant 2 rigid | Semi-dry rigid | Semi-dry rigid | Semi-dry rigid |
| Variant 2 simple | Dry shear | Dry shear | Semi-dry hinged |

| | Sides of elements | Back side of element to front side or rib plate |
|---|---|---|
| Variant 3 rigid | Semi-dry rigid | Semi-dry rigid |
| Variant 3 simple | Dry shear | Semi-dry hinged |

The DfD requirements, mentioned in Section 2.1, are used to compare the six variants. For each requirement, it is stated to what extent the requirement is met in the variant that is discussed. DfD requirement 13 to 16 are not considered, as mentioned in Section 2.1. Requirements 1 to 5 focus on the global design of the DfD structure. Requirement 5 is not considered especially in this research, as mentioned in Section 4.1. Therefore, only requirements 1 to 4 are considered for the global design, these are treated per variant. Requirements 6 to 12 are treated per variant with the connection solution.

## E.5.1. Variant 1

1. *Minimise the number of different types of components to reduce the number of different disassembly procedures*: A total of 47 prefab concrete components of four different sizes are needed in this variant. The different types can be reduced to two when a modular variant is made. This number is high compared to variants 2 and 3, but is still manageable as it is comparable to the number of elements needed in the reference jetty;
2. *Make components sized to suit the means of handling*: The components are all placeable with the regular crane operating from the water. This means all components are a convenient size for the (dis)assembly of the structure;
3. *Use a standard structural grid to optimise material use and obtain components in standard sizes*: This variant can be made modular. After additional research on other jetty dimensions, this can be made in a standard structural grid especially for jetty platforms, due to which the elements can make up the approximate dimensions of each jetty for the port of Rotterdam. The modular variant can be expanded to each side. However, when making a single module stable in itself, there is no simple connection solution, disagreeing with requirement 10;
4. *Use prefabrication and mass production to reduce site work and ease the (dis)assembly process*: All elements are prefabricated. Only small amounts of in situ concrete are needed in the form of a grout layer to protect the steel shoe and bolts, making this a semi-dry connection. This can be considered demountable, but makes disassembly a little harder than when a dry connection would be needed.

**Rigid**

6. *Use mechanical connections rather than chemical ones to allow easy separation of components*: An amount of chemical connections is used in the in situ grout. This grout does take loads, which is why a plastic solution is not considered. This is the only chemical connection that is used in this variant, making it sufficient but not ideal;
7. *Design to use common tools and equipment and avoid specialist plant*: The largest challenge of the semi-dry solution is to include the bolts and shoes in the prefabricated element. This is done in the factory, where sufficient specialist knowledge is assumed to be present. In the reference variant, a steel plate and rods are included in the prefab element which raises no concerns for the construction, supporting this assumption. Mounting the bolts on sight is a familiar procedure

in the construction industry and thus it is expected that this will require only common tools and equipment;

8. *Provide access to all parts and connection points*: The connection in the rib plates will be easily accessible for mounting, as they can be placed and connected before putting the deck plates on top. For the connection of the deck plates, the nuts will have to be tightened from below, which is not as easy to access, while a large amount of the bolts are placed underneath the deck plates. This is expected to increase the difficulty of (dis)assembly;
9. *Provide realistic tolerances for (dis)assembly, which may be larger than tolerances for only one-time assembly*: The placement tolerance of the semi-dry solution is only 2 mm. This is expected to raise large problems, as the deck plates will have to be placed on the rib plates precisely at the two opposite sides. This makes the placement tolerances of the rib plates only 1 mm, which is assumed to be unrealistic;
10. *Use a minimum number of connectors to reduce the complexity of (dis)assembly*: Although the number of different connection types is very small, the number of connectors to be installed during assembly is large. Although (dis)assembly is possible, it becomes more complex. A total of $54 \cdot 5 \cdot 2 = 540\ connectors$ in the rib plate to deck plate connections alone. The largest beam shoe and anchor bolts that are available by Peikko are chosen, so this number cannot be decreased significantly;
11. *Use a minimum number of different types of connectors to reduce the complexity of (dis)assembly*: The amount of different connections in this variant is only one, as beam shoes and anchor bolts will be used between all elements. However, in this connection two actions are needed, which are tightening the bolts and casting and pouring the concrete grout;
12. *Design joints and components to withstand repeated use*: The joints and components are tested products on which sufficient knowledge exists. They should be designed for a sufficiently long lifetime, but (dis)assembly in itself should not cause problems for repeated use. However, in this variant the possibility of damaging the components and connections during disassembly is increased, due to the use of in situ concrete that has to be removed. It is believed that this is feasible, but not ideal.

**simple**

6. *Use mechanical connections rather than chemical ones to allow easy separation of components*: The shear connection will not require any chemical bonds. However, both the hinged and the rigid connection between the rib plates and deck plates, do need a protection material to close the steel off from the environment. In the rigid connection, the protection layer is loaded, so it has to be a concrete grout, which is also the cased for part of the hinged connection. The protection needed on top of the nut can also be a plastic material. The preference can be decided at a later stage;
7. *Design to use common tools and equipment and avoid specialist plant*: The only connection assembly that has to take place on sight is tightening the nuts and applying the protection layer both in the hinged and the rigid connection. This is a familiar procedure and is not expected to raise any problems. Constructing the steel parts in the prefabricated concrete is done in the factory, which is also familiar and thus does not raise any concerns;
8. *Provide access to all parts and connection points*: The hinged connections can be made from the top of the deck, as the bolts will stick through the deck plate. The rigid connections are made from the bottom of the deck plates, which are harder to access. However, as only the edge rib plates will be rigidly connected, the number of connections that are not easily accessed decreases;
9. *Provide realistic tolerances for (dis)assembly, which may be larger than tolerances for only one-time assembly*: Although the hinged connections provide a larger placement tolerance compared to the rigid connection, still the deck plates will have to be connected from two sides to the rib plates. The placement tolerance for the rib plates becomes $\frac{33}{2} = 16.5\ mm$. Although this is considerably larger than for the rigid connection, it is still assumed that force is needed to place the elements, creating initial stressed;
10. *Use a minimum number of connectors to reduce the complexity of (dis)assembly*: The number of connectors remains large, as there are bolts both in the hinged and rigid connections. However, the total number of bolts that need assembly decreases compared to the rigid variant;

11. *Use a minimum number of different types of connectors to reduce the complexity of (dis)assembly*: Different types of connections are the hinged and the rigid rib plate to deck plate connections. Tightening the nuts in both types is a similar procedure. The grout that has to be placed in the rigid connection also requires a casting, where the grout or plastic protection layer in the hinged connection can be poured into the prefab created hole. The shear rib plate to rib plate connection does not require any assembly after placement and thus is not considered to add to the complexity of (dis)assembly;
12. *Design joints and components to withstand repeated use*: As for disassembly, the concrete grout layer has to be removed by destroying it. This increases the risk of damaging the components during disassembly, which makes it not ideal.

### E.5.2. Variant 2

1. *Minimise the number of different types of components to reduce the number of different disassembly procedures*: Two different element types make up the deck of this variant. In total, 18 elements are needed. This is a small number compared to the reference variant. This eases the (dis)assembly procedure and creates an easy overview. However, a large number of foundation piles is needed for this variant, making it less easy to assembly;
2. *Make components sized to suit the means of handling*: All components are too heavy to be carried by a crane that is regularly used. The use of a large crane solves this problem, but that does decrease the ease of handling;
3. *Use a standard structural grid to optimise material use and obtain components in standard sizes*: By creating a modular variant, a standard structural grid for jetties can be made. This variant is easily made modular and each module can be made in either a fully rigid or a fully simple configuration. The deck will be expandable to all sides, but the step to expand in the length direction is rather large;
4. *Use prefabrication and mass production to reduce site work and ease the (dis)assembly process*: All elements are made prefabricated, except for the protection layer around the steel that is needed both in the rigid and the hinged connections. It is inevitable to make these prefabricated, as they are meant to close the to be tightened steel parts off from the environment. This procedure is needed in both the rigid and simple variants.

**Rigid**

The rigid connections will be made similar to that of rigid variant 1, namely with the use of the semi-dry connections as made by Peikko. Therefore, some DfD requirements regarding the connections will be similar. Requirements 6, 7, 9, 11 and 12 will not change for this variant and thus are not elaborated again. The explanation for these requirements can be found in the elaboration of the rigid type described in Section E.5.1.

8. *Provide access to all parts and connection points*: Some of the connections will remain to be below the deck. However, the number of connections here is much smaller. Furthermore, the elements can be connected before placing all the elements to the side at once. Therefore, a smaller distance has to be bridged to reach the connections from underneath, which makes the connections somewhat more accessible;
10. *Use a minimum number of connectors to reduce the complexity of (dis)assembly*: The amount of connectors needed is considered to be significantly larger, as the plates are stiffer and the deck is divided into fewer elements, creating fewer element edges to be connected.

**simple**

6. *Use mechanical connections rather than chemical ones to allow easy separation of components*: The use of a chemical connection is only applied in the hinged connection and only serves to close off the steel elements from the environment. The use of this chemical connection does thus not raise critical concerns;
7. *Design to use common tools and equipment and avoid specialist plant*: Both the procedures needed in the prefabrication factory and on site are common. This is including the steel products in the prefabricated concrete elements, assembling them on sight and pouring a protection material in the holes surrounding the bolts;

8. *Provide access to all parts and connection points*: Connections can all be made from above, as the anchor bolts will be sticking through the deck and can be tightened from there. There is no need to reach below the deck, which makes all connection points easily accessible;
9. *Provide realistic tolerances for (dis)assembly, which may be larger than tolerances for only one-time assembly*: The tolerances are increased a little compared to the rigid variant. However, it is still expected that this will cause problems, as the element should be connected at two opposite sides to two elements that are already placed. The placement tolerance of those already placed elements becomes 16.5 mm, which is too small to be realistic;
10. *Use a minimum number of connectors to reduce the complexity of (dis)assembly*: The amount of connectors used is small compared to the rigid options. This is because the anchor bolts do not need to transfer any moments. No other connectors are needed in the structure;
11. *Use a minimum number of different types of connectors to reduce the complexity of (dis)assembly*: The number of different connection types is limited to two, which are the shear rib-part to rib-part and the hinged n-shaped to T-shaped element connection. In those connections, only one connector type is used, namely the anchor bolts in the hinged connections. The other loads can be transferred by the prefab concrete shapes that fit together;
12. *Design joints and components to withstand repeated use*: The joints only need a disassembly procedure that is removing the protection material and detaching the bolts. The removal of the protection layer can be easier, as not necessarily a grout is used for this, but plastic alternatives can be applied instead.

## E.5.3. Variant 3

1. *Minimise the number of different types of components to reduce the number of different disassembly procedures*: A total of 20 elements form the deck of the jetty in this variant. There are four element types, which can be reduced to two when a modular variant is made. The number of elements is lower than in the reference jetty;
2. *Make components sized to suit the means of handling*: The components should be carried by a large crane. If desired, the rib plates can be placed with a regular crane. However, as the large crane is needed immediately at the next step of construction, it is expected that all elements will be placed with the large crane;
3. *Use a standard structural grid to optimise material use and obtain components in standard sizes*: The variant can be made into a modular one. The module can be stable on its own without using rigid connections. It is expandable in each direction;
4. *Use prefabrication and mass production to reduce site work and ease the (dis)assembly process*: All elements are prefabricated, including the shapes and materials to form the connections. Only the protection layer that will be poured has to be constructed on site. This will not any problems for assembly, as no casting is needed and only small amounts are needed in a limit number of places.

**Rigid**

The rigid connection type will be the same as is used in variants 1 and 2. As the use of these semi-dry bolted connections is similar, some DfD requirements will also be met similarly. Requirements 6, 7, 11 and 12 will not change compared to variant 1 and can be found at the elaboration of the rigid type described in Section E.5.1. Requirements 8 and 10 will not change compared to variant 2, which is why their elaboration can be found in the rigid part of Section E.5.2.

9. *Provide realistic tolerances for (dis)assembly, which may be larger than tolerances for only one-time assembly*: The tolerances during construction are 2 mm. As the elements can be placed and connected at one side at the time, this tolerance becomes realistic. High accuracy can be obtained in the prefabricated elements, which will ensure that they will fit onto each other. By allowing the exact location of the element to easily change with the location of the previously placed element, the placement tolerances become realistic to apply.

**simple**

For the simple connections of variant 3, most DfD requirements do not change compared to the simple type of variant 2. DfD requirement 6, 7, 8, 10, 11 and 12 can be found in the simple part of Section E.5.2.

9. *Provide realistic tolerances for (dis)assembly, which may be larger than tolerances for only one-time assembly*: As explained in the rigid part of this section, the placement tolerances are realistic, because of the placement sequence of the elements. Furthermore, the hinged connection also allows for a larger total placement tolerance of 33 mm.

### E.5.4. Multi criteria analysis

To choose between the variants, a multi criteria analysis is performed. This is done for the DfD requirements and the scores are based on the descriptions above. For each requirement, each variant is given a score from 1 to 5, representing how well the requirement is met. In this, 1 means poor and 5 means excellent. The result is given in Table E.7.

It is not unexpected that all rigid configurations score lower than the simple configuration of the same variant. Variant 1 overall has the lowest score, after which the rigid version of variant 2 is very close. Variant 3 has the best rigid and simple configurations. It can be concluded that the simple configuration of variant 3 is most compatible. This solution has the overall highest score. The rigid solution for variant 3 and the simple configuration of variant 2 are the only solutions to come somewhat close to this score. However, simple variant 3 scores higher or the same in each requirement, so no compromises are made when comparing these three solutions. When also comparing the other solutions, only one compromise is made, which is that the elements are too heavy for a regular crane and thus a larger crane is needed for (dis)assembly. As those cranes are constantly present in the port of Rotterdam, this is not considered critical. However, this compromise should be noted.

Notably, the difference between the scores of the configurations is led by the connection types. With a score of requirements 1 to 4 for variants 1 to 3 of 14, 12 and 14, barely any difference is made. The most important differences in scores are made with DfD requirement 8, 9, 10 and 11.

**Table E.7:** Multi criteria analysis

| Requirement | Variant 1 | | Variant 2 | | Variant 3 | |
|---|---|---|---|---|---|---|
| | Rigid | simple | Rigid | simple | Rigid | simple |
| 1 | 3 | | 3 | | 5 | |
| 2 | 5 | | 2 | | 2 | |
| 3 | 3 | | 4 | | 4 | |
| 4 | 3 | | 3 | | 3 | |
| 6 | 3 | 3 | 3 | 4 | 3 | 4 |
| 7 | 5 | 5 | 5 | 5 | 5 | 5 |
| 8 | 2 | 3 | 3 | 5 | 3 | 5 |
| 9 | 1 | 1 | 1 | 1 | 4 | 4 |
| 10 | 1 | 2 | 4 | 5 | 4 | 5 |
| 11 | 4 | 3 | 4 | 5 | 4 | 5 |
| 12 | 3 | 3 | 3 | 4 | 3 | 4 |
| | | | | | | |
| Total score out of 55 | 33 | 34 | 35 | 41 | 40 | 46 |

# F

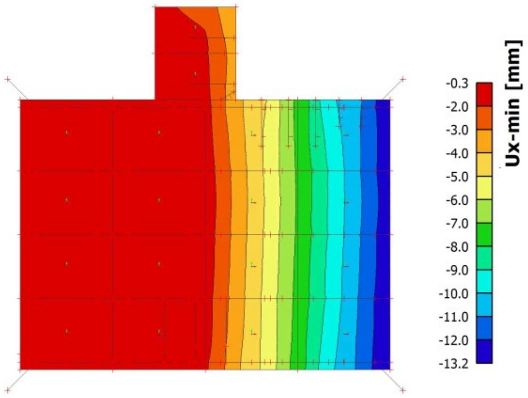
# Reusable jetty design

## F.1. Global calculations

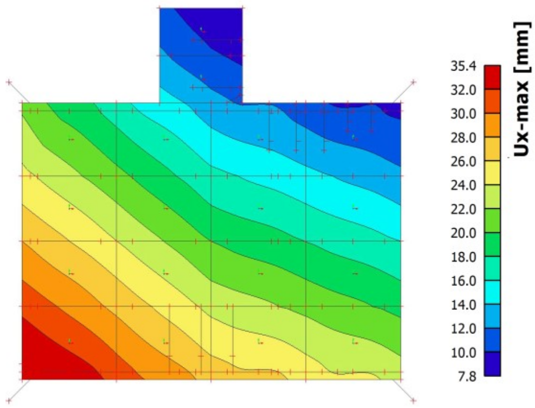
To understand the behaviour of the structure, different connection solutions were explored. The calculations are all done in the same model, in which only the connections between the elements are adjusted. For the modelling of the rigid variant, all interfaces of elements are rigidly connected. After this, the plate-part to plate-part connections are modelled freely, obtaining no interaction. The rib-part to rib-part connections are modelled with a linear spring on each side of the rib element that only obstructs movement the vertical direction. As describe in Equation 4.1, this connection does not need tension resistance in the vertical direction. The hinged connections are modelled as linear springs on a line that allow rotations in all direction, but no translations.

The maximum displacement of the rigid solution is 38.5 mm. This is a little smaller than for the reference variant, which is expected to be a result of adding five extra piles to the layout. When exploring the option of making simpler connections, they are considered in two different places: The position where the sides of the elements intersect and the place where the elements rest on the previously placed element in width direction, connecting the front of the previous element with the back of the placed element. Those connections are displayed in Figure 4.4.

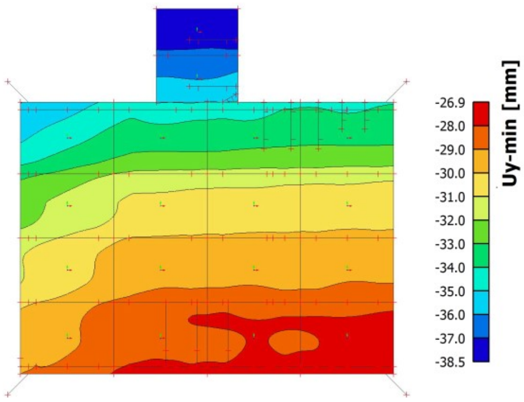
The connections on the side of each element can be made simpler. When considering the robustness of the structure, for connecting the rib-parts of the elements, a shear connection can be made and for the plate-parts, no connection is needed at all. This is similar to the results that were found in variants 1 and 2. When making the plate-part to plate-part connection type simpler, the effect on the maximal displacements is minimal, the maximum displacement becomes 37.6 mm, as is shown in Figure F.2. This is an explainable result, as the rib plate and deck plates are rigidly connected, so still a rigid connection between the element sides is obtained. When also applying the simpler connection in the rib-part to rib-part, no more rigid connection exists between the sides of the elements. It is therefore predictable that the influence of this simplification is larger. This is seen in the results shown in Figure F.3, as the maximum displacement becomes 48.3 mm, which is still within the allowable range.



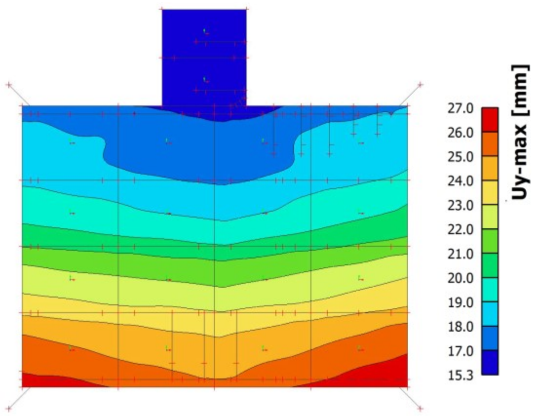

**(a)** Displacement in negative x-direction



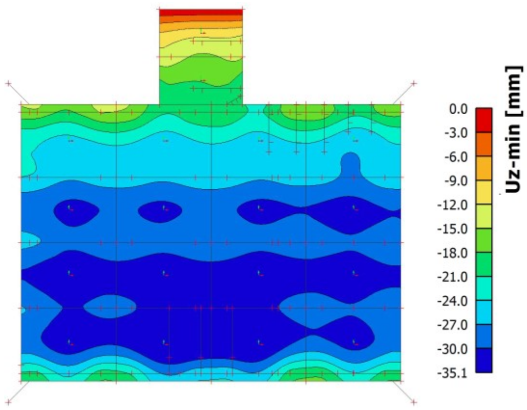

**(b)** Displacement in positive x-direction




**(c)** Displacement in negative y-direction

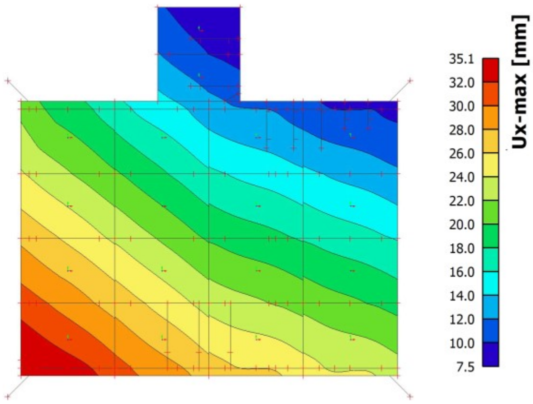



**(d)** Displacement in positive y-direction

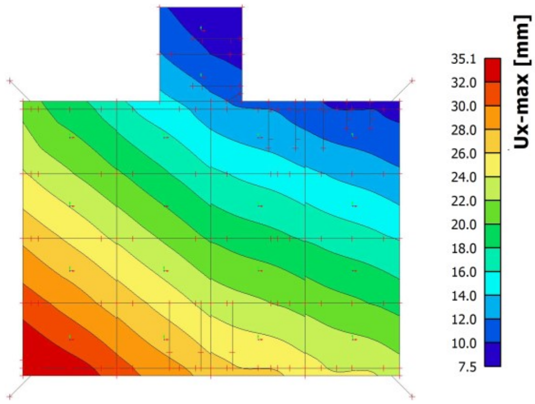



**(e)** Displacement in z-direction

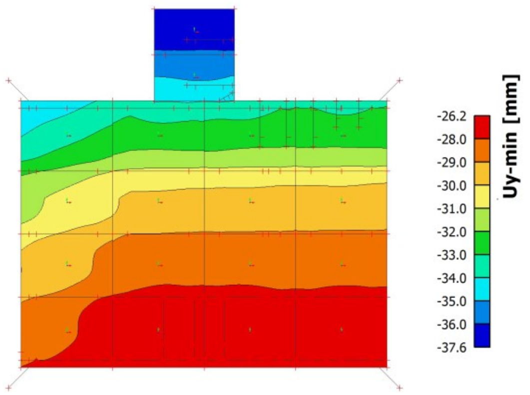
**Figure F.1:** Displacement of rigid solution for variant 3



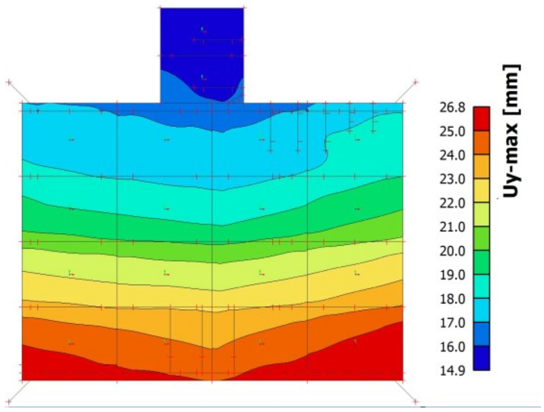

**(a)** Displacement in negative x-direction



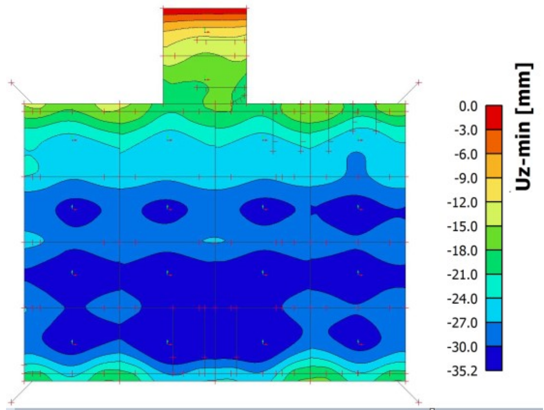

**(b)** Displacement in positive x-direction




**(c)** Displacement in negative y-direction

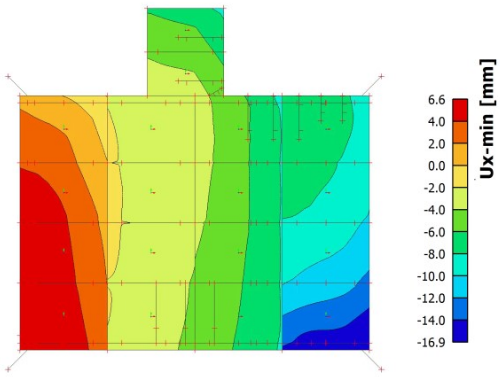



**(d)** Displacement in positive y-direction

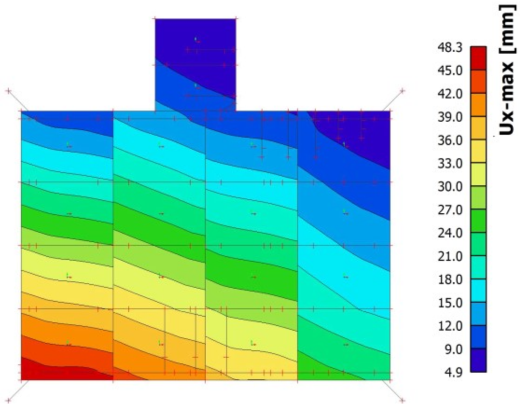



**(e)** Displacement in z-direction

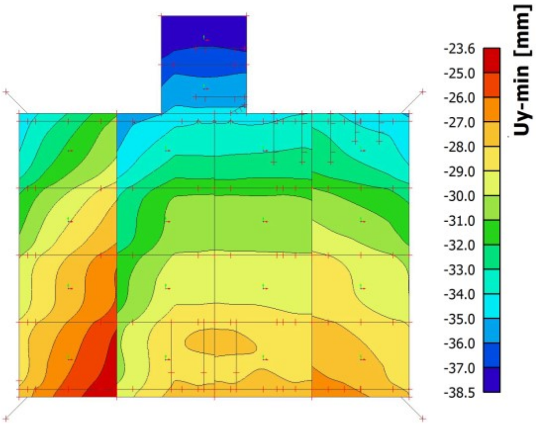
**Figure F.2:** Displacement with no deck plate to deck plate connection variant 3



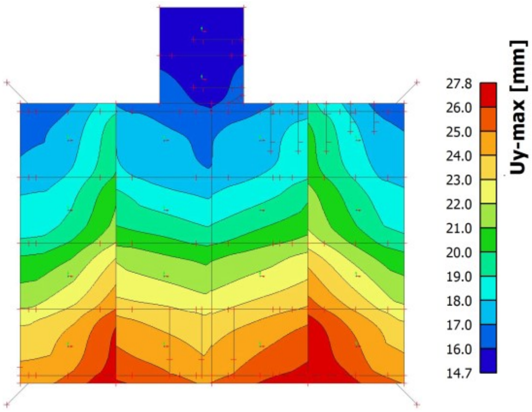

**(a)** Displacement in negative x-direction



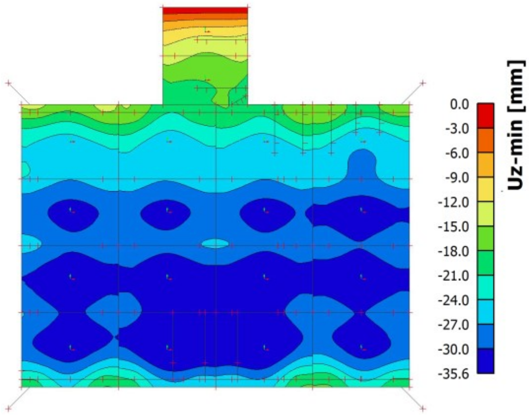

**(b)** Displacement in positive x-direction




**(c)** Displacement in negative y-direction



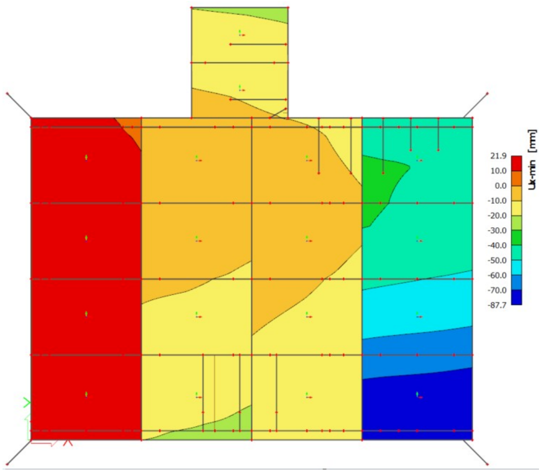

**(d)** Displacement in positive y-direction



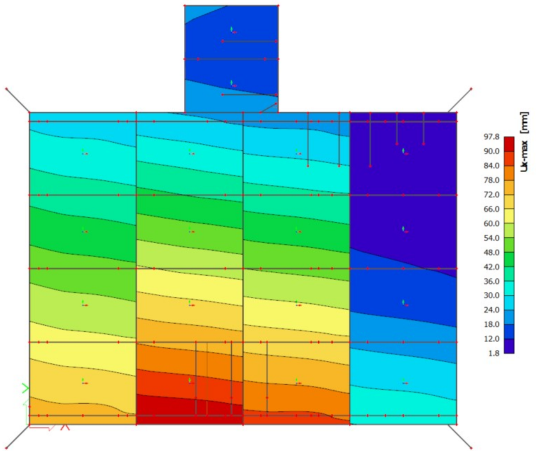

**(e)** Displacement in z-direction

**Figure F.3:** Displacement of no plate-part to plate-part and shear rib-part to rib-part connection variant 3

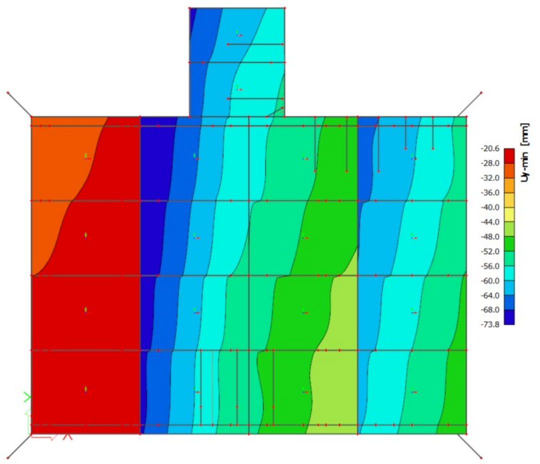
## F.2. Displacements of variant with less piles



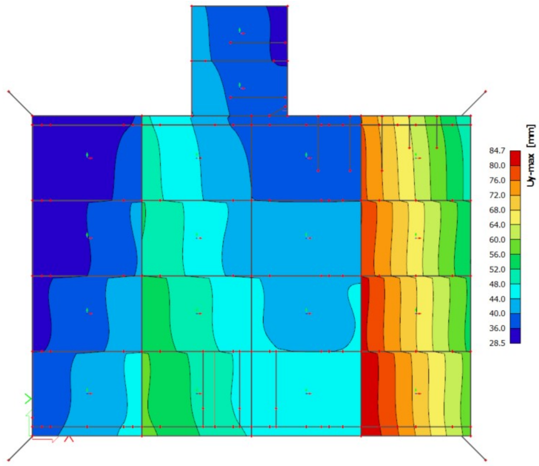
**(a)** Displacement in negative x-direction



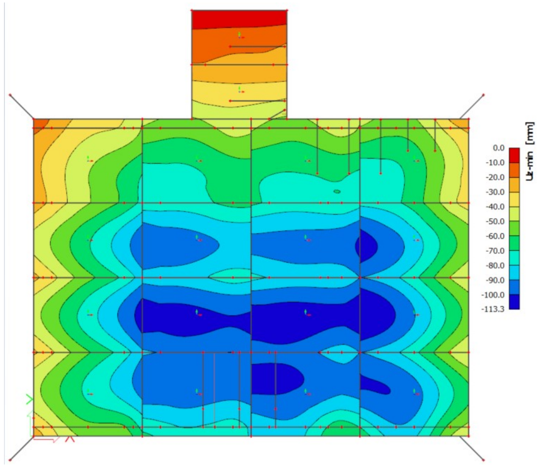
**(b)** Displacement in positive x-direction



**(c)** Displacement in negative y-direction



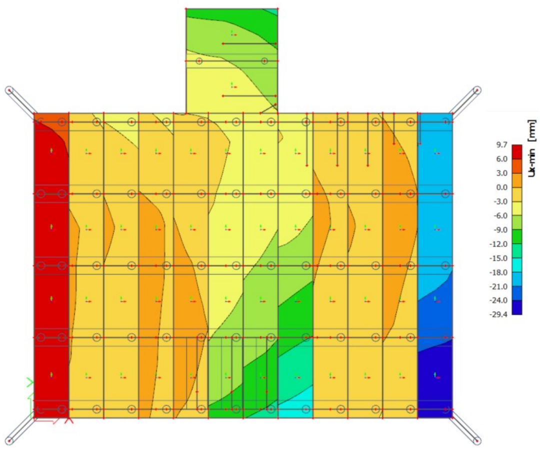
**(d)** Displacement in positive y-direction



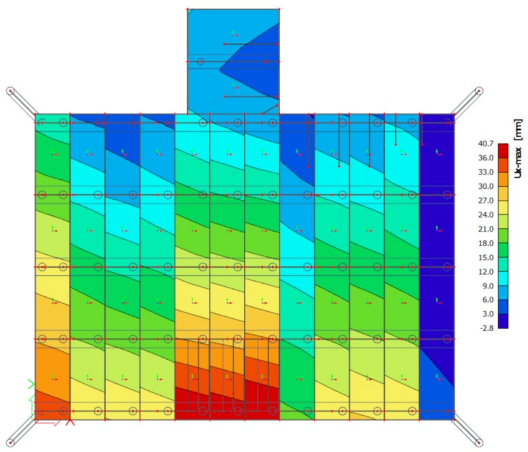
**(e)** Displacement in z-direction

**Figure F.4:** Displacement of the simple solution using the piles needed for construction

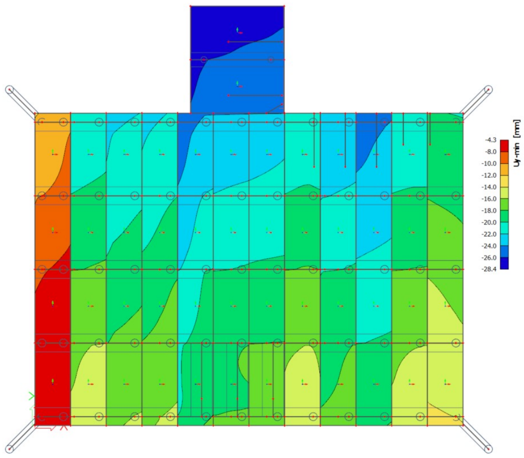
# F.3. Displacements for the regular crane variant



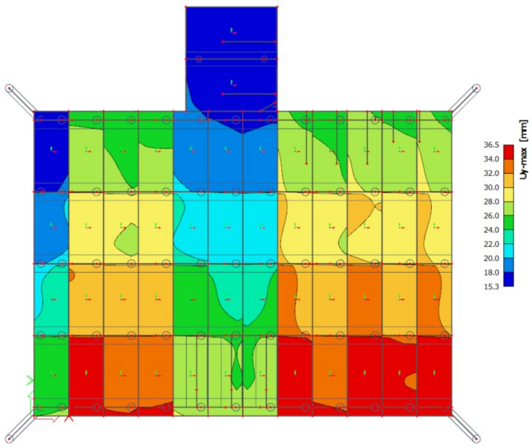
**(a)** Displacement in negative x-direction



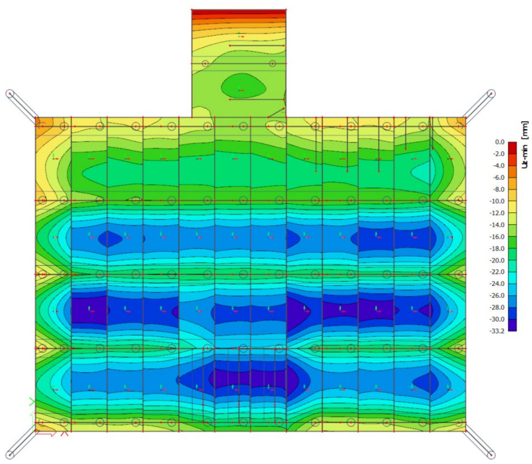
**(b)** Displacement in positive x-direction



**(c)** Displacement in negative y-direction



**(d)** Displacement in positive y-direction



**(e)** Displacement in z-direction

**Figure F.5:** Displacement of the simple solution using a regular crane for construction

# F.4. Semi-dry hinged connection

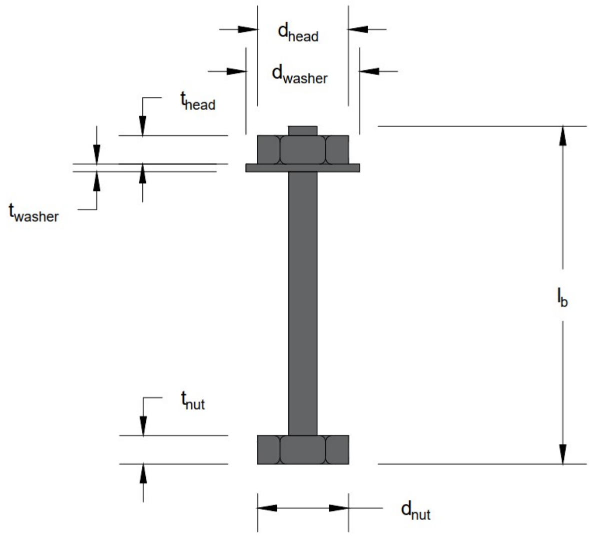



**Figure F.6:** Dimensions of the anchor bolt

In the calculations, the safety factor that apply are the material factor for steel in tension ($\gamma_{Ms,tension}$), steel in shear ($\gamma_{Ms,shear}$), concrete in tension ($\gamma_{Mc,tension}$) and concrete in shear ($\gamma_{Mc,shear}$). The factors for concrete depend on the material factor $\gamma_c = 1.5$ and the installation sensitivity factor $\gamma_{inst} = 1$ for both tension and shear.

$$\begin{aligned} \gamma_{Ms,tension} &= max(1.2\frac{f_{uk}}{f_{yk}}; 1.4) = 1.4 \\ \gamma_{Ms,shear} &= 1.5 \text{ for } f_{uk} \geq 800N/mm^2 \\ \gamma_{Mc,tension} &= \gamma_c \gamma_{inst} = 1.5 \\ \gamma_{Mc,shear} &= \gamma_c \gamma_{inst} = 1.5 \end{aligned} \tag{F.1}$$

**Concrete cone failure**

$$\begin{aligned} k_1 &= k_{cr,N} = 7.7 \text{ for cracked concrete} \\ N^0_{Rk,c} &= k_1 \sqrt{f_{ck}} h_{ef}^{1.5} = 236.70\ kN \end{aligned} \tag{F.2}$$

$$\begin{aligned} A^0_{c,N} &= s^2_{cr,N} = 810000\ mm^2 \\ A_{c,N} &= (c_1 + 0.5s_{cr,N})(c_2 + 0.5s_{cr,N}) = 1140000\ mm^2 \end{aligned} \tag{F.3}$$

$$\begin{aligned} &\Psi_{s,N} = min(0.7 + 0.3\frac{c}{c_c r, N}; 1) = 1 \\ &\Psi_{re,N} = 1 \text{ because } h_{ef} \geq 100mm \\ &\Psi_{ec,N} = 1 \text{ because no eccentricity was found} \\ &\Psi_{M,N} = 1 \text{ because } \frac{z}{h_{ef}} \geq 1.5 \text{ in which } z = min(2h_{ef}; 2c_1; 0.85 \cdot 0.9h_{cb}) = 535.5\ mm \end{aligned} \tag{F.4}$$

**Pull-out failure of fastener**

$$\begin{aligned} k_2 &= 7.5 \text{ for cracked concrete} \\ A_h &= (\frac{\pi}{4}(d^2_{nut} - d^2_b) = 1632.84\ mm^2 \end{aligned} \tag{F.5}$$

**Steel shear failure**

$$k_6 = 0.5 \text{ for } 500\ N/mm^2 \leq f_{uk} \leq 1000\ N/mm^2$$
$$V^0_{Rk,s} = k_6 A_s f_{uk} = 488.00\ kN \quad \text{(F.6)}$$
$$k_7 = 1 \text{ for fasteners acting in a group}$$

**Concrete edge failure**

$$k_9 = k_{cr,N} = 1.7 \text{ for cracked concrete}$$
$$l_f = h_{ef} = 300\ mm \leq max(8d_{nom}; 300\ mm)$$
for a post-installed fastener with a uniform diameter of $d_{nom} > 24\ mm$
$$\alpha = 0.1(\frac{l_f}{c_1})^{0.5} = 0.08 \quad \text{(F.7)}$$
$$\beta = 0.1(\frac{d_{nom}}{c_1})^{0.2} = 0.07$$

$$V^0_{Rk,c} = k_9 d^{\alpha}_{nom} l^{\beta}_f \sqrt{f_{ck}} c_1^{1.5} = 210.33\ kN \quad \text{(F.8)}$$

$$A^0_{c,V} = 4.5c_1^2 = 1125000\ mm^2$$
$$A_{c,V} = (2 \cdot 1.5c_1 + (n-1)s_2)h_{ct} = 6275000\ mm^2 \quad \text{(F.9)}$$
for $s \leq 3c_1,\ c_2 \leq 1.5c_1$ and $h \geq 1.5c_1$

$$\Psi_{s,V} = min(0.7 + 0.3\frac{c_2}{1.5c_1}; 1) = 1$$
$\Psi_{re,V} = 1$ which is a conservative assumption
$\Psi_{ec,V} = 1$ because no eccentricity was found (F.10)
$$\Psi_{h,V} = max((\frac{1.5c_1}{h})^{0.5}; 1) = 1.04$$
$\Psi_{\alpha,V} = 1$ which is a conservative assumption

# F.5. Calculation results

| Staaf | Belasting | elem | sigx+ [MPa] | sigy+ [MPa] | sigxy+ [MPa] |
|---|---|---|---|---|---|
| | | | sigx- [MPa] | sigy- [MPa] | sigxy- [MPa] |
| E62 | UGT | 15558 | **-72,9** | -14,5 | -0,1 |
| | | | -72,6 | -14,6 | -0,5 |
| E48 | UGT | 3786 | **27,0** | 34,0 | 0,5 |
| | | | -6,2 | 0,1 | 24,7 |
| E78 | UGT | 29102 | -1,8 | **-21,0** | -5,3 |
| | | | 0,0 | -11,0 | -12,2 |
| E78 | UGT | 29180 | 20,4 | **42,6** | **26,7** |
| | | | -0,4 | 15,3 | 9,5 |
| E78 | UGT | 29177 | 1,1 | -11,1 | **-26,9** |
| | | | -23,6 | -43,4 | -7,5 |
| E62 | UGT | 15558 | -72,7 | -14,5 | -0,2 |
| | | | **-73,4** | -14,9 | -0,6 |
| E65 | UGT | 18731 | 11,6 | 2,4 | 0,0 |
| | | | **11,6** | 2,3 | 0,0 |
| E78 | UGT | 29180 | -1,1 | -15,1 | -10,6 |
| | | | -25,2 | **-45,9** | **-31,6** |
| E78 | UGT | 29182 | 3,7 | 16,8 | 9,2 |
| | | | 4,7 | **22,5** | 26,9 |
| E78 | UGT | 29177 | 20,0 | 41,6 | 8,0 |
| | | | -2,4 | 11,7 | **30,1** |

**Figure F.7:** Extreme stresses in the deck

| Staaf | css | dx [m] | Belasting | N [kN] | Vy [kN] | Vz [kN] | Mx [kNm] | My [kNm] | Mz [kNm] |
|---|---|---|---|---|---|---|---|---|---|
| S283 | CS1 - Rechthoek | 10,000 | UGT-3a/77 | **-1561** | -21 | -1052 | -49 | -666 | 84 |
| S283 | CS1 - Rechthoek | 6,700 | UGT-3a/806 | **3201** | -23 | -353 | 311 | 439 | -297 |
| S280 | CS1 - Rechthoek | 2,000 | UGT-3b/679 | -207 | **-594** | 906 | -228 | -491 | -214 |
| S284 | CS1 - Rechthoek | 2,700 | UGT-4b/707 | 103 | **612** | 505 | 395 | 38 | -620 |
| S283 | CS1 - Rechthoek | 10,000 | UGT-3b/814 | -1313 | -167 | **-1665** | -198 | -783 | -31 |
| S284 | CS1 - Rechthoek | 2,000 | UGT-3a/703 | -692 | -283 | **1584** | -159 | -389 | -180 |
| S289 | CS1 - Rechthoek | 10,000 | UGT-7b/750 | -305 | -368 | -821 | **-659** | -242 | -497 |
| S287 | CS1 - Rechthoek | 2,000 | UGT-7b/10 | -363 | 376 | 804 | **674** | -238 | -502 |
| S279 | CS1 - Rechthoek | 10,000 | UGT-3b/841 | 243 | 23 | -850 | 7 | **-1309** | -24 |
| S279 | CS1 - Rechthoek | 6,700 | UGT-5b/839 | 439 | -8 | -700 | 0 | **1283** | -34 |
| S284 | CS1 - Rechthoek | 2,700 | UGT-3b/709 | 724 | 422 | 442 | 511 | 167 | **-682** |
| S279 | CS1 - Rechthoek | 6,700 | UGT-8b/837 | 440 | -233 | -372 | -121 | 744 | **448** |

**Figure F.8:** Extreme internal forces in rib plates

**Table F.1:** Governing forces in rib part to rib part connections in reusable jetty

| Staaf | css | dx [m] | Belasting | Vz [kN] |
|---|---|---|---|---|
| S283 | CS1 - Rechthoek | 12 | UGT-3a/698 | -693 |
| S284 | CS1 - Rechthoek | 0 | UGT-4a/694 | 356 |

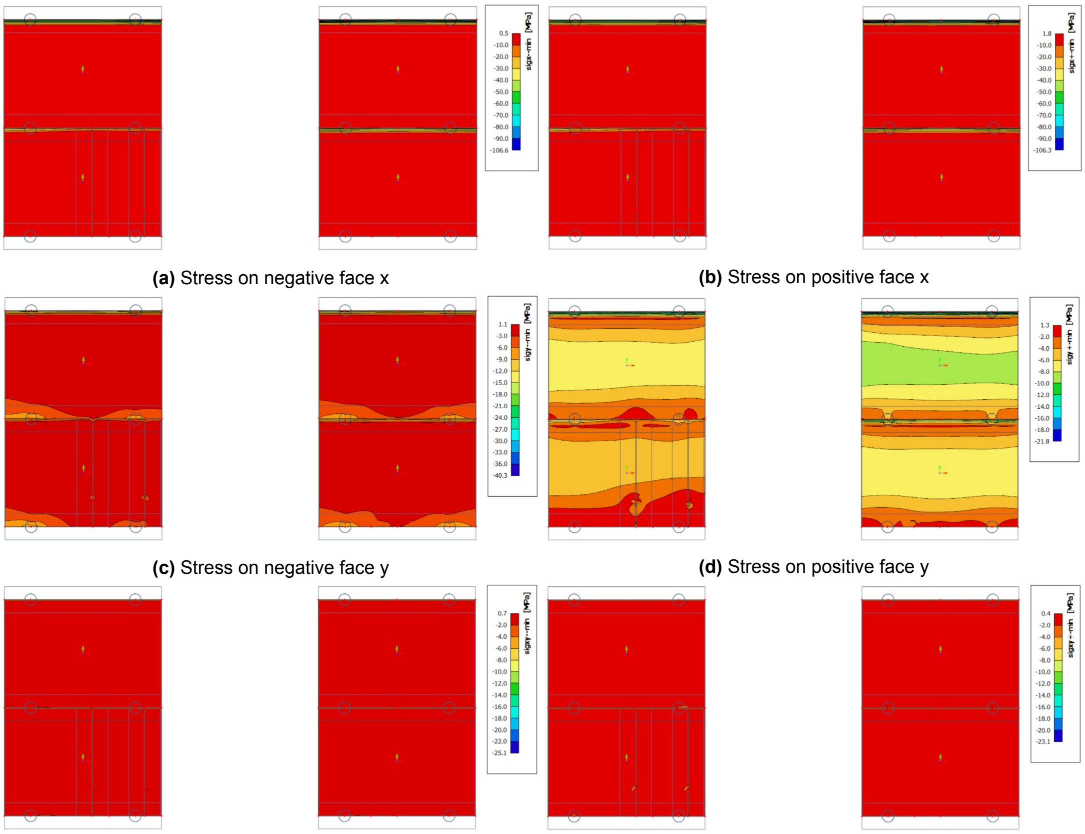
| Staaf | css | dx [m] | Belasting | N [kN] | Vy [kN] | Vz [kN] | Mx [kNm] | My [kNm] | Mz [kNm] |
|---|---|---|---|---|---|---|---|---|---|
| S251 | CS10 - Buis | 30,250 | UGT-3a/1 | **-2762** | 2 | 1 | 0 | -1 | -2 |
| S238 | CS10 - Buis | 0,000 | UGT-8a/2 | **-221** | -165 | 14 | 0 | -101 | 645 |
| S274 | CS10 - Buis | 0,000 | UGT-7b/3 | -1344 | **-218** | -10 | 0 | 26 | 1421 |
| S268 | CS10 - Buis | 0,000 | UGT-3a/4 | -1197 | **250** | -12 | 0 | 68 | **-1307** |
| S277 | CS10 - Buis | 31,428 | UGT-3b/5 | -1722 | 204 | **-202** | 0 | 0 | 0 |
| S237 | CS10 - Buis | 31,428 | UGT-3b/6 | -1635 | 194 | **191** | 0 | 0 | 0 |
| S237 | CS10 - Buis | 14,833 | UGT-7b/7 | -1221 | -7 | 0 | **0** | 687 | -259 |
| S237 | CS10 - Buis | 15,500 | UGT-7b/7 | -1227 | 12 | -43 | **0** | 687 | -263 |
| S242 | CS10 - Buis | 0,000 | UGT-3b/8 | -1561 | -32 | 146 | 0 | **-1317** | 502 |
| S242 | CS10 - Buis | 15,500 | UGT-3a/9 | -1676 | -21 | 3 | 0 | **761** | 18 |
| S126 | CS10 - Buis | 0,000 | UGT-7b/10 | -1504 | -193 | 7 | 0 | -23 | **1497** |

**Figure F.9:** Extreme internal forces in piles in reusable jetty

**Table F.2:** Governing forces in pile to rib plate connections in reusable jetty

| Staaf | css | dx [m] | Belasting | N [kN] | Vy [kN] | Vz [kN] | My [kNm] | Mz [kNm] |
|---|---|---|---|---|---|---|---|---|
| S134 | CS10 - Buis | 0 | UGT-3b/71 | **-2285** | 1 | -28 | 320 | 226 |
| S274 | CS10 - Buis | 0 | UGT-7b/3 | -1344 | **-218** | -10 | 26 | 1421 |
| S268 | CS10 - Buis | 0 | UGT-3a/4 | -1197 | **250** | -12 | 68 | -1307 |
| S268 | CS10 - Buis | 0 | UGT-3b/612 | -1141 | 193 | **-62** | 367 | -1055 |
| S240 | CS10 - Buis | 0 | UGT-3a/185 | -2116 | -36 | **154** | -1184 | 524 |
| S242 | CS10 - Buis | 0 | UGT-3b/8 | -1561 | -32 | 146 | **-1317** | 502 |
| S267 | CS10 - Buis | 0 | UGT-3a/513 | -1532 | 11 | -45 | **455** | 228 |
| S268 | CS10 - Buis | 0 | UGT-3a/4 | -1197 | 250 | -12 | 68 | **-1307** |
| S126 | CS10 - Buis | 0 | UGT-7b/10 | -1504 | -193 | 7 | -23 | **1497** |

# F.6. Modularity



**(a)** Stress on negative face x

**(b)** Stress on positive face x

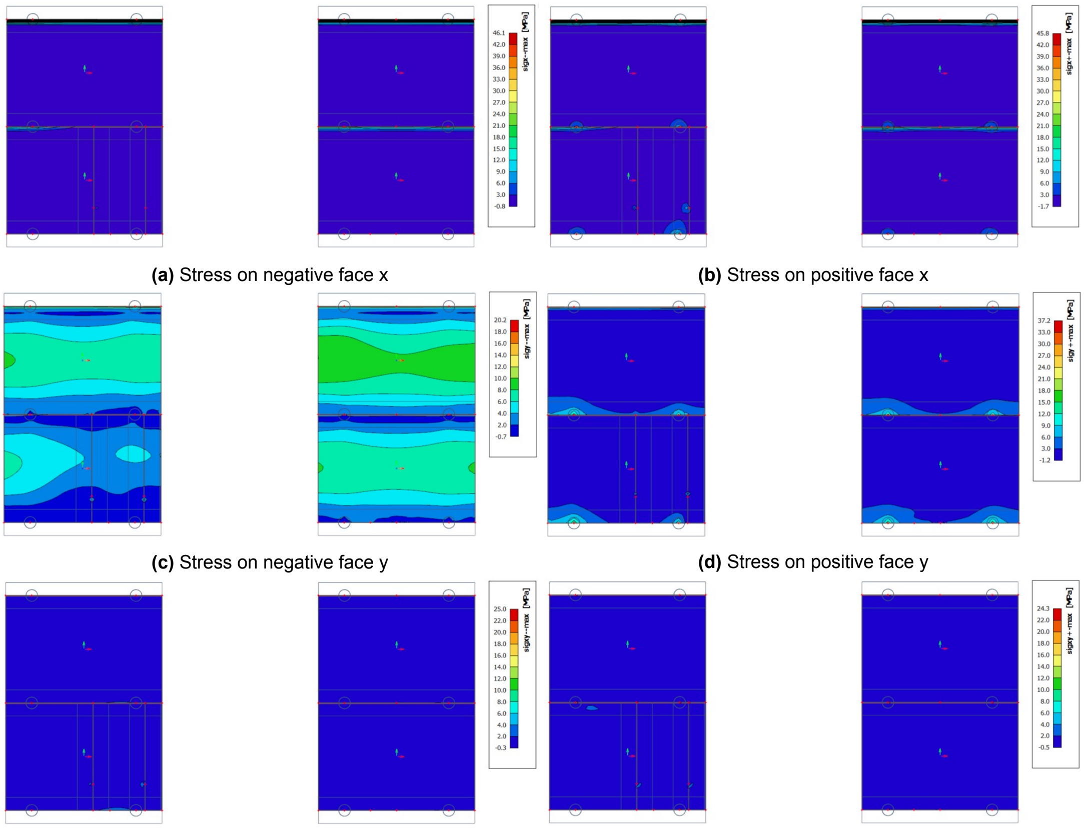
**(c)** Stress on negative face y

**(d)** Stress on positive face y

**(e)** Stress on negative face xy

**(f)** Stress on positive face xy

**Figure F.10:** Extreme negative stresses in faces of modules



**(a)** Stress on negative face x
**(b)** Stress on positive face x
**(c)** Stress on negative face y
**(d)** Stress on positive face y
**(e)** Stress on negative face xy
**(f)** Stress on positive face xy

**Figure F.11:** Extreme positive stress in faces of modules

## F.7. Comparison with reference variant

All PoR requirements are stated in Appendix B. Most requirements are either out of scope or the extent to which they were met did not change in any way when comparing the reference design to the reusable design. The requirements that are taken into account for this comparison are those that changed or that are not yet discussed. For example, requirement 3.1.2 (loads) is not taken into account, as the same loads and load combinations were checked for the reference jetty as for the reusable jetty. The requirements that are taken into account are listed below, including changes that were made or uncertainties that remain in meeting the requirement.

1.2.9.1. *Constructability 01: The work must be designed in such a way that it can be built smoothly and safely.* The constructability of the reusable variant is increased compared to the reference variant. By eliminating the need to use large amounts of in situ concrete and using prefab elements and (semi)dry connections instead, the construction can be done significantly faster on site. Wormmeester (Appendix A) agrees with this expectation;

1.5. *Environment disturbance: The system should not hinder existing infrastructure (including ports, cables and pipelines, shipping routes, dyke bodies, quays, sea walls, etc.) and should not cause existing infrastructure to be functionally negatively affected. If this is not possible, the Contractor (in consultation with the relevant manager) must take appropriate measures so that the nuisance is minimal during implementation and all functionality is restored from completion at the latest.* For construction of the reusable variant, a larger crane is needed due to the heavier prefab elements. Although it is unknown what the exact hindrance of this larger crane is, it is expected that some hinder will occur. This is a compromise to be made by PoR. However, due to the significantly decreased construction time, this hindrance can be decreased;

3.1.4.1. *Top of deck: Upon delivery, the deck must have a non-slip concrete surface, with a value of the Leroux number of 70 or higher, in accordance with NEN 2873+w99.* The surface of the deck is not yet covered. It is however expected that this surface can be made in the prefab elements. In the reference jetty this can be made with in situ concrete, which gives reason to believe that this can be done just as easily in the factory;

3.1.7. *Pipeline streets: The jetty must be suitable for placing and fixing pipelines of and by the operator.* For the reusable variant, no concerns arise regarding the pipeline placing. However, when a modular variant is made attention should be paid to the connection of the pipeline streets to the deck, which cannot be fixed in a place as this would decrease the modularity;

3.1.9. *Casting: The entire deck is surrounded by a raised concrete edge for the purpose of collecting (extinguishing) water and spill. The liquid-tight loading zone is also surrounded by a concrete edge. In addition, casting facilities are provided for the MLA, JIB Cranes and the Fire monitor.* As for requirement 3.1.7, the rising concrete edge can be easily included in the prefab elements in the reusable variant, but when making the modular structure this will need to be worked out in further detail;

3.1.15. *Liquid tightness: Loading zones suitable for the storage and transfer of chemical products must be liquid-tight. The loading zones are the zones within the raised edges.* By adding a connection profile, for example made of rubber, between the prefab element, it is expected that the deck can be made liquid-tight. This however needs further research;

5.1.4. *Not floating: Do not use floating sleepers, but a rigid construction.* PoR has made this requirement because of concerns for the robustness of the structure and additional maintenance that would be needed. However, the robustness is proven in the calculations in Chapter 4. Furthermore, Wormmeester (Appendix A) disagrees with the expectation of additional maintenance and has no concerns regarding the maintainability of the simple reusable design. However, flexibility of placing the superstructure decreases due to this change, as steps in the displacements can cause stresses in the superstructure, for which is is not designed. Those should thus be placed in the four columns as described in Section 4.3.

# G

# Life cycle assessment

## G.1. NMD data

The materials that are used are taken from DuboCalc at 14-04-2022, which uses the Nationale Milieu Database (NMD) version 3.0 as a source. (bron assessment method)

### G.1.1. Concrete deck

The concrete elements exist of concrete and reinforcement, which are elaborated below.

**Concrete**

The material that is used from the NMD is 'Betonmortel voor GWW C3545 CEMI 2331 kgm3 compleet' and for the lower clinker concrete it is 'Betonmortel voor GWW C3545 CEM I + CEM III 5050% 2346 kgm3 compleet'. This is concrete of strength class C35/45 and does not use recycled materials. The functional life time is set to 50 years. The numbers are given per m3. Per life cycle step, it is indicated what is accounted for. This can be found in more detail in the LCA rapportage [66]

- A1 The materials that are accounted for are gravel (1050 kg/m3), sand (785 kg/m3), CEM I (325 kg/m3), plasticizer (0.6 kg/m3) and water (170 kg/m3).
- A2 For the transport of the raw materials to the producer, a distance of 300 km is assumed, as cement often comes from Germany. For the water, this is not accounted, as this can be used from local sources. Transport by truck is assumed.
- A3 For the production, the energy use is calculated by accounting for use of electricity (3.63 kWh/m3), diesel (4.43 MJ/m3) and gas (4.96 MJ/m3) based on averaged numbers.
- A4 For the transport to site, a distance of 116.5 km is assumed. For the transport of the concrete that will be reused, this number is lowered to 80 km. This number is assumed based on the length of the port (approximately 40 km). In the worst case the elements will be transported over the entire length of the port for treatment or storing and will be transported back to site over the entire length. Because of this, in the reuse scenario a factor of $\frac{80}{116.5} = 0.67$ is applied to this step.
- A5 For the construction, the use of a concrete pump and an excavator is assumed. To this, the use of a crane is added manually by assuming a diesel use for both the regular crane and the large crane. The larger crane uses 4.36 times as much diesel (bron matador 1)(bron matador 3), but needs $\frac{121}{71} = 1.7$ times less time. So this step is multiplied by a factor of $4.36 - 1.7 = 2.66$. A 5% loss of material is accounted for in this stage (due to mistakes in orders, damage and fabrication mistakes).
- B1-B7 These steps are not accounted for.
- C1 This steps accounts for the deconstruction of the concrete and loading it for transport. The loading will also be done by a larger crane for the reusable jetty variant, due to which also the factor of 2.66 is applied.
- C2 The transport to a waste processor is assumed to be with trucks and is assumed to be 117.7 km.

C3 It is assumed that 99% of the concrete will be recycled, so for the waste processing only 1% of the concrete is assumed. The concrete is broken into pieces.

C4 For this step, also 1% of the concrete is assumed. The material will end up at landfill.

D The 99% of the concrete that is assumed to be recycled is assumed to be used as a road base. Material that is already used for a second life time is not included in this. Per kg of concrete 0.99 kg can be used as road base.

**Reinforcement**

For the reinforcement, no standard element exists. Therefore the type 'Deelproduct: Constructies in kg of m3, Wapeningsstaal' is used per kg [67].

A1-A3 The material that is used is steel, which is accounted for per mass. No further details on the reinforcement are thus relevant. The impact of welds are considered to be so small that they can be disregarded.

A4 The transport distance is assumed to be 150 km to the site.

A5 On site, the use of a crane is assumed to place the reinforcement. As this is done per kg, it can just be added, although a crane is already also accounted for for the concrete placement. A 3% loss of elements is accounted for.

B1-B7 By assuming the reinforcement to have sufficient concrete cover, this steps are not taken into account.

C1-C4 For deconstruction, demolition is assumed with a excavator and cutters. A second excavator is used to clean up. A distance of 50 km to the waste processing is assumed, to which a 100 km distance for disposal is added.

D It is assumed that 95% of the steel can be recycled, after which it can obtain similar properties and thus fulfill a similar function. 5% is assumed to and up at landfill.

### G.1.2. Steel piles

The steel foundation piles consists of S355 steel and a coating to prevent corrosion. Those are worked out below.

**Piles**

For the steel piles, the product 'buispaal; staal' is taken into account, which include the placement of the piles [68]

A1-A3 The steel pile that is assumed has a diameter of 101.6 mm, which has to be scaled to the actually used 914 mm. For this, a multiplication factor of $\frac{914}{101.6} = 8.99$ is used for the entire product.

A4 150 km transport to site is assumed.

A5 The placement is done with a crane and a 3% loss of material is accounted for.

B1-B7

C1 A crane running on diesel will remove the piles in 10 m per hour.

C2 The transport to the waste processing is assumed to be 150 km.

C3 5% of the steel will be broken down. For the recycled steel, it is assumed that a coating will remain on the steel until it gets molten again for recycling, which is why combustion emissions are taken into account for this.

C4 This steel will go to a landfill.

D For the primary used steel, a recycling rate is assumed of 87% and a reusing rate of 12%. The other 1% will end up at landfill.

**Coating**

For the coating, the NMD product 'Natlaksysteem voor staalconstructies' is used [69].

A1-A3 A primary base of resin is assumed with a top layer of polyurethane, to which a mixture of 80% xylene and 20% ethylbenzene is added. In the base layer this mixture is 25% and in the top layer 40%.

A4 Transport to site of 150 km is accounted for.

A5 It is assumed that 25% of the applied coating is overspray and will end up in the environment, emitting phenol, iron and zinc in the water. Also, the xylene and ethylbenzene mixture will evaporate partly and end up in the atmosphere.

B1-B7 The coating will not last as long as the steel it is applied to, so after 15 years it is assumed that 3% of the surface will have to be redone and after a total of 50 years everything will have to be redone. However, the jetties are assumed to have a life time of 50 years, due to which the coating will not have to be replaced entirely. To account for the 3% maintenance, a factor of $\frac{3}{103} = 0.029$ will be applied to this step.

C1-C4 To remove a coating, slagblasting is applied. Per m2, 50-70 kg of slag will be used and is won from the steel industry. The procedure to make the slag applicable for blasting is also taken into account. It can be used only once and will be processed as hazardous waste afterwards.

D No material is being recycled or reused.

### G.1.3. Connections

**Steel pile to concrete rib plate connection**

The connection consists of a steel plate and rods. For the steel plate, the most comparable product is chosen to be 'Staal constructieprofiel, Middelgroot IPE300' [70], which is elaborated below. For the rods, 'Deelproduct: Constructies in kg of m3, Wapeningsstaal' is used, which is the same as for the reinforcement. This is elaborated above.

A1-A3 The steel profiles are made with hot rolled steel. Although the unit is per m, it can also be calculated per kg. This is done to manipulate the weight of the profile to the weight of the steel plate. The weight of the steel is assumed to be the same for both products, so the volume of steel can be used. A meter of profile has a volume of $300 \cdot 7.1 + 2 \cdot (150 - 7.1) \cdot 10.7 = 5188060\ mm^3$ and for the plate is $1200^2 \cdot 40 = 57600000\ mm^2$, due to which it is changed with a factor of $\frac{57600000}{5188060} = 11.10$ over the entire life cycle. For the 20% larger plate, this value is $\frac{(1200 \cdot 1.2)^2 \cdot 40}{5188060} = 15.98$.

A4 The transport is assumed to be an average for manufacturers in Europe, which is 470 km by heavy trucks.

A5 Placement of the steel is already taken into account in the concrete placement part, as it is included in the casting and in placing the prefab concrete beam. Therefore this step is not taken into account for this case.

B1-B7 This is accounted for in the coating.

C1 For deconstruction, cutters and an excavator are assumed to be needed. This is to cut the profile loose from other elements and to move it to a truck that will transport it.

C2 For the transport to the waste processing, a distance of 50 km is assumed.

C3 1% of the product is assumed to be processed as waste.

C4 The 1% that is waste will be brought to a landfill.

D It is assumed that 94% of the steel will be recycled and 5% will be reused. The value that is found in the NMD seems to be a mistake, as this value for the other steel products that are partly being reused and partly being recycled lied around 30-50% of the value used in the product stage, whereas in this case it is here is only 4%. It is therefore chosen to work with a value that is 45% of the product stage, which is 2.25.

**Bolts**

For the bolts, NMD element 'slotbout; Verzinkt' is used. This is scaled to the size of the actually used bolts [69].

A1-A3 This is similar as for the production of steel. The bolts that are used are 8x140 mm, which can be scaled to the 39x600 mm anchor bolt that is used in the jetties. A factor of $\frac{39}{8} = 4.88$ is used for the entire life cycle.

A4-A5 Only a 3% loss of material is accounted for, as it is assumed that constructing bolts will not have a significant impact.

B1-B7 This is not taken into account.

C1-C4 It is assumed that deconstructing the bolts will not have a significant impact. Only the transport and waste processing of 5% of the material is taken into account.

D No reuse and 95% recycling is assumed.

## G.2. Material magnitudes used in LCA

**Table G.1:** Material magnitudes for LCA

| Object | Material | Relation | Amount | Unit |
|---|---|---|---|---|
| Reference jetty | | | | |
| Foundation piles | Steel piles | $31.428 \cdot 9 \cdot 4 + 31 \cdot 9 \cdot 31$ | 9780.41 | p |
| Foundation piles | Coating | $4 \cdot \pi \cdot 0.914 \cdot 14.2 \cdot \sqrt{37}/6$ $+31 \cdot \pi \cdot 0.914 \cdot 14.2$ | 1429.34 | m2 |
| Rib plates | Concrete | $5 \cdot 48000 \cdot 2000 \cdot 700 \cdot 10^-9$ | 336.00 | m3 |
| Rib plates | Reinforcement | $200 \cdot 336$ | 67200.00 | kg |
| Rib plates | Steel plate | $11.01 \cdot 35$ | 385.35 | m |
| Rib plates | Rods | $35 \cdot 48 \cdot 800 \cdot 25^2 \cdot \pi/4 \cdot 7850 \cdot 10^-9$ | 5178.91 | kg |
| Deck plates | Concrete | $(8 \cdot 8000 \cdot 6550 \cdot 250 + 14 \cdot 8000 \cdot 6550 \cdot 250$ $+6550 \cdot 1650 \cdot 250 + 2 \cdot 6550 \cdot 1900 \cdot 250$ $+6550 \cdot 4250 \cdot 250) \cdot 10^-9$ | 304.08 | m3 |
| Deck plates | Reinforcement | $200 \cdot 304.08$ | 60816.00 | kg |
| MLA support beams | Concrete | $3 \cdot 6550 \cdot 2400 \cdot 700 \cdot 10^-9$ | 33.01 | m3 |
| MLA support beams | Reinforcement | $200 \cdot 33.01$ | 6602.00 | kg |
| Compression layer | Concrete | $(48000 \cdot 35000 \cdot 250$ $+3 \cdot 48000 \cdot 1700 \cdot 2502 \cdot 48000 \cdot 1850 \cdot 250) \cdot 10^-9$ | 525.60 | m3 |
| Compression layer | Reinforcement | $200 \cdot 525.60$ | 105120.00 | kg |
| | | | | |
| Reusable jetty | | | | |
| Foundation piles | Steel piles | $31.428 \cdot 9 \cdot 4 + 36 \cdot 9 \cdot 31$ | 11175.41 | p |
| Foundation piles | Coating | $4 \cdot \pi \cdot 0.914 \cdot 14.2 \cdot \sqrt{37}/6 + 36 \cdot \pi \cdot 0.914 \cdot 14.2$ | 1633.21 | m2 |
| Rib plates | Concrete | $4 \cdot 12000 \cdot 2000 \cdot 700 \cdot 10^-9$ | 67.20 | m3 |
| Rib plates | Reinforcement | $200 \cdot 67.20$ | 13440.00 | kg |
| Roof tile elements | Concrete | $(8 \cdot (12000 \cdot 2000 \cdot 700 + 12000 \cdot 8250 \cdot 500)$ $+8 \cdot (12000 \cdot 2000 \cdot 700 + 12000 \cdot 9250 \cdot 500)) \cdot 10^-9$ | 1108.80 | m3 |
| Roof tile elements | Reinforcement | $200 \cdot 1108.80$ | 221760.00 | kg |
| Rib plates | Steel plate | $11.01 \cdot 40$ | 440.40 | m |
| Rib plates | Rods | $48 \cdot 48 \cdot 800 \cdot 25^2 \cdot \pi/4 \cdot 7850 \cdot 10^-9$ | 5919.00 | kg |
| MLA support beams | Concrete | $3 \cdot 6550 \cdot 2400 \cdot 700 \cdot 10^-9$ | 33.01 | m3 |
| MLA support beams | Reinforcement | $200 \cdot 33.01$ | 6602.00 | kg |
| Hinged connections | Anchor bolts | $4.9 \cdot 176$ | 862.40 | p |
| Hinged connections | Concrete (grout) | $176 \cdot 0.5 \cdot 1/4 \cdot \pi \cdot 0.126$ | 8.70 | m3 |
| | | | | |
| Modular reusable jetty | | | | |
| Foundation piles | Steel piles | $31.428 \cdot 9 \cdot 4 \cdot 1.2 + 31 \cdot 9 \cdot 36 \cdot 1.2$ | 13410.49 | p |
| Foundation piles | Coating | $4 \cdot \pi \cdot 0.914 \cdot 14.2 \cdot \sqrt{37}/6 \cdot 1.2$ $+36 \cdot \pi \cdot 0.914 \cdot 14.2 \cdot 1.2$ | 1959.86 | m2 |
| Rib plates | Concrete | $4 \cdot 12000 \cdot (2000 \cdot 1.2) \cdot 700 \cdot 10^-9$ | 80.64 | m3 |
| Rib plates | Reinforcement | $200 \cdot 80.64$ | 16128.00 | kg |
| Roof tile elements | Concrete | $16 \cdot (12000 \cdot (2000 \cdot 1.2) \cdot 700$ $+12000 \cdot 8250 \cdot 500) \cdot 10^-9$ | 1114.56 | m3 |
| Roof tile elements | Reinforcement | $200 \cdot 1114.56$ | 222912.00 | kg |
| Rib plates | Steel plate | $15.98 \cdot 40$ | 639.20 | m |
| Rib plates | Rods | $(40 \cdot (48 \cdot 1.2) \cdot 25^2 \cdot \pi/4 \cdot 800)$ $\cdot 7850 \cdot 10^-9$ | 7102.51 | kg |
| MLA support beams | Concrete | $3 \cdot 6550 \cdot 2400 \cdot 700 \cdot 10^-9$ | 33.01 | m3 |
| MLA support beams | Reinforcement | $200 \cdot 33.01$ | 6602.00 | kg |
| Hinged connections | Anchor bolts | $4.9 \cdot 176$ | 176.00 | p |
| Hinged connections | Concrete (grout) | $176 \cdot 0.5 \cdot 1/4 \cdot \pi \cdot 0.126$ | 8.70 | m3 |

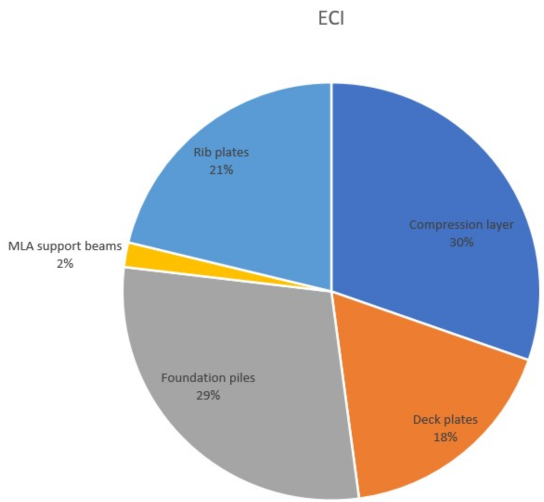
# G.3. Results

## G.3.1. Reference jetty

ECI of reference jetty

| Onderdeel/object | Hoeveelheid2 | Eenheid3 | Item | Opmerking | Hoeveelheid | Eenheid | Levensduur (jaar) | Vervang-ingen | MKI per eenheid | MKI aanleg | MKI gebruik | MKI onderhoud | MKI einde levensduur | MKI totaal A t/m D | | MKI totaal | Aandeel MKI per onderdeel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Foundation piles | 9.780,41 | p | Steel piles | Placing foundation piles | 9.780 | p | 50 | - | 2,41 | 41.234 | - | - | -17.694 | 23.541 | € | 23.541 | 25,5% |
| Foundation piles | 1.429,34 | m2 | Coating | +Coating | 1.429 | m2 | 50 | - | 2,26 | 1.158 | 43,47 | - | 2.030 | 3.232 | € | 3.232 | 3,5% |
| Rib plates | 336,00 | m3 | Concrete installed with regular crane | Placing rib plates | 336 | m3 | 50 | - | 35,45 | 10.578 | - | - | 1.333 | 11.911 | € | 11.911 | 12,9% |
| Rib plates | 67.200,00 | kg | Reinforcement | +Reinforcement | 67.200 | kg | 50 | - | 0,09 | 13.333 | - | - | -7.333 | 6.000 | € | 6.000 | 6,5% |
| Rib plates | 385,35 | m | Steel plate | Steel plates for pile connection | 385 | m1 | 50 | - | 3,20 | 1.936 | - | - | -701 | 1.235 | € | 1.235 | 1,3% |
| Rib plates | 5.178,91 | kg | Reinforcement | Rods for pile connection | 5.179 | kg | 50 | - | 0,09 | 1.028 | - | - | -565 | 462 | € | 462 | 0,5% |
| Deck plates | 304,08 | m3 | Concrete installed with regular crane | Placing deck plates | 304 | m3 | 50 | - | 35,45 | 9.573 | - | - | 1.206 | 10.779 | € | 10.779 | 11,7% |
| Deck plates | 60.816,00 | kg | Reinforcement | +Reinforcement | 60.816 | kg | 50 | - | 0,09 | 12.067 | - | - | -6.636 | 5.430 | € | 5.430 | 5,9% |
| MLA support beams | 33,01 | m3 | Concrete installed with regular crane | Placing MLA support beams | 33 | m3 | 50 | - | 35,45 | 1.039 | - | - | 131 | 1.170 | € | 1.170 | 1,3% |
| MLA support beams | 6.602,00 | kg | Reinforcement | +Reinforcement | 6.602 | kg | 50 | - | 0,09 | 1.310 | - | - | -720 | 590 | € | 590 | 0,6% |
| Compression layer | 525,60 | m3 | Concrete installed with regular crane | Placing in situ compression layer | 526 | m3 | 50 | - | 35,45 | 16.547 | - | - | 2.085 | 18.632 | € | 18.632 | 20,2% |
| Compression layer | 105.120,00 | kg | Reinforcement | +Reinforcement | 105.120 | kg | 50 | - | 0,09 | 20.857 | - | - | -11.470 | 9.386 | € | 9.386 | 10,2% |
| **Totaal** | | | | | | | | | | | | | | | € | **92.369** | |

**Figure G.1:** ECI of reference jetty




| Materialen | | Totale MKI | Bijdrage |
|---|---|---|---|
| **Coating** | € | **3.232** | **3,5%** |
| Foundation piles | € | 3.232 | 3,5% |
| **Concrete installed with regular crane** | € | **42.492** | **46,0%** |
| Compression layer | € | 18.632 | 20,2% |
| Deck plates | € | 10.779 | 11,7% |
| MLA support beams | € | 1.170 | 1,3% |
| Rib plates | € | 11.911 | 12,9% |
| **Reinforcement** | € | **21.869** | **23,7%** |
| Compression layer | € | 9.386 | 10,2% |
| Deck plates | € | 5.430 | 5,9% |
| MLA support beams | € | 590 | 0,6% |
| Rib plates | € | 6.463 | 7,0% |
| **Steel piles** | € | **23.541** | **25,5%** |
| Foundation piles | € | 23.541 | 25,5% |
| **Steel plate** | € | **1.235** | **1,3%** |
| Rib plates | € | 1.235 | 1,3% |
| **Totaal** | € | **92.369** | **100,0%** |

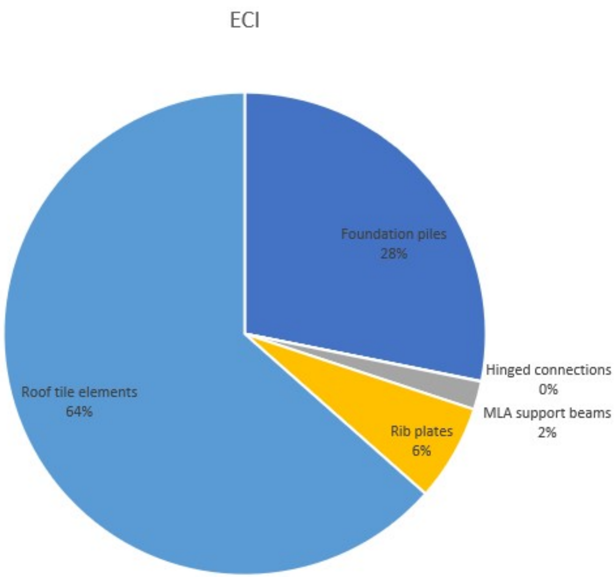
**Figure G.2:** Relative impact per material and element for reference jetty

## G.3.2. Reusable jetty

ECI of reusable jetty

| Onderdeel/object | Hoeveelheid2 | Eenheid3 | Item | Opmerking | Hoeveelheid | Eenheid | Levensduur (jaar) | Vervang-ingen | MKI per eenheid | MKI aanleg | MKI gebruik | MKI onderhoud | MKI einde levensduur | MKI totaal A t/m D | MKI totaal | Aandeel MKI per onderdeel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Foundation piles | 11.175,41 | p | Steel piles complete | Placing foundation piles | 11.175 | p | 50 | - | 2,41 | 47.116 | - | - | -20.217 | 26.899 | € 26.899 | 24,7% |
| Foundation piles | 1.633,21 | m2 | Coating complete | +Coating | 1.633 | m2 | 50 | - | 2,26 | 1.324 | 49,67 | - | 2.320 | 3.693 | € 3.693 | 3,4% |
| Rib plates | 67,20 | m3 | Concrete installed with large crane complete | Placing rib plates | 67 | m3 | 50 | - | 44,36 | 2.414 | - | - | 567 | 2.981 | € 2.981 | 2,7% |
| Rib plates | 13.440,00 | kg | Reinforcement complete | +Reinforcement | 13.440 | kg | 50 | - | 0,09 | 2.667 | - | - | -1.467 | 1.200 | € 1.200 | 1,1% |
| Roof tile elements | 1.108,80 | m3 | Concrete installed with large crane complete | Placing roof tile elements | 1.109 | m3 | 50 | - | 44,36 | 39.833 | - | - | 9.355 | 49.188 | € 49.188 | 45,3% |
| Roof tile elements | 221.760,00 | kg | Reinforcement complete | +Reinforcement | 221.760 | kg | 50 | - | 0,09 | 43.999 | - | - | -24.198 | 19.801 | € 19.801 | 18,2% |
| Rib plates | 440,40 | m | Steel plate complete | Steel plates for pile connection | 440 | m1 | 50 | - | 5,24 | 2.212 | - | - | 96 | 2.308 | € 2.308 | 2,1% |
| Rib plates | 5.919,00 | kg | Reinforcement complete | Rods for pile connection | 5.919 | kg | 50 | - | 0,09 | 1.174 | - | - | -646 | 529 | € 529 | 0,5% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane complete | Placing MLA support beams | 33 | m3 | 50 | - | 44,36 | 1.186 | - | - | 279 | 1.464 | € 1.464 | 1,3% |
| MLA support beams | 6.602,00 | kg | Reinforcement complete | +Reinforcement | 6.602 | kg | 50 | - | 0,09 | 1.310 | - | - | -720 | 590 | € 590 | 0,5% |
| Hinged connections | 862,40 | p | Anchor bolt complete | Placing anchor bolts and nuts | 862 | p | 50 | - | 0,03 | 45 | - | - | -15 | 30 | € 30 | 0,0% |
| Totaal | | | | | | | | | | | | | | | € 108.683 | |

**Figure G.3:** ECI of reusable jetty




| Materialen | Totale MKI | Bijdrage |
|---|---|---|
| **Anchor bolt complete** | **€ 30** | **0,0%** |
| Hinged connections | € 30 | 0,0% |
| **Coating complete** | **€ 3.693** | **3,4%** |
| Foundation piles | € 3.693 | 3,4% |
| **Concrete installed with large crane complete** | **€ 53.634** | **49,3%** |
| MLA support beams | € 1.464 | 1,3% |
| Rib plates | € 2.981 | 2,7% |
| Roof tile elements | € 49.188 | 45,3% |
| **Reinforcement complete** | **€ 22.120** | **20,4%** |
| MLA support beams | € 590 | 0,5% |
| Rib plates | € 1.729 | 1,6% |
| Roof tile elements | € 19.801 | 18,2% |
| **Steel piles complete** | **€ 26.899** | **24,7%** |
| Foundation piles | € 26.899 | 24,7% |
| **Steel plate complete** | **€ 2.308** | **2,1%** |
| Rib plates | € 2.308 | 2,1% |
| **Totaal** | **€ 108.683** | **100,0%** |

**Figure G.4:** Relative impact per material and element for reusable jetty

ECI of reuse of reusable jetty with 5% replacement

| Onderdeel/object | Hoeveelheid | Eenheid | Item | Opmerking | Hoeveel heid | Eenheid | Levensduur (jaar) | Vervang- ingen | MKI per eenheid | MKI aanleg | MKI gebruik | MKI onderhoud | MKI einde levensduur | MKI totaal A t/m D | | MKI totaal | Aandeel MKI per onderdeel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hinged connections | 862,40 | p | Anchor bolt complete | Bolts 100 % will be replaced | 862 | p | 50 | - | 0,03 | 45 | - | - | -15 | 30 | € | 30 | 0,1% |
| Roof tile elements | 1.100,10 | m3 | Concrete installed with large crane C1 | 95% will be reused (1100,10*0,95) | 1.045 | m3 | 50 | - | 7,16 | - | - | - | 7.487 | 7.487 | € | 7.487 | 23,8% |
| Roof tile elements | 1.100,10 | m3 | Concrete installed with large crane A4-A5 | 95% will be reused (1100,10*0,95) | 1.045 | m3 | 50 | - | 8,36 | 8.740 | - | - | - | 8.740 | € | 8.740 | 27,8% |
| Roof tile elements | 1.100,10 | m3 | Concrete installed with large crane complete | 5% will be replaced (1100,10*0,95) | 55 | m3 | 50 | - | 44,36 | 1.976 | - | - | 464 | 2.440 | € | 2.440 | 7,8% |
| Roof tile elements | 220.020,00 | kg | Reinforcement complete | 5% will be replaced (220020*0,05) | 11.001 | kg | 50 | - | 0,09 | 2.183 | - | - | -1.200 | 982 | € | 982 | 3,1% |
| Hinged connections | 8,70 | m3 | Concrete installed with large crane complete | Grout 100% will be replaced | 9 | m3 | 50 | - | 44,36 | 313 | - | - | 73 | 386 | € | 386 | 1,2% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane C1 | 95% will be reused (33,01*0,95) | 31 | m3 | 50 | - | 7,16 | - | - | - | 225 | 225 | € | 225 | 0,7% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane A4-A5 | 95% will be reused (33,01*0,95) | 31 | m3 | 50 | - | 8,36 | 262 | - | - | - | 262 | € | 262 | 0,8% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane complete | 5% will be replaced (33,01*0,05) | 2 | m3 | 50 | - | 44,36 | 59 | - | - | 14 | 73 | € | 73 | 0,2% |
| MLA support beams | 6.602,00 | kg | Reinforcement complete | 5% will be replaced (6602*0,05) | 330 | kg | 50 | - | 0,09 | 65 | - | - | -36 | 29 | € | 29 | 0,1% |
| Rib plates | 67,20 | m3 | Concrete installed with large crane C1 | 95% will be reused (67,20*0,95) | 64 | m3 | 50 | - | 7,16 | - | - | - | 457 | 457 | € | 457 | 1,5% |
| Rib plates | 67,20 | m3 | Concrete installed with large crane A4-A5 | 95% will be reused (67,20*0,95) | 64 | m3 | 50 | - | 8,36 | 534 | - | - | - | 534 | € | 534 | 1,7% |
| Rib plates | 67,20 | m3 | Concrete installed with large crane complete | 5% will be replaced (67,20*0,05) | 3 | m3 | 50 | - | 44,36 | 121 | - | - | 28 | 149 | € | 149 | 0,5% |
| Rib plates | 13.440,00 | kg | Reinforcement complete | 5% will be replaced (13440*0,05) | 672 | kg | 50 | - | 0,09 | 133 | - | - | -73 | 60 | € | 60 | 0,2% |
| Rib plates | 440,40 | m | Steel plate complete | 5% will be replaced (440,4*0,05) | 22 | m1 | 50 | - | 3,20 | 111 | - | - | -40 | 71 | € | 71 | 0,2% |
| Rib plates | 5.919,00 | kg | Reinforcement complete | 5% will be replaced (5929*0,05) | 296 | kg | 50 | - | 0,09 | 59 | - | - | -32 | 26 | € | 26 | 0,1% |
| Foundation piles | 11.175,41 | p | Steel piles C1 | 95% will be reused (11175,4*0,95) | 10.617 | p | 50 | - | 0,14 | - | - | - | 1.501 | 1.501 | € | 1.501 | 4,8% |
| Foundation piles | 11.175,41 | p | Steel piles A4-A5 | 95% will be reused (11175,4*0,95) | 10.617 | p | 50 | - | 0,28 | 2.983 | - | - | - | 2.983 | € | 2.983 | 9,5% |
| Foundation piles | 11.175,41 | p | Steel piles complete | 5% will be replaced (11175,4*0,05) | 559 | p | 50 | - | 2,41 | 2.356 | - | - | -1.011 | 1.345 | € | 1.345 | 4,3% |
| Foundation piles | 1.633,21 | m2 | Coating complete | Coating 100% will be replaced | 1.633 | m2 | 50 | - | 2,26 | 1.324 | 49,67 | - | 2.320 | 3.693 | € | 3.693 | 11,7% |
| **Totaal** | | | | | | | | | | | | | | | € | **31.474** | |

**Figure G.5:** ECI of reuse of reusable jetty with 5% replacement

ECI of reuse of reusable jetty with 10% replacement

| Onderdeel/object | Hoeveelheid2 | Eenheid3 | Item | Opmerking | Hoeveelheid | Eenheid | Levensduur (jaar) | Vervang-ingen | MKI per eenheid | MKI aanleg | MKI gebruik | MKI onderhoud | MKI einde levensduur | MKI totaal A t/m D | | MKI totaal | Aandeel MKI per onderdeel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hinged connections | 176,00 | p | Anchor bolt complete | Bolts 100 % will be replaced | 862 | p | 50 | - | 0,03 | 45 | - | - | -15 | 30 | € | 30 | 0,1% |
| Roof tile elements | 1.100,10 | m3 | Concrete installed with large crane C1 | 90% will be reused (1100,1*0,9) | 990 | m3 | 50 | - | 7,16 | - | - | - | 7.093 | 7.093 | € | 7.093 | 19,9% |
| Roof tile elements | 1.100,10 | m3 | Concrete installed with large crane A4-A5 | 90% will be reused (1100,1*0,9) | 990 | m3 | 50 | - | 8,36 | 8.280 | - | - | - | 8.280 | € | 8.280 | 23,3% |
| Roof tile elements | 1.100,10 | m3 | Concrete installed with large crane complete | 10% will be replaced (1101,1*0,1) | 110 | m3 | 50 | - | 44,36 | 3.952 | - | - | 928 | 4.880 | € | 4.880 | 13,7% |
| Roof tile elements | 220.020,00 | kg | Reinforcement complete | 10% will be replaced (220020*0,1) | 22.002 | kg | 50 | - | 0,09 | 4.365 | - | - | -2.401 | 1.965 | € | 1.965 | 5,5% |
| Hinged connections | 8,70 | m3 | Concrete installed with large crane complete | Grout 100% will be replaced | 9 | m3 | 50 | - | 44,36 | 313 | - | - | 73 | 386 | € | 386 | 1,1% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane C1 | 90% will be reused (33,01*0,9) | 30 | m3 | 50 | - | 7,16 | - | - | - | 213 | 213 | € | 213 | 0,6% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane A4-A5 | 90% will be reused (33,01*0,9) | 30 | m3 | 50 | - | 8,36 | 248 | - | - | - | 248 | € | 248 | 0,7% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane complete | 10% will be replaced (33,01*0,1) | 3 | m3 | 50 | - | 44,36 | 119 | - | - | 28 | 146 | € | 146 | 0,4% |
| MLA support beams | 6.602,00 | m3 | Reinforcement complete | 10% will be replaced (6602*0,1) | 660 | kg | 50 | - | 0,09 | 131 | - | - | -72 | 59 | € | 59 | 0,2% |
| Rib plates | 67,20 | m3 | Concrete installed with large crane C1 | 90% will be reused (67,2*0,9) | 60 | m3 | 50 | - | 7,16 | - | - | - | 433 | 433 | € | 433 | 1,2% |
| Rib plates | 67,20 | m3 | Concrete installed with large crane A4-A5 | 90% will be reused (67,2*0,9) | 60 | m3 | 50 | - | 8,36 | 506 | - | - | - | 506 | € | 506 | 1,4% |
| Rib plates | 67,20 | m3 | Concrete installed with large crane complete | 10% will be replaced (67,2*0,1) | 7 | m3 | 50 | - | 44,36 | 241 | - | - | 57 | 298 | € | 298 | 0,8% |
| Rib plates | 13.440,00 | kg | Reinforcement complete | 10% will be replaced (13440*0,1) | 1.344 | kg | 50 | - | 0,09 | 267 | - | - | -147 | 120 | € | 120 | 0,3% |
| Rib plates | 440,40 | m | Steel plate complete | 10% will be replaced (440,4*0,1) | 44 | m1 | 50 | - | 5,24 | 221 | - | - | 10 | 231 | € | 231 | 0,6% |
| Rib plates | 5.919,00 | kg | Reinforcement complete | 10% will be replaced (5919*0,1) | 592 | kg | 50 | - | 0,09 | 117 | - | - | -65 | 53 | € | 53 | 0,1% |
| Foundation piles | 11.175,41 | p | Steel piles C1 | 90% will be reused (11175,41*0,9) | 10.058 | p | 50 | - | 0,14 | - | - | - | 1.422 | 1.422 | € | 1.422 | 4,0% |
| Foundation piles | 11.175,41 | p | Steel piles A4-A5 | 90% will be reused (11175,41*0,9) | 10.058 | p | 50 | - | 0,28 | 2.826 | - | - | - | 2.826 | € | 2.826 | 7,9% |
| Foundation piles | 11.175,41 | p | Steel piles complete | 10% will be replaced (11175,41*0,1) | 1.118 | p | 50 | - | 2,41 | 4.712 | - | - | -2.022 | 2.690 | € | 2.690 | 7,6% |
| Foundation piles | 1.633,21 | m2 | Coating complete | Coating 100% will be replaced | 1.633 | m2 | 50 | - | 2,26 | 1.324 | 49,67 | - | 2.320 | 3.693 | € | 3.693 | 10,4% |
| **Totaal** | | | | | | | | | | | | | | | € | **35.572** | |

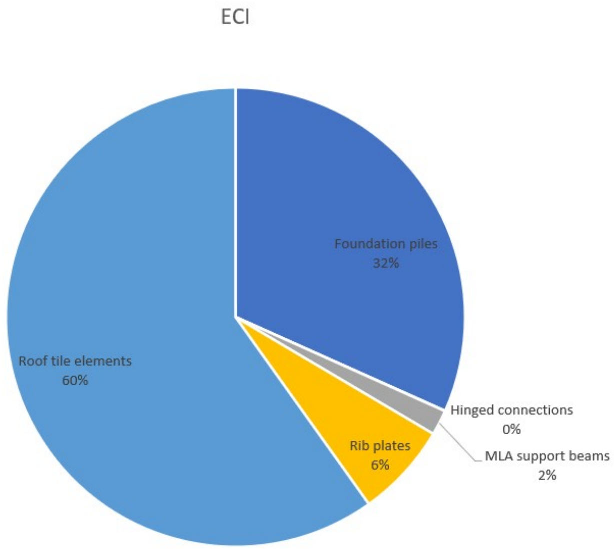
**Figure G.6:** ECI of reuse of reusable jetty with 10% replacement

### G.3.3. Modular reusable jetty

ECI of modular reusable jetty

| Onderdeel/object | Hoeveelheid2 | Eenheid3 | Item | Opmerking | Hoeveelheid | Eenheid | Levensduur (jaar) | Vervang-ingen | MKI per eenheid | MKI aanleg | MKI gebruik | MKI onderhoud | MKI einde levensduur | MKI totaal A t/m D | | MKI totaal | Aandeel MKI per onderdeel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Foundation piles | 13.410,49 | p | Steel piles complete | Placing foundation piles | 13.410 | p | 50 | - | 2,41 | 56.539 | - | - | -24.261 | 32.278 | € | 32.278 | 27,9% |
| Foundation piles | 1.959,86 | m2 | Coating complete | +Coating | 1.960 | m2 | 50 | - | 2,26 | 1.588 | 59,61 | - | 2.784 | 4.432 | € | 4.432 | 3,8% |
| Rib plates | 80,64 | m3 | Concrete installed with large crane complete | Placing rib plates | 81 | m3 | 50 | - | 44,36 | 2.897 | - | - | 680 | 3.577 | € | 3.577 | 3,1% |
| Rib plates | 16.128,00 | kg | Reinforcement complete | +Reinforcement | 16.128 | kg | 50 | - | 0,09 | 3.200 | - | - | -1.760 | 1.440 | € | 1.440 | 1,2% |
| Roof tile elements | 1.114,56 | m3 | Concrete installed with large crane complete | Placing roof tile elements | 1.115 | m3 | 50 | - | 44,36 | 40.040 | - | - | 9.404 | 49.444 | € | 49.444 | 42,7% |
| Roof tile elements | 222.912,00 | kg | Reinforcement complete | +Reinforcement | 222.912 | kg | 50 | - | 0,09 | 44.228 | - | - | -24.324 | 19.904 | € | 19.904 | 17,2% |
| Rib plates | 639,20 | m | Steel plate complete | Steel plates for pile connection | 639 | m1 | 50 | - | 3,20 | 3.211 | - | - | -1.162 | 2.048 | € | 2.048 | 1,8% |
| Rib plates | 7.102,51 | kg | Reinforcement complete | Rods for pile connection | 7.103 | kg | 50 | - | 0,09 | 1.409 | - | - | -775 | 634 | € | 634 | 0,5% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane complete | Placing MLA support beams | 33 | m3 | 50 | - | 44,36 | 1.186 | - | - | 279 | 1.464 | € | 1.464 | 1,3% |
| MLA support beams | 6.602,00 | kg | Reinforcement complete | +Reinforcement | 6.602 | kg | 50 | - | 0,09 | 1.310 | - | - | -720 | 590 | € | 590 | 0,5% |
| Hinged connections | 862,40 | p | Anchor bolt complete | Placing anchor bolts and nuts | 862 | p | 50 | - | 0,03 | 45 | - | - | -15 | 30 | € | 30 | 0,0% |
| **Totaal** | | | | | | | | | | | | | | | € | **115.842** | |

**Figure G.7:** ECI of modular reusable jetty




| Materialen | Totale MKI | Bijdrage |
|---|---|---|
| **Anchor bolt complete** | **€ 30** | **0,0%** |
| Hinged connections | € 30 | 0,0% |
| **Coating complete** | **€ 4.432** | **3,8%** |
| Foundation piles | € 4.432 | 3,8% |
| **Concrete installed with large crane complete** | **€ 54.485** | **47,0%** |
| MLA support beams | € 1.464 | 1,3% |
| Rib plates | € 3.577 | 3,1% |
| Roof tile elements | € 49.444 | 42,7% |
| **Reinforcement complete** | **€ 22.568** | **19,5%** |
| MLA support beams | € 590 | 0,5% |
| Rib plates | € 2.074 | 1,8% |
| Roof tile elements | € 19.904 | 17,2% |
| **Steel piles complete** | **€ 32.278** | **27,9%** |
| Foundation piles | € 32.278 | 27,9% |
| **Steel plate complete** | **€ 2.048** | **1,8%** |
| Rib plates | € 2.048 | 1,8% |
| **Totaal** | **€ 115.842** | **100,0%** |

**Figure G.8:** Relative impact per material and element for modular reusable jetty

ECI of reuse of modular reusable jetty with 5% replacement

| Onderdeel/object | Hoeveelheid2 | Eenheid3 | Item | Opmerking | Hoeveelheid | Eenheid | Levensduur (jaar) | Vervang-ingen | MKI per eenheid | MKI aanleg | MKI gebruik | MKI onderhoud | MKI einde levensduur | MKI totaal A t/m D | MKI totaal | Aandeel MKI per onderdeel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hinged connections | 176,00 | p | Anchor bolt complete | Bolts 100 % will be replaced | 862 | p | 50 | - | 0,03 | 45 | - | - | -15 | 30 | € 30 | 0,1% |
| Roof tile elements | 1.105,86 | m3 | Concrete installed with large crane C1 | 95% will be reused (1105,86*0,95) | 1.051 | m3 | 50 | - | 7,16 | - | - | - | 7.526 | 7.526 | € 7.526 | 22,3% |
| Roof tile elements | 1.105,86 | m3 | Concrete installed with large crane A4-A5 | 95% will be reused (1105,86*0,95) | 1.051 | m3 | 50 | - | 8,36 | 8.786 | - | - | - | 8.786 | € 8.786 | 26,0% |
| Roof tile elements | 1.105,86 | m3 | Concrete installed with large crane complete | 5% will be replaced (1105,86*0,05) | 55 | m3 | 50 | - | 44,36 | 1.986 | - | - | 467 | 2.453 | € 2.453 | 7,3% |
| Roof tile elements | 221.172,00 | kg | Reinforcement complete | 5% will be replaced (221172*0,05) | 11.059 | kg | 50 | - | 0,09 | 2.194 | - | - | -1.207 | 987 | € 987 | 2,9% |
| Hinged connections | 8,70 | m3 | Concrete installed with large crane complete | Grout 100% will be replaced | 9 | m3 | 50 | - | 44,36 | 313 | - | - | 73 | 386 | € 386 | 1,1% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane C1 | 95% will be reused (33,01*0,95) | 31 | m3 | 50 | - | 7,16 | - | - | - | 225 | 225 | € 225 | 0,7% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane A4-A5 | 95% will be reused (33,01*0,95) | 31 | m3 | 50 | - | 8,36 | 262 | - | - | - | 262 | € 262 | 0,8% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane complete | 5% will be replaced (33,01*0,05) | 2 | m3 | 50 | - | 44,36 | 59 | - | - | 14 | 73 | € 73 | 0,2% |
| MLA support beams | 6.602,00 | m3 | Reinforcement complete | 5% will be replaced (6602*0,05) | 330 | kg | 50 | - | 0,09 | 65 | - | - | -36 | 29 | € 29 | 0,1% |
| Rib plates | 80,64 | m3 | Concrete installed with large crane C1 | 95% will be reused (80,64*0,95) | 77 | m3 | 50 | - | 7,16 | - | - | - | 549 | 549 | € 549 | 1,6% |
| Rib plates | 80,64 | m3 | Concrete installed with large crane A4-A5 | 95% will be reused (80,64*0,95) | 77 | m3 | 50 | - | 8,36 | 641 | - | - | - | 641 | € 641 | 1,9% |
| Rib plates | 80,64 | m3 | Concrete installed with large crane complete | 5% will be replaced (80,64*0,05) | 4 | m3 | 50 | - | 44,36 | 145 | - | - | 34 | 179 | € 179 | 0,5% |
| Rib plates | 16.128,00 | kg | Reinforcement complete | 5% will be replaced (16128*0,05) | 806 | kg | 50 | - | 0,09 | 160 | - | - | -88 | 72 | € 72 | 0,2% |
| Rib plates | 639,20 | m | Steel plate complete | 5% will be replaced (639*0,05) | 32 | m1 | 50 | - | 3,20 | 161 | - | - | -58 | 102 | € 102 | 0,3% |
| Rib plates | 7.152,00 | kg | Reinforcement complete | 5% will be replaced (7152*0,05) | 358 | kg | 50 | - | 0,09 | 71 | - | - | -39 | 32 | € 32 | 0,1% |
| Foundation piles | 13.410,49 | p | Steel piles C1 | 95% will be reused (13410,49*0,95) | 12.740 | p | 50 | - | 0,14 | - | - | - | 1.802 | 1.802 | € 1.802 | 5,3% |
| Foundation piles | 13.410,49 | p | Steel piles A4-A5 | 95% will be reused (13410,49*0,95) | 12.740 | p | 50 | - | 0,28 | 3.579 | - | - | - | 3.579 | € 3.579 | 10,6% |
| Foundation piles | 13.410,49 | p | Steel piles complete | 5% will be replaced (13410,49*0,05) | 671 | p | 50 | - | 2,41 | 2.827 | - | - | -1.213 | 1.614 | € 1.614 | 4,8% |
| Foundation piles | 1.959,86 | m2 | Coating complete | Coating 100% will be replaced | 1.960 | m2 | 50 | - | 2,26 | 1.588 | 59,61 | - | 2.784 | 4.432 | € 4.432 | 13,1% |
| **Totaal** | | | | | | | | | | | | | | | **€ 33.759** | |

**Figure G.9:** ECI of reuse of modular reusable jetty with 5% replacement

ECI of reuse of modular reusable jetty with 10% replacement

| Onderdeel/object | Hoeveelhe | Eenheid3 | Item | Opmerking | Hoeveelheid | Eenheid | Levensduur (jaar) | Vervang-ingen | MKI per eenheid | MKI aanleg | MKI gebruik | MKI onderhoud | MKI einde levensduur | MKI totaal | Aandeel MKI per onderdeel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hinged connections | 176,00 | p | Anchor bolt complete | Bolts 100 % will be replaced | 862 | p | 50 | - | 0,03 | 45 | - | - | -15 | € 30 | 0,1% |
| Roof tile elements | 1.105,86 | m3 | Concrete installed with large crane C1 | 90% will be reused (11065,86*0,9) | 995 | m3 | 50 | - | 7,16 | - | - | - | 7.130 | € 7.130 | 18,7% |
| Roof tile elements | 1.105,86 | m3 | Concrete installed with large crane A4-A5 | 90% will be reused (1106*0,9) | 995 | m3 | 50 | - | 8,36 | 8.323 | - | - | - | € 8.323 | 21,9% |
| Roof tile elements | 1.105,86 | m3 | Concrete installed with large crane complete | 10% will be replaced (1106*0,1) | 111 | m3 | 50 | - | 44,36 | 3.973 | - | - | 933 | € 4.906 | 12,9% |
| Roof tile elements | 221.172,00 | kg | Reinforcement complete | 10% will be replaced (221172*0,1) | 22.117 | kg | 50 | - | 0,09 | 4.388 | - | - | -2.413 | € 1.975 | 5,2% |
| Hinged connections | 8,70 | m3 | Concrete installed with large crane complete | Grout 100% will be replaced | 9 | m3 | 50 | - | 44,36 | 313 | - | - | 73 | € 386 | 1,0% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane C1 | 90% will be reused (33,01*0,9) | 30 | m3 | 50 | - | 7,16 | - | - | - | 213 | € 213 | 0,6% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane A4-A5 | 90% will be reused (33,01*0,9) | 30 | m3 | 50 | - | 8,36 | 248 | - | - | - | € 248 | 0,7% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane complete | 10% will be replaced (33,01*0,1) | 3 | m3 | 50 | - | 44,36 | 119 | - | - | 28 | € 146 | 0,4% |
| MLA support beams | 6.602,00 | kg | Reinforcement complete | 10% will be replaced (6602*0,1) | 660 | kg | 50 | - | 0,09 | 131 | - | - | -72 | € 59 | 0,2% |
| Rib plates | 80,64 | m3 | Concrete installed with large crane C1 | 90% will be reused (80,64*0,9) | 73 | m3 | 50 | - | 7,16 | - | - | - | 520 | € 520 | 1,4% |
| Rib plates | 80,64 | m3 | Concrete installed with large crane A4-A5 | 90% will be reused (80,64*0,9) | 73 | m3 | 50 | - | 8,36 | 607 | - | - | - | € 607 | 1,6% |
| Rib plates | 80,64 | m3 | Concrete installed with large crane complete | 10% will be replaced (80,64*0,1) | 8 | m3 | 50 | - | 44,36 | 290 | - | - | 68 | € 358 | 0,9% |
| Rib plates | 16.128,00 | kg | Reinforcement complete | 10% will be replaced (16128*0,1) | 1.613 | kg | 50 | - | 0,09 | 320 | - | - | -176 | € 144 | 0,4% |
| Rib plates | 639,20 | m | Steel plate complete | 10% will be replaced (639,2*0,1) | 64 | m1 | 50 | - | 3,20 | 321 | - | - | -116 | € 205 | 0,5% |
| Rib plates | 7.152,00 | kg | Reinforcement complete | 10% will be replaced (7152*0,1) | 715 | kg | 50 | - | 0,09 | 142 | - | - | -78 | € 64 | 0,2% |
| Foundation piles | 13.410,49 | p | Steel piles C1 | 90% will be reused (13410,49*0,9) | 12.069 | p | 50 | - | 0,14 | - | - | - | 1.707 | € 1.707 | 4,5% |
| Foundation piles | 13.410,49 | p | Steel piles A4-A5 | 90% will be reused (13410,49*0,9) | 12.069 | p | 50 | - | 0,28 | 3.391 | - | - | - | € 3.391 | 8,9% |
| Foundation piles | 13.410,49 | p | Steel piles complete | 10% will be replaced (13410,49*0,1) | 1.341 | p | 50 | - | 2,41 | 5.654 | - | - | -2.426 | € 3.228 | 8,5% |
| Foundation piles | 1.959,86 | m2 | Coating complete | Coating 100% will be replaced | 1.960 | m2 | 50 | - | 2,26 | 1.588 | 59,61 | - | 2.784 | € 4.432 | 11,6% |
| Totaal | | | | | | | | | | | | | | € 38.071 | |

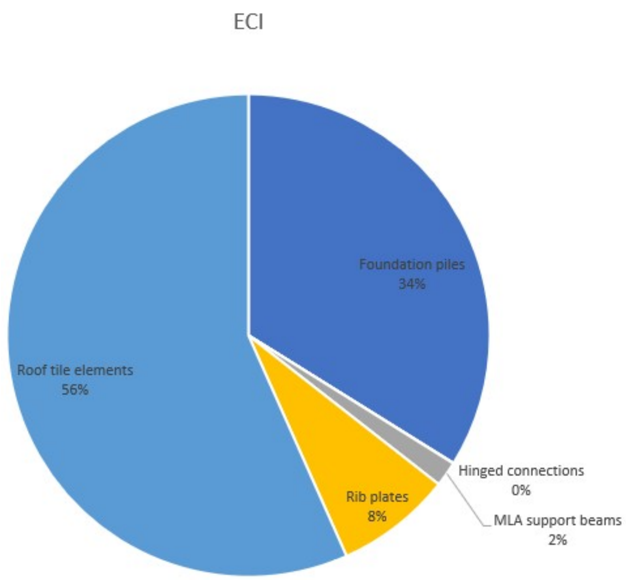
**Figure G.10:** ECI of reuse of modular reusable jetty with 10% replacement

## G.3.4. Modular reusable jetty with low clinker concrete

ECI of modular reusable jetty with low clinker concrete

| Onderdeel/object | Hoeveelheid2 | Eenheid3 | Item | Opmerking | Hoeveelheid | Eenheid | Levensduur (jaar) | Vervang-ingen | MKI per eenheid | MKI aanleg | MKI gebruik | MKI onderhoud | MKI einde levensduur | MKI totaal A t/m D | MKI totaal | Aandeel MKI per onderdeel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Foundation piles | 13.410,49 | p | Steel piles complete | Placing foundation piles | 13.410 | p | 50 | - | 2,41 | 56.539 | - | - | -24.261 | 32.278 | € 32.278 | 30,1% |
| Foundation piles | 1.959,86 | m2 | Coating complete | +Coating | 1.960 | m2 | 50 | - | 2,26 | 1.588 | 59,61 | - | 2.784 | 4.432 | € 4.432 | 4,1% |
| Rib plates | 80,64 | m3 | Concrete installed with large crane using less clinker cor | Placing rib plates | 81 | m3 | 100 | - | 37,24 | 2.322 | - | - | 681 | 3.003 | € 3.003 | 2,8% |
| Rib plates | 16.128,00 | kg | Reinforcement complete | +Reinforcement | 16.128 | kg | 50 | - | 0,09 | 3.200 | - | - | -1.760 | 1.440 | € 1.440 | 1,3% |
| Roof tile elements | 1.114,56 | m3 | Concrete installed with large crane using less clinker cor | Placing roof tile elements | 1.115 | m3 | 100 | - | 37,24 | 32.098 | - | - | 9.413 | 41.511 | € 41.511 | 38,8% |
| Roof tile elements | 222.912,00 | kg | Reinforcement complete | +Reinforcement | 222.912 | kg | 50 | - | 0,09 | 44.228 | - | - | -24.324 | 19.904 | € 19.904 | 18,6% |
| Rib plates | 639,20 | m | Steel plate complete | Steel plates for pile connection | 639 | m1 | 50 | - | 3,20 | 3.211 | - | - | -1.162 | 2.048 | € 2.048 | 1,9% |
| Rib plates | 7.102,51 | kg | Reinforcement complete | Rods for pile connection | 7.103 | kg | 50 | - | 0,09 | 1.409 | - | - | -775 | 634 | € 634 | 0,6% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane using less clinker cor | Placing MLA support beams | 33 | m3 | 100 | - | 37,24 | 951 | - | - | 279 | 1.229 | € 1.229 | 1,1% |
| MLA support beams | 6.602,00 | kg | Reinforcement complete | +Reinforcement | 6.602 | kg | 50 | - | 0,09 | 1.310 | - | - | -720 | 590 | € 590 | 0,6% |
| Hinged connections | 862,40 | p | Anchor bolt complete | Placing anchor bolts and nuts | 862 | p | 50 | - | 0,03 | 45 | - | - | -15 | 30 | € 30 | 0,0% |
| Totaal | | | | | | | | | | | | | | | € 107.101 | |

**Figure G.11:** ECI of modular reusable jetty with low clinker concrete




| Materialen | Totale MKI | Bijdrage |
|---|---|---|
| **Anchor bolt complete** | **€ 30** | **0,0%** |
| Hinged connections | € 30 | 0,0% |
| **Coating complete** | **€ 4.432** | **4,1%** |
| Foundation piles | € 4.432 | 4,1% |
| **Concrete installed with large crane using less clinker complete** | **€ 45.744** | **42,7%** |
| MLA support beams | € 1.229 | 1,1% |
| Rib plates | € 3.003 | 2,8% |
| Roof tile elements | € 41.511 | 38,8% |
| **Reinforcement complete** | **€ 22.568** | **21,1%** |
| MLA support beams | € 590 | 0,6% |
| Rib plates | € 2.074 | 1,9% |
| Roof tile elements | € 19.904 | 18,6% |
| **Steel piles complete** | **€ 32.278** | **30,1%** |
| Foundation piles | € 32.278 | 30,1% |
| **Steel plate complete** | **€ 2.048** | **1,9%** |
| Rib plates | € 2.048 | 1,9% |
| **Totaal** | **€ 107.101** | **100,0%** |

**Figure G.12:** Relative impact per material and element for modular reusable jetty with low clinker concrete

ECI of reuse of modular reusable jetty with low clinker concrete with 5% replacement

| Onderdeel/object | Hoeveelhe | Eenh | Item | Opmerking | Hoeveel heid | Eenheid | Levensduur (jaar) | Vervang- ingen | MKI per eenheid | MKI aanleg | MKI gebruik | MKI onderhoud | MKI einde levensduur | MKI totaal A t/m D | MKI totaal | Aandeel MKI per onderdeel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hinged connections | 176,00 | p | Anchor bolt complete | Bolts 100 % will be replaced | 862 | p | 50 | - | 0,03 | 45 | - | - | -15 | 30 | € 30 | 0,1% |
| Roof tile elements | 1.105,86 | m3 | Concrete installed with large crane using less clinker C1 | 95% will be reused (1105,86*0,95) | 1.051 | m3 | 100 | - | 7,16 | - | - | - | 7.526 | 7.526 | € 7.526 | 22,8% |
| Roof tile elements | 1.105,86 | m3 | Concrete installed with large crane using less clinker A4-A5 | 95% will be reused (1105,86*0,95) | 1.051 | m3 | 100 | - | 8,08 | 8.490 | - | - | - | 8.490 | € 8.490 | 25,8% |
| Roof tile elements | 1.105,86 | m3 | Concrete installed with large crane using less clinker complete | 5% will be replaced (1105,86*0,05) | 55 | m3 | 100 | - | 37,24 | 1.592 | - | - | 467 | 2.059 | € 2.059 | 6,3% |
| Roof tile elements | 221.172,00 | kg | Reinforcement complete | 5% will be replaced (221172*0,05) | 11.059 | kg | 50 | - | 0,09 | 2.194 | - | - | -1.207 | 987 | € 987 | 3,0% |
| Hinged connections | 8,70 | m3 | Concrete installed with large crane using less clinker complete | Grout 100% will be replaced | 9 | m3 | 100 | - | 37,24 | 251 | - | - | 73 | 324 | € 324 | 1,0% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane using less clinker C1 | 95% will be reused (33,01*0,95) | 31 | m3 | 100 | - | 7,16 | - | - | - | 225 | 225 | € 225 | 0,7% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane using less clinker A4-A5 | 95% will be reused (33,01*0,95) | 31 | m3 | 100 | - | 8,08 | 253 | - | - | - | 253 | € 253 | 0,8% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane using less clinker complete | 5% will be replaced (33,01*0,05) | 2 | m3 | 100 | - | 37,24 | 48 | - | - | 14 | 61 | € 61 | 0,2% |
| MLA support beams | 6.602,00 | m3 | Reinforcement complete | 5% will be replaced (6602*0,05) | 330 | kg | 50 | - | 0,09 | 65 | - | - | -36 | 29 | € 29 | 0,1% |
| Rib plates | 80,64 | m3 | Concrete installed with large crane using less clinker C1 | 95% will be reused (80,64*0,95) | 77 | m3 | 100 | - | 7,16 | - | - | - | 549 | 549 | € 549 | 1,7% |
| Rib plates | 80,64 | m3 | Concrete installed with large crane using less clinker A4-A5 | 95% will be reused (80,64*0,95) | 77 | m3 | 100 | - | 8,08 | 619 | - | - | - | 619 | € 619 | 1,9% |
| Rib plates | 80,64 | m3 | Concrete installed with large crane using less clinker complete | 5% will be replaced (80,64*0,05) | 4 | m3 | 100 | - | 37,24 | 116 | - | - | 34 | 150 | € 150 | 0,5% |
| Rib plates | 16.128,00 | kg | Reinforcement complete | 5% will be replaced (16128*0,05) | 806 | kg | 50 | - | 0,09 | 160 | - | - | -88 | 72 | € 72 | 0,2% |
| Rib plates | 639,20 | m | Steel plate complete | 5% will be replaced (639*0,05) | 32 | m1 | 50 | - | 3,20 | 161 | - | - | -58 | 102 | € 102 | 0,3% |
| Rib plates | 7.152,00 | kg | Reinforcement complete | 5% will be replaced (7152*0,05) | 358 | kg | 50 | - | 0,09 | 71 | - | - | -39 | 32 | € 32 | 0,1% |
| Foundation piles | 13.410,49 | p | Steel piles C1 | 95% will be reused (13410,49*0,95) | 12.740 | p | 50 | - | 0,14 | - | - | - | 1.802 | 1.802 | € 1.802 | 5,5% |
| Foundation piles | 13.410,49 | p | Steel piles A4-A5 | 95% will be reused (13410,49*0,95) | 12.740 | p | 50 | - | 0,28 | 3.579 | - | - | - | 3.579 | € 3.579 | 10,9% |
| Foundation piles | 13.410,49 | p | Steel piles complete | 5% will be replaced (13410,49*0,05) | 671 | p | 50 | - | 2,41 | 2.827 | - | - | -1.213 | 1.614 | € 1.614 | 4,9% |
| Foundation piles | 1.959,86 | m2 | Coating complete | Coating 100% will be replaced | 1.960 | m2 | 50 | - | 2,26 | 1.588 | 59,61 | - | 2.784 | 4.432 | € 4.432 | 13,5% |
| Totaal | | | | | | | | | | | | | | | € 32.937 | |

**Figure G.13:** ECI of reuse of modular reusable jetty with low clinker concrete with 5% replacement

ECI of reuse of modular reusable jetty with low clinker concrete with 10% replacement

| Onderdeel/object | Hoeveelheid2 | Eenheid3 | Item | Opmerking | Hoeveelheid | Eenheid | Levensduur (jaar) | Vervang- ingen | MKI per eenheid | MKI aanleg | MKI gebruik | MKI onderhoud | MKI einde levensduur | MKI totaal A t/m D | MKI totaal | Aandeel MKI per onderdeel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hinged connections | 176,00 | p | Anchor bolt complete | Bolts 100 % will be replaced | 862 | p | 50 | - | 0,03 | 45 | - | - | -15 | 30 | € 30 | 0,1% |
| Roof tile elements | 1.105,86 | m3 | Concrete installed with large crane using less clinker C1 | 90% will be reused (11065,86*0,9) | 995 | m3 | 100 | - | 7,16 | - | - | - | 7.130 | 7.130 | € 7.130 | 19,4% |
| Roof tile elements | 1.105,86 | m3 | Concrete installed with large crane using less clinker A4-A5 | 90% will be reused (1106*0,9) | 995 | m3 | 100 | - | 8,08 | 8.043 | - | - | - | 8.043 | € 8.043 | 21,8% |
| Roof tile elements | 1.105,86 | m3 | Concrete installed with large crane using less clinker complete | 10% will be replaced (1106*0,1) | 111 | m3 | 100 | - | 37,24 | 3.185 | - | - | 934 | 4.119 | € 4.119 | 11,2% |
| Roof tile elements | 221.172,00 | kg | Reinforcement complete | 10% will be replaced (221172*0,1) | 22.117 | kg | 50 | - | 0,09 | 4.388 | - | - | -2.413 | 1.975 | € 1.975 | 5,4% |
| Hinged connections | 8,70 | m3 | Concrete installed with large crane using less clinker complete | Grout 100% will be replaced | 9 | m3 | 100 | - | 37,24 | 251 | - | - | 73 | 324 | € 324 | 0,9% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane using less clinker C1 | 90% will be reused (33,01*0,9) | 30 | m3 | 100 | - | 7,16 | - | - | - | 213 | 213 | € 213 | 0,6% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane using less clinker A4-A5 | 90% will be reused (33,01*0,9) | 30 | m3 | 100 | - | 8,08 | 240 | - | - | - | 240 | € 240 | 0,7% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane using less clinker complete | 10% will be replaced (33,01*0,1) | 3 | m3 | 100 | - | 37,24 | 95 | - | - | 28 | 123 | € 123 | 0,3% |
| MLA support beams | 6.602,00 | m3 | Reinforcement complete | 10% will be replaced (6602*0,1) | 660 | kg | 50 | - | 0,09 | 131 | - | - | -72 | 59 | € 59 | 0,2% |
| Rib plates | 80,64 | m3 | Concrete installed with large crane using less clinker C1 | 90% will be reused (80,64*0,9) | 73 | m3 | 100 | - | 7,16 | - | - | - | 520 | 520 | € 520 | 1,4% |
| Rib plates | 80,64 | m3 | Concrete installed with large crane using less clinker A4-A5 | 90% will be reused (80,64*0,9) | 73 | m3 | 100 | - | 8,08 | 587 | - | - | - | 587 | € 587 | 1,6% |
| Rib plates | 80,64 | m3 | Concrete installed with large crane using less clinker complete | 10% will be replaced (80,64*0,1) | 8 | m3 | 100 | - | 37,24 | 232 | - | - | 68 | 300 | € 300 | 0,8% |
| Rib plates | 16.128,00 | kg | Reinforcement complete | 10% will be replaced (16128*0,1) | 1.613 | kg | 50 | - | 0,09 | 320 | - | - | -176 | 144 | € 144 | 0,4% |
| Rib plates | 639,20 | m | Steel plate complete | 10% will be replaced (639,2*0,1) | 64 | m1 | 50 | - | 3,20 | 321 | - | - | -116 | 205 | € 205 | 0,6% |
| Rib plates | 7.152,00 | kg | Reinforcement complete | 10% will be replaced (7152*0,1) | 715 | kg | 50 | - | 0,09 | 142 | - | - | -78 | 64 | € 64 | 0,2% |
| Foundation piles | 13.410,49 | p | Steel piles C1 | 90% will be reused (13410,49*0,9) | 12.069 | p | 50 | - | 0,14 | - | - | - | 1.707 | 1.707 | € 1.707 | 4,6% |
| Foundation piles | 13.410,49 | p | Steel piles A4-A5 | 90% will be reused (13410,49*0,9) | 12.069 | p | 50 | - | 0,28 | 3.391 | - | - | - | 3.391 | € 3.391 | 9,2% |
| Foundation piles | 13.410,49 | p | Steel piles complete | 10% will be replaced (13410,49*0,1) | 1.341 | p | 50 | - | 2,41 | 5.654 | - | - | -2.426 | 3.228 | € 3.228 | 8,8% |
| Foundation piles | 1.959,86 | m2 | Coating complete | Coating 100% will be replaced | 1.960 | m2 | 50 | - | 2,26 | 1.588 | 59,61 | - | 2.784 | 4.432 | € 4.432 | 12,0% |
| Totaal | | | | | | | | | | | | | | | € 36.833 | |

**Figure G.14:** ECI of reuse of modular reusable jetty with low clinker concrete with 10% replacement

# G.4. Results for taking into account energy transition

## G.4.1. Reference jetty

ECI of reference jetty

| Onderdeel/object | Hoeveelheid2 | Eenheid3 | Item | Opmerking | Hoeveelheid | Eenheid | Levensduur (jaar) | Vervang-ingen | MKI per eenheid | MKI aanleg | MKI gebruik | MKI onderhoud | MKI einde levensduur | MKI totaal A t/m D | MKI totaal | Aandeel MKI per onderdeel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Foundation piles | 9.780,41 | p | Steel piles | Placing foundation piles | 10.269 | p | 50 | - | 2,02 | 40.730 | - | - | -20.031 | 20.700 | € 20.700 | 24,2% |
| Foundation piles | 1.429,34 | m2 | Coating | +Coating | 1.501 | m2 | 50 | - | 1,93 | 1.216 | 45,65 | - | 1.632 | 2.894 | € 2.894 | 3,4% |
| Rib plates | 336,00 | m3 | Concrete installed with regular crane | Placing rib plates | 353 | m3 | 50 | - | 30,08 | 10.163 | - | - | 449 | 10.612 | € 10.612 | 12,4% |
| Rib plates | 67.200,00 | kg | Reinforcement | +Reinforcement | 70.560 | kg | 50 | - | 0,09 | 14.000 | - | - | -7.699 | 6.300 | € 6.300 | 7,4% |
| Rib plates | 385,35 | m | Steel plate | Steel plates for pile connection | 405 | m1 | 50 | - | 2,79 | 2.032 | - | - | -902 | 1.130 | € 1.130 | 1,3% |
| Rib plates | 5.178,91 | kg | Reinforcement | Rods for pile connection | 5.438 | kg | 50 | - | 0,09 | 1.079 | - | - | -593 | 486 | € 486 | 0,6% |
| Deck plates | 304,08 | m3 | Concrete installed with regular crane | Placing deck plates | 319 | m3 | 50 | - | 30,08 | 9.197 | - | - | 407 | 9.604 | € 9.604 | 11,2% |
| Deck plates | 60.816,00 | kg | Reinforcement | +Reinforcement | 63.857 | kg | 50 | - | 0,09 | 12.670 | - | - | -6.968 | 5.702 | € 5.702 | 6,7% |
| MLA support beams | 33,01 | m3 | Concrete installed with regular crane | Placing MLA support beams | 35 | m3 | 50 | - | 30,08 | 998 | - | - | 44 | 1.043 | € 1.043 | 1,2% |
| MLA support beams | 6.602,00 | kg | Reinforcement | +Reinforcement | 6.932 | kg | 50 | - | 0,09 | 1.375 | - | - | -756 | 619 | € 619 | 0,7% |
| Compression layer | 525,60 | m3 | Concrete installed with regular crane | Placing in situ compression layer | 552 | m3 | 50 | - | 30,08 | 15.898 | - | - | 703 | 16.600 | € 16.600 | 19,4% |
| Compression layer | 105.120,00 | kg | Reinforcement | +Reinforcement | 110.376 | kg | 50 | - | 0,09 | 21.900 | - | - | -12.044 | 9.856 | € 9.856 | 11,5% |
| Totaal | | | | | | | | | | | | | | | € 85.545 | |

**Figure G.15:** ECI of reference jetty with energy transition

# G.5. Results for taking into account energy transition

## G.5.1. Reference jetty

ECI of reference jetty

| Onderdeel/object | Hoeveelheid2 | Eenheid3 | Item | Opmerking | Hoeveelheid | Eenheid | Levensduur (jaar) | Vervang-ingen | MKI per eenheid | MKI aanleg | MKI gebruik | MKI onderhoud | MKI einde levensduur | MKI totaal A t/m D | MKI totaal | Aandeel MKI per onderdeel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Foundation piles | 9.780,41 | p | Steel piles | Placing foundation piles | 10.269 | p | 50 | - | 2,02 | 40.730 | - | - | -20.031 | 20.700 | € 20.700 | 24,2% |
| Foundation piles | 1.429,34 | m2 | Coating | +Coating | 1.501 | m2 | 50 | - | 1,93 | 1.216 | 45,65 | - | 1.632 | 2.894 | € 2.894 | 3,4% |
| Rib plates | 336,00 | m3 | Concrete installed with regular crane | Placing rib plates | 353 | m3 | 50 | - | 30,08 | 10.163 | - | - | 449 | 10.612 | € 10.612 | 12,4% |
| Rib plates | 67.200,00 | kg | Reinforcement | +Reinforcement | 70.560 | kg | 50 | - | 0,09 | 14.000 | - | - | -7.699 | 6.300 | € 6.300 | 7,4% |
| Rib plates | 385,35 | m | Steel plate | Steel plates for pile connection | 405 | m1 | 50 | - | 2,79 | 2.032 | - | - | -902 | 1.130 | € 1.130 | 1,3% |
| Rib plates | 5.178,91 | kg | Reinforcement | Rods for pile connection | 5.438 | kg | 50 | - | 0,09 | 1.079 | - | - | -593 | 486 | € 486 | 0,6% |
| Deck plates | 304,08 | m3 | Concrete installed with regular crane | Placing deck plates | 319 | m3 | 50 | - | 30,08 | 9.197 | - | - | 407 | 9.604 | € 9.604 | 11,2% |
| Deck plates | 60.816,00 | kg | Reinforcement | +Reinforcement | 63.857 | kg | 50 | - | 0,09 | 12.670 | - | - | -6.968 | 5.702 | € 5.702 | 6,7% |
| MLA support beams | 33,01 | m3 | Concrete installed with regular crane | Placing MLA support beams | 35 | m3 | 50 | - | 30,08 | 998 | - | - | 44 | 1.043 | € 1.043 | 1,2% |
| MLA support beams | 6.602,00 | kg | Reinforcement | +Reinforcement | 6.932 | kg | 50 | - | 0,09 | 1.375 | - | - | -756 | 619 | € 619 | 0,7% |
| Compression layer | 525,60 | m3 | Concrete installed with regular crane | Placing in situ compression layer | 552 | m3 | 50 | - | 30,08 | 15.898 | - | - | 703 | 16.600 | € 16.600 | 19,4% |
| Compression layer | 105.120,00 | kg | Reinforcement | +Reinforcement | 110.376 | kg | 50 | - | 0,09 | 21.900 | - | - | -12.044 | 9.856 | € 9.856 | 11,5% |
| Totaal | | | | | | | | | | | | | | | € 85.545 | |

**Figure G.16:** ECI of reference jetty with energy transition

## G.5.2. Modular reusable jetty with low clinker concrete

ECI of modular reusable jetty with low clinker concrete

| Onderdeel/object | Hoeveelheid2 | Eenheid3 | Item | Opmerking | Hoeveelheid | Eenheid | Levensduur (jaar) | Vervang-ingen | MKI per eenheid | MKI aanleg | MKI gebruik | MKI onderhoud | MKI einde levensduur | MKI totaal A t/m D | MKI totaal | Aandeel MKI per onderdeel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Foundation piles | 13.410,49 | p | Steel piles complete | Placing foundation piles | 14.081 | p | 50 | - | 2,02 | 55.848 | - | - | -27.465 | 28.383 | € 28.383 | 32,0% |
| Foundation piles | 1.959,86 | m2 | Coating complete | +Coating | 2.058 | m2 | 50 | - | 1,93 | 1.668 | 62,59 | - | 2.237 | 3.968 | € 3.968 | 4,5% |
| Rib plates | 80,64 | m3 | Concrete installed with large crane using less clinker cor | Placing rib plates | 85 | m3 | 50 | - | 23,82 | 1.909 | - | - | 109 | 2.017 | € 2.017 | 2,3% |
| Rib plates | 16.128,00 | kg | Reinforcement complete | +Reinforcement | 16.934 | kg | 50 | - | 0,09 | 3.360 | - | - | -1.848 | 1.512 | € 1.512 | 1,7% |
| Roof tile elements | 1.114,56 | m3 | Concrete installed with large crane using less clinker cor | Placing roof tile elements | 1.170 | m3 | 50 | - | 23,82 | 26.381 | - | - | 1.500 | 27.881 | € 27.881 | 31,4% |
| Roof tile elements | 222.912,00 | kg | Reinforcement complete | +Reinforcement | 234.058 | kg | 50 | - | 0,09 | 46.439 | - | - | -25.540 | 20.899 | € 20.899 | 23,6% |
| Rib plates | 639,20 | m | Steel plate complete | Steel plates for pile connection | 671 | m1 | 50 | - | 2,79 | 3.371 | - | - | -1.497 | 1.874 | € 1.874 | 2,1% |
| Rib plates | 7.102,51 | kg | Reinforcement complete | Rods for pile connection | 7.458 | kg | 50 | - | 0,09 | 1.480 | - | - | -814 | 666 | € 666 | 0,8% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane using less clinker cor | Placing MLA support beams | 35 | m3 | 50 | - | 23,82 | 781 | - | - | 44 | 826 | € 826 | 0,9% |
| MLA support beams | 6.602,00 | kg | Reinforcement complete | +Reinforcement | 6.932 | kg | 50 | - | 0,09 | 1.375 | - | - | -756 | 619 | € 619 | 0,7% |
| Hinged connections | 862,40 | p | Anchor bolt complete | Placing anchor bolts and nuts | 906 | p | 50 | - | 0,03 | 46 | - | - | -15 | 30 | € 30 | 0,0% |
| **Totaal** | | | | | | | | | | | | | | | **€ 88.675** | |

**Figure G.17:** ECI of modular reusable jetty with low clinker concrete with energy transition

ECI of reuse of modular reusable jetty with low clinker concrete with 5% replacement

| Onderdeel/object | Hoeveelhe | Eenh | Item | Opmerking | Hoeveelheid | Eenheid | Levensduur (jaar) | Vervang-ingen | MKI per eenheid | MKI aanleg | MKI gebruik | MKI onderhoud | MKI einde levensduur | MKI totaal A t/m D | MKI totaal | Aandeel MKI per onderdeel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hinged connections | 176,00 | p | Anchor bolt complete | Bolts 100 % will be replaced | 906 | p | 50 | - | 0,03 | 46 | - | - | -15 | 30 | € 30 | 0,4% |
| Roof tile elements | 1.105,86 | m3 | Concrete installed with large crane using less clinker C1 | 95% will be reused (1105,86*0,95) | 1.051 | m3 | 50 | - | - | - | - | - | - | - | € - | 0,0% |
| Roof tile elements | 1.105,86 | m3 | Concrete installed with large crane using less clinker A4-A5 | 95% will be reused (1105,86*0,95) | 1.051 | m3 | 50 | - | - | - | - | - | - | - | € - | 0,0% |
| Roof tile elements | 1.105,86 | m3 | Concrete installed with large crane using less clinker complete | 5% will be replaced (1105,86*0,05) | 55 | m3 | 50 | - | 23,82 | 1.246 | - | - | 71 | 1.317 | € 1.317 | 16,0% |
| Roof tile elements | 221.172,00 | kg | Reinforcement complete | 5% will be replaced (221172*0,05) | 11.059 | kg | 50 | - | 0,09 | 2.194 | - | - | -1.207 | 987 | € 987 | 12,0% |
| Hinged connections | 8,70 | m3 | Concrete installed with large crane using less clinker complete | Grout 100% will be replaced | 9 | m3 | 50 | - | 23,82 | 206 | - | - | 12 | 218 | € 218 | 2,6% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane using less clinker C1 | 95% will be reused (33,01*0,95) | 31 | m3 | 50 | - | - | - | - | - | - | - | € - | 0,0% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane using less clinker A4-A5 | 95% will be reused (33,01*0,95) | 31 | m3 | 50 | - | - | - | - | - | - | - | € - | 0,0% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane using less clinker complete | 5% will be replaced (33,01*0,05) | 2 | m3 | 50 | - | 23,82 | 37 | - | - | 2 | 39 | € 39 | 0,5% |
| MLA support beams | 6.602,00 | m3 | Reinforcement complete | 5% will be replaced (6602*0,05) | 330 | kg | 50 | - | 0,09 | 65 | - | - | -36 | 29 | € 29 | 0,4% |
| Rib plates | 80,64 | m3 | Concrete installed with large crane using less clinker C1 | 95% will be reused (80,64*0,95) | 77 | m3 | 50 | - | - | - | - | - | - | - | € - | 0,0% |
| Rib plates | 80,64 | m3 | Concrete installed with large crane using less clinker A4-A5 | 95% will be reused (80,64*0,95) | 77 | m3 | 50 | - | - | - | - | - | - | - | € - | 0,0% |
| Rib plates | 80,64 | m3 | Concrete installed with large crane using less clinker complete | 5% will be replaced (80,64*0,05) | 4 | m3 | 50 | - | 23,82 | 91 | - | - | 5 | 96 | € 96 | 1,2% |
| Rib plates | 16.128,00 | kg | Reinforcement complete | 5% will be replaced (16128*0,05) | 806 | kg | 50 | - | 0,09 | 160 | - | - | -88 | 72 | € 72 | 0,9% |
| Rib plates | 639,20 | m | Steel plate complete | 5% will be replaced (639*0,05) | 32 | m1 | 50 | - | 2,79 | 161 | - | - | -71 | 89 | € 89 | 1,1% |
| Rib plates | 7.152,00 | kg | Reinforcement complete | 5% will be replaced (7152*0,05) | 358 | kg | 50 | - | 0,09 | 71 | - | - | -39 | 32 | € 32 | 0,4% |
| Foundation piles | 13.410,49 | p | Steel piles C1 | 95% will be reused (13410,49*0,95) | 12.740 | p | 50 | - | - | - | - | - | - | - | € - | 0,0% |
| Foundation piles | 13.410,49 | p | Steel piles A4-A5 | 95% will be reused (13410,49*0,95) | 12.740 | p | 50 | - | - | - | - | - | - | - | € - | 0,0% |
| Foundation piles | 13.410,49 | p | Steel piles complete | 5% will be replaced (13410,49*0,05) | 671 | p | 50 | - | 2,02 | 2.659 | - | - | -1.308 | 1.352 | € 1.352 | 16,4% |
| Foundation piles | 1.959,86 | m2 | Coating complete | Coating 100% will be replaced | 2.058 | m2 | 50 | - | 1,93 | 1.668 | 62,59 | - | 2.237 | 3.968 | € 3.968 | 48,2% |
| **Totaal** | | | | | | | | | | | | | | | **€ 8.230** | |

**Figure G.18:** ECI of reuse of modular reusable jetty with low clinker concrete with 5% replacement with energy transition

ECI of reuse of modular reusable jetty with low clinker concrete with 10% replacement

| Onderdeel/object | Hoeveelheid2 | Eenheid3 | Item | Opmerking | Hoeveelheid | Eenheid | Levensduur (jaar) | Vervang-ingen | MKI per eenheid | MKI aanleg | MKI gebruik | MKI onderhoud | MKI einde levensduur | MKI totaal A t/m D | MKI totaal | Aandeel MKI per onderdeel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hinged connections | 176,00 | p | Anchor bolt complete | Bolts 100 % will be replaced | 906 | p | 50 | - | 0,03 | 46 | - | - | -15 | 30 | € 30 | 0,8% |
| Roof tile elements | 1.105,86 | m3 | Concrete installed with large crane using less clinker C1 | 90% will be reused (11065,86*0,9) | | m3 | 100 | - | - | | | | | - | € - | 0,0% |
| Roof tile elements | 1.105,86 | m3 | Concrete installed with large crane using less clinker A4-A5 | 90% will be reused (1106*0,9) | | m3 | 100 | - | - | - | - | - | - | - | € - | 0,0% |
| Roof tile elements | 1.105,86 | m3 | Concrete installed with large crane using less clinker complete | 10% will be replaced (1106*0,1) | \begin{figure}[H] | m3 | 100 | - | 23,82 | | | | | - | € - | 0,0% |
| Roof tile elements | 221.172,00 | kg | Reinforcement complete | 10% will be replaced (221172*0,1) | \centering | kg | 50 | - | 0,09 | | | | | - | € - | 0,0% |
| Hinged connections | 8,70 | m3 | Concrete installed with large crane using less clinker complete | Grout 100% will be replaced | \includegraphi | m3 | 100 | - | 23,82 | | | | | - | € - | 0,0% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane using less clinker C1 | 90% will be reused (33,01*0,9) | \caption{ECI | m3 | 100 | - | - | | | | | - | € - | 0,0% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane using less clinker A4-A5 | 90% will be reused (33,01*0,9) | \end{figure} | m3 | 100 | - | - | | | | | - | € - | 0,0% |
| MLA support beams | 33,01 | m3 | Concrete installed with large crane using less clinker complete | 10% will be replaced (33,01*0,1) | | m3 | 100 | - | 23,82 | - | - | - | - | - | € - | 0,0% |
| MLA support beams | 6.602,00 | m3 | Reinforcement complete | 10% will be replaced (6602*0,1) | \begin{figure}[H] | kg | 50 | - | 0,09 | | | | | - | € - | 0,0% |
| Rib plates | 80,64 | m3 | Concrete installed with large crane using less clinker C1 | 90% will be reused (80,64*0,9) | \centering | m3 | 100 | - | - | | | | | - | € - | 0,0% |
| Rib plates | 80,64 | m3 | Concrete installed with large crane using less clinker A4-A5 | 90% will be reused (80,64*0,9) | | m3 | 100 | - | - | | | | | - | € - | 0,0% |
| Rib plates | 80,64 | m3 | Concrete installed with large crane using less clinker complete | 10% will be replaced (80,64*0,1) | | m3 | 100 | - | 23,82 | | | | | - | € - | 0,0% |
| Rib plates | 16.128,00 | kg | Reinforcement complete | 10% will be replaced (16128*0,1) | | kg | 50 | - | 0,09 | | | | | - | € - | 0,0% |
| Rib plates | 639,20 | m | Steel plate complete | 10% will be replaced (639,2*0,1) | | m1 | 50 | - | 2,79 | | | | | - | € - | 0,0% |
| Rib plates | 7.152,00 | kg | Reinforcement complete | 10% will be replaced (7152*0,1) | | kg | 50 | - | 0,09 | | | | | - | € - | 0,0% |
| Foundation piles | 13.410,49 | p | Steel piles C1 | 90% will be reused (13410,49*0,9) | | p | 50 | - | - | | | | | - | € - | 0,0% |
| Foundation piles | 13.410,49 | p | Steel piles A4-A5 | 90% will be reused (13410,49*0,9) | | p | 50 | - | - | | | | | - | € - | 0,0% |
| Foundation piles | 13.410,49 | p | Steel piles complete | 10% will be replaced (13410,49*0,1) | \end{figure} | p | 50 | - | 2,02 | | | | | - | € - | 0,0% |
| Foundation piles | 1.959,86 | m2 | Coating complete | Coating 100% will be replaced | 2.058 | m2 | 50 | - | 1,93 | 1.668 | 62,59 | - | 2.237 | 3.968 | € 3.968 | 99,2% |
| **Totaal** | | | | | | | | | | | | | | | **€ 3.998** | |

**Figure G.19:** ECI of reuse of modular reusable jetty with low clinker concrete with 10% replacement with energy transition