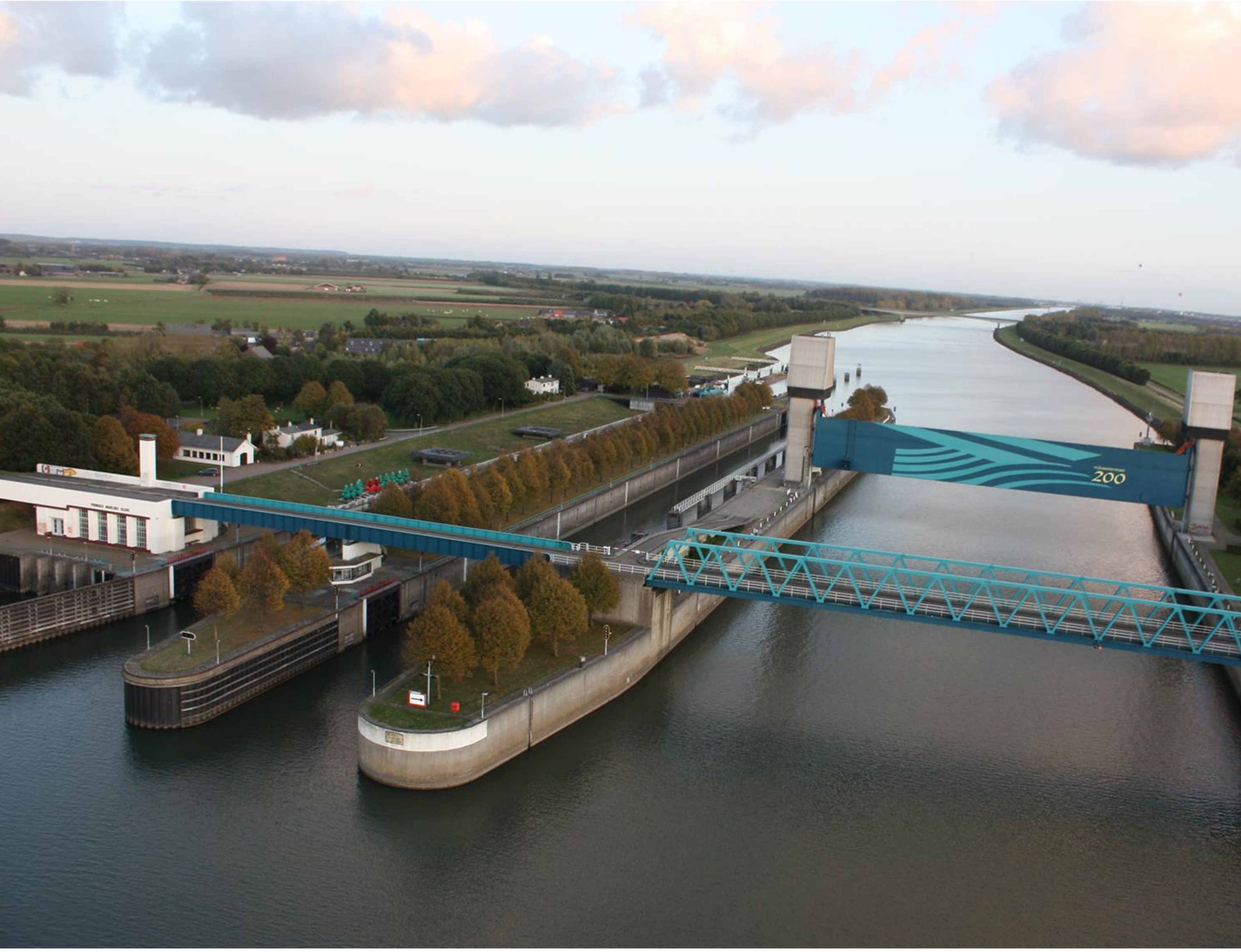
A parametric decision model for navigational lock components

With the Prinses Marijkesluizen as case study



TU Delft

Rijkswaterstaat
Ministry of Infrastructure and Water Management

A parametric decision model for navigational lock components

With the Prinses Marijkesluizen as case study

By

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Thesis Committee:

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Rijkswaterstaat
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Preface

This thesis is part of my master program Hydraulic Engineering with specialisation track Hydraulic Structures at the faculty of Civil Engineering of Delft University of Technology.

After finishing most of the Master courses, the search for an interesting master thesis subject began. I am used to sailing around the Dutch waterways, and one of the most important hydraulic structures you come around by doing so is a navigational lock. I was always wondering why every navigational lock you come across is totally different from the next one and from the previous one. This was the main reason why I immediately responded when I found out about the graduation topic of standardization of navigational locks proposed by Rijkswaterstaat. After a conversation with a very enthusiastic Erik-Jan Houwing of Rijkswaterstaat and Mark Voorendt of the TU Delft, I knew I had found my topic.

After reading myself into the work already done regarding the standardization of navigational locks, I had drawn the conclusion that there were already reports about standardization of navigational locks in a qualitative sense, but there was not a quantitative approach which could support these qualitive works from a civil engineering perspective. This has led to the making of a parametric model for navigational lock components for this thesis.

I would like to thank the people of my committee who have put an enormous effort in helping me to finish this thesis. I would like to thank dr. E.J. Houwing, for his enthusiasm and his natural talent to motivate, but also for the enormous effort he put in improving the quality of the thesis. I would like to thank dr. ing. M.Z. Voorendt, for all the time he spent in reading and improving draft versions of the thesis. I would like to thank prof. dr. ir. S.N. Jonkman for his clear and to the point feedback, which has helped by making the report better in quality and better to understand, and I would like to thank dr. ir. R. Abspoel for all the help he gave me regarding the parametric model.

Besides the members of the committee, I would like to thank the people of the unit 'Grote Projecten en Onderhoud' of Rijkswaterstaat, for the good ambiance there was during work and I would like to thank Gerard Bouwman of Rijkswaterstaat for his expertise about steel designs of navigational lock gates and his willingness to help me with the parametric design regarding this subject.

Bart Dudink

Delft, 31 Oktober 2018

Summary

Motivation
There are many different lock-layouts with different kinds of components in the Netherlands. This makes it difficult and expensive to maintain the navigation locks and keep reliability and availability at a high level. Rijkswaterstaat needs to renovate or replace more than 50 locks in the coming 40 years. This enormous task leads to an opportunity of standardising certain components in the locks in the Netherlands. Standardization potentially reduces costs (both construction costs and maintenance costs) and would reduce differences in lock layouts which potentially leads to a higher reliability and availability. Implementing standardization in the design process for the lock replacement/renovation has great potential for the lock replacement/renovation project of Rijkswaterstaat.

Standardization in the design process
A navigational lock consists of several different components. These components could have several variants. For example, one component of a navigational lock is the gate type. This gate type can be a mitre gate, a rolling gate or another variant of this component.

Using one specific, standardised component for every situation would lead to over dimensioning of this component (there is often not one component which is best in every situation). Therefore, a decision method is proposed to decide what gate type is best in which specific case. This decision model potentially leads to a case specific prescription (standardization) of a specific component. Having this prescription clear for all the possible cases in the Netherlands will help with standardising the gate types, since it is clear what component should be used in what situation and no other options of variants for this component will be used. A parametric design for the component chosen to be standardised is used to evaluate several variants for this component, this design will be the heart of the decision model. This parametric design can be used in the general design process in several ways. Design choices can be made earlier on with the information obtained by the designs of the various variants (having a design for several variants from the start on makes it easier to assess what variants will be worked out in more detail and what not). The design of a specific variant can be optimised using the model as well.

Highest standardization potential components
A navigational lock consists of numerous different components. Not every component is worth standardising. According to a literature study and an overview of the different lock components the gate types have the highest potential for standardization. Since the gate type also has the biggest influence on the design of the navigational lock as a whole, the way of standardising the gate type for navigational locks is the focus at the thesis. The gate types investigated in more detail by the use of a parametric model are mitre gate without clearance, mitre gate with clearance and rolling gate. For every location in the Netherlands one of these gate types can be used as a solution. Only designs of these gate types in steel are considered. This consideration is made since steel is the most widely used material for navigational lock gates, and since steel could be used for all boundary conditions present in the Netherlands.

Parametric decision model to standardise
The parametric model is used to generate an optimised design based on steel volume used. The boundary conditions are made variable, so in every situation in the Netherlands an optimised design could be generated by the model. The variable boundary conditions used are water level on both sides, and total lock width. Every gate type variant consists of a set of elements which have as function to carry the load to the lock heads. These elements are optimised in such a way that the loads are resisted but the material volume used is minimised. The specific lay out of the structural elements in terms of which structural element is present in what gate is not variable, the number and location of structural elements present in the gate is variable.

A proposition is made to turn the material volume used and the design of the gate variants into costs. The availability could be translated to costs, with the right information. Besides costs, a final decision should be made based on space occupation and functional requirements such as the ability to close the gate with water level differences.

Findings

The parametric model can be used to assess a wide range of boundary conditions, and can be used to compare material volume for the Prinses Marijkesluizen case for different gate types.
A prescription for a specific gate type variant can’t be made based on the model output for bilateral retaining gates, since the output results of the model are almost similar for both gate types. One reason could be that the model only contains one layout per gate variant. The addition of more components related to the gate type variants (such as actuators and lock heads) could also give better comparable results. Due to lack of information (and a large uncertainty in estimation), the steel volume used can’t be turned into costs with a large precision. For the Prinses Marijkesluizen case study an estimation of costs based on welding costs and material costs is calculated. The model was able to estimate those costs and to give an optimised design. The mitre gate with clearance gave the best results in terms of lowest steel volume used. The addition of availability and reliability costs isn’t possible since not enough data about reparations is available. A better record of information would lead to better estimates for important design parameters (existing design recordings), and would lead to make addition of several components easier (availability and maintenance recordings).
The parametric model can be very useful to optimise gate type variant designs, and to obtain information about relevance of parameters. The model provides a good starting point for making a more detailed design afterwards.

Content

1 Introduction

1.1 Motivation for the thesis

Nowadays navigational locks in The Netherlands all have different, case specific, features (different gate types, different actuators etc.). This makes maintenance complicated. Spare parts are not always on stock and knowledge about maintenance is not always readily available. An example of this diverse number of specific features can be found in Figure 1. In Figure 1 different used locks in the world for specific boundary conditions are presented. For locks up to around 10m in head and 25m in width (which are quite common in the Netherlands), mitre gates, rolling gates, sector gates and lift gates are being used. This indicates that a lot of different possibilities are being used for this component for 1 set of boundary conditions.

More than 50 locks owned by Rijkswaterstaat need replacement or renovation in the coming 40 years. Due to this fact an opportunity for changing the traditional way of building and maintaining navigational locks has arisen. Due to the replacement/renovation of locks in the coming time implementing a new owning and building strategy is relatively easy.

Because of this opportunity, MultiWaterWerken (MWW) has been founded by Rijkswaterstaat. The goal of MWW is to increase availability and reliability, and to decrease the maintenance and construction costs. This goal could potentially be partly reached by standardization.

Standardization could make an end to the diversification of navigational lock features. This would make maintaining locks easier, since the ask for different spare parts and case specific knowledge about maintenance would decrease. Besides the positive effects of standardization on maintenance, standardization could help reaching the other MWW goals as well. Experience in the use of specific components will increase if instead of different parts with the same purpose, always one standardised component is used. This would lead to more knowledge about the behaviour of the component in different circumstances, which has positive effects on the reliability of the standardised component. With a higher reliability and better maintainability, the availability of locks would increase (which will be discussed in more detail later on in Chapter 8). Construction costs will potentially be reduced while standardising components, because of scale effects of applying the same standardised component several times.

Having one standard lock for every situation would lead to an over dimensioned design which compromises the optimal situation. For different situations, different standardized component variants will be advised by means of a generic decision model. The problem of which component variant should be chosen in what situation will be solved in this thesis. A design in detail will not be presented for these component variants. The 'market' should come up with detailed designs, the market competition will lead to better detailed designs for the component variants, since there is a strong drive to come up with optimal designs between different parties. To check whether the model can be applied, a case study is carried out.

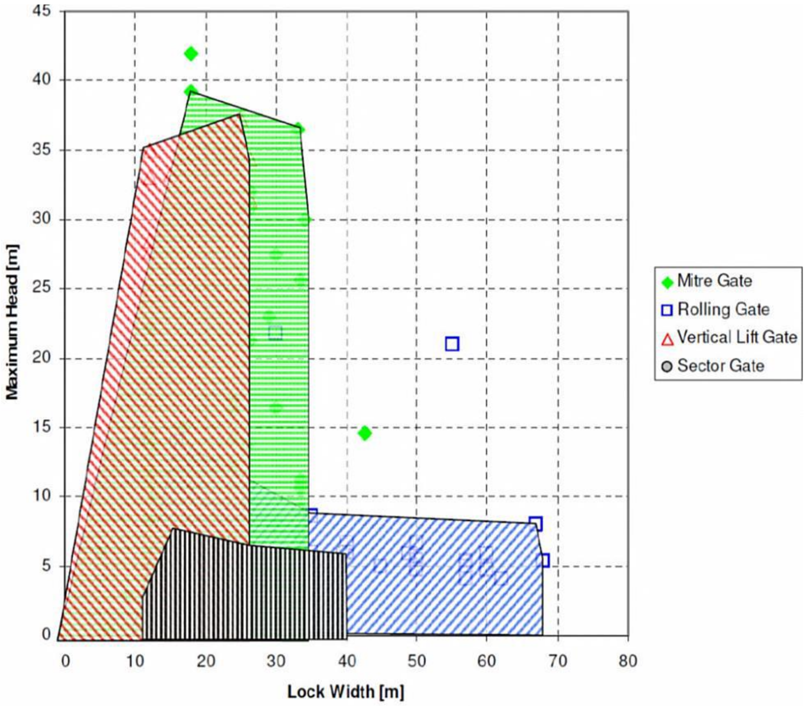


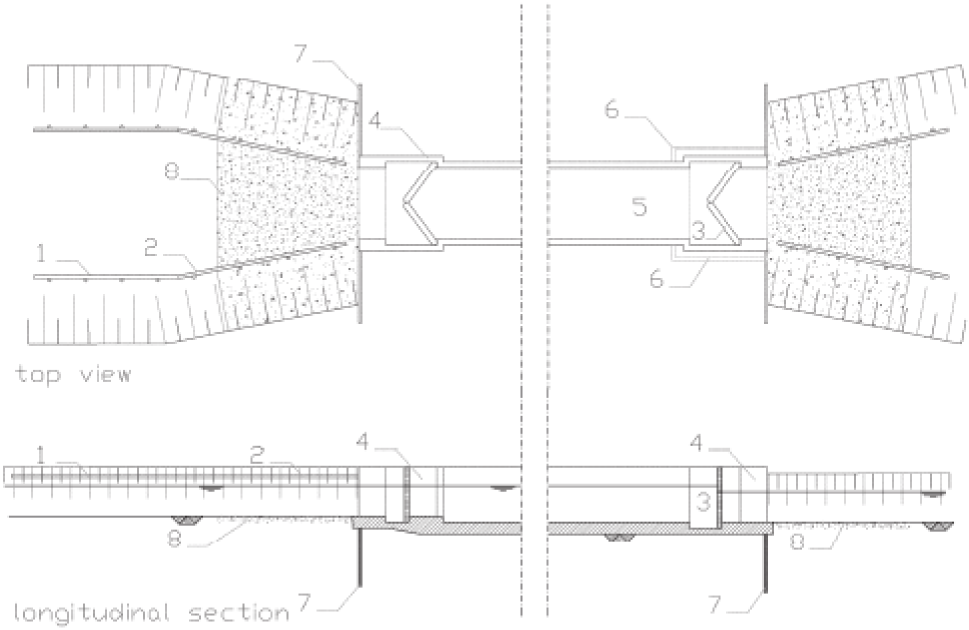
Figure 1 Existing navigational lock gates of several locks in the world for specific boundary conditions (Alphen, 2013)

1.2 Problem exploration

In the previous chapter the word standardization was one of the key words. The key words which are often used in this thesis will be explained in this chapter, this gives an impression of the problems accounted for in the thesis. The term standardization is used for the process of prescribing a specific variant for a specific range of situations. An example is prescribing a mitre gate (variant) for a gate width of 5-20 m (boundary condition). The advantages and disadvantages of standardization from different perspectives will be discussed in chapter 3.

Standardization can be applied on different levels, there is a difference between prescribing a totally standardised navigation lock, with standardised gates, actuators and levelling systems, or only prescribing a lock with standardised gates. To investigate standardization of navigational locks, the navigation lock is divided into different (smaller) parts. This process is called modularization. The word modularization is used for the process of dividing an object in different parts. These parts should be independent from each other. These components should be integrated to function as a whole system. (https://www.igiglobal.com/dictionary/modularisation/19144, sd).

The parts which are created in the process of modularization are called components in this thesis.
A lock consists of several components that can have several forms of appearance in different locks. Not every lock consists of all the possible components. The most important lock components are presented below in Figure 2. Components can have subcomponents: A gate type (component) needs an actuator (subcomponent) for movement. The term component is related to a function, not to a form of appearance.



1.	Waiting- or lay-by berths	1.	*Wachtplaatsen*
2.	Guard- or guide wall or lead-in jetty	2.	*Geleidewerken*
3.	'Closing elements' – lock gates	3.	*Afsluitmiddelen – sluisdeuren*
4.	Lock heads	4.	*Sluishoofden*
5.	Lock chamber	5.	*Schutkolk*
6.	Filling and emptying system	6.	*Vul- en ledigsysteem*
7.	Cut-off walls and screens (sheetpiles) to prevent piping	7.	*Voorzieningen tegen onderloopsheid en achterloopsheid (kwelschermen)*
8.	Bottom protection	8.	*Bodembescherming*

Figure 2 Lock components (Molenaar, 2011)

A specific component can have several variants. The same holds for subcomponents. Variants describe the form of appearance of the component. A gate type (component) can be a mitre gate (variant for the component gate type) and this mitre gate can have as actuator (subcomponent) a panama wheel (variant for the subcomponent gate type). In Figure 3, several variants (mitre gate, rolling gate, lift gate etc.) of the component gate type are presented. The corresponding subcomponents for the most used gate type variants (guidance, actuator, levelling system are subcomponents for variant lift gate for instance) are presented too.

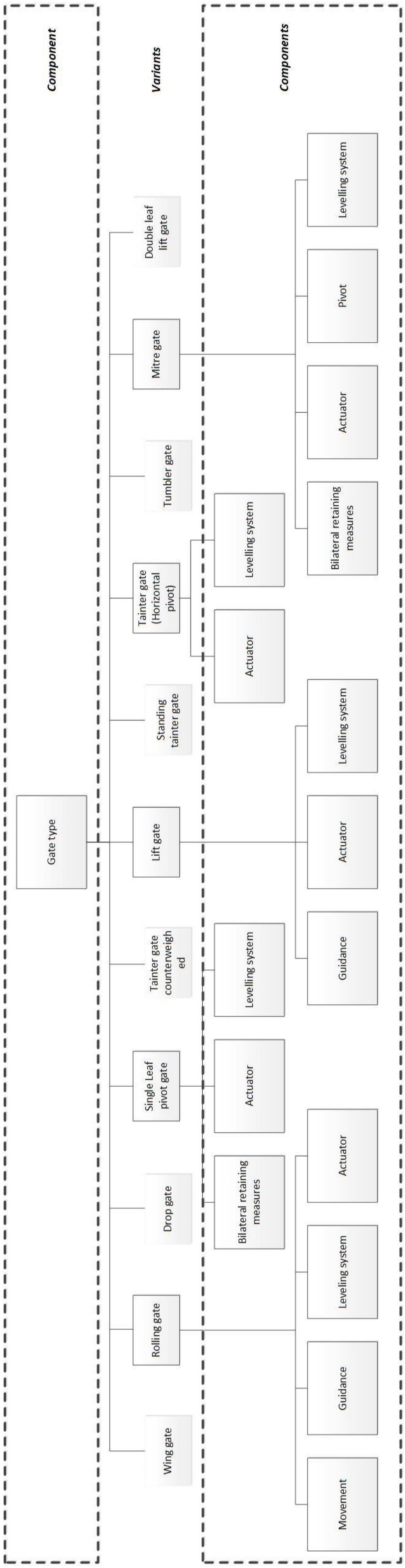


Figure 3 Gate types

To investigate whether component variants can resist the loads they are subjected too, the boundary conditions should be known. Boundary conditions are conditions at the location of the design which have to be accounted for by the design of an object (navigational lock for instance). What variant is most suitable depends on the boundary conditions at the location of the project and on the functional requirements (functional requirements are treated below). Water level, head difference, soil type present and wind speed are examples of boundary conditions. The final design will follow from this load. Functional requirements are the requirements that have to be fulfilled by an object to ensure its functioning (navigational lock at this thesis). Specific ship class passage and allowable lock cycle time are examples of functional requirements. Boundary conditions and general requirements usually lead to the governing loads or to other criteria which are governing for the component variant.

1.3 Research Objective

1.3.1 Problem Statement

There are different lock-layouts with different kinds of components. This makes it difficult and expensive to maintain the navigation locks and keep reliability and availability at a high level.

1.3.2 Goal

A method which helps with implementing standardization hasn't been described yet. There are currently several designs of standardised lock components for locks in the Netherlands, but the high potential standardised components haven't been designed yet. The goal of the thesis is therefor to create a decision model for the standardization of lock components. This decision model will be applicable for every situation in the Netherlands and will take the MWW goals (increasing reliability, availability and maintainability) into account. The decision model is made for the lock component with the highest potential for standardization.

1.3.3 Scope

In this thesis it is determined which navigational lock component has the highest potential for standardization. The thesis only investigates variants for this component. Only alternatives which are suitable for the situation in the Netherlands are investigated in more detail for only one material type. The main focus is on the method used, therefor only one type of variants is investigated. The main evaluation will be based on structural designs of the variants made in the thesis. The method presented should be easy to use by Rijkswaterstaat. Changes or additions to the model should be relatively easy to implement by Rijkswaterstaat.

1.3.4 Research questions

First of all, the advantages and disadvantages of standardization should be known in order to come up with a good decision model which helps with standardization. This decision model won't be applied to every navigational lock component, so the different lock components are made clear, and the components which have high potential reaching the goal are made clear. With this information known a decision model is made which is based on quantitative arguments. Qualitative arguments are presented as well.

The goal will be reached by answering the following research questions:

1. What are the advantages and disadvantages of standardization with the help of a decision model?
2. How can standardization be applied to the general design process?
3. Of what components does a navigation lock consist?
4. What navigation lock components have the biggest potential for reaching the MultiWaterWerken goals by means of standardization?
5. How will a decision be made based on quantitative and qualitative arguments?

1.4 Research method

A decision model is the product of the thesis. The research questions answered to come to this model have been derived in the previous Chapter. The way of coming to the answers to the research questions is discussed in this paragraph.

1. Process question 1: "What are the advantages and disadvantages of standardization with the help of a decision model?"

The first step is to have an answer to the question why standardization is beneficial in the first place. This is done with the help of a literature study. This question is answered with help of the thesis of Robert Slijk, Standardization in river locks! (Slijk, 2013). How this standardization could be achieved with the help of a decision model is explained as well.

2. Process question 2: "How could standardization be applied in the general design process?"

A way of implementing a standardization strategy in the general design process leads to the answer to question 2. An analysis of the design methodology has been performed to come to this answer. This standardization strategy will be used as backbone for the other research questions.

3. Process question 3: "Of what components does a navigational lock consist?"

The next is to inventory the different lock components, this is essential background information which is needed for the decision which components benefit from standardising and which not. These components and the relations between these components are presented in a graphical manner. The variants of the components are presented in addition.

The main component variants are compared and the advantages and disadvantages of the specific variants are presented. The advantages and disadvantages will be used for deciding which component variants are the 'best variants' for a specific case at the decision method.

The relations between the main components are presented in this chapter too. This is helpful to understand how a decision for a certain component variant has an effect on the other components.

4. Process question 4: "What navigation lock components have the biggest potential for reaching the MultiWaterWerken goals by means of standardization?"

A literature study is performed to decide which components have the highest potential for standardization. With the help of 3 documents (Thesis by Robert Slijk, expert study by IV infra and a proposed paper by Tim Wilschut) it is decided which components are worth considering in more detail in this thesis, with the focus on standardization. This is important, since the aim of the thesis is to come to a method which helps to make decisions in an early stadium of the design process which will help with standardising components. This standardization will be achieved since certain component variants can already be prescribed.

5. Process question 5: "How will a decision be made based on quantitative and qualitative arguments?"

In question 3 and 4 the existing components with variants, the relation between these components and the components which have high potential for standardization are investigated. This leads to the components that will be considered in more detail. Only the high potential components are considered in question 5. How the components will be evaluated is explained below.

Modelling of the different component variants leads to the answer of this research question. The component variants are evaluated to know which variant is the 'best variant' for a specific set of boundary conditions and functional requirements. In this thesis a parametric model is presented to compare different variants for several sets of boundary conditions and functional requirements. This model gives the amounts of material needed for every component with a variable input. This amount of material can be translated to costs (construction costs and maintenance costs). A proposal for the translation to construction costs is given in this thesis. The costs are only a part of the variant evaluation. The qualitative considerations which are important to consider to make a final decision are presented as an answer to research question 5 as well.

A case study is performed to show how the decision will be made in practice. From this case study the advantages of the decision method presented will become clear.

1.5 Thesis outline

This thesis can roughly be divided into 3 main parts:

1. A general part regarding standardization, consisting of Research question 1 and 2 (Chapter 2 and 3)
2. A general part regarding lock components, consisting of research question 3 and 4 (Chapter 4 and 5)
3. The actual decision model and it's design principles, consisting of research question 5 (Chapter 6, 7, 8 and 9)

The division of these main parts per chapter, and the focus per chapter is explained below:

Part 1:
Chapter 2 and 3 have a more general character regarding standardization.
Chapter 2 explains the advantages and disadvantages of standardization in general, this is the answer to research question 1.
Chapter 3 explains how standardization in general could be applied to the design process, this is the answer to research question 2.

Part 2:
Chapters 4 and 5 are related to lock components in general.
Chapter 4 gives and overview of the lock components present in a navigation lock, this is the answer to research question 3.
Chapter 5 gives an answer to which navigation lock component has the highest potential for standardization. This is the answer to research question 4

Part 3:
Chapter 6,7,8 and 9 present the decision model, the working principles behind the model and the results. These chapters combined give an answer to research question 5.
Chapter 6 show the working principles of the parametric design itself, including the lay outs of the different designs included in the model.
Chapter 7 gives the results of the parametric model.
Chapter 8 gives an overview of several qualitative arguments, and a way of implementing costs in the evaluation of the component variants.
In Chapter 9 a case study is performed to show the working principles of the decision model with a real-life case.

Chapter 10 and 11 present the overall conclusions and recommendations of this thesis.

2 Advantages and disadvantages of standardization in the decision model

This Chapter gives an answer to the first research question: "what are the advantages and disadvantages of standardization with the help of a decision model?".
As discussed in the introduction, due to the need of replacement or restauration of over 50 navigational locks in the coming decades, an opportunity has arisen in order to implement standardised designs. Standardised designs could potentially reduce overall costs and increase the predictability and maintainability of the navigational locks. The purpose of this chapter is to explain (briefly) the potential of standardization, and to explain why a decision model could be helpful in standardization.

2.1 Possible advantages and disadvantages of standardization

In the thesis written by Robert Slijk (Slijk, 2013) several effects of standardization have been discussed. The most important direct advantages and disadvantages discussed by Robert Slijk will be discussed in more detail at this paragraph.

2.1.1 Advantages of standardization

- Reduced Costs due to scale effects

This reduction can be seen on different levels. First of all, the construction costs are likely to decrease, since components will be built over and over, optimising the way of building a certain component. Scale effects are likely to occur because of the higher volumes needed of a certain product.

- Reduced costs due to same maintenance procedure

Maintenance will tend to become easier in case of standardised lock components, since all the components will be maintained in the same way, and therefore the maintenance workers will get more accustomed to the components. The information about maintaining the components is better accessible too, since the detailed drawings are interchangeable, and not every component need its own manual.

- Less components in stock

Decreasing the number of different components will lead to a decrease in number of components needed in stock too. This is particularly useful in case of locks with mitre gates, since locks with mitre gates have usually a spare gate. Decreasing the number of spare gates needed from 1 per mitre gate lock, to 1 per a set of mitre gate locks have potentially a big impact.

- Increased predictability due to more data

Since the same components will be used in more cases, there will be more data available about the behaviour of the standardised components. This will lead to a higher predictability of the components, and better knowledge about the characteristics of the components (which can lead to better designs).

- Recycling of standardised components

Recycling will be easier when the components have the same characteristics. This will decrease future costs and have a possible positive influence on environmental issues.

2.1.2 Disadvantages of standardization

- Over dimensioning

Having standardised components potentially leads to less optimal designs, since situations differ from situation to situation (which all could have different optimal designs).

- Loss of flexibility in design

The use of standardised components could lead to a situation where it is prescribed that certain components should be used. This leaves less room for adjusting components to the specific situation at the location of the navigational lock.

- Less competition on the market

Different parties normally have different solutions for a specific situation. If only a certain solution is prescribed, there is a possibility less parties have the experience and expertise to be able to make a component in such a way.

- Relatively high replacement costs at start

Since standardization is most beneficial when all components which are suitable for standardization have been adjusted to the new standard, a lot of components would need replacement when implementing a standardised component. Of course the replacement doesn't have to be performed at once necessarily

- Systematic errors

When there is an error in one component, standardization would lead to have this error at all standardised locks instead of only one.

2.2 Use of a decision model with the aim for standardization

One important aspect of standardization is prescribing specific standardised components. The model which is the product of this thesis has as goal to gain knowledge about prescribing components for the component which has highest potential for standardization. Since in civil engineering environmental boundary conditions tend to differ to quite a large extent, it is not likely that for every situation, 1 standard component will suffice, without over dimensioning enormously. Therefore, it should be investigated in what case (as in, for what set of boundary conditions and functional requirements) a certain component variant should be used. When this question has been answered, component variants can be prescribed (based on thoughtful decisions).

2.3 Thesis in Perspective of other research

In previous studies it has been made clear that standardization could potentially be very beneficial for Rijkswaterstaat to implement in the maintaining and replacement strategy for navigational locks. When standardization will be applied for navigational locks it should be applied in the coming years, since most locks need replacement or renovation in the coming 40 years.
Studies have been performed about which components have the highest potential of standardization (which is described in the second next Chapter). This logically leads to the next step, which is research on how standardization could be implemented. This is investigated in this thesis.

2.4 Concluding remarks

Standardization has potential for lowering costs and to increase the predictability of navigational lock components. Special attention should be paid to the fact that the lock components won't get over dimensioned too much and that standardization could lead to less competitive designs. When conforming to a certain standardised design from the start on the replacement costs are potentially relatively high.

3 Decision model as part of the design process

This chapter will give an answer to research question 2: ‘How can standardization be applied to the general design process?’
Information about how the decision model could be used as a tool in the design process, and what place it will take in the design process is presented. The model must be seen as part of the design process, not as a tool to come directly to an optimal, functional, detailed design.

3.1 The design process in general

The design process can be described with Figure 5. The design process is a cyclical process. First a rough design is made and used as starting point for a more detailed design. For every design stage the steps in Figure 4 will be taken (De Ridder, Suddle, & Soons, 2009), *“http://wikid.io.tudelft.nl/WikID/index.php/Basic_design_cycle”*. The analysis is meant to come to the criteria needed, the synthesis leads to a design, based on the criteria, the simulation tests the design and the evaluation values the design. The first design usually doesn’t lead to the best design, so the cycle has to be walked through several times in order to have a good design. Knowledge obtained in a previous design can be used to improve the new design. It can take a long time to walk through the whole process. It is common to make designs for several alternatives and to compare those alternatives. The alternatives will be valued and the ‘best alternative’ will be chosen. It is often time consuming to design several alternatives, and it is sometimes difficult to assess which alternative is best.

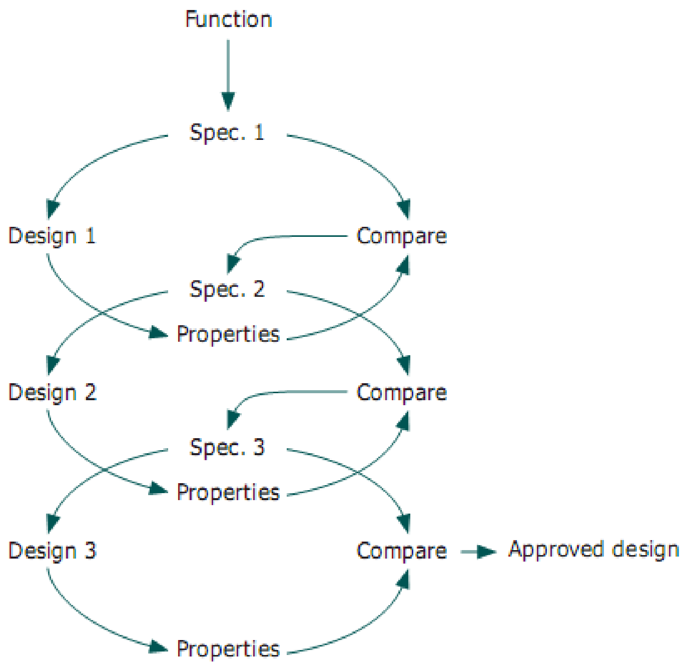


Figure 4 Design process, from coarse to fine

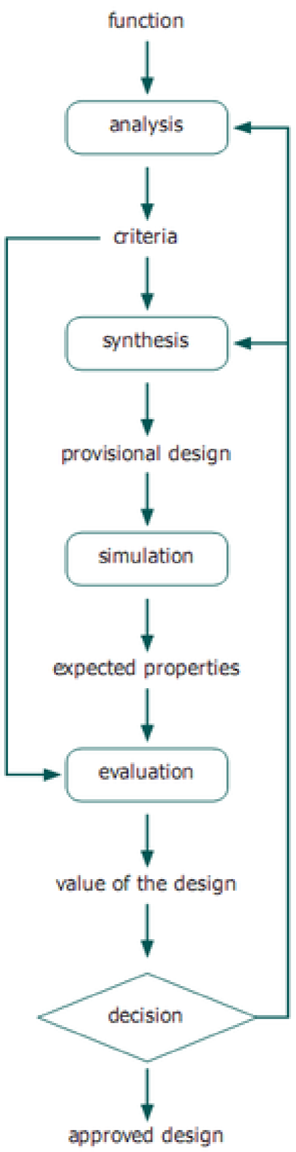


Figure 5 Basic design cycle (http://wikid.io.tudelft.nl/WikID/index.php/Basic_design_cycle)

3.2 Decision model in general in the design process

A decision model in general helps with making decisions in the design process, on several levels. First of all, the normal design process leads to the consideration of several alternatives for a specific case. This leads in reality to several totally different design alternatives from which one design will be ultimately chosen. A decision model could help making this decision in an earlier stage, which leads to choosing few design alternatives from start without considering the other alternatives.

On a more detailed level, a decision model could be very helpful as well. The design of one specific alternative starts with a very coarse design, which leads to knowledge about how the more detailed design should look like, or in other words, the decisions made to improve the specific alternative design follow from the coarse design. Having had several designs, from coarse to fine, leads to knowledge how the specific design alternative will be the most competitive. If decisions made in this process are already known from start, the very coarse design can already be a bit finer, which reduces the amount of designs made (and therefor reduce the amount of time needed for the design).

3.3 Parametric model as decision model

A parametric model is programmed in Microsoft Excel as backbone of the decision model. A parametric model is a design in which the boundary conditions and are implemented as variables. This has as advantage that the input of the model can be totally variable, so a design as output can be generated for several boundary conditions and functional requirements.
The advantage of such a model is that it is easy to assess different situations. It is also easy to assess different designs for a specific location (with specific boundary conditions and functional requirements). The effects of changing a certain parameter can easily be assessed too. The output of the model is material need, which can be translated to construction costs. The parametric model enables the user to make a first design for a specific location (with corresponding functional requirements and boundary conditions). This helps in the design process (as discussed above). The effect of a change in boundary conditions and functional requirements can be seen quickly too (only change the input in the model and compare the differences in the designs).

Since different gate types have been programmed in the model, an assessment can be made about which gate type to design in detail and which not. The effects of making small changes in the designs can be seen in the model too. Altogether, a parametric model will provide valuable information for comparing gate types, comparing different boundary conditions and functional requirements and for a detailed design in the next phase, just as discussed in the previous paragraph.

Excel is used as software because of several reasons. First of all, excel can be used by every firm, and almost every engineer will be able to use excel. Excel can be used to present the output in an orderly manner too. Excel enables other engineers to add information, designs or loads in a relatively easy way too. A disadvantage of excel is that it is relatively slow. Luckily, more than enough information about a certain situation can be extracted in less than a week, so the model won't be so slow that it causes any troubles.

3.4 Parametric model in the design process

The parametric model can be used to replace the synthesis, simulation and evaluation in the design process of Figure 5 for the relatively coarse designs. The first design for Figure 4, from coarse to fine, can be replaced by the parametric model design. The amount of design variants needed can be reduced by the parametric model as well.

The parametric model can be used in several ways, it can be used by the client and by the contractor. The contractor could use it in the ways described in the previous paragraph. As a tool to quicken the design process, as a starting point for a detailed design. And as a quick estimation for costs. The model can also be used to implement standardization in the design (which is the starting point of the thesis) and can be used to evaluate the effects of changes in boundary conditions, functional requirements and changes in design.

The client (Rijkswaterstaat for example) could use the model to prescribe certain (standardised) component variants, and to substantiate these prescriptions. The client could also use the model to check the contractors design, and to gain some knowledge about how the design could (with a certain band width) look like. How the parametric decision model will lead to standardization will be discussed in the next paragraph

3.5 A parametric decision model for standardization

The goal of the thesis is to investigate how standardization could be applied for navigational lock components. So far, in this chapter the advantages of using a parametric model to streamline the design process has been made clear, to reduce the amounts of variants made and to reduce the amount of time needed to come with a specific competitive design of a certain variant. How this will lead to standardization hasn't been explained yet.

The decision model can be used to decide which alternative should be applied, in a specific case. This could lead to a prescription of a specific variant for a specific case. This leads to a standard variant in a specific case. For example, the prescription of always using mitre gates for navigation locks between 10m and 20m width. With this prescription the number of different alternatives used is reduced to one alternative, and a mitre gate is a standard gate for the 10m to 20m width.

The model can also be used to standardise how a specific alternative should look like for a specific case. For example, the model can be used to determine that the best mitre gate design for certain boundary conditions has a specific lay out (always an x number of horizontal beams of dimensions y by z). This would lead to a specific standardised design. In addition, since the design is made in a parametric model, the implementation of standardised components is also relatively easy since it just leads to a modification of the same model. The effect of the implementation of standardised components for several different dimensions can be seen immediately.

The difference of designing with and without the decision model in practice with respect to standardization will be made clear by an example, gate type is used as component type. With the decision model a prescribed (best) alternative for a specific range of boundary conditions will potentially be the outcome. So instead of having rolling gates, mitre gates and lifting gates in the range of 10 to 20m as alternatives (as is the case nowadays), The model could potentially limit those alternatives to only mitre gates.
Instead of having several different lay outs for these mitre gates, the model could potentially predict the best structural lay out for the mitre gate, in a specific range. Instead of having pivots with and without clearance, the model could predict the difference in outcome for both pivots, and the decision can be made to always use a specific type of pivot. This changes the amount of options drastically and therefor adding to standardization.

It is possible that a specific prescription for an alternative can't be made based on the results from the model. This can't be known on beforehand. If this is the case, information is gained about the difference between alternatives, this could be used in the making of a decision for a specific alternative (even though the model has no clear best alternative).

3.6 Main principles parametric model

The basics of the parametric model have already been discussed. Some more detailed aspects will be clarified in this section. This makes the rest of the Chapters better understandable.
The parametric model is basically a design of a specific component. The component with the highest potential for standardization will be chosen to be the subject to the parametric model. The hypothesis is that this is the component 'gate type'. This is the hypothesis since the gate type is one of the most determining components for the lay out for the lock. Gate types also have a significant contribution to costs (maintenance and construction). In this sub section the gate type will be used as example for this reason.
Several boundary conditions (water levels, and total lock width) are implemented as input in the model and the model is able to give an optimised design as output. Different design consideration can also be evaluated.

3.6.1 Different input parameters parametric model

There are several different types of parameters in the parametric model. All parameters are inserted in a different way.

- Constants

Some input parameters stay constant in the model, for example gravitational acceleration (which is about 9,81m/s^2 in the Netherlands
- Variable parameters

Some parameters are changed manually to assess the different (load) cases which are evaluated by the parametric model. For example lock width and water levels. Not only loads are inserted as variable parameters. Also the lay out can partly be inserted as variable parameters, to assess differences in design considerations. For example, the amount of vertical or horizontal beams for a specific gate type could be inserted as a variable parameter. With this information the differences between having for example 6 or 7 vertical beams for a specific case can be evaluated.
- Changeable optimisation parameters

With given variable parameters the resistance of the designed elements should be able to resist the loads, and give an optimal result. The model is designed in such a way that the optimal solution for the resisting parameters will be sought by the model. Examples are plate thicknesses and flange and web dimensions for the profiles. The model gives these parameters as output.

3.7 Concluding remarks

A parametric model can be used to optimise the standard design process. By implementing a parametric model in the design process, standardization could be implemented as well. Making design choices early on in the design process with the help of the parametric model would lead to recommendations on specific component variants. This would lead to standardization of component variants for specific boundary conditions and functional requirements.

4 Lock components and their relations

This chapter gives an answer to the second research question: “Of what components does a navigational lock exist?”. A short description of the components has been provided together with the advantages and disadvantages of the components. This chapter starts with a diagram which shows what components have a physical relation/ are connected. From this diagram a sensible order to decide which component should be evaluated first will become clear.

4.1 Lock components

Before Figure 6 will be explained with an example two important definitions will be elaborated, since both definitions will occur often in this thesis.

- Actuator

An actuator is the component that is directly used for operation of the lock gates. The actuator is the component which converts the power needed to move the gate to the actual movement of the gate. (Panama wheel and hydraulic cylinder are examples for variants of actuators for a mitre gate).

- Bilateral retaining

If higher water can occur on both sides of a lock gate, the gate has to be able to resist a load in both directions. A gate which should be able to resist is said to be able to bilateral retain water (NL: Dubbelkerend).

In Figure 2 the most important components of a lock are displayed. The relations between these components (not the corresponding variants) have been displayed below in Figure 6 (Nieman, 2016; Vrijburght A. , Ontwerp van Schutsluizen Deel 1; Brolsma & K.Roelse, 2011) . The directions of the arrows have a meaning in the sense of which component will be determining for the design if there is a relation between two components. So, a gate-type component pointing to a gate actuator component means that first a consideration will be made which gate type should be chosen, and then the actuator is chosen corresponding to the gate type decision. Arrows pointing to two sides represent a relation between two components with no real dominant component.

Boxes which are dotted mean that they are not necessarily present in every lock. These have also dotted ‘relation lines’. A component which influences another component (arrow pointing from one component to another) can determine how the component which is influenced will look like (the component at which the arrow points). An example is: Lock gate type influences actuator type (so an arrow points from lock gate type to actuator type). If the lock gate type (component) looks like a mitre gate (component variant), the actuator (component) will be a panama wheel, an electro mechanical cylinder, electro hydraulic cylinder or a rack bar actuator (component variants). If the lock gate type is another variant, for instance a tainter gate with horizontal pivot, then the actuator would look entirely different, the variants would be an indirect cylinder with lever arm or a direct actuator at the pivot.

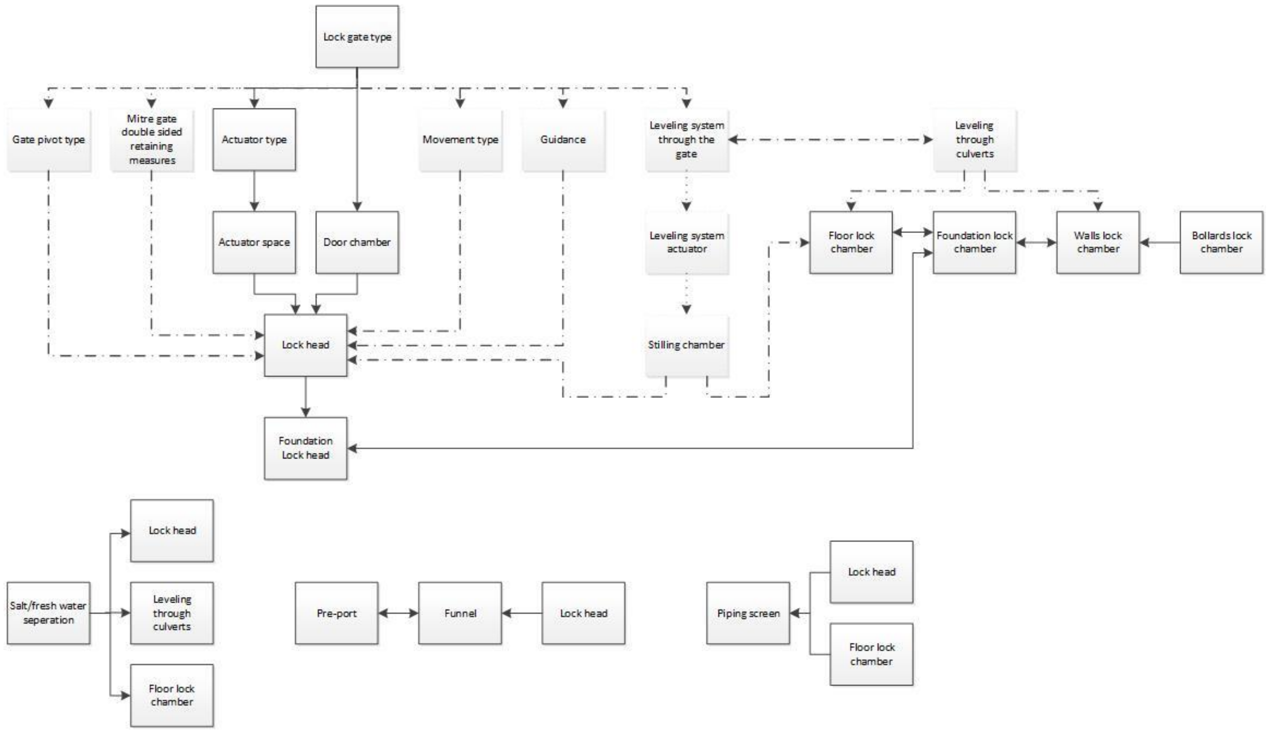


Figure 6 Component relations

In the next paragraphs the variants per components are displayed. Starting with gate types, since this is (following from the relation diagram) the most dominant component. The other component variants follow from the gate type choice.

4.1.1 Gate types general

The component variants have been inventoried from gate type down to subcomponents at specific gates. This has been done because the gate type is one of the most determining features of a lock. The gate type determines which actuators could be used for instance (not the other way around). That's why this way of displaying variants has been used. In Chapter 5 the components which are most suitable for standardising, while achieving the goals of MWW have been discussed.

4.1.1.1 Gate types general, advantages and disadvantages

All the possible gate types have been inventoried and have been presented in Figure 3
The advantages and disadvantages of the gate types are summarized in Table 1. These follow from *handbook schutsluizen*, common sense and Wilco Meijerink from Rijkswaterstaat (who helped with the tainter gate part). The criteria in the table match a gate type, a --, -, 0, + or ++ is presented at the table for every criterion with matching gate type. A -- means that the corresponding gate type has a relatively very negative effect on the criterion, a ++ a very positive effect and a 0 means that the gate type has no effect on the criterion at all.
In Appendix A pictures of all the gate types can be found (which make the valuation of some gates on a specific criterion more logical).

Gate type: / **Criteria:**	*1.Mitre Gate*	*2.Single leaf pivot gate*	*3.Standing tainter gate*	*4.wing gates*	*5.Tainter gate, counterweighed*	*6.Tainter gate not counterweighed*	*7.Tumblergate*	*8.Rolling/ sliding gate*	*9.Lifting gate*	*10.Drop gate*	*11.Double leaf lift gate*
Length lock	-	--	-	-	+	+	-	++	++	++	++
Length gate chamber	--	--	--	--	+	+	+	+	++	++	++
Width gate chamber	+	+	-	-	+	+	+	--	++	++	++
Space below gate	+	+	+	+	--/+	--/+	-	+	+	--	+
Gate dimensions	++	+	--	-	-	-	+	--	--	-	--
Actuator complexity	+	-	0	+	+	+	-	+	+	+	+
Forces at Actuator	-	--	+	+	+	-	-	++	-	+	-
Forces at Hinge	+	+	--	--	--	-	+	0	0	0	0
Bilateral retaining	-	+	++	++	++	++	++	++	++	++	++
Debris/ice problems	-	-	-	-	-	-	-	-	+	-	+
opening due to ship collision	--	-	+	+	+	+	-	+	+	+	+
Inspect /maintainability	+	+	+	+	+	+	--	--	++	--	++
Water movement	-	--	+	-	+	+	-	++	++	++	++
Limiting ship height	+	+	+	+	+/--	+/--	+	+	-	+	-
Movement with wl difference	-	-	+	+	+	+	+	+	+	+	+

Table 1 Advantages and disadvantages gate types, general

Example: a mitre gate has long gate chambers (which is negative since they occupy a lot of space in the longitudinal direction) so -, but these gate chambers are not wide at all (which is positive) so +.

4.1.1.2 Gate type choices

Since there are so many gate types, a selection is made which gate types will be considered in the thesis in more detail. 4 Gate types are currently mainly used in the Netherlands. These are: rolling gates, single leaf pivot gates, lift gates and mitre gates. Lift gates have been designed in the past, and are therefore still operational, but there are no newly designed lift gates in the Netherlands. So this gate type is only evaluated briefly, not in depth. Single leaf pivot gates are only applicable in very specific situations, therefor there is chosen to evaluate single leaf pivot gates also only briefly.
Another interesting gate type to consider is the standing tainter gate. This gate will be used in Eefde and is in Germany used as the standard gate for the upper head (with a water level difference up to 10m) (Haarman, 2016). Since it will be used in a newly made design in the Netherlands, and it is used as a standard gate type in Germany, this gate will only be evaluated (briefly) too. The other 6 gate types will not be evaluated in the thesis. These gate types are not or seldom used in The Netherlands and haven't been used in recently designed locks. The whole spectrum of boundary conditions and functional requirements in the Netherlands can be handled by the chosen gate types. The various relevant component variants and the advantages and disadvantages of the gate types which will be considered in more detail are displayed at the subsequent paragraphs. Pictures which show how the gates look like will be presented in these paragraphs too.

4.1.2 Rolling gate

A rolling gate is a gate with horizontal movement which slides or roles over the floor of the lock chamber. In the Netherlands a rolling gate is usually used for big sea locks. The component, component variants, advantages and disadvantages are presented in Figure 7, Figure 7 Rolling/sliding gate, www.beeldbank.rws.nlFigure 8 and Table 2.

Figure 7 Rolling/sliding gate, www.beeldbank.rws.nl

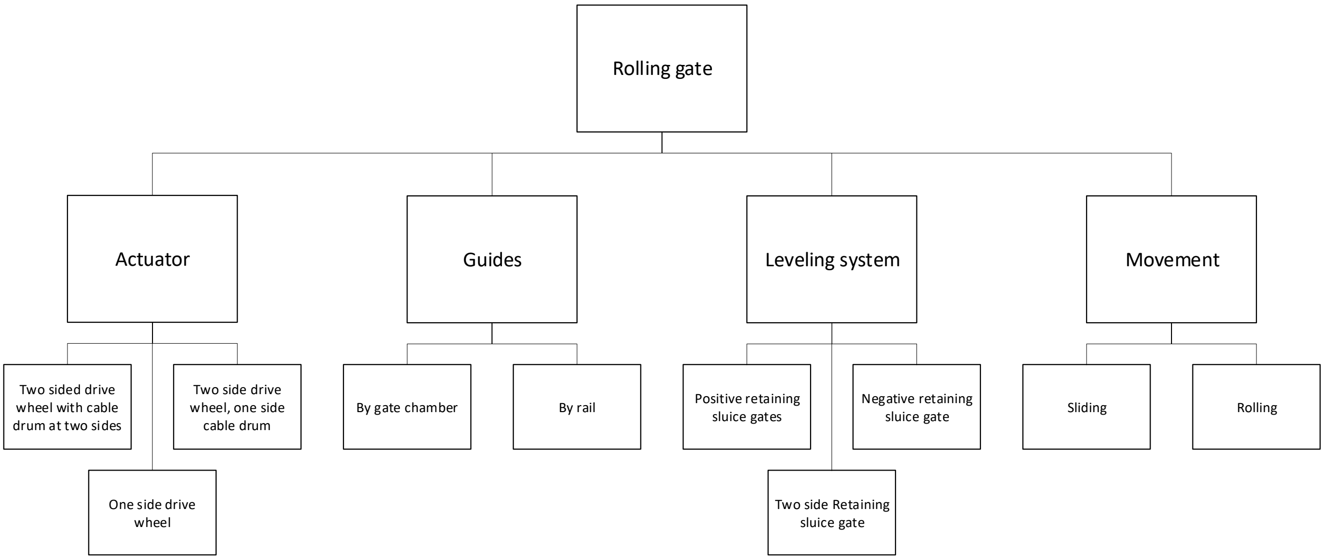


Figure 8 Rolling gate component variants

Advantages	Disadvantages
Able of bilaterally retaining water	Huge width needed for door chamber
Light movement equipment	Expensive guidance needed for doors
Small door chamber length	Could be negatively influenced by waves
	Could tilt due to force of actuator

Table 2 Rolling gate advantages/disadvantages

4.1.3 Single leaf pivot gate

A single leaf pivot gate is a gate which moves around a single vertical axis. In the Netherlands a single leaf pivot gate is mainly used for small locks. A picture of this gate type, the component variants corresponding to the gate type and advantages and disadvantages are presented in Figure 9,Figure 10 and Table 3.

Figure 9 Single leaf pivot gate, www.jansen-venneboer.com

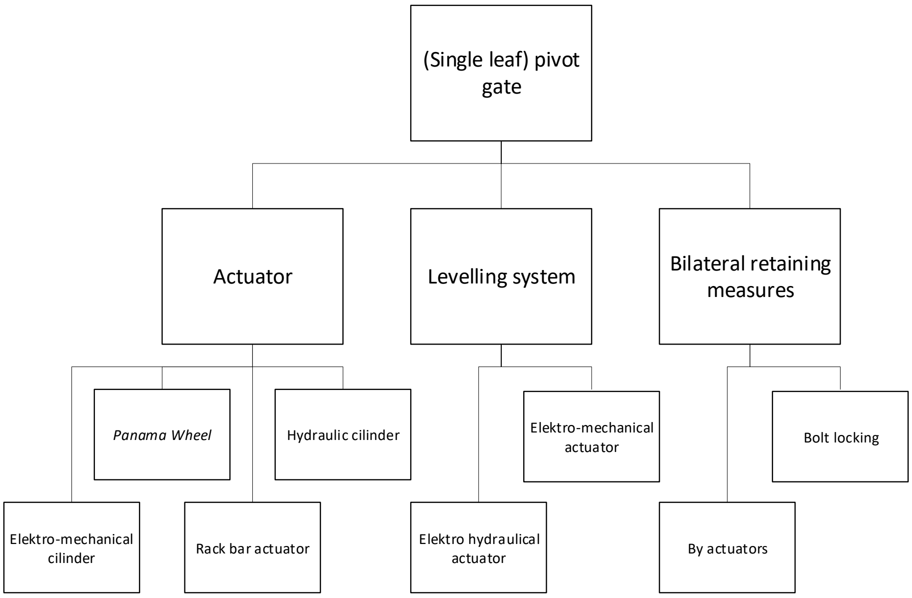


Figure 10 Single leaf pivot gate component variants

Advantages	Disadvantages
Able of bilaterally retaining water	Very large door chamber length
Small width lock chamber	Large dimensions actuators
	Problems with ice/debris
	Lot of water movement while opening

Table 3 Single leaf pivot gate Advantages and Disadvantages

4.1.4 Lift gate

A lift gate is a gate which moves in a vertical direction. A lift gate is used for medium to large locks (based on width and retaining height) in The Netherlands.A picture of a lifting gate, the component variantsand advantages and disadvantages are presented in Figure 11, Figure 12 and Table 4.


Figure 11 lifting gate, www.debinnenvaart.nl

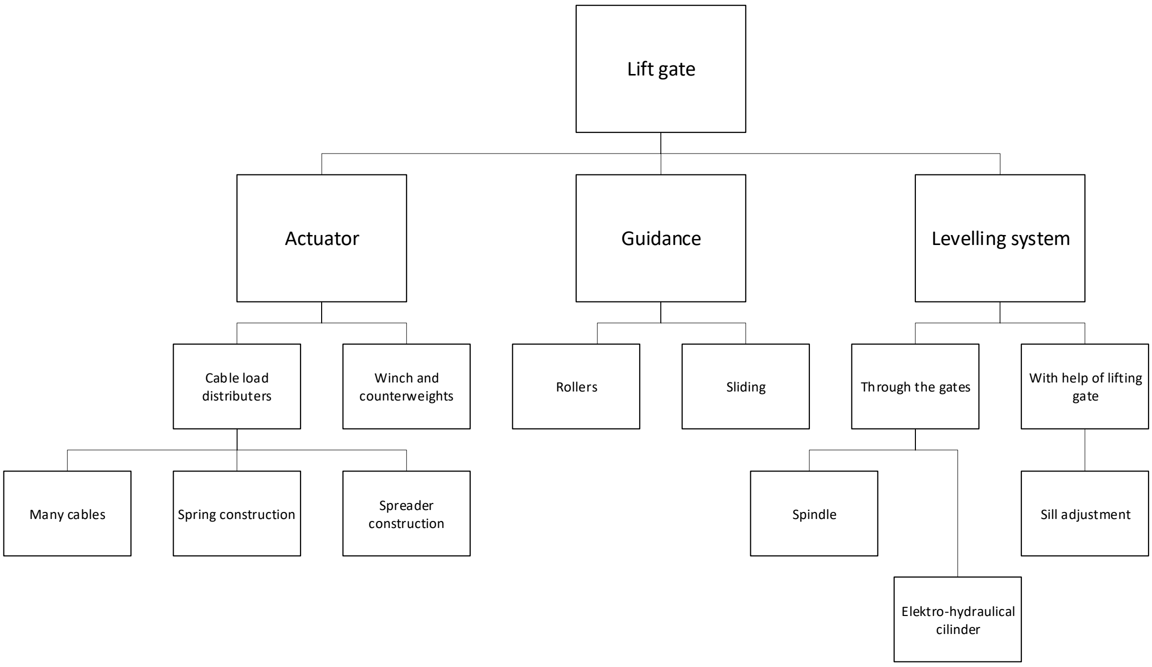


Figure 12 Lift gate component variants

Advantages	Disadvantages
Small lock head needed	Limiting ship height
Able of bilaterally retaining water	Expensive structure needed
Easy to maintain	'Visual pollution'
Easy to repair	Complicated gate guidance
Allmost no problems with ice or debris	

Table 4 Advantages and Disadvantages Lift gate

4.1.5 Tainter gate

A tainter gate hasn't been used in the Netherlands yet, but is currently designed for the lock at Eefde. It is a gate moving around a horizontal axis. A picture of a tainter gate, the component variants, advantages and disadvantages are presented in Figure 13, Figure 14 and Table 5.

Figure 13 Tainter gate, without counterweight, www.debinnenvaart.nl

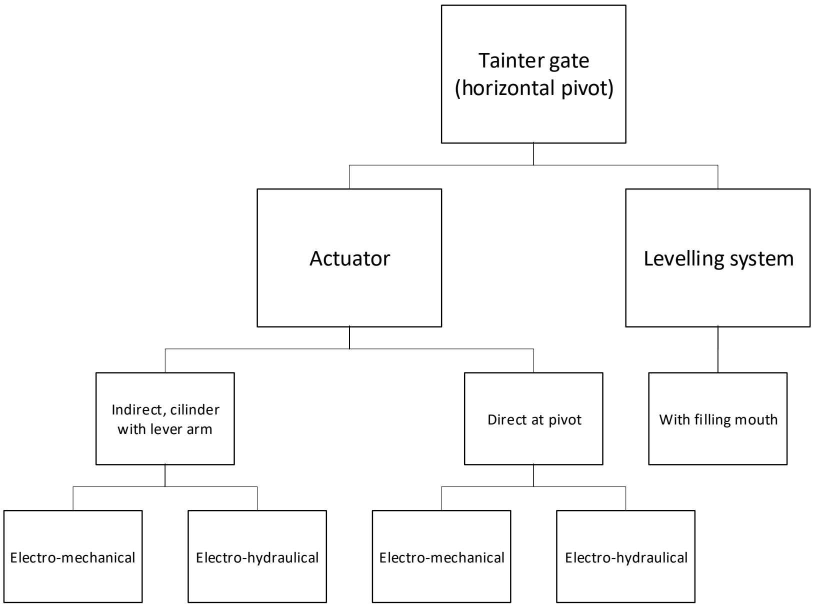


Figure 14 Tainter gate component variants

Advantages	Disadvantages
Low costs	Maximal levelling discharge (turbulence)
Low maintenance costs	Pivot underneath water
Simple structure	Gate not visible when operating
Low space occupation	Space in gate floor needed
Can be closed with flow velocity	
Can have weir function	

Table 5 Tainter gate advantages and disadvantages

4.1.6 Mitre gate

A mitre gate consists of 2 gates moving around vertical axis and meeting in the middle of the lock width. Mitre gates are very commonly used in The Netherlands. A picture of a mitre gate, the component variants and advantages and disadvantages of mitre gates are presented in Figure 15, Figure 16 and Table 6.

Figure 15 Mitre gate, source:www.rolanco.nl

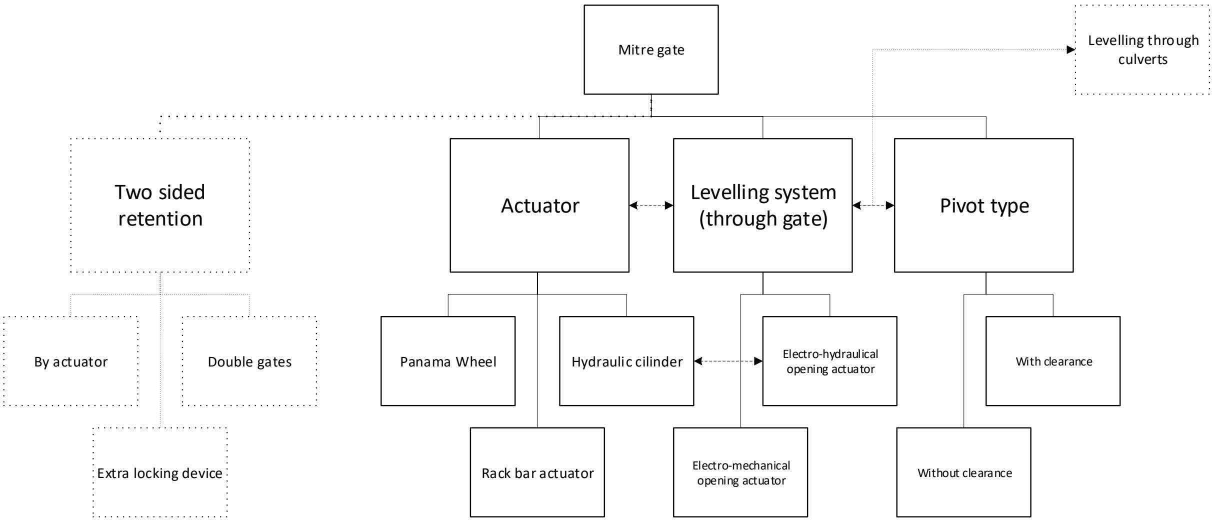


Figure 16 Mitre gate component variants

Advantages	Disadvantages
Small width lock chamber	Large length door chamber
Economic structural design	Extra measures needed when Bilateral retaining
Simple moving equipment	Problems with ice/debris
	Accidental opening by ship collision
	High precision dimensioning

Table 6 Mitre gate advantages and disadvantages

4.1.7 Additional components

Additional components with variants of navigational locks are presented in Figure 17, Figure 18 and Figure 19. The ultimate aim is to consider those components in real depth at the thesis, but the focus will be on the gates with corresponding components.

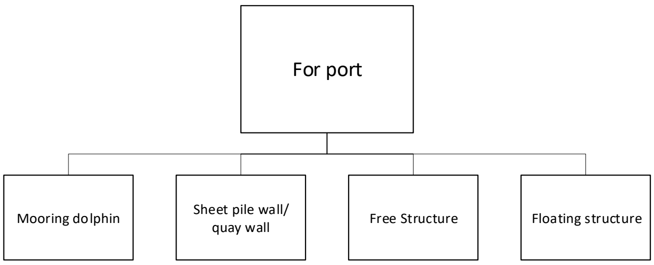


Figure 17 For-port component variants

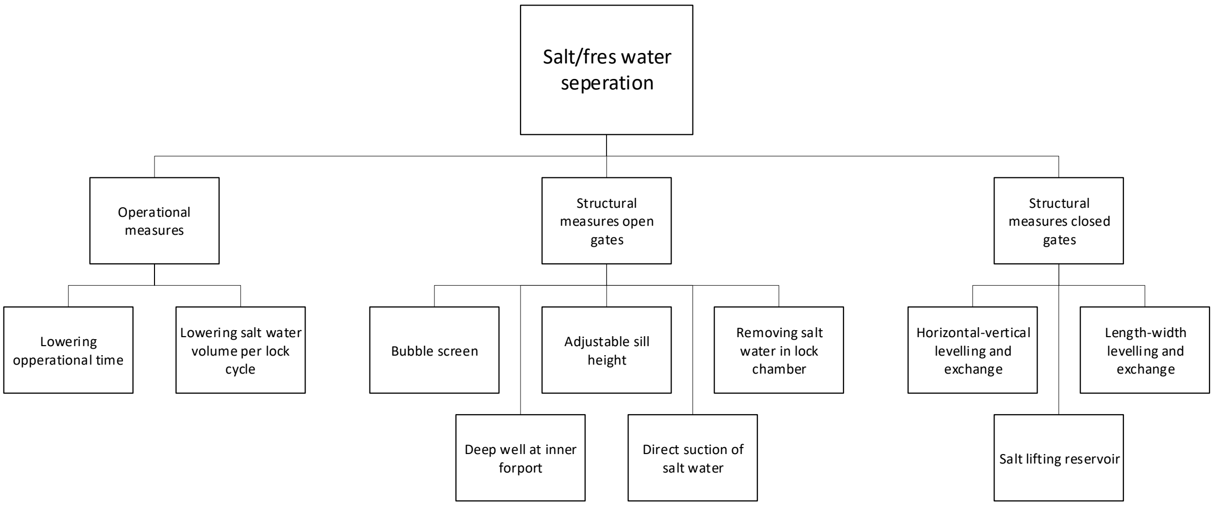


Figure 18 Salt/fresh water separation component variants

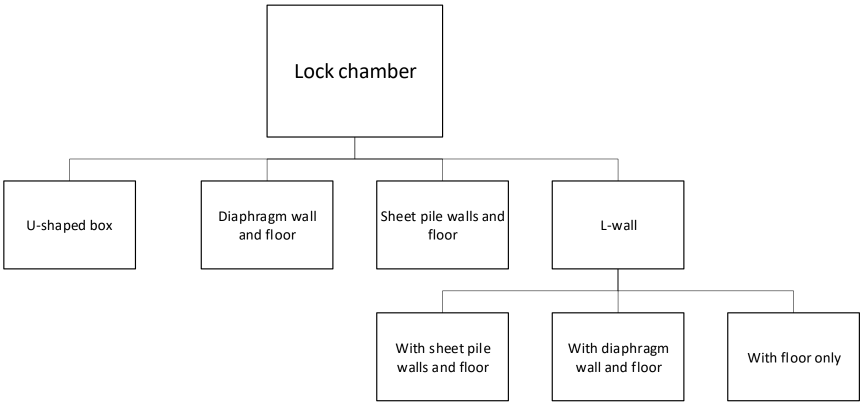


Figure 19 Lock chamber component variants

4.2 Concluding remarks

The gate type is the most determining navigational lock component in terms of physical relations and in terms of navigational lock appearance. The gate types which are potentially most worth considering in detail are mitre gate and rolling gate. These gate types are mainly used in the Netherlands. All boundary conditions and functional requirements present in the Netherlands can be handled by using one of those 2 gate types.

5 High potential standardization components

This Chapter gives an answer to the 3rd research question, "What navigational lock components have the biggest potential for reaching the MultiWaterWerken goals by means of standardization?".

5.1 Component Standardization

With the lock components and variants per component made clear, the potential of standardization of a component will be examined. In this chapter it is decided what components will be examined in more detail in the rest of the thesis. In Figure 2 all existing the lock components are presented. This Chapter will be used to make a selection of these components.

5.1.1 Standardization advantages per party

Standardization can have advantages and disadvantages for several parties.
For the contractor standardization could lead to lower construction costs due to repetition and lower maintenance costs due to limited amount of parts on stock. Another positive effect on maintenance costs is the knowledge about the parts which is increased, so the mechanic will be more experienced, and there will be more information available per part.

The users know better how to proceed a navigational lock and what to expect when arriving at the lock, if the lock has been standardised.

The owner has advantages because the costs will be lower, and the repair time (and therefore availability) will be lower. With the knowledge gained due to owning the same parts in more cases, the predictability of the components will increase too, this could lead to better maintenance strategies.

5.1.2 Effects of components on reliability, availability, construction costs and maintenance costs

PhD graduate Tim Wilschut who graduates at Rijkswaterstaat uses an analytical method (a Dependency Structure Matrix or DSM matrix) to give insight in different lock components and how those components can be clustered together in bigger modules (Wilschut, 2017). This manuscript also gives insight in relations between existing locks, and clusters these locks into families. The interesting part of this manuscript is the insight in relations between lock components due to clustering. Furthermore, the impact on Life Cycle Costs (LCC) and reliability and availability (RA) of the clusters (which are based upon existing locks) has been investigated, this can be used to prioritize which components will be investigated further at the thesis. The impacts on LCC and RA have been made numerical by an assumed score per component, this assumption has been checked by experts (but is not a hard quantitative value based on hard data).

From Tim Wilschut it follows that, based on the LCC and RA scores, the mechanical components of the upper and lower lock heads (e.g. Gates, actuators) are most beneficial for standardization since they have the highest impact on those criterion. The civil structures in the lock heads and lock chamber are also beneficial to standardise, as well as the controls and electronics. The controls and electronics will be beyond the scope of the thesis, since it has no relation with civil engineering and since the replacement/updating time of controls and electronics(1-5 years) is of a totally different order then the time scale of the rest of the lock components (75-100 years). For higher reliability, standardization on control and electronics, lock head and accessories and mechanical components is beneficial. For higher availability and lower construction costs, standardization of lock head and accessories, mechanical components lock heads and civil structure is beneficial. For lower maintenance costs, standardization of mechanical components in the locks heads and standardization of the pre-port is beneficial.
A summary of the results of Tim Wilschut can be found in Table 7. Dots at the table represent a high impact of a certain component cluster on the criterion at the top of the column. From the table it becomes clear that the Pre-port only has a high impact on maintenance costs for example.

Component cluster	Reliability	Availability	Construction costs	Maintenance costs
Control and electronics	■			
Lock head and accessories	■	■	■	
Mechanical components lock heads	■	■	■	■
Civil structure		■	■	
Pre-port				■

Table 7 Lock component effect on MWW goals, based on (Wilschut, 2017)

5.1.3 Suitability and desirability to standardise components

In the thesis of Robert Slijk, the suitability and desirability to standardise specific components is investigated (Slijk, 2013). The basis of this investigation is a literature/ expert study. The positive effects of a repetitive design/ production, the effects of standardization on maintenance, the effects of standardization on predictability and the effects of standardization on availability are taken into account in the study.

The results of most desirable and suitable components to standardise with the effects taken into consideration presented above according to Slijk are the movement equipment, control system and gate type. The least desirable and suitable components are bed protection and lock head. These results are presented in Figure 20.

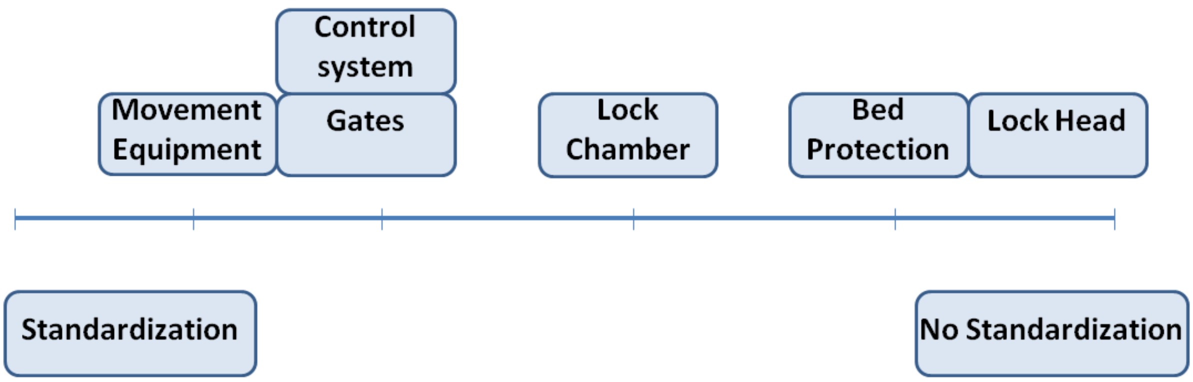


Figure 20 Standardising specific lock components, by Slijk (2013)

According to the thesis of Robert Slijk, improving availability and predictability by means of standardization of certain components could be very useful.

5.1.4 Expert study and data analyses on the effect of standardization of specific lock components on MWW goals

From the data analyses by Iv infra the conclusion has been drawn that there is not enough information available about the locks to give much insight in to the effect of standardization of specific lock components on the MWW goals (Markus, Molendijk, & Anijs, 2015). In order to perform a data analyses in the future more information should be registered and documented.

Besides the data analysis, an expert study has been performed. For this study 4 lock configurations with differences in: lock dimensions, soil, water salinity, negative head, total head, and amount of cycles per year have been considered. Those configurations have been scored by the use of the AHP method of Saaty. This method is a way of evaluating a 'difficult' problem by breaking it up in smaller sub problems which can be scored or evaluated relatively easily. The expert study also makes use of

the Roger Cooke's Classical model. The Roger Cooke's Classical model takes the experts ability to give a certain score into consideration. The criterion on which the experts have given their opinion are: uncertainty in construction time, uncertainty in construction costs, Life Cycle Costs (LCC), availability and reliability. The components which are considered by the experts are 29 different components which can be categorized by: civil components, mechanical engineering components, control systems and electro technical installations, steel components and hydraulic engineering components.
From the expert study performed by Iv infra the conclusion has been drawn that the uncertainty in construction costs and building time mainly followed from the civil structures of the lock. The Life Cycle Cost mainly follow from gate types and the availability and reliability follow from gate actuators and power supply.

From the dual comparison analyses and the Roger Cooke's Classical model the conclusions presented in Table 8, are drawn.
A number in the table represents the ranking in terms of biggest effect at the given criterion, 1 has biggest effect, 2 smaller etc. Only the biggest drivers have been taken into account per category. So the top 3 of component variants which have the biggest effect on maintenance costs are rolling gate, mitre gate and lifting gate. A rolling gate has the highest influence on maintenance costs of these 3, followed by a mitre gate and a lifting gate.

	Uncertainty Building costs	Uncertainty Building time	LCC		Reliability and Availability
			Replacement interval	Maintenance cost	
Foundation	1	1			
Lock head	2	2			
Lock chamber walls	3				
Culverts	4				
Lock chamber floor		3			
Lifting gate			1	3	
Rolling gate			2	1	
Mitre gate			3	2	
Electro-mechanical gate actuator					1
Electro-hydraulic gate actuator					2
Energy source					3

Table 8 Effects of specific lock components on MWW Goals, based on (Markus, Molendijk, & Anijs, 2015)

5.2 Concluding remarks

According to Wilschut, actuators, gates and civil components have the biggest effects on reliability, availability, construction costs and maintenance. According to the experts interviewed by Iv infra bv, civil components influence uncertainty in building costs and time most, gates have the biggest influence on LCC and actuators have the biggest influence on availability and Reliability. According to Slijk, gates and actuators are the components which are easiest to standardize, civil structures are more difficult to standardise. From all the components presented at Figure 2, the components 'Gate type' and 'actuator' turned out to be the components with the highest potential for standardization. For that reason, the focus of the thesis will be on standardization of navigational lock gates.

6 Parametric model general working principles

This chapter partly answers the 5th research question: "How will a decision be made based on quantitative and qualitative arguments?". The main working principles of the parametric model are presented in this chapter. At Chapter 3, the method of using a parametric model to implement standardization in the design process has been explained. The parametric model will be used as a way of quantifying the decision to choose between different components, the quantification is based on material use. The parametric model will also be used to optimise a specific component variant in terms of material use. In Chapter 5, the component which has the highest potential for standardization turns out to be the gate type. A parametric model is made for the component gate type, only the gate types which are potentially used are designed in this model. Only one design per gate type is made. The designs are made in steel only. The basic lay outs, assumptions made, and design checks performed per gate type are presented in this Chapter. For the specific calculations, reference is made to Appendix B and Appendix C. The calculations are performed according to NEN-EN 1993-1-1 and NEN-EN 1993-1-5.

6.1 Component focus

From the literature study presented in the previous chapters it has become clear that the gate type and actuator type have the greatest potential for standardization. The gate type determines the variants which can be applied as actuators. The main focus will be on gate type, followed by actuator type. In this thesis, a parametric model is made to investigate gate types only. A proposition is given about implementing actuators and other components in the parametric model

Not every gate type will be assessed either. Only the most commonly applied gate types will be assessed. These are, mitre gate (with and without clearance) and rolling gate. The method works in such a way that other gate types could be added relatively easily when necessary, the goal is to have a working method which could be used to assess all situations of gate width and retention height.

The model is only made for one material. Since steel is often used for every gate type and applicable in every situation, all gate types will be assessed in steel.

The lock heads are affected by the gate types, but are not the focus of the thesis. For this reason, the lock heads are not added in the parametric model, but are only described qualitatively.

The effect of different structural lay outs is not investigated in this thesis. Since the main building blocks of the model are programmed in the model, more structural lay outs could be added to the model relatively easily. With a structural lay out, the way of positioning beams to resist the loads for a specific gate type variant is meant. It should be taken into account that in this thesis some competitive designs are evaluated and compared, not that all possible competitive designs are compared. Comparing all competitive designs would be a time-consuming task. The method itself should be tested, that is done by making the parametric model for some competitive designs.

6.2 General working principle parametric model

The principle of the parametric model is that an optimised design for a specific structural lay out will be found for every set of input parameters. The input parameters are inserted manually, these are the boundary conditions, the loads acting on the gate will follow from this. Examples of input parameters are water levels on both sides of the gate and lock width.

With the input parameters and therefor the load known, the dimensions of the load resisting parts can be calculated. A specific structural lay out has been chosen for the gates. This lay out can be divided in beams which are loaded. Every beam has to resist the load acting on the beam. The dimensions of the beams can be changed to resist the load acting on them. These parameters are called, changeable optimisation parameters. Examples of optimisation parameters are plate thickness, web height, flange width.

The model uses a special solver algorithm to calculate the changeable optimisation parameters in such a way that a minimal amount of steel is used but that the load is resisted. It is important to note that the gate is optimised in terms of material (so steel) use. For every new set of input parameters a different optimal solution will be found by the model.

So summarised, the input of the model is a set of input parameters, the model goes through a set of calculations and checks in such a way that the loads match the resistance for a given structural lay out, and give a design as output (in terms of dimensions of the important beams). This design is optimal in terms of material (steel) use.

6.3 Profile types

There are several types of profiles and ways of constructing steel gates. Since plates with T-beam shaped stiffeners are often used for the design of steel gates this construction type is used. This should give a competitive design. Other designs could be used as well but is beyond the scope of the thesis, the main goal is to compare some competitive designs, not to compare all competitive designs.

6.4 General governing loads

The most determining loads acting on the gate are described below. The specific load per element is described later on. The loads described in this paragraph are valid for both gate type variants considered

- Ship collision

  Ship collision events are very rare in the Netherlands, but the effects are immense. In order to estimate the loads because of ship collision advanced FEM models have been used. The collision load depends also heavily on the ship class and it's shape. These kinds of calculations outrun the parametric models' possibilities, so these can't be performed. Luckily, there are measures (such as constructions in front of the gate) to avoid ship collision, so the gate doesn't necessarily have to be designed for ship collision
- Operating load

  Load due to operating the gate (opening and closing of the gate)is usually very low with the right dimensions.
- Wave load

  Wave load leads to an increase in hydrostatic pressure. Since the model designs the gate for a range of fictitious hydrostatic pressures and compares these gate designs with other gate type designs for this range of hydrostatic pressures, wave load doesn't differ from hydrostatic pressure in load sense. The idea is that a certain water level difference A and a wave load A equals another (higher) water level difference B without wave load, in terms of load.
- Water level difference
- The main load acting on the gate is the load due to difference in water pressure on both sides of the gate. This pressure can be induced by water level difference or by density difference. This results in a triangular shaped resultant load (when seen from the side) or in a triangular shaped resultant load with a rectangular shaped resultant load below (depending on both water levels). The load and resultant load are presented in Figure 21 and Figure 22.
- Self-weight

  The weight of the structure is mostly carried directly to the ground and relatively low. This load is acting in another direction then the main load so can be neglected (also determined in consultancy with Gerard Bouwman).

6.5 Parametric model gate type variants

As discussed earlier, two component variants are evaluated, the mitre gate and the rolling gate. The lay out and main working principles of the model are discussed per variant. First the mitre gate is discussed. 2 sub variants for the mitre gate are evaluated, mitre gate with pivots with clearance and mitre gate with pivots without clearance. The rolling gate is discussed later on in this chapter the mitre gate.

6.6 Mitre gate parametric model design

The first gate type discussed is the mitre gate. First some general statements are made (applicable to mitre gate with pivots with clearance and to mitre gate with pivots without clearance). After these statements the lay out and design principles of both subvariants are discussed apart, starting with the mitre gate with clearance design.

6.6.1 Mitre gate Loads

The hydrostatic loads acting on the mitre gate are visualised below, regardless from the type of pivots. Water level difference at both sides of the gate result in a (trapezoidal shaped) resulting pressure acting on the gate. From Figure 21 and Figure 22Figure 22 top view mitre gate below, it can be seen that the load acting on each web and flange can be schematised as a uniformly distributed load (with a magnitude corresponding to the part which every web flange and front plate part carries). The load will be carried to the point where the gates meet and to the lock heads at the sides.

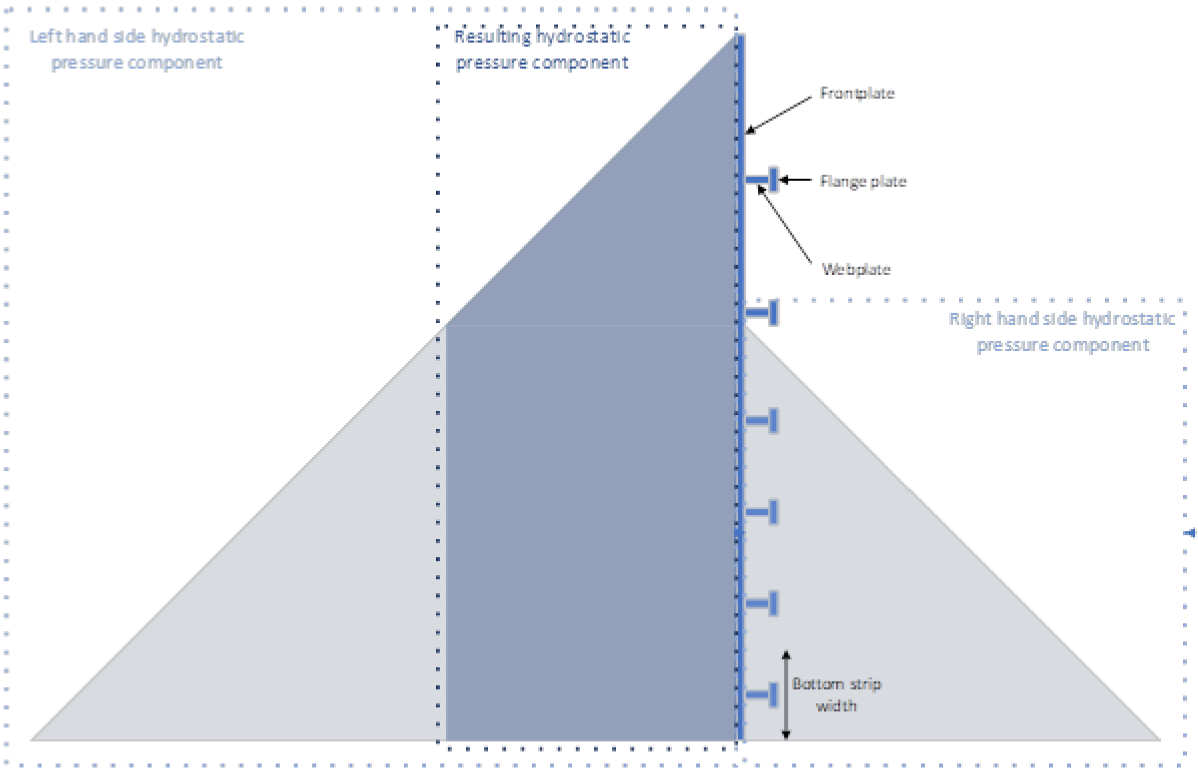


Figure 21 side view mitre gate, with hydrostatic pressure

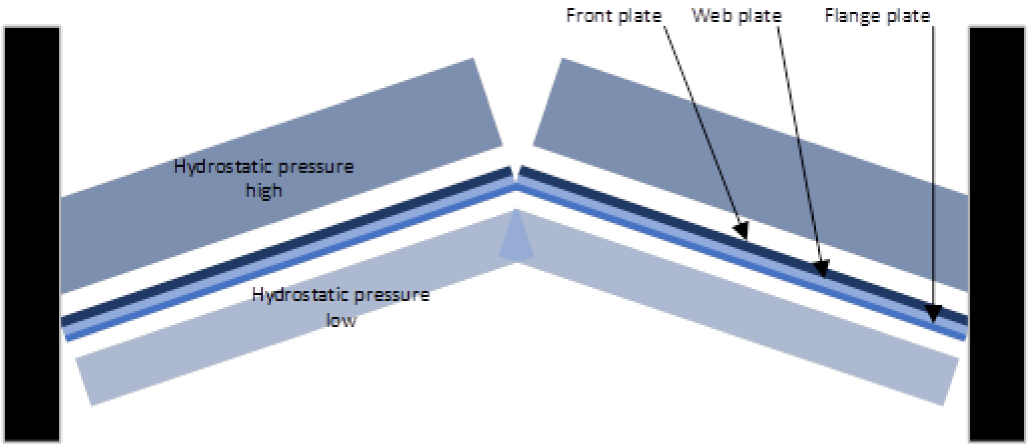


Figure 22 top view mitre gate, with hydrostatic pressure

6.6.2 Torsional resistance elements mitre gate

Torsional moments due to gate movement, debris stuck between the gate while closing and ship collision haven't been considered. These loads haven't been considered since movement of the gate leads generally (for normal gate lengths) to small moments, and ship collision and debris stuck between the gate can be resisted by additional measures. Ship collision events are luckily very rare in the Netherlands and normally a gate can't resist the enormous forces of this event anyway.
Torsional moment resistance is normally calculated with the help of finite element programs. This can't be done in a proper way in the parametric model which has been programmed for this thesis. Usually, a frame work of hollow sections at the sides of the gate and diagonal cross dressings lead to enough torsional resistance. These elements lead to a relatively low contribution to the total material need, so neglecting these elements doesn't give a big deviation from reality.

6.6.3 Mitre gate pivots

The most important decision for the design of a mitre gate is the type of pivots. There are two distinctly different pivot types available for mitre gates: pivots with clearance and pivots without clearance.
Apart from advantages and disadvantages with respect to placing and reliability of the pivot, the lay out of the gate itself is affected a lot by the pivots. The principle of distributing the forces through the gate is different and therefor the way of constructing the gate itself will be different with both types of pivots. The pivots with clearance will distribute the forces over the whole height of the gate. With pivots without clearance the forces are focussed at the pivots. The way of distributing the forces becomes clear from Figure 23 and Figure 24 presented below. The forces from water pressure for a gate with pivots with clearance are directly taken by a set of horizontal beams, the forces from water pressure for a mitre gate without clearance are distributed to two horizontal beams with the help of vertical beams. The vertical beams will use a larger vertical beam at the end to distribute the forces to the pivots.

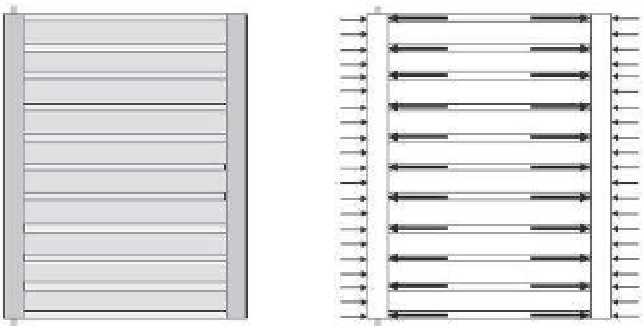


Figure 23 Pivots with clearance (Molenaar, 2011)

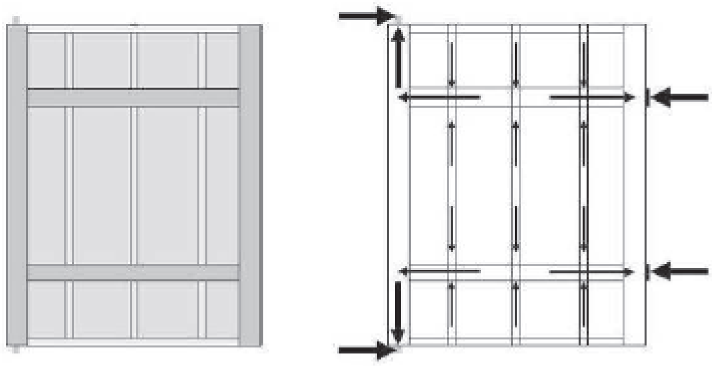


Figure 24 Pivots without clearance (Molenaar, 2011)

6.6.4 Lay out mitre gate with clearance

The mitre gate with clearance has been modelled as a set of H beams on top of each other. The H beams consist of a flange plate part, a web plate part and a front plate part (the effective width part of the front plate corresponding to the web plate). The beams (consisting of a web and flange plate welded to the front plate) are placed in such a way that the resulting load acting on each beam is the same. Therefore, for the beams at the top, where the resulting load is lower, the spacing between the webs becomes bigger.
The forces will be transferred directly from the supported front plate (which is a beam) to the sides, so only 1 structural element will be present for this gate configuration. In Figure 25 the lay out of the structural elements for 1 single mitre gate is presented.

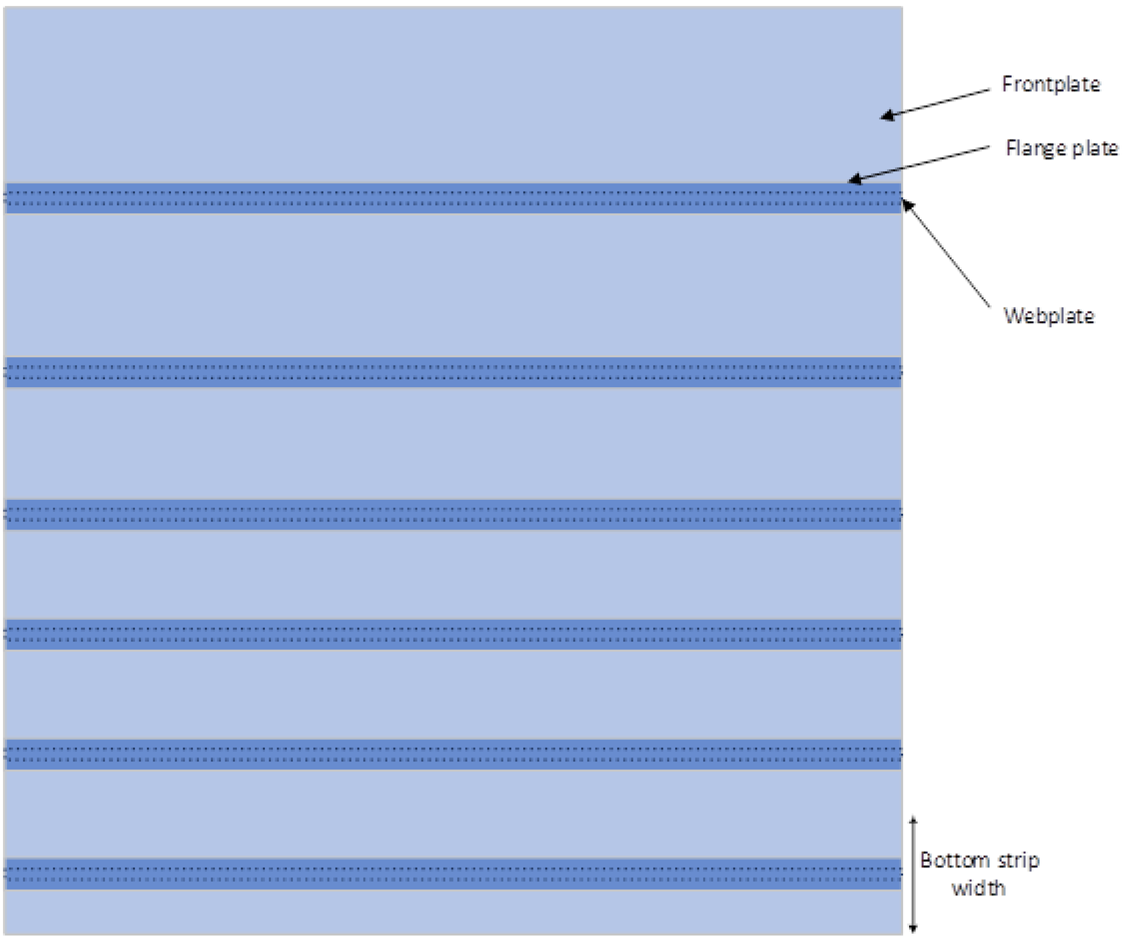


Figure 25 front view structural elements 1 mitre gate with clearance

6.6.5 Relevant checks mitre gate with clearance

In Appendix B all possible design checks programmed in the parametric model are presented. This paragraph will include the checks performed in the model. For detailed information about the checks reference is made to Appendix B. Since the gate has been subjected to bending moment, shear force and normal (compressive) force, all checks should be applied. The bending moment and buckling resistance formula is elaborated in more detail for this case in the Appendix E. The structural scheme and design loads can be found in Appendix C.
The checks performed by the parametric model for the mitre gate with clearance are:

- Cross-section class
- Normal force resistance
- Bending moment resistance
- Shear force resistance
- *Eventually bending moment and shear resistance*
- *Eventually bending moment and normal force resistance*
- *Eventually bending moment, normal force and shear resistance*
- Buckling resistance
- Bending moment and buckling resistance

6.6.6 Assumptions mitre gate with clearance

For the design of the mitre gate with clearance, some assumptions are made. These assumptions are discussed in this subsection.

6.6.6.1 Assumptions regarding loads

- Load is evenly distributed over the width

This will always be the case in this situation, if the water level can be assumed to be constant over the width on both sides.

- Torsional moment due to pressure differences at top and bottom side of the beam is negligible

The pressure differences are relatively small when the beam height is not immense. The stiffness of the gate as a whole will be able to resist them, the top front plate flange of a beam is obviously solidly connected with the bottom front plate flange of the beam above. This creates a lot of stiffness. The vertical beams at the sides provide extra stiffness as well.

- Self- weight is negligible for the beams

The weight of the beams is very small compared to the loads due to water level difference, and the direction is different too, so the effect is negligible

6.6.6.2 Assumptions regarding resistances

- The profile design is limited to cross-section class 2, this gives a better design.

This limitation has as a positive effect that local buckling won't occur, and that the beam can be calculated plastically. The beam is more robust too, which is positive since small ship collisions can occur quite easily, this should not immediately lead to bended webs or flanges or other sorts of damage.

6.6.7 Optimisation parameters mitre gate with clearance

The mitre gate with clearance consist of only one resisting element type which has to be checked, a horizontal beam. The changeable optimisation parameters, the parameters which are used to resist the load and have an optimal design are:

- Thickness front plate
- Thickness web plate
- Web height
- Thickness flange plate
- Flange width
- Minimum strip width

The minimum strip width leads to a different spacing of the beams. The current model can only handle a maximum of 20 beams.

6.6.8 Changeable Input parameters mitre gate with clearance

The input parameters which can be manually changed to asses different situations (and which make up the boundary conditions are:

- Water level high water side
- Water level low water side
- Total lock width

6.7 Mitre gate without clearance parametric

Another alternative for the mitre gate is the mitre gate without clearance. The mitre gate without clearance is another sub alternative for the mitre gate alternative.

6.7.1 Lay out mitre gate without clearance

The mitre gate without clearance has 3 main structural elements to carry the load from the hydrostatic pressure difference at the front plate, to the pivots and the other gate at the sides.
The vertical beams (structural elements 1) carry the load to the horizontal beams (structural elements 2), which carry the loads to the heelpost (structural elements 3) where the load can be transferred through the pivots to the lock head. This way of distributing the loads has been chosen since the location of the vertical beam reduces the otherwise enormous bending moments at the heel post as much as possible (the more the horizontal beams are located at the height of the hinges, the lower the bending moments in the heelpost). The horizontal beams aren't located at the hinge position, since this would increase the bending moments at the vertical beams. The horizontal beams have equal loads at both sides, so they are located at ¼ of the gate height from the top and bottom. The lay-out is presented in Figure 26.

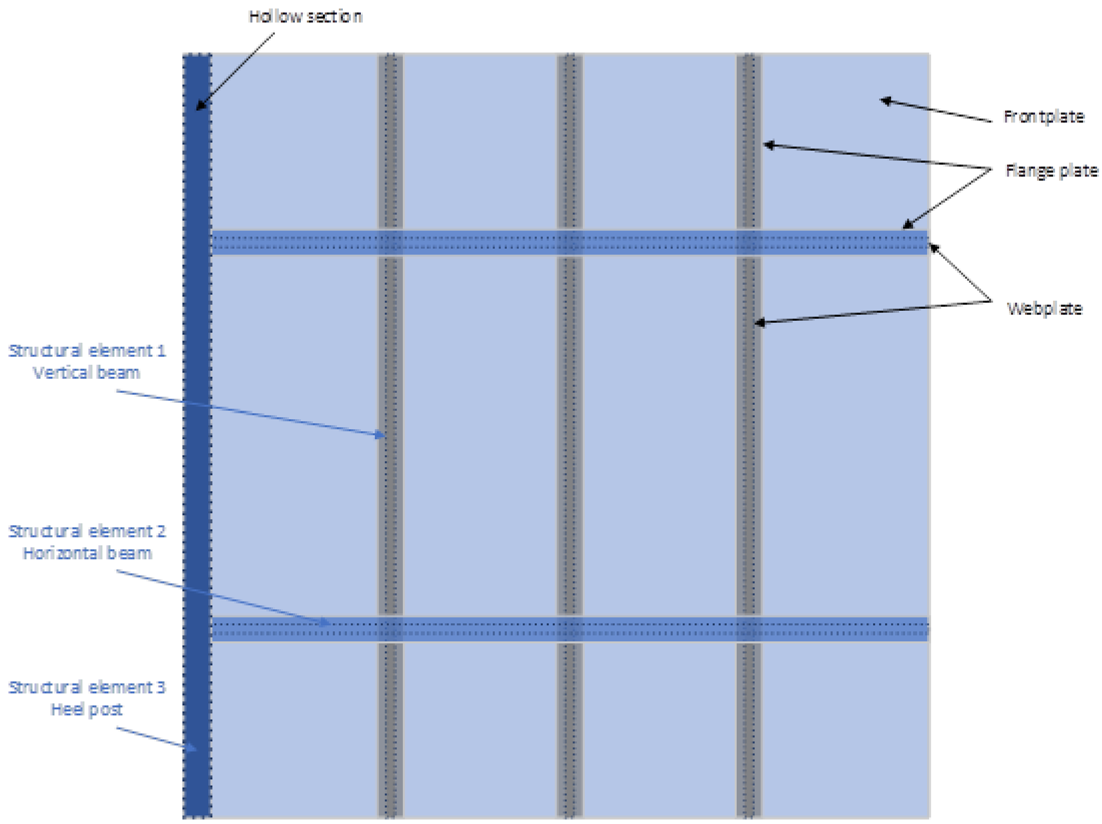


Figure 26 front view single mitre gate without clearance

6.7.2 Design checks mitre gate without clearance

The procedure of most design checks is discussed in Appendix B. For every structural element, the design checks performed are summarized below. Some checks need an extra comment.

6.7.2.1 Design checks structural element 1, Vertical beam

The Vertical beam is checked for the checks summarised below, all the checks are performed according to Appendix B about design checks:

- Shear force
- Bending moment
- *Bending moment and shear force combined, when necessary*
- Cross section class (web plate in bending, flange plate and front plate in compression)

6.7.2.2 Design checks structural element 2, horizontal beam

The horizontal beam is checked for the checks summarised below. An extra statement has been made about the buckling and bending moment procedure. The procedure is just performed as with the mitre gate with clearance, to validate this an extra statement should be made the detailed elaboration can be seen in Appendix E.

- Shear force
- Bending moment
- Normal force
- *Shear force and bending moment combined (if necessary)*
- *Normal force and bending moment combined (if necessary)*
- *Shear force, normal force and bending moment combined (if necessary)*
- Buckling

- Buckling and moment combined
- Cross-section class (web plate in bending, web plate in compression, front plate in bending, front plate in compression)

6.7.2.3 Heel post

Checks performed for the heelpost are as follows:

- Bending moment distribution in two directions
- Shear force distribution in two directions
- *Combination of bending moment and shear force when necessary*
- Cross-section class checks (for all the plates in bending)

The determining bending moment check (solely due to bending moments or bending moments combined with shear force) should be applied as follows:

$$UC_{Mdety} + UC_{Mdetz} \leq 1$$

So both checks together should be smaller than 1.

6.7.3 Assumptions made for the mitre gate without clearance loads

- Load is evenly distributed over the width

This will always be the case in this situation, since the water level can be assumed to be constant over the width on both sides.

- Own weight is negligible for the beams

The weight of the beams is very small compared to the loads due to water level difference, and the direction is different too, so the effect is negligible

- The pivots without clearance lead to a fixed support schematization

The pivots should be relatively tight, which leads to a fixed connection at the pivot.

6.7.4 Assumptions made for the mitre gate without clearance resistance

- The profile design is limited to cross-section class 2.

This limitation has as a positive effect that local buckling won't occur, and that the beam can be calculated Plastically. The beam is more robust too, which is positive since small ship collisions can occur quite easily, this should not immediately lead to bended webs or flanges or other sorts of damage.

- Spacing between vertical beams is the same

This is a design related decision.

- Spacing between vertical beams is the same

This has been done to reduce the loads at the heelpost. Further optimisation could lead to another design. The interaction between the vertical beams, horizontal beams and heelpost could give another optimal solution, this hasn't been evaluated in detail.

- Fillet radius is 3/8 of plate thickness (on both sides of the connection)

This rule of thumb only has effect on the cross-section class, the effect is very small. "*https://www.linkedin.com/pulse/rule-thumb-fillet-weld-size-thomas-lakas*"

6.7.5 Optimisation parameters mitre gate without clearance

The mitre gate without clearance consist of 3 resisting structural elements wich has to be checked. The changeable optimisation parameters, the parameters which are used to resist the load and have an optimal design in term of steel volume used are summarised in this paragraph.

Vertical beams

- Thickness front plate
- Effective front plate width
- Thickness web plate
- Web height
- Thickness flange plate
- Flange width
- Vertical beam spacing (currently maximum of 10 vertical beams can be used)

Horizontal beams

- Thickness front plate (same as vertical beams)
- Effective front plate width
- Thickness web plate
- Web height
- Thickness flange plate
- Flange width

Heel post

- Thickness profile
- Total profile width
- Total profile height

6.7.6 Changeable Input parameters mitre gate without clearance

The input parameters which can be manually changed to asses different situations are:

- Water level high water side
- Water level low water side
- Total lock width

6.8 Rolling gate parametric design

In the same way the mitre gate design considerations for the mitre gate variants are discussed, the rolling gate is as last discussed in this subsection.

6.8.1 General lay outs

Several types of layouts for rolling gates exists. When a gate needs to retain bilateral (Design high water can be on both sides of the gate) the basic lay out of structural elements of most rolling gates is the same, and consist generally of 6 main element types:

- A front and a backplate which directly retain high water
- Horizontal beams to transfer the load exerted on the front and backplate
- Vertical beams, which transfer the load from the horizontal beams
- Horizontal truss frames, which transfer the load from the vertical beams to the lock heads
- Diagonal stiffening frames in between the truss frames, which stiffen the gate and transfer the own weight of the gate to the floor.
- Ballast tanks, to decrease the weight of the gate while in operation

3 different types of existing lay outs are presented in Figure 27

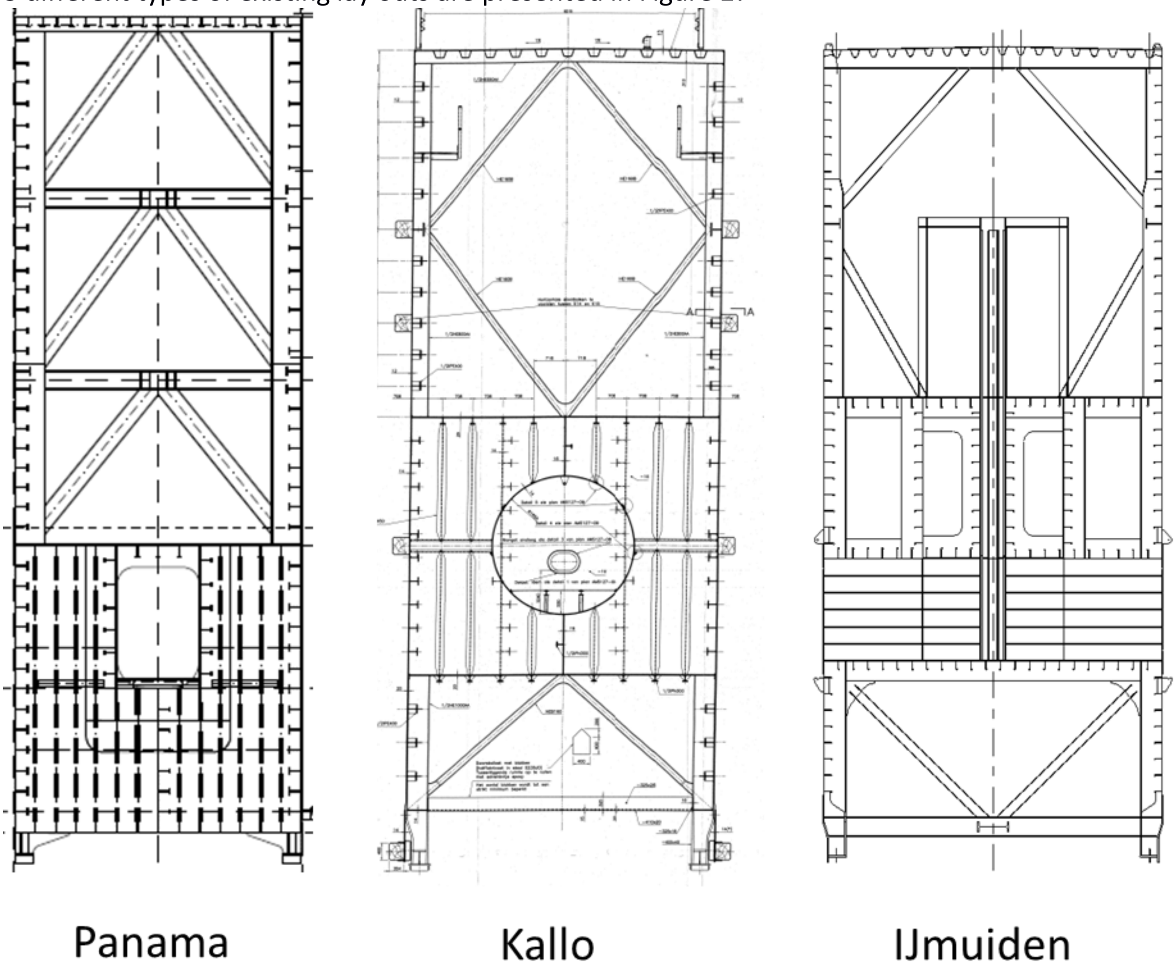


Figure 27 Basic structural lay outs (powerpoint about Ijmuiden gate, sent bij Gerard Bouwman)

6.8.2 Chosen lay out

The lay out of the rolling gate used at the parametric model has been based upon the Panama rolling gate lay out. The chosen lay out has been discussed with Roland Abspoel. The layout has been described in the design of locks book too. There are several reasons to choose this type of lay out:

-Lay out can be designed with a parametric model and can be used at all possible gate heights and gate widths because of its symmetry.
-Gate consists of a few different elements, so can be standardised (having a higher gate would lead to the addition of an extra K frame with the same elements only).
-Lay out has been used at previous projects, so gives a competitive design.

6.8.3 Designed elements and simplifications

For the parametric model it is important that the design can be decomposed to smaller objects which can be designed separately. This should be done with care, since the results of the model should represent reality, obviously. In order to have a model which can be used for nearly every situation, use has been made of the fact that the basic shape of the design stays the same, but the element dimensions and the number of elements can be changed. This way of designing leads to a simplification. The flow of the force through the structure (water load needs to be retained and transferred to the lock heads) can be modelled by means of decomposing the gate into different beams. Optimising the front and backplate, the horizontal beams, the vertical beams and the horizontal truss by means of the parametric model is very well possible.
The diagonal stiffening frames which are needed for stiffness can't be modelled by the parametric model, since the stiffness calculations have to be performed by more advanced FEM models and all the elements have to be considered as a whole. Luckily, according to Gerard Bouwman, who is senior advisor at Rijkswaterstaat and has a lot of experience with steel designs and lock gate designs, in practice the diagonal stiffening frames are estimated. The diagonal frames are not designed at this thesis, but standard profiles have been chosen. The ballast tanks are not designed at the thesis too. In order to add the ballast tank design, the structure has to be assessed as a whole, which can't be done by the parametric model. Instead of ballast tanks the trusses and diagonals have been placed at those locations, instead to add structural integrity.

6.8.4 Rolling gate loads

The basic loads acting on the whole structure are the same for the rolling gate, as for the mitre gates. A trapezoidal hydraulic load is acting on the rolling gate, this load is visualised in Figure 21.

6.8.5 Specific design rolling gate

The rolling gate will have the general lay out as prescribed above. A structural design is made for the front plate, backplate, horizontal girder, vertical girders and horizontal trusses. For the horizontal stiffeners standard HEB profiles have been used, with the same width of the truss frame elements (with advice of Gerard Bouwman). The front and backplate are used as parts of the vertical and horizontal beams (and so are designed with them). So, the structural design consists of 3 main elements:
-Horizontal beams
-Vertical beams
-Horizontal trusses

The design per element will be discussed below.

Figure 28, Figure 29 and Figure 30represent a typical gate rolling gate as designed in the parametric model. Since the calculations have been performed with a parametric model, the number of elements (horizontal beams, trusses and vertical beams) can vary from the pictures presented.

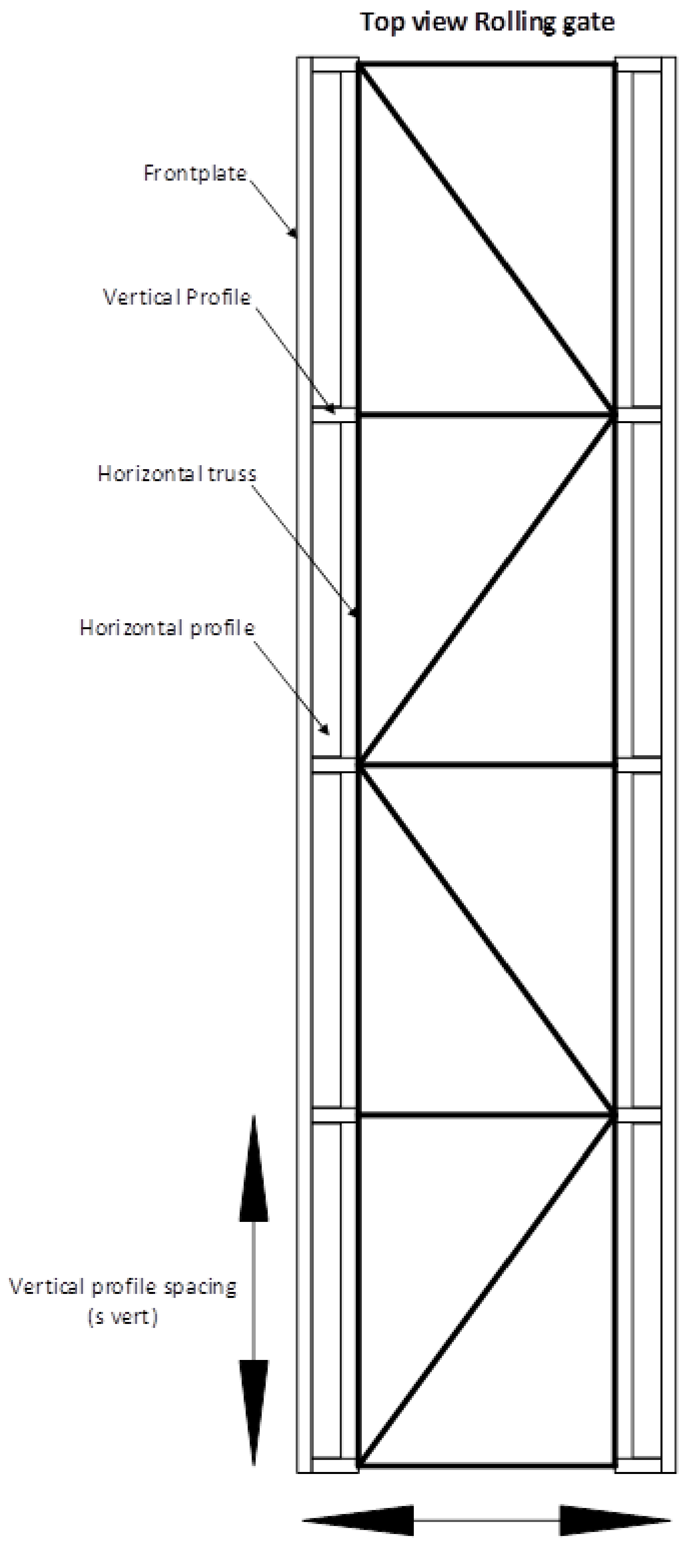


Figure 28 Top view rolling gate (not to scale)

Side view rolling gate

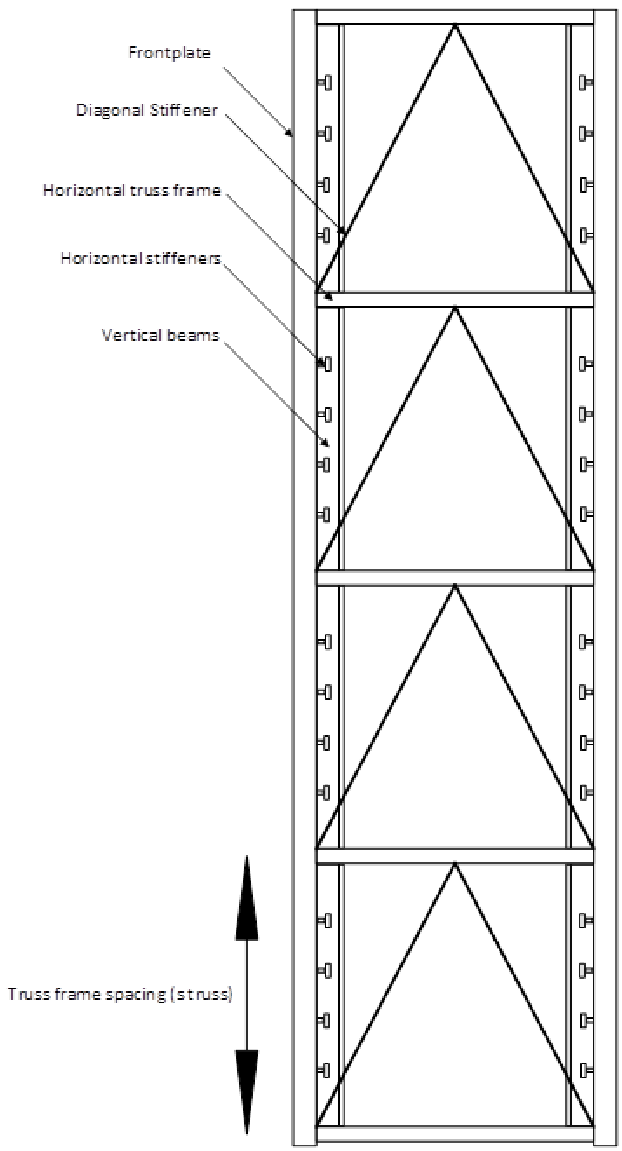


Figure 29 Side view rolling gate (not to scale)

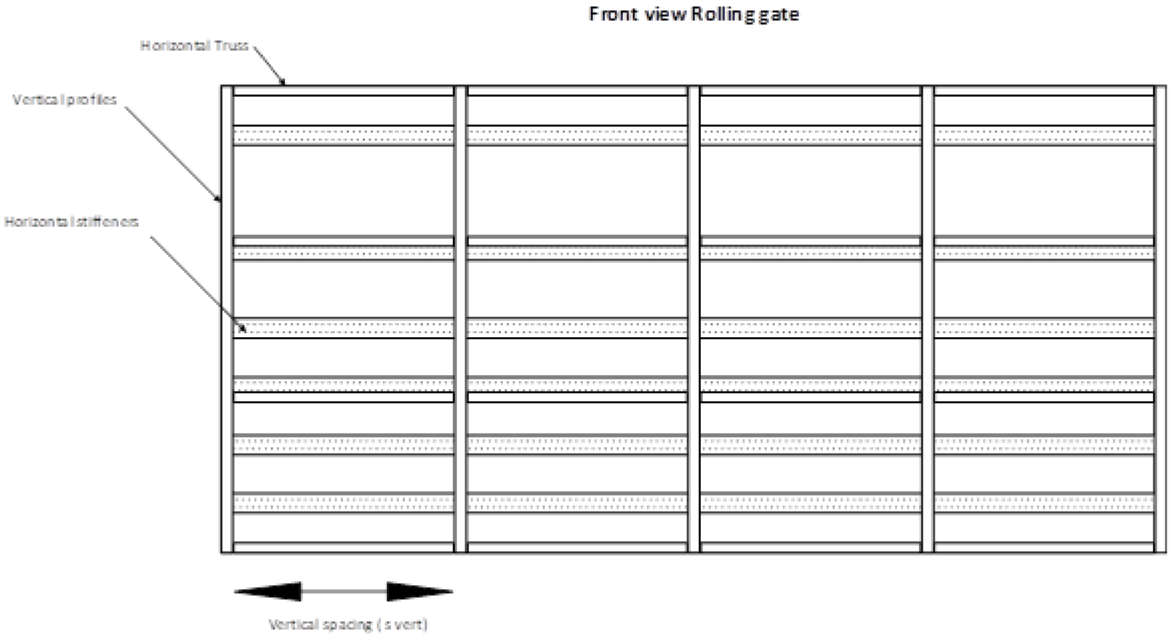


Figure 30 Front view rolling gate (not to scale)

6.8.6 Flow chart parametric model

The force of the load induced by the water level difference has to be transferred to the lockheads. Three different element types will be used to transfer this force to the lockheads. First of all, the relation between these elements is showed with a flow chart. Then the calculations and assumptions which have been made will be presented per element type.

The basic idea of the flow chart is that there are 3 elements, which are related to each other. The assessment of the top element leads to input for the element located below (at the scheme). The loads should match the resistances in such a way that the unity checks have a value of 1 or lower. Excel uses an algorithm to get the right parameters in order to match the unity check requirement, and the minimal steel volume used requirement. The algorithm used is discussed in more detail in Paragraph 6.9.

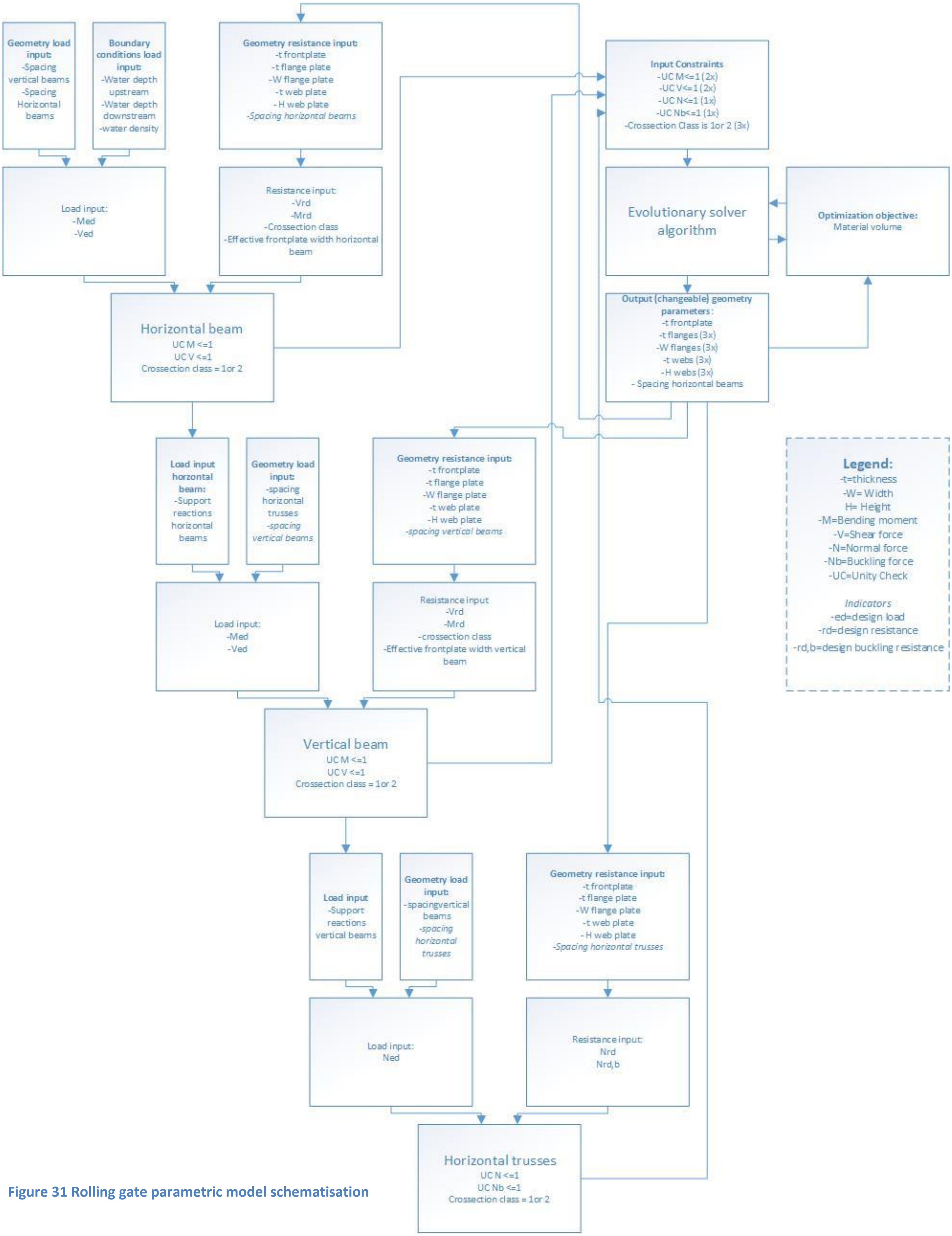


Figure 31 Rolling gate parametric model schematisation

6.8.7 Horizontal beams rolling gate

The horizontal beam has as function to transfer the load because of the water level difference at both sides of the front plate to the vertical beams. These beams are located in such a way, that the load on every beam is the same. Every beam will have the same dimensions. This leads to an increasingly spacing from bottom to top. There is chosen to differ the spacing instead of the beam dimensions, because this is easier with standardization.

6.8.7.1 Lay out horizontal beam

The front plate is part of the horizontal beam. The beam consists of the effective width of the front plate (the part of the front plate which can be used to carry the load) a web and a flange. Everything is welded together. Since the beam has to carry the load from the front plate to the vertical beams, the length of the beam is the distance between the vertical beams. This type of beam have already been discussed throughout the thesis (same type as described in the general parametric model part and the mitre gate part).

6.8.8 Resistance horizontal beam

The beam will be an H profile, consisting of the front plate of the gate, a web plate and a flange plate. The resistance calculations have been performed in the same manner as the resistance calculations for the mitre gate. The differences with those calculations are that the beam hasn't been subjected to an axial force (so no buckling and normal force criteria have been checked) and that compression can occur in both flange and web plate (so cross section class should be checked for both plates).

6.8.8.1 Design checks Horizontal beam

The checks performed are checks on bending and shear force. There are also cross section checks performed in order to check that local buckling won't occur. The checks have been performed as described in the general paragraph. Summarized the checks performed are:

- Bending moment
- Shear force
- *Bending and Shear force combined, when necessary*
- Cross-section class (front plate and flange plate)

6.8.9 Assumptions made for the horizontal beam load

- Load is evenly distributed over the width

This will always be the case in this situation, since the water level can be assumed to be constant over the width on both sides.

- Spacing between vertical beams is the same (so length horizontal beams is the same)

It should be kept in mind in the design (so in the parametric model) that the modelling of the load is only valid in this way if the spacing between the vertical beams is kept constant.

- Torsional moment due to pressure differences at top and bottom side of the beam is negligible

The pressure differences are relatively small when the beam height is not immense. The stiffness of the gate as a whole will be able to resist them, the top front plate flange of a beam is obviously solidly connected with the bottom front plate flange of the beam above. This creates a lot of stiffness. The vertical beams at the sides provide extra stiffness as well.

- Own weight is negligible for the beams

The weight of the beams is very small compared to the loads due to water level difference, and the direction is different too, so the effect is negligible

If these assumptions hold, every horizontal beam has the same moments at the sides (since the angular rotation at the sides, so where the vertical beams are located, should be 0). Without these assumptions the beam would have to be modelled as an ongoing beam over the total width of the gate instead of the width between two vertical beams, supported by the vertical beams. This last way of modelling would unnecessarily increase the complexity of the model.

The assumption with respect to vertical beam spacing is also beneficial for standardization, since the gate will consist of less different components.

6.8.10 Assumptions made for the horizontal beam resistance

- The profile design is limited to cross-section class 2, this gives a better design.
    This limitation has as a positive effect that local buckling won't occur, and that the beam can be calculated Plastically. The beam is more robust too, which is positive since small ship collisions can occur quite easily, this should not immediately lead to bended webs or flanges or other sorts of damage.

6.8.11 Vertical beams rolling gate

The Vertical beams have as function to carry the load from the horizontal beams to the horizontal truss frames.

6.8.12 General lay out vertical beams

The vertical beams consist of the effective width of the front plate, reinforced with a web plate and a flange plate. The beams are evenly distributed over the width of the gate (reasons for this decision have already been given). The web heights of the vertical beams may not be to high, since this would lead to problems with closing the door (water must be able to flow parallel to the front plate through the door, otherwise the piston effect would lead to high forces when in operation.

6.8.13 Resistance vertical beam

The beam will be an I profile, consisting of the front plate of the gate, a web plate and a flange plate.
The resistance calculations have been performed in the same manner as the resistance calculations for the horizontal beam. The beam has been subjected to shear force and bending moment only and is checked for cross-section class (as is the case with the horizontal beam).

6.8.14 Assumptions made for load calculations

- Maximum of 7 horizontal truss frames to support the vertical beam
    With these 7 truss frames a gate height of 18m could be supported, when the spacing is 3m, this should be ok for The Netherlands. If there are more truss frames needed, the model can be changed quite easily.
- Maximum of 20 horizontal beams which load the vertical beams.
    When these beams have a spacing of 1m, a gate height of 19m can be supported. This should be a reasonable height for The Netherlands. The model can be changed quite easily to increase the number of horizontal beams when needed.
- Spacing between truss frames is kept constant.
    This assumption leads to more components of the same sizes (beneficial for standardization)
- Spacing of horizontal beams is inserted separately from the spacing of the horizontal truss frames.
    This assumption is needed to be able to make the model parametric. The assumption follows from the fact that the horizontal beams are spaced such that every beam caries the same load, but the spacing of the truss frames is constant. Using the truss frames for horizontal beams to could be beneficial, but can't be implemented parametrically, this would also lead to bending moments in the truss frame.

6.8.15 Assumptions made for resistance calculation

- Contribution of own weight can be neglected in the vertical beams
  Own weight doesn't act in the same direction as the load from hydrostatic pressure and has a negligible magnitude.
- Side Vertical beams have the same dimensions as the middle vertical beams
  Middle vertical beams carry a higher load, so the side beams are over dimensioned. Because the vertical beam contribution to the steel volume is very small, this over dimensioning is negligible.

6.8.16 Horizontal truss rolling gate

The horizontal truss frame carries the load from the vertical girders to the lock heads. The vertical beams are located at the nodes of the truss, so only normal forces will be present in the truss. The gate should be bilateral retaining, so the load can be on both sides of the truss. The best configuration for this situation is determined.

6.8.17 Lay out truss frame

2 different basic lay outs are considered for the truss frame. The lay-outs can be seen in Figure 32 Different truss frames.

- Diagonal beams of one half are parallel (Pratt/Howe truss)
  The advantage is that the diagonals are loaded in tension if the load is one sided and the diagonals are positioned in the right way (so no buckling in the diagonals). In this case the load comes from 2 sides so this advantage is not present.
- Diagonal beams change direction (Warren truss with vertical beams)

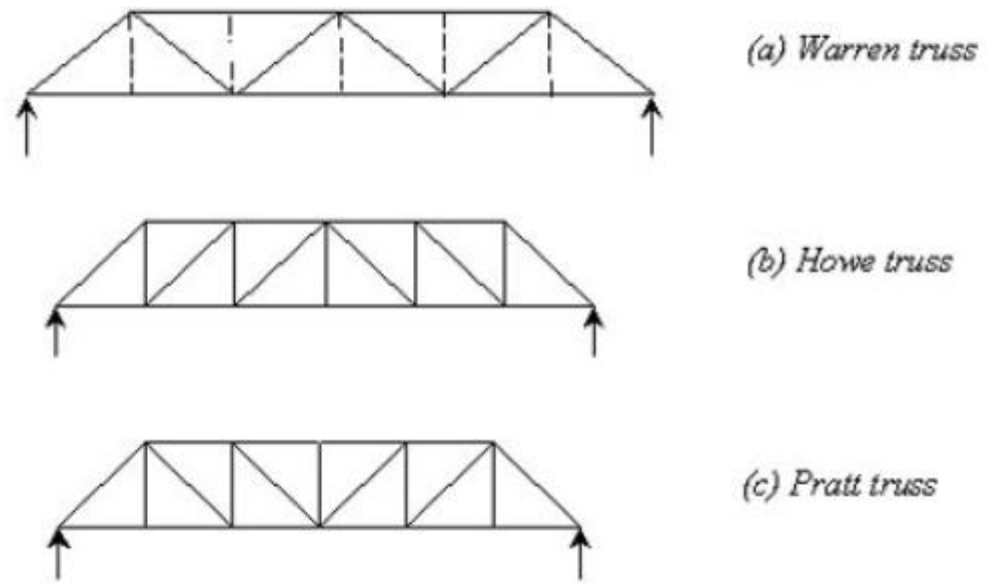


Figure 32 Different truss frames (https://nptel.ac.in/courses/105106113/9_bridges/7_truss_bridges.pdf)

From Appendix D it becomes clear that the Warren truss with vertical beams gives the best configuration.

6.8.18 Resistance truss frame

The truss frame beams have only been subjected too normal force. This can lead to buckling and to failure because of yielding. The truss frame has been designed such, that every beam has the same dimensions. Later on, comparison is made in terms of material use when applying different beams per truss frame. The checks performed are shown below (besides cross section class checks, which are performed as before). The truss frame will consist of H profile elements (with identical flanges).

6.8.19 Load assumptions truss frame

- Own weight can be neglected
  Own weight is carried by the diagonal stiffeners. The magnitude own weight is relatively small, and not acting in the same direction as the main load

6.8.20 Resistance assumptions truss frame

- For the beams a H-Profile has been taken as standard profile
  A circular hollow section would have a better resistance with the same cross-sectional area, hollow sections are relatively expensive though, therefor there has been chosen to apply H profiles
- Standard HEB truss frames have been taken to meet the resistance requirements, per beam
  HEB beams have a relative symmetric buckling resistance in both directions. The resistance is not completely the same. For an optimal design in terms of material need, a circular hollow section would be chosen, circular hollow sections are relatively expensive, so therefor HEB sections have been used.

6.8.21 Optimisation parameters rolling gate

The rolling gate consist of 3 resisting element types which has to be checked, vertical beams, horizontal beams and a truss frame. The changeable optimisation parameters, the parameters which are used to resist the load and have an optimal design are only used to optimise the vertical and horizontal beams, since the truss frame uses standard HEB profiles. Summarised, the optimisation parameters for the rolling gate are:

Horizontal beam

- Thickness front plate
- Strip height
- Thickness flange plate
- Flange plate width
- Thickness web plate
- Web height

Vertical Beam

- Thickness front plate
- Effective frontplate width
- Thickness web plate
- Web height
- Thickness flange plate
- Flange width
- Vertical beam spacing (maximum of 10 vertical beams possible)

6.8.22 Changeable Input parameters mitre gate with clearance

The input parameters which can be manually changed to asses different situations are:

- Water level high water side
- Water level low water side
- Total lock width

6.9 Solver algorithm

The solver algorithm is the algorithm used by the parametric model to optimise the input parameters in such a way that all the conditions regarding strength have been met and that the material volume used is minimal.

6.9.1 Model input parameters

The model has been made parametric, so every value can be changed easily. The purpose of the model is to compare different gate types in terms of material used. This comparison will be performed for different total widths and different retaining heights. At the first phase the material use of the mitre gate model as described above for different retaining heights and widths will be evaluated.
The variable optimisation parameters are discussed for in the previous paragraph, and are for example flange width, flange thickness, web height and web thickness, front plate width and front plate thickness and center to center distance of the webs. By varying these parameters, the gate gains enough resistance to resist the loads.

Several constraints have been implemented in the model. These constraints have the function to maximize the potential of the material. An example of this is the limiting of possible cross section classes to class 1 or 2, at a higher class the norms oblige to use elastic material calculations instead of plastic. Another example is the limiting of plate thickness to 0,04 m, above this value the strength of the material should be decreased according to the norms.

6.9.2 Model output and solver algorithm

In order to make a valid comparison, the output results (material use) should be the optimal solution for given input values. This has been achieved by the use of the solver algorithm in excel. 2 solver algorithms have potential to optimize the steel profile while resist the forces acting on the profile.

6.9.2.1 GRG nonlinear algorithm

One solver algorithm is the GRG Nonlinear algorithm. This algorithm seeks for a minimum with the use of derivatives. The algorithm is very fast (less than a second per run for the current model). In spite of the advantage of its computational time, the algorithm has its drawbacks, this can be seen from Figure 33. The method gives the following output for m^3 steel for a certain width, with a maximum water retaining height of 9m.

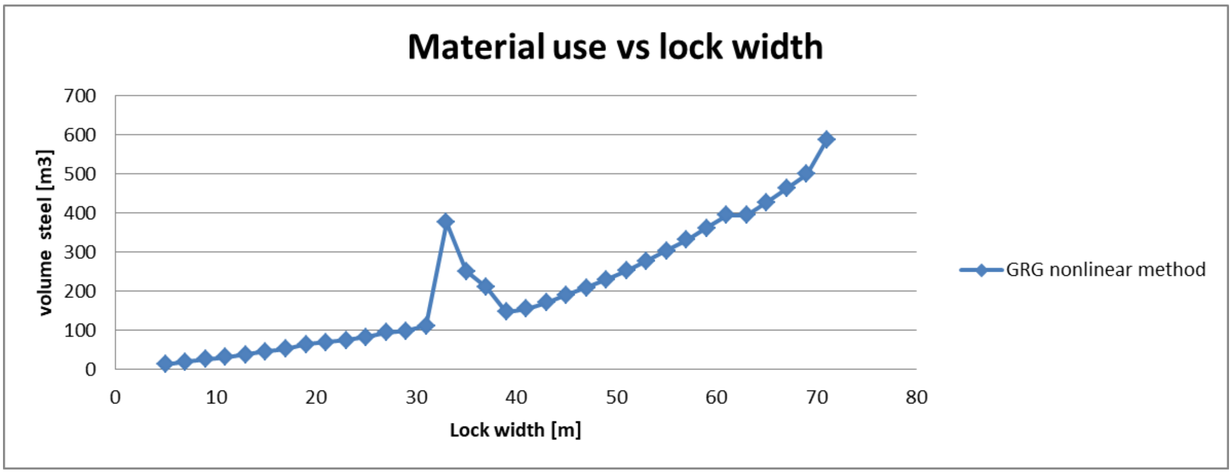


Figure 33 GRG nonlinear method graph, material vs width

It can be clearly seen that the results between the 30m and 40m don't represent reality, since it is impossible that a smaller gate has a higher material usage if optimised for the same boundary conditions. The reason for this is the nature of the optimization algorithm. The algorithm will find an optimum, but this optimum is not always a global optimum. When the starting values are near a local optimum, this local optimum will be the output, the global (real) optimum won't be presented in that case. Another drawback of this method is that the functions should be smooth, the 'if statements' in the functions applied at the model won't lead to smooth functions, this could give problems when optimising with the help of the GRG nonlinear method. For this reason, another method will be used to optimise.

6.9.2.2 Evolutionary method, runtime and population size

The evolutionary solver method doesn't necessarily give an optimal solution, but tends to find a good solution. The reason for this is the nature of the solver algorithm. In contrast to the GRG nonlinear method, the evolutionary method doesn't use derivatives or gradient information to come to the solution. The evolutionary method tries (semi) randomly input parameters, and memorizes the set of input parameters which give the best result after every run. Since the result doesn't converge to an optimum solution, the evolutionary method would go on for an infinite time, if no restrictions would have been made. The restrictions implemented are the amount of time spend running without finding a better solution, and the size of the population. The meaning of 'population' in this context is explained below.

The input parameters will not be generated completely random, the solver method learns from the outcomes. Several strategies of generating high potential input parameter sets (in terms of input parameters with a high chance to find a good solution) are implemented in the evolutionary algorithm. Input parameters which lie around the input parameters which give a good result will be generated as new input parameters, the group of input parameters around a set of input parameters with a good result is called the population size. By increasing the population size, the algorithm generates more input parameter sets around a high potential input parameter set. The population strategy tends to find the best solution around a fixed point, which increases the chance to find a local or possibly global best solution.
Since the population strategy only tries solutions around one fixed point, this strategy could very well create local instead of global best solutions (as is the problem with the GRG nonlinear method). In order to prevent this from occurring the mutation strategy is implemented.
Some input parameter sets tend to change randomly by a random amount. This leads to a totally different solution, which could lead to a totally different (local or global) best solution. The higher the mutation rate, the more totally different input parameter (sets) are generated.

6.9.2.3 Graphical example solver methods

In order to give an idea about the differences of the solver methods a simple function will be evaluated with the help of the solver. If we for instance want to evaluate the minimum value of the function:

$$f(x) = x * \sin(5x)$$

For:

$$0 \leq x \leq 10$$

This gives the graph of Figure 34.

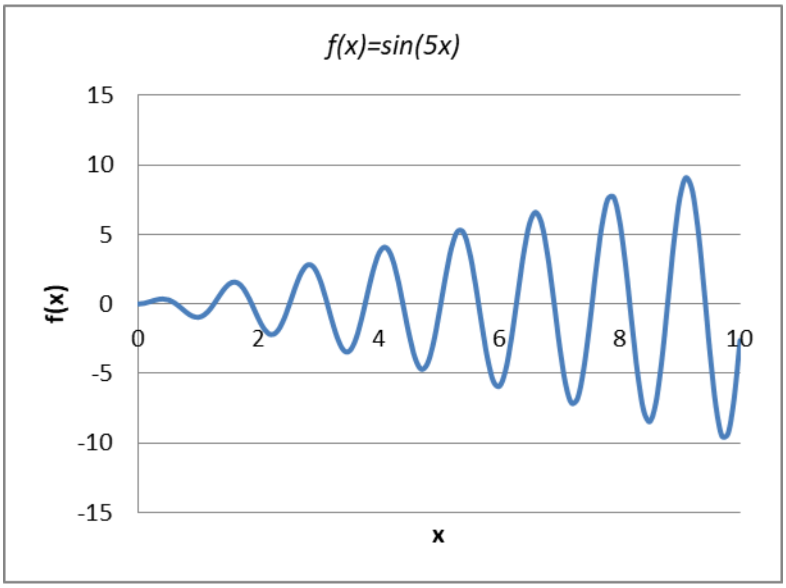


Figure 34 Sine function example

In this example x is the only input parameter, in the model used to evaluate lock gates there is a set of input parameters (for example: t_{web}, h_{web}, t_{flange}, h_{flange}, $t_{frontplate}$, $h_{frontplate}$, strip height). All those parameters are variable, the set with the lowest material use should be found.

Evaluating this problem via the analytical way:

$$f(x)' = \sin(5x) + 5x\cos(5x) = 0$$

For:

$$0 \leq x \leq 10$$

This gives 8 local minima, one of these is the global minima. This global minimum can obviously be found near x=10 (information obtained from the graph presented above). With the help of the graphical calculator the minimum value for x can be found to be about 9,7430,this gives a value of -9,7410 for f(x) . Important to note is that the location of the global minimum should be given to the graphical calculator.

The graphical calculator uses numerical schemes to analyse the minimum values, just like the GRG nonlinear method. The difficulty with more difficult problems is that the location of the global minimum isn't know, since there are more than 1 input parameters, no graph can be plotted.

When the GRG nonlinear method has been used to analyse the problem, and the starting value is 5 (which is randomly chosen), the GRG nonlinear method finds the (local) minimum which is situated at x=4,7210 and which has a value of -4,7166. In this example it is clear that the solver found a local minimum instead of a global minimum, but this is not immediately clear at complex problems. Only if the starting value of x is in the domain where the global minimum can be found, the GRG nonlinear method can find the global minimum. This is the region between one extreme before and one extreme after the global minimum. In this case this is the region between x=9,115 (extreme before global minimum) and x=10 (maximum value for x since the objective was to evaluate only the domain $0 \leq x \leq 10$).

The evolutionary method for starting value x=5, gives after a few seconds x=9,7430 with f(x)= 9,7410, which is the global minimum. For more complex problems the runtime can be several minutes before a good answer is obtained, there is no absolute certainty that a minimum has been found.

Since There is a good possibility that he evolutionary method finds a solution near the global optimum, but doesn't find the global optimum, the GRG nonlinear method will be used when the evolutionary method has been used to find a good solution, in order to find a minimum.

In the example presented above global minimum would be found if the evolutionary method finds a value of x between 9,115 and 10 and the GRG nonlinear method would be used afterwards. The graph with the outcomes of the different methods is presented in Figure 35.
Since the evolutionary method alone is already good enough for this simple problem, the combined method (evolutionary and GRG nonlinear) lead to the same result.

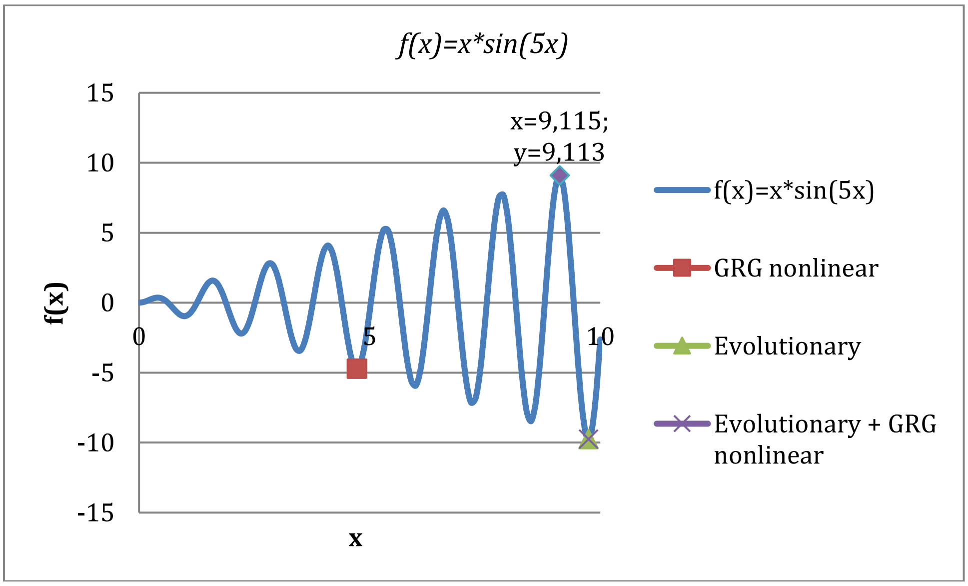


Figure 35 sine example solver method comparison

6.9.3 Results

The results of the steel volume as a function of lock width are presented in Figure 36 for a retaining height of 9m. The last part of the graph doesn't seem to give realistic results. More runs with the model will be performed to give better results.

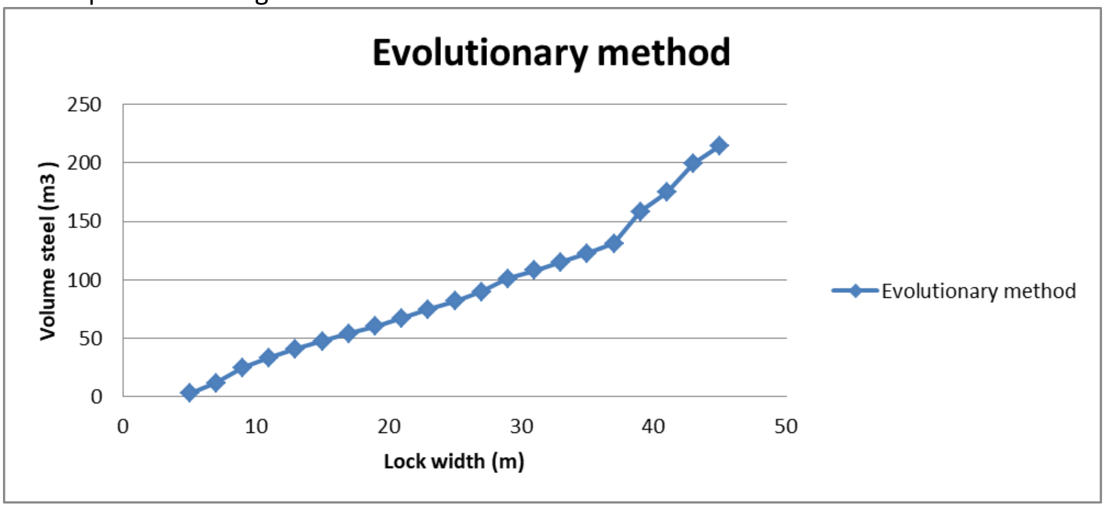


Figure 36 Evolutionary method graph, material vs width

6.10 Concluding remarks

Two specific gate types are programmed in the parametric model, the rolling gate and mitre gate. The output of the loaded elements is validated with matrix frame. The main constructive elements can be programmed parametrically. The torsional stiffening elements can't be calculated with the model. These elements are included as standard profiles (rolling gate) or have a relatively small contribution to the total amount of material used (mitre gate). The evolutionary solver algorithm needs to be used to get the optimised results for material use for specific boundary conditions, special attention should be payed to the setup of the solver algorithm.

7 Results parametric model

This Chapter is part of the answer of the 5th research question: “How will a decision be made based on quantitative arguments?”. This Chapter presents the results of the parametric model for several boundary conditions.

7.1 Mitre gate with clearance Results

Like in a normal design process, the parametric model has been adjusted several times, after running the model. Following from the results the model can be adjusted. This process is presented at this chapter. The changes made in the model following from the output are described too. The upstream water depths used are 12m and 8m, the downstream water depths are 5m and 0m. These upstream water depths are quite common in the Netherlands. The downstream water depth of 5m represents the minimal water depth of a CEMT Va-VII ship (4,50 loaded water depth, plus 0,5m keel clearance) (Brolsma & K.Roelse, 2011), the 0m represents the situation where a lock has been pumped completely dry for maintenance for example.

7.1.1 First mitre gate results

The first results for the mitre gate are presented in this paragraph. The steel volume results are for 1 mitre gate. The widths are the total lock widths (and 2 mitre gates can close of 1 lock with a specific total lock width).

7.1.1.1 Input parameters

In Table 9, the (changeable) input parameters and their boundary values are presented.

Variable input parameter	**Minimal value [m]**	**Maximal value [m]**
Thickness front plate	0,008	0,04
Thickness web plate	0,008	0,04
Thickness flange plate	0,008	0,04
Web height	0,15	
Flange width	7 x thickness web plate	Strip height
Minimum strip height	*Different values taken **	

Table 9 input parameters mitre gate

The plate thicknesses are restricted to be between 8mm and 40mm since smaller plates are not practical to work with and will be damaged fairly easily by minor accidents, larger plates need reductions. The flange width should be minimal around 7 times as wide as the web thickness, to work as a flange (discussed with Roland Abspoel). This rule is implemented in the model, since the model will otherwise extend the web and call it a flange, which is beneficial for the cross-section class calculation, but which doesn’t give a representation of how the checks should be performed. A minimum web height of 0,15m has been chosen, since otherwise welding would be very difficult. The flange width can’t be larger than the strip width for obvious practical reasons.

*The minimum value of strip height has been implemented manually. Smaller strip heights reduce the amount of material needed but increase the amount of welding needed. Since welding is not implemented in the model, very small strip heights will be the result. This is not representative. The effect of different strip heights is shown in a figure.

7.1.1.2 Runtime and population size calibration

First of all, important parameters for the solver have been adjusted. This adjustment is crucial for the running time and the quality of the results. For several running times without improvement, and population sizes (total of 7 combinations) the mitre gate model has been run. The results are presented in Table 10. The minimal values of all the 7 runs are presented in the last column. It is likely that that is the global minimum. The difference per run (in %) is presented in the table as well, the average difference of a specific set up of the solver fir all the runs is presented underneath the Δ% column. The results are plotted in Figure 37. Running the model with a time without improvements of 300 seconds and a population size of 200, gives the lowest difference from the minimal answer.
For the higher gate widths, a bigger population size could be beneficial to be used. This can be expected, since with higher gates, more input parameters are higher than their practical minimal values, so more input parameters will differ, increasing the population size will increase the chance of finding the global optimum.

The minimal value line is a smooth, nonlinear increasing line. This result is expected, since the load is increasing quadratically. If the population size and stoppage time aren't chosen correctly, local instead of global optima can be found, this can be seen by the great differences with the minimal values, and by the higher material need for a specific situation which has a lower load then another situation (the high result for a gate width of 15m with the t300/p200 run for example).

up:8/dwn:5	**15min+/p500**		**t300/p400**		**t300/p300**		**t300/p200**		**t300/p100**		**t200/p200**		**t400/p200**		
Width:	Vsteel	Δ%	Vsteel	Δ%	Vsteel	Δ%	Vsteel	Δ%	Vsteel	Δ%	Vsteel	Δ%	Vsteel	Δ%	**Min**
7	**0,37**	0,27	0,41	12,20	0,41	12,20	**0,37**	0,00	0,41	9,76	0,45	20,87	**0,37**	0,00	**0,37**
11	0,65	0,62	0,65	0,46	**0,65**	0,00	**0,65**	0,00	**0,65**	0,00	0,65	0,15	**0,65**	0,00	**0,65**
15	1,00	0,17	1,00	0,37	1,02	2,47	**1,00**	0,00	1,02	1,87	1,34	34,03	1,00	0,07	**1,00**
19	**1,42**	0,00	1,52	7,20	**1,42**	0,00	**1,42**	0,00	1,51	6,64	1,47	3,53	1,44	1,41	**1,42**
23	2,02	6,32	**1,90**	0,00	2,22	16,84	1,93	1,58	2,12	11,58	2,00	5,26	1,92	1,00	**1,90**
27	2,57	0,55	2,60	1,52	2,63	2,73	2,69	5,16	3,03	18,36	**2,56**	0,00	2,78	8,67	**2,56**
	avg:	*1,32*	*avg:*	*3,63*	*avg:*	*5,71*	*avg:*	*1,12*	*avg:*	*8,03*	*avg:*	*10,64*	*avg:*	*1,86*	

Table 10 Solver calibration first run mitre gate with clearance

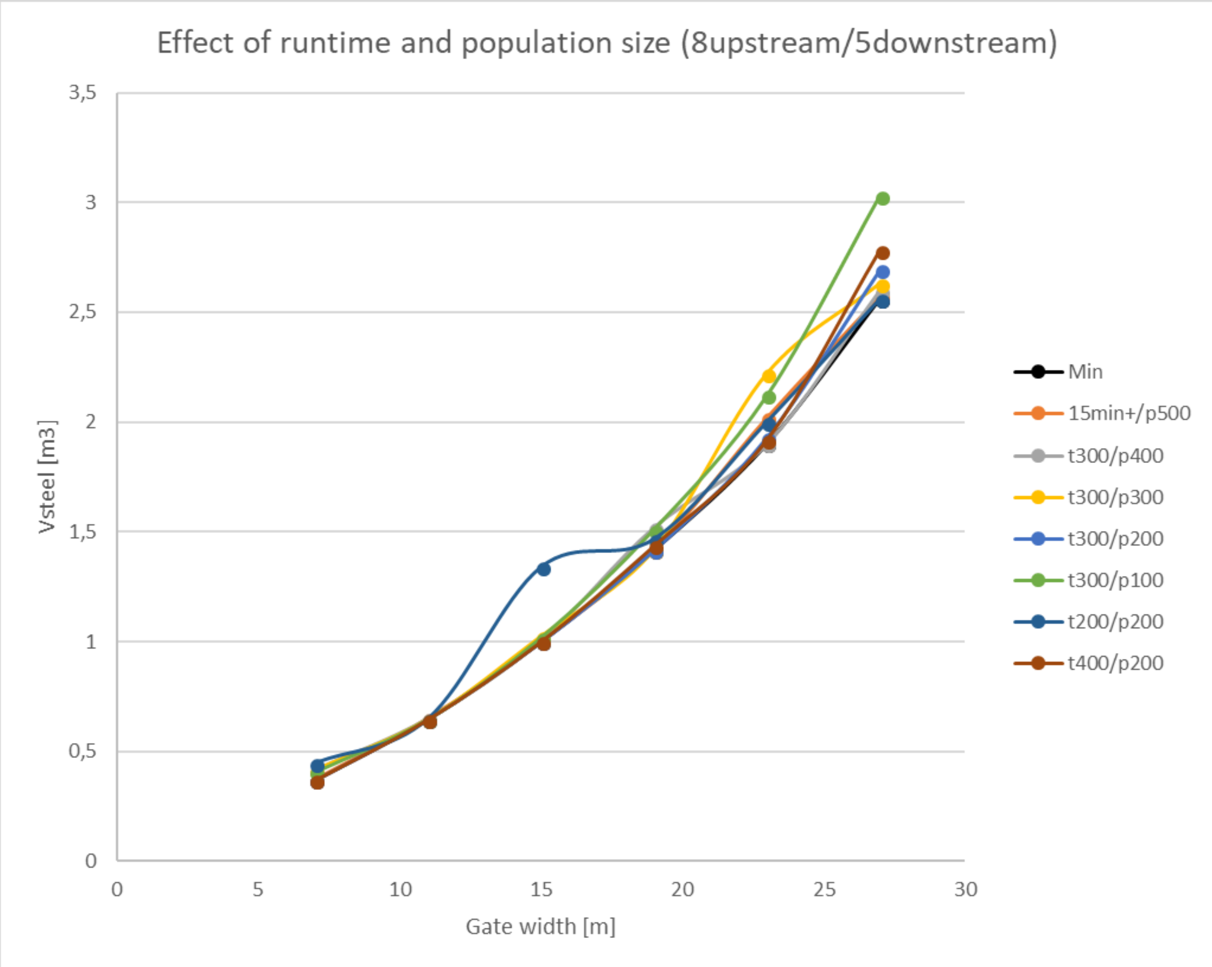


Figure 37 Mitre gate effect of population size and stoppage time

7.1.1.3 Effect of water level difference

The mitre gate model has been run for several situations. The results of running the mitre gate model for 3 different water pressure differences for gate widths between 5m and 36m are presented in Figure 38.
For the lower gate widths, the lines are smooth, which indicates that global optimum situations are found. The higher gate widths give non-smooth lines, which indicates local optima. It is clear that the run time and population size should be adjusted if the model is used for the higher gate widths.

In general, the smaller water level difference, the smaller the steel volume (which obviously should be the case). The global shape of the line is also nonlinear. This indicates that the model works as it should.

The water level difference looks like to have a relatively low influence on the steel volume. This indicates that a lot of steel parts are dimensioned at their minimal practical values.

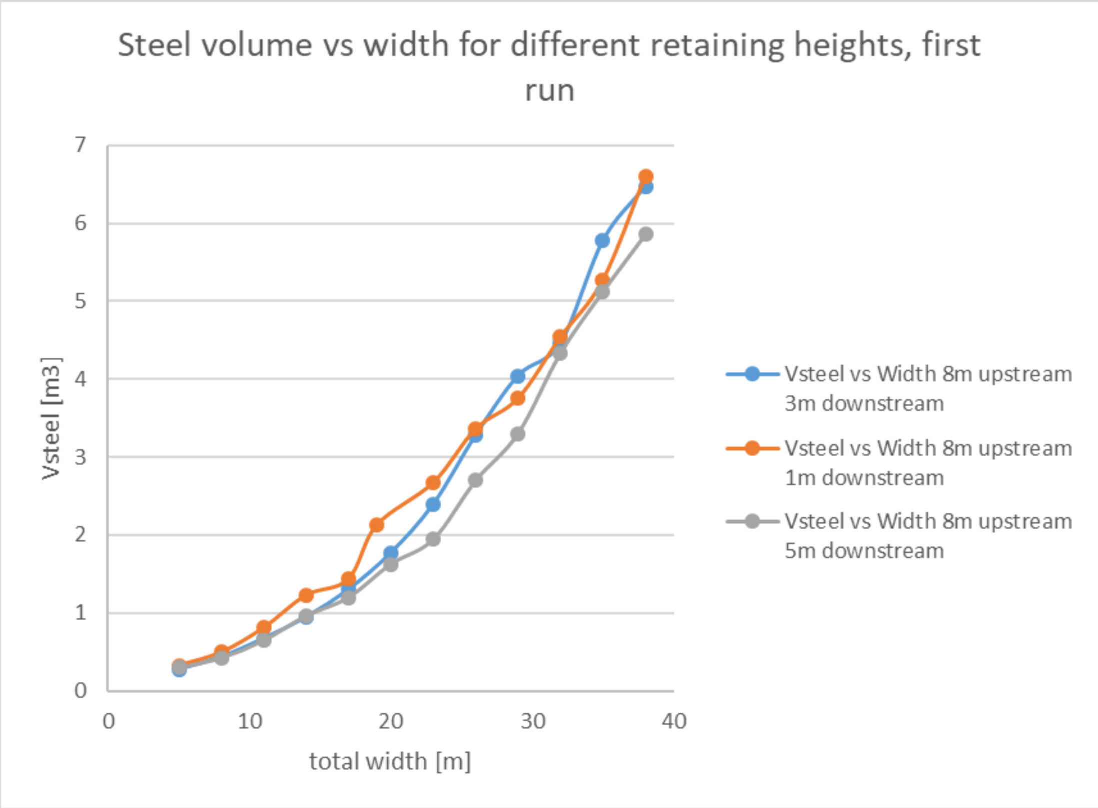


Figure 38 first results mitre gate

7.1.1.4 Effect of strip width

The decision for strip width size has a large effect on steel volume. Since smaller strip widths require more welding a comparison with welding costs should be made. Figure 39, presents the effect of minimum strip widths.

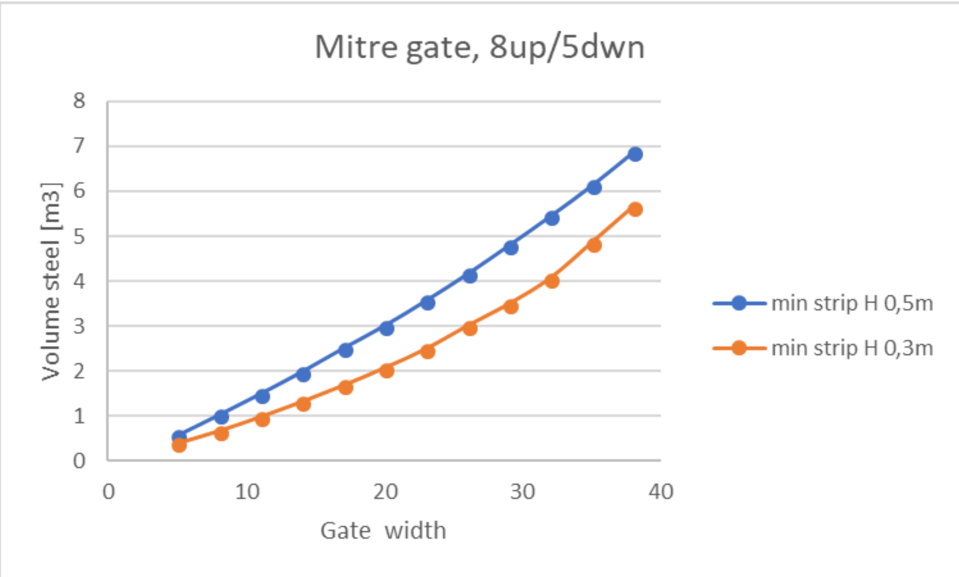


Figure 39 first results, mitre gate strip width comparison

7.1.1.5 First mitre gate result Conclusions

In general, the first results give a good starting point for the second simulation test.
The minimum front plate thickness will be increased from 8mm to 12mm. This change in thickness has been chosen to have a more robust design. This change has been implemented on advice of Gerard Bouwman. A reflection on the difference results because of this change will be given in the next concluding remarks of this Chapter. Extra care should be taken while setting up the solver

algorithm (population size and stoppage time). The minimum strip width taken has a large influence on the results and will be investigated in more detail in Chapter 9.

7.1.2 Second simulation mitre gate with clearance

The first simulation has led to the increase of front plate thickness and to the increase in population size and stoppage time, to get results which give a global optimum with more certainty to be a global minimum.

With the lessons learnt discussed in the conclusion of the previous sub section, a 2^{nd} run has been performed to obtain more results and to obtain more realistic results. The input parameters are the same except for the minimal front plate thickness, which is changed from 8mm to 12mm (as discussed in the previous paragraph).

7.1.2.1 Global optima test

To test whether the results are likely to be global optima instead of local optima, 2 runs for the same situation are performed. Since with a high load case, no changeable input parameters are bound to its minimal value (which leaves more room for variation and higher chances of local instead of global optima), a high load case is chosen for this test. A load case of 12m upstream and 0m downstream has been chosen, with a strip height of 0,5m. When Figure 40, is examined carefully, it becomes clear that instead of 1 line, there are actually 2 lines on top of each other. This shows that almost exactly the same results have been obtained, which makes it very likely that global optima have been found with the given solver algorithm parameters.

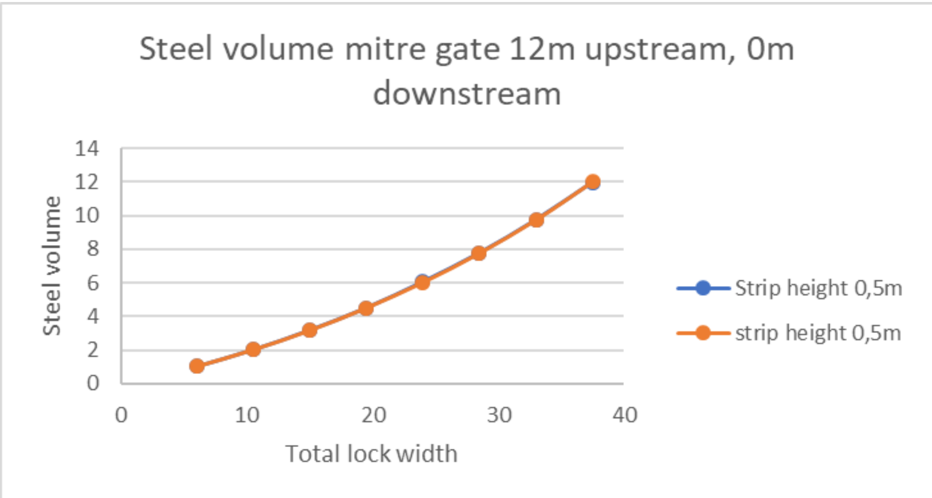


Figure 40 mitre gate population size/stoppage time comparison

7.1.2.2 Strip height comparison

For 2 different cases in water levels (8m upstream, 5m downstream and 8m upstream, 0m downstream) the differences in material volume are shown, both for a strip height of 0,5m and 0,3m. These differences are shown in Figure 41 and Figure 42.

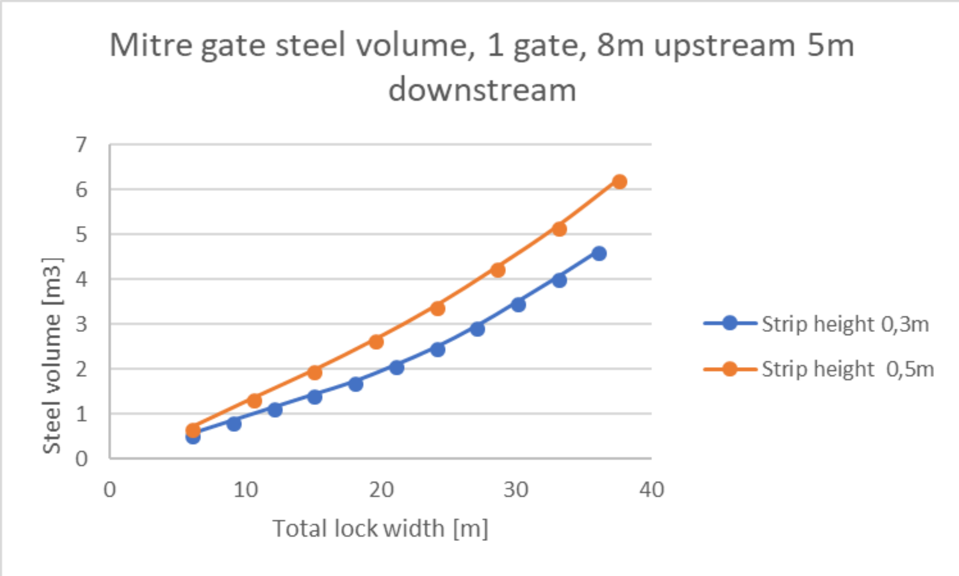


Figure 41 mitre gate 2nd results strip height comparison (1/2)

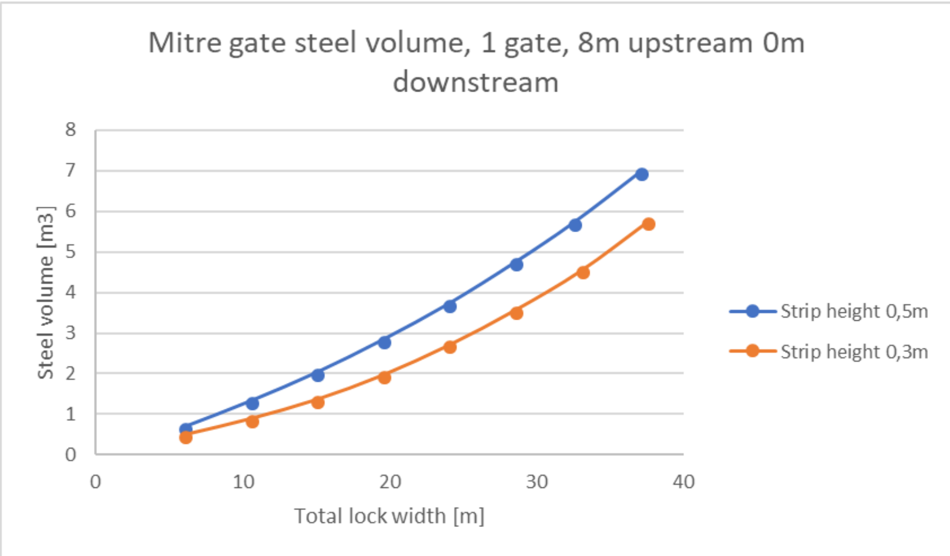


Figure 42 mitre gate 2nd results comparison (2/2)

The difference in material volume use, for a difference in strip height, stays a point of attention. The difference in material volume use between the two load cases stays relatively low. The results look like global minima. Since a strip height of 0,3m is in reality not very practical, and due to the welding costs probably quite expensive, for now a strip height of 0,5m will be used. Higher strip heights will need stiffeners in order to keep the cross-section class of class 2. In the case study in Chapter 9 the welding costs will be calculated as well, so both alternatives can be compared better.

7.1.2.3 Steel volume different load cases

For different load cases, the results are presented in Figure 43. The difference in material volume is mainly gate height driven, not water load driven, since it doesn’t really matter if the downstream water depth is 0m or 5m. This could indicate that the cross-section class is determining for the type of profiles used, since cross-section class isn’t dependent on loads.

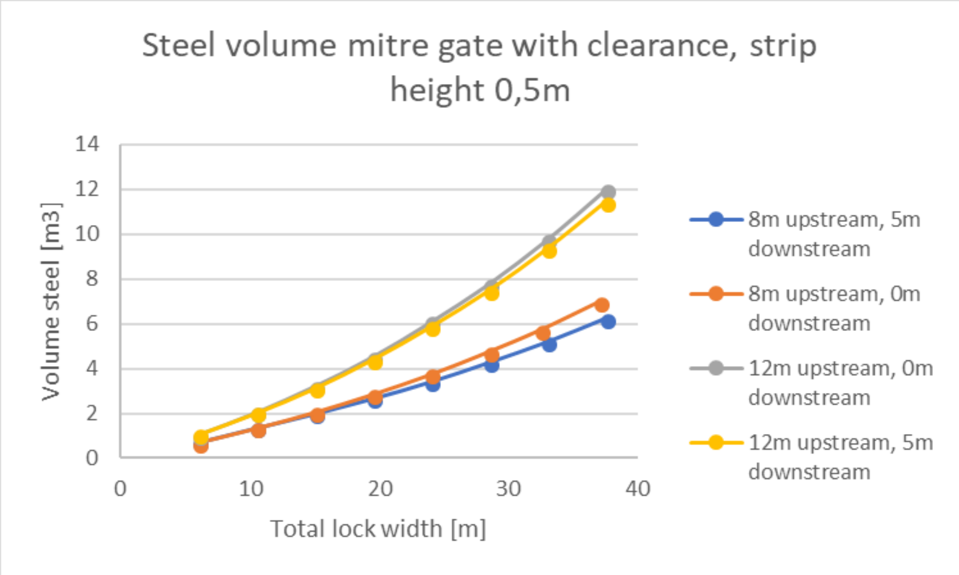


Figure 43 Mitre gate water level difference comparison

7.1.2.4 Unity Check comparison results

To get an idea about the determining checks for the mitre gate, the unity checks of the calculated model outputs for the 8m upstream water level and 5m downstream water level with both 0,3m strip width and 0,5m strip width cases have been summarized in Table 11 and Table 12. The unity check values correspond with the data points calculated for the graph of Figure 41. Every model run corresponds to 1 data point in Figure 41. The values in the table represent the Unity check of the label of the row in the left column. Unity checks closely to 1 are highlighted in red, since those values are determining from a structural point of view. It can be seen that for the higher widths buckling and moment check 1 and the cross-section class check for the web become determining, for the lower widths only the cross-section class of the flange is determining. The fact that no load unity checks are determining for the lower widths can be explained by the minimal plate thicknesses implemented in the model. The profiles should have minimal dimensions, otherwise the dimensions become unrealistically small, this gives a minimal resistance for the profiles which is apparently higher than the loads acting on the gate for the relatively low widths (under the 19,5 m). It can be concluded that since the cross-section class only is determining for this lower widths, extra measures could be considered to reduce the cross-section class for this widths, such as extra stiffeners to gain a more optimal result. A more carefull evaluation of the minimal used dimensions of the cross-sections used (such as flange width and frontplate thickness) potentially result in more optimal designs.

Model run no:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Total width	**6,0**	**9,0**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**	**36**
Volume steel	0,5	0,8	1,1	1,4	1,7	2,0	2,4	2,9	3,4	4,0	4,6
Cross section class UC											
Web (compression and	0,3	0,3	0,3	0,3	0,3	0,4	0,5	0,6	0,5	0,5	0,5
Web (compression)	0,4	0,4	0,4	0,4	0,4	0,6	0,8	0,9	0,9	**1,0**	**1,0**
Web (Bending)	0,2	0,2	0,2	0,2	0,2	0,2	0,3	0,4	0,4	0,4	0,4
Flange (compression)	**1,0**	**1,0**	**1,0**	**1,0**	**1,0**	**1,0**	**1,0**	**1,0**	**1,0**	**1,0**	**1,0**
Load Unity Checks											
Mpl, rd (PNA in frontplate)	0,1	0,2	0,4	0,6	0,9	0,9	0,9	0,9	0,9	0,9	0,9
Vpl,rd	0,0	0,0	0,0	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
Npl,rd	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Nb, Rd	0,0	0,0	0,0	0,1	0,1	0,1	0,1	0,1	0,2	0,2	0,2

Buckling and moment											
Check 1	0,1	0,2	0,4	0,7	0,9	**1,0**	**1,0**	**1,0**	**1,0**	**1,0**	**1,0**
Check 2	0,5	0,5	0,6	0,6	0,7	0,7	0,7	0,7	0,7	0,7	0,8

Table 11 Unity checks mitre gate with clearance, 8m upstream water level, 5m downstream water level, 0,3m minimal strip width

Model run no:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Total width	**6**	**10,5**	**15**	**19,5**	**24**	**28,5**	**33**	**37,5**
Volume steel	0,70	1,34	1,97	2,65	3,41	4,27	5,19	6,23
Cross section class UC								
Web (compression and	0,35	0,36	0,36	0,58	0,77	0,71	0,68	0,63
Web (compression)	0,48	0,48	0,48	0,74	**0,99**	**0,99**	**0,99**	**0,99**
Web (Bending)	0,22	0,22	0,22	0,34	0,45	0,45	0,45	0,45
Flange (compression)	**0,99**	**1,00**	**1,00**	**0,99**	**0,99**	**0,99**	**0,99**	**0,99**
Load Unity Checks								
Mpl, rd (PNA in	0,14	0,40	0,81	0,94	0,94	0,94	0,93	0,94
Vpl,rd	0,07	0,13	0,19	0,17	0,16	0,19	0,16	0,18
Npl,rd	0,01	0,01	0,02	0,03	0,03	0,04	0,04	0,05
Nb, Rd	0,01	0,05	0,13	0,14	0,13	0,16	0,17	0,19
Buckling and moment								
Check 1	0,16	0,45	0,87	**0,99**	**0,99**	**0,99**	**0,99**	**0,99**
Check 2	0,59	0,64	0,75	0,74	0,71	0,70	0,71	0,72

Table 12 Unity checks mitre gate with clearance, 8m upstream water level, 5m downstream water level, 0,5m minimal strip width

7.1.2.5 Comparison with existing gates

3 mitre gates have been found on the internet with corresponding dimensions and weights. These gates have been dimensioned with the model as well. This gives the results presented in Table 13.

	Real life case values				**Model case values**				
Existing gate	Width [m]	Height [m]	*Depth [m]*	**Mass [ton]**	Width [m]	Height [m]	*Depth [m]*	**Mass [ton]**	Δ%
Sluisdeuren Vlissingen	13,75*	13,30*	1,20*	**70***	13,70	13,30	0,61	**61**	14,8
Zeesluis Farmsen	9,00**	9,00**	0,5**	**32****	8,96	9,00	0,33	**21,2**	50,9
Harlinger keersluis	9,19***	10,74***	[-]	**38*****	9,22	10,75	0,4	**27,0**	40,7

Table 13 Results mitre gate compared with real life cases

The model values are clearly to low compared to the real-life values. For the bigger gate, the difference is significant, for the smaller gate the differences are high. The depth of the calculated model gate is relatively small compared to the real-life gates. This indicates smaller strip widths (smaller loads, less depth needed). Higher strip widths are likely to give better results. The lay outs are different too, this will cause differences in results as well. Another factor is that there is no information about steel type used, this clearly has a big influence on the results too, although S355 steel is commonly applied.

*http://www.vd-straaten.nl/projecten/61/sluisdeuren-vlissingen.html

**http://www.jansen-venneboer.com/nieuws/nieuwsbericht/detail/vier-stalen-sluisdeuren-voor-zeesluis-farmsum/

***https://maritiemnieuws.nl/5187/nieuwe-sluisdeur-in-de-takels/

7.1.2.6 2nd run mitre gate conclusion

The model results are smooth and are likely to be global optima. The effect of using stiffeners to influence the gate height driven behaviour (instead of load driven behaviour) of the material volume could be investigated in following studies. Minimum strip height has a big influence on the results. With a more detailed investigation of the results, the results are not affected by the change of front plate thickness (from 8mm to 12mm). The lower gate widths (till about 19,5m) have only cross-section class as determining unity check. In a next study, measures could be taken to increase resistance of the cross-section class to improve the designs. A more careful evaluation of minimal cross-sectional dimensions could also result in more efficient designs .

7.2 Rolling gate Results

7.2.1 First rolling gate results

Like with the mitre gate, the rolling gate model has also been run several times. As shown in Chapter 6, the rolling gate model is more complicated than the mitre gate model, and consists of more different parts. This increases the runtimes.

7.2.1.1 Input parameters rolling gate

The model uses the following parameters (with corresponding minimum and maximum values) to come to an optimized gate the values are displayed in Table 14.

Variable input parameter	min	max
Thickness frontplate	0,008	0,04
Thickness web hor. Beam	0,008	0,04
Thickness flange hor. beam	0,008	0,04
Thickness web vrt. beam	0,008	0,04
Thickness flange vrt.beam	0,008	0,04
Thickness web truss	0,008	0,04
Thickness flanges truss	0,008	0,04
Web height hor. beam	0,15	
Web height vrt. beam	0,15	
Web height truss	0,15	
Flange width hor. beam	7x thickness web plate	Minimum strip height
Flange width vrt. beam	7x thickness web plate	Minimum strip height
Fange width truss	7x thickness web plate	Minimum strip height
Minimum strip height	*Different strip heights taken*	

Table 14 Minimal input parameters rolling gate

The decision to use these values has been discussed above at the mitre gate input parameters paragraph. The vertical beam spacing and horizontal truss spacing are inserted manually. Those spacings are chosen such that the vertical elements and horizontal elements have the same center to center distances.

7.2.1.2 Stoppage time and population size analysis

As for the mitre gate, a comparison for different stoppage times and population sizes has been made for the rolling gate, for a upstream water level of 8m and a downstream water level of 5m. All the population sizes and stoppage time combinations give reasonably good results. The best results are obtained for a population size of 500 and a stoppage time of 700 s. This can be seen in Table 15 Rolling gate population size and stoppage time analysis and Figure 44.

8up/5dwn

	p300/s500		p300/s700		p500/s500		p500/s700		
width [m]	Volume [m3]	Δ% [-]	Volume [m3]	Δ% [-]	Volume [m3]	Δ% [-]	volume[m3]		min
9,00	2,29	0,00	2,29	0,02	2,29	0,05	2,29	0,17	2,29
13,50	3,59	0,16	3,59	0,17	3,58	0,00	3,59	0,28	3,58
18,00	5,10	0,32	5,09	0,00	5,09	0,01	5,09	0,09	5,09
22,50	6,90	0,96	6,84	0,00	6,91	1,10	6,89	0,76	6,84
27,00	9,32	1,17	9,21	0,00	9,32	1,25	9,25	0,40	9,21
31,50	12,00	0,62	12,05	1,06	11,94	0,10	11,92	0,00	11,92
36,00	15,44	1,39	15,54	2,06	15,57	2,25	15,23	0,00	15,23
40,50	19,23	0,00	19,89	3,41	19,69	2,37	19,30	0,36	19,23
45,00	25,48	8,12	23,57	0,00	24,22	2,75	24,17	2,55	23,57
	average:	1,42	*average:*	0,75	*average:*	1,10	*average:*	0,51	

Table 15 Rolling gate population size and stoppage time analysis

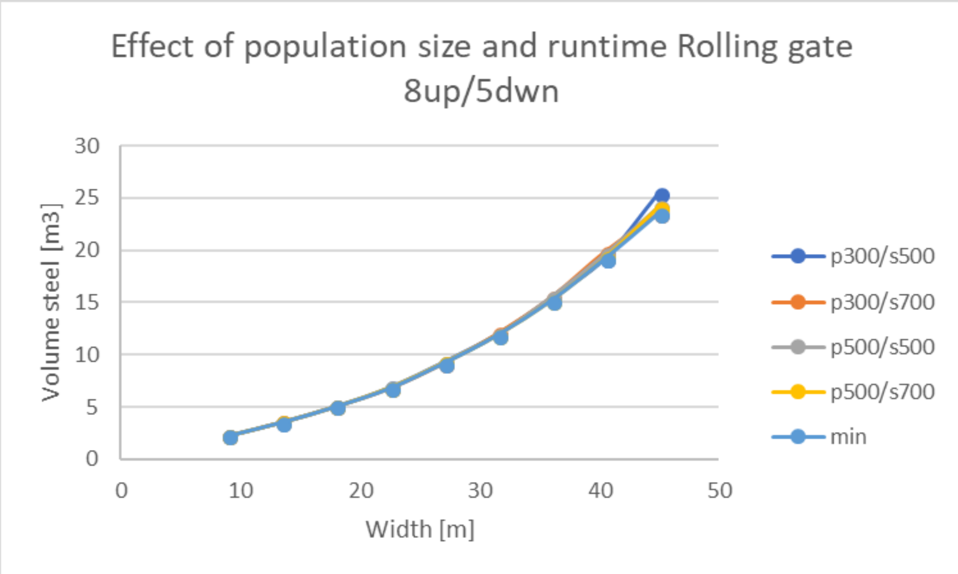


Figure 44 rolling gate population and stoppage time comparison

7.2.1.3 Vertical beam spacing comparison

A comparison has been made to determine the optimal vertical beam spacing, for a gate of 8m high. A higher vertical beam spacing is beneficial in most cases. It should be kept in mind that the vertical element spacing also determines the truss dimensions, and width of the gate. For the lower widths a smaller vertical spacing (and therefore smaller gate depth) gives better results. This is as expected, higher gate depths reduce the loads in the truss elements, so for higher loads this should be beneficial. From Figure 45 presented below the effect of vertical beam spacing becomes clear.

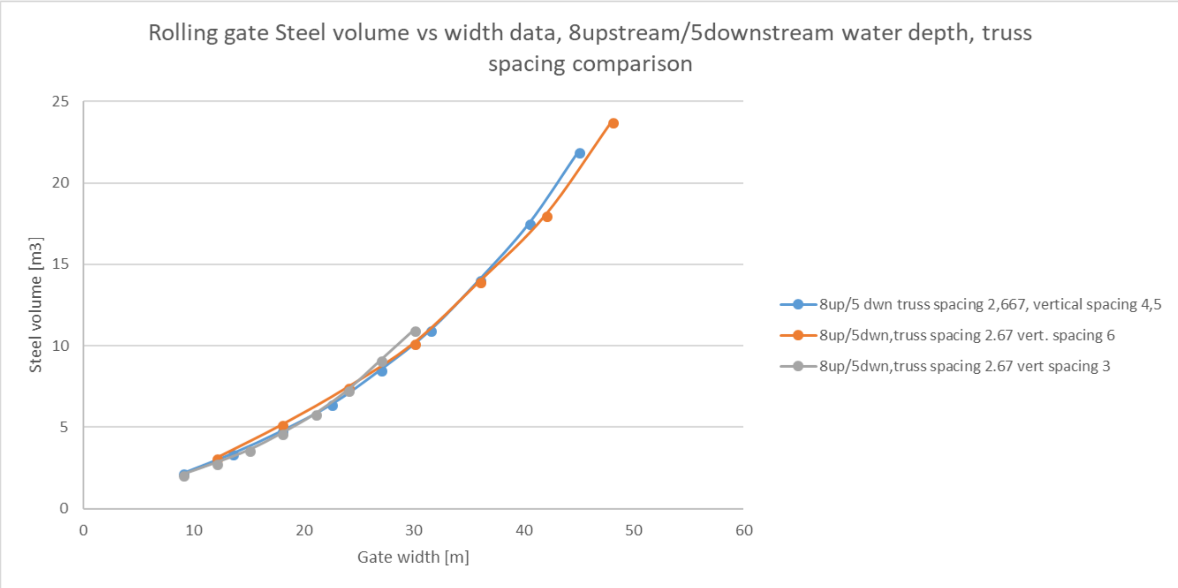


Figure 45 rolling gate vertical spacing comparison

Figure 46 shows the same results as the graph presented above but zoomed in on the mid-range widths.

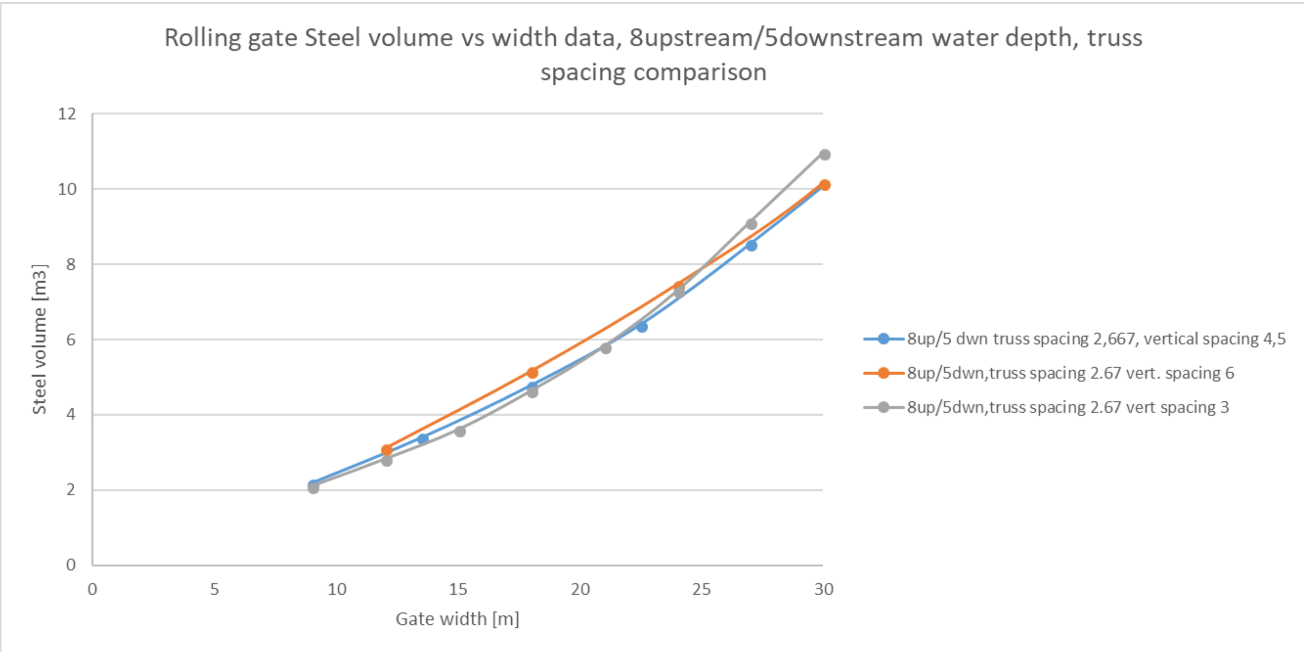


Figure 46 Rolling gate truss spacing comparison

7.2.1.4 Truss steel volume

The percentage of steel volume of the truss frame for different gate widths is presented in Figure 47. The higher the load (gate width) the lower the contribution of the truss frames with bigger vertical spacings (and truss depths). This is an intuitive result, since the loads are easier carried by bigger truss frames. The truss frames have a high contribution to the total steel volume.

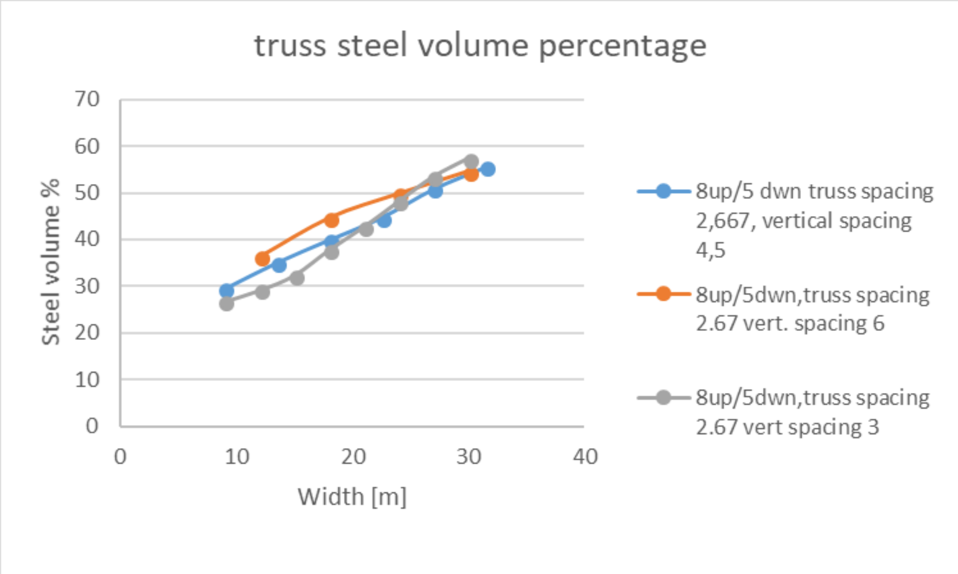


Figure 47 rolling gate relative truss volume

7.2.1.5 First Conclusions rolling gate

In the following runs more cases will be investigated for the rolling gates. For the higher gate widths, bigger truss frames are beneficial. The truss frames have a large contribution to total material volume used. This will be investigated in more detail.

7.2.2 2nd Simulations rolling gate

Several changes are made to the rolling gate model to obtain better results. After closer inspection, a mistake in the inclusion of strip height came to light. Not all the cross-section classes where performed in the right way because of this. The adjustment of this led to higher material volumes. Another adjustment made to the model is the way the truss-frame is calculated. Instead of using 1 type of bar for the whole frame, for every bar in the frame a standard H-profile has been chosen. The range of possible H-profiles is HE160B to HE400B. Smaller HE beams would lead to unrealistic small beams (a minor ship collision could lead to damage), larger beams are not needed to carry the load. HEB type of beams have been chosen since they are relative symmetrical in terms of buckling resistance, and they are commonly used. This adjustment leads to an enormous decrease in the contribution of the steel needed for the truss frame compared to the total amount of steel needed.

7.2.2.1 Adjusted results rolling gate, steel volume

With the adjustments made, the steel volume as function of the gate width, for the standard water levels of 8m upstream and 5m downstream is presented in Figure 48.

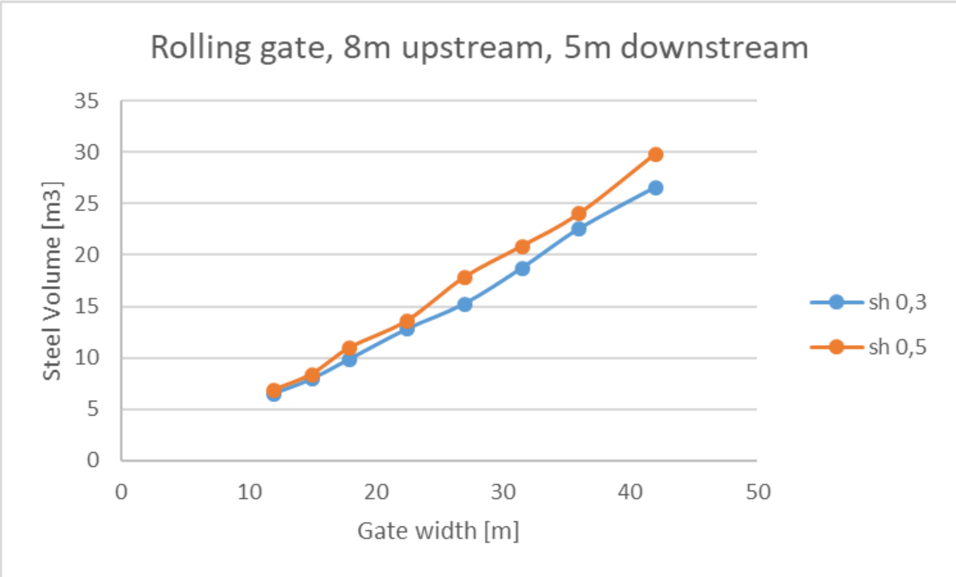


Figure 48 rolling gate second results gate width vs steel volume

At Figure 45 and Figure 46the effects of differences in rolling gate design are showed (difference in number of trusses and number of vertical profiles). The configurations which give the minimum amount of steel for a certain width have been used to obtain the graph. The non-smooth behaviour of the graph is due to the fact that different configurations have been used for different widths, and due to the fact that standard profiles have been used.

The difference in amount of steel due to the difference in strip height is less then with the mitre gate. This can be explained by the fact that the truss frame isn't influenced by this decision. The slope at higher widths is smaller than with the mitre gate as well (which gives the graph a more linear behaviour). This could be explained by the fact that truss frames can handle higher loads relatively easily.

7.2.2.2 Adjusted results, percentage of truss volume rolling gate

The relative steel volume of the truss is plotted in Figure 49. The jumps in the graph can mainly be explained by the fact that different configurations are used for different gate widths the use of standard profiles for the truss frames is another reason for the jumps in the graph. The increase in relative truss volume is to be expected, since the load is mainly carried by the truss frame. Compared to the previous case, the relative truss volume is half. Using a truss frame which consist of identical elements, which could be done for the sake of standardization, will result in an almost 2 times as heavy truss frame.

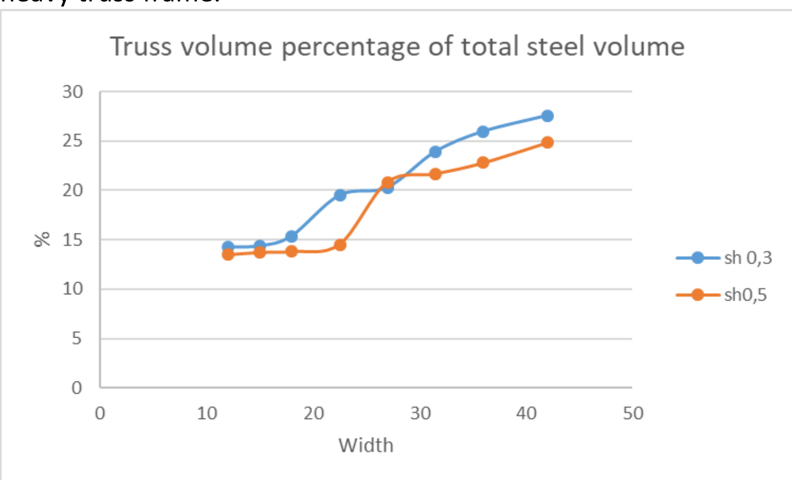


Figure 49 rolling gate relative truss volume, 2nd results

7.2.3 Unity checks rolling gate

The unity checks and cross-section classes for the data model runs of the 8m upstream water level and 5m downstream water level for both 0,3m and 0,5m minimal strip heights are summarized in Table 16 Unity checks and cross-section classes rolling gate, 8m upstream water level, 5m downstream water level 0,3m minimal strip heightTable 16 and Table 17. A unity check of 1 means this value is maximal allowable and a cross-section class of 2 means this value is the maximal allowable value. The determining parameter for the horizontal girder is only cross-section class. For the vertical beam the bending moments or cross-section class is determining. When the cross-section class is determining the minimal possible cross-sectional parameters are enough to resist the load. The vertical beam isn't influenced by the total width (only by the configuration of vertical beams which influences the vertical beam spacing, since vertical beam spacing determine the load on the beam). Therefor the higher widths doesn't lead to higher load unity checks of the vertical beam. By examining the minimal values for the components or increasing cross-section class only (by extra stiffeners for example) the capacity to resist loads of the beams could potentially increase, since those factors seems to give the determining strength of the cross-sections.

Model run no:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Total Width	12	15	18	22,5	27	31,5	36	42
Total volume	6,46	7,90	9,85	12,77	15,21	18,68	22,52	26,57
Horizontal girder								
Cross-section class web:								
Compression and bending	1	1	1	1	1	1	1	1
Compression	1	1	1	1	1	1	1	1
Bending	1	1	1	1	1	1	1	1
Crossection Class flange:								
Compression	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
Load Unity Checks:								
Mpl, rd (PNA in frontplate)	0,08	0,08	0,17	0,17	0,17	0,17	0,31	0,31
Vpl,rd	0,04	0,04	0,07	0,07	0,07	0,07	0,09	0,09
Vertical Beam								
Cross-section class Web:								
Bending	1	1	1	1	1	1	1	1
Cross-section class flange:								
Compression	1	1	1	1	1	1	1	1
Load Unity Checks:								
Med,vrt, max, yy:	0,19	0,19	0,13	0,07	0,07	0,04	0,03	0,03
Med, vrt, min, yy:	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**
Ved,vrt,yy:	0,24	0,30	0,32	0,22	0,21	0,16	0,21	0,21

Table 16 Unity checks and cross-section classes rolling gate, 8m upstream water level, 5m downstream water level 0,3m minimal strip height

Model run no:	1	2	3	4	5	6	7	8
Total Width	12	15	18	22,5	27	31,5	36	42
Total volume	6,83	8,37	10,95	13,59	17,82	20,84	24,02	29,85
Horizontal girder								
Cross-section class web:								
Compression and bending	1	1	1	1	1	1	1	1
Compression	1	1	1	1	1	1	1	1
Bending	1	1	1	1	1	1	1	1
Crossection Class flange:								
Compression	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
Load Unity Checks:								
Mpl, rd (PNA in frontplate)	0,12	0,12	0,23	0,23	0,23	0,23	0,23	0,40
Vpl,rd	0,07	0,07	0,11	0,11	0,11	0,11	0,11	0,15
Vertical Beam								
Cross-section class Web:								
Bending	1	1	1	1	1	1	1	1
Cross-section class flange:								
Compression	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
Load Unity Checks:								
Med,vrt, max, yy:	**1,00**	**1,00**	**1,00**	**1,00**	0,36	0,36	0,36	0,46
Med, vrt, min, yy:	0,79	0,79	0,79	0,79	0,28	0,28	0,28	0,36
Ved,vrt,yy:	0,57	0,57	0,62	0,62	0,47	0,47	0,47	0,62

Table 17 Unity checks and cross-section classes rolling gate, 8m upstream water level, 5m downstream water level, 0,5m minimal strip height

7.2.3.1 Conclusion rolling gate results

The parametric model for the rolling gate can be used very well to optimise the rolling gate design, and give insight in making changes to the rolling gate design.
The change in truss resistance calculations lead to a lower overall contribution to material use of the truss frame. The higher the gate width, the higher relative contribution to the total material volume used by the truss-frame, this is as expected since the truss frame is mainly used to resist higher loads. Cross sectional classes are most of the time the determining feature of the cross-sections.

7.3 Mitre gate without clearance results

To compare the difference in pivots, the material use for the mitre gate with and mitre gate without clearance should be compared. The results for the mitre gate without clearance are presented in Figure 50.

7.3.1 Material volume versus gate width results

The results for the material needed over total width of different vertical profile spacing and different downstream water level is presented in Figure 50. The vertical profile spacing has minor influence on total material volume needed. The difference in downstream water level has a big effect, this indicates that the design values are mainly influenced by loads, not on minimal restrictions and cross-section class restrictions.

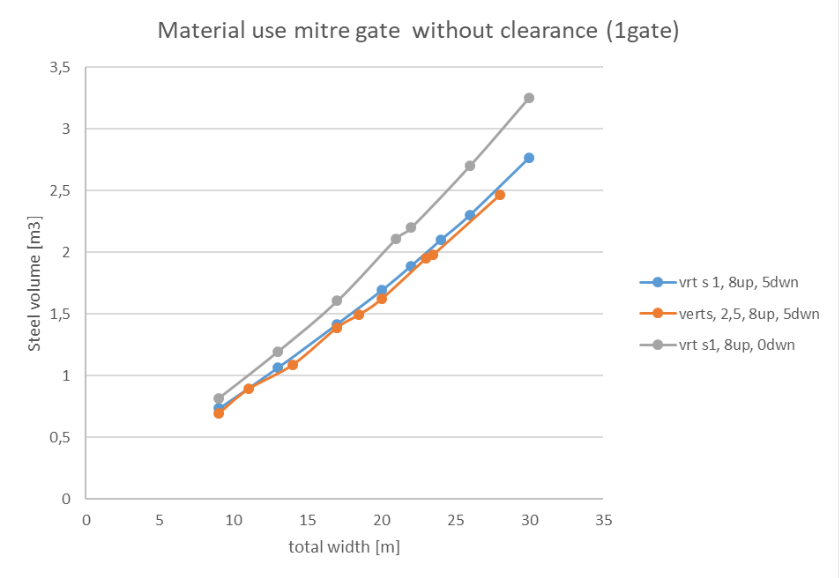


Figure 50 mitre gate without clearance results

7.4 Gate types compared

To get an indication in the difference in material volume for the rolling gate and mitre gate with clearance, the material volumes are compared.
4 mitre gate gates equal 1 rolling gate, since the rolling gate is bilateral retaining to great water level differences (1 set of mitre gate gates can be made bilateral retaining, but only for small water level differences).

7.4.1 Rolling gate vs mitre gate with clearance results

The results are presented in Figure 51 and Figure 52. The mitre gate with clearance is for all the widths the best option. A reason for this can be the fact that with the mitre gate, all the material used is used to resist the load, a rolling gate has elements to gain stability, but are not directly related to resisting load from water level difference (diagonal stiffeners). The effect of this will be made visible in the next section.
A difference in strip height has a big influence on the material use for the mitre gate with clearance, but a smaller influence on the rolling gate material use. For higher minimal strip heights, the rolling gate gives (surprisingly seeing the difference in design) almost identical results as the mitre gate with clearance.

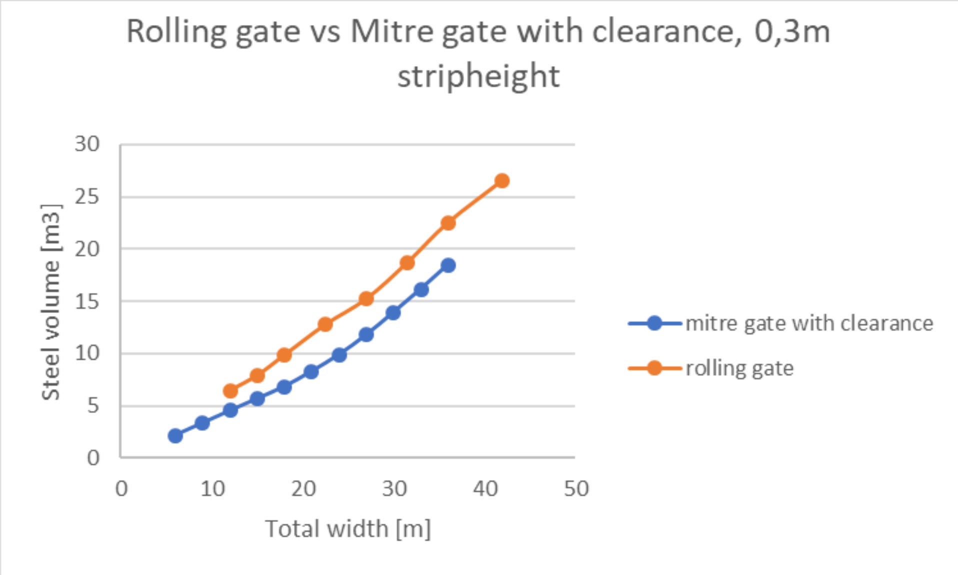


Figure 51 mitre gate vs rolling gate (1/2)

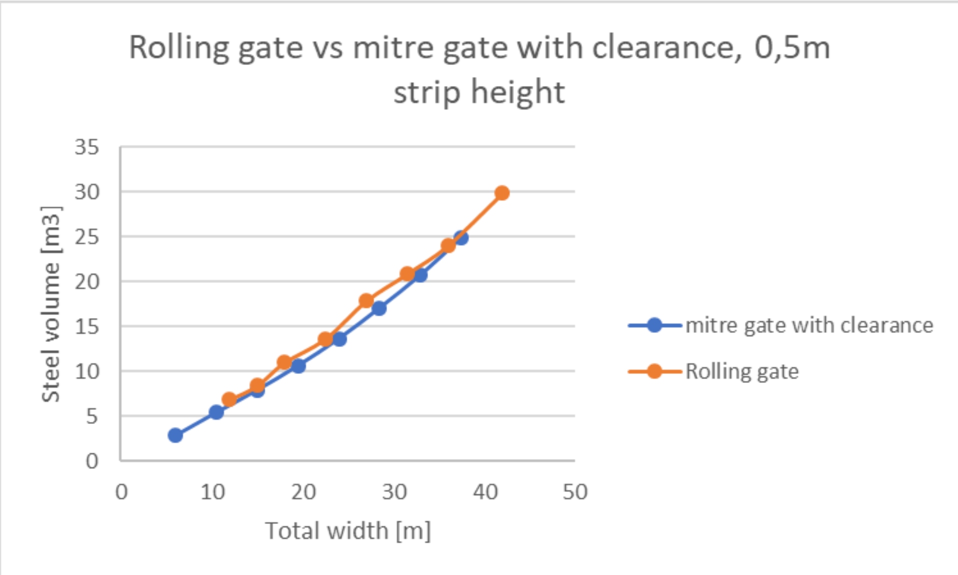


Figure 52 mitre gate vs rolling gate (2/2)

7.4.1.1 Rolling gate (theoretical value) vs mitre gate with clearance results

To find out the difference in material use of both types of gates when looking to the part of the gate which is needed to resist water level difference, the rolling gate is stripped down. The value for material volume used is a theoretical value only, it is an indication about how much of the material need in the gate is directly used to resist water load for a certain width. The changes with respect to the realistic value of the material use are:

- increased width of rolling gate (since the rolling gate has been made larger than the lock width, a perfectly fitting rolling gate wouldn't be able to be supported at the sides.
- Theoretical material volume needed for the rolling gate excludes the volume of the diagonal stiffeners, since the diagonal stiffeners aren't needed to resist the water level difference load directly.

In Figure 53 and Figure 54, the results for the theoretical value of the of the rolling gate compared to the mitre gate with clearance can be found.

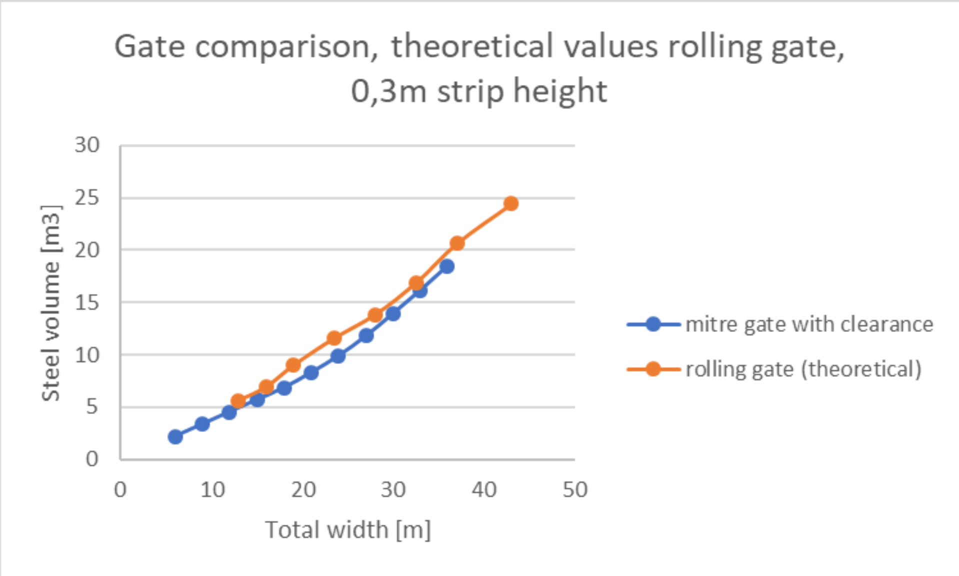


Figure 53 mitre gate vs theoretical rolling gate (1/2)

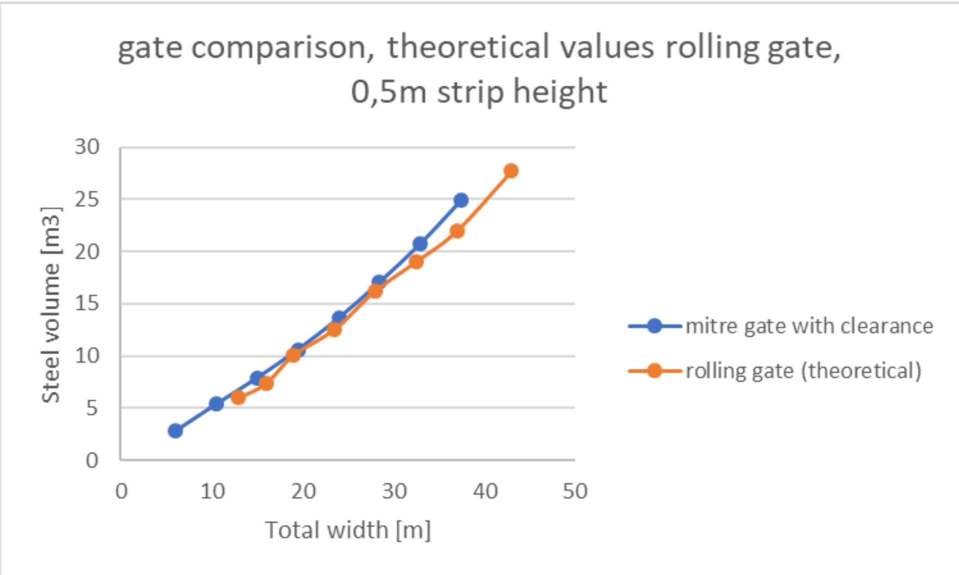


Figure 54 mitre gate vs theoretical rolling gate (2/2)

With the theoretical values of the rolling gate, both gate types are very comparable in terms of material use. For the higher widths, the rolling gate is more efficient in terms of material use. This can be explained by the fact that a truss is a relatively efficient way to carry large loads.

7.5 Concluding remarks results

The parametric model for the mitre gate is highly dependent on the minimum strip height chosen. The effect of downstream water level is relatively small

The parametric model for the rolling gate is very useful to investigate the effect of different configurations in the design. The effect of increasing the amount of truss frames and the effect of changing the depth of the gate becomes clear and is ready to use to optimise the design. The relative steel volume of the truss frame rapidly increases when the gate width increases. The minimum strip height chosen has a relative low effect on the steel volume, compared to the mitre gate with clearance.

The configuration of the vertical strips for the mitre gate without clearance has a relatively low effect on the total steel volume needed.

For relatively high minimum strip heights, the results of both rolling gate and mitre gate with clearance are remarkably the same. For lower minimum strip heights, the mitre gate with clearance is always the best option, according to the model. This can be explained by the fact that the mitre gate with clearance directly uses all the material needed to resist the load. When the rolling gate is stripped down to such an extent that only the parts which are needed to resist the load are still present, the rolling gate gives comparable results as the mitre gate. For the higher widths, the rolling gate becomes more efficient in terms of material needed, this is an expected result.

There are to many differences and uncertainties in designs to use the parametric models of different gates to compare both gates in terms of material use. When used to compare different gate types, different models give remarkably identical results for material usage for a certain width. This makes it clear that a significant decision can’t be made based on the material use, as calculated with the different models. But the models cán be very usefull to optimise designs.

Extra measures to increase the cross-section classes of the designs, and a more careful evaluation of the minimal dimensions for the cross-section used could result in more optimal designs.

8 Costs and other decision criteria

The optimization parameter in the model is chosen to be volume of steel. This is not the parameter which is directly the parameter which should be minimized. To provide a working decision method, this parameter could be used as optimisation parameter, since a comparison can be made between the gate types which gives a good indication about the costs. The real optimisation parameter should be costs. Costs include more factors then material use only and gives a more complete view of the best gate type in a certain situation. To implement costs is more difficult than material type only. Propositions about ways to implement costs are provided in this chapter.

8.1 Material costs

Since the lock gate will be subjected to sub-zero temperatures in the Netherlands, material which could resist these temperatures without brittle failure should be used. The whole design has been made in S355 steel at the examples (S235 steel could be implemented in the model right away, just by adjusting one parameter). To be able to resist brittle failure when the steel is subjected to low temperatures, S355 J2 steel should be used (Chou, 2013) .The base price for steel in Europe (in April 2018) is 655 €/ton "*http://www.meps.co.uk/EU%20price.htm*" . The extra cost for this steel is 50 €/ton. (TATA, 2018)

The total costs are about 705 €/ton, or 5534 €/m^3. These costs will vary per month by quite a large extent.

8.2 Welding costs

Besides material costs, the costs of labour are an important cost post as well. The determination of welding costs is not very straight forward. A lot of factors influence the costs of welding. Important influencing factors are:

- Location of the weld, a fix located below the material sometimes needs 3 welds, where a fix on top of the material (with the same tensile strength needed) only need 1 weld, since gravity pulls welding material away from the fix in the first situation
- Type of weld, some welds need more preparing work then other welds
- Accessibility of the fix, the easier a welder can access the location of welding, the faster and better the process goes.
- Location of the project as a whole, the more controlled the environment is where welding is performed, the better.

All those influences make it difficult to implement welding in the parametric model very precisely. Even in engineering practice it is difficult to estimate welding costs very precisely. 2 methods of estimating welding costs will be described at the following paragraphs.

8.2.1 Welding costs determination by a contractor

According to Gerard Bouwman, the method of estimating welding costs by the big contracters (His experience by Hollandia) is to have an educated guess based on expert vision. After a rough design has been made, 3 experts with 15-20 years of experience in the steel sector are asked to estimate the percentage of welding costs compared to material costs. This method can't be applied to the parametric model. Inserting different boundary conditions gives different amounts of welding lengths (also as a percentage), and every situation should be reviewed by experts. Nevertheless, after the model has done its work, experts using the model could derive an estimate about the welding costs based on the design given as an output in the model.

A better optimization of the lock gate would include costs in the model, not material. This could give other (more optimal) designs. Since this hasn't been done in the engineering world (yet) optimizing only on material costs shouldn't give a difference in answer compared to optimizing to total costs.

8.2.2 Welding costs determination by formula

The determination of welding costs by rules of thumb is not very easy, and an exact answer can't be given. First of all, there are a lot of ways of welding. For big projects, which need a fast and relatively inexpensive welding method, MIG/MAG welding is most widely applied (Gales, 2003). This method uses a special gas to protect the weld when the metal is fluid. A welding wire adds material constantly "*http://www.technischwerken.nl/kennisbank/techniek-kennis/wat-is-migmag-lassen-en-waarvoor-is-het-geschikt/*". Welding costs of MIG/MAG welding are dependent on a lot of factors. The formula to calculate welding costs is as follows (Neesen, 2008):

$$W = V * \beta * (\frac{100}{i} * \frac{1}{F} * L + M * \frac{100}{\eta} + V_g * \frac{G}{F})$$

With:
W =welding costs per meter [€/m]
V= welding volume per meter (including extra thickness) [m^3/m]
β= density welding material [kg/m^3]
i= duty cycle welder [%]
F= melting pace weld [kg/hr]
L=labour costs [€/hr]
M=welding wire costs [€/kg]
η= efficiency
V_g=gas usage [m^3/hr]
G=costs gas [€/m^3]

The factors are case dependant, and dependent on certain considerations. Costs of machinery could be added to the calculation as well, but are left out, since the depreciation of the machinery is relatively low compared to the other costs, and since the formula is only used to give a rough idea of the welding costs. Typical values for the parameters presented above are (for steel plate material of 8mm, and a T-weld) presented in Table 18

Para-meter	Typical value	Assumptions	Source
V	31,4 [mm^3/m]	a=0,7*t, t=8mm	https://www.tosec.nl/wiki/lassen-wiki/
β	8000 [kg/m^3]		http://www.lasgroepzuidlimburg.nl
i	25%	Manual weld	http://www.osgbk.nl/lijm/LinkedDocuments/Lasprocessen.pdf
F	8 [kg/h]	Open arc (350A)*, 1,2mm wire**	*average value: http://www.nil.nl/public/cms/lists/upload/43_app_migmag.pdf ** normally used wire: https://www.rustbuster.nl/Quickshop/index.php?144,l000901512-lasdraad-staal-15-kg-1-2-mm final value from table: http://www.lasgroepzuidlimburg.nl
L	37 [€/h]	Average salary	https://uurtarief.tips/nl/zzp/uurtarieven-zzp/metaal/uurtarief-zzp-constructiewerker-lasser
M	5 [€/kg]	75€ for 15kg	https://www.rustbuster.nl/Quickshop/index.php?144,l000901512-lasdraad-staal-15-kg-1-2-mm

η	100 %	Assumption, follows from table F values	http://www.lasgroepzuidlimburg.nl
V_g	0,6 [m^3/hr]	Highest value is 10 [l/min]	https://www.rustbuster.nl/Lasapparaten/Gasflessen.htm
G	15 [€/m^3]	Cheapest fillings, 60€ per 4000l, 85% argon gass as recommended	https://www.rustbuster.nl/Lasapparaten/Gasflessen.htm

Table 18 input welding cost formula

With those values the welding costs are around 7,34 €/m. The costs can be divided as summarized in Table 19, with one-meter T-profile welded on both sides weighs about 0,25kg:

Cost post	Costs (€ per kg welded welding material)	% of total
Labour	23,13	79
Welding material	5,00	17
Gass	1,13	3,9
Total:	*29,26*	*100*

Table 19 relative welding cost contributions

To get a good idea of the total welding costs, all the welds in the parametric model could be accounted for and a costs per meter length factor could be calculated for every weld. This is quite a tedious task to implement in the model, but it isn't a difficult task. The principles behind this addition to the model are not different from the elaboration presented above. The more lock gates have been welded, the better the estimate for the values for welding cost will be.

8.3 Maintenance costs

Apart from construction costs, maintenance costs should be added as well when evaluating the different alternatives in terms of costs. Maintenance costs are related to the lay out of the gate. This is the case since more different elements lead to more (and more difficult) maintenance since the protection of the elements against water will be more difficult. Maintenance costs will be paid over the lifetime of the gate. With more information better maintenance strategies could be applied.

8.4 Costs of reliability and availability

Reliability of components has an effect on availability of the lock complex. A lock complex has maximal 2 functions, an economical function and a function as a flood protection. The economic value of a certain ship corridor can be expressed in a monetary value, with this information availability of a lock in the specific corridor can be expressed in a monetary value too. The reliability leads to a certain availability, with this information coupled with the value of availability (of a specific lock in a specific corridor) reliability has a monetary value. This value can be added to the model in order to have a good comparison for the costs of a specific variant of a lock. The numbers needed for this valuing method could follow from expert opinion and manufacturers predictions.

$$V_{reliability} = Vt_{shipcorridor} * (T_{life} * f_{faillure}) * T_{repair}$$

With:

$V_{reliability}$= Value of reliability [€]

$Vt_{shipcorridor}$= Value of the shipcorridor [€/time]

T_{life}=Lifetime [time]

$f_{faillure}$=Frequency of failure over the lifetime [events/time]

T_{repair}=Repair time [time/event]

Due to a deficit in information the valuing of reliability can become hard to perform. Recording the information about failures and repair time could be very beneficial, and should be done in the future. An important note should be made. The material costs and availability are uncoupled at this strategy. The effect of reducing the amount of maintenance, and increasing the availability by making a more robust design (more material), can't be taken into account in the parametric model presented, directly.

8.5 Other costs related to different gate types

There are several other costs which are influenced by the gate type choice. First of all, the actuator type is different for different gate types, so the costs of these actuators will be different too. It is thought that the difference in costs is relatively small. Another important factor is the addition of wagons underneath the rolling gate. These wagons also add costs to this kind of gate. Where a rolling gate needs wagons, a mitre gate has relatively complicated pivot joints, these should also be accounted for in a more complete model. An important difference between the gates is the lock head. The lock head of a rolling gate will be more expensive (more extra material needed) then the lock head of a mitre gate, following the shape of both lock heads. The locks heads haven't been included in the model, but could be added, roughly, just using the dimensions of the gates (neglecting calculations following from the specific soil conditions).

8.6 Present value costs

Costs aren't constant over time. This effect should be taken into account while valuing variants. There is a difference between direct investments, which are the construction costs and the costs which have to be paid over time, such as the value of reliability and maintenance costs. This difference is important, since money paid now is worth more than money paid over 10 years (if you have to choose between €100 now and €100 over 10 years, you would choose to get the €100 now since you could invest it etc.). To calculate the present value, costs paid in a later stage should be discounted by the discount rate "*https://www.investopedia.com/terms/p/presentvalue.asp*". The discount rate is the expected amount of interest over time. Usually the discount rate is about 10%. *"https://www.investopedia.com/terms/d/discountrate.asp*".The costs of maintenance and availability should be discounted and added to the construction costs (which are paid right from the start of the project, when complicated financing strategies haven't been considered) to calculate the present value of the costs. Present values of costs should be used for the costs of the different alternatives to make a proper comparison. Financing of a specific project is usually more complicated than just paying all the construction costs when a project starts. Evaluating different financing strategies is beyond the scope of this thesis (almost a whole master thesis could be written solely about the best financing strategies for civil engineering projects). It is assumed that from the start of the lifetime of the project all the construction costs are paid, the relative maintenance costs and costs of availability per year could be discounted over the lifetime of the project and added to the construction costs to come up with a comparable cost evaluation of a specific project. The formula to calculate the present value of costs has been given below.

$$PV_{costs} = C_{construction} + \sum_{t=1}^{T} \frac{C_{avgmaintenance}}{(1+r)^t} + \sum_{t=1}^{T} \frac{C_{avgreliability}}{(1+r)^t}$$

With:

PV_{costs} is present value of the costs [€]
$C_{construction}$ is total value of construction costs [€]
$C_{avgmaintenance}$ is the average, yearly, value of maintenance costs (for the lifetime of the project) [€]
$C_{avgreliability}$ is the average, yearly, value of the costs of reliability (for the lifetime of the project) [€]

T is the total expected lifetime of the project [year]
t is the time in years [year]
r is the average, yearly, discount rate [-]

8.7 Other decision criteria

This Chapter gives an answer to research question 6: “What qualitative consideration should be made, which are not found quantitatively?”

Besides differences in material needs and costs, there are several other differences between rolling gate and mitre gates. These differences have to considered to get a proper decision about deciding which gate type is best for a specific situation.

- Land occupation

A rolling gate needs relatively wide gate chambers, while a mitre gate needs relatively long gate chambers. Not every it is not always easy to implement both types of gates.

- Water movement during operation

A mitre gate generally leads to more water movement during operation then a rolling gate. This could affect environment, or operation speeds.

- operate with water level difference

Sometimes it could be beneficial to operate the lock while there is still a water level difference. A rolling gate is more suitable for this situation then a mitre gate.

- Opening in case of ship collision

Mitre gates tend to open when a ship collides, while a rolling gate is often more stable in this situation, and could resist a ship collision more easily.

- Secondary functions of the gate

Apart from retaining water a lock gate could have other functions as well. Rolling gates could be used as a bridge for cars to cross the water way (for example used at the locks in Ijmuiden). This function can’t be applied with mitre gates, since mitre gates are usually smaller and are at an angle.

8.8 Schematic representation decision making

The implementation of costs to the decision model can be schematised by Figure 55. With the boundary conditions inserted in the parametric model the steel volume needed for the gate can be estimated. This steel volume can be translated to construction costs. With the right data about repairs of the components used and the value of the ship corridor the Value of reliability can be calculated. Using the Present Values for maintenance and availability combined with the construction costs the value of the variant can be calculated for a specific component variant. Finally, with qualitive considerations kept in mind, the decision can be made for a specific component variant.

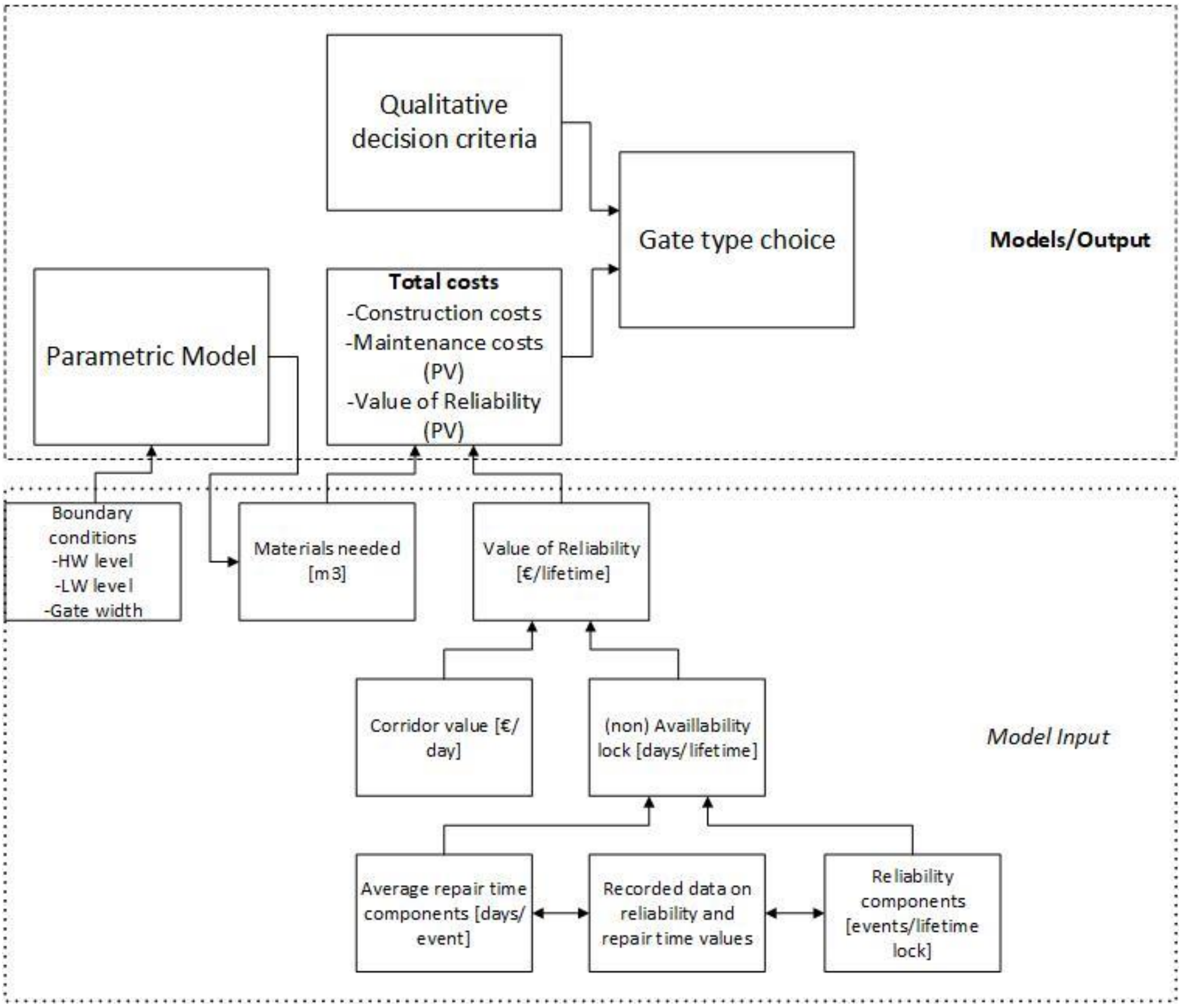


Figure 55 implementing costs to make a component choice

8.9 Concluding remarks

With the design of the gate known and the amount of steel needed for the gate known a rough estimation of costs can be made. Welding costs could be estimated from the structural lay out of the gate, although a lot of factors influence welding costs. The reliability of components can be translated to costs as well. Data about repair times and the reliability of components should be recorded to include the value of reliability of components. The maintenance costs and the value of reliability should be discounted to obtain the present values. The total costs will consist of the construction costs, discounted maintenance costs and discounted value of reliability. The final decision should be made based on costs and qualitive arguments (for example space occupation) and specific features of the gate type variants. To get an even better comparison, extra costs because of components related to the gate type variant should be included as well. These costs are costs for actuators, pivots and lock heads for example.

9 Case study, Prinses Marijkesluizen

In order to have a general idea about the possibilities of the parametric model, a case study has been performed. As object, the Prinses Marijkesluizen have been chosen. The Prinses Marijkesluizen have been chose, since these navigational locks need renovation. Rijkswaterstaat wants to use these locks as a test case for the MWW project, to see how standardization could be achieved. This Chapter is part of the answer to research question 5, and is used as a test for the decision model.

9.1 General boundary conditions Prinses Marijkesluizen

The conditions at the Prinses Marijkesluizen are presented in Table 20 General boundary conditions Prinses Marijkesluizen. These values follow from (van Erp & van Corven, 2017).

Description	Value
Length lock chamber	260 m
Width lock chamber	18 m
Maximum ship height	NAP 15,0m
Exceedence frequency	1/1250
MHW innerhead	NAP 5,55m
MLW innerhead	-
Floor depth innerhead	NAP -2,35
MHW outerhead	NAP 8,15
MLW outerhead	NAP 1,2
Floor depth outerhead	NAP -2,35

Table 20 General boundary conditions Prinses Marijkesluizen

The input needed for the model are the lock width, the upstream water level and the downstream water level. The design downstream water level is always a point of debate with locks. Some locks have been designed to resist a case where there is no water at the downside of the gate. This design criterion has been used for the case study, so downstream water level has been set to 0. Since the model sets the floor level to 0 (without referring to NAP), the upstream water level has been set to 10,5 (=8,15+2,35). An overheight of 1m is assumed. The other input parameters are case specific and will be made visible in the following Paragraphs. Table 21 present the input parameters used.

Changeable Model input parameter	Value [m]
Total lock width	18
Upstream water level	10,5
Downstream water level	0

Table 21 changeable input parameters case study

9.2 Mitre gate with clearance results

The first model which is used to estimate the minimum material costs for the Prinses Marijkesluizen case is the mitre gate model, with clearance at the joints. The other models used will be the Rolling gate and the mitre gate without clearance at the joints.

9.2.1 Input parameters model

The same minimal and maximal values (boundaries for input parameters) have been used as explained at the result paragraph. As discussed before, there are 2 types of input parameters.

- Variable input parameters, which serve as variables of the evolutionary algorithm in order to make the structure resisting the loads.
- Input parameters manually inserted by the user.

The manually inserted parameters are needed to match the boundary conditions at the location. The evolutionary algorithm will find the variable input parameters in such a way that all the boundary conditions are satisfied, ánd that the amount of steel needed is minimized. The fixed, manually inserted, input parameters are as presented in Table 22.

Manually inserted input parameters	Value [m]
Total lock width	18
Upstream water level	10,5
Downstream water level	0
Over height gate*	1
Minimum strip width**	0,3 & 0,5

Table 22 manual inserted input parameters mitre gate, case study

*Since the gate needs to be a little bit higher in order to prevent water flowing over, an over height of 1 m has been chosen. This value is used in all the models, it has no theoretical background, but is based on engineering judgement.
**A lower minimum strip width leads to a lower material volume, but to more welding, so the value should be fixed. Runs for a minimum strip width of 0,3m and 0,5m have been performed.

The variable input parameters (qualitative) with corresponding boundaries are presented in Table 23.

	Lower boundary:	Upper boundary:
thickness front plate	0,012	0,04
thickness web plate	0,008	0,05
web height	0,15	0,8
plate thickness flange	0,008	0,04
flange width	0,15	0,400

Table 23 bounds variable input mitre gate, case study

9.2.2 Results Modelmitre gate with clearance

Runs for both a minimum strip height of 0,3m and 0,5m have been performed. To check whether the results obtained are (near) a global optimum, for both cases 2 runs have been performed. When those runs give approximately the same results it is reasonable that the results are global minima. The results are presented in Table 24.

Optimization case	Steel volume (1 gate) [m^3]
0,3 m strip height, run 2	2,59
0,5 m strip height, run 2	3,69

Table 24 Results mitre gate, case study

2 runs with the same input gave (almost) the same output. Therefor these results will probably be global minima. For the detailed output, including specific profile dimensions and unity checks, reference is made to the Appendix F.

9.2.3 Considerations

The differences between material use when the strip height is taken into account remains big. A measure for welding costs compared to material costs will be given, to get a feeling about the best configuration.

9.3 Mitre gate without clearance results

9.3.1 Input parameters model

The same minimal and maximal values (boundaries for input parameters) have been used as explained in paragraph 7 . As discussed before, there are 2 types of input parameters.

- Variable input parameters, which serve as variables of the evolutionary algorithm in order to make the structure resisting the loads.
- Input parameters manually inserted by the user.

The manually inserted parameters are needed to match the boundary conditions at the location. The evolutionary algorithm will find the variable input parameters in such a way that all the boundary conditions are satisfied, and that the amount of steel needed is minimized. The fixed, manually inserted, input parameters are as presented in Table 25

Manually inserted input parameters	Value [m]
Total lock width	18
Upstream water level	10,5
Downstream water level	0
Over height gate*	1
Number of vertical profiles per gate**	2-5

Table 25 manual input parameters mitre gate without clearance, case study

*Since the gate needs to be higher in order to prevent water flowing over, an over height of 1 m has been chosen. This value is used in all the models, it has no theoretical background, but is based on engineering judgement.

**The amount of vertical profiles will be changed until the optimal setup has been found. The model can handle 5 profiles as maximum (more are not needed in many cases, the optimum is usually towards lower amounts of vertical profiles). 2 profiles will be needed as a minimum.

The variable input parameters (qualitative) with corresponding boundaries are presented in Table 26.

Vertical girders			Lower boundary:	Upper boundary:
	thickness front plate	m	0,012	0,04
	max effective strip height	m	0,01	1
	thickness web plate	m	0,008	0,04
	Web height	m	0,15	1
	plate thickness flange	m	0,008	0,04
	flange width	m	0,1	0,8
Horizontal Girders				
	Bottom			
	thickness web plate (Hor)	m	0,008	0,04
	web height (Hor)	m	0,05	2,5
	plate thickness flange (Hor)	m	0,008	0,04
	flange width (Hor)	m	0,1	1,000
	Top			
	thickness web plate (Hor)	m	0,008	0,04
	web height (Hor)	m	0,15	2,5
	plate thickness flange (Hor)	m	0,008	0,04
	flange width (Hor)	m	0,1	1
Heel post dimensions:				
	plate thickness hollow section	m	0,008	0,04
	outer width hollow section	m	0,1	1,5
	Outer height hollow section	m	0,1	1,5

Table 26 variable input parameters bounds mitre gate without clearance, case study

9.3.2 Results model mitre gate with clearance

Runs for different amounts of vertical beams per gate have been performed, until the optimum situation (in terms of minimum material use) has been found. 4, 3 and 2 vertical beams have been tried as manual input in order to come to the optimal solution (in this case the minimal amount of 2 vertical beams). As discussed at the 'Results' Chapter, the effects of changing the configuration is relatively small. For the detailed output, including specific profile dimensions and unity checks, reference is made to the Appendix F. The results of the model runs can be found in Table 27.

Optimization case	Steel volume (1 gate) [m^3]
4 vertical beams per gate	3,15
3 vertical beams per gate	3,14
2 vertical beams per gate	3,11

Table 27 Results mitre gate without clearance, case study

9.4 Rolling gate

9.4.1 Input parameters model

The manually inserted parameters are needed to match the boundary conditions at the location. The evolutionary algorithm will find the variable input parameters in such a way that all the boundary conditions are satisfied, and that the amount of steel needed is minimized. The fixed, manually inserted, input parameters are presented in Table 28.

Manually inserted input parameters	Value [m]
Total lock width	18
Upstream water level	10,5
Downstream water level	0
Over height gate*	1
Minimum strip height**	0,3m
Number of truss frames needed***	2-5
Number of truss elemental parts****	4-8

Table 28 manual input parameters rolling gate, case study

*Since the gate needs to be a little bit higher in order to prevent water flowing over, an over height of 1 m has been chosen. This value is used in all the models, it has no theoretical background, but is based on engineering judgement.

** Since the assumption is that the Mitre gate with clearance is far more competitive then the rolling gate, only the most competitive design of the rolling gate will be used to look if this assumption is correct. If the assumption doesn't hold, both strip heights will be used.

***The amount of truss frames will be changed until the optimal setup has been found. The model can handle 5 frames as maximum (more are not needed in many cases the optimum is usually towards lower amounts of vertical profiles). 2 frames will be needed as a minimum.

****The amount of truss elemental parts has influence on the width of the gate. The maximum amount of parts the model can handle is 10, with more parts the gate becomes too unstable to open. For this gate a width of at least 2,25m has been used, this has been done in order to be able to open and close the gate properly.

The variable input parameters (qualitative) with corresponding boundaries are as presented in Table 29.

			Lower boundary:	Upper boundary:
Horizontal Girders	0	m	0,012	0,04
	thickness front plate	m	0,012	0,04
	thickness web plate (Hor)	m	0,008	0,04
	web height (Hor)	m	0,15	0,5
	plate thickness flange (Hor)	m	0,008	0,04
	flange width (Hor)	m	0,1	0,5
Vertical girders				
	thickness web plate (Hor)	m	0,008	0,04
	web height (Hor)	m	0,15	0,5
	plate thickness flange (Hor)	m	0,008	0,04
	flange width (Hor)	m	0,1	0,5

Table 29 bounds rolling gate, case study

9.4.2 Results Model

Runs for different amounts of vertical beams per gate have been performed, until the optimum situation (in terms of minimum material use) has been found. 4, 3 and 2 vertical beams have been tried as manual input in order to come to the optimal solution (in this case the minimal amount of 2 vertical beams). As discussed at Chapter 7, the effects of changing the configuration is relatively small. For the detailed output, including specific profile dimensions and unity checks, reference is made to the Appendix F.

Optimization case	Steel volume rolling gate [m^3]
N truss 5, n elemental parts 4	12,69
N truss 4, n elemental parts 4*	12,40
N truss 3, n elemental parts 4	12,48
N truss 4, n elemental parts 3	12,56
N truss 4, n elemental parts 5	12,19
N truss 4, n elemental parts 6	12,06
N truss 4, n elemental parts 7	11,98
N truss 4, n elemental parts 8	**11,92**

Table 30 results rolling gate, case study

* N truss 4 gives best results for the number of truss comparison, so this value will be used to investigate how many elemental parts should be used

9.4.3 Considerations

When this gate type will be chosen as the best gate type, extra attention should be payed to the minimum depth of the gate for operating conditions. The use of the model has led to a decrease in materials needed of over 6% for this case. More knowledge has been gained about the behaviour of the gate with regards to the configuration of the elements.

9.5 Output Material volume optimisation case study

Since there is no need to have bilateral retaining measures in the Prinses Marijkesluizen case, 2 mitre gate gates are needed, where 1 rolling gate is needed. This gives the results presented in Table 31, in terms of material use, for the optimal solutions of the gates.

Gate type	Use of steel [m^3]
Mitre gate with clearance, 0,3m strip height	5,18
Mitre gate with clearance, 0,5m strip height	7,38
Mitre gate without clearance	6,22
Rolling gate	11,92

Table 31 concluding results case study

Based on material use only, mitre gates with clearance should be used for the Prinses Marijkesluizen. These are the gates which are used for these locks. Further investigation should be done to decide which minimum strip height should be used.

The model can be used to predict the material need. The model does where it is designed for. Of course there are more criteria then material need only. As explained in Chapter 8 for a better decision the costs should be considered. Data to implement maintenance costs and costs regarding availability isn't available. Since all alternatives considered are totally different, a decision based on only part of the costs doesn't give a representative result (the percentages of construction costs, maintenance costs and availability costs aren't necessarily the same for the different gate types). The final decision to choose between a rolling gate and mitre gate will be based on material use and qualitative arguments. The designs of the mitre gate with clearance with a strip width of 0,3m and 0,5m are comparable. To conclude which design is 'better' in terms of costs, both designs are compared taking into account the material costs and welding costs.

9.5.1 Mitre gate minimal strip height construction cost comparison

A simple cost comparison is made to include the welding costs for the different minimal strip heights. This has been done to be able to make a better decision which minimal strip height should be chosen in this case. The general values for welding costs of Chapter 8 have been used to estimate gas costs, labour costs and material costs. The plate thicknesses as calculated in the case study have been used. The front plate will consist of several plates welded together to form one front plate, since a plate with the total gate isn't produced. To estimate the weld volume needed the minimal plate thickness should be used of the two connected plates. There are 3 connections:

- Front plate connected to other front plate (one, relatively 'thick' weld)
- Front plate connected to web plate (welds at both sides of the connection)
- Web plate connected to flange plate (welds at both sides of the connection)

General dimensions needed to calculated the total welding costs (same for both 0,3m minimal strip width and 0,5m minimal strip width) are presented in Table 32.

Value description	Value	Dimension
Gate length	9490	mm
Total gate height	11500	mm
Maximum front plate section width	2070*	mm
Number of front plate sections needed	6	[-]

Table 32 General weld cost calculation gate dimensions

* https://www.tatasteeleurope.com/en/products/engineering/hot-rolled#widthtol

Important dimensions related to the 0,3m minimal strip width are presented in Table 33.

Value description	Value	Dimension
Number of horizontal profiles	18	[-]
Thickness front plate	16	mm
Minimum front plate/ web plate connection thickness	8	mm
Minimum web plate/ flange plate connection thickness	8	mm

Table 33 welding costs dimensions 0,3m minimal strip width

With the cost formula for welding costs and material costs as presented in Chapter 8, the costs for welding and material are as presented in Table 34.

Value description	Value	Dimension
Welding costs:		
Front plate welding costs per meter	31,1	€/m
Front plate total weld length	113,8	m
Total front plate weld costs	3.540	€
Front plate/ web plate connection costs per meter	8,3	€/m
Front plate/web plate connection weld length	683.1	m
Total Front plate/ web plate connection weld costs	5.640	€
Web plate/ flange plate connection welding costs per meter	8,3	€/m
Web plate/flange plate connection weld length	683.1	m
Total Front plate/ web plate connection weld costs	5.640	€
Total welding costs	14.820	€
Material costs:		
Material volume needed	5,18	m^3
Material costs	5534	€/m^3
Total material costs	28.670	€
Total solution costs	43.490	€

Table 34 Welding and material costs 0,3m minimal strip width

Important dimensions related to the 0,5m minimal strip width are presented in Table 35 Table 33.

Value description	Value	Dimension
Number of horizontal profiles	11	[-]
Thickness front plate	28	mm
Minimum front plate/ web plate connection thickness	11	mm
Minimum web plate/ flange plate connection thickness	11	mm

Table 35 welding costs dimensions 0,5m minimal strip width

With the cost formula for welding costs and material costs as presented in Chapter 8, the costs for welding and material are as presented in Table 36.

Value description	Value	Dimension
Welding costs:		
Front plate welding costs per meter	93,5	€/m
Front plate total weld length	113,8	m
Total front plate weld costs	10.640	€
Front plate/ web plate connection costs per meter	14,1	€/m
Front plate/web plate connection weld length	417,4	m
Total Front plate/ web plate connection weld costs	5.890	€
Web plate/ flange plate connection welding costs per meter	14,1	€/m
Web plate/flange plate connection weld length	417,4	m
Total Front plate/ web plate connection weld costs	5.890	€
Total welding costs	22.410	€
Material costs:		
Material volume needed	7,38	m^3
Material costs	5534	€/m^3
Total material costs	40.840	€
Total solution costs	63.250	€

Table 36 Welding and material costs 0,5m minimal strip width

The construction costs and welding costs are both higher for the 0,5m minimal strip width alternative. Even though the length of the welds of the 0,3m minimal strip width is significantly higher (due to the greater number of horizontal beams in the 0,3m minimal strip width alternative) the smaller welds which are needed for the 0,3m minimal strip width gate makes the total welding costs of the 0,3m minimal strip width alternative lower. The 0,5m minimal strip width construction cost estimation is about 50% higher then the 0,3m minimal strip width alternative (€63.250 and €43.490 respectively).

9.6 Qualitative arguments case study

The Prinses Marijkesluizen site is as presented in Figure 56. There are 2 locks present at the site, the 2 top small 'channels' visible in the figure. And one retaining structure, the wider bottom 'channel' visible in the figure. The locks are only needed when the retaining structure is down, this is a few days per year, at most. A bridge crosses the channel.

A rolling gate needs space for the gate chamber which widens the navigational lock, a mitre gate needs space for the gate chamber which lengthens the lock. Since the area next to the locks is most of the time of the year used for ship traffic, and rolling gate locks tend to be wider then mitre gate locks (due to the wider gate chambers), the rolling gate lock could negatively influence the ship traffic, since the main channel would become narrower when applying rolling gate locks.
Opening of the lock during a ship collision event is a possible danger when using mitre gate locks. Since the locks are only used a few days per year, and a ship collision event is already very rare in the Netherlands, the chance that a ship collision event will occur during the time of the year the locks are operational is very low. Extra measures could be taken to prevent ship collision when necessary.

Normally, it could be beneficial to use rolling gates, since they could be used as a bridge to cross the channel. Since there is water next to the locks, a bridge would be needed anyway to cross the channel, even when the locks could be used to cross the channel. So this wouldn't be a real advantage in this case.

Figure 56 Prinses Marijkesluizen site

9.7 Concluding remarks

Based on material use and construction costs estimation, a mitre gate with a 0,3m minimal strip width would be the best alternative out of the gate types evaluated (mitre gate with clearance with 0,3m minimal strip width, mitre gate with clearance without 0,5m minimal strip width, mitre gate without clearance, rolling gate). The Parametric model can be very well used to optimise the structural lay out of the different gate types in terms of material use.
Looking to the qualitative aspects of the decision, the rolling gate could potentially decrease the width of the main channel and therefore partly block ship traffic. A rolling gate usually closes off the lock better during a ship collision event, since these events are rare, especially when the lock is in operation since this is only a few days a year, this positive effect doesn't way against the extra costs and the loss of width of the main channel. A mitre gate with clearance is the best option for this case, based on material use and qualitative arguments. A detailed design should be made for the mitre gate only.

10 Discussion

- The parametric model optimises the results based on material need. Costs would give a better decision criterion than material need. The decision to optimise with respect to material need has been made since there is a large uncertainty in calculating the costs of a design. This uncertainty can for example be seen in calculating the welding costs. In Chapter 8 a proposition is made for the implementation of costs in the model. With the right information, the costs can be added to the model this would give results with a better optimisation criterion.

- Some structural elements of the steel gates which are present in the gates haven't been added to the model. This are structural parts regarding torsional stability. This has been done in discussion with Gerard Bouwman, who is senior advisor hydraulic structures at Rijkswaterstaat. According to Gerard Bouwman these parts have a relative low contribution to steel volume used. In Chapter 6 the considerations regarding these elements are discussed. The actual steel volume needed would be higher when these elements are included.

- Wave load isn't included in the model. The method itself is the part which has been examined in the thesis. Including waves would result in more different boundary conditions, leading to more different results (instead of having gate width, and retention height as important variables, wave height would be added as a third important variable). More different results wouldn't result in a better method, the extra knowledge obtained by adding wave load wouldn't result in a different conclusion about the model. Wave load just leads to a difference in hydraulic pressure, it has already been proven that the model can be used to calculate the hydraulic pressure, and to calculate the resistance needed to resist this pressure, since the retention height calculation results in a hydraulic pressure as well.

- Different structural layouts per gate type could result in difference in results. Having more different structural lay outs per gate type won't change the decision method itself. The results could only be more optimal. The resemblance in results presented in Chapter 7 of the 2 totally different lay outs which have been programmed give the assumption that different lay outs per gate type wouldn't lead to a very different conclusion.

- The optimisation calculation of the model is performed without coupling the gate type to the rest of the lock components. The effect of the difference in lock heads hasn't been considered in the decision model for example. This factor could lead to a better decision criterion. Addition of other components is beyond the scope of this thesis.

- The loads due to movement of the gates in the operational phase haven't been included. According to Gerard Bouwman, the loads in the operation phase of the lock gates are relatively small. These loads would increase the moments and a torsional force component would be added to the gate. Torsion is resisted by extra elements which haven't been included in the model. These structural elements tend to have a relatively low contribution to material volume (as described in the 2nd discussion point of this chapter.

- The steel volumes calculated are relatively small compared to reality. Designs in reality are more robust then the optimal designs calculated in the model. More robust designs will lead to a higher availability, a way to add this effect to the model is presented in Chapter 8. The right information to add the effects of availability to the decision model isn't available.

- Minimal values are used for cross-section dimensions in the structural calculations. These values are sometimes quite determining in terms of profile layout. More research to these minimal values could potentially give better optimal solutions.

11 Conclusion and recommendations

11.1 Conclusion

- The goal of the thesis is to create a decision model which helps implementing standardization on navigational lock components. A decision method is presented in the thesis for the navigational lock component: gate type. This decision method could help with standardising designs of a specific variant (rolling gate or mitre gate). A clear conclusion about what gate type should be used for which boundary conditions in case of bilateral retaining gates can't be drawn from the model. When a gate doesn't have to be bilateral retaining, a decision based on material volume used can be drawn, this is showed in the case study. Several conclusions are drawn which give more insight about standardization in navigational locks. These conclusions are the answers to the research questions presented in this thesis.
- In order to get an answer to research question 1, a literature study has been performed to examine the advantages and disadvantages of standardization. Standardization has potential for lowering costs and to increase the predictability of navigational lock components. Special attention should be paid to the fact that the lock components won't get over dimensioned too much and that standardization could lead to less competitive designs. When conforming to a certain standardised design from the start on the replacement costs are potentially relatively high.
- For answering research question 2, the general design process has been analysed to see how standardization could be applied to the design process. A parametric model can be used to optimise the standard design process. By implementing a parametric model in the design process, standardization could be implemented as well. Making design choices early on in the design process with the help of the parametric model would lead to recommendations on specific component variants. This would lead to standardization of component variants for specific boundary conditions and functional requirements.
- Research question 3 is answered by an inventory of the different navigational lock components. The gate type is the most determining navigational lock component in terms of physical relations and in terms of navigational lock appearance. The gate types which are potentially most worth considering in detail are mitre gate and rolling gate. These gate types are mainly used in the Netherlands. All boundary conditions and functional requirements present in the Netherlands can be handled by using one of those 2 gate types.
- As an answer to research question 4, a literature study has been performed to determine the navigational lock components with the highest potential for standardization. The navigational lock component with the highest potential for standardization is the navigational lock gate type.
- Research question 5 has been answered to draw conclusions on how decisions of the decision model could be drawn based on quantitative and qualitative arguments. This has been done with the help of a parametric model, with optimised results in terms of material use.
    - The main constructive elements of the rolling gate and mitre gate can be programmed parametrically. The torsional stiffening elements can't be evaluated with the model. These elements are included as standard profiles (rolling gate) or have a relatively small contribution to the total amount of material used (mitre gate)
    - With the design of the gate known and the amount of steel needed for the gate known a rough estimation of costs can be made. Welding costs could be estimated from the structural lay out of the gate, although a lot of factors influence welding costs. The reliability of components can be translated to costs as well, to do so data about repair times and reliability of components should be recorded.

- The parametric model can be used to optimise designs of specific gate types very well. The optimal configurations of elements for a gate with a specific design can be found. The effects of changing these lay outs can be made visible too.
- When used for bilateral retaining, a decision based on quantitative arguments between a rolling gate and a mitre gate is difficult. The mitre gate material need highly depends on the strip height parameter. The higher the strip height, the more beneficial the rolling gate becomes. The mitre gate is always beneficial for lower strip heights.
- Based on qualitative and quantitative arguments, the Prinses Marijkesluizen should have a mitre gate with clearance. This conclusion is drawn after evaluating a mitre gate with clearance, a mitre gate without clearance and a rolling gate.
- Extra measures to increase the cross-section classes of the designs, and a more careful evaluation of the minimal dimensions for the cross-section used could result in more optimal designs.

11.2 Recommendations

- To add value to the decision method it is recommended to record the failures of the actuators, and the mean repair times of these components. A cost factor could be added to the gate costs when the economic value of a certain river or canal is known, and therefore the actuators could be added in the decision method.
- Recording the difference in availability due to a more robust design would lead to a better (more realistic) decision method as well.
- More structural layouts should be added to the parametric model for the different gate type alternatives in order to have more competitive designs for a specific gate type. This would lead to better (more realistic) results in the gate type comparison.
- In order to get a feeling about the contribution of the torsional stiffening equipment to the total material need, a FEM should be used to calculate the torsional stiffening equipment needed for several designs. This information could be used to add the extra steel volume in terms of a percentage to the model, if the results of the FEM calculation can be predicted for all possible cases when they are known for some cases.
- The minimum and maximum values used for input parameters in the model could be investigated in more detail too. In some cases, a flange shouldn't be used while the model uses a minimal flange width. This would lead to more realistic values. Information of existing locks could help by determining these minimum values. The minimum front plate thickness is for example based upon expert opinion of Gerard Bouwman, but information of plate thicknesses in existing locks would probably lead to more realistic values for minimum plate thickness in the design.
- Some components which are gate type dependent haven't been included since the material volume isn't changed because of these components. These components should be included to know the exact costs for a certain gate type. Examples of these components are: pivots, actuators, wagons underneath a rolling gate, levelling systems.

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Photograph front page: Wiep Keikes

Appendix

A. Gate type pictures

A quick overview of the gate types discussed in the thesis is presented in the appendix. These pictures are presented to get an idea how the gate types look like in real life.

1. Mitre Gate

Figure 57 Mitre gate, www.rolanco.nl

2. Single leaf pivot gate

Figure 58 Single leaf pivot gate, www.jansen-venneboer.com

3. standing tainter gate

Figure 59 standing tainter gates, www.kustvaartforum.com

4. wing gates

Figure 60 Wing gates, http://wordpress.mediarelease.nu/restauraties-waaiersluizen-en-taveerne-opgeleverd

5. Tainter gate, counterweighed

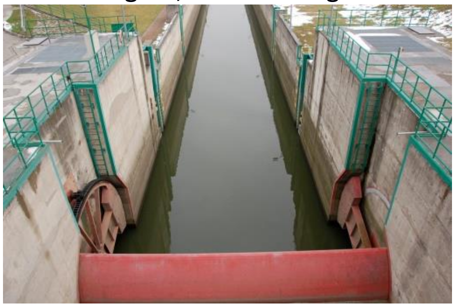

Figure 61 Tainter gate, counterweighed, www.kustvaartforum.com

6. Tainter gate, without counterweight

Figure 62 Tainter gate, without counterweight, www.debinnenvaart.nl

7. tumbler gate

Figure 63 Tumbler gate (not used for a navigational lock at the picture) www.vortexhydradams.com

8. Rolling/sliding gate


Figure 64 Rolling/sliding gate, www.beeldbank.rws.nl

9. Lifting gate


Figure 65 lifting gate, www.debinnenvaart.nl

10. Drop gate

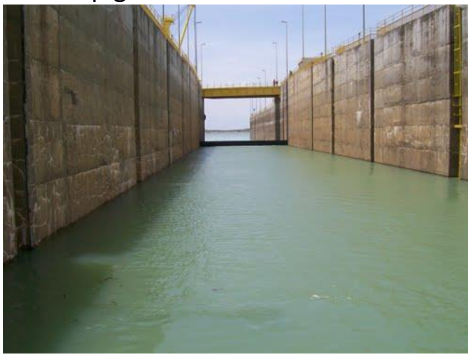
Figure 66 Drop gate, www.kustvaartforum.com

11. Double leaf lift gate
(as lifting gate but with two parts)

B. Basic design checks parametric model

The design checks performed in the parametric model are discussed in detail in this appendix. Everything is designed according to NEN-EN 1993-1-1 and NEN-EN 1993-1-5.

a. Basic input values

The properties of steel that have been used can be found in Table 37.

Property name	Symbol	Value	Source, page
Yield strength steel	f_y	355 N/mm^2*	1993-1-1 pg 33
Tensile strength steel	f_u	490 N/mm^2*	1993-1-1 pg 33
Elastic modulus steel	E	210000 N/mm^2	1993-1-1 pg 41
Poisson ratio steel	ν	0,3	1993-1-1 pg 41
Shear modulus steel	G	≈81000 N/mm^2**	1993-1-1 pg 41

Table 37 Basic input values parametric model

**Values for commonly used construction steel, only holds for plate thickness<40mm*

****Shear modulus has been calculated as follows:*

$$G = \frac{E}{2 * (1 + \nu)}$$

The partial factors used, according to NEN-EN 1993-1-1, are presented in Table 38:

Symbol	Value
γ_{m0}	1,0
γ_{m1}	1,0
γ_{m2}	1,25

Table 38 Material factors parametric model

The properties for environmental properties used are presented in Table 39:

Property name	Symbol	Value	Source, page
Gravitational acceleration, The Netherlands	g	9,81 m/s^2	[-]
Density fresh water	$\rho_{w,fresh}$	1000 kg/m^3	Manual hydraulic structures, page 56
Density salt water	$\rho_{w,salt}$	1025 kg/m^3	Manual hydraulic structures, page 56
Specific weight fresh water	$\gamma_{w,fresh}$	9,81 kN/m^3***	
Specific weight salt water	$\gamma_{w,salt}$	10,06 kN/m^3***	

Table 39 Environmental input factors parametric model

***** Specific weights calculated as follows:*

$$\gamma = \rho * g$$

b. Basic cross-sectional properties

The profiles which are used at the parametric model are I-profiles, the dimensions of the parts are parameters in the parametric model. The names of the corresponding parts are presented in Figure 67.

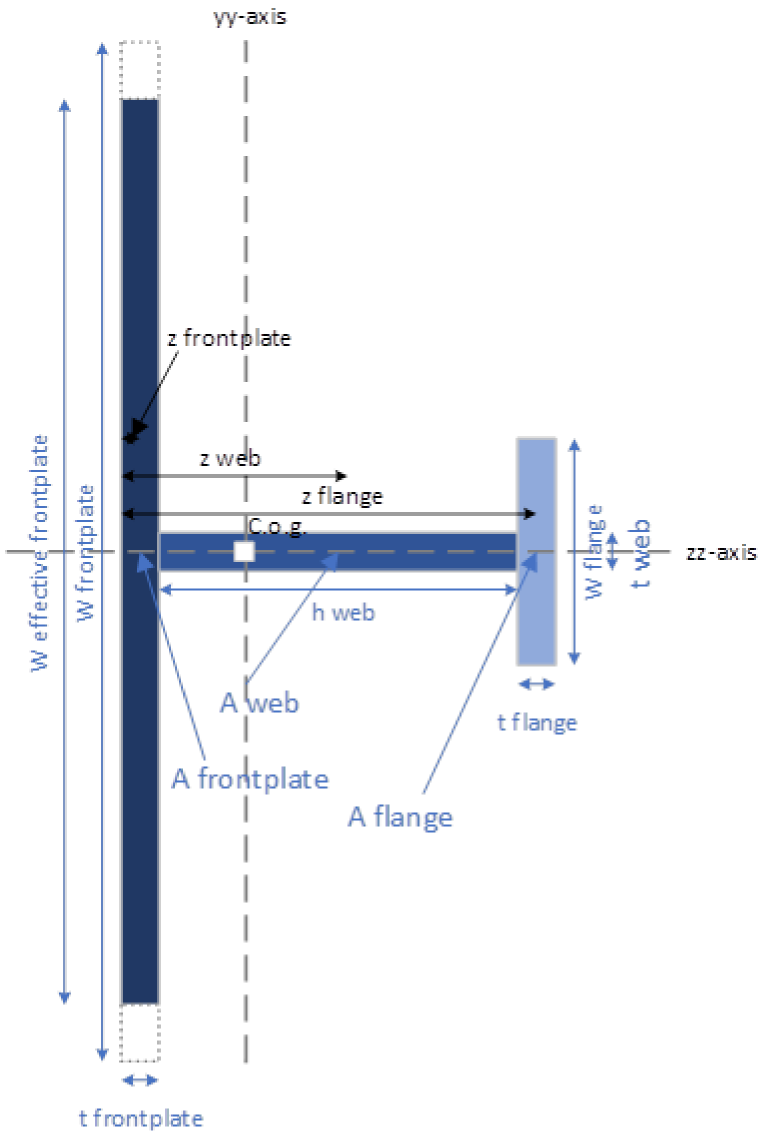

Figure 67 cross-sectional parameters

The centre of gravity of the profile has been determined by the use of the following formula:

$$c.o.g = \frac{A_{front\ plate} * z_{frontplate} + A_{web} * z_{web} + A_{flange} * z_{flange}}{A_{total}}$$

With:

A: Cross sectional area of the given part

z: Distance from the centre of gravity of the given part to the high-water side of the front plate

The Plastic neutral axis (PNA) is the height at which the area of the parts above the axis is the same as the area of the parts below this axis.

When the neutral axis is positioned at the web, x should be solved for the following equation:

$$t_{frontplate} * w_{frontplate} + x * t_{web} = (h_{web} - x) * t_{web} + t_{flange} * w_{flange}$$

With
t: plate thickness
h: height of the sub element
w: Width of the sub element
x: the to be solved variable

The position of the plastic neutral axis w.r.t. outer fibre of the front plate will then be:

$$PNA_{frontplate} = t_{frontplate} + x$$

Since the PNA could also be located at the front plate or the flange, a procedure (similar to the one above) have been implemented in the parametric model to find the right position of the PNA.

The plastic section modulus can be calculated by calculating the contribution of every part of the profile to moment resistance around the PNA. A rectangular stress distribution at the whole profile should be assumed since the calculation is fully plastic. For a PNA situated in the web the calculation becomes as follows (at the model calculations for a PNA situated in the front plate or flange have been added as well):

$$W_{plRd} = A_{frontplate} * z_{frontplatePNA} + t_{web} * x * 0{,}5 * x + (h_{web} - x) * t_{web} * 0{,}5 * (h_{web} - x) + A_{flange} * z_{flangePNA}$$

With:

$z_{frontplatePNA}$: The distance from the centre of gravity of the front plate to the PNA
$z_{flangePNA}$: The distance from the centre of gravity of the flange to the PNA

The part of the front plate which contributes to the profile in terms of resistance to the forces acting on the profile (effective width) is calculated as follows:

$$b_{eff} = b_0 * \beta$$

Where:
b_{eff}: half of the effective front plate width
b_0 : Half of the total front plate width
β: reduction factor effective width

Since there is a sagging bending moment for the locations where bending moments are maximal, the formula for β will be as follows (for different ranges):

$\kappa \leq 0{,}02$:

$$\beta = 1{,}0$$

$0{,}02 < \kappa \leq 0{,}7$:

$$\beta = \frac{1}{1 + 6{,}4 * \kappa^2}$$

$\kappa > 0{,}7$:

$$\beta = \frac{1}{5{,}9 * \kappa}$$

κ can be calculated as follows:

$$\kappa = \alpha_0 * b_0 * L_e$$

With:

L_e: length between the points at which the bending moments are 0 (=L for this case)

α_0 can be calculated as follows:

$$\alpha_0 = \sqrt{1 + \frac{A_{sl}}{b_0 * t}}$$

With:
A_{sl}: Area of vertical stiffeners inside half front plate width b_0

c. Cross section classes

In order to prevent local buckling to occur, the cross-section class in the model will be maximal cross section class 2. This leads also to the possibility of a plastic analyses of the cross section. A lower cross section class indicates a more robust cross section (thicker flanges and web), this is favourable at a lock door too (when ships could collide with the gates relatively easily). The cross section is calculated as a welded cross section. This has been done since the gate will consist of a front plate with girders behind it to increase strength, the easiest way to construct such a gate is by welding.

A typical cross section which is checked for cross sectional class is presented in Figure 67. The dotted lines at the tips of the front plate represent the total height of the front plate. The height of the front plate between the solid lines represent the effective area.

The cross-section class of the web has been determined as follows:

Since axial force and bending moment could both be present at the web three checks will be performed in order to determine the class of the cross section.

Class 1 if:
Bending:

$$\frac{c}{t} \leq 72 * \varepsilon$$

Compression:

$$\frac{c}{t} \leq 33 * \varepsilon$$

Bending and compression:
$\alpha > 0,5$

$$\frac{c}{t} \leq \frac{396 * \varepsilon}{13 * \alpha - 1}$$

$\alpha \leq 0,5$

$$\frac{c}{t} \leq \frac{36 * \varepsilon}{\alpha}$$

Class 2 if:
Bending:

$$\frac{c}{t} \leq 83 * \varepsilon$$

Compression:

$$\frac{c}{t} \leq 38 * \varepsilon$$

Bending and compression:
$\alpha > 0,5$

$$\frac{c}{t} \leq \frac{456 * \varepsilon}{13 * \alpha - 1}$$

α≤0,5

$$\frac{c}{t} \leq \frac{41{,}5 * \varepsilon}{\alpha}$$

With:

$$c = h_{web} - 2 * a$$

$$\varepsilon = \sqrt{\frac{235}{f_y}}$$

$$\alpha = \frac{h_{web} - PNA}{h_{web}}$$

a: Fillet weld width
t: plate thickness web

Since the compressed flange (=front plate) has only been subjected to a compressive force, the cross-section class for the compressed flange (= front plate) is determined as follows:

Cross section class 1:

$$\frac{c}{t} \leq \frac{9}{\varepsilon}$$

Cross section class 2:

$$\frac{c}{t} \leq \frac{10}{\varepsilon}$$

With:

$$c = 2 * b_{eff} - 2 * a - t_{web}$$

t: plate thickness front plate

Since the maximum cross section class is restricted to class 2, for reasons explained above, the cross-section class checks for class 3 and 4 haven't been presented.

d. Possible unity checks

The possible unity checks are presented below. Not every structure needs to be checked according to all the checks presented below. Which checks will be applied depend on the loads acting on the structure. At Appendix C the loads acting on the different structures will be presented. At these paragraphs an explanation about the necessary design checks will be given, referring back to the design checks presented at this paragraph.

i. Shear force check

Unity check:

$$\frac{V_{ed}}{V_{plRd}} \leq 1$$

With:

$$V_{plRd} = \frac{A_v * \frac{f_y}{\sqrt{3}}}{\gamma_{m0}}$$

$$A_v = \eta * \sum h_w * t_w$$

η=1,2 (if f_y < 460)

Extra check to avoid local buckling due to shear to occur:

$$\frac{h_w}{t_w} > \frac{72 * \varepsilon}{\eta}$$

ii. Normal force check

Normal force Unity check:

$$\frac{N_{ed}}{N_{crd}} \leq 1$$

With:

$$N_{cRd} = \frac{A_{total} * f_y}{\gamma_{m0}}$$

iii. Bending moment check

Unity check:

$$\frac{M_{Ed}}{M_{cRd}} \leq 1{,}0$$

$$M_{cRd} = M_{plRd} = \frac{W_{pl} * f_y}{\gamma_{m0}}$$

iv. Shear and bending moment combined check

A reduction in yield strength (which determines moment capacity of the profile) should be applied if the shear force exceeds a certain limit. This reduction is added in the model.

If the following condition has been satisfied, no reduction in yield strength should be taken into account:

$$V_{ed} < 0{,}5 * V_{plRd}$$

If the condition presented above hasn't been satisfied, the yield strength needed to calculate the moment capacity should be reduced as follows:

$$f_{yRedMV} = (1 - \rho) * f_y$$

No torsion so:

$$\rho = \left(\frac{2 * V_{Ed}}{V_{plRd}} - 1\right)^2$$

The reduced moment resistance becomes:

$$M_{VRd} = \frac{W_{pl} * f_{yRedMV}}{\gamma_{m0}}$$

v. Normal force and bending moment combined check

If the normal force exceeds a certain limit, the moment capacity of the profile should be reduced.
If the conditions presented below have been met, no reduction in moment capacity should be applied:

$$N_{Ed} \leq 0{,}25 * N_{plRd}$$

And:

$$N_{Ed} \leq \frac{0{,}5 * h_{web} * t_{web} * f_y}{\gamma_{m0}}$$

If the conditions presented above haven't been met, the moment capacity should be reduced as follows:

$$M_{NRd} = M_{plRd} * \left(1 - \left(\frac{N_{Ed}}{N_{PlRd}}\right)^2\right)$$

vi. Shear, normal force and bending moment combined check

If both reductions due to shear and normal force should be applied (according to the conditions described at the preceding two paragraphs), the reduced moment resistance becomes as follows:

$$M_{VNRd} = M_{VRd} * \left(1 - \left(\frac{N_{Ed}}{N_{PlRd}}\right)^2\right)$$

With:

$$M_{VRd} = \frac{W_{pl} * f_{yRedMV}}{\gamma_{m0}}$$

vii. Buckling check

If a normal compressive force acts at the gate, buckling should be taken into account.
The basic buckling formula is as follows:

$$N_{bRd} = \frac{\chi * A * f_y}{\gamma_{m1}}$$

With:

A: Area of the cross section, using the effective flange width at the front plate
χ: Reduction factor for buckling

The reduction factor χ is calculated by the use of the following formula's:

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \lambda_{rel}^2}}$$

With:

$$\phi = 0{,}5 * \left(1 + \alpha * (\lambda_{rel} - 0{,}2) + \lambda_{rel}^2\right)$$

And:

$$\lambda_{rel} = \frac{L_{cr}}{i * \lambda_1}$$

α: Is the imperfection factor, and follows from the buckling curve. For welded I or H profiles and buckling around the axis as described above (y-y axis in the tables):

If $t_{frontplate} < 40$mm, buckling curve b should be used and:

$$\alpha = 0{,}34$$

If $t_{frontplate} > 40$ mm, buckling curve c should be used and:

$$\alpha = 0{,}49$$

L_{cr}: If the beam has been modelled as a **simply supported beam**:

$$L_{cr} = L_{beam}$$

λ_1: is only material dependent:

$$\lambda_1 = \pi * \sqrt{\frac{E_{steel}}{f_y}}$$

i: is the radius of gyration and can be calculated according to standard cross-sectional parameters:

$$i = \sqrt{\frac{I_{yy}}{A_{tot}}}$$

If the compressive flange of the profile (front plate in most cases) is supported by the profile situated on to no checks have been performed regarding the tilting of the compressive flange due to buckling (NL: kippen).

1. Buckling combined check

M_y is the moment around the y-axis and M_z is the moment around the z axis, when the y and x axis are located as follows as in the figure presented above. The resisting cross sectional properties resist the load in the corresponding direction, so section modulus W_y resist load M_y.

When a moment has been applied to a beam loaded by a normal force, an adapted buckling check should be applied (NEN EN 1993-1-1). This check consists of 2 main conditions which should be fulfilled:

$$\frac{N_{ed}}{\frac{\chi_y * N_{Rk}}{\gamma_{M1}}} + k_{yy} * \frac{M_{yEd} + \Delta * M_{yEd}}{\chi_{LT} * \frac{M_{yRk}}{\gamma_{M1}}} + k_{yz} * \frac{M_{zEd} + \Delta * M_{zEd}}{\frac{M_{zRk}}{\gamma_{M1}}} \leq 1$$

$$\frac{N_{ed}}{\frac{\chi_z * N_{Rk}}{\gamma_{M1}}} + k_{zy} * \frac{M_{yEd} + \Delta * M_{yEd}}{\chi_{LT} * \frac{M_{yRk}}{\gamma_{M1}}} + k_{zz} * \frac{M_{zEd} + \Delta * M_{zEd}}{\frac{M_{zRk}}{\gamma_{M1}}} \leq 1$$

Since this check only has to be performed at the mitre gate, and most of the factors needed at this formula are relatively case specific, and tedious to find, an elaboration of the parameters present in this formula in general won't be given at this chapter. In the mitre gate chapter an in debt elaboration of these checks is presented.

2. *Normal force truss frame*

To check the beams for normal force (compression or tension) the check presented below has been performed.

Unity check:

$$\frac{N_{ed}}{N_{crd}} \leq 1$$

With:

$$N_{cRd} = \frac{A_{total} * f_y}{\gamma_{m0}}$$

3. *Buckling check truss beam*

Because a normal compressive force acts at the gate, buckling should be taken into account too. Buckling can only occur in horizontal direction, since the profile is supported by the profile welded on top in the vertical direction.

The basic buckling formula is as follows:

$$N_{bRd} = \frac{\chi * A * f_y}{\gamma_{m1}}$$

With:

A: Area of the cross section, using the effective flange width at the front plate

χ: Reduction factor for buckling

The reduction factor χ is calculated by the use of the following formula's:

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \lambda_{rel}^2}}$$

With:

$$\phi = 0{,}5 * \left(1 + \alpha * (\lambda_{rel} - 0{,}2) + \lambda_{rel}^2\right)$$

And:

$$\lambda_{rel} = \frac{L_{cr}}{i * \lambda_1}$$

α: Is the imperfection factor, and follows from the buckling curve. For welded I or H profiles and buckling around the axis as described above (y-y axis in the tables):

If $t_{frontplate}$ < 40mm, buckling curve b should be used and:

$$\alpha = 0{,}34$$

If $t_{frontplate}$ > 40 mm, buckling curve c should be used and:

$$\alpha = 0{,}49$$

L_{cr}: Since the beam has been modelled as a simply supported beam:

$$L_{cr} = L_{gate}$$

λ_1: is only material dependent:

$$\lambda_1 = \pi * \sqrt{\frac{E_{steel}}{f_y}}$$

i: is the radius of gyration and can be calculated according to standard cross-sectional parameters:

$$i = \sqrt{\frac{I_{yy}}{A_{tot}}}$$

With the help of standard HEB profiles, every beam in the truss frame has been chosen such that the resistance of the HEB profile match the load.

C. Structural schemes and loads gate types

The loads acting on the structural elements as modelled in the parametric model of the mitre gate with clearance, mitre gate without clearance and rolling gate are presented in this appendix.

a. Structural scheme and loads mitre gate with clearance

The gate has been schematized as a set of simply supported beams subjected to a uniformly distributed load (due to water pressure) and a normal force. This normal force is the effect of the gate angle with respect to the normal axis of the lock. Beam length L is the gate length of 1 single mitre gate. This schematization is presented in Figure 68.

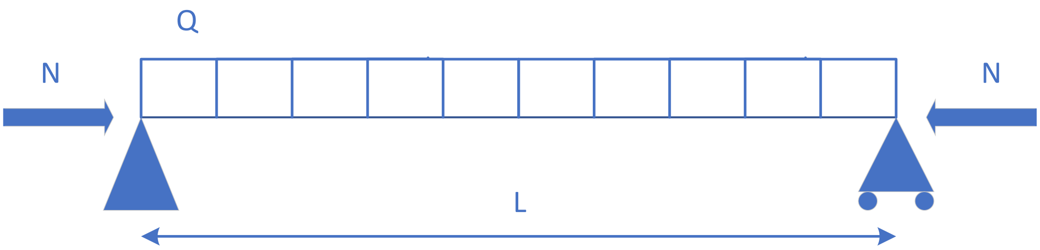

Figure 68 Structural scheme gate

i. Loads horizontal beam mitre gate with clearance

The bending moment and shear force distribution of the beam follow from the scheme presented at the previous paragraph, the beam is simply supported and subjected to a distributed load. This gives for the maximum bending moment:

$$M_{max} = \frac{1}{8} * Q * L^2$$

The maximum shear force is:

$$V_{max} = \frac{1}{2} * Q * L$$

The procedure to determine the unity check for buckling is described in the paragraph below.
The normal force follows from the gate angle:

$$N = \frac{Q * L}{2 * \tan(\alpha_{gate})}$$

b. Structural scheme and loads mitre gate without clearance

The load from the water pressure will be carried first by the vertical beams. This beam passes the load to the horizontal beams, which pass the load at one side to the adjacent gate and at the other side to the heel post. In other words, the vertical beams are supported by the horizontal beams and pass the load through as support reactions. The horizontal beams are supported by the heel post and the other gate and also pass the load through as support reactions. The heel post is supported by the pivots at the top and bottom of the post.
Due to the angle of the gate, a normal force will be present at the horizontal girders. The heel post is loaded in two directions. A schematization of the loads acting on all the components will be given below.

1. Structural element 1, vertical beam

Since the vertical water pressure isn't distributed uniformly (which has been showed above at the loads mitre gate paragraph), the beam is subjected to a non-uniform distributed load. The beam is a H profile with the effective width of the front plate, a web plate and a flange plate, as parts (as discussed before). The shear force and moment distribution can be obtained from Figure 69, the beam is supported by the horizontal beam.

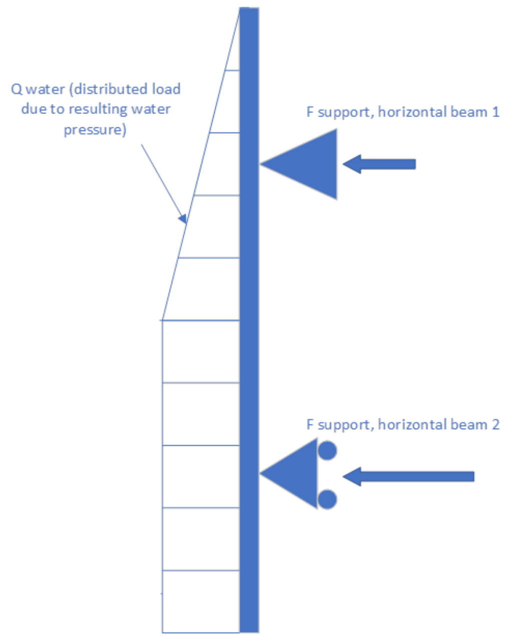

Figure 69 Load scheme vertical beam mitre gate without clearance

2. Structural element 2, horizontal beam

The vertical beams support the horizontal beams and are supported at the sides. The sides can rotate so can be modelled as hinges. A normal force is present due to the gate angle (as is the case with the mitre gate with clearance). The schematization is made clear in Figure 70.

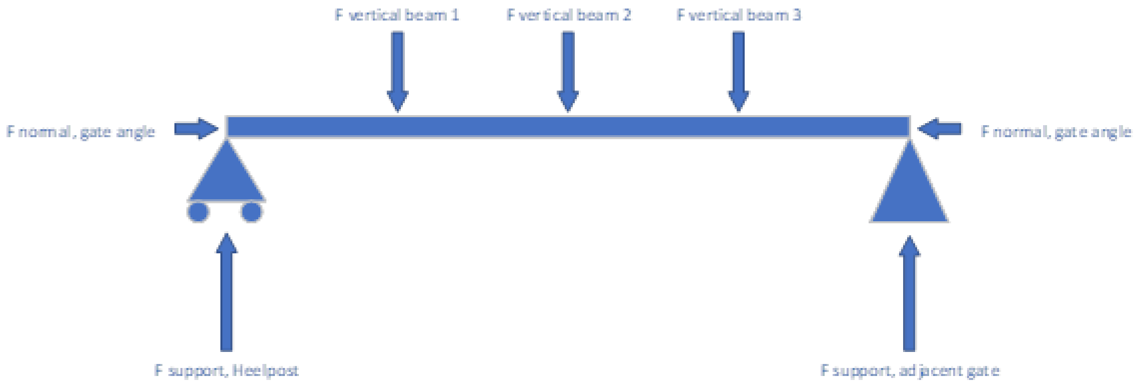

Figure 70 Load scheme horizontal beam mitre gate with clearance

3. Structural element 3, heel post

The heelpost supports the horizontal beams. Due to the loads acting in two directions on the horizontal beam the heel post is loaded in to two directions (normal force has to be resisted and water load has to be resisted). Since the pivot ends should remain fixed in position (that is the whole purposed of this way of designing the pivots), the gate will be schematised with fixed supports as can be seen in Figure 71.

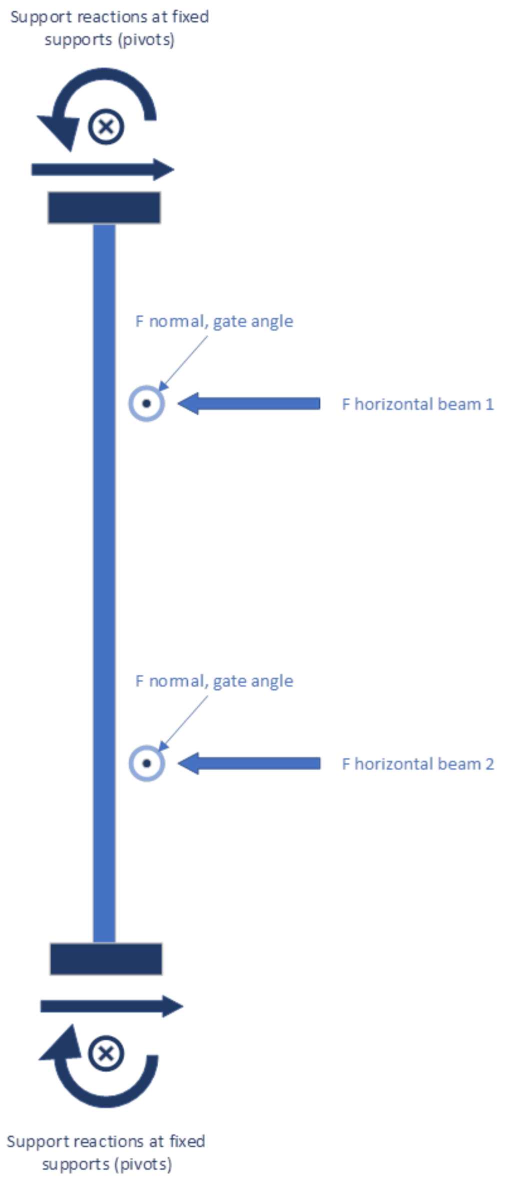

Figure 71 Load scheme heelpost mitre gate without clearance

ii. Loads mitre gate without clearance

The loads follow from the structural schemes presented above. The loads will be different for every beam. The vertical beam is subjected to shear force and bending moment, the horizontal beam is subjected to shear force, bending moment and normal force and the heelpost is subjected to shear force and bending moment, in 2 directions.

c. Structural scheme and loads rolling gate

i. Structural scheme horizontal beams

The horizontal beams can be modelled as a set of fixed supported beams. These beams have a length equal to the spacing of the vertical beams. This is the case since the load is evenly distributed in the horizontal direction, so at every vertical profile the angular rotation of the horizontal beam should be 0, this implies that the beam can be schematised as fixed at these points. The load acting on the beam is the distributed load because of the water pressure difference of the part which is carried by the beam. Figure 72 represents the load schematisation of the horizontal beam of the configuration of the rolling gate as showed in Figure 30.

For some beams it can be that at the top side of the front plate flange the water pressure difference is lower that at the bottom side of the front plate flange (if the pressure difference at the beam is triangular). This would lead to a torsional moment in the beam. It is assumed that the gate is stiff enough to resist this torsional moment.

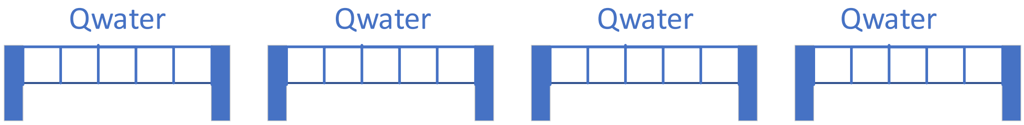

Figure 72 Load schematisation horizontal beams (with fixed supports at the sides)

This schematization implies that the beams are fixed at the corners. This can be achieved by adding stiffeners at the corners when necessary. Since these stiffeners will have a negligible effect on the material volume, no further calculations are performed regarding the stiffeners at the corners.

ii. Loads Horizontal beam

With an upstream water level of 6meter, a downstream water level of 2m and a beam length of 4,5m (randomly chosen values, since the model is parametric these values could be any value) the bending moment and shear diagram of the beams look as follows (graphs directly imported from the model):

The bending moment diagram can be obtained with the help of "forget me nots": at the supports the bending moment is:

$$M_{support} = \frac{1}{12} * Q_{water} * l^2$$

And at midspan the bending moment is*:*

$$M_{midspan} = \frac{1}{24} * Q_{water} * l^2$$

The (vertical) support reactions follow from horizontal equilibrium and from the fact that the load is evenly distributed in horizontal direction:

$$V_{support} = \frac{1}{2} * Q_{water} * l$$

1. Model output

With the parameters from Table 40 used in the parametric model, the bending moment distribution and shear force distribution of Figure 73 and Figure 74 are found by the parametric model.

Name	Value	Dimension
Max water depth front gate	8	m
Minimum water depth back	4	m
strip height	1,38	m
Qload bottom strip	54	kN/m
beam length	4,5	m

Table 40 Load output rolling gate vertical beams

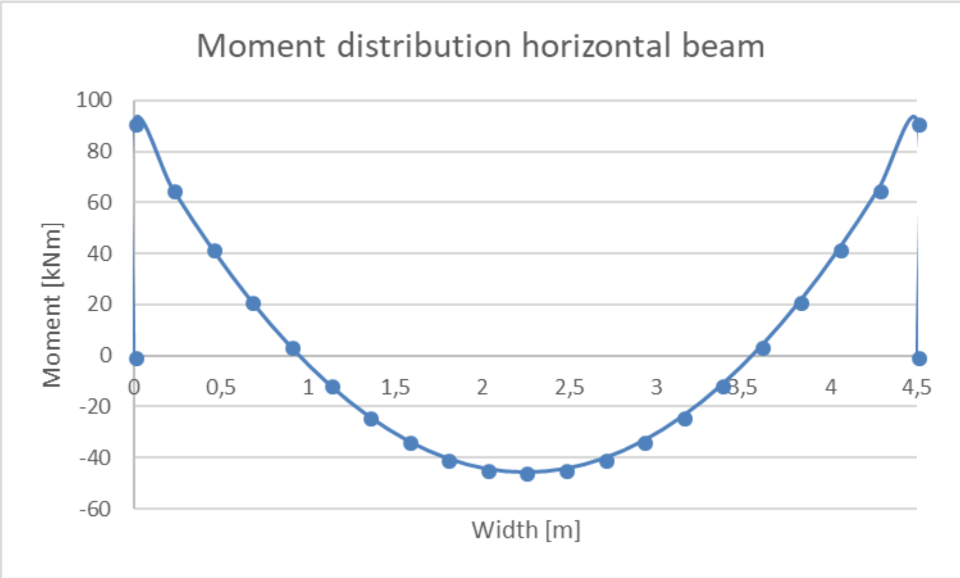

Figure 73 Moment distribution horizontal beam output parametric model rolling gate

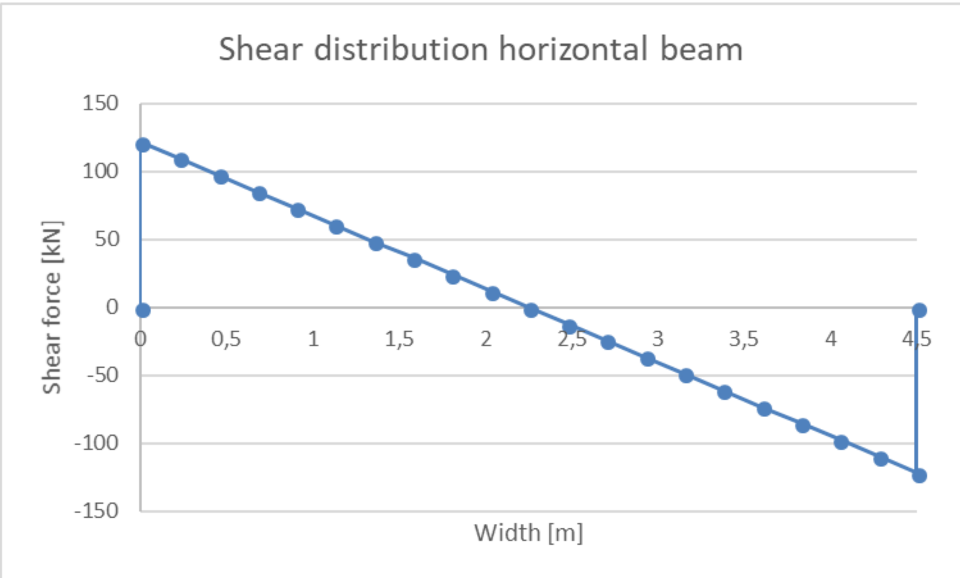

Figure 74 Shear force distribution parametric model rolling gate horizontal beam

2. Validation model output horizontal beam

The horizontal beam has been modelled with the help of Matrix Frame (which is specialised software used to calculate force distributions). The same output as the model has been obtained. This shows that the model gives reasonable output. The data obtained is displayed in Figure 75:

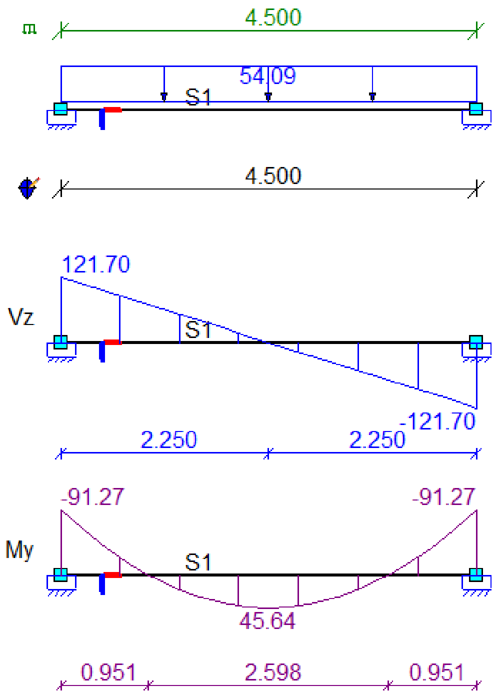

Figure 75 Rolling gate matrix frame horizontal beam load checks

The values correspond with the values obtained from the parametric model. More cases have been checked too.

iii. Modelling of the structural elements vertical beam

The Vertical beams are modelled as an ongoing supported beam (with several supports). Since the load isn't evenly distributed in the vertical direction, the beam can't be modelled as separate fixed beams (like the horizontal beams). This makes the vertical beam statically indeterminate, so increases the difficulty of the problem. The load acting on the vertical beam are the support reactions of the horizontal beams (as discussed above). Figure 76 represents the load schematisation of the vertical beam of the configuration of the rolling gate as showed in Figure 30.

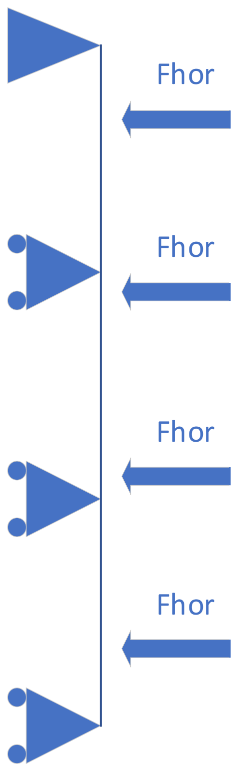

Figure 76 Load schematisation Vertical beams

iv. Loads vertical beam

The vertical beam is a statically indeterminate girder. The moment distribution of this girder has been calculated with the help of the fact that the angular rotations at every support needs to be the same (per support). These angular rotations can be calculated with the help of forget-me-nots. The model has been made parametric, this means that the loads with corresponding locations (number of horizontal beams) can change and the amount of supports can change. The maximum number of loads (horizontal beams) is 20. The maximal amount of supports (horizontal large beams) is 7. The spacing of the vertical large beams is equal, otherwise the system would get too complicated. The following system of equations needs to be solved:

$$B = A * M$$

With:

$$A := \begin{bmatrix} -\frac{2\,l}{3\,EI} & -\frac{l}{6\,EI} & 0 & 0 & 0 \\ -\frac{l}{6\,EI} & -\frac{2\,l}{3\,EI} & -\frac{l}{6\,EI} & 0 & 0 \\ 0 & -\frac{l}{6\,EI} & -\frac{2\,l}{3\,EI} & -\frac{l}{6\,EI} & 0 \\ 0 & 0 & -\frac{l}{6\,EI} & -\frac{2\,l}{3\,EI} & -\frac{l}{6\,EI} \\ 0 & 0 & 0 & -\frac{l}{6\,EI} & -\frac{2\,l}{3\,EI} \end{bmatrix}$$

$$B := \begin{bmatrix} -thetaB1 - thetaB2 \\ -thetaC1 - thetaC2 \\ -thetaD1 - thetaD2 \\ -thetaE1 - thetaE2 \\ -thetaF1 - thetaF2 \end{bmatrix}$$

$$\begin{bmatrix} MA \\ MB \\ MC \\ MD \\ ME \\ MF \end{bmatrix}$$

Matrix A corresponds to the system of equations that states that at every support (except the begin and end support) the angular rotations induced by the moments in the beam at the support should be the same, these angular rotations can be obtained with the help of forget me nots.

Vector B gives the angular rotations at the inbetween supports because of the loads acting between the supports. These angular rotations can be obtained with the help of forget me nots too.

The last Vector is the set of moments which have to be obtained in order to be able to determine the load distribution of the beam.

This gives the following solution for the moments at the supports:

$$sol := \begin{bmatrix} \frac{(209\, thetaB1 + 209\, thetaB2 - 56\, thetaC1 - 56\, thetaC2 + 15\, thetaD1 + 15\, thetaD2 - 4\, thetaE1 - 4\, thetaE2 + thetaF1 + thetaF2)\, EI}{130\, l} \\ -\frac{2\,(-56\, thetaC1 - 56\, thetaC2 + 14\, thetaB1 + 14\, thetaB2 + 15\, thetaD1 + 15\, thetaD2 - 4\, thetaE1 - 4\, thetaE2 + thetaF1 + thetaF2)\, EI}{65\, l} \\ \frac{3\,(15\, thetaD1 + 15\, thetaD2 - 4\, thetaC1 - 4\, thetaC2 + thetaB1 + thetaB2 - 4\, thetaE1 - 4\, thetaE2 + thetaF1 + thetaF2)\, EI}{26\, l} \\ -\frac{2\,(-56\, thetaE1 - 56\, thetaE2 + 15\, thetaD1 + 15\, thetaD2 - 4\, thetaC1 - 4\, thetaC2 + thetaB1 + thetaB2 + 14\, thetaF1 + 14\, thetaF2)\, EI}{65\, l} \\ \frac{(209\, thetaF1 + 209\, thetaF2 - 56\, thetaE1 - 56\, thetaE2 + 15\, thetaD1 + 15\, thetaD2 - 4\, thetaC1 - 4\, thetaC2 + thetaB1 + thetaB2)\, EI}{130\, l} \end{bmatrix}$$

The top formula corresponds to the moment at the first support, the formula below the top formula to the moment at the second support etc.

1. *Load distribution vertical beam example case*

The bending moments and shear forces presented in Figure 77 and Figure 78 are obtained from the model for the model input presented in Table 41 and Table 42 :

Location forces [m}:		Forces yy axis [kN]:	
eFyy1	0,689177137	**Fyy1**	243,3897979
eFyy2	2,067531412	**Fyy2**	243,3897979
eFyy3	3,447066013	**Fyy3**	243,3897979
eFyy4	5,082220075	**Fyy4**	243,3897979
eFyy5	7,013508337	**Fyy5**	85,92080853

Table 41 vertical beam rolling gate loads

Support location	Support reaction
0	129,582701
2	414,2866934
4	307,2313484
6	187,5152884
8	20,86396872

Table 42 vertical beam rolling gate supports

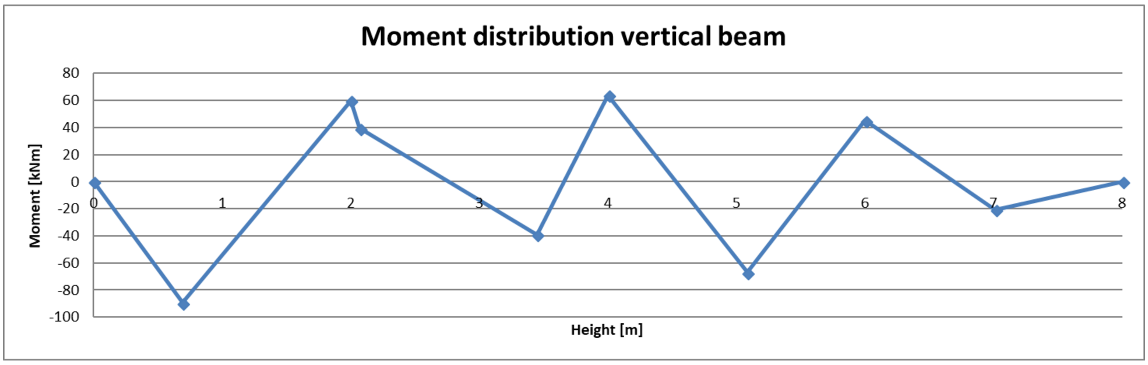

Figure 77 moment distribution vertical beam rolling gate

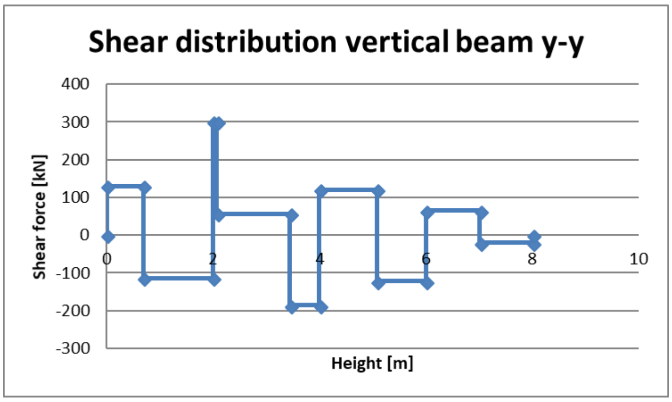

Figure 78 shear force distribution vertical beam rolling gate

2. *Validation loads vertical beam*

With the help of Matrix frame, the loads for the vertical beam presented in Figure 79 with the same parameters as inserted in the model have been obtained.

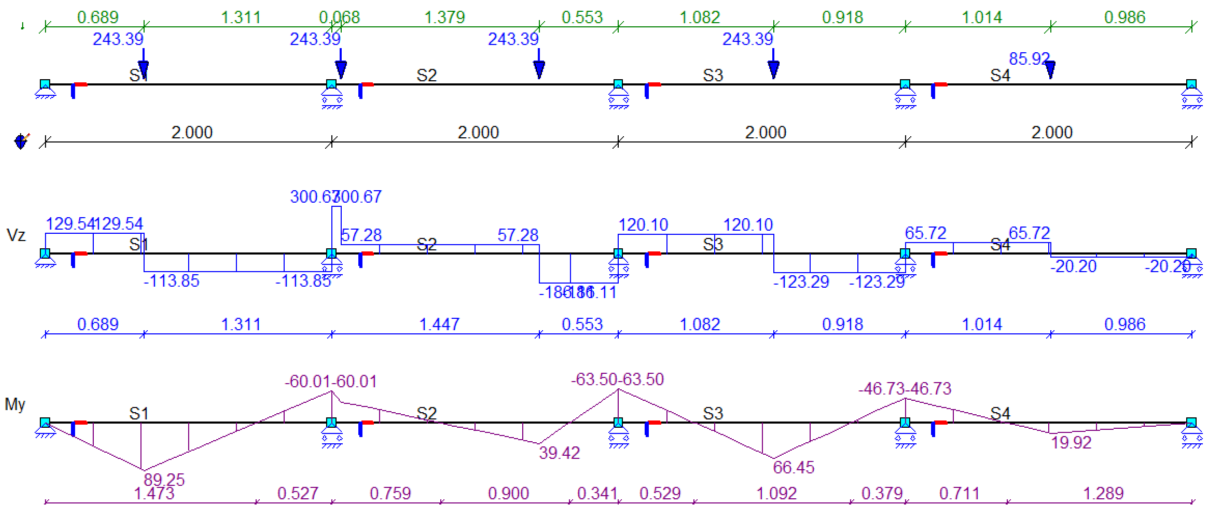

Figure 79 matrix frame check vertical beam rolling gate

Comparing the Matrix Frame output to the parametric model output leads to the conclusion that the model output give the expected results. (more cases have been checked too).

v. Loads truss frame

The Truss frames have to support the vertical beams. The support reactions of the vertical beams act as the loads on the truss frames. At the sides the loads are 0,5 x the support reactions, since the vertical beams carry half of the water pressure.

The connections of the truss frame are all hinges, this results in the fact that only normal forces are present in the beams of the truss.
The support reactions at the sides can be determined by:

$$V_{support} = 0,5 * \Sigma F_{load}$$

With the help of:

$$\Sigma M = 0$$

And:

$$\Sigma F_v = 0$$

And choosing the right points at the truss frame, all the normal forces in the truss can be determined. When choosing the loads to be 1*F at the middle nodes and 0.5*F at the side nodes, the multiplication factors to determine the precise loads will be obtained. Multiplying these factors by the support reactions obtained at the vertical beam gives the load at the truss

1. Load truss frame validation

The output of the parametric model for a Warren truss frame with 5 elemental parts (as presented above) has been compared to the Matrix frame solutions. Since the loading from bottom has been applied at the bottom nodes in reality, the results are slightly different as compared at the previous paragraph.

The truss frame has a depth of 1m, a width of 5m (with elemental parts of 1m wide) and is loaded at the sides by 0,5kN and at the middle nodes 1kN. The results can be seen in Table 43. From this table it can be seen that both outputs are the same. This validates the truss frame parametric model calculations. (more cases have been checked too).

	Loaded from top		Loaded from bottom	
	Parameteric model	MatrixFrame	Parametric model	MatrixFrame
S1	-2,5	-2,5	-0,5	-0,5
S2	-2	-2	2	2
S3	2,828427125	2,83	-2,828427125	-2,83
S4	0	0	0	0
S5	-1	-1	0	0
S6	-2	-2	2	2
S7	-1,414213562	-1,41	1,414213562	1,41
S8	3	3	-3	-3
S9	0	0	-1	-1
S10	-3	-3	3	3
S11	0	0	0	0
S12	3	3	-3	-3
S13	-1	-1	0	0
S14	-3	-3	3	3
S15	1,414213562	1,41	-1,414213562	-1,41
S16	2	2	-2	-2
S17	0	0	-1	-1
S18	0	0	0	0
S19	-2,828427125	-2,83	2,828427125	2,83
S20	2	2	-2	-2
S21	-0,5	-0,5	-2,5	-2,5

Table 43 matrix frame truss validation

D. Pratt vs Warren truss frame comparison

For both types of truss frames a truss frame with an even (4) and an odd (5) number of elements has been compared, since both situations can arise in the parametric model.

An even amount of elements Warren truss with verticals is shown in Figure 80. An even amount of elements Pratt truss is shown in Figure 81.

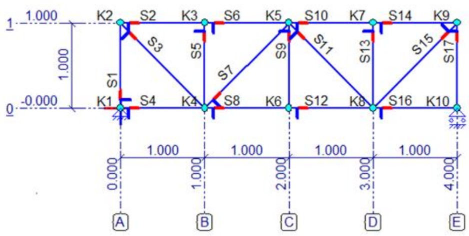

Figure 80 Warren with verticals with even amount of elemental parts (4)

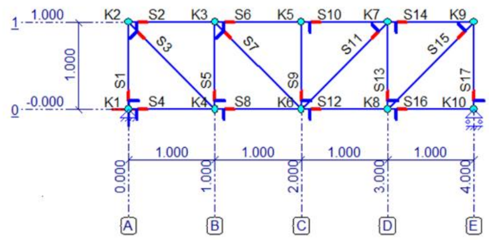

Figure 81 Pratt truss with even amount of elemental parts (4)

For a load of 0,5kN at the side nodes and a load of 1kN at the middle node (which is representative since the side nodes carry half of the middle nodes) the comparison presented in Table 44 is made.

	Loaded from top		Loaded from bottom	
	Warren with verticals	Pratt	Warren with verticals	Pratt
S1	-2.00	-2.00	2.00	2.00
S2	-1.50	-1.50	1.50	1.50
S3	2.12	2.12	-2.12	-2.12
S4	0.00	0.00	0.00	0.00
S5	-1.00	-1.50	1.00	1.50
S6	-1.50	-2.00	1.50	2.00
S7	-0.71	0.71	0.71	-0.71
S8	2.00	1.50	-2.00	-1.50
S9	0.00	-1.00	0.00	1.00
S10	-1.50	-2.00	1.50	2.00
S11	-0.71	0.71	0.71	-0.71
S12	2.00	1.50	-2.00	-1.50
S13	-1.00	-1.50	1.00	1.50
S14	-1.50	-1.50	1.50	1.50
S15	2.12	2.12	-2.12	-2.12
S16	0.00	0.00	0.00	0.00
S17	-2.00	-2.00	2.00	2.00
n worst	**4**	**5**	**2**	**7**
min	**-2.00**	**-2.00**	**-2.12**	**-2.12**

Table 44 matrix fram truss comparison

From this table it follows that the Warren truss with verticals has less maximal loads then the Pratt truss. The determining loads are the same.

The same comparison is made for both truss configurations with an odd amount of elemental parts, this is presented in Figure 82, Figure 83 and Table 45.

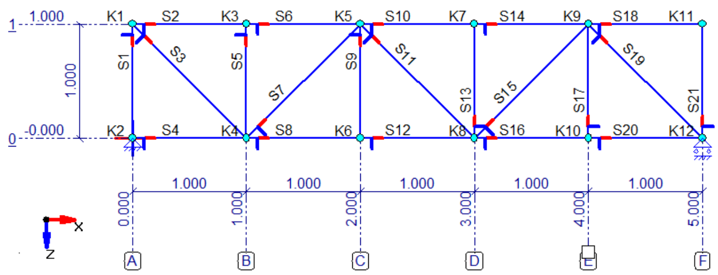

Figure 82 Warren with verticals for an odd number of elemental parts (5)

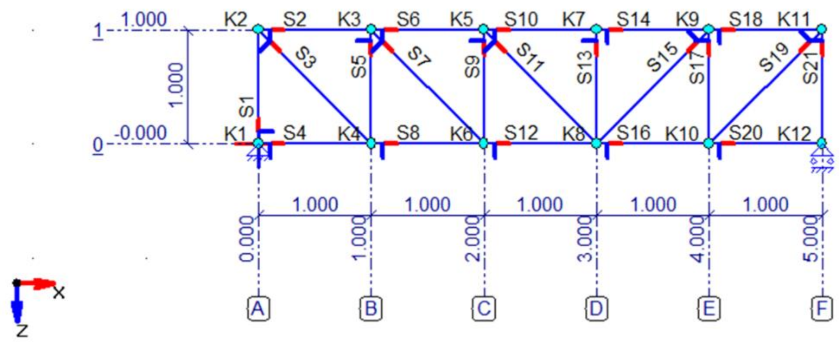

Figure 83 Pratt truss for an odd number of elemental parts (5)

	Loaded from top		Loaded from bottom	
	Warren with verticals	Pratt	Warren with verticals	Pratt
S1	-2,5	-2,5	2,5	2,5
S2	-2	-2	2	2
S3	2,83	2,83	-2,83	-2,83
S4	0	0	0	0
S5	-1	**-2**	1	**2**
S6	-2	**-3**	2	**3**
S7	**-1,41**	1,41	1,41	**-1,41**
S8	**3**	2	**-3**	-2
S9	0	**-1**	0	**1**
S10	-3	-3	3	3
S11	0	0	0	0
S12	3	3	-3	-3
S13	-1	-1	1	1
S14	-3	-3	3	3
S15	1,41	1,41	-1,41	-1,41
S16	2	2	-2	-2
S17	0	**-2**	0	2
S18	0	**-2**	0	2
S19	**-2,83**	2,83	2,83	**-2,83**
S20	**2**	0	**-2**	0
S21	-0,5	**-2,5**	0,5	**2,5**
Mean	**-0,24**	**-0,41**	**0,24**	**0,41**
n worst:	**4**	**6**	**2**	**6**
Min:	**-3**	**-3**	**-3**	**-3**

Table 45 Matrix frame truss comparison, odd number of truss ellemental parts

From this comparison it follows that in both cases the Warren configuration gives lower loads then the Pratt configuration. The Warren configuration will be used in the rest of the calculations.

E. Buckling and moment combined check mitre gate with clearance

The main checks which are used have already been shown in Appendix B:

$$\frac{N_{ed}}{\frac{\chi_y * N_{Rk}}{\gamma_{M1}}} + k_{yy} * \frac{M_{yEd} + \Delta * M_{yEd}}{\chi_{LT} * \frac{M_{yRk}}{\gamma_{M1}}} + k_{yz} * \frac{M_{zEd} + \Delta * M_{zEd}}{\frac{M_{zRk}}{\gamma_{M1}}} \leq 1$$

$$\frac{N_{ed}}{\frac{\chi_z * N_{Rk}}{\gamma_{M1}}} + k_{zy} * \frac{M_{yEd} + \Delta * M_{yEd}}{\chi_{LT} * \frac{M_{yRk}}{\gamma_{M1}}} + k_{zz} * \frac{M_{zEd} + \Delta * M_{zEd}}{\frac{M_{zRk}}{\gamma_{M1}}} \leq 1$$

The more detailed elaboration has been done with the help of several assumptions which only hold for the mitre gate design. These are discussed below.

Since only a moment around the y-axis is present in this case, M_z is 0. Lateral torsion can't occur since the flange under compression is supported (by the beam welded on top) so χ_{LT} is 1. The beam is supported in the z- direction by another beam so no buckling will occur around the z-axis. This leads to χ_z=1. Finally, it is stated in the Norm that for cross section class 1 and 2, $\Delta M_{y,Ed}$ and $\Delta M_{z,Ed}$ are equal to 0.The norm allows to use $W_{pl,y}$ and $W_{pl,z}$ for cross section class 1 and 2 (as with the other checks). Since profiles of cross section class 2 are applied, the conditions reduce to:

$$\frac{N_{ed}}{\frac{\chi_y * N_{Rk}}{\gamma_{M1}}} + k_{yy} * \frac{M_{yEd}}{1 * \frac{M_{yRk}}{\gamma_{M1}}} \leq 1$$

$$\frac{N_{ed}}{\frac{1 * N_{Rk}}{\gamma_{M1}}} + k_{zy} * \frac{M_{yEd}}{1 * \frac{M_{yRk}}{\gamma_{M1}}} \leq 1$$

With:

$$N_{Rk} = f_y * A$$

$$M_{yRk} = f_y * W_{pl.y}$$

$$M_{zRk} = f_z * W_{plz}$$

The process to find k_{yy} and k_{zy} is quite tedious, several factors have to be calculated first. The first step is to decide which method will be chosen. The norm proposes 2 methods. Since the moment distribution in this case fits better with the distribution described in method 1, method 1 is chosen. Both methods should be applicable. For the mitre gate with clearance the procedure discussed below is performed. The same procedure is performed for the mitre gate without clearance horizontal beam.

Method 1, for class 1 and 2 profiles:

$$k_{yy} = C_{my} * C_{mLT} * \frac{\mu_y}{1 - \frac{N_{Ed}}{N_{cry}}} * \frac{1}{C_{yy}}$$

$$k_{zy} = C_{my} * C_{mLT} * \frac{\mu_z}{1 - \frac{N_{Ed}}{N_{cry}}} * \frac{1}{C_{zy}} * 0,6 * \sqrt{\frac{w_y}{w_z}}$$

With help terms:

$$\mu_y = \frac{1 - \frac{N_{Ed}}{N_{cry}}}{1 - \chi_y * \frac{N_{Ed}}{N_{cry}}}$$

$$\mu_z = \frac{1 - \frac{N_{Ed}}{N_{crz}}}{1 - \chi_z * \frac{N_{Ed}}{N_{crz}}} = 1$$

$$w_y = \frac{W_{ply}}{W_{ely}} \leq 1,5$$

$$w_z = \frac{W_{plz}}{W_{elz}} \leq 1,5$$

C_{yy} can be calculated as follows:

$$C_{yy} = 1 + (w_y - 1) * \left(\left(2 - \frac{1,6}{w_y} * C_{my}^2 * \lambda_{relmax}^2 - \frac{1,6}{w_y} * C_{my}^2 * \lambda_{relmax}^2\right) * n_{pl} - b_{LT}\right) \geq \frac{W_{ely}}{W_{ply}}$$

With:

$$b_{LT} = 0,5 * a_{LT} * \lambda_{rel0}^2 * \frac{M_{yEd}}{\chi_{LT} * M_{plyRd}} * \frac{M_{zEd}}{M_{plzRd}}$$

Since M_{zEd} is 0, b_{LT} is 0.

Since no lateral torsion can occur:

$$C_{my} = C_{my0}{}^*$$

And:

$$C_{mLT} = 1,0$$

With the uniformly distributed load, C_{my0} becomes:

$$C_{my0} = 1 + 0,03 * \frac{N_{Ed}}{N_{cry}}$$

Furthermore:

$$n_{pl} = \frac{N_{Ed}}{\frac{N_{Rk}}{\gamma_{M0}}}$$

And λ_{relmax} is the maximum value of the relative slenderness. Since the beam can only buckle around the y-axis:

$$\lambda_{relmax} = \lambda_{rely}$$

Finally, C_{zy} can be obtained by the following equation:

$$C_{zy} = 1 + (w_y - 1) * \left(\left(2 - 14 * \frac{C_{my}^2 * \lambda_{relmax}^2}{w_y^5} \right) * n_{pl} - d_{LT} \right) \geq 0{,}6 * \sqrt{\frac{w_y}{w_z} * \frac{W_{ely}}{W_{ply}}}$$

With:

$$d_{LT} = 2 * a_{LT} * \frac{\lambda_{rel0}}{0{,}1 + \lambda_{relz}^4} * \frac{M_{yEd}}{C_{my} * \chi_{LT} * M_{plyRd}} * \frac{M_{zEd}}{C_{mz} * M_{plzRd}}$$

And since M_{zEd}=0:

$$d_{LT} = 0$$

*The procedure has been performed for the mitre gate without clearance the same as with the mitre gate with clearance. Since the moment distribution is different for the mitre gate without clearance, the fact $C_{my,0}$, which is load distribution dependent, could be determined different. The proposed calculations for this factor which represent this case the best way is: uniformly distributed load (as is the case with the mitre gate with clearance) and one single point load at the middle of the beam. The more vertical beams are present, the more the distribution will look like the uniformly distributed load distribution. Since it is expected that there will be quite a lot of vertical beams (3 or more) the uniformly distributed load distribution will be used, this distribution gives also the most conservative result. In reality the boundaries of C_{my0} will be:

$$1 - 0{,}18 * \frac{N_{ed}}{N_{cry}} \leq C_{my0} \leq 1 + 0{,}03 * \frac{N_{ed}}{N_{cry}}$$

To get a feeling of the difference in results, a standard case is optimised, results of both values are presented. For a 18m wide lock with a water level of 8m at the high-water side and 0m at the low water side (so relatively large normal force can be expected, which leads to a dominant buckling and bending moment combined load) the results are presented in Figure 84.

Schematisation	**C_{my0}**	**UC 1**	**UC 2**
Uniformly distributed load (As in the model)	1,0023	1,0000	0,6667
Point load	0,9865	0,9910	0,6566

Figure 84 relative difference in assumed simplified buckling and moment combined check

These differences can be considered to be negligible, so the assumption is on the safe side and has a negligible effect on the end result.

F. Detailed results case study

The detailed output for the evaluated optimal designs per gate type of the case study are presented in this appendix.

a. Detailed Output mitre gate with clearance

The variable optimisation parameters are presented in Table 46 for both strip heights:

Variable parameter	Values Strip height 0,3m	Values strip height 0,5m
thickness front plate	0,016	0,028
Strip height (horizontal beam)	0,3	0,5
thickness web plate (Hor)	0,008	0,011
web height (Hor)	0,28	0,36
plate thickness flange (Hor)	0,013	0,012
flange width (Hor)	0,20	0,21

Table 46 resulting input parameters mitre gate, case study

These parameters result in the cross-section classes presented in Table 47

Cross-section Class check name:	Value strip height 0,3 m	Value strip height 0,5 m
Crossection Class web:		
compression and bending	1	1
compression	2	2
bending	1	1
Crossection Class flange:		
compression	2	2

Table 47 cross section class checks mitre gate, case study

Model checks

The relevant loads acting on the gate are as presented in Table 48.

Load name	Value strip height 0,3 m	Value strip height 0,5 m
M ed per strip	343 [kNm]	566 [kNm]
V ed per strip	144 [kN]	238 [kNm]
N ed per strip	275 [kN]	402 [kNm]

Table 48 loads mitre gate, case study

The unity check outputs of the model can be found in Table 49.

UC name	UC value strip height 0,3 m	UC value strip height 0,5 m
Bending moment	0,86	0,89
Shear force	0,25	0,25
Axial Force	0,08	0,06
Buckling	0,13	0,08
Buckling and moment:		
Check 1	1,00	1,00
Check 2	0,67	0,64

Table 49 Unity Checks mitre gate, case study

b. Detailed output mitre gate without clearance

The variable parameters for the optimal (2 vertical beams per gate) case are found in Table 50Table 50

Vertical girders			
	thickness front plate	0,012	m
	max effective strip height	0,24	m
	thickness web plate	0,014	m
	Web height	0,99	m
	plate thickness flange	0,015	m
	flange width	0,21	m
Horizontal Girders			
	Bottom		
	thickness web plate (Hor)	0,025	m
	web height (Hor)	0,81	m
	plate thickness flange (Hor)	0,029	m
	flange width (Hor)	0,72	m
	Top		
	thickness web plate (Hor)	0,016	m
	web height (Hor)	0,52	m
	plate thickness flange (Hor)	0,014	m
	flange width (Hor)	0,33	m
Heel post dimensions:			
	plate thickness hollow section	0,019	m
	outer width hollow section	1,33	m
	Outer height hollow section	0,91	m

Table 50 Resulting input parameters, mitre gate without clearance, case study

These parameters result in the following cross-section classes presented in Table 51.

Cross-section Class check name:	Value
Crossection Class vertical girders:	
web bending	2
Frontplate compression	2
Flange plate compression	1

Cross section Class Horizontal Top girder web	
compression and bending	2
compression	2
bending	1
Cross section Class Horizontal Top girder web	
compression and bending	1
compression	2
bending	1
Cross section class Heelpost	
Bending yy	2
Bending zz	2

Table 51 cross section class checks, mitre gate without clearance, case study

i. Model checks

The relevant loads acting on the gate are presented in Table 52.

Load name	Value
Vertical girder	
M ed	2316 [kNm]
V ed	1214 [kN]
Horizontal top girder	
M ed	633 [kNm]
V ed	279 [kN]
N ed	4056 [kN]
Horizontal bottom girder	
M ed	5438 [kNm]
V ed	2289 [kN]
N ed	4056 [kN]
Heelpost	
M yy ed	3853 [kNm]
V yy ed	1975 [kN]
M zz ed	8745 [kNm]
V zz ed	4056 [kN]

Table 52 resulting loads mitre gate without clearance, case study

The Unity checks outcomes of the parametric model are presented in Table 53.

UC name	UC value
Vertical girder	
Bending moment	1,00
Shear force	0,35
Top girder	
Bending moment	0,55
Shear force	0,14
Axial force	

Buckling	0,39
Buckling and moment:	
Check 1	1,00
Check 2	0,90
Bottom girder	0,86
Bending moment	0,73
Shear force	0,46
Axial force	
Buckling	0,19
Buckling and moment:	
Check 1	1,00
Check 2	0,70
Heelpost	
Bending moment yy	0,36
Shear yy	0,24
Bending moment zz	0,64
Shear zz	0,34
Bending moment both directions combined	1,00

Table 53 resulting unity checks mitre gate without clearance, case study

c. Detailed output Rolling gate

The variable optimisation parameters for the optimal (4 truss frames, 8 elemental part) case can be found in Table 54.

	Variable name:	**Value**	
Horizontal Girders			m
	thickness front plate	0,126	m
	thickness web plate (Hor)	0,008	m
	web height (Hor)	0,15	m
	plate thickness flange (Hor)	0,008	m
	flange width (Hor)	0,10	m
Vertical girders			
	thickness web plate (Hor)	0,008	
	web height (Hor)	0,28	m
	plate thickness flange (Hor)	0,011	m
	flange width (Hor)	0,11	m

Table 54 resulting input parameters rolling gate, case study

These parameters result in the cross-section classes presented in Table 55.

Cross-section Class check name:	Value
Crossection Class horizontal girders:	
Crossection Class web:	
compression and bending	1
compression	1
bending	1
Crossection Class flange / frontplate:	
compression	2
Crossection Class horizontal girders:	
Cross section class web:	
compression and bending	2
compression	2
bending	1
Cross section class frontplate/flange	
compression	1

Table 55 resulting cross section checks rolling gate, case study

i. Model checks

The relevant loads acting on the gate are presented in Table 56.

Load name	Value
Vertical girder	
M ed	12,85 [kNm]
V ed	34,27 [kN]
Horizontal girder	
M ed	256 [kNm]
V ed	363 [kN]

Table 56 resulting loads rolling gate, case study

The unity check parametric model output is found in Table 57.

UC name	UC value strip height 0,3 m
Vertical girder	
Bending moment	0,16
Shear force	0,12
Horizontal girder	
Bending moment	1,00
Shear force	0,67

Table 57 resulting unity checks rolling gate, case study