INVESTIGATION OF A GENERIC DESIGN METHOD FOR THE PRELIMINARY DESIGN OF A DRY DOCK

TU-DELFT

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Preface

This report concludes my MSc. Civil Engineering at Delft University of Technology. The research is carried out in cooperation with Arcadis and describes an investigation in a generic design method for the preliminary design of a dry dock. This is done by developing a Decision Support System that supports a designer to choose between the different design options per object of a dry dock. To make it applicable to other hydraulic structures an investigation is made on the implement ability of a Building Information Model when designing a dry dock.

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I want to express my gratitude to Arcadis for providing me with the resources to work on my thesis. I appreciated the generosity and the willingness from my ‘colleagues’ at Arcadis for answering all kind of questions and enlightening coffee moments outside.

I would like to thank my thesis committee, Prof. Ir. T. Vellinga, Ir. V.J.W. Hombergen, Dr. Ir. G.A. van Nederveen and Ir. B. Wijdeven for their reviewing and comments on all the work throughout this thesis. The meetings were very pleasant and the discussions helped me to obtain the result I have achieved.

I want to thank my friends who supported me writing this thesis and reminded me that some distraction is needed to fulfill this thesis with success. Furthermore I want to thank the people who helped me by revising my thesis, Roald, Gavin and Marie-Louise. Last but certainly not least, I want to thank my family for their continuous support, in both my choices and finance, throughout all these years.

Jaap Treffers,

Den Haag, August 2015

Summary

For the development of the preliminary design of a dry dock, the present design methods are based on information gained from experience and manuals. Dry docks are not as frequently designed and built as other maritime structures and due to this many information is lost in time. To improve the process for the preliminary design of dry docks this thesis has investigated the implementation of existing and new design methods for the creation of the preliminary design of dry docks.

In the design process of dry docks, the first design stages: sketch design, conceptual design and preliminary design are of interest for a Decision Support System. In these phases the design is still on main elements. For these phases engineering firms use the design manuals on dry docks and experience from designers. In this research the new techniques System Engineering (SE), Decision Support System (DSS) and Building Information Modelling (BIM) are used. SE is used to create, in a systematic and structured way, a parametric design that can be used for the DSS. The DSS determines the first estimation of the design for a dry dock in a quick and objective manner.

To create the preliminary design of a dry dock following SE, the first step is the creation of the basic specification for a dry dock. The basic specification is based on firstly the Functional Flow Block Diagram, from this diagram all the functions of a dry dock are mapped. To fulfill these functions from the diagram, objects need to be build. These objects are described by the object decomposition. From this object decomposition it becomes clear that walls, floor and gates need to be designed for the preliminary design of a dry dock. Finally the requirements are described. The requirements consist of functional and technical requirements. The technical requirements are used to check which objects are possible for the specific project and to create a parametric design for these objects. The functional requirements are used to rank the possible types within a Trade-Off Matrix (TOM).

The DSS is created in Excel and with the guidance of the literature study on DSS and the design rules for the objects. The DSS gives guidance which options for the construction method, wall type, floor type and gate type are possible and preferred in the preliminary design of a dry dock. To investigate which types can be used in the project specific situation, technical requirements have to be checked. When the possible types are determined, they are weighted against the functional requirements by means of a TOM.

To investigate if this generic design method for the preliminary design of a dry dock is implementable a verification and validation is performed. The verification determines if the calculations made in the DSS are correct. This is done by checking the embedded anchored walls and concrete calculations with verified computer programs. For the embedded anchored walls the program D-Sheet piling is used and for the concrete calculations SCIA engineering is used. From the verification it becomes clear that for the embedded anchor wall type, the results in case of sand and mixed soil are accurate. When the wall is situated in a soil layer with cohesion the calculation gives inaccurate results. The solution of this problem is described in the verification and can be adjusted in the DSS. The verification of the concrete calculations shows that these are accurate for the wall and floor with shallow foundation without a vessel. For the cases of the shallow foundation with vessel and the floor with pile foundation and with or without vessel, the DSS results for the floor are not adequately reproduced. This is due to the assumptions made in the schematization of the foundation. These should be further developed to give a more accurate result.

The validation checks if the outcome of the DSS is realistic, by comparing the design of the DSS with the design of a case study from Arcadis. Despite the oversimplification the DSS gives a quick preliminary design for the main objects of a dry dock. This design is in line with the case study, however it is only validated with one case study. Therefore it is advised to include more case studies to further validate the DSS.

From this investigation it has become clear that the implementation of SE, DSS, and BIM helps to create a quick preliminary design of a dry dock. The current DSS gives some inaccurate results, as described above, but it supports a quick first design of a dry dock. With the recommendations given in this research, the inaccuracies can be filtered out. With the help of BIM a quick first 3D sketch design can be created, with little effort, for each design that is given by the DSS.

It is therefore advised to use these new techniques because they support a systematic and structured method to give an objective and quick preliminary design of a dry dock, without the need of extensive knowledge about dry dock designs.

List of abbreviations

AEC	Architecture, Engineering and Construction
BIM	Building Information Modelling
BS	British Standard
c	Cohesion
CRS	Customer Requirements Specification
DSS	Decision Support System
F	Flap gate
FFBD	Functional Flow Block Diagram
FFC	Free Floating Caisson gate
h	Height
HFC	Hinged Floating Caisson gate
HSE	Health Safety and Environment (iso1400)
KS	Knowledge System
LS	Language System
m	Meters
MBSE	Model-Based System Engineering
N	Newton
NAP	Normaal Amsterdams Peil
NASA	National Aeronautics and Space Administration
PhD	Doctor of Philosophic
PIANC	The World Association for Waterborne Transport Infrastructure
PPS	Problem-Processing System
PS	Presentation System
RAMS	Reliability Availability Maintainability Safety
SCIA	Scientific Applications
SE	System Engineering
SRC	Sliding or Rolling Caisson De-ballasting gate
t	depth
TOM	Trade-Off Matrix
ULS	Ultimate Limit State
USACE	United State Army Corps of Engineers

Contents

1 Introduction

1.1 PROBLEM CONTEXT

According to the British Standard (2013) a dry dock is defined as "a fixed structure usually of concrete construction with mobile dock gates at the seaward end with a floor below water level into which ships can be floated and subsequently be made dry. The gates are closed and the water removed from the dock to form the dry dock. The nomenclature for this type of dock varies, both geographically and historically. Dry docks have often been referred to as graving or basin docks."

These dry docks are used for two main reasons, the first one is to conduct maintenance and repair on the underwater part of a vessel. The second reason is for the building of new vessels. There is a growing amount of vessels all over the world (UNCTAD 2015). This growth is causing a growing demand for more dry docks. These are needed to build the vessels or to do maintenance and repair work on the vessels.

1.2 PROBLEM DESCRIPTION

When an engineering firm starts a project for the preliminary design of a hydraulic structures object, they have to start from scratch, to create a precise set of requirements. These requirements need to be agreed on with the client. The previous projects and design manuals are used as a guideline for the preliminary design of the new object. Dry docks are not as frequently designed and built as other maritime structures and for this reason the previous projects need to be used as a knowledge database. Engineers, who have worked on the previous projects, often do not work on the follow up projects. The past information is lost with regard to previous design procedures. Valuable knowledge about possible pitfalls is lost as a consequence. This is an ineffective process, causing higher production costs for the engineering firm that gives a lower chance on winning a proposal. By optimizing this process, costs for the preliminary design becomes lower, benefitting the client and the engineering firm. An additional problem is that most design manuals are outdated or not in corporation with the restrictions and design codes for a particular country.

Arcadis experiences the same challenges when designing civil structures and would like to investigate a different design method or approach, encapsulating previous experiences. In one of their previous projects, the preliminary design of a dry dock, they found that it could be possible to improve the design procedure by implementing new techniques. In this thesis the options are investigated, how most recent and proven techniques combined with System Engineering (SE), Decision Support System (DSS) and Building Information Modelling (BIM) can be integrated to simplify the preliminary design of a dry dock. This thesis studies the benefits of introducing these new techniques in comparison with the current design method for the preliminary design of a dry dock.

1.3 OBJECTIVES

The research objective of this master thesis is "to investigate the implementation of existing and new design methods for the creation for the preliminary design of dry docks". This objective is fulfilled by postulating the following research questions, that are based on the problem description given in the previous paragraph.

1. *What is the current design method of a dry dock?*
2. *What new design methods and tools can be used for the design of dry docks?*
3. *What are the basic specifications of a dry dock?*
4. *Is it possible to develop a generic and implementable design method for the preliminary design of a dry dock?*
5. *What are the possibilities to integrate a Building Information Model for the preliminary design of a dry dock?*

1.4 METHODOLOGY

The flowchart, given in Figure 1.1, describes an eight-step plan to answer the postulated research questions. These eight steps are further discussed in this paragraph and are the guiding principles for this master thesis.

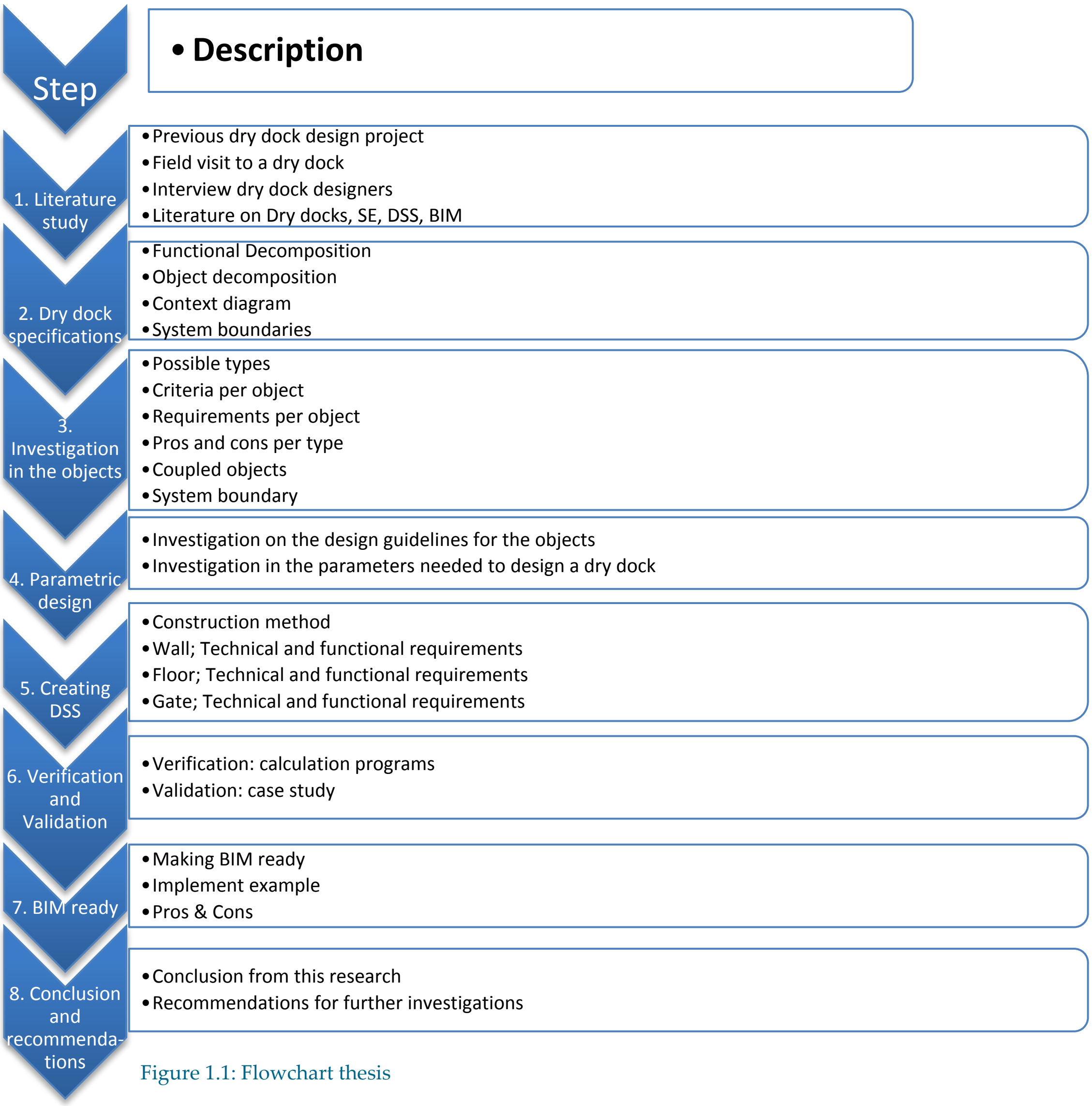


Figure 1.1: Flowchart thesis

Step 1 literature study

The first step of this master thesis is to answer the first two research questions from the previous paragraph. These two research questions are answered by a literature study done on dry docks, the current design method and researching the implementation of techniques SE, DSS and BIM. The objective of this step is to ensure that all latest design principles, experiences in the design of a dry dock and knowledge concerning design processes of dry docks are collected. This is necessary to focus this research on the missing links in the design of dry docks. This objective is met by this literature study.

The following literature will be reviewed:
- Background information of dry docks, including all available design manuals
- Literature about SE, DSS and BIM
- Previous dry dock design project
- Field visit to a dry dock
- Interview dry dock designers

This literature study describes what a dry dock consists of, the important objects of a dry dock and the docking process. The literature research on SE, DSS and BIM will review what the options are for using these systems and what the best methods for implementing these systems are for the preliminary design of a dry dock.

Step 2 dry dock specifications

The second step is answering the third research question, '*What are the basic specifications of a dry dock*', this is answered by formulating basic specifications. From the previous question it becomes clear that with the use of SE, a structured design method could be created to be applicable or not to dry docks. The basic specification is implemented in Chapter 3, DSS outline methodology. To create the basic specification the following points are described:
- Functional decomposition
- Object decomposition
- Context diagram

By conducting this research an overview is created on what functions a dry dock needs to provide, as well as a list or compilation of the objects, that need to be designed to fulfill on these functions. This is done with the help of the literature on dry docks, previous projects, field visit and interviews. From this basic specification a choice is made on the objects and functions that are of most importance, costs and technical feasibility, for the preliminary design.

Step 3 investigation in the objects

The third step is to further investigate these objects to determine which selection of types are available per object, what criteria there are for the selection of object types and what the pros and cons are per type. The interaction between the different objects are investigated as well, this describes what the options are between the different object types and how they influence each other.

For the objects that will be designed, the function description gives guidance for the functional requirements that these objects should meet. The requirements assist in selecting the best solution for the particular dry dock situation. After this is done a clear overview is created by means of a system boundary.

This part of the research presents a clear view on the main objects that need to be designed in the preliminary design stage and the functions and requirements that are acquired.

Step 4 parametric design

From the previous step, the object types that need to be designed are identified. The next step is to investigate the design guidelines for the different object types that will be designed. These guidelines give the information needed for the development of the DSS, because these can be implemented in a DSS to design the dry dock. From this investigation the parameters can be determined that need to be present for the design of the objects, so the overall design and composition of objects becomes clear to the designer and from this follows a list of the information needed when designing the dry dock, can be formulated.

Step 5 creating DSS

Within the fifth step the fourth research question, '*Is it possible to develop a generic and implementable design method for the preliminary design of a dry dock*', is answered by creating the DSS itself. In the steps 2, 3 and 4 the outline for the development of the DSS is created.

To create a DSS, the system needs to be chosen first. This can be a flowchart or a computer program, like Excel or Matlab. The choice is made with the input from the literature study on DSS.

During step 2 it becomes clear that from a civil engineering point of view the following objects have the most influence on the preliminary design of a dry dock:

- Gate
- Wall
- Floor

These objects are designed in the DSS. To determine the floor and walls that needs to be designed, the construction method must be determined to see which construction methods suits which type of objects and what the possibilities are to design for the particular location and competencies of the local contractors.

When it is known what type of construction method is possible, the wall type can be designed. This is done by checking the technical feasibility and finally which type of wall scores the best with regard to its functional value:

- Technical requirements; these give an overview on which types are possible to use and what the best solution is with respect to:
  - Construction method
  - Soil conditions
  - Maximum momentum (to see which type of embedded anchored wall is possible)
- Functional requirements; to give scores on project specific preferences are
  - Created from the functional requirements, described in step 2
  - Score on the basis of the relative importance which will be decided for each individual project (e.g. sustainability, safety)

If the wall type is determined the next step can be made: the design of the floor. This is done by checking the technical feasibility of the different types of floor and finally with a Trade-Off Matrix with regard to functional requirements:

- Technical requirements
  - Downward force due to vessel
  - Concrete calculations due to downward vessel force
  - Downward force needed
  - Downward force available
- Functional requirements; to give scores on project specific preferences

Gate types are chosen by the technical and functional requirements. For the first estimation the literature gives information about the types that can be used in which situation. So, it is unnecessary to make calculations about the different gate types, if they can for example withstand a certain width of the dock. The literature already gives information about the width range a gate type can withstand.

Step 6 verification and validation

The calculations made in the DSS will be verified. All the construction methods can be verified with hand calculations, because these are straightforward calculations. The calculations made for the wall, such as momentum, shear stress and type, can be verified with the proven calculation program of Deltares program D-Sheet Piling. Floor calculations can be verified with *Scientific Application* (SCIA) Engineering.

The validation is obtained by comparing the design with a case study.

Step 7 BIM ready

Step seven answers the fifth and last research question, '*What are the possibilities to integrate a Building Information Model for the preliminary design of a dry dock'.* The option to implement the parametric design into a BIM system is investigated. To test it, parts of the design are implemented in a BIM program, which in this case is Revit, to see how the design can be integrated in a BIM model.

Step 8 conclusion and recommendation

The final step of this master thesis is to conclude information gained from the previous seven steps. From the conclusion and the seven steps, recommendations are made for further investigations and usage of the DSS.

1.5 READERS GUIDE

In this research the possibilities of applying SE, DSS and BIM in the preliminary design is examined. The objectives and the framework of this study have been provided in this chapter.

Chapter 2 provides an overview of the relevant processes of a dry dock, SE, DSS, BIM and the current design process, this is step 1 of this thesis.

Chapter 3 describes steps 2, 3 and 4. For step 2 the DSS outline methodology is created. By giving the object-, functional decomposition and system requirements. Step 3 shows the different types per object and the requirements per object and type. Finally step 4 gives the parametric design rules of the dry dock.

Chapter 4 creates a DSS for the design determined in Chapter 3, this is step 5. Finally this chapter does a validation and verification step for the design of the dry dock, this is step 6.

Chapter 5 will investigate step 7. This step checks the possibilities for implementing the design in a BIM model. This is done by making the design BIM ready and doing tests by implementing small parts of the design into a BIM model.

Finally step 8 is discussed in Chapter 6. This will give the conclusions and recommendations for this master thesis.

2 Literature study

2.1 INTRODUCTION

This chapter describes the available literature on dry docks, System Engineering, Decision Support System, Building Information Modelling and the current design process. In the dry dock part, a description is given on dry docks, the types, alternatives and the available dry dock design manuals are described. SE, DSS and BIM are described on what steps these design processes consist of and what the advantages are on implementing these principles. For the BIM there are also options described on how this software program can be implemented for the design of dry docks and what the boundaries are.

2.2 DRY DOCK

2.2.1 DESCRIPTION

Dry docks are narrow basins where a ship can be locked. This basin can be closed and pumped dry, making it possible to have a dry area to work on a ship. Otherwise it is impossible or too expensive to reach the vessels hull below the waterline. There are two main functions for a dry dock, namely shipbuilding and ship maintenance & repair. A shipbuilding dock is used for building new vessels and a maintenance dock is used for (emergency) repair and (regular) maintenance work. For small underwater investigations of a ship it is often not profitable to use a dry dock. Divers will be used instead, to do the inspection for economic reasons.

A dry dock, an example is given in Figure 2.1, consists of the main elements or principle, described in the literature (British Standards 2013), namely:

- Gate
- Floor
- Walls
- Pumphouse
- Equipment and mechanical and electrical services
  - Pumps
  - Winches
  - Hauling-in system
  - Dock arms
  - Mechanical piped services
  - Electrical services, communication and control systems
  - Contaminated water treatment

Figure 2.1: Dry dock in preparation of a vessel (Royal HaskoningDHV 2012)

2.2.2 TYPES

2.2.2.1 *DRY DOCKS TYPES*

There are two main types for dry docks, the first type is for new vessel building and the second type for vessel maintenance & repair docks. The main difference is the total docking time. The docking time for vessel maintenance & repair docks is less than for vessel building docks. Because of the rapid exchanges between vessels in a maintenance & repair dry dock the opening and closing, dry pumping and filling, must be done fast. This is due to the fact that this is a relatively big period in the total docking cycle, as given in Figure 2.2, compared to the cycle of a building dock, where the work time is much longer. The costs of docking must therefore be minimised in the second type. The docking cycle is determined after an interview with Damen Shipyard dry dock operators.

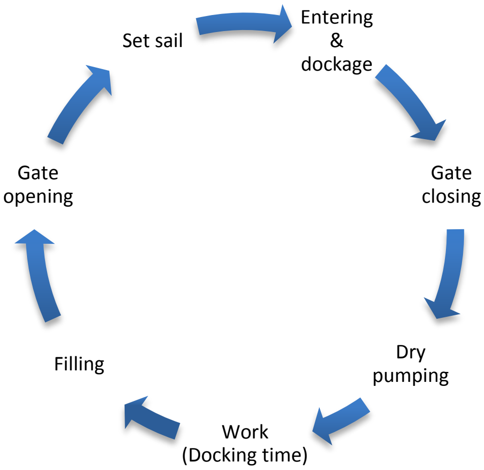


Figure 2.2: Dry Docking procedure

In a maintenance & repair dock the floor has a longitudinal slope between, the 1:100 – 1:300, for dewatering of the dock to the lower part, the gate side (Kuhn 1988). The water will be collected in a basin, at the side of the gate and under the floor, so the dock equipment and pumps will have enough head to of water to raise the water out of the dock. In a building dock type the floor is mostly without significant longitudinal slope, this is due to the ease of building a ship if the keel is horizontal.

The layout of a maintenance & repair dock should be aligned in the prevailing wind direction. For the building dock it is more important to have the most efficient layout, launches can usually be delayed to await suitable weather conditions (British Standards 2013).

Table 2.1: Differences between maintenance and building docks

Aspects	Maintenance & repair dock	Build dock
Time	Short	Long
Inner slope	1:100-1:300	0:0
Filling	1-2 hrs	1-2 hrs
Dewatering	1.5-4 hrs	4-12 hrs
Door movement	10 min	30 min
Layout	Prevailing wind	Efficiency

2.2.2.2 ALTERNATIVES

There are also alternatives for vessel building and maintenance & repair dry docks. These are not included in this thesis but for general interest and to give some context to the building and maintenance & repair dry dock a short description is given. These alternatives are:

- Shiplift
- Slipway (250m)
- Marine railway
- Floating Dry dock

Shiplift
The concept of a shiplift is similar to a dry dock. But instead of pumping an area dry, the bottom is lifted up, so the vessel is lift out of the water, as shown in Figure 2.3.

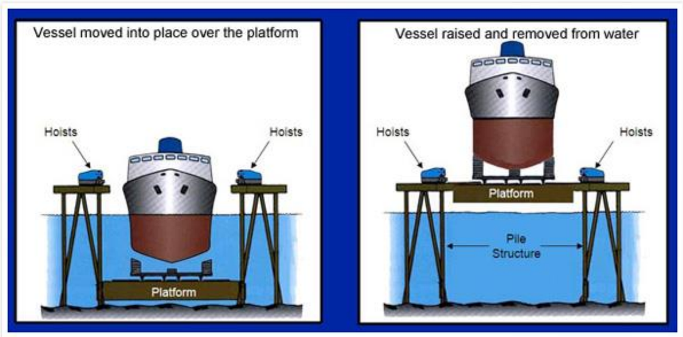


Figure 2.3: Shiplift *(www.penta-ocean.co.jp)*

The main advantage is the operation rapidity and that the shiplift can be used in combination with a transfer system that places the vessel onshore (British Standards 2013). This gives as advantage that the shiplift can be used for emergency ship repair jobs. Disadvantages are the high initial costs and the reliability of the hydraulics.

Slipway and shipbuilding berths

Slipway, as shown in Figure 2.4, and shipbuilding berths differ from each other by the hauling system in a slipway to retrieve vessels from the water to land. Shipbuilding berths can only launch a ship into the water and not retrieve it. A slipway can be built for vessel with a length of 150 m and a tonnage of 5.000 ton, a shipbuilding berth can be designed for a ship up to 250 m (British Standards 2013).

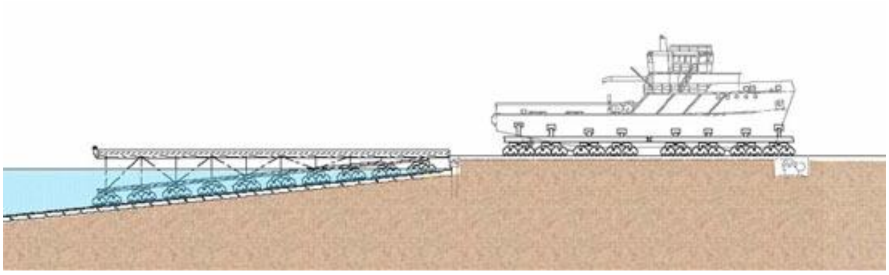


Figure 2.4: Slipway *(www.superyachttimes.com)*

The advantages of a slipway are the low initial costs and quick recovery & launch time. The disadvantages are the limited size of the vessel for recovery, otherwise the force required to recover a larger vessel will be too high. Also the space needed for a slipway is much bigger than for a dry dock.

Marine railway

Marine railway, as shown in Figure 2.5, is a combination of shiplift and a slipway. Instead of the vertical lifting as with a shiplift the pontoon is lifted diagonal over a rail. The advantage is that there is no need for a hydraulic system but a pull crane is sufficient. The disadvantage is that it is only feasible for smaller ships, otherwise the pull forces for recovery would be too high.

Figure 2.5: Marine railway *(mvislandhopper.blogspot.nl)*

Floating dry dock

Floating dry docks, as given in Figure 2.6, are U-shaped pontoons that are submergible. When the pontoon is submerged, a ship can be positioned inside. When the ship is positioned the buoyancy chambers of the pontoon will be pumped dry, so that the U-shaped part of the pontoon rises out of the water. There is no need for dock gates, because it is not the chamber that will be pumped dry but the buoyancy chambers. The main advantage of the floating dry dock is that it is possible to couple more U-shaped elements, so that it is possible to handle longer vessels with a floating dry dock (British Standards 2013).

Figure 2.6: Floating dry dock (*www.navsource.org)*

2.2.3 APPLICABLE DRY DOCK STANDARDS

There are multiple standards written on dry docks. In this paragraph the four most applicable standards are generally described. The list presented here consists out of standards, made in Europe and America, created for the design of dry docks and the use of dry docks.

2.2.3.1 *BRITISH STANDARD 6349-3 MARTIME WORKS – PART 3 CODE OF PRACTICE FOR THE DESIGN OF SHIPYARDS AND SEA LOCKS (2013)*

British standard republished in 2013 their report of 1988. This is the most up-to-date design manual for dry docks. It does not only consist of the design of graving dry docks but also the design of shipyard layout, shipyard quays, piers and dolphins, slipways and shipbuilding berths, shiplift facilities, floating docks, sea locks and hydrolifts. This manual has also an extensive chapter on different gate types that can be used for docks and locks. There are additional chapters about piped services and electrical distribution systems and about control systems in the British Standard report.

From this report the following points are of interest in this thesis:

- Operational parameters of dry docks
- Elements of dry docks
- Equipment of dry docks

These points are of interest because the operational parameters give information on how to use a dry dock. This helps to develop a dry dock that fulfills to these parameters. The elements and equipment describe what a dry dock consists of. This helps to make the objects decomposition in Chapter 3. The report gives a good overview on the dry dock design standards. It contains good illustrations on the different object types, these are used in this thesis. This report gives basic information for the technical and functional requirements of a dry dock.

2.2.3.2 *DEPARTMENT OF DEFENCE (USA) DESIGN: GRAVING DRYDOCKS (2012)*

This report is written by the United States Department of Defence in 2002 and updated in 2012. It provides the planning, design, construction, sustainment, restoration and modernization criteria for graving dry docks. The main focus is on the design of dry docks for military vessels like carriers, submarines and destroyers. From this report the following point are of interest in this thesis:

- Determination of graving dock dimensions
- Structural types of dry docks
- Structural design

This report helps this thesis to indicate how the dimensions of dry docks are chosen, what structural types there are and how they are designed. A note has to be placed that the focus of this report is on military vessels, that have different specifications and therefore different constructions are needed than for commercial vessels.

2.2.3.3 *DOCKMASTER TRAINING MANUAL (2005)*

This manual is created for dockmasters; these are the people controlling the dock. In addition it gives a good overview on the different aspects of dry docks, how the dock is used and an important chapter about how dry dock inspection works. From this report the following points are of interest in this thesis:

- Dry dock types
- Block loading
- Stability

This report is specialized on how the dry dock is used. It helps this thesis for the calculation of the block loads, this is how the weight of the vessel works on the floor. The report indicates different types of dry docks and the advantages and disadvantages from the users point of view.

2.2.3.4 *PIANC DRY DOCKS (1988)*

This report is created by PIANC in 1988 and is already 26 years old. The design methods of this report are outdated but still give a good overview on the planning and design of graving dry docks. This report consists also out of a list of dry docks built in the period 1942-1988. This list gives general statistical information about different types of dry docks. From this report the following point are of interest in this thesis:

- Definitions of dimensions and size of docks in order to achieve standardisation of information
- Planning of dry docks, including their size, location and arrangement of facilities, services and equipment
- Overall structural design of a dry dock
- Notes on the design of various types of dry dock floors that may be adopted
- Notes on the design of various types of dry dock walls that may be adopted
- Notes on the design of various types of dry dock gates that may be adopted

Although it is an old report, it gives a good overview on how a dry dock is designed, what different options there are for the different types of floor, walls and gates. The report contains a list with built dry docks that can be used to check for the most common designs. This report gives a basis for the technical and functional requirements of a dry dock.

2.2.4 SUMMARY ON DRY DOCKS LITERATURE

It can be concluded that the main difference in the graving dry docks is the speed of operation. In the maintenance and repair type of dry dock the speed of operation of the dock itself is of importance. Therefore these docks have a slope, to drain the water faster, gates that operate faster, the volume of water is minimised and is positioned in the prevailing wind direction, to fasten the entering and positioning process. Building dry docks are built to have the layout as efficient as possible. The speed of operation is of less importance because it is a smaller percentage of the total docking cycle and the space is maximised.

The dry dock is not the only solution for doing dry works on a vessels hull. To find out what the alternative is, a quick first estimation must be made on the feasibility of each alternative. In this thesis a tool is developed that gives the preliminary design of a graving type dry dock. When such tools are also created for the other alternatives it will help to give a quick decision on which alternative must be further investigated.

2.3 DESIGN PROCESS

The design process of almost all hydraulic structure objects follows the same procedures. These procedures are the steps that have to be taken to create a hydraulic object. It starts with the idea of building a hydraulic object. This idea is than concretized into a business case. This is the starting point of the procedure given in the next seven phases (Hombergen 2015):

1. Business case
    a. First sketch design
    b. Feasibility check (cost benefit analysis)
2. Scope definition
    a. How and what of the project
    b. Available budget
    c. Design specifications
3. Research and Design
    a. Field
    b. Model
    c. Design
        i. Conceptual design (40% cost accuracy)
        ii. Preliminary design (25% cost accuracy)
        iii. Final design (10% cost accuracy)
4. Contracting
    a. Approach
    b. Tender documents
    c. Procurements
5. Construction management
6. Completion work
    a. Lessons learned
    b. Handoffs
    c. Close project
7. Maintenance

Phases 1 and 2 check the feasibility of the project before an investment is made. Phase 3 is the research and design phase. This phase investigation is done to gain information for the design. The design part consists of three steps that give a more accurate view on the end result and the total cost of the design. The preliminary design gives a cost accuracy of about 40%, conceptual 25% and final design 10%. In the contract phase, phase 4, the design is made ready for contractors to make offers, and when these offers are made they are procured. Phase 5 is the construction phase: the design is build. Phases 6 and 7 are the closing phases of the project and aftercare.

This thesis will focus on the preliminary design of the dry dock. From the first sketch design a feasibility check is done by comparing the benefits and costs. On the preliminary design report the client makes a tender decision.

2.4 SYSTEM ENGINEERING

2.4.1 DEFINITION

According to NASA System Engineering (SE) (United, National et al. 2007) (Rijkswaterstaat 2013) is defined as "a robust approach to the design, creation, and operation of systems. In simple terms, the approach consists of identification and quantification of system goals, creation of alternative system design concepts, performance of design trades, selection and implementation of the best design, verification that the design is properly built and integrated, and post-implementation assessment of how well the system meets (or met) the goals. The approach is usually applied repeatedly and recursively, with several increases in the resolution of the system baselines (which contain requirements, design details, verification procedures and standards, cost and performance estimates, and so on)."

2.4.2 DESCRIPTION

SE is based on systematic thinking. The system consists of a collection of elements that have a mutual relationship. Each system is a part of a bigger picture. This particular systematic thinking, the organization takes the complete system, lifecycle and all the involved parties into account (Rijkswaterstaat 2013).

Projects that use SE, will analyse the problems and opportunities that are related to the clients question. Specifying these, the client needs and requirements will be translated in the project requirements. These requirements will be written down in a Customer Requirements Specification (CRS).

SE works from the abstract to concrete. The project starts with an abstract client question; this question will be iteratively specified and decomposed to the final concrete solution. From the chosen solutions within the scope, the decomposition follows. This decomposition will give a clear view on the different objects and connects the information with each other in simple overview. An example of this methodology used by SE will be given further up in this chapter of this study.

The working method SE uses, from abstract to concrete, are often showed in a V-model, given in Figure 2.7. In the top left, the V begins with abstract solutions. When following the V down a concrete solution will be specified. From the point where the line goes up, the solution will be realized, untill the system will comply with the clients' demands.

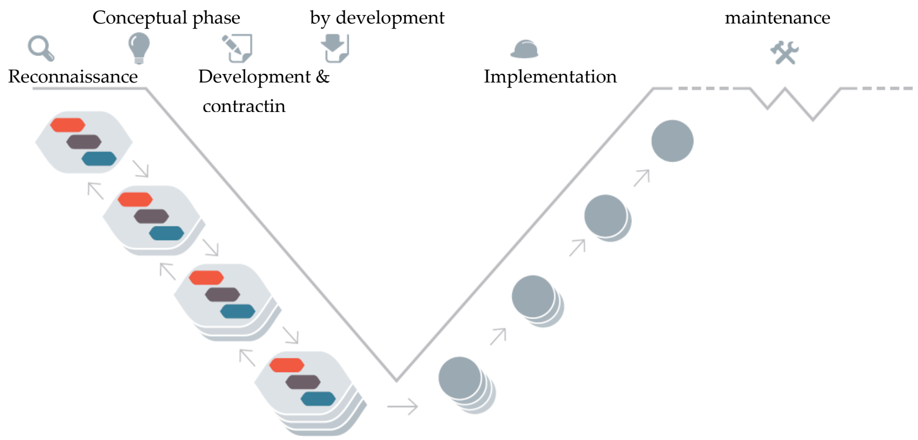


Figure 2.7: SE V-model (Rijkswaterstaat, 2013)

To fulfill the client needs, the system has to comply with a couple of functions. From these functions and with the applicable conditions the system requirements follow. Within the scope there are more solutions possible that meet the requirements. The procedure within SE works with the iteration between the functions, requirements and solutions, to get the most favourable solution. This iterative process is shown in Figure 2.8.

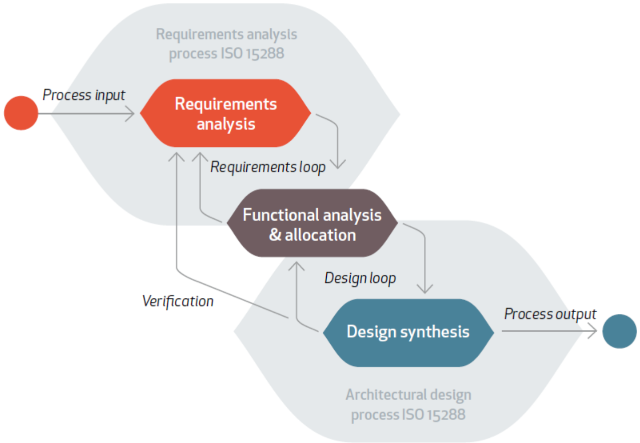


Figure 2.8: Iterative procedure in SE (Rijkswaterstaat, 2013)

This process describes the verification and validation process, that is done throughout the project. The verification determines in an objective and explicit way, if the solution fulfills the requirements. The validation determines, if the solution is suitable for the intended results. The purpose of the verification and validation method is to obtain enough objective evidence that the developed system works (Rijkswaterstaat 2013).

Different types of methodologies are available for developing the system. That can be used in several phases throughout the project. Different types of methodology are available for developing the system that can be used (Rijkswaterstaat 2013):

- Functional Analysis System Technique (FAST)
  Determines the basic functions and finds the critical path for these functions, supporting functions and other functions. It uses the How and Why questions to determine the structure of the functions and confirm the hierarchy of the functions.
- Functional Flow Block Diagram (FFBD)
  This method is used to find the critical path between the different functions. It combines a verb and an noun to find the functions. Lines connect the different functions and creates a path through a system, using ‘If … Then’, ‘and’ and ‘or’ relationships.
- Model-based System Engineering (MBSE)
  It uses formal languages to create a model of the system. It helps to formulate the characteristics of the system in a precise manner. It can offer options for semi-automatic performance of verification and validation.

- Object decomposition
  It uses the functions, determined in one of the previous methods, to determine which objects are needed to fulfill on the functions that are described. The object decomposition starts with the main object, this main object is then decomposed into smaller objects. These smaller objects together describe the object on a layer above.
- Hamburgermodel
  Couples the Functional Unit (FU) to a Technical Solution (TS). An FU collects all the information required to make a choice for a TS. A TS has characteristics that needs to be verified using information of the FU.
- Interface analysis
  The interaction of different systems happen at the interface. To control these interfaces a context diagram can be used to control the different interactions. When these are identified, the requirements can be described and tested at critical moments. The different interfaces can than be made clear by a context diagram.
- Morphological analysis
  This analysis breaks a product into two different parts, the needs which it satisfies and the technological component out of it compose. This method is ideal to create new ideas and solutions. It uses the morphological map, in this case a matrix, to subdivide the problems and solutions that are created for these problems. On the top stands the function where a solution for has to be determined and below stands different solutions.
- Trade-Off Matrix
  This method uses a table to weigh each option in order to make a rational choice between various alternatives. The criteria are the system requirements, these and the weighing factors are determined in advance.

2.4.3 SUMMARY ON SE LITERATURE

This chapter shows that System Engineering gives a systematic way for the successful realisation of large projects. This method will give a structure in the development of a generic design method for the preliminary design of a dry dock. Paragraph 2.4.2 gives different methodologies on how SE can be used in practice. From this list the following methodologies will be used:

1. Functional Flow Block Diagram
   The choice of an FFBD instead of FAST is made because the FFBD makes the time sequence and interconnection of functions within a system more clear.
2. Object decomposition
   The function of this step is to work from abstract to concrete. The abstract, in this case the dry dock, will be decomposed to find all the elements needed for the development of a dry dock. After this step the main objects needed for the preliminary design are determined.
3. Hamburgermodel
   This model gives the different alternatives per object. In this thesis an analysis is done on what types there are available per object that is designed.
4. Interface analysis
   This will help to see how the dry dock interacts with the surrounding. Creating this overview will help to make the requirements clearer for the sub areas to the main dry dock.
5. Requirements analysis
   This is created, based on the functions determined in the FFBD. The interface analysis shows how the dry dock will interacts with the surrounding. Which indicates what requirements it has to fulfill.

6. Trade-Off Matrix
   This is used to make the option for the best solution. The design is focused on the preliminary design of a dry dock, therefore the Trade-Off Matrix only consists of the main elements determined in the object decomposition. These are weighted against the requirements determined in the previous analysis. To make the Trade-Off Matrix a decision support system is created to make an objective choice, this is described in the next paragraph

Only the MBSE and morphological analysis are not described above because they are of no use for this thesis. The MBSE is used to create a model that describes how all objects interact which each other and how the whole system is coupled. In this thesis only a small part of a dry dock is designed and therefore it is not possible to create such a model, due to the fact that too much information is missing. Morphological analysis is not used because it is designed for the development of new and unknown products. The design of dry dock is based on already known techniques.

2.5 DECISION SUPPORT SYSTEM

2.5.1 DEFINITION

A Decision Support System (DSS) is a computerized flow chart that supports making decisions within the design phase of a project for complex systems. DSS consists of three elements: database, model and user interface. During the design of a civil structure there are some main elements that can be designed and build in different forms and different methods. For example a soil retaining wall can be made out of bricks, concrete, sheet piles, wood, etc. The DSS will support making a choice between these different designs.

A more general definition of a DSS is described by a characteristic approach (Sprague 1980). Four characteristics describe the needed capabilities to achieve the final goal of the DSS, Sprague has defined them as follow (Sprague 1980):

- They tend to be aimed at the less well structured, underspecified problems that upper level managers typically face.
- They attempt to combine the use of models or analytic techniques with traditional data access and retrieval functions.
- They specifically focus on features which make them easy to use by non-computer people in an interactive mode.
- They emphasize flexibility and adaptability to accommodate changes in the environment and the decision making approach of the user.

2.5.2 DESCRIPTION OF DSS

In a DSS the designer has to put in the parameters for the design, such as for example vessel type, soil conditions, etc. The DSS will then give options that are feasible for the design and which the advantages and disadvantages of each option are. The DSS will give these solutions based on pre-stored design guidelines. For example if the soil is very wet the DSS will advise the designer not to use wood, because the lifespan of wood in a moist environment is short.

After implementing design rules and integrating a calculation system, the DSS can give a first estimation of each element. In the case of the soil retaining wall, a DSS can give options on what types are possible, the thickness of the wall, how it can be anchored, what the foundation should be and this for different materials. For the case of the preliminary design of a dry dock, it will support the designer to make a quick first design draft, without the need for a designer to have extensive knowledge on dry docks, because this knowledge is already processed in the DSS.

In essence all DSS composes out of the same 4 components, these components determines the capabilities and behaviour (Burstein and Holsapple 2008):

- Language System (LS)
- Presentation System (PS)
- Knowledge System (KS)
- Problem-Processing System (PPS)

The LS exists out of the manner how the DSS can conceive information from the user, the PS component is how the DSS communicates with the user. KS is the 'knowledge' of the DSS, this is all the information stored and retained by the DSS. The PPS is the component that is the working part of a DSS. It tries to recognize the information that the user puts in the DSS, through the LS component. After receiving this information the PPS selects the needed parts of the KS to acquire the knowledge to solve the question that is received from the LS. The PPS can adapt the knowledge held in the KS by assimilating the generated or acquired knowledge. Finally the PPS sends its findings back to the user by means of the PS. This interaction scheme is expressed in Figure 2.9.

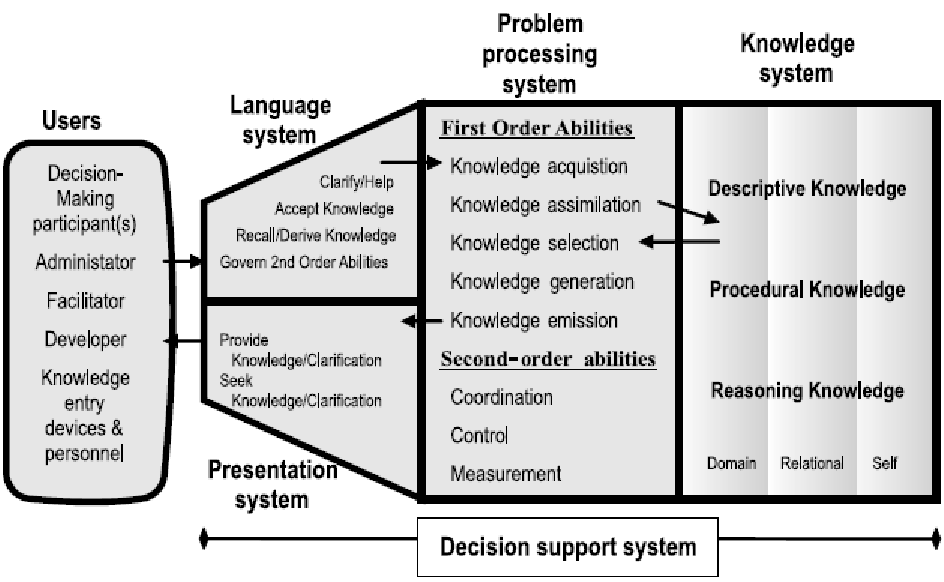


Figure 2.9: Generic components DSS interaction (Handbook DSS, F. Burstein, 2008)

In the case when a dry dock is designed, the user of the DSS will be the 'developer' of the dry dock. The 'developer' uses the LS to 'recall/derive knowledge', in this case information about the soil and vessel type, to the DSS. The PPS will then use the 'knowledge acquisition' to find the right 'procedural' from the KS system. In this case, which objects are possible and what dimensions are needed. This information is fed back to the user with the PS component 'provide knowledge/clarification'.

2.5.3 DSS TYPES

As described in the previous paragraph, all the DSS essentially consists of the same components, but there are different types of DSSs. The eight most common specialized frameworks are given below (Burstein and Holsapple 2008):

1. Text-Oriented Decision Support System
   Uses text input as LS, the PPS finds potentially interesting passages from the KS, which is made up of electronic documents, and sends these passages to the user as pictures from these documents. Such a DSS allows documents to be managed. The problem with this is, that there is no explicit relation between the knowledge from one text file to another.
2. Hypertext-Oriented Decision Support System
   The problem text-oriented DSS encounters are resolved by the use of hypertext oriented Decision Support Systems. This means that the texts from different files, that are related, are linked with each other. This supports the user to make the connections between the different information.
3. Database-Oriented Decision support System
   In comparison to the text DSS, the database uses a highly structured organization of information by means of tables and records.
4. Spread sheet-Oriented Decision Support System
   A user can create, view and modify procedural knowledge assimilated in the KS and also instructs the PPS to execute the obtained instructions. This type is often used for what-if analyses in order to see what assumptions in particular cells do to the final result. Macros can ease the task for the user when imputing commands.
5. Solver-Oriented Decision Support System
   Consists mostly of more than one solver. For each problem there is a different solver that consists of instructions that the user can select and the computer will run to find the solution. This is a well-defined problem type (e.g. linear programming). The LS consists not only out of problem statements, but also out of requests that let a user edit the KS.
6. Rule-Oriented Decision Support System
   This involves representing and processing rules; these rules offer a straightforward and convenient mean for representing fragments of knowledge. A rule consists of the basic form ‘If, Then, Because’. Rules can be used in the LS to retain advice or requests for explanation from the DSS. This is also known as an expert system, because it excludes the need of human experts for the decision-making and clarification of the result.
7. Compound Decision Support System
   This is a DSS that combines several DSS types, by means of a single DSS that incorporates different types or it uses multiple DSSs that consist of one type.
8. Multi-participant Decision Support System
   This is when multi participants contribute with making a decision. When a DSS supports these kinds of decision-making it can be called a multi-participant DSS (MDSS).

In the case of designing a dry dock the decisions are not based on text. Due to the amount of different possibilities, for example different soil layers, it is not possible to select these with only text. A calculation is needed to verify the solution. For the same reason a database will not fulfill the needs because the large amount of different options. A spread sheet is a suitable tool to include calculations in order to verify the design. Calculations can be inputted in the spread sheet, where with the support of a solver and rules a decision will be made. The advantage of using a spread sheet in this situation is that the user can easily modify the procedural and macro’s will support to simplify the usage of the system. The DSS incorporates multiple types of systems, namely 'spread sheet ', 'solver oriented' and 'rule oriented', causing the DSS type used for the preliminary design will be a 'compound Decision Support System'.

2.5.4 DSS IN PRACTICE

Decision Support Systems are broadly accepted as systems in multiple fields of engineering. For container terminals a DSS is created and verified for the design of container terminal yards (Mohseni, Vellinga et al. 2011). In the daily operations of these kind of terminals a DSS can also be used. In Hong Kong they use a DSS since 2005 (Murty, Liu et al. 2005). It is expected that this will support the Hong Kong terminal to be one of the most competitive in the global transportation logistics industry.

In building projects DSS is also used for construction procurement, an investigation of the effects of using a DSS have been done in Hong Kong (Kumaraswamy and Dissanayaka 2001). The report supports the positive conclusions on the viability and value of a client advisory system. The DSS can be implemented for the support with the construction, planning, control, information flows, quality, safety and dispute resolution.

2.5.5 ADVANTAGE OF USING DSS

The advantages of implementing a DSS have been noticed in the conceptual design and development stages for any complex evaluations and decision-making tasks in the field of concurrent engineering (Xu, Li et al. 2007). The six main advantages are:

- Gives a quick first estimation on what the design will look like.
- Helps taking all the design objectives into account.
- In the design stage it is hard to quantify and weigh design objectives precisely due to the available information
- Helps to exclude subjective preferences from the designer
- Evaluate alternative using weighted means and by doing this ranking the alternatives
- What-if-analysis shows what effects certain decisions have on the whole system

It is expected that these advantages also apply to development of dry docks and the object of this master thesis.

2.5.6 SUMMARY ON DSS LITERATURE

When designing a dry dock, DSS is a good tool to make the preliminary design. In Paragraph 2.5.5 an overview of advantages are given. The type most suitable for this situation is the compound DSS. The DSS will combine in this case the 'spread sheet ', 'solver oriented' and 'rule oriented' types. Excel is chosen as a system for the spread sheet as it is the most used spread sheet program, making it easier to use and adjust by various people.

2.6 BUILDING INFORMATION MODELING

2.6.1 INTRODUCTION

BIM stands for Building Information Modelling. BIM makes it possible to create a virtual model of a construction in the Architecture, Engineering and Construction (AEC) industries. This model contains precise geometry and all relevant data needed to support the construction, fabrication and procurements activities needed to realize the building (Eastman 2008).

In 1992 G.A. van Nederveen and F.P. Tolman mentioned Building Information Modelling in their paper (Nederveen 1992). In this paper the problems are described with different views on an object by several parties, like the designer, the structural engineer and the energy engineer. These different views can cause that the designs from the different parties are not in coherent with each other. Often these conflicts are only determined when the construction is already in the construction phase, because these conflicts are determined in such a late phase it is very expensive to redesign the building to make up for these faults. To prevent the occurrence of these mistakes Van Nederveen and Tolman want to integrate these designs in one model, so that all the building information can be stored in a simple and clear way.

BIM has the capacity to minimise errors as a result of incorrect or miscommunicated information through the early identification of any potential clashes. As the design information is more readily accessible, there is a greater degree of quality control over the contract, as the modelling allows the project team to visualise the impact of any amendments to the design. This in turn allows for closer monitoring and control of costs.

2.6.2 PROS AND CONS

In this paragraph an overview of the advantages and disadvantages for using BIM are given.

2.6.2.1 *PROS*

- 3D view
- Identification of clashes between objects in earlier stages
- Faster drawings
- Adjusts costs as changes occur
- Reduces ultimate costs (by compressing time for construction, generating specific costs for changes, and handling changes up front)
- Single entry for all parties
- Easy changes
- Coordinated drawings (no need to change all drawings, only the 3D model)
- Life cycle evaluations
- Material take offs (with a press of the button it is possible to see how much material will be used)

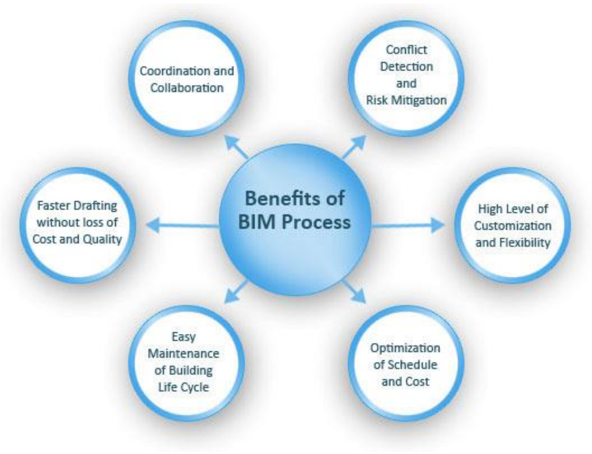


Figure 2.10: Benefits of BIM process (blog.synchroltd.com)

2.6.2.2 CONS

- Initial costs of software, training, scoping and implementing
- All the team members do not always have access to the right software and/or resources to utilise
- File size
- Who is responsible when the software fails
- Information ownership

2.6.3 OPTIONS

There are a few options that BIM can be used for this thesis on the design of dry docks, these are:

1. Full BIM system for the preliminary design of a dry dock with integrated parametric design, DSS system and calculation program
2. Multiple BIM models for different dry dock types with or without parametric features
3. Multiple BIM models for each element with or without parametric features
4. Making the design BIM ready and show how it can be implemented with some examples

The first option will give a complete system for designing a dry dock. This system will be a technologically complex model, to fit and couple all the elements in one system. The second option is easier to create. The idea behind this option is that there are already multiple BIM models for different dry docks. After a separate DSS a choice is made between the different dry docks. When this choice is made, the designer can easily pick the right model and adapt this to his particular situation. The third option is, that for each element of a dry dock there is a BIM model. When finishing a DSS, the designer gets a list of different elements needed for completion of the dry dock. These detached BIM models will then be put together to get one model of a dry dock. The advantage is that the loose elements, like a gate, can also be used for other purposes, like a sluice. The last option is to make the parametric design, with DSS, BIM ready. This will be done by investigating the options on how they can be implemented and how they should work. The only step that won't be taken is making the software.

2.6.4 BOUNDARIES

The BIM model, which is going to be built for this master thesis, will be a model for the preliminary design. It will contain the main elements and dimensions, but it will not go into detail about nuts and bolts, different types of pump, electrical systems, etc. With the main elements the gates, the floor and the walls are meant. For these elements different materials and constructions will be investigated.

The integration of a DSS into a BIM will be investigated, but it is not an obligation that the BIM should have these features. The program that is going to be used, is Revit. This is the standard program that Arcadis uses for the design of their projects. Revit is a BIM software for architects, structural engineers, contractors and designers. With this program 3D designs can be made and coupled to different disciplines in the building design sphere.

2.6.5 SUMMARY ON BIM LITERATURE

For the preliminary design of a dry dock BIM can be a great asset. When the design, made with the DSS, can be coupled with BIM, it can give a good first 3D view on what the design will actually look like. From the design a quick material take off can be created, giving a first estimation of the costs. In the next phase of the design, when for example the drainage systems with pumps are designed, it is easier to add these different designs to the whole project. It will help to show where clashes between the different designs lay. The initial costs of software, training and implementing is not an issue for this thesis because BIM is already used by Arcadis. Point of attention is the information ownership, because the files have to be protected so they will not be used by other companies.

In this thesis the objective is to make the parametric design BIM ready. This will be done by investigating the options on how it can be implemented and how it should work. The next step would be to create the software, which will be developed later or other software that will be modified.

2.7 CONCLUSION

This chapter describes what a dry dock is, how it works and what the alternatives are. There are two main types of dry docks: Repair & Maintenance dry docks and Building dry docks. The difference between these two types is the speed of operation: ship positioning, gate operations, pumping and filling of the dock. The time a vessel is in a building dock is much longer than in a Repair & Maintenance dock, therefore the operational speed can be less.

It is concluded that this thesis will focus on the feasibility stage of a project as in this stage little information is available and many different solutions are still open. A tool that supports decision making and allows for a quick selection of a preferred solution has the most impact in this stage.

System Engineering will form the basis for this thesis, it gives a systematic way for the successful realisation of large projects. It supports the creation of the DSS for the preliminary design of a dry dock in a structured manner by creating the following components:

- Object decomposition
- Functional Flow Block Diagram
- Hamburger model
- Interface analysis
- Requirements analysis
- Trade-Off Matrix

The DSS system will help to give an objective first estimation on what the design will look like and by means of a what-if-analysis it shows what effects certain decisions have on the whole system. The DSS will combine in this case the 'spread sheet ', 'solver oriented' and 'rule oriented' types. It uses a Trade-Off Matrix to determine the best solution, based on the technical and functional requirements, this is further elaborated in Paragraph 4.2 and Appendix 7.

The outcome of the DSS will be used to investigate how this can be used for the Building Information Modelling, described in Paragraph 2.6. For the preliminary design of a dry dock BIM can be a great asset to a project. When the design made with the DSS can be coupled with BIM, it can give a good first 3D view on how the design will actually look like. This is a benefit to the client, who is required to present plans for approval for funding.

3 DSS outline methodology

3.1 INTRODUCTION

In this chapter the outline of the DSS is created with the guidance of the literature on System Engineering, described in Paragraph 2.4, and Decision Support Systems, described in Paragraph 2.5. The flowchart given in Figure 3.1 shows the steps that are made for the creation of the DSS. These are divided in the paragraphs where they are described. 3.2 design preparations, 3.3 object types and 3.4 parametric design are discussed in this chapter and 4. DSS is discussed in the next chapter.

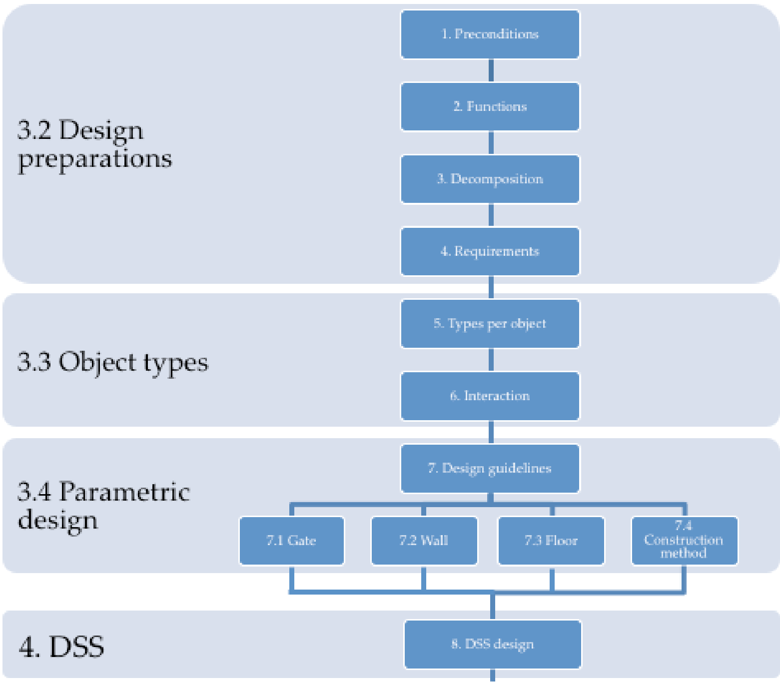


Figure 3.1: Flowchart DSS design

To get a view on which objects need to be designed for a dry dock, Paragraph 3.2 gives a top-down break down of the dry dock. With the support of SE a structured manner is created. Firstly the functions a dry dock needs are mapped, by using a Functional Flow Block Diagram (FFBD). When the functions are described, the objects that are needed to fulfill these functions are mapped, by means of an object decomposition. From these two paragraphs the functions and objects needed for the preliminary design will become clear. To make a decision between the different object types, that are discussed in Paragraph 3.3, the different types will be compared. This is done by checking how different types score on the requirements. These requirements consist of two types, functional requirements that are based on the functions and technical requirements that are based on the objects.

In conclusion, Paragraph 3.2 discusses the following points:

1. Functional Flow Block Diagram
2. Object decomposition
3. Requirements

From Paragraph 3.2 it becomes clear which objects need to be designed. The DSS will support the decision making for the different objects, therefore first an investigation is needed to find which types are possible per object, this is done in Paragraph 3.3. To see how the interaction between the different types for the different objects works, an investigation is done on the coupled objects.

The parametric design is created in Paragraph 3.4. This paragraph uses the information gained from Paragraph 3.2 and 3.3, namely what types there are for the objects that will be designed and the requirements for these objects. From this information the design guidelines per object are investigated. These guidelines can than be added in the DSS, this is described in Chapter 4.

After finishing this chapter the reader will have a clear overview on how the DSS should be built, what objects will be designed in the DSS and based on which information the decisions are made.

3.2 DESIGN PREPARATIONS

3.2.1 FUNCTIONAL FLOW BLOCK DIAGRAM

To understand all the functions that coincide with a dry dock a top-down functional decomposition is created for the dry dock. This is done by using the FFBD, as described in Paragraph 2.4.2. When all the functions are organised in an accessible manner, it will help to make a list of all the requirements that are needed for each object. When a design is made, verification can be done to see if the design fulfills all the requirements. To investigate the functions a field visit to a dry dock is made and the literature available is consulted, including previous projects.

The main function is given at the top of the decomposition and is *'to conduct maintenance, repair and building activities on the underwater part of a vessel in a safe manner'*. To realize this main function the system has to compile to three functions that are on the secondary layer of the function decomposition, as given in Figure 3.2. The total decomposition is given in Appendix 1.

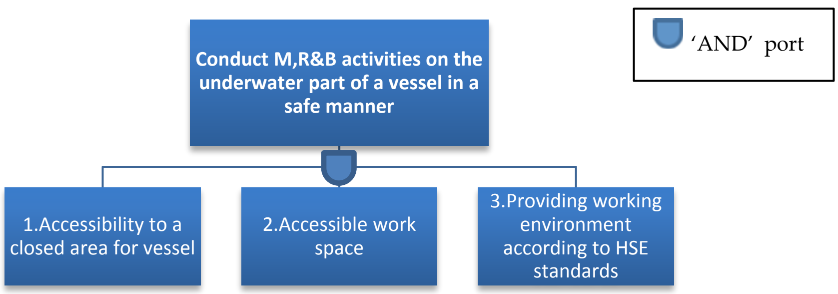


Figure 3.2: Flowchart FFBD

From the functional decomposition the functional requirements per function can be created. These requirements support the decision making between the different types per object, this will be further discussed in Paragraph 3.2.3.

3.2.2 OBJECT DECOMPOSITION

The object decomposition is a top-down breakdown of the dry dock. Meaning that on the top level the total dry dock system is situated. Each level lower describes which objects, the object on the level above consists. By doing this, an overview is created of the elements a dry dock consists of. The object decomposition provides understanding of the elements of a dry dock that requires designing work.

The object decomposition is created with the support of the following literature on dry docks:

- British Standard on dry docks (British Standards 2013)
- Department of Defence design report on graving dry docks (Defense 2012)
- Docking manual (Heger 2005)
- PIANC report on dry docks (Kuhn 1988)

The verification and validation of the object decomposition is done with a review from dry dock designers from Arcadis. The resulting object decomposition is given in Appendix 2.

3.2.2.1 *PRELIMINARY DESIGN OBJECTS*

For the preliminary design of the dry dock it is not necessary to design all the objects determined in Appendix 2. When all the objects are designed, it results into an expensive activity to check the feasibility of a dry dock. To make a first estimation on the feasibility of a dry dock, a choice is made to create a preliminary design on only the main objects of a dry dock. Based on literature study and discussion with Arcadis experts, the following objects are defined as main object:

- Gate
  Moving vertical part that closes the dock
- Walls
  The non-moving vertical parts that closes the dock
- Floor
  The horizontal part that closes the dock
- Pump house
  The house where the pumps are situated
- Terrain
  All the area surrounding the dock that is used for the dry dock, such as storage areas

From a civil engineering point of view the gates, walls and floor are the most important objects. The design of the pump house is to a large extent not influenced by the specific surrounding. Therefore this is less important in the preliminary design of a dry dock and not included in this thesis. The terrain depends on the size available and the size required, therefore not influenced by the specific surroundings. The pump house and terrain are for that reason not included in the DSS.

The first two of sub functions, given in the previous paragraph are:

- Accessibility to a closed area for vessel
- Accessible work space

These sub functions will be accomplished by the three main objects: gate, walls and floor. This gives the closed area for the vessel and the accessibility to this location.

Figure 3.3 describes a summarization of the object decomposition. This figure consists of four different types of blocks. The blue blocks are the objects that are designed by the DSS, the green blocks are the objects that influence the design of the blue objects. The orange blocks are also taken into account for the design of the blue objects, but simplified into one top load for the design of the wall. The red blocks are the objects that are not in the scope of this research.

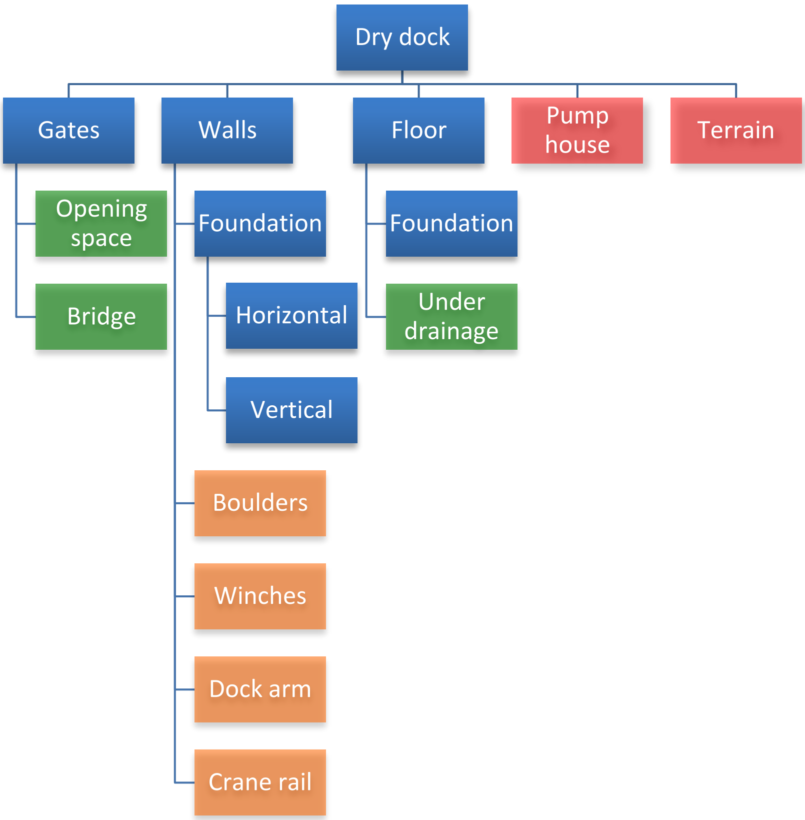


Figure 3.3: DSS objects

3.2.3 DESIGN REQUIREMENTS

This paragraph describes the requirements that each function of the dry dock has. The requirements are the basis for the Trade-Off Matrix. The functions are described in Paragraph 3.2.1. The list of requirements per function is given in Appendix 1.2. In this paragraph the list of requirements for the objects that are designed, is given. The requirements are split in technical requirements and functional requirements. The functional requirements are the same for all the objects that need to be designed. The technical requirements are different for each object and will be described per object.

3.2.3.1 *FUNCTIONAL REQUIREMENTS*

The main function of a dry dock is to conduct maintenance and repair or building activities on a vessel in a safe manner. For this main function a set of RAMS (Reliability, Availability, Maintainability and Safety) requirements are defined (Bakker, Blom et al. 2010), as described in Table 3.1.

Table 3.1: RAMS requirements

Reliability	Availability
• The dry dock may not fail in more than 1/xx docking cycles	• The dry dock is in xx% of the time available, under design conditions
Maintainability	**Safety**
• The probability that the maintenance can be done within xx hrs	• The chance of flooding is less than 1/xx yrs • The chance of accident containing an injury is less than 1/xx yrs

For the development of the walls, floor and gate, not only Reliability, Availability, Maintainability and Safety (RAMS) requirements are important for the preliminary design of a dry dock. These objects have additional functional requirements, namely:

- Availability of material
  If steel and concrete are available and if the quality of this material is sufficient
- Expandability
  The possibility that the dry dock can be expanded
- Costs
  Total costs of construction must be minimized
- Sustainability
  The CO_2 footprint of the object should be minimized. In this phase it is chosen to only use the CO_2 footprint for the sustainability because the volumes are calculated with the DSS, this can than be coupled to the CO_2 footprint. This gives a first indication on how sustainable the different types are.
- Technical score
  From the technical requirements the different types of objects get a score, the best applicable type of object receives the highest score.

3.2.3.2 TECHNICAL WALL REQUIREMENTS

These are the technical requirements to check if the wall types can actually be built. The different types will be ranked on the basis of these technical requirements.

Technical requirements (British Standards 2013):

- Construction method possible
  With different soil conditions, different construction methods are possible. Not all the wall types can be built with each construction method. The following construction methods will be investigated:
  - Building pit with natural slopes
  - Building pit with retaining walls
  - Building pit with retaining walls and underwater concrete
  - Building pit with retaining walls and grouting layer
  - Construction from waterside
- Available space
  The different types of wall needs different space available when built. Have enough space to built the type of wall
- Soil conditions
  The influence of the soil can have different impacts on the wall types
  - Enough bearing capacity to handle the wall without deformation
  - The soil should be penetrable enough to use the construction methods
  - Is it possible to use drainage system
- Maximum momentum
  Withstand the maximum momentum that can occur
- Top load
  This is the top load due to boulders, winches, dock arms and cranes. The top load must not cause deformation of the wall

3.2.3.3 TECHNICAL FLOOR REQUIREMENTS

The technical requirements for the floors show which alternatives are possible. It becomes clear from the requirements that the type of wall influences the type of floor, this will be discussed in Paragraph 3.3.2.

The technical requirements for the floor are (British Standards 2013):

- Soil condition
  - Floor is not too heavy for the bearing layer when shallow foundation is used
  - There is a bearing layer present when a piling foundation is used
  - Drainage is possible
- The upward force is not higher than the downward force at any moment
  - Upward force due to groundwater pressure
- Downward force can be withstand by the floor
  - Force due to the walls
  - Force due to vessel load
- Construction method
  With the construction method used, it is possible to built the floor type

3.2.3.4 *TECHNICAL GATE REQUIREMENTS*

The technical requirements the gate has to fulfill, is given by British Standard (British Standards 2013) and PIANC (Kuhn 1988).

- Width of entrance
  This is the length of the gate. This is of importance for the construction of the gate and speed of operation.
- Speed of operation
  This is the time needed for opening and closing of the gate. When the docks opening and closing time is of small impact on the total docking time a construction can be chosen with a slower operational speed but with a lower initial cost.
- Labour force available
  The different gate types use different methods for opening and closing of the gate. Some need more labour force for this operation, therefore it is important to know what the availability is of the labour force and the costs. This is also important for the maintainability.
- Reverse head capability
  Not all gates are designed to retain a reverse head. Therefore it is of importance to know of a reverse head is a requirements for the gate.
- Depth available outside dock
  When using flap gates, the water depth outside the dock must be enough.
- Maintainability
  The difference in maintainability is of importance for the design because this gives an indication on the cost for maintenance and the downtime when it is maintained.
- Provision of power
  Some gates need a lot of electricity when in operation, this is not everywhere available.
- Access across top of gate
  This is for a bridge across the gate. To see what kind of forces there are on top of the gate.
- Methods of construction
  Not all methods are applicable in each country. Therefore it is important to check what experiences there are in the country where the dock is going to be built.
- Cost of construction
  Each gate types come with its own cost. To find the best solution it is necessary to find the cheapest type that fulfills to the requirements.

3.3 OBJECT TYPES

3.3.1 TYPES PER CHOSEN OBJECT

In this paragraph the different types for the main objects of a dry dock are given, these main objects are the gate, wall and floor.

3.3.1.1 *WALL TYPES*

In Figure 3.4 the different wall types that are used are given (Kuhn 1988, British Standards 2013). Appendix 3.1 gives the pros and cons for the different walls and in Appendix 4.1 are drawings of the different types.

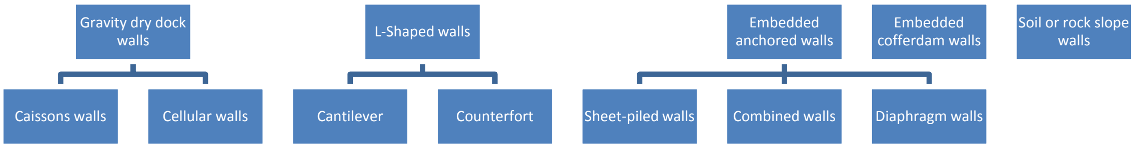


Figure 3.4: Wall types

3.3.1.2 *FLOOR TYPES*

There are two types of conditions that the floor has to withstand, to withstand these forces different floor types are available. This is shown in Figure 3.5 (Kuhn 1988, British Standards 2013). The pros and cons for the different floor types are given in Appendix 3.2.

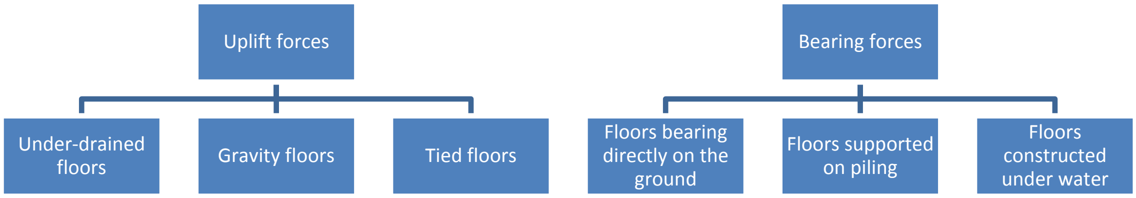


Figure 3.5: Floor types

3.3.1.3 *GATE TYPES*

Figure 3.6 describes the different gate types that are used in the design of dry docks (Kuhn 1988, British Standards 2013). On the next page drawings of different types are presented and in Appendix 4.2 these drawings of the different types are further elaborated. In Appendix 3.3 the pros and cons are given of the different types of gate. This will support the decision making when the requirements are given.

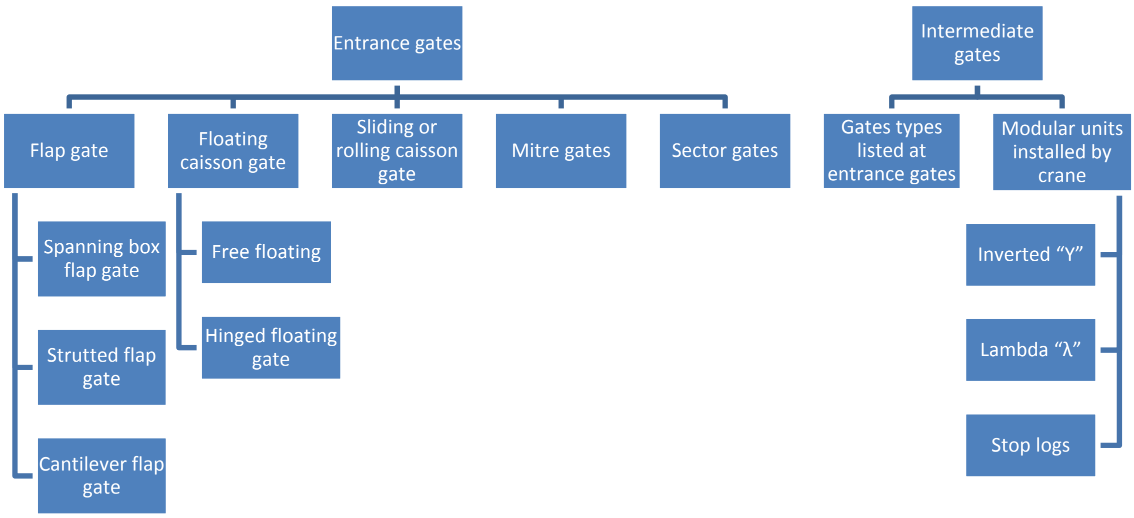
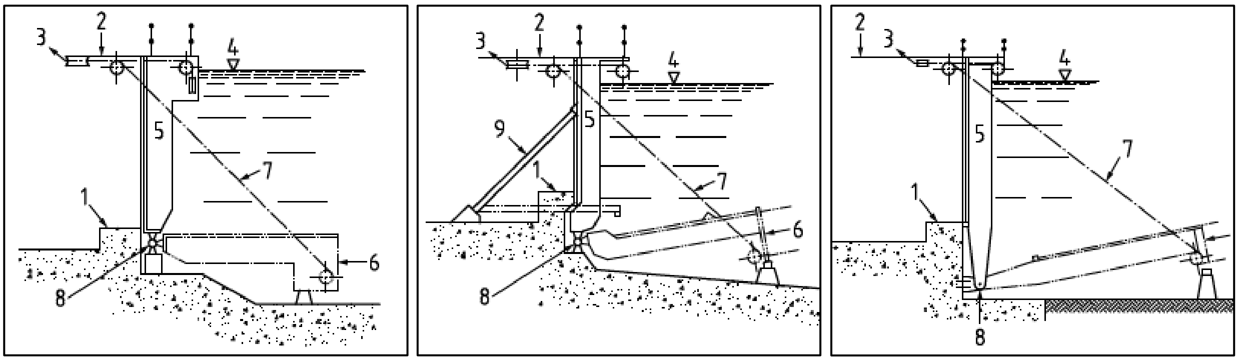


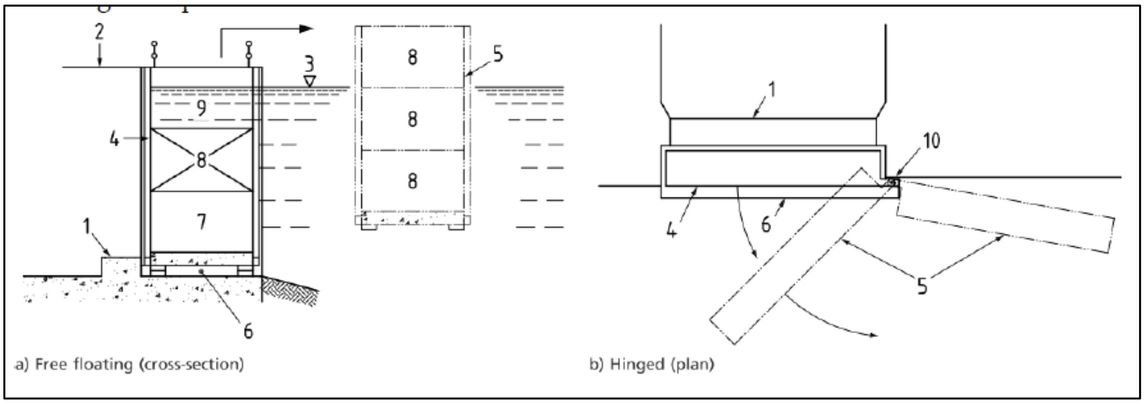
Figure 3.6: Gate types

Gate drawings (British Standards 2013)

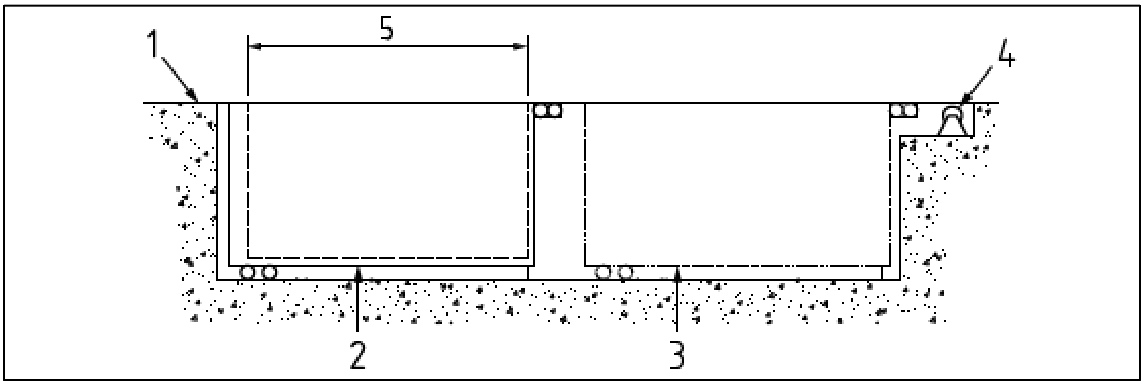
a. Flap gate (from left to right: spanning box, strutted flap, cantilever)



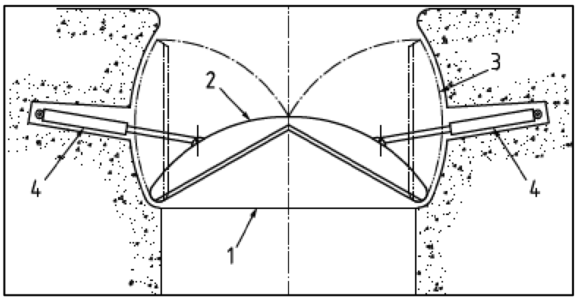
b. Floating caisson gate



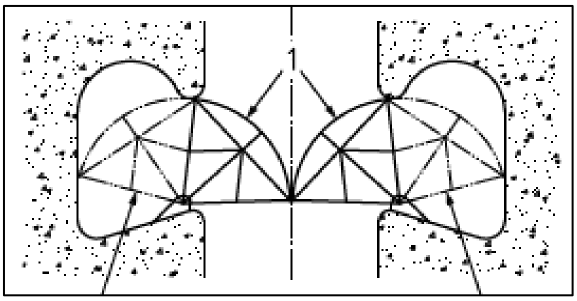
c. Sliding or rolling caisson gate



d. Mitre gates



e. Sector gates



3.3.2 COUPLED OBJECTS

This paragraph discusses how the different objects are connected with each other. This is done by looking at the interaction between the different interfaces of the objects designed. This is needed for the investigation in the interaction of the objects on each other. For example not all floor types are possible with a chosen wall type.

- Force balance between floor and walls
- Construction method
- Connection wall and gate
- Sill

3.3.2.1 *FORCE BALANCE BETWEEN FLOOR AND WALLS*

Gravity based walls support the floor to retain the upward force due to the water pressure on the bottom of the floors. This is the effective downward pressure, meaning the weight of the walls minus the weight of the water times the gravitational constant.

Embedded anchored walls, such as sheet pile wall, retain the upward water pressure by means of shear stress among the shaft of the piles.

3.3.2.2 *CONSTRUCTION METHOD*

Based on previous Arcadis projects the following construction methods are evaluated, see Table 3.2. This table gives an overview on which wall types can be built with different constructions methods:

Table 3.2: Possible wall types per construction method

Wall types	Ground level	Open excavation with slopes	Building excavation with retaining wall	Building excavation with underwater concrete	Building excavation with deep grouted layer	Construc-tion from waterside
Caissons/ cellular	1	3	3	3	3	5
L-shaped	3	5	5	5	5	3
Embedded anchored walls	5	1	5	5	5	3
Diaphragm wall	5	1	3	3	3	1
Rock slope walls	5	5	1	1	1	1

1 = not possible
3 = possible but not advised
5 = possible

From the table above it can be concluded that not all the construction methods are possible for each wall type. When a construction method is chosen within the DSS, the DSS can immediately see which types of walls are not possible and which types are not advisable to use. This will help in making the decision for a wall type. For example when the construction method building excavation with retaining walls is chosen it is not possible to create a wall that consist of a rock slope. A caisson wall cannot be built from ground level, it needs a building pit to be placed.

The construction method is of importance for the floor as well. When the construction method of underwater concrete is used, meaning that there is already a layer of concrete where the floor is built on top of. This helps to retain the upward water pressure and the downward vessel forces.

3.3.2.3 CONNECTION WALL AND GATE

In some cases when the gate is connected with the wall, the wall has to be built in a different way. For example when a hinged gate is used, the wall needs to be strong enough to hold the gate in place. This is very specific and for this reason it will only be designed in the detailed design and it is therefore not in the scope of this thesis.

3.3.2.4 SILL

The sill is the part of the floor where the gate stands in a closed condition. The top of the sill lays above the dock floor, at the same height as the docking blocks. This is done to minimize the retaining height of the gates. The sill needs to withstand the force of the gate on the floor and therefore it is a special part of a dry dock. It is a small object in the whole design of the dock and will only be designed when the gate type is chosen. This area of interaction is small in comparison with the floor, gate and walls and not of interest in the preliminary design of a dry dock.

3.3.3 SYSTEM BOUNDARY

As concluded in Paragraph 3.2.2 the focus will be on the design of dry dock gates, floor and walls. In Appendix 5 a visual view is given on the objects that are taken into account of the design and which are not. For the preliminary design the type of the objects will be defined. The choice between the different types of walls, floor and gate will be done with the use of a Trade-Off Matrix as described in Paragraph 2.5.5. This trade off will take the loads into account that are in orange, as shown in Figure 3.3: boulders, winches, dock arms and crane rail. This load is transferred to one top load. The opening space and bridge in front of the gate are taken into account in the needed space for these objects.

3.4 PARAMETRIC DESIGN

For the parametric design the parameters are investigated that influence the design of the objects. The design rules for the different types of objects are determined, so that these can be implemented in the DSS. When the design rules are coupled with the parameters the DSS will give the preliminary design.

The parametric design will be made for the different types per object, given in Paragraph 3.3.1, with the help of design rules for the project specific conditions and with the requirements, given in Paragraph 3.2.3.

The wall types: sheet piles, combined and L-shaped walls, are designed quantitatively by means of a parametric design that gives a first estimation about the material usage. The material usage is then used to find the CO2 footprint of the particular design and the cost. This gives a good view on how the parametric design could be extended in the future for the development of a dry dock in the different phases of the design. The floor is also calculated in a quantitative manner by means of a parametric design. This is done for the case of pile and shallow foundation. To make a choice between the different types of gates a parametric design is made in a qualitative manner. This is done because a gate does not have to be designed fully to make a choice between the different types. Checking the design rules with the project specific requirements gives enough information for the type of gate.

The design rules used for the preliminary design are the basic calculation methods to get a quick first impression on the design. When further designed these calculations must be verified with programs specific programs such as D-Sheetpiling, Plaxis, etc.

3.4.1 DESIGN GUIDELINES PER OBJECT

From the object decomposition it becomes clear that the walls, the floor and the gate needs to be designed and from Paragraph 3.3.2 that the construction method is of importance for the design of these objects. For the construction methods, the walls, the floor and the gate design guidelines are described, so it can be implemented in the DSS.

The calculations for this phase of the DSS do not include safety factors. This is choice is made because the safety factors depend on the country the design is created and it is not of importance of the feasibility of a new design method (DSS). Therefore per country the safety factors needs to be added.

For the concrete calculations the situation of non-cracked concrete is used and the temperature influences are neglected. For the preliminary design these can have influence on the thickness of the concrete needed but for the sake of simplicity these are neglected. In further development of the DSS these options helps to create a more precise result.

3.4.1.1 *DESIGN GUIDELINES PER CONSTRUCTION METHOD*

There are six main types of construction methods, as given in Table 3.2. For these six construction methods the design guidelines are given:

Construction from waterside
This is when the dock is created from reclaimed land. A caisson or cellular wall type is the best option for this case.

Ground level
When it is not possible to first excavate the ground, it is needed to build from ground level. An embedded anchored wall or diaphragm wall is needed before it can be excavated. After this is done, it is still possible to build a different type in the building pit. This must be done if there is not enough space for natural slope or a permeable layer with groundwater needs to be cut off.

Open excavation with slopes
In this case the dry dock is built by excavation of the ground. There is no need for retaining walls in the construction phase. Often drainage is needed to keep the dock dry in construction phase. When building in a clay layer attention has to be given to this layer to see if it does not burst open. This will be done by comparison of the upward water pressure, on the bottom of this layer, with the downward soil pressure.

Building excavation with retaining wall
In this case there is either not enough space to build with natural slopes or it is needed to retain the groundwater. The retaining wall will be placed at the depth of an impermeable layer. The upward water pressure on the bottom of an impermeable layer must not be larger than the downward pressure of the soil above the bottom of the impermeable layer.

Building excavation with underwater concrete
If none of the above mentioned construction methods are applicable the option of underwater concrete could be an alternative. In this case the underwater concrete also helps to withstand the upward force due to the water pressure.

Building excavation with deep grouted layer
In case the underwater concrete is not sufficient or that the thickness of the concrete layer will get too high, the option of a grouted layer must be investigated. The depth of this layer is the place where the upward water pressure equals the downward soil pressure.

3.4.1.2 DESIGN GUIDELINES PER WALL TYPE

First is checked which wall types can be applied. This is done by checking the technical requirements, given in Paragraph 3.2.3.2: construction method, available space, bearing capacity and the possibility to hammer a sheet pile wall. To see how the DSS can be further developed to help with making a decision on the different sub types, the embedded anchored walls types, sheet pile and combined wall types, and concrete wall will be designed in more detail.

For the design of the wall types the boulder forces are neglected. These are not in all cases necessary and as described in the object decomposition these are not in the scope of this thesis. Furthermore if these forces are active the dock is still filled with water, giving counter resistance to the wall, minimizing the influence on the wall.

The different construction methods and wall type options are given in Table 3.2. The space needed per wall type is Table 3.3. Table 3.4 describes to which depth a sheet pile can be hammered with a particular cone resistance.

Table 3.3: Width needed per wall type

Wall types	>natural slope	>then retaining height	>then L-wall width	<L-wall width
Rock slope walls	1	0	0	0
Caissons/ cellular	1	1	0	0
L-shaped	1	1	1	0
Embedded anchored walls	1	1	1	1
Diaphragm wall	1	1	1	1

0 = not possible
1 = possible

Table 3.4: Ramming depth of interlocking sheet piles (Regelgeving 2012)

Cone resistance [MPa]	Depth [m]
<5	54
5-10	47
10-15	40
15-20	35
>20	0

If it is not possible to use a sheet pile, it is not possible to build a gravity wall in case of a construction method with retaining wall is chosen. A diaphragm wall would be the solution.

From the information above the best technical feasible option will be determined. The technical score will give information about which main types are technical feasible and what is technically the best solution. The technical score is than rated from 5 to 1, with 5 the best option and 1 the least viable solution.

Embedded anchor wall

The difference between the two types of embedded anchored walls is given by the maximum bending moment it can handle. The strongest sheet pile wall that, for example, Arcelor Mittal can provide is the AZ 50 with the steel quality S430. This can handle a maximum momentum of 2156 kNm (ArcelorMittal 2008). Combined walls can handle 6284 kNm with a GU-16-400 system and the steel quality S430 (ArcelorMittal 2008). To calculate the maximum momentum Blum's method is used (Visschedijk and Trompille 2011).

When designing an embedded anchor wall the following points need to be calculated:

- Embedded depth
- Anchor force
- Maximum momentum

For the first two calculations the soil profile is simplified to one soil layer. This is done by taking the mean of the density and friction coefficient (Molenaar, Baars et al. 2008). In this case it is supposed that the wall is anchored with only one anchor and that there is no strut force. For these calculations Blum's schematization is used, see Figure 3.7. In this situation the soil on the right side is fully active and on the left side is fully passive.

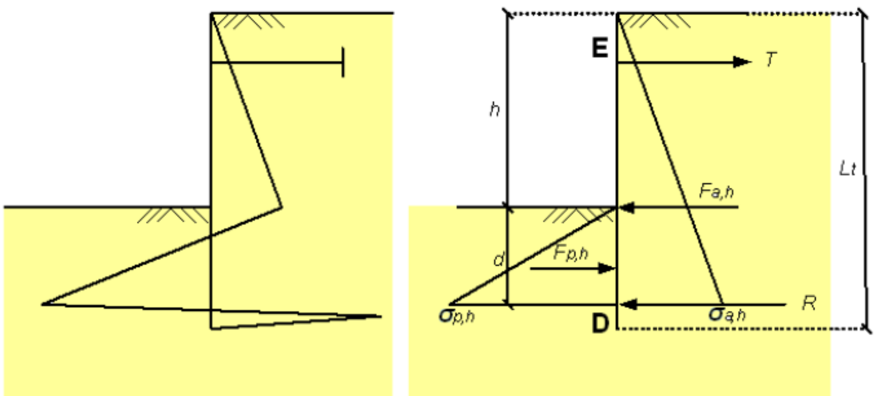


Figure 3.7: left: 'real' situation; right: Blum's schematisation (Molenaar 2013)

By taking the momentum around the anchor, the embedded depth can be calculated. The momentum around this point must be zero. When this point is determined a horizontal force equilibrium can be determined. Resulting force needs to be absorbed by the anchor.

The soil forces are calculated with Blum's method, first the effective vertical force is calculated, then the horizontal soil forces, shear stress and finally the momentum, the formulas used for these steps is given in Appendix 6.1.

<u>Maximum anchor force</u>

The maximum force that an anchor can handle is given by the depth of the anchor. The force overview on an anchor is given in Figure 3.8.

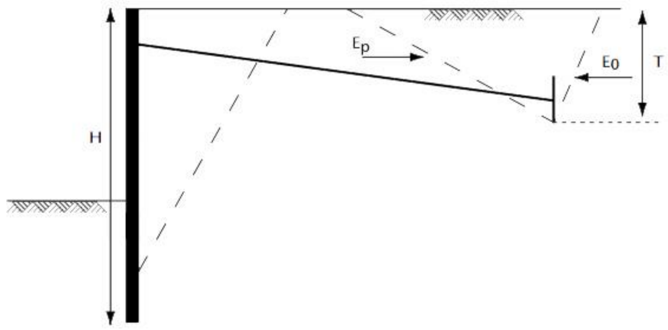


Figure 3.8: Stability of long anchors (Deltares 2010)

The formula to calculate the maximum anchor force is given in Appendix 6.2.

Concrete wall

To calculate the concrete wall, the dock is schematized as a U-shaped dock. By doing this it is assumed that the walls and the floor are stiffly connected and that the dock will not slip off. The maximum shear stress and momentum is on the bottom of the wall from the soil calculations given in Appendix 6.1. From the maximum shear stress and momentum, the height of the concrete can be calculated. The shear stress is the decisive value to calculate the thickness of the concrete and with the momentum the reinforcement is calculated. If the reinforcement percentage is too high than the wall thickness must be adjusted (Molenaar, Baars et al. 2008). The concrete is schematized as in Figure 3.9. The formulas used to find the concrete thickness is given in Appendix 6.3.

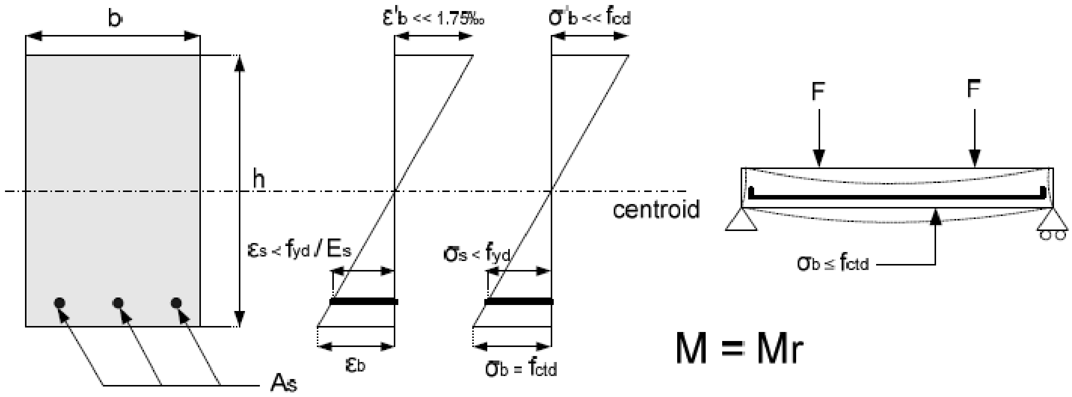


Figure 3.9: Deformation and stress diagram for non-cracked beam (Molenaar 2013)

3.4.1.3 DESIGN GUIDELINES PER FLOOR TYPE

The floor calculations are divided in two main types, namely:

- Shallow foundation
- Pile foundation

For these two main types the concrete is calculated for the two Ultimate Limit States (ULS):

- ULS1 empty dock
- ULS2 with vessel

ULS1 is when the dock is totally empty, in this case there is the most upward force, due to the upward water force, on the concrete. ULS2 is when the dock is dry and the design vessel is in the dock, this gives the highest forces on the dock that cause the biggest momentum in the floor.

The maximum moment, in the concrete wall calculation, are added at both sides of the concrete floor, as given in Figure 3.10.

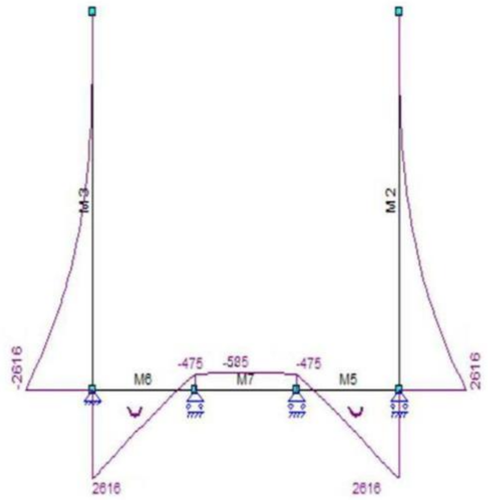


Figure 3.10: Forces on a fixed supported dry dock (Molenaar 2013)

Downward force wall on floor

The maximum downward force given by the wall depends on the type of wall used, as discussed in Paragraph 3.3.2.1. The gravity based walls use their own weight of the wall to retain the upward pressure. For embedded anchored walls, such as sheet pile wall, retains the upward water pressure by means of shear stress among the shaft of the piles, as given in Appendix 6.4.

Shallow foundation

In this case there are 5 forces. These can be subsidise in upward and downward forces:

Upward forces

- Water pressure
- Soil resistance

Downward forces

- Concrete floor
- Walls
- Vessel

The sum of the downward forces must be higher than the sum of the upward forces. The ULS1 is when the dock is empty and without a vessel. From this situation it is possible to find how thick the concrete has to be to withstand the upward forces. Other options for withstanding this force: to tie the floor or to use a drainage system.

The ULS2 is when the dock is empty and there is a vessel stationed in the dock. The limiting state is than the maximum shear force within the dock. In this case the upward soil resistance force is the sum of the downward forces minus the upward water pressure. This soil resistance force is then schematized as an evenly distributed upward pressure. This pressure may not be negative, because that means the dock will flood upwards. Normally this load will be schematized as a spring system, for simplifying reasons this has not been done, in the verification the error of this system must be determined and checked if this is acceptable.

The vessel load is calculated as three evenly distributed loads, one keel block and two bilge blocks. The keel blocks have 60% of the vessels loads and the bilge blocks 25% (British Standards 2013).

These loads are then integrated over the length of the dock to find the maximum shear stress. These shear forces is then integrated one more time to find the maximum momentum. From the maximum shear stress and bending moment the thickness of the concrete floor can be calculated in the same manner as the concrete wall thicknes calculation in Paragraph 3.4.1.2.

Pile foundation

The difference between pile foundation and shallow foundation is that there is no evenly distributed upward soil resistance but a pile resistance. These forces are more centred, giving locally higher upward forces. This force is the total upward force needed and divided over the amount of piles times the length of one pile. Another difference between pile and shallow foundation is that an additional downward force is available: pile shaft force. This means that not only the floors own weight and walls help to resist the upward force in ULS1 but also the shaft resistance from the piles. In this case the schematization of the piles in an uniform force must be verified by checking this with a system that uses the spring system.

3.4.1.4 DESIGN GUIDELINES PER GATE TYPE

The choice for the type of gate is made in a qualitative manner. This is done by checking each type to the technical requirements, given in Paragraph, 3.2.3.4, and the project specific situation. Table 3.5 shows the allowable width per type of gate (Glerum, Vrijburcht et al. 2000).

Table 3.5: Allowable width Gate types

Entrance Gate Type	Width of entrance [m]
Flap gate	
Spanning Box	W>16
Strutted	W>16
Cantilever	W>16
Floating Caisson Gate	
Free	W
Hinged	4<W<16
Sliding or rolling caisson gate	W<16
Sliding or rolling caisson gate (deballasting)	W>16
Mitre gates	6<W<24
Sector gates	6<W<24
Intermediate gates	
Inverted "Y"	W
Lambda "λ"	W
Stop logs	W

Appendix 3.3 gives information on how the different gate types score to the technical requirements given in Paragraph 3.2.3.4.

3.4.2 COSTS

The costs for the objects can be parametrically determined by using the quantities used for the different object types. In this thesis not all objects are determined quantitatively, therefore the costs cannot be determined for every object. The objects that are quantitatively determined are:

- Wall types:
  - Sheet pile wall
  - Combined wall
  - Concrete wall
- Floor types

For the sheet pile walls and combined walls the unit rates per embedded depth are used and for the concrete wall and floor types the unit rate for volume of concrete and reinforcement is used. This gives a first impression on how the costs for the different objects can ben added to the DSS.

3.5 CONCLUSION

This chapter gives the outline that is needed for the development of the DSS. This is done with the guidance of System Engineering by first giving an overview on the functions and objects of a dry dock. From the overview of the objects it is decided to make the choice to develop a DSS for the walls, floor and gate. This is done because these are the main elements within a dry dock and these have to be designed for each specific project, because these have a lot of variables and are critical for decision making.

By means of a Functional Flow Block Diagram, the functions of a dry dock are mapped. From these functions the requirements are determined on what the dock has to fulfill. These requirements are divided in functional and technical requirements. The functional requirements are the same for all the objects and are based on RAMS requirements with dry dock specific functional requirements. The technical requirements are object specific. The different types per object are then tested against these requirements. From the technical requirements it becomes clear if a type is actually possible in the particular project and gives a score how applicable each type is. The client can indicate a score per functional requirement and by means of this score the different object types are numbered on how well they fit for the particular project.

The final step in the preparation of the design is the investigation in the coupled objects. From this investigation the following coupled objects are determined:

1. Force balance between floor and walls
2. Construction method
3. Connection wall and gate
4. Sill

In Paragraph 3.3.2 it is discussed that for this preliminary design only the first two coupled systems are of importance. This means that the DSS not only has to be created for the walls, floor and gate but also for the construction method. The force balance between floor and walls will also be taken into account in the DSS.

From the parametric design the design rules for the construction method, walls, floor and gate are determined. The first three are made quantitatively, meaning the choice is supported with calculations. This is needed because the choice between the different types are made on the technical feasibility coming from the maximum allowable force and/or maximum allowable momentum. The choice between gates is made qualitatively because a gate does not have to be designed fully to make a choice between the different types. Checking the design rules with the project specific requirements gives enough information for the type of gate. All the gate types can be built in a way that they can be used for each dry dock, but the decision is made on how well they suit the purpose needed for the specific project.

For the wall types it is chosen to show how the DSS can work when it is fully developed by investigating three types more profound. The most common types that are used, following PIANC (Kuhn 1988), are chosen. Namely sheetpile, combined and concrete wall.

4 Design, Verification and Validation of DSS

4.1 INTRODUCTION

From Paragraph 2.5 it became clear that a DSS is a useable tool to create the preliminary design of a dry dock. As discussed the compound type DSS is the most appropriate to be used. Before the creation of the DSS a list of requirements has been made to formulate how the DSS must work:

- The DSS is easy to use, even without any experience of designing dry docks but technical knowhow is needed
- The DSS is flexible and adaptable in case of changes of any kind
- The DSS gives an overview on the alternatives and the impact of these on the preliminary design of a dry dock

In Chapter 3 the DSS outline is made. From this chapter it becomes clear that the DSS should be made for the following objects:
- Construction method
- Wall types
- Floor types
- Gate types

This chapter uses the steps as described in Figure 4.1. How the DSS is designed will be described in Paragraph 4.2. This design is verified in Paragraph 4.3 to check if the calculations are compatible with the state of the art software used in the calculation. Paragraph 4.4 describes the validation of the DSS by comparing the outcome of DSS with a case study. Finally the conclusion of the applicability of the DSS is given in Paragraph 4.5.

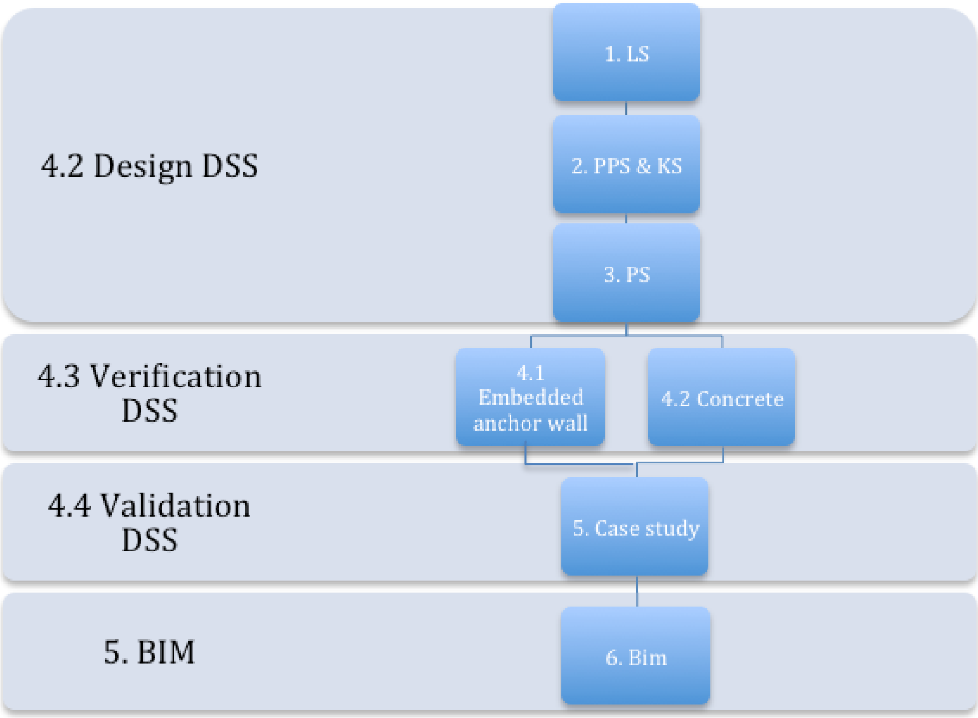


Figure 4.1: Flowchart Chapter 4

4.2 DESIGN DSS

This paragraph describes the design of the DSS by following the steps where each DSS consists of, as described in Paragraph 2.5.2 and illustrated in Figure 4.2. These steps are divided in paragraphs, Paragraph 4.2.1 describes the Language System of the DSS, Paragraph 4.2.2 the Problem-Processing System (PPS) and Knowledge system (KS) and finally Paragraph 4.2.3 describes the Presentation System (PS). The examples given in this chapter are the results from the case study.

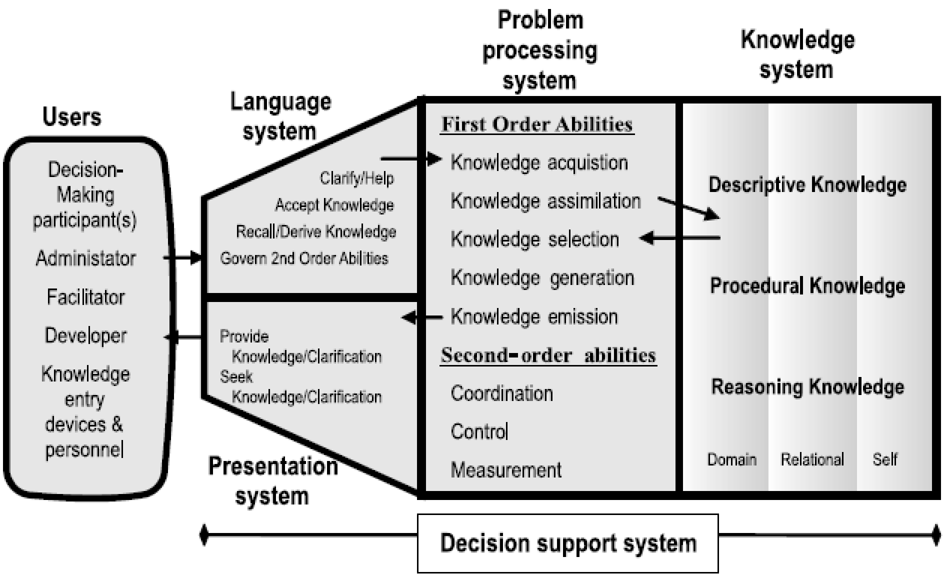


Figure 4.2: Generic components DSS interaction (Handbook DSS, F. Burstein, 2008)

4.2.1 LANGUAGE SYSTEM (LS)

The language system is the interface how the user communicates with the DSS. In this case it is the first sheet of the DSS called the '*Input Sheet (IS)*'. This is the part where all the information is put in. In this sheet the cells that have to be entered are yellow. The information needed to insert in the DSS is successively order:

- Soil information
  - Soil structure
    - Layer thickness
    - Permeable/impermeable layer
    - Density (wet and dry)
    - Phi
    - Cohesion
    - Cone resistance
  - Groundwater level
- MHWN
- Density
  - Concrete
  - Water
- Type of vessel
- Anchor
  - Depth below surface
  - Angle
  - Length
  - Diameter
- Struts
  - Force
- Functional requirements, see Paragraph 3.2.3.1
- Technical requirements, see Paragraphs 3.2.3.2 - 3.2.3.4

After the 'IS' is filled in, the Knowledge System (KS) is advised by the Problem-Processing System (PPS) and a solution is determined. For example the width of the dry dock is calculated by the PPS by checking what the length of the vessel is. This is given from the LS with the rule determined in the KS, that the width of the dock must be the width of the vessel plus two times working space (3m). The Presentation System (PS) feeds this information back to the user, these are the grey cells.

4.2.2 PROBLEM-PROCESSING SYSTEM (PPS) AND KNOWLEDGE SYSTEM (KS)

This part of the system is the brain of the DSS. The input sheet is the start of the DSS, after this sheet is filled in it is possible to see the outcome of the particular situation. To get to this point the best types for the construction method, walls, floor and gate are calculated. How the DSS comes to this result is discussed in this paragraph, starting with the construction method, and then the wall type will be discussed. Finally the floors and gate are discussed in the PPS.

4.2.2.1 PPS & KS FOR CONSTRUCTION METHOD

The DSS for the construction method helps the user by making a choice between the following construction methods:

1. Open excavation with slopes
2. Building excavation with retaining wall
3. Building excavation with underwater concrete
4. Building excavation with deep grouted layer

This means that not all construction methods are included in this DSS, from the waterside and from ground level are not taken into account. This choice is made because the decision for one of these two is not based on calculations. Instead it depends on the project location, whether it is built from the water or from land. These two choices between construction methods will be taken into account for the further development of the walls, floor and gate in the technical requirements.

The first two are calculated to investigate if it is technically feasible to use this method without the use of drainage. For the third option the thickness of the underwater concrete floor will be calculated. The last option will identify the depth where the grouting layer has to be located, to make the balance between the upward water pressure and the downward soil pressure. The uplift capacity is calculated by dividing the upward pressure by the downward pressure. When this value is smaller than 1 it is possible to use this method without the use of drainage. This is further described in Appendix 7.1.

4.2.2.2 PPS & KS FOR WALL TYPE

To make a choice between the different wall types a Trade-Off Matrix is created. This enables a decision on the different types of walls to be taken in a qualitative manner, by checking it with the technical and functional requirements, given in Paragraph 3.2.3.2. To investigate the further development of the wall type, three types are also investigated in a quantitative way, these are the sheet pile wall, combined wall and the concrete wall. The concrete wall is simplified in a simple vertical wall that is stiffly connected with the floor, creating a U-shaped structure. This investigation is done by calculating the forces that act on the wall. By doing this, the dimensions that are needed can be determined when these types are built. With these dimensions also the costs and CO2 footprint can be given.

The PSS and KS for the wall consist of 4 elements:

1. Embedded anchor walls
2. L-Wall
3. Wall volumes
4. Wall feasibility

Embedded anchor walls

To check the feasibility of an embedded anchor wall the following points are calculated:

- Embedded depth
- Anchor force
- Maximum allowable anchor force
- Maximum force, shear stress and bending moment

For the first two points calculate the soil profile is simplified to one soil layer. For the last two calculations the more precise method is used, without the simplification into one soil layer. These calculations are described in Paragraph 3.4.1.2. The outcome of the maximum forces is given in Figure 4.3, this figure describes the outcome of the DSS with the input of the case study. From this maximum momentum it becomes clear which construction type is possible. As described in Paragraph 3.4.1.2, a sheet pile wall can handle a maximum momentum of 2156 kNm and a combined wall 6284 kNm. From the maximum momentum the type of sheet pile and the quality of the steel is also determined.

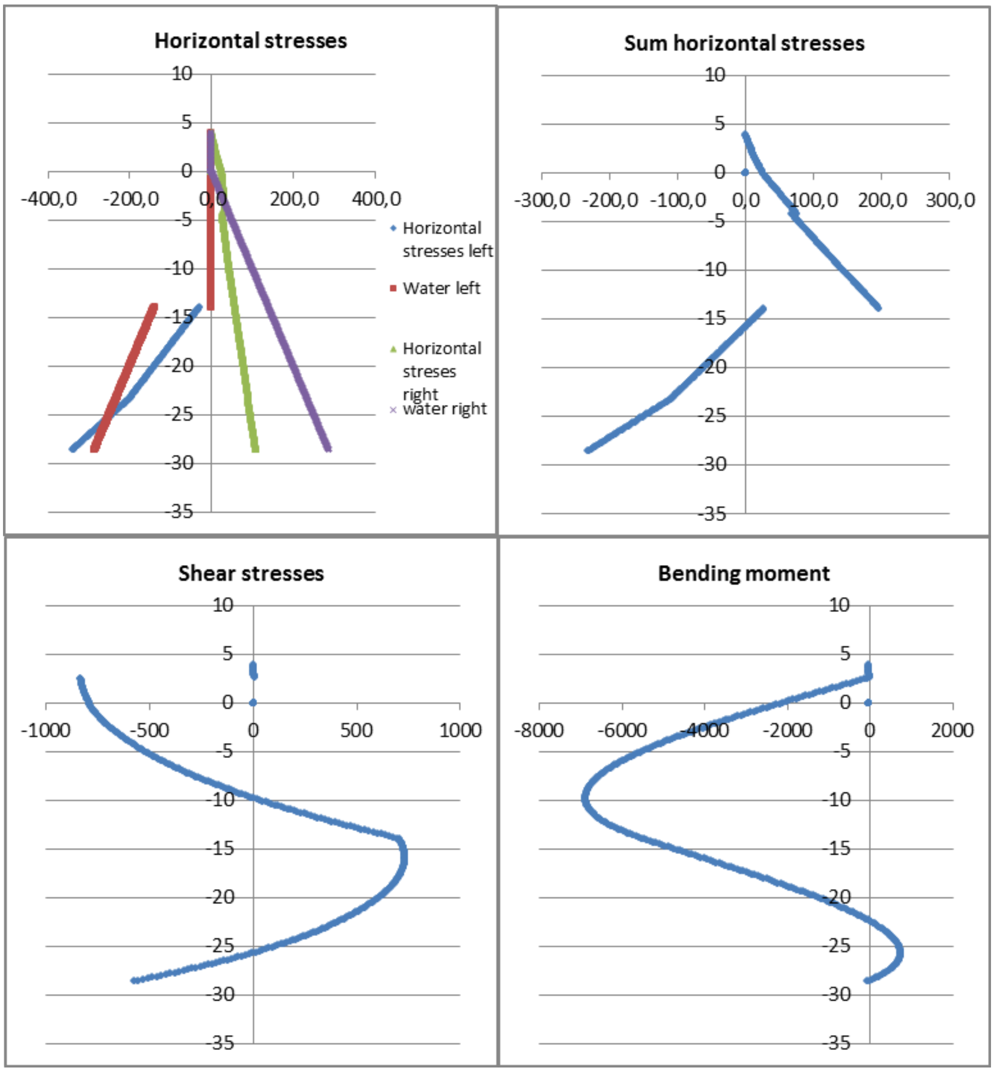


Figure 4.3: Top left: Horizontal forces; Top right: sum horizontal forces;
Bottom left: Shear stresses; Bottom right: Bending moment; ; X-axis: forces [kN/m2], stresses [kN/m], moment [kNm/m]; Y-axis: depth [m]

L-wall

For the L-wall the option of a concrete wall is calculated. A first estimation of the wall is simplified to a straight concrete wall. The two walls are connected with the floor, causing the structure to be stable for horizontal sliding and rotational forces. In further investigations the option with the horizontal part of the L-wall has to be checked. This can help to counteract the forces at the wall – floor node.

To calculate the maximum bending moment and shear stress that the concrete wall needs to withstand, the soil calculations from Blum, as mentioned in the previous paragraph, are used. In this case there is only neutral soil forces working on the wall (Veen 2014). A schematization of the forces on a dry dock wall, in the dry, is given in Figure 4.4.

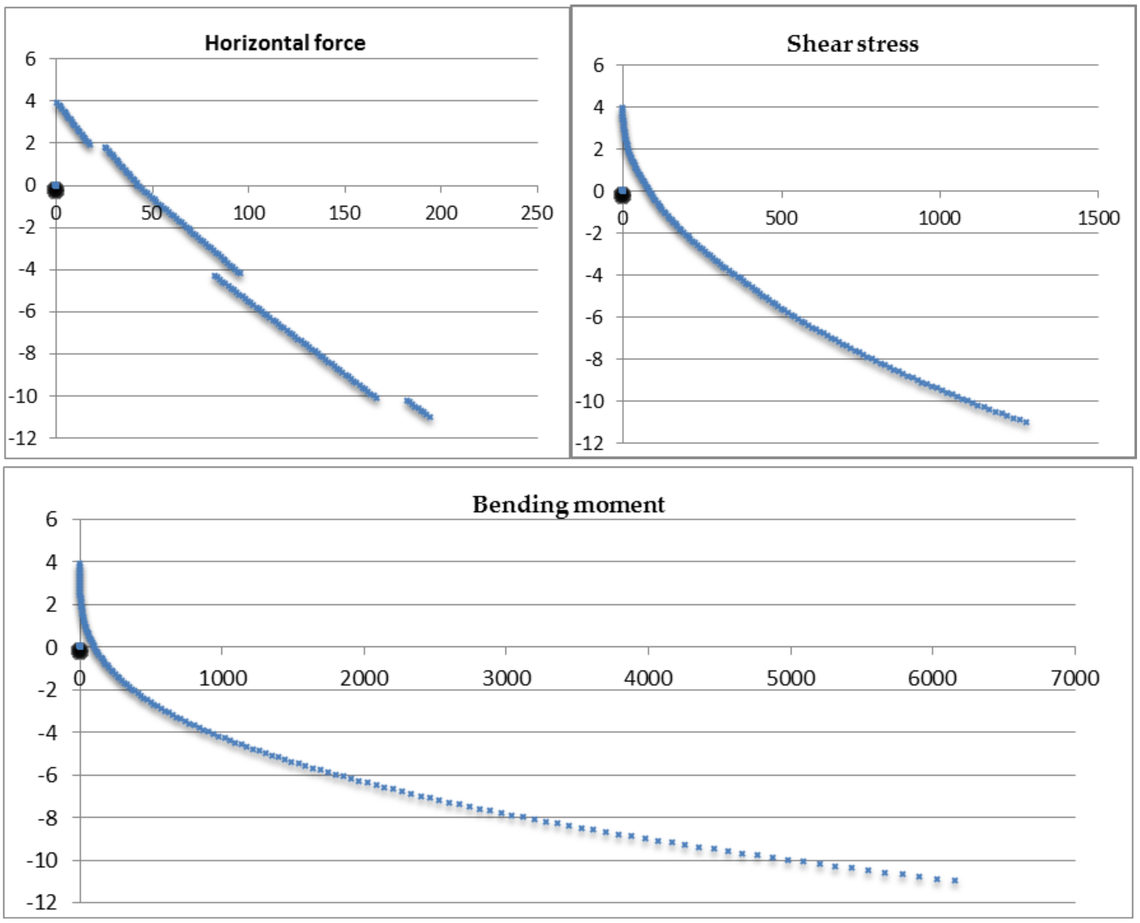


Figure 4.4: Sum horizontal forces, shear stress and bending moment on a concrete wall; X-axis: forces [kN/m2], stresses [kN/m], moment [kNm/m]; Y-axis: depth [m]

From these figures the maximum shear stress and bending moment are determined. The rules given in Paragraph 3.4.1.2, calculates the wall thickness and the amount of steel required. From these amounts the costs and CO2 footprint indication are provided.

Wall volumes for quantities assessment

For this part the volumes for the wall types sheet pile, combined and concrete wall are calculated. This is done by choosing a type of sheet pile or combined wall and a steel class. This gives the maximum moment that these walls can accommodate, compared with a check on what is the maximum allowable acting moment on the wall, a type is chosen. From this type an area is determined, which is multiplied with the height of the wall and the wall length. This gives a cubic meter of steel.

The volume of the concrete wall is the amount of concrete minus the amount of steel used for reinforcement. The reinforcement is determined with the help of the steel area in the wall.

The CO2 footprint is given by multiplying the weight of steel and concrete needed for the wall with a coefficient (BAM 2010). The weight of the wall is determined by multiplying the volume against the density, see Table 4.1.

Table 4.1: Weight and CO2 parameters (BAM 2010)

Material	Density [kg/m3]	kg CO2/kg material
Steel	7,8	1,77
Concrete	2,5	0,13

Wall feasibility

The feasibility of the wall is calculated by checking each type with the technical and functional requirements given in Chapter 3, by means of a Trade-Off Matrix, this Trade-Off Matrix is further described in Appendix 7.2. Firstly, the technical requirements are checked, an example from the case study is given in Figure 4.5. This gives an overview of which types are possible to build and which are technically not possible to build.

Score	Subscore	nr	Technical requirements Wall Wall type		Embedded anchored walls	L-shaped walls
			Achievable		**YES**	**YES**
1		1.0	Installation from ground level possible	yes	5	0
	2	2.0	Building pit with natural slopes possible	no	3	0
4	1	2.1	Drainage needed	no	0	0
	1	2.2	Sheet pile needed to close permeable layer	no	0	0
	3	3.0	Building pit with retaining walls possible	yes	5	3
	2	3.1	Drainage needed	no	3	3
7	1	3.2	Underwater concrete needed	yes	2	4
	1	3.3	Grouting layer needed	no	3	3
	1	4.0	Sufficient bearing capacity	no	5	0
2	1	4.1	Possible to improve bearing	indecisive	3	3
1		5.0	Construction from waterside	no	3	3
1		6.0	Available space	>natural slope	5	5
1		7.0	Dock embedded in impervious rock	no	3	3
1		8.0	Pile-driving possible	5-10 / <35	5	5
			Total score		30,2	20,6
			Rank (5 is best)		5	3

Figure 4.5: Outcome technical requirements wall types: embedded anchor and L-shaped

Before the wall types get a rank on the score, it is checked if the different types are achievable. This is done by checking the answers from the technical requirements with the possibilities for building the wall types. For example the following requirements are given for the embedded anchor walls:

- The dry dock may not be situated in impervious rock
- The dry dock may not have a combination of a high cone resistance and installation depth as described in Table 3.4

These requirements are needed because it is otherwise not possible to place the sheet piles.

For the L-wall the following requirements must not occur:
- Both 2.0 and 3.0 may not be both answered with 'no', otherwise it is not possible to place a L-wall because it is impossible to create the building pit to place the walls. If the embedded anchor walls is not possible the Trade-Off Matrix will indicate that 3.0 is also not possible
- Both 4.0 and 4.1 may not be both be answered with 'no', otherwise it is not possible to place a L-wall without the soil settle to much
- 5.0 may not be answered with 'yes', because it is not possible to place the walls in the sea
- 6.0 may not be answered with smaller than 'L-shaped wall', otherwise there is not enough space available

The wall types that are possible are then ranked on the score from the technical requirements. The wall type with a 5 is the preferred solution and with a 1 is the less preferred solution.

The functional Trade-Off Matrix, as given in Figure 4.6, describes how the final choice between the wall types is determined. This is done by multiplying the weight of each requirement against the requirements specific score. Each wall type has a personal score per functional requirement. The functional requirement score is determined by discussion with the client, who can give the preference for the particular requirements. This figure indicates that the functional requirements 'availability' and 'durability' are not used. Availability is not used because there is no difference between the availability of the different wall types. Durability is not used because the durability results are not available for all different wall types. This is because the dimensions of not all the different wall types are available. When this is known a CO2 footprint can be made.

Figure 4.6 indicates that the sheet pile wall scores a 0. This is due to the maximum momentum that occurs, this is to high for a sheet pile wall.

The Trade-Off Matrix for the wall is elaborated in Appendix 7.2.

Functional requirements	***Wall type***	Cantilever	Sheet-piled walls
	Total score	**196**	**0**
Maximum momentum			Not possible
Technical score	*Score*	3	5
	Weight	10	10
Reliability	*Score*	5	2
	Weight	8	8
Availability	*Score*		
	Weight	8	8
Maintainability	*Score*	5	2
	Weight	7	7
Safety	*Score*	5	2
	Weight	8	8
Expandability	*Score*	1	5
	Weight	8	8
Availability of steel	*Score*	0	5
	Weight	-1	-1
Availability of concrete	*Score*	5	0
	Weight	-1	-1
Engineering cost	*Score*	3	5
	Weight	7	7
Building cost	*Score*	3	7
	Weight	9	9
Sustainability	*Score*		
	Weight	7	7

Figure 4.6: Outcome functional requirements wall types: embedded anchor and L-shaped

4.2.2.3 *PPS & KS FOR FLOOR TYPE*

For the floor types the shallow and pile foundation are calculated qualitatively. In case of an under-drained floor the water pressure must be taken to zero. When a tied floor is chosen the pile foundation must be calculated in a manner that the piles, in case of the pile foundation, give a downward force instead of an upward force.

The PSS and KS for the floor consist of four calculations:

1. Vessel load calculations
2. Floor shallow calculations
3. Floor pile calculations
4. Floor feasibility trade-off

Vessel load calculations
This is an Arcadis sheet that calculates the load from the vessel on the floor. This sheet uses the weight of the vessel in tonnes, the working length of the bilge blocks, the working length of the keel blocks, width of the blocks and distance between the blocks. The distribution of the weight is 60% on the keel blocks and 25% on the bilge blocks. This sheet gives the value for the keel block and bilge blocks.

Floor shallow calculations
These calculations contain the floor shallow calculations as given in Paragraph 3.4.1.2. It uses two macros buttons to calculate the floor thickness for respectively USL1 and USL2 case. An example of the result of these outcomes is given in Figure 4.7. From these maximum momentums, shear stresses and upward water pressure the concrete thickness is calculated.

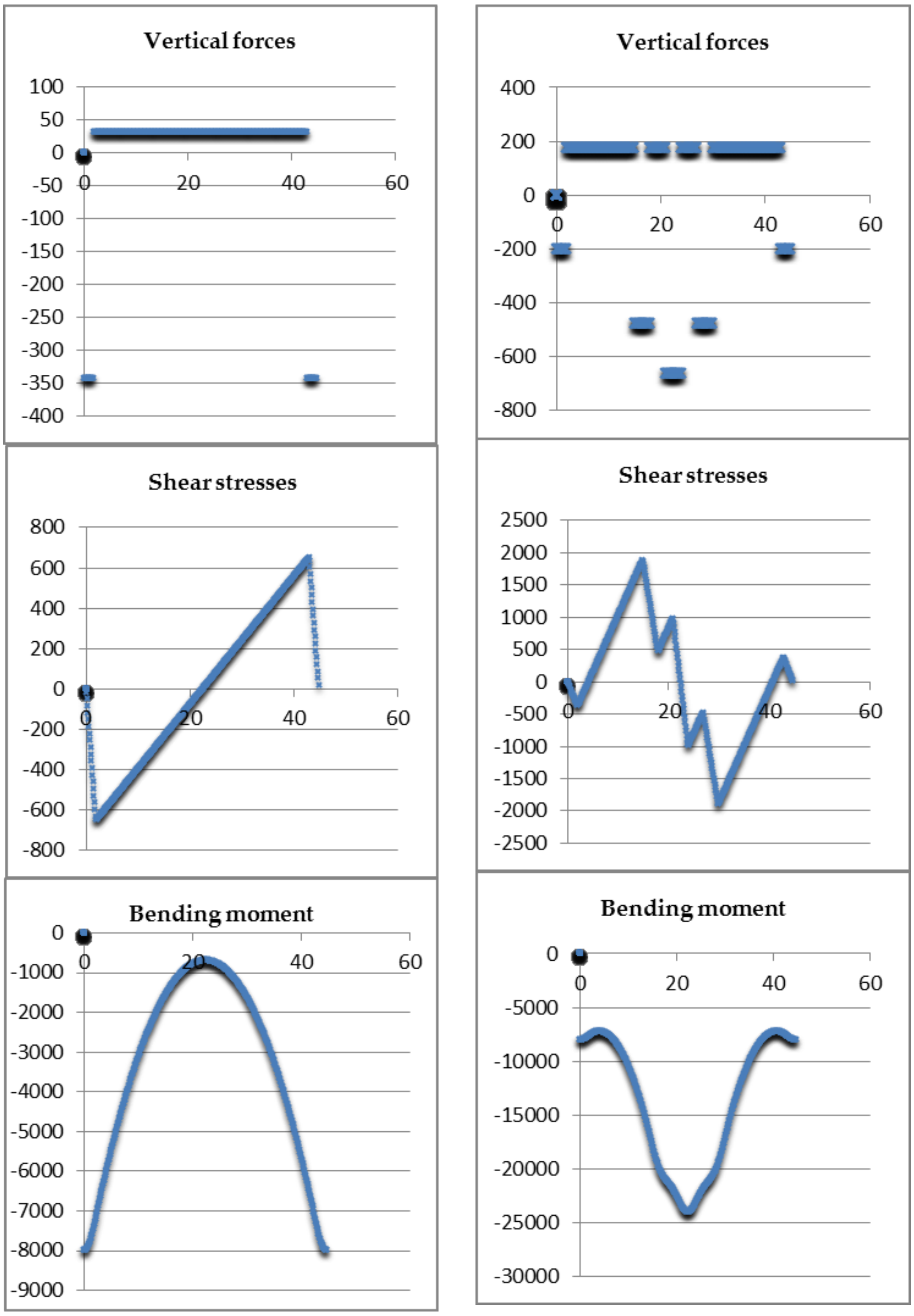


Figure 4.7: Floor forces shallow foundation; Left: ULS1; Right: ULS2;
Y-axis: forces [kN/m2], stresses [kN/m], moment [kNm/m]; X-axis: Width [m]

Floor pile calculations

These calculations contain the floor pile calculations as given in Paragraph 3.4.1.2. These calculations are made by two macros to calculate the floor thickness for respectively USL1 and USL2 case. An example of the result of these outcomes is given in Figure 4.8. From these maximum momentums, shear stresses and upward water pressure the concrete thickness is calculated.

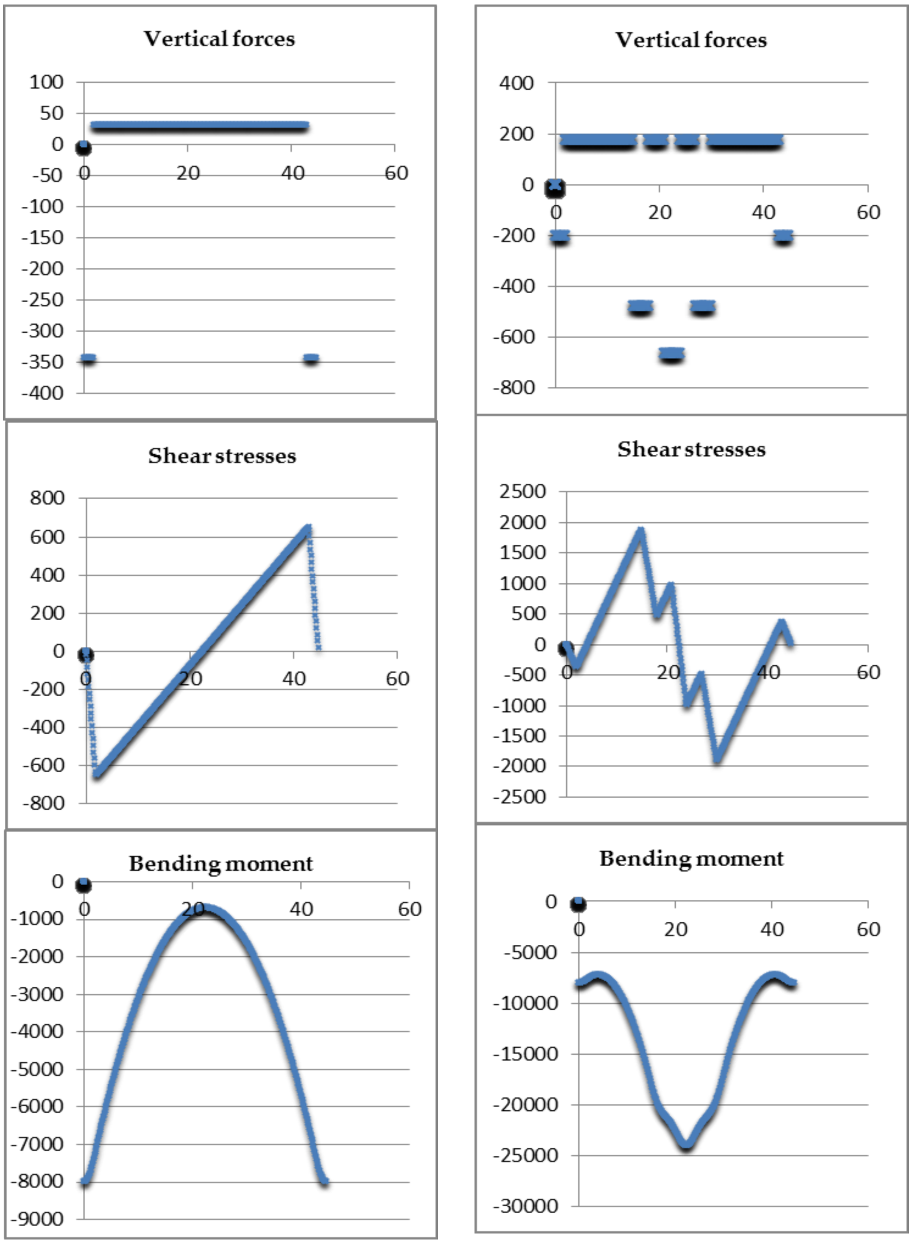


Figure 4.8: Floor forces pile foundation; Left: ULS1; Right: ULS2;
Y-axis: forces [kN/m2], stresses [kN/m], moment [kNm/m]; X-axis: Width [m]

Floor feasibility Trade-Off Matrix

The floor feasibility is calculated by checking each type with the technical and functional requirements given in Chapter 3, by means of a Trade-Off Matrix. First the technical requirements are checked. This gives an overview on which types are possible to build and which are technical not possible to use. In Figure 4.9 an example is given on the technical floor requirements Trade-Off Matrix from the case study. The possible types get ranked on how favourable the project is for this particular type. If a type scores a 0 for a question, it means it is not technical possible to use that type. Therefore the total score is a 0.

The technical score is then used in the functional Trade-Off Matrix, as given in Figure 4.10. The Trade-Off Matrix is elaborated in Appendix 7.3.

	Floor type	Uplift alternatives Under-drained floors	Gravity floors
	Rank	10	0
	Result	19	0
2.0	Bearing capacity stronger than:	5	0
2.1	NVT	1	1
2.2	NVT	1	1
3.0	Drainage possible	5	3
4.0	Possible to tie floor	4	4
5.0	Pile foudation possible	3	3

Figure 4.9: Outcome technical requirements floor types: under-drained and gravity

Figure 4.10 describes that in some of the functional requirements, the different floor types have the same score. Therefore these are neglected, as shown in Figure 0.24. These functional requirements are:

- Expandability
- Safety
- Availability of steel

Functional requirements floor trade-off		*Uplift alternatives*	
Entrance Floor Type		Under-drained floors	Gravity floors
Total score		239	0
Technical score	Score	10	0
	Weight	10	10
Reliability	Score	2	5
	Weight	8	8
Availability	Score	2	5
	Weight	8	8
Maintainability	Score	2	5
	Weight	7	7
Safety	Score		
	Weight	8	8
Expandability	Score		
	Weight	8	8
Availability of steel	Score		
	Weight	-1	-1
Availability of concrete	Score	5	5
	Weight	-1	-1
Engineering cost	Score	2	5
	Weight	7	7
Building cost	Score	7	5
	Weight	9	9
Sustainability	Score	3	1
	Weight	7	7

Figure 4.10: Functional floor Trade-Off Matrix

4.2.2.4 *PPS & KS FOR GATE TYPE*

For the gate only a Trade-Off Matrix is used, without the use of calculations. This Trade-Off Matrix uses the technical and functional requirements to determine the best solution for a gate type. By checking the technical requirements, as described in Figure 4.11, a list of technical possible gate types is determined. These are scored based on the pros and cons of the gate types as described in Appendix 3.3 These types are then ranked on their functional score. The functional score per gate type is calculated with the Dutch standard '*Leidraad Kunstwerken (LK)*' (Veendorp and Niemijer 2003) and the information from British Standard (BS). The Trade-Off Matrix for the gate is elaborated in Appendix 7.4.

The weight of the functional requirements, as described in Figure 4.12, are determined with the following source:

- Reliability LK
- Availability LK
- Maintainability BS
- Safety LK
- Expandability BS
- Engineering cost BS
- Building cost BS

LK: 'Leidraad Kunstwerken'; BS: 'British Standard'

Entrance Gate Type	Spanning Box	Free caisson
Width of entrance	5	5
Speed of operation [min]	1	2
Labour	5	5
Reverse head capability	5	5
Ability to open against a head	3	3
Depth available outside dock	5	5
Provision of power	5	5
Access across top of gate	5	5
Total score	**34**	**35**
rank	**8**	**11**

Figure 4.11: Outcome technical requirements gate types: spanning box and free-floating caisson

In Figure 4.12 describes that the sustainability is neglected for the gate types, because material usage is not known at this design stage.

Functional requirements gate trade-off			
	Entrance Gate Type	Spanning Box	Free-floating
	Total score	261	345
Technical score	*Score*	8	11
	Weight	10	10
Reliability	*Score*	5	5
	Weight	8	8
Availability	*Score*	4	3
	Weight	8	8
Maintainability	*Score*	3	9
	Weight	7	7
Safety	*Score*	3	2,7
	Weight	8	8
Expandability	*Score*	*1*	*3*
	Weight	*8*	*8*
Availability of steel	*Score*	5	0
	Weight	-1	-1
Availability of concrete	*Score*	0	5
	Weight	-1	-1
Engineering cost	*Score*	1	2
	Weight	7	7
Building cost	*Score*	6	6
	Weight	9	9
Sustainability	*Score*		
	Weight	7	7

Figure 4.12: Outcome functional requirements gate Trade-Off Matrix

4.2.3 PRESENTATION SYSTEM

This part of the system is where the DSS shows the results to the user. The result is shown by means of the '*results*' sheet. This sheet gives the result on the following topics:

- Dry dock dimensions
- Maximum forces that occur
- Diagram of the maximum forces
  - Horizontal stresses
  - Sum horizontal stresses
  - Shear stresses
  - Bending moment
- Which construction methods are possible without the use of drainage
- Wall trade-off
- Floor trade-off
- Gate trade-off

4.2.4 DESIGN DSS CONCLUSION

This paragraph describes the design of the DSS. The information from Chapter 3 is successfully implemented in an Excel based DSS. When a client wants a first estimation about the design of a dry dock, the DSS gives within 20 minutes a first estimation of the design for the particular case. All calculations are programmed in the DSS, therefore the user of the DSS will not have to make their own calculations. Making it possible for non-experienced dry dock designers to use this DSS. This answers the first requirement from the introduction.

The second requirement is if the DSS is flexible and adaptable in case of changes of any kind. For changes in the input parameter the DSS is very flexible, by changing the parameters a different design is formed. The PPS part of the DSS is not easy to change, because the formulas that are used in Excel are complex and therefore difficult to change.

The last requirement is that the DSS gives an overview on the alternatives and the impact of these on the preliminary design of a dry dock. The DSS fulfills to this requirement because it determines the possible alternatives and how a choice for a particular object influences the choice for another object. For example how the choice of a wall type influences the choice of a floor type. A concrete wall type helps to resist the upward water force better than a sheet pile wall type.

To check if the DSS results are in line with the state of the art engineering programs the DSS is verified in the next paragraph. After that the DSS is validated by comparing it to a case study to check if the design is in line with an Arcadis dry dock design.

4.3 VERIFICATION DSS BY MEANS OF VERIFIED SOFTWARE PROGRAMS

This paragraph discusses the verification of the wall and floor calculations. The verification is done to check if the results from the DSS are comparable with design results when using verified computer programs. These verifications are split into two checks, firstly the embedded anchor walls and secondly the concrete walls and floor. These two checks are done because these influence all the calculation made. The embedded anchor wall calculations are verified with the program *D-sheet piling* and the concrete wall and floor calculations are verified with the *SCIA*. Paragraph 2.3 describes that the accuracy of the conceptual design is 40% cost accurate and the preliminary design 25%. The DSS is created for the first design of a dry dock, therefore the accuracy of 25% is used as an acceptable boundary for the verification of the values.

4.3.1 VERIFICATION EMBEDDED ANCHORE WALLS

D-Sheet piling (formally known as MSheet) is a tool used to design sheet pile and diaphragm walls and horizontally loaded piles (Visschedijk and Trompille 2011). With the help of this program the anchor force, embedded depth, maximum shear stress and maximum momentum from the DSS are verified.

To verify these calculations 6 cases are discussed to compare the outcome of the DSS with *D-Sheet piling*. The cases consist of two depths and three soil conditions, as given in Table 4.2. The depths are chosen to see the difference of precision when checking with a relatively shallow dock and with a deep dock. The different soil conditions are to check how the DSS reacts on sand and clay. From these two it becomes clear how the dock reacts to the different soil types. The mixed situations determines if the DSS is also more precise for a more realistic soil condition.

Table 4.2: Verification cases embedded anchor walls

Depth	Sand	Clay	Mixed
5 m	1	2	3
15 m	4	5	6

Results

The results of the verifications for the six cases are given in Appendix 8.1. From these results the errors from the different cases are summarized in Table 4.3. The negative values indicate the percentage that the DSS underestimates the results and positive values indicate the percentage that the DSS overestimates the results. From this table it can be concluded that the DSS gives accurate results in cases 1 and 4. These are the cases with only one sand layer. In cases 3 and 6 it gives adequate results with a maximum error less than 20%. These are the cases with a mixed layer. In cases 2 and 5 the DSS gives inadequate results. The force, shear strength and momentum are overestimated by the DSS. These are the cases when the dock is only situated in a clay layer.

Table 4.3: Verification cases error results (+overestimation; - underestimation)

error [%]	case1	case2	case3	case4	case5	case6
Anchor force	-1,7	62,3	4,3	0,6	29,9	7,3
Depth	-12,8	23,6	18,6	-5,1	6,5	-7,0
Normative shear stress	-2,0	226,3	5,3	0,6	30,8	7,4
Normative Momentum	0,2	577,5	5,9	1,7	52,8	13,1

To check the cause of the overestimation, the anchor force issued from D-Sheet piling is used in the DSS calculations. The results from this test are given in Table 4.4. From this table it can be concluded that when the anchor force is known the calculations are more accurate. The cause for the overestimation from Table 4.3 is due to an error in the calculation of the anchor forces. This means that the calculations for the anchor force need further investigation to find a more accurate method for the calculation of this force.

Table 4.4: Verification cases error with anchor force from D-Sheet (+overestimation; - underestimation)

error [%]	case1	case2	case3	case4	case5	case6
Anchor force	0,0	0,0	0,0	0,0	0,0	0,0
Normative shear stress	0,0	-0,1	-0,5	0,0	0,4	-0,1
Normative Momentum	3,9	4,3	2,8	0,8	1,5	0,8

The results from Table 4.3 for the sand are already accurate, therefore a further investigation is done in the influences of clay on the anchor force. From this investigation it became clear the error in the calculation for the anchor force in the clay layer is due to the formula used for the horizontal active soil pressure, as given in Appendix 6.1:

$$\sigma'_{h,a} = K_a * \sigma'_v - 2c * \sqrt{K_a}$$

This calculates the first part of the soil layer, where the following condition is applicable:

$$K_a * \sigma'_v < 2c * \sqrt{K_a}$$

A negative value for the horizontal active soil pressure. If this is the case the cohesion (c) should be taken to zero (Molenaar, Baars et al. 2008). This is done for case 3 with manual calculations to determine the anchor force and depth of the wall, see Appendix 8.3 for the calculations. An overview of the results is given in Table 4.5. These results are much more in line with the D-Sheet piling results. An error of less than 10% for the anchor force is within the boundary of 25% and the error of the maximum momentum is just above the 25%. For now it is assumed that this is acceptable for the preliminary design. However, further investigation in anchor force is recommended tot further reduce the error.

Table 4.5: Verification results case 2; 5m clay, manual anchor calculation (+overestimation; - underestimation)

	Sheet pile	DSS	Error [%]
Anchor force [kN]	77	84	9,1
Depth [m]	-7,2	-6,8	-5,6
Normative shear stress [kN]	-65,8	-72,7	10,6
Normative Momentum [kNm]	-86,1	-107,7	25,1

Points of attention

These proposed solutions are not yet applied in the DSS, therefore designers must pay attention to what kind of soil they use with this version of the DSS. In cohesive soil the DSS cannot be used without an already known anchor force.

Two other points that need to be addressed from Appendix 8.1 are the depth and the forces at the deepest points. The DSS underestimates the embedded anchor walls depth for all the accepted cases, see Table 4.6. This underestimation of the embedded depth can be partly addressed to the fact that the DSS only takes the height (h) and depth (t) as given in Figure 4.13. The DSS neglects the 0,2t below point D, that is added since the passive pressure at the front side of the wall is underestimated in this schematization (Molenaar, Baars et al. 2008). When this length is added the depth error is reduced as described in Table 4.6.

Table 4.6: Embedded anchor wall depth per case

Depth [m+NAP]	D-Sheet	DSS	DSS +0,2t	Error DSS [%]	Error DSS +0,2t [%]
Case 1	-8,6	-7,6	-8,12	-11,6	-5,6
Case 2*					
Case 3	-9,7	-7,9	-8,48	-18,6	-12,6
Case 4	-25,3	-24	-25,8	-5,1	2,0
Case 5*					
Case 6	-25,8	-24	-25,8	-7,0	0,0
Case 2 manual anchor	-7,2	-6,8	-7,16	-5,6	-0,6

* *Omitted due to unrealistic anchor force calculation*

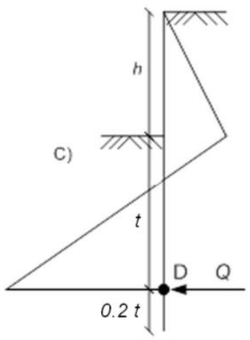


Figure 4.13: Embedded depth (Molenaar, 2008)

The second noteworthy point from the Appendix 8.1 is that at great depth the sum of the horizontal forces determined in the DSS deviates from the forces given by the *D-Sheet model*. The DSS only calculates with a full active or full passive horizontal soil force. *D-Sheet* calculates what the percentage is of active and passive horizontal force. This gives a deviation in the results at the bottom of the wall, but it does not affect the maximum moment or shear stress in the wall, because this effect acts on the wall well below the point where the maximum shear stress and momentum is located.

4.3.2 VERIFICATION CONCRETE WALLS AND FLOORS

The verification of the concrete walls and floor is done by checking if the forces determined in the DSS are corresponding with the forces from the calculation program SCIA. SCIA is a computer aided engineering program that uses the final element method to calculate how a construction reacts on forces. The following initial conditions are set for both the DSS and SCIA model:

Soil condition	
Type	Sand
Density (ρ)	20 kN/m3
Internal friction (φ)	30°
Neutral soil pressure coefficient	0,5
Groundwater	ground level

Concrete structure conditions	
Density (ρ)	25 kN/m3
Concrete thickness	2,6m
Wall height	variable
Floor thickness	variable
Vessel weight	variable

Table 4.7, are three variables that have two alternatives. These variables are the dry dock internal height, dry dock internal width and the weight of the vessel. These alternatives all have a high value and a low value. By changing these alternatives one by one the impact of these parameter on the error is determined.

The dry dock is schematized as an U-shaped concrete structure, with the walls situated on top of the floor. This results in the dock floor being the internal width of the dock plus two wall thicknesses. For this verification 8 cases are checked.

Table 4.7: Verification cases concrete strutctures

Parameter	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Height	B	B	S	S	B	B	S	S
Width	G	G	G	G	M	M	M	M
Weight	H	L	H	L	H	L	H	L

With:
Height is the internal dock height; S=5m and B=18m
Width is the internal dock width; M=13m and G=24m
Weight is the vessels weight; L=20.000ton and H=60.000ton

Boundary condition
The boundaries for the DSS are as described in Paragraph 4.2. The dry dock is schematized in two models, like the DSS. The first model is the dry dock with shallow foundation and the second is the dry dock with pile foundation.

When the pile foundation is used, the piles are schematized as a linear spring at the centre of the spring. The spring constant is taken at 100N/m/m (A. Verweij, geological expert Arcadis), this is a schematization.

In the case of shallow foundation, the soil is schematized as uncoupled springs under the whole structure. In this case the spring is not linear as in the case of pile foundation but nonlinear with a downward pressure constant of 20N/m/m and an upward pressure constant of 0N/m/m. The upward pressure constant is taken at zero because a shallow foundation cannot resist upward pressure.

Results
The results of the verification for the eight cases are described in Appendix 8.4. Appendix 8.5 presents the SCIA report and the DSS results from case 1. Table 4.8 shows the results from the error of the maximum shear stress determined in these 8 cases, Table 4.9 gives the results of the error of the maximum bending moment. If the results are positive it means that the DSS underestimates the SCIA results, negative means the DSS overestimates the SCIA results. A minus (-) means that this option is not possible because the upward water force is more than the downward force of the structure, this follows from the DSS and SCIA. The shallow foundation without vessel in the cases 1, 2, 5 and 6 are left empty. In these cases the upward force is higher than the downward force, this would result in uplift, which will cause the foundation to fail.

Table 4.8: Verification results concrete cases; shear stresses

Error max shear stress [%]			case 1	case 2	case 3	case 4	case 5	case 6	case 7	case 8
Wall			0	0	0	0	0	0	0	0
Floor	shallow foundation	without vessel	-	-	-4	-4	-	-	10	10
		with vessel	-6	-6	-51	-53	0	42	-27	-15
	pile foundation	without vessel	40	66	9	69	20	20	6	6
		with vessel	26	39	-37	-1	13	13	5	-3

Table 4.9: Verification results concrete cases; bending momentum

Error max bending momentum [%]			case 1	case 2	case 3	case 4	case 5	case 6	case 7	case 8
Wall			0	0	0	0	0	0	0	0
Floor	shallow foundation	without vessel	-	-	-58	-58	-	-	0	0
		with vessel	-20	-20	-52	-51	-10	1	-10	-9
	pile foundation	without vessel	1	1	-119	-76	1	1	-2	-2
		with vessel	-18	-15	-63	-59	-3	-3	-12	-10

Shear stresses

From these results, given in Table 4.8, can be concluded that the DSS results are not adequately reproduced with the results from SCIA. The error is due to the schematization of the foundation forces into one uniform load. From the SCIA results it becomes clear that the parts where larger forces press on the floor, the foundation will locally adapt more force, as described in Figure 4.14 and Figure 4.15. Figure 4.14 shows the resulting force from the shallow foundation on the dry dock and Figure 4.15 shows the resulting force from the pile foundation on the dry dock. The Figure 4.14 shows that the forces from the shallow foundation are not uniform and the right figure shows that the forces on a pile foundation can consist of upward and downward forces. In the case of shallow foundation without vessel, the results are more in line. In this case, the loads on the floor are more uniformly distributed causing the reaction force from the foundation also to be more uniform.

Bending momentum

The momentum working on the floor is also not adequately represented by the DSS, as described in Table 4.9. Only in the cases when the largest momentum in the floor is the same as in the wall, the results are accurate. The error in the momentum is due to the incorrect reaction forces of the foundation, as described with the shear stresses. If the shear stresses are correctly represented but the momentum is not, it means that there is an error in the shear stress diagram. The maximum of this diagram can be the same as the DSS but the form can be for example more parabolic instead of linear.

4.3.3 VERIFICATION DSS CONCLUSION

The verification describes the embedded anchor walls situated in a sand or mixed soil layer with one anchor, the DSS provides results in line with 25% accuracy wanted for the preliminary design compared with those obtained using verified models. In case of clay soil profile the results from the DSS deviates from D-Sheet, due to an oversimplification of the formula to calculate the anchor force, when situated in a cohesive soil type. The calculations with the cohesive parameters are implemented wrongly in the DSS. When changes in the calculations, as proposed, are implemented in the DSS the calculations made give an accurate result within the limits for preliminary design, which is 25%. The calculations for the embedded anchor wall can be used in sand and mixed soils. But when it is situated in a cohesive soil the DSS will give inaccurate results.

The verification on the concrete calculations presents precise results for the concrete wall calculation and for the floor on shallow foundation without a vessel. For the other floor calculations, the shallow foundation with vessel and the floor with pile foundation with or without vessel, the results are not within the 25% accuracy range from the SCIA engineering results. The error is due to the schematization of the foundation. In this schematization the reaction forces from the foundation are a constant, resulting in an evenly distributed reaction force. From the SCIA results it can be concluded that this is an oversimplification. For future studies it is recommended to schematize the foundation as a spring system, so it can locally resist more force.

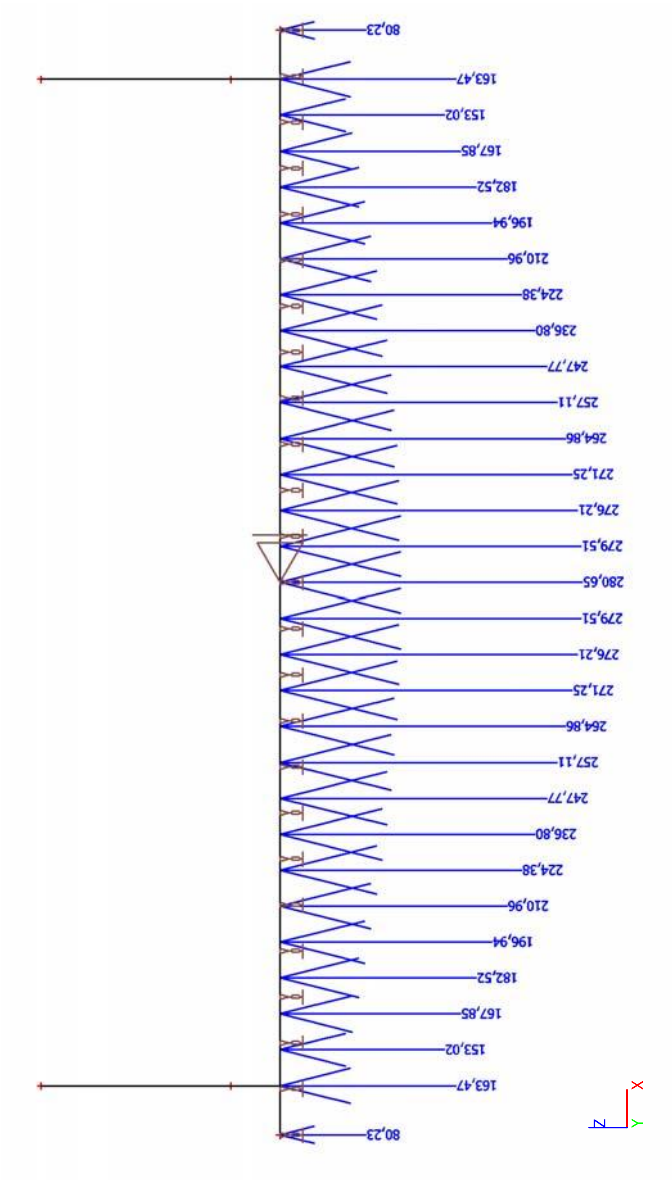


Figure 4.14: Case 3; pile; with vessel

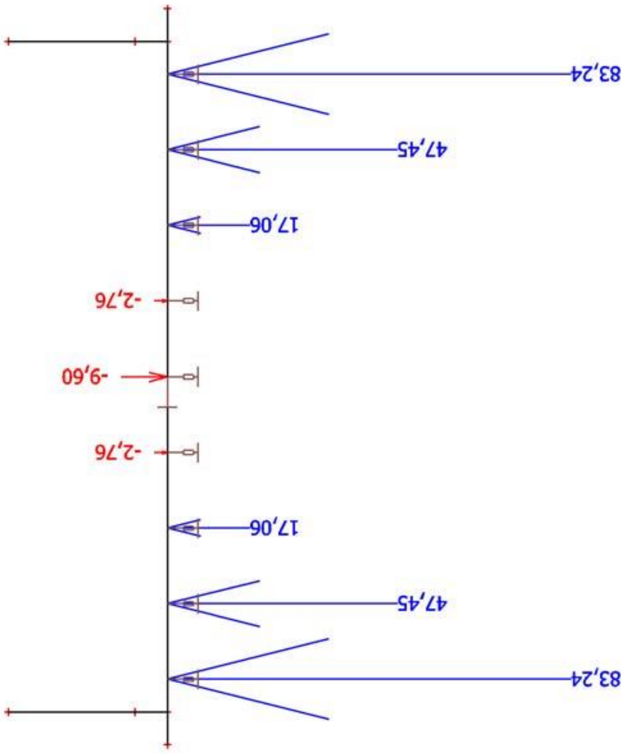


Figure 4.15: Case 3; pile; without vessel

4.4 VALIDATION DSS BY MEANS OF A CASE STUDY

The validation is done to check if the DSS produces the outcome that can be used in the design of dry docks. To check if the DSS generates a proper design, the design from the DSS is validated by comparing the outcome of the DSS with a case study on dry docks. This case study is done by Arcadis, for the preliminary design of a dry dock. In this validation the types for the construction method, type of wall, floor and gate is compared to the results from the case study. This validation describes if the outcome is comparable to the outcome of a real case study. The dry dock in this case study is confidential, therefore all names and confidential information is kept out of this thesis.

This case study is prepared for the construction of a dry dock along a tidal river. The dock will be used for manufacturing and modification of support vessel for the offshore market. This means that the dock type will be a vessel building dock.

The validation in this paragraph describes two cases. In the first case a design is made with the input parameters given in Paragraph 4.4.1. In the second case the design is made with the dock dimensions the client wants, this is the actual case Arcadis has investigated. Both options are investigated to determine the differences in forces calculated by the DSS and by D-sheet. With the forces from the DSS only anchor forces are calculated and with D-Sheet anchor and strut forces are used. Figure 4.16 visualises the steps that are taken in this paragraph.

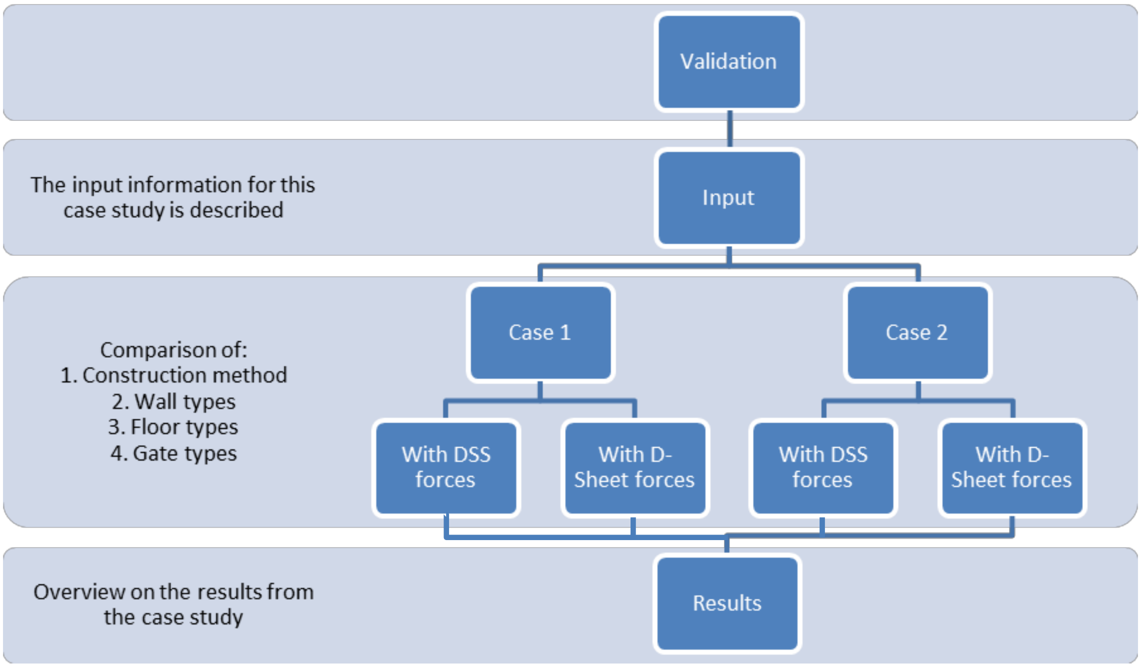


Figure 4.16: Flow chart validation

4.4.1 INPUT

The vessel used in this case study is named the '*Design Vessel*' in the DSS and has the following dimensions:

- LOA 206,4 meter
- Width 35 meter
- Draught 12 meter
- LWT 60.000 tonnage

The soil layers are the same as the mixed layers described in Appendix 8.1, only the ground level starts 4 meters higher, as given in Table 4.10.

Table 4.10: Soil condition case study

Layer	Depth +NAP [m]	Density [kN/m3]	φ [degree]	Cohesion [kPa]
Sand (landfill)	4	19	30	0
Clay (soft)	1,8	14	18	5
Sand (loose)	-4,3	19	30	0
Clay (moderate)	-10,3	18	23	10
Sand (loose very silty)	-23,3	20	27	0
Sand (silty moderate)	-33,3	20	35	0
Sand (moderate)	-60	20	30	0

Furthermore are the following boundary conditions:

- MHWN 0,8m+NAP
- Groundwater level 0,6m-NAP
- Density concrete 25kN/m3
- Density water 10kN/m3
- Gravitational acceleration 9,81 m/s2

The technical and functional requirements are filled in by Arcadis main designer from the case study. The information input information is given Appendix 9.1.

4.4.2 RESULT CASE STUDY

The first step is the comparison of the dry dock dimension result. The DSS results of the dimensions are based on the vessel dimensions. Given the input the following dimensions are determined:

Table 4.11: Dry dock dimension case study

Dock	DSS	Case study	[-]
Length	221,6	240	m
Internal width	41	48	m
Depth	-14	-12	m + NAP
Sill level	-12,4	-10,4	m +NAP
Level top gate	1,6	4	m +NAP
Entrance width	35,6	42	m

Table 4.11 describes that the case study results deviate from the results obtained with the DSS. The dimensions from the case study are not based on the design guidelines but on dimensions the client specifically requested Arcadis to use. To investigate the difference between these results, the option of the dimensions determined by the DSS is investigated firstly and then the option of the client is used to keep in line with the case study.

In this case study the dock is built with an underwater concrete layer. This layer has two advantages, namely that it makes it possible to built the dock in the dry and that this layer acts as a strut for the embedded cofferdam walls. In the DSS it is not possible to calculate the strut forces therefore there are two options to be taken into account for both cases, input DSS and input case study. The first option is calculating the anchor force with the DSS excluding the strut. The second option is to use the anchor force and strut force calculated by D-Sheet in the DSS.

4.4.2.1 *RESULT WITH DSS INPUT (CASE 1)*

The outcome of this case is given in Appendix 9.2, for the option with anchor force calculated with the DSS, and in Appendix 9.3, for the case that the anchor and strut force are calculated by D-Sheet.

Construction method

The outcome of the construction method calculations, given in Table 4.12, describes that it is not possible to use open excavation or retaining walls without the help of an underwater concrete layer. When a deep grouted layer is used, this should be done at an extreme depth of 120 m-NAP. When underwater concrete is used, it should have a thickness that should be more than 10 meter. Therefore it is recommended to use an underwater concrete layer that is anchored or in combination with an under drainage system.

Table 4.12: Trade-Off Matrix construction method

	Construction method			
	Method	Safety factor		
1	Open excavation with slopes	2,1		
2	Retaining walls (impermeable1)	N.A.		
3	Retaining walls (impermeable2)	2,1		
4	Retaining walls (impermeable3)	1,1		
5	Retaining walls with underwater concrete	1,0	9,99	meter concrete
6	Retaining walls with deep grouted layer	1,0	-120,6545555	m+NAP

Wall type

Anchor by DSS, no strut

In this case there are four options possible, namely the caissons, cellular, cantilever and counterford wall, as shown in Table 4.13. The technical score is the highest for the embedded anchor wall, but the maximum momentum determined is 9926 kNm/m, which is too high for the embedded anchor walls, as described in Paragraph 3.4.1.2. Therefore it is not possible to use this type. The concrete wall will require a thickness of 2.3m. The DSS report of this outcome is given in Appendix 9.2. Table 4.13 indicates the costs for the concrete walls, sheet-pile walls and combined walls, as described in Appendix 6.5. This option can be extended to all wall types to make a more financial based decision for the client.

Table 4.13: Trade-Off Matrix wall type

	Wall trade-off			
	Wall type	***Technical score***	***Total score***	***Cost***
	Gravity dry dock walls	22,6		
1	Caissons walls		139	
2	Cellular walls		103	
	L-Shaped walls	23,1		€ 10.343.288
3	Cantilever		196	
4	Counterfort		183	
	Embedded anchor walls	31,2		
5	Sheet-piled walls		X	€ 6.583.769
6	Combined walls		X	€ 9.777.939
7	Embedded cofferdam walls		X	
8	**Diaphragm walls**	25,5	X	
9	**Soil or rock slope walls**	X	X	

Anchor and strut force by D-Sheet

From calculations with D-Sheet the following forces are determined and used in the DSS:

- Anchor force of 572 kN/m
- Strut force 2817 kN/m

By using these forces the maximum momentum determined in the wall is 2637,6 kNm/m. This is too high for the sheet-piled walls, but a construction using a combined wall and diaphragm wall is possible to use. Table 4.14 gives the result of this Trade-Off Matrix. Based on the DSS, the combined wall or diaphragm wall is recommended. For building the dry dock, the combined wall scores higher on the functional requirement in comparison with the diaphragm wall.

Table 4.14: Trade-Off Matrix wall type (anchor and strut by D-Sheet)

	Wall trade-off			
	Wall type	***Technical score***	***Total score***	***Cost***
	Gravity dry dock walls	*22,6*		
1	Caissons walls		139	
2	Cellular walls		103	
	L-Shaped walls	23,1		€ 10.343.288
3	Cantilever		196	
4	Counterfort		183	
	Embedded anchor walls	31,2		
5	Sheet-piled walls		X	€ 6.583.769
6	Combined walls		213	€ 9.777.939
7	Embedded cofferdam walls		204	
8	**Diaphragm walls**	25,5	160	
9	**Soil or rock slope walls**	X	X	

Floor type

The outcome of the floor type Trade-Off Matrix is shown in Table 4.15. From this table it can be concluded that the uplift force due to water pressure is best retained by an under-drained floor. When a gravity floor is used, it requires a thickness of 6m. In case of the under-drainage or pile variant, a thickness of 2,6m is required. The under-drainage option scores better than the pile option because it is not possible to use shallow foundation due to the low bearing capacity of the ground. Therefore a pile foundation is required. It is not advisable to use piles for both upward and downward forces because this reduces the cohesion between the piles and the ground, reducing the capacity to handle these forces (British Standards 2013). The costs indication is based on the floor volumes used.

Table 4.15: Trade-Off Matrix floor type

	Floor trade-off		
	Entrance Floor Type	***Technical score***	***Total score***
	Uplift alternatives		
1	Under-drained floors	10	239
2	Gravity floors	0	0
3	Tied floors	5	197
	Bearing alternatives		
4	Shallow foundation	0	0
5	Pile foundation	10	308

Under-drained with shallow foundation	€	4.525.603,16	+under draining cost
Under-drained with pile foundation	€	12.613.331,99	+under draining cost
Gravity with shallow foundation	€	11.642.816,45	
Gravity with pile foundation	€	18.245.772,87	
Tied with shallow foundation	€	12.613.331,99	
Tied with pile foundation	€	12.613.331,99	

Gate type

The gates that are recommended, following the Trade-Off Matrix, are firstly the free-floating caissons and secondly the sliding or rolling caisson gate that uses de-ballasting. The scores are given in Table 4.16.

Table 4.16: Trade-Off Matrix gate type

	Gate trade-off **Entrance Gate Type**	**Technical score**	**Total score**
	Flap gate		
1	Spanning Box	34	253
2	Strutted	34	239
3	Cantilever	34	230
	Floating Caisson Gate		
4	Free	35	321
5	Hinged	32	272
6	Sliding or rolling caisson gate	X	X
	Sliding or rolling caisson gate (deballasting)	35	285
7	Mitre gates	X	X
8	Sector gates	X	X
	Intermediate gates		
	Modular units installed by crane		
9	Inverted "Y"	X	X
10	Lambda “λ”	X	X
11	Stop logs	X	X

4.4.2.2 *RESULT WITH CLIENT INPUT (CASE 2)*

For the calculation of the embedded anchor walls the depth used is 14m-NAP, where the top of the floor is at 12m-NAP. In this case Arcadis has estimated firstly that the floor will be 2 meters thick. These assumptions are also used in this case. The results of the DSS is given in Appendix 9.4.

Construction method

The outcome of the construction method calculations with the DSS, described in Table 4.17, shows that it is possible to use retaining walls without underwater concrete. A note must be placed, that this is a silt sand layer, where it is not fully clear how impermeable this layer is. When this construction method is chosen further soil investigation is required to verify this layer and the depth of this layer. The underwater concrete would be the second ranked recommended solution for the construction method in case the retaining walls are determined to be insufficient.

Table 4.17: Trade-Off Matrix construction method Client

	Construction method			
	Method	Safety factor		
1	Open excavation with slopes	1,5		
2	Retaining walls (impermeable1)	N.A.		
3	Retaining walls (impermeable2)	1,5		
4	Retaining walls (impermeable3)	1,0		
5	Retaining walls with underwater concrete	1,0		9,99 meter concrete
6	Retaining walls with deep grouted layer	1,0	-120,6545555	m+NAP

Wall type

Anchor by DSS, no strut

The results of the wall are shown in Table 4.18. In this case the results are the same as given in Table 4.13. The difference between these two tables is in costs, because the dimensions are different. The maximum moment determined in this case is 6113 kNm/m with an anchor force of 979 kN/m, causing the options of embedded anchor walls to be non-viable.

Table 4.18: Trade-Off Matrix wall type Client

	Wall trade-off			
	Wall type	***Technical score***	***Total score***	***Cost***
	Gravity dry dock walls	22,6		
1	Caissons walls		139	
2	Cellular walls		103	
	L-Shaped walls	23,1		€ 9.589.886
3	Cantilever		196	
4	Counterfort		183	
	Embedded anchor walls	31,2		
5	Sheet-piled walls		X	€ 6.801.048
6	Combined walls		X	€ 9.917.515
7	Embedded cofferdam walls		X	
8	**Diaphragm walls**	25,5	X	
9	**Soil or rock slope walls**	X	X	

Anchor and strut force by D-Sheet

From calculations with D-Sheet the following forces are calculated and used in the DSS:

- Anchor force of 424 kN/m
- Strut force 2042 kN/m

By using these forces the maximum moment calculated in the wall is 2515 kNm/m. This is still too high for the sheet-piled walls, that can handle 2156 kNm/m. The result of this Trade-Off Matrix, given in Table 4.19, is the same as given in Table 4.14.

Table 4.19: Trade-Off Matrix wall type Client (anchor and strut by D-Sheet)

	Wall trade-off			
	Wall type	***Technical score***	***Total score***	***Cost***
	Gravity dry dock walls	22,6		
1	Caissons walls		139	
2	Cellular walls		103	
	L-Shaped walls	23,1		€ 9.589.886
3	Cantilever		196	
4	Counterfort		183	
	Embedded anchor walls	31,2		
5	Sheet-piled walls		X	€ 6.801.048
6	Combined walls		213	€ 9.917.515
7	Embedded cofferdam walls		204	
8	**Diaphragm walls**	25,5	160	
9	**Soil or rock slope walls**	X	X	

Floor type

The results of the floor Trade-Off Matrix, given in Table 4.20, gives the same results as with the calculations with the design vessel in the previous paragraph. The costs are different because of the difference in dimension.

Table 4.20: Trade-Off Matrix floor type Client

	Floor trade-off		
	Entrance Gate Type	***Technical score***	***Total score***
	Uplift alternatives		
1	Under-drained floors	10	279
2	Gravity floors	0	0
3	Tied floors	5	237
	Bearing alternatives		
4	Shallow foundation	0	0
5	Pile foundation	10	355

Under-drained with shallow foundation	€	5.290.145,62	+under draining cost
Under-drained with pile foundation	€	14.853.205,63	+under draining cost
Gravity with shallow foundation	€	12.831.528,24	
Gravity with pile foundation	€	20.587.905,46	
Tied with shallow foundation	€	14.853.205,63	
Tied with pile foundation	€	14.853.205,63	

Gate type

The wall Trade-Off Matrix, shown in Table 4.21 gives the same results as the design in the previous paragraph

Table 4.21: Trade-Off Matrix gate type Client

	Gate trade-off Entrance Gate Type	Technical score	Total score
	Flap gate		
1	Spanning Box	34	253
2	Strutted	34	239
3	Cantilever	34	230
	Floating Caisson Gate		
4	Free	35	321
5	Hinged	32	272
6	Sliding or rolling caisson gate	X	X
	Sliding or rolling caisson gate (deballasting)	35	285
7	Mitre gates	X	X
8	Sector gates	X	X
	Intermediate gates		
	Modular units installed by crane		
9	Inverted "Y"	X	X
10	Lambda “λ”	X	X
11	Stop logs	X	X

4.4.3 VALIDATION RESULTS

This paragraph gives the overview on the results from the validation in comparison with the case study done by Arcadis. The outcome for the different objects is given in Table 4.22.

Table 4.22: Validation results

Object	DSS		DSS Client		Arcadis
Construction method					
1. Retaining wall	Not possible		Possible		Not possible
2. Underwater concrete	Possible		Possible		Possible
Wall					
Anchor force by	DSS	D-Sheet	DSS	D-Sheet	
1e	Cantilever	Combi	Cantilever	Combi	Combi
2e	Counterfort	Cofferdam	Counterfort	Cofferdam	Cantilever
3e	Caisson	Cantilever	Caisson	Cantilever	
Floor					
	Underwater concrete with pile foundation		Underwater concrete with pile foundation		Floor with tensile /compression piles
Gate					
1e	FFC		FFC		FFC
2e	SRCD		SRCD		F
3e	HFG		HFG		

FFC= Free Floating Caisson gate

SRC= Sliding or Rolling Caisson De-ballasting gate

HFG=Hinged Floating Caisson gate

F= Flap gate

Construction method

The outcome of the construction methods corresponds with those obtained by Arcadis. Only when using the clients' input in the DSS the case of retaining walls seems possible. However, as described in Paragraph 4.4.2.2 the option is on the limit of what is possible and therefore it is recommended to first further investigate the soil layer before using this option.

Wall type

As described in Paragraph 4.3.1, the calculation of the forces is not accurately calculated by the DSS, which causes a deviation for the outcome of the walls from the DSS in comparison with Arcadis design. This is due to the incapability of the DSS to calculate not only the anchor force but also the strut force. The DSS only calculates with an anchor force, causing the moment within the wall to get too high, leading to the failure of a combined wall. When the anchor and strut forces are calculated using a different program this problem is solved. From Table 4.22 the outcome from the DSS is in coherent with the outcome of Arcadis. Arcadis has made the decision to check only one embedded anchored wall, the combined wall, and one concrete wall. The DSS shows that a cofferdam could also be an interesting option.

Floor type
To design the floor, the DSS recommends to build a concrete floor with an under-drainage system and a pile foundation. Arcadis recommended piling foundation for tensile and compression forces. In the literature it is strongly advised against to use piles for tensile and compression forces, due to the loss of cohesion between the pile and ground (Kuhn 1988, Defense 2012, British Standards 2013).

After discussing with an Arcadis expert, it became clear that there was a lack of soil information to be certain that an under-drainage system was possible or required. In addition there was a lack of time to investigate this solution.

Gate type
The first option for the gate type is similar for both cases. Only as second option Arcadis recommended to use a flap gate. This recommendation is due to the fast opening and closing of this gate, shortening the docking procedure. When a client wants this requirement for the docking procedure the technical requirements must be changed within the DSS, changing the operation speed from 1 day to one hour, to change the result of the DSS.

4.5 CONCLUSION

This chapter describes the design, verification and validation of the Decision Support System (DSS), which for this subject is chosen to be an Excel based system. The design is created with the guidance of the literature study on DSS and the design rules described in Chapter 3. The DSS gives guidance on which option for construction method, wall type, floor type and gate type are possible and preferred in the preliminary design of a dry dock. The capability to use an alternative is checked by comparing the technical requirements for the different types with the project specific situation. When the types that are possible are determined, they are weighted against the functional requirements by means of a Trade-Off Matrix.

The design of the DSS is described by the four components that all DSS consist of, the Language System (LS), Knowledge System (KS), Problem-Processing System (PPS) and the Presentation System (PS).

The verification describes that for the embedded anchor walls situated in a sand or mixed soil layer with one anchor, the DSS provides results in line with the 25% accuracy range wanted for the preliminary design compared with those obtained using verified models. In case of clay soil profile the results from the DSS deviates from D-Sheet, due to an oversimplification of the formula to calculate the anchor force, when situated in clay. When the proposed changes are implemented the calculations made give an accurate result within the limits for the preliminary design stage.

The verification of the concrete calculations presents precise results for the concrete wall calculation and for the floor on shallow foundation without a vessel. For the other three floor calculations, the shallow foundation with vessel and the floor with pile foundation with or without vessel, the results are not within the 25% accuracy range from the SCIA engineering results. The error is determined in the schematization of the foundation. In this schematization the reaction forces from the foundation are a constant, resulting in an evenly distributed reaction force. From the SCIA results it can be concluded that this is an oversimplification. For future studies it is recommended to schematize the foundation as a spring system, so that the resisting force can deviate locally.

The validation is done for the one case study available, provided by Arcadis. From the result of this validation it can be concluded that the results from the DSS gives comparable results as the case study on the different types of construction method, gates and floor. The wall results are not the same as the case study. This is due to excluding strut forces in the DSS calculation, which result in other reaction forces and requirements. The DSS is not capable to calculate the combination of an anchor with a strut. Therefore a higher moment is determined in the wall, this causes the embedded anchor wall option to be excluded. When these anchor and strut forces are known the wall Trade-Off Matrix gives the same results as the case study.

In this case study two different types of gates are described, these gates vary in opening speed. In the preliminary design projects the choice for different types are often not based on one input but the effect of different inputs is evaluated, for example: the effect of fast or slow closing gates on the whole design, as in the case study. This can also be investigated by the DSS by running the DSS multiple times with different technical requirements.

The DSS is easy to use, one page where information has to be put in and it makes use of macros to perform the calculations. Also inexperienced dry dock designers can use this program to obtain a first impression on the design of a dry dock. As described in the validation, the DSS gives a good overview on the possible alternatives for the preliminary design of a dry dock. However, the DSS is not easily adjustable and the formulas used, are long and complex.

Concluding, the DSS is a system that can be used to make a choice between the different object types. But when the DSS is used in the present state the following points needs to be taken into account:

- It is only possible to calculate with one anchor.
- The anchor force is only reliable when it is situation in non cohesive soil.
- The floor thickness calculation can only be used in the case of shallow foundation without a vessel. It is not known in advance if this is the limiting state en therefore it cannot be used.
- The DSS only calculates the sheet pile wall, combined wall and concrete wall in a quantitative method the other wall types are described in a qualitative manner.

5 Integration of Building Information Modelling

5.1 INTRODUCTION

In this chapter the option of implementing Building Information Modelling (BIM) for the preliminary design of a dry dock is investigated. In Chapter 3 is discussed what objects of a dry dock are the most crucial to address in a preliminary design of a dry dock and what corresponding design rules are applicable to these objects. In Chapter 4 the design of the DSS is described. The DSS will provide a step by step first design of the dry dock. Using a Trade-Off Matrix helps substantiate the type of construction method, wall type, floor type and gate type that is preferred for a specific case.

To give a visual view on how the design will look like a 3D drawing can be made with the use of BIM. Revit is used to create the design, as described in Paragraph 2.6.4, this is the standard BIM program that Arcadis uses. Revit has a simple user interface that has options to couple parametric design and SE in the BIM.

The software that BIM supports is in a stage of development. This chapter investigates the options that are now available to couple SE and CAD program with BIM. Due to the on going development of this software new options, created within the market, need to be investigate to check if these can facilitate the process in this specific project.

The flowchart, in Figure 5.1, describes the main steps to come to a 3D Revit design for the BIM model of a dry dock. To investigate how the design can be coupled to BIM Paragraph 5.2 investigates the options of making the design BIM ready by:

- Firstly investigate how the outcome of the DSS can be coupled to a Revit model, this is described in Paragraph 5.2.1.
- Secondly it is investigated how the SE can help the development of the BIM model, this is described in Paragraph 5.2.2.

In Paragraph 5.3 an example of an object from the DSS developed to BIM is given. Finally Paragraph 5.4 gives the pros and cons determined in this example and Paragraph 5.5 gives the conclusions.

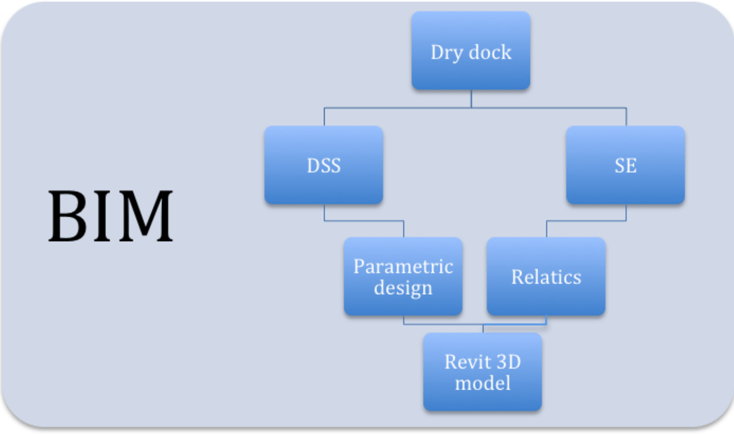


Figure 5.1: Flowchart Chapter 5

5.2 BIM READY

BIM ready means, as mentioned in Paragraph 2.6.3, to make the parametric design, created with DSS, fit to be used in a BIM model. This will be done by investigating the options on how BIM can be implemented and how it should work. Developing the BIM software for this purpose is not part of the scope of this thesis. Though as described in Chapter 6 it is recommended to pursue this option.

Firstly it is investigated how the DSS design can be exported to a BIM model, in this case Revit. This model is chosen because it is often used within Arcadis. Secondly it is investigated how the information from the design can be coupled to the design made in Revit. The information is described with SE and therefore it is investigated how SE can be coupled to Revit.

5.2.1 COUPLING DSS WITH REVIT

To couple the design from the DSS with Revit the following 5 steps need to be taken:

1. Make families of objects in Revit that can be changed with parameters
2. Determine the parameters from DSS
3. Export parameters from DSS to Notepad
4. Import Notepad parameters to Revit
5. Use family

Step 1: Make families of objects in Revit that can be changed with parameters
A family is an object within Revit. For example a concrete wall is a family within Revit, in the DSS it is called an object. In Revit it is possible to create a project, in this case the design of a dry dock, and a family, in this case the concrete wall. Within a project multiple families, such as a wall, floor and gate, can be added to create the dry dock design.

All the objects that are designed within the DSS must be created with parameters in Revit. These objects are the different objects that the designer requires for the preliminary design of the dry dock (e.g. wall types, floor types, gate types, etc.).

In Revit it is possible to subscribe parameters to a family, in the case of a concrete wall these can be the width, length and height. By entering the parameters, Revit automatically draws the object.

When this is determined it is possible to couple these parameters to the DSS as described in the next steps.

Step 2: Determine the parameters from DSS
The parameters described in the previous step must be determined from the DSS. For the concrete wall these are thickness, length and height. By placing the different dimensions of the objects in a new sheet it remains organised which values are coupled with each object.

Step 3: Export parameters from DSS to Notepad
With the help of a macro (to be developed) it is possible to export the parameters determined in the DSS to a Notepad file. The name and the dimensions of the parameters must be the same in the DSS, Notepad and Revit.

Step 4: Import Notepad parameters to Revit
When the family of the wall is opened in a Revit project it is possible to import the parameters from the Notepad to the object that is designed.

Step 5: Use object
The object can now be used in the Revit design. In Figure 5.2 is an example that shows the 3D sketch design of a dry dock in Revit. This is a sketch of the case study from Paragraph 4.4.

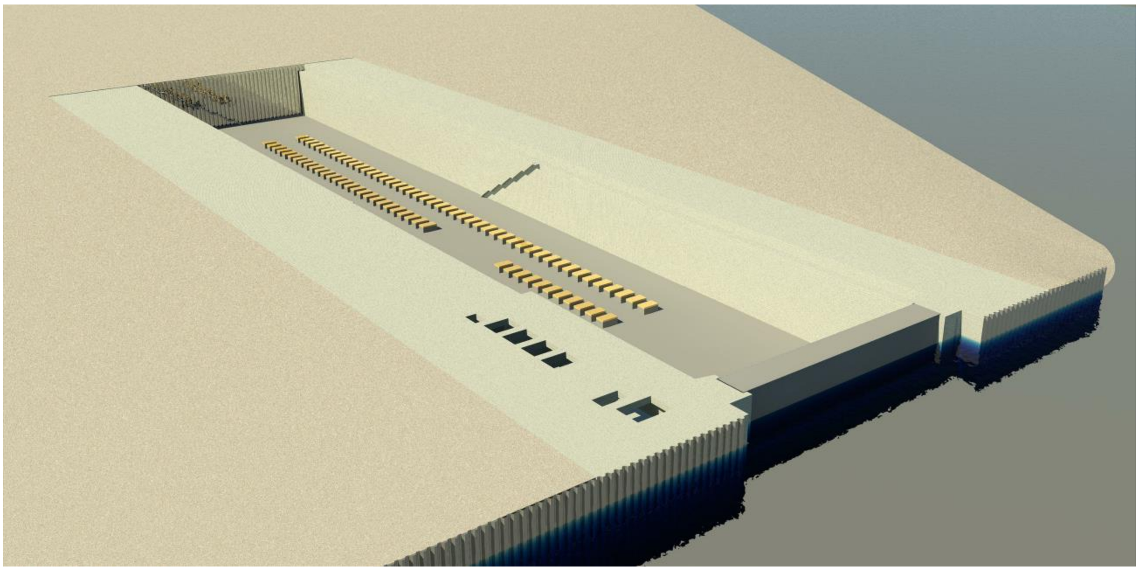


Figure 5.2: Case study design dry dock in Revit (Arcadis 2014)

5.2.2 COUPLING SE WITH REVIT

Revit has an option to couple SE with the design made in Revit. In Chapter 3 an object decomposition is made for a dry dock. This object decomposition describes which objects are required during the design process of a dry dock. Within Revit it is possible to couple the requirements described in Chapter 3 to these objects. The objects and requirements can be coupled with the design in Revit. The advantage of coupling the objects to the design in Revit is that a check can be done to determine if all the objects needed for the design are present. The input of requirements in Revit allows for checking if all objects designed fulfill to the specific requirements.

To couple SE with Revit the following 5 steps need to be taken:

1. Export object decomposition from Appendix 2 into Relatics
2. Determine the different objects per design stage
3. Determine the requirements per object
4. Couple objects designed in Revit with objects from Relatics
5. Check if the object fulfills to the requirements

Step 1: Export object decomposition from Appendix 2 into Relatics

Relatics is a web-based database where decompositions can be filled in and accessed by different parties. To get all the objects in Relatics, the object decomposition, described in Paragraph 3.2.2, can be put in the Relatics database.

Step 2: Determine the different objects per design stage

To use BIM within all the design stages, described in Paragraph 2.3, it is advised to divide the objects in these different stages. With the interaction of Relatics with BIM a check can be performed to see if all the required objects of that design stage are accounted for.

Step 3: Determine the requirements per object

It is possible within Relatics to classify all the system requirements. These requirements are coupled to the objects so it can be checked if all the objects fulfill these requirements. Another possibility is to add information about who is responsible for the object, the contract for the object, interfaces between objects, etc.

Step 4: Couple Objects designed in Revit with objects from Relatics

Arcadis has a tool that connects the Relatics objects with the objects from Revit. By using this tool, an object can be selected in the Revit project and coupled to an object in Relatics. An object can be selected in Revit and with a pop-up screen it shows the information from the Relatics database.

It is only possible to couple one Revit object to one Relatics object, but it is possible to couple one Relatics object to multiple Revit objects. This means that all information that a Revit object needs must be in one Relatics object. For example, a wall in the length position of a dock can have different requirements than a wall in the width direction. It is therefore not possible to give these walls in Revit the same Relatics object. These must be segregated in Relatics. But for both length walls, that have the same requirements, one Relatics object can be used.

Step 5: Check if the object fulfills to the requirements

The last step is to check if the objects fulfill all the requirements. From Revit it is possible to check if all requirements per object are completed. In the Relatics database it is described how the design fulfills to the requirements.

5.3 EXAMPLE OF PARAMETERIC DESIGN IN BIM

To check how 'BIM ready' can be implemented in this design, it is chosen to take the simple example of the object 'concrete wall'. For simplification only the length, thickness and height are taken into account. The reinforcement steel is therefore not taken into account.

In Revit an object is created with the parameters width, length and height. The dimensions of these parameters are determined from the information out of the DSS, see Figure 5.3. This is converted to a

Notepad file with the help of the macro button, called ' Make a family-txt'. The macro behind this button is explained in Appendix 10.

	A	B	C	D
1	Concrete Wall	height##LENGTH##MILLIMETERS	length##LENGTH##MILLIMETERS	width##LENGTH##MILLIMETERS
2	40000x10000x1700	18000,000000000000	206400,000000000000	2300,000000000000
3				
4				
5				
6				
7				
8		Make a family-txt		
9				

Figure 5.3: DSS output for concrete wall

When small changes are made, these can be exported to the Notepad file, creating a list of different dimensioned wall types that may be used. This list is then imported in Revit with the option 'Import Family Types'.

After importation of the family it can be used in the Revit project. From a list in Revit the dimensions of the family can be chosen. This is an easy setup that allows including a large number of different families, which together form the preliminary design of a dry dock, in Revit.

5.4 PROS AND CONS

This paragraph describes the pros and cons determined after the implementation of the concrete wall into BIM, as described in the example of the previous paragraph.

Pros

- Quick 3D sketch of design
- Pre defined objects can be re-used in other designs such as retaining walls
- Database to store all information
- Easy to adapt changes from the DSS in BIM
- Easy object and requirements check
- Families can be reused in other projects

Cons

- A lot of work to make the initial parametric object in Revit
- A lot of effort to create the macro's for the objects in the DSS

5.5 CONCLUSION

It is possible to implement BIM in the preliminary design of a dry dock. It helps to give a quick first visual 3D sketch design of the dry dock. Thereby SE can be implemented within BIM by using the software program Relatics, in this program the object decomposition can be posed and connected with requirements of the design. This supports checking if all the objects that are required for the particular design stage are designed in Revit and fulfills to all the SE requirements of this object.

However, it is time-consuming and resources intensive work to set up this model and obtain a design that is BIM ready. The different objects, such as the different wall types, must be designed parametrically in Revit. The outcome of the DSS must be categorized in the exact manner so it can be input by Revit.

After this initial time consuming and resource intensive work, it is easy to get a quick 3D design of the dry dock. From this design it is possible to get a material take off, that can be used to make a quick cost estimation. Whenever these objects are defined within Revit it is possible to use these different objects in other projects, by selecting these from the Revit library, that can be shared within the company where it is designed.

It is therefore recommended to use BIM in the design process of a dry dock because with the DSS coupled to BIM a quick 3D sketch of the design can be created, it uses a database to store all information of the project in one location and it supports an easy check on the fulfillments of the requirements. BIM not only supports the preliminary design, but can be used throughout the whole design process.

6 Conclusions and Recommendations

Based on the research question from chapter one and the results from the previous chapters, conclusions are drawn. Furthermore, recommendations for future research are given.

6.1 CONCLUSIONS

The conclusions are divided in 6 parts. The first five parts each consist each of one research question. These research questions are described in Paragraph 1.3. The last part gives the final conclusion on the research question at the beginning of this thesis *"to investigate the implementation of existing and new design methods for the creation of the preliminary design of dry docks"*.

What is the current design method of a dry dock?
The scope of this thesis focused on the first design stage, sketch design, conceptual design and preliminary design. In these phases the design is focussed on the main objects of a dry dock, which include the wall, floor and gate. Engineering firms are using different design manuals, such as British Standard (2012) and PIANC dry docks (1988), and design experience to develop the dry dock. New technologies such as System Engineering and BIM are not systematically applied.

What new design methods and tools can be used for the design of a dry dock?
There are three design methods that were investigated in this thesis: System Engineering (SE), Decision Support System (DSS) and Building Information Modelling (BIM).

The design method SE is based on a systematic way for the successful realization of large and complicated projects. It helps to give a structure in the development of a generic method for the preliminary design of a dry dock by working from an abstract client question to a concrete solution.

A DSS supports the decision making for a design. With a DSS it is possible to develop a quick and objective first estimation of the design based on only limited information. Such a system can be used in an on-going development and improves over time.

When a BIM model is coupled with a DSS, it is possible to create a quick virtual model of a civil structure, it uses one model to store all information of a design. This helps identifying conflicts between different objects in an early design stage. Combining all information in one model makes it easier to extend the design, therefore it can be used throughout all the design stages, where the BIM continuously (in the different design stages) is being developed and detailed.

What are the basic specifications of a dry dock?

The basic specifications consist of Functional Flow Block Diagram (FFBD), object decomposition and the requirements. The FFBD determines the main functions as '*conduct maintenance, repair and build activities on the underwater part of a vessel in a safe manner*'. To fulfill this function the five main objects are determined in the object decomposition, namely the gate, wall, floor, pump and terrain. The requirements consist of two parts: 1) the technical requirements test the types on the feasibility and 2) the functional requirements test which types score the best in the Trade-Off Matrix (TOM).

Is it possible to develop a generic and implementable design method for the preliminary design of a dry dock?

It is possible, with the help of basic calculations, to make a first estimation of the preliminary design. This is done by focussing on the main elements, as they are necessary to obtain a preliminary design. Excel makes it possible to develop a model that provides the desired output. However, simplification of formulas shows that not all phenomena were correctly represented. During the validation and verification the following conclusions were drawn:

- From the verification it became clear that for the embedded anchor wall type, the results in case of sand and mixed soil are accurate. When this wall is situated in a cohesive clay layer the calculations give inaccurate results. Mainly due to oversimplification of the anchor force calculations. The solution of this problem is to change the calculation for the horizontal active soil pressure in the DSS. It can now have a negative value due to the cohesion. If this is the case the cohesion must be neglected. The verification of the concrete calculations have shown that these are accurate for the wall and shallow floor without a vessel. However, in the other three cases, the shallow foundation with vessel and the floor with pile foundation with or without vessel, the DSS results for the floor are not adequately reproduced. This is due to the underlying assumptions made in the schematization of the foundation. These should be further developed to get a more accurate result.

- The validation reveals that when the anchor and strut forces from a D-Sheet piling calculation are used, the design from the DSS is in line with the design from the case study. The DSS is, however, not able to calculate the combination of anchor and strut force. In case only one anchor force is used the DSS overestimates the momentum in the wall causing the option of embedded anchor walls to be omitted while in the case study the embedded anchor wall was the preferred solution.

In general, despite the schematization of some of the underlying calculations, the DSS provides a quick preliminary design for the main objects of a dry dock. Given certain assumptions, this design is in line with the case study. It should be noted that this is only validated with one case study. Therefore it is advised to evaluate extra case studies to further validate the DSS.

What are the possibilities to integrate a Building Information Model for the preliminary design of a dry dock?

BIM supports the parametric design of objects and the use of SE for the design of dry docks. The objects determined in the DSS can be drawn parametrically in Revit, as shown with a concrete wall. In Revit the length, width and height of a concrete wall are parametrically determined. The values from the DSS can then be exported into Revit, creating the wall needed in a 3D Revit design. It is then possible to couple the requirements from SE for a wall with the wall designed in Revit by using Relatics. However, to develop a BIM model in which the objects from the design are BIM ready, is time-consuming and resources intensive. After defining these objects within Revit it is possible to use them to create a quick 3D design of the dry dock or other projects. From this design it is possible to get a quantity estimation of required materials, which can be used to develop a cost estimation.

The connection between Relatics and Revit supports a well-organized and structured design possible in multiple design stages. It describes which objects need to be designed in each design stage and which requirements these objects must fulfill.

To investigate the implementation of existing and new design methods for the creation of the preliminary design of dry docks.

From this investigation it has become clear that the implementation of SE, DSS, and BIM helps to create a quick preliminary design of a dry dock. The current DSS supports a qualitative choice by means of a TOM for the different construction methods, wall types, floor types and gate types. The TOM is divided into two steps, firstly it checks which types are possible, by means of the technical requirements TOM. Secondly it checks which is preferred by means of the functional requirements TOM.

The DSS also shows how it can be extended to make a quantitative choice for the different types by means of calculations. This has been done for the wall types: sheet pile, combined and concrete wall. The floor types on shallow and pile foundations with or without a vessel are also calculated. However the DSS still provides some inaccurate results, due to underlying assumptions in the formulas, it supports a quick first design of a dry dock. The model can be improved based on the recommendations included in the next section. With the help of BIM a quick first 3D sketch design can be created, with little effort, for each design that is given by the DSS.

6.2 RECOMMENDATIONS

A number of recommendations on further research are deduced based on the conclusion.

General DSS recommendations

- The DSS is only validated with one case study. Therefore it is recommended to include more case studies to further validate and optimize this DSS
- The calculations that have been made in the DSS do not include safety factors, because these vary by country. For further development it is advised to add these into the calculations
- Keep the DSS in a stage of development, hereby preventing the DSS to get out-dated and insuring that the newest standards are used
- Add boulder forces and top loads in the calculations of the DSS, these are neglected but can have a significant impact on the whole design
- Extend the DSS calculations for the wall types that are not in the scope of this thesis, this complements the design options within the DSS
- Implement the costs for all objects, as has been done for the sheet pile wall, combined wall, concrete wall and floors

Embedded anchor wall recommendations

The following points are recommended for further investigation on the development of the embedded anchor walls:

- The anchor and strut forces calculations require improvement with the following points of attention:
  - Option to calculate the combination of strut and anchor forces within the wall
  - Option to calculate with multiple anchors
  - Anchor force and strut forces in clay layers

  The DSS experiences inaccuracies in the momentum calculations: in the existing schematised calculations of the DSS the anchor and strut forces appear not to be represented with sufficient accuracy. This underlines the importance of further detailing these calculations.
- Within the embedded anchor wall calculations no account is taken of the normal force within the walls, this can influence the choice for a wall type. Therefore these calculations should be added.

Concrete calculation recommendations

For the further development of the DSS the following points are recommended to determine the concrete objects in a more accurate way, the first one is required to create a design for all the floor calculations and the last three will support a more accurate result for the concrete thickness:

1. Change the uniform foundation into a spring system, this will result in more realistic representation of the actual floor forces
2. Temperature can play a part in the design of concrete. This is neglected for this preliminary design but is recommended to add in the DSS
3. The concrete calculations assume that the concrete is non-cracked. This can result in an overestimation of the concrete strength. A situation of cracked concrete must be examined, to learn what the difference is between the two situations
4. In the floor calculations a symmetric load is schematized in the middle of the dry dock. This is not always the case, a vessel can be situated off the centre of the dock. Therefore the influences of a non-symmetric load case should be investigated

Future vision on DSS

For future progression of DSS it is advised to develop a DSS that is coupled with different software systems. This way an easy usable interface software can communicate with different calculation programs. By using such software the calculations are not made with an Excel based program anymore but with already validated and widely accepted calculation programs. From these programs the most accurate approximations of the forces can be obtained and then used in the Trade-Off Matrix, which can still be Excel based.

In this case an application could be created where the input interface communicates with different programs through the internet. A designer only has to take his/her iPad to the client. In cooperation with the client the initial and boundary conditions can be discussed and added to the DSS. With this information the DSS creates a quick first estimation of the design. In combination with BIM a virtual 3D image can be created with a walk-through animation so the client gets a first impression how the dry dock will look like when it is finished.

A second vision is that the DSS can be extended so that all objects, described in the object decomposition, are implemented in the DSS. With all the objects implemented a more precise result is given on the final design of a dry dock.

Finally it is advised to use these new techniques because they support an organised, objective and quick preliminary design of a dry dock, without the need of making extensive calculations.

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Appendix 1 Functional decomposition

This appendix describes the functional decomposition and the functional requirements of a dry dock. The functional decomposition is made with a Functional Flow Block Diagram, as described in Paragraph 2.4.2. This analysis is made by investigating the design manuals on dry docks, as described in Paragraph 2.2.3, checking previous dry dock design, field visit to dry docks and interviewing Arcadis experts on the design of dry dock.

6.2.1.1 FUNCTIONS

The main function is given at the top of the decomposition and is 'to conduct maintenance, repair and building activities on the underwater part of a vessel in a safe manner'. To realize this main function the system has to compile to three functions that are on the secondary layer of the function decomposition. The total decomposition is given in Appendix 1. To be able to meet this function three sub-functions need to be fulfilled. These sub-functions have their own sub-functions as given in the table below:

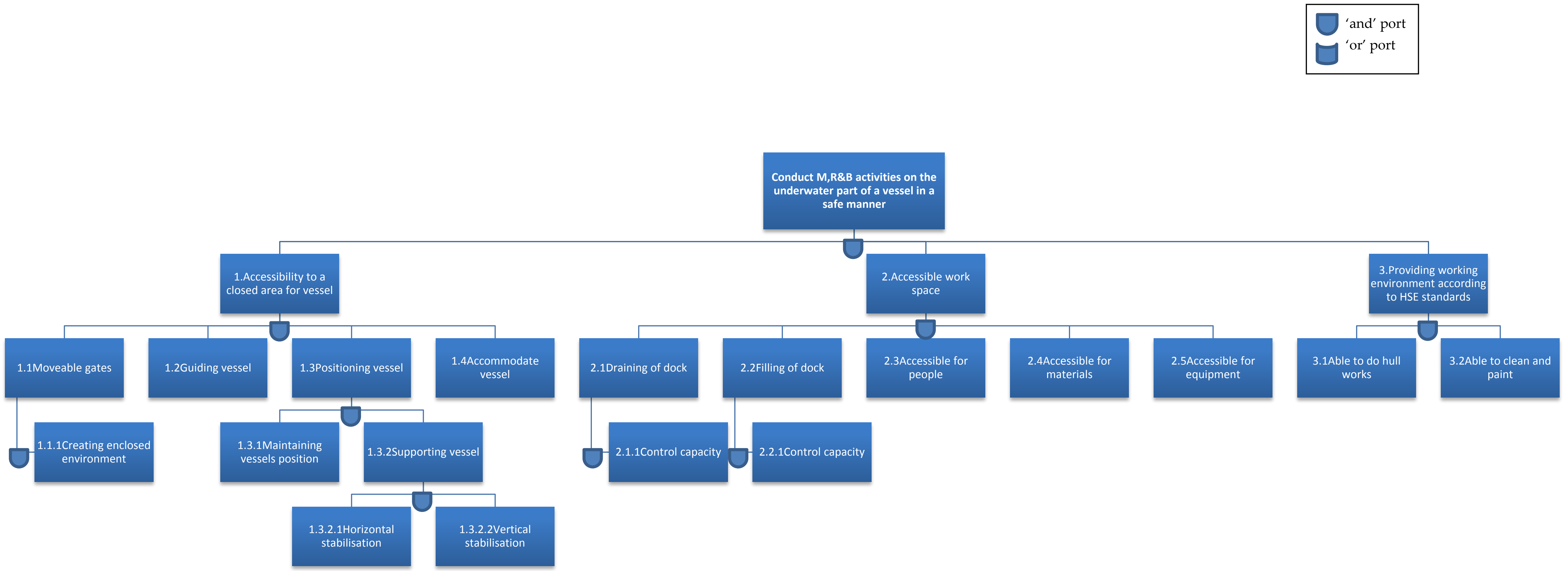
6.2.1.2 CONCLUSION

This paragraph describes all the functions that a dry dock should have. From this list the functional requirements per function can be created. These requirements help to make a decision between the different types per object. The first two of sub functions:

- Accessibility to a closed area for vessel
- Accessible work space

Will be accomplished by the three main objects described in Paragraph 3.2.2: gate, walls and floor. This gives the closed area for the vessel and the accessibility to this location.

Appendix 1.1 Functional Flow Block Diagram



Appendix 1.2 Functional requirements

Function/component		Requirements
#	**Name**	**Name**
	Conduct M,R&B activities on the underwater part of a vessel in a safe manner	**RAMS** **1. Reliability** **2. Availability** **3. Maintainability** **4. Safety** **5. Expandability** 6. Availability of material 7. Costs 8. CO2 footprint 9. Vessel with the largest width, length, draft and weight (dwt) that can enter the dry dock shall be referred to as design vessel.
1.	Accessibility to a closed area for vessel	1. The design vessel must be able to enter in a safe manner under the design conditions. 2. The dock provides in mooring facilities
1.1	Moveable gates	1. One of the four walls of the dock can be removed and replaced. This will be the gate 2. It is possible to do maintenance on the gate 3. The maintenance on the gate will be ever XXyears 4. The gate has a lifespan of xxyears 5. Opening of the gate will cost less than X hours 6. Closing of the gate will cost less than X hours 7. Grid power failure shall never result in opening of the gate 8. The gate will function also as a bridge with a width of the deck of Xm including railing and barrier (in case of gate is open) 9. There are signals for opening and closing of the gate 10. Gates can withstand outward water pressure and if required it can retain water from both ways 11. The leakage of the gate is not more than Xm^3/hour
1.1.1	Creating enclosed environment	1. The dock can be closed off, so that an enclosed area is created, which is stable and watertight 2. The dock can also be re-opened so that the design vessel can get in/out 3. Flooding probability of the dock is less than 1/xxxx years

Function/component		Requirements
#	Name	Name
1.2	Guiding vessel	1. Dock should have a hauling system that can haul the vessel in a safe manner or have the space for thugs to help guiding the vessel
1.3	Positioning vessel	1. Within the dock is the possibility to trim the vessel into position with the accuracy of centimeters
1.3.1	Maintaining vessels position	1. Vessel is required to stay horizontal (longitude and latitude) in position with centimeter accuracy, also when draining the dock
1.3.2	Supporting vessel	1. The design vessel must be docked in a safe manner 2. The dock is built in a way that it can handle a variety of vessels
1.3.2.1	Horizontal stabilisation	1. The ship has to be stabilised taking in account wind force, unbalance of the vessel or unit and unbalance as the result of modifications. This will result in a vertical force on the bilge blocks or on studs that are placed between the hull of a vessel and the side walls of the dock.
1.3.2.2	Vertical stabilisation	1. The max weight that can be expected is expressed in dwt/m. This will result in a vertical load on the keel block 2. The floor must resist the force from the keel and bilge blocks
1.4	Accommodate vessel	1. The dock is required to accommodate a vessel within the time it is build or maintenance and repair works are carried out
2.	Accessible work space	1. Everyplace should be easily accessible, if possible in two ways (in case of emergency) 2. Enough emergency exits must be available, as given in British Standard. 3. Enough space available to work around the design vessel
2.1	Draining of dock	1. When the dock is closed of it is possible to drain the dock. This means the water level will be reduced to the level of the floor 2. The drainage of the dock, filled to the maximum capacity without an object inside the dock, will cost not more than Xhrs 3. Should be arranged so that the flow of water does not cause disturbance to the vessel in the dock creating a risk of damage to the vessel or dock 4. The dock will be drained by means of a pumping system 5. There is a minimal of two pumps needed that delivers a combined capacity, which is needed as given in 3.0.0.1. When one pump is out of order the second pump can drain the system as well 6. Draining of the docks can be done remotely from one our more positions outside the dock and where the operator has sufficient oversight over the dock 7. Floor has dewatering channels, so that the water can flow easily to the pumps 8. Floor has a sump entrance, leading to a sump, this helps to create a higher water head for the pumps 9. Sump entrance has bars for preventing debris to enter the sump 10. The outlet of the drainage must be positioned to minimize the erosion

Function/component		Requirements
#	Name	Name
2.1.1	Control capacity	1. The pumping discharge can be adjusted by the operator
2.2	Filling of dock	1. When the dock is closed of it is possible to fill the dock till the water level outside the dock 2. If required it is possible to fill the dock till a level higher than outside water with the use of pumps 3. The filling time of the dock is the time needed to fill the dock till high water level outside the dock, without an object in the dock. The filling time will not be more than Xhrs 4. Filling of the docks can be done remotely from one our more positions outside the dock and where the operator has sufficient oversight over the dock 5. Should be arranged so that the flow of water does not cause disturbance to the vessel in the dock creating a risk of damage to the vessel or dock 6. The filling will be done by gravitational water flow from outside the dock 7. The inlet of the dock must be positioned so that it minimize the inflow of sediment to the dock
2.2.1	Control capacity	1. It is possible for the controller to control the discharge of the valves by means of a mechanical or electrical system
2.3	Accessible for people	1. The dock is accessible for authorized personal in a safe manner 2. The dock is inaccessible for unauthorized personal
2.4	Accessible for materials	1. The dock is accessible for materials that are needed within the dock, this can be done by: - Cranes - Ramp - Manarms
2.5	Accessible for equipment	1. The dock is accessible for equipment that are needed within the dock, this can be done by: - Cranes - Ramp - Manarms
3.	Providing working environment according to HSE standards	1. A workable environment have to be accomplished by the health and safety standards for the particular country 2. Standard health and safety standards will be used 3. Fire alarm system 4. Firefighting system 5. Emergency exits and signals (with a max spacing of 60m) 6. High water alarm system
3.1	Able to do hull works	1. For the design vessel the dock must be large enough to have sufficient access when working on and replacing parts of the hull, engines, thrusters, heat exchangers (etc)
3.2	Able to clean and	1. When cleaning/painting the vessel there is a possibility on contaminations, for this reason it is treated separately 2. When there is contaminated water, this water must be collected separate from the drainage water. This is done to

Function/component		Requirements
#	Name	Name
	paint	prevent this water from reaching the river 3. A water treatment plant must be available when there is contaminated water or a way to transport the contaminated water to a water treatment plant

Appendix 2 Object Decomposition

In this appendix a visual overview on the different objects of a dry dock is given. This decomposition is created by checking the different literature on dry docks, as given below, field visits to dry docks and checking which functions and requirements a dry dock must fulfill.

- British Standard on dry docks (British Standards 2013)
- Department of Defence design report on graving dry docks (Defense 2012)
- Docking manual (Heger 2005)
- PIANC report on dry docks (Kuhn 1988)

The verification and validation of the object decomposition is done with a review from dry dock designers from Arcadis.

The decomposition describes of which objects, the object of the layer above, consists of. The decomposition begins with the dry dock itself. From the decomposition it becomes clear that the dry dock consists of five main objects:

- Gate
- Walls
- Floor
- Pump house
- Terrain

The objects decomposition consists of 4 different coloured blocks. These colours indicate in which manner the objects are being used in this thesis.

- Blue
  These are the objects that will be designed in the report.
- Red
  The objects in red are not in the scope of this report.
- Orange
  These objects are taken into account for the design, only simplified to one top load. Meaning that the individual objects are not designed but only taken into account.
- Green
  These are only taken qualitatively into account, meaning that these influence the design choices for the blue blocks. For example: bridge, this is the part on top of the gate where, in case needed, a bridge can be created to move objects from one side to the other. The bridge will not be designed but when a bridge is needed, the gate type that can support such a bridge will be chosen.


Dry dock
Gates
Walls
Floor
Pump house
Terrain
Entrance gate
Intermediate gate
Length walls
width wall
Foundation
Pump
Gate storage
Filling valves
Filling valves
Boulders
Boulders
Dewatering channels
Lifting gear for components
Working space
Opening space
Opening space
Winches
Winches
Keel & Bilge blocks
Hatches & doors (for removal of components)
storage
Operating equipment
Operating equipment
Dock arm
Dock arm
Sump Entrance
Bars for Preventing debris
Sump
Facilities
Sealing
Sealing
GWE connections
GWE connections
Under drainage
Piping system
lighting
Bridge
Bridge
Stairs
Stairs
Filter layer
Gate winches
Hinge
Hinge
Emergency ladders
Emergency ladders
Pipe system (leading to sump)
Electric system
Signals
Filling valves
Ramp
Pump
Discharge valve
Pipes
Foundation
Pressure reliefsystem (incase of pump failure)
Filling Valve
Crane rail
horizontal
Foundation
vertical
Bottom protection
horizontal
vertical

Appendix 3 Pros & cons object types

Appendix 3.1 Pros & cons wall types

Table 0.1: Pros and cons wall types (Gijt and Broeken 2013)

Types	Pro	Cons
A. Gravity dry dock walls	+ Self supporting structure + When subsoil is not suitable for sheet pile wall because it consists of rock or very firm sand + When the subsoil has sufficient bearing capacity	- Needs foundation (might need preloading) - Construction width is proportional to the retaining height - Because of the width, difficult future expansion
a. Caissons walls	+ No need for initial dewatering of the site + Economical in material use	- All super-structure work above sea level should be formed after the caissons have been bedded and subjected to the majority of the horizontal pressure which can cause movement - Should be constructed where there is deep water - Needs foundation that is hard and impervious - Under-drained is needed - Labour intense
b. Cellular walls	+ Relatively little material is required + Earthwork required is limited	- Not advisable when bearing layer is not or very deep available - Steel is needed - Sensitive for collision - Corrosion sensitive
B. L-Shaped walls	+ If bearing capacity is not sufficient for gravity walls + Less material costs	- In situ construction - Needs ground retaining walls when constructed (building pit is needed with extensive dewatering system) or placement from waterside - Needs foundation when softsoil

		- Extra attention between joints between wall segments as well as wall and floor - Different settlements per segment can happen
a. Cantilever		
b. Counterfort		
C. Embedded anchored walls		- Anchors can be a problem for future expansion
a. Sheet-piled walls	+ Limited space needed + No need for open-cut excavation (in case ground conditions do not favour) + Can act as a ground water cut-off + In subsoil that has poor bearing capacity	- Horizontal deflection - Potential leakage from dock into the under-drainage system - Sensitive for interlock problems - Corrosion sensitive - Need easily penetrable ground - Steel must be available
b. Combined walls	+ Good for higher retaining heights + Economical attractive +Open tubular piles can relatively easily vibrated or driven through firm sand layers	- Potential leakage from dock into the under-drainage system - Sensitive for interlock problems - Corrosion sensitive - Steel must be available
c. Diaphragm walls	+ Depth of the wall can be extended to terminate in impervious layers below dock floor level and hence form the ground water cut-off for an under-drained dock floor + High bearing capacity + Stiff so the deformation are minimal	- Must take from ground level negating open excavation - Needs continuous record of the actual soils along the line of the wall, verifying the ground conditions adopted for the design - Width of panel is limited - Need good covering of reinforcement
D. Embedded cofferdam walls	+ Need for anchorages or ties might be eliminated by the use of a stiff plan section such as a T-shape + Building from existing ground level, prior to excavation	- Sensitive for interlock damage - Tie rod and back wall can be considered as obstacles for future expansion - Durability and corrosion options
E. Soil or rock slope walls	+ Suitable rock conditions can have indefinite life	- No side cranes - Limited life spam of slope - Lot of space needed

Appendix 3.2 Pros & cons floor types

Table 0.2: Uplift alternatives

Type	Pros	Cons
Under-drained floors	+ When ground water can be controlled in such a way it can be collected by drainage pipes + no permanent tension piles	- When it is not possible to drain
Gravity floors	+ Better for smaller docks + When soil is highly permeable and the continuous pumping of large volumes of ground water would be required throughout the life of the dock	- Huge thickness of the floor when there is a lot of uplift
Tied floors	+ When insufficient weight to withstand the hydrostatic uplift of ground water	- Tension piles / compression piles should be used with caution, since reversal of load can tent to break down the adhesion between pile and soil

Table 0.3: Bearing alternatives

Type	Pros	Cons
Bearing directly on the ground	+ Enough bearing capacity + If dock is designed as gravity structure	
Supported on piling	+ Weak soils	- Limits flexibility in the layout of ship supporting blocks
Constructed under water	+ Where dewatering is impossible + If inordinate temporary works are required	- Only gravity design and therefore thick - Difficult to make watertight

Appendix 3.3 Pros & cons gate types

Table 0.4: Pros and cons gate types (1 of 2) (British Standards 2013)

Type of gate	Structural form	Speed of operation	Reverse head capability	Method of operation	Ease of maintenance	Gate location when open	Main support requirements
Entrance							
Flap gate	Spanning	Fast (10 min)	In special circumstances	One person with winch operation	Unstepped and floated to dry berth	Fully recessed below sill level	Quoins and sill
Flap gate	Strutted	Fast (10 min)	No	One person with winch operation	Unstepping (very difficult) and floated to dry berth	Fully recessed below sill level	Sill and dock floor
Flap gate	Cantilever	Fast (10 min)	In special circumstances	One person with winch operation	Unstepping (very difficult) and floated to dry berth	Fully recessed below sill level	Sill
Floating caisson	Free floating and spanning	Slow (1 h to 5 h)	Yes	>4 person team plus tugs	Can be reversible and majority of exposed structure is maintainable when closed	Moored at berth while floating	Quoins and sill
Floating caisson	Free floating and gravity	Slow (2 h to 6 h)	No	>4 person team plus tugs	Can be reversible and majority of exposed structure is maintainable when closed	Moored at berth while floating	Sill

Table 0.5: Pros and cons gate types (2 of 2) (British Standards 2013)

Type of gate	Structural form	Speed of operation	Reverse head capability	Method of operation	Ease of maintenance	Gate location when open	Main support requirements
Floating caisson	Hinged floating	Slow (1 h to 2 h)	Yes	Two persons	Can be reversible and majority of exposed structure is maintainable when closed	Moored at berth while floating	Quoins and sill
Sliding or rolling caisson	Spanning	10 min with no deballasting, 1 h to 2 h with deballasting	Yes	1 to 2 persons with winch operation	Can be maintained behind stop logs inside recess	Fully recessed in large camber in dock or lock wall	Quoins and sill
Mitre	Three pin arch	Fast (10 min)	No	One person with hydraulic ram operation	Unstepped and floated to dry berth	Small recesses each side of entrance	Quoins
Sector	Truss	Fast (10 min)	Yes	One person with hydraulic ram operation	Removal by crane needed	Large recesses each side of entrance	Via vertical hinges
Intermediate – Entrance as listed above and Modular as listed below							
Modular	Inverted "Y"	Up to 1 day	No	5 to 10 person team with crane	Easily maintainable when not in use	Stored near dock cope	Dock floor
Modular	Lambda "λ"	Up to 1 day	No	5 to 10 person team plus crane	Easily maintainable when not in use	Flat on dock floor or stored near dock cope	Dock floor
Modular	Stop log	Up to 0.5 day	Yes	3 to 4 person team plus crane	Easily maintainable when not in use	Stored near dock cope	Dock wall quoins

NOTE For seals at quoins or sills, a small force is imposed on the supporting structure to create the seal effect.

Appendix 4 Drawings object types

Appendix 4.1 Wall drawings

1. Gravity dry dock walls

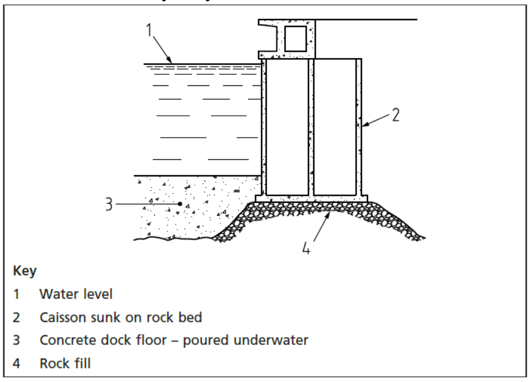


Figure 0.2: Gravity dry dock walls type caissons

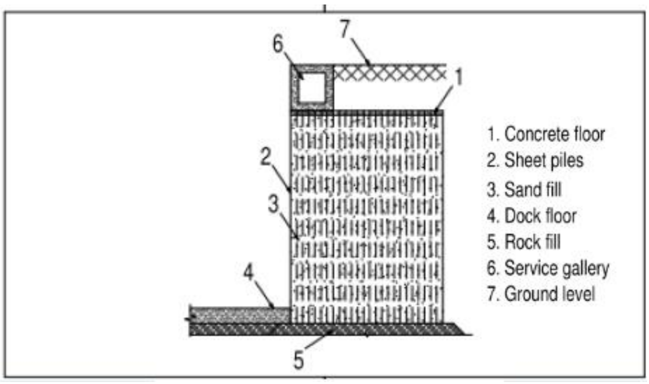


Figure 0.1: Gravity dry dock walls type cellular

2. L-Shaped walls

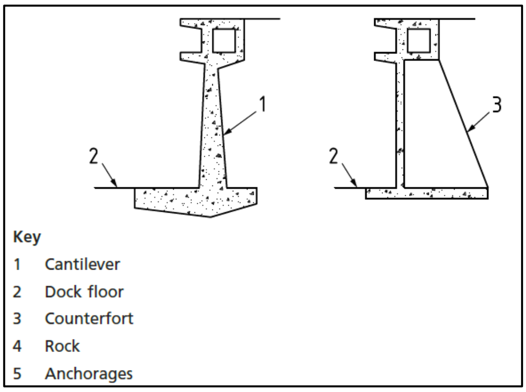


Figure 0.3:L-Shaped walls; left cantilever; right counterfort

3. Embedded anchored walls

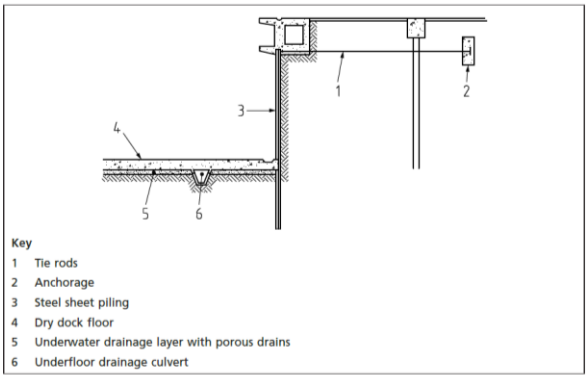


Figure 0.5: Embedded anchored wall type sheet-piled

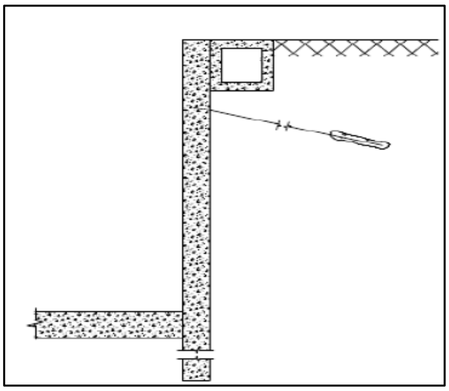


Figure 0.4: Embedded anchored wall type diaphragm

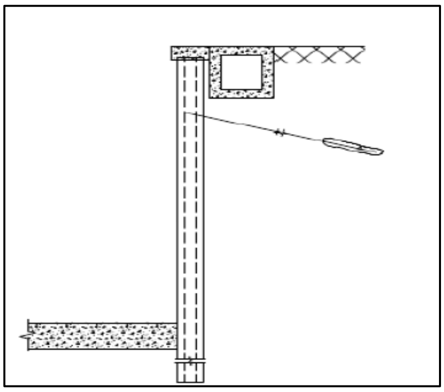


Figure 0.6: Embedded anchored wall type combined

4. Embedded cofferdam walls

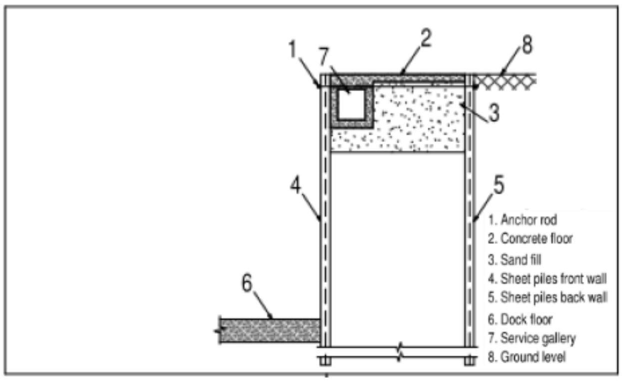


Figure 0.7: Embedded cofferdam

Appendix 4.2 Gate drawings

A. Entrance gates

a. Flap gate

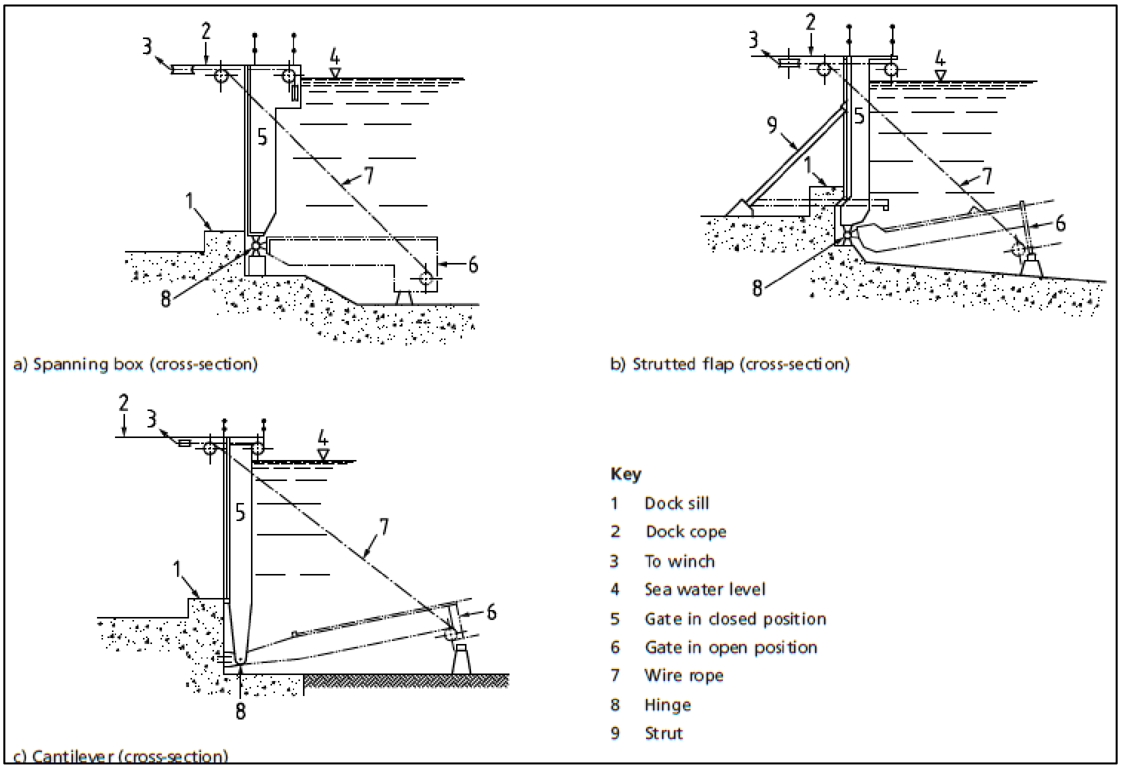


Figure 0.8: Flap gates (British Standard 2013)

b. Floating caisson gate

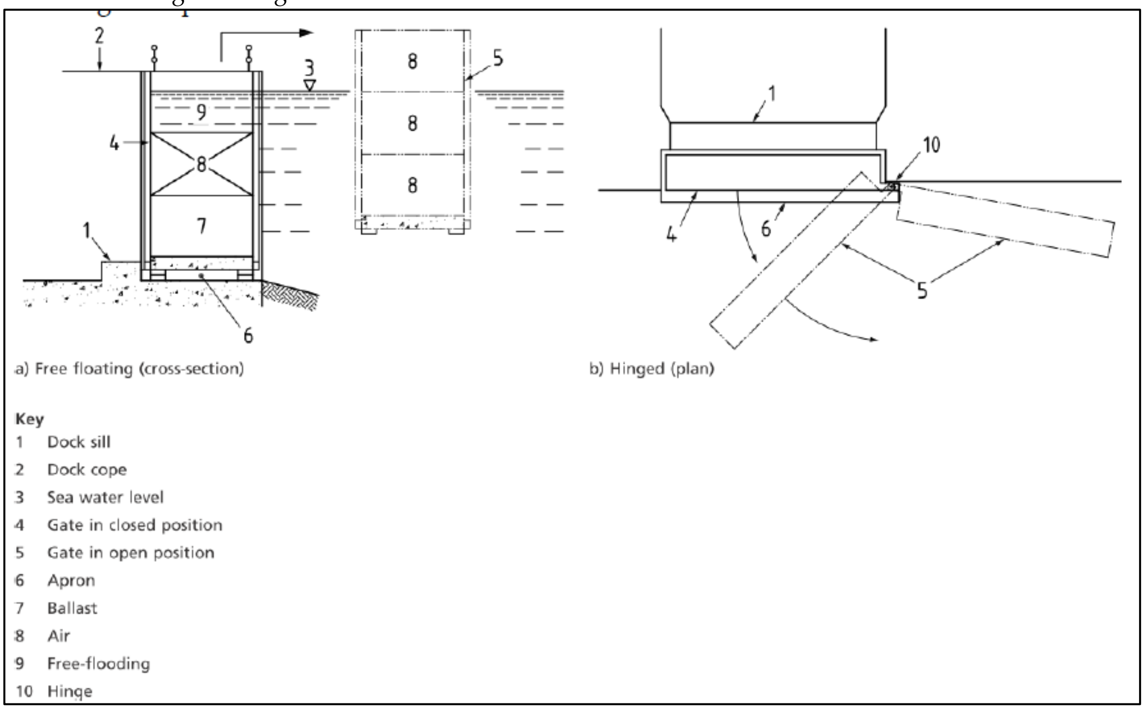
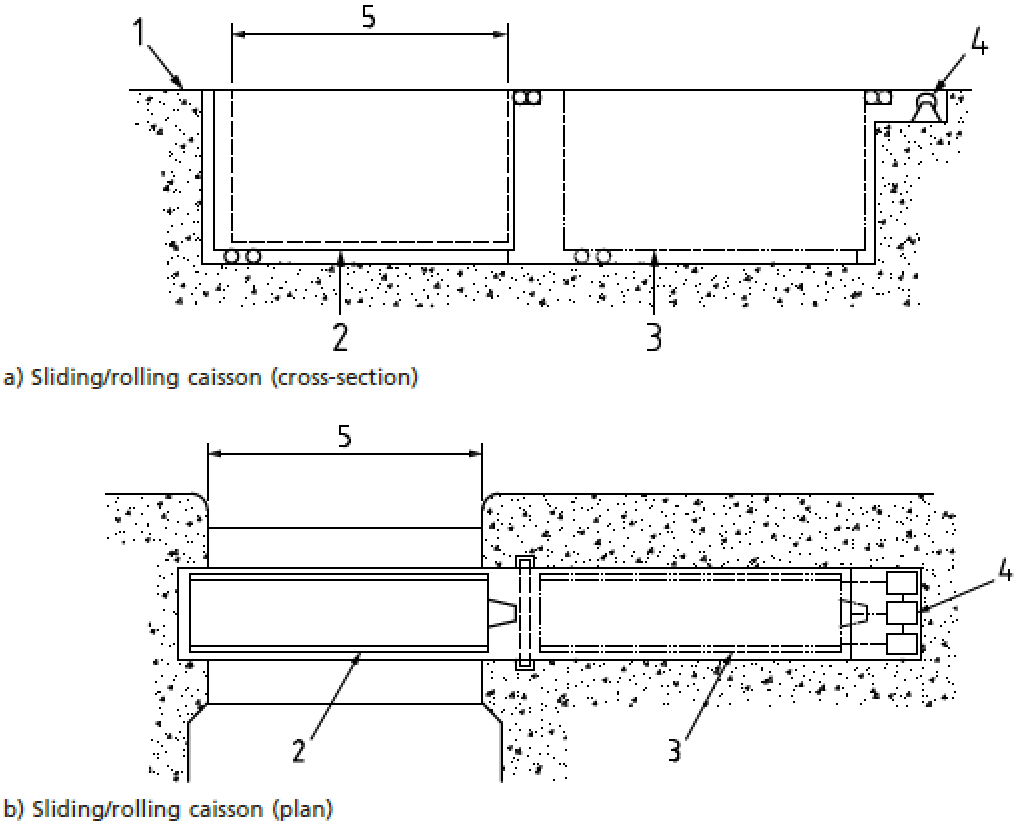


Figure 0.9: Floating gates (British Standard 2013)

c. Sliding or rolling caisson gate

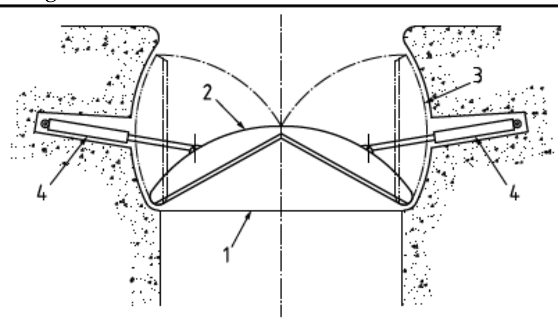


Key

1 Dock cope
2 Gate in closed position
3 Gate in open position in camber recess
4 Winch
5 Dock or lock entrance

Figure 0.10: Sliding and rolling gates (British Standard 2013)

d. Mitre gates

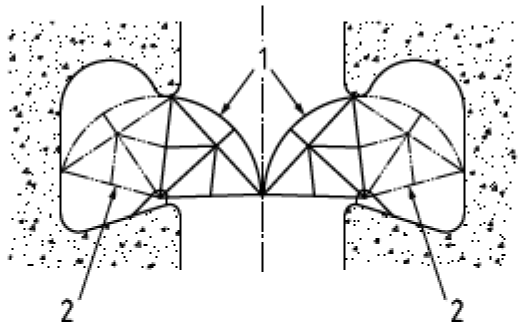


Key

1 Dock sill
2 Gate in closed position
3 Gate in open position in recess
4 Hydraulic cylinder

Figure 0.11: Mitre gates (British Standard 2013)

e. Sector gates



Key

1 Gate in closed position

2 Gate in open position in recess

Figure 0.12: Sector gate (British Standard 2013)

B. Intermediate gates

b. Modular units installed by crane

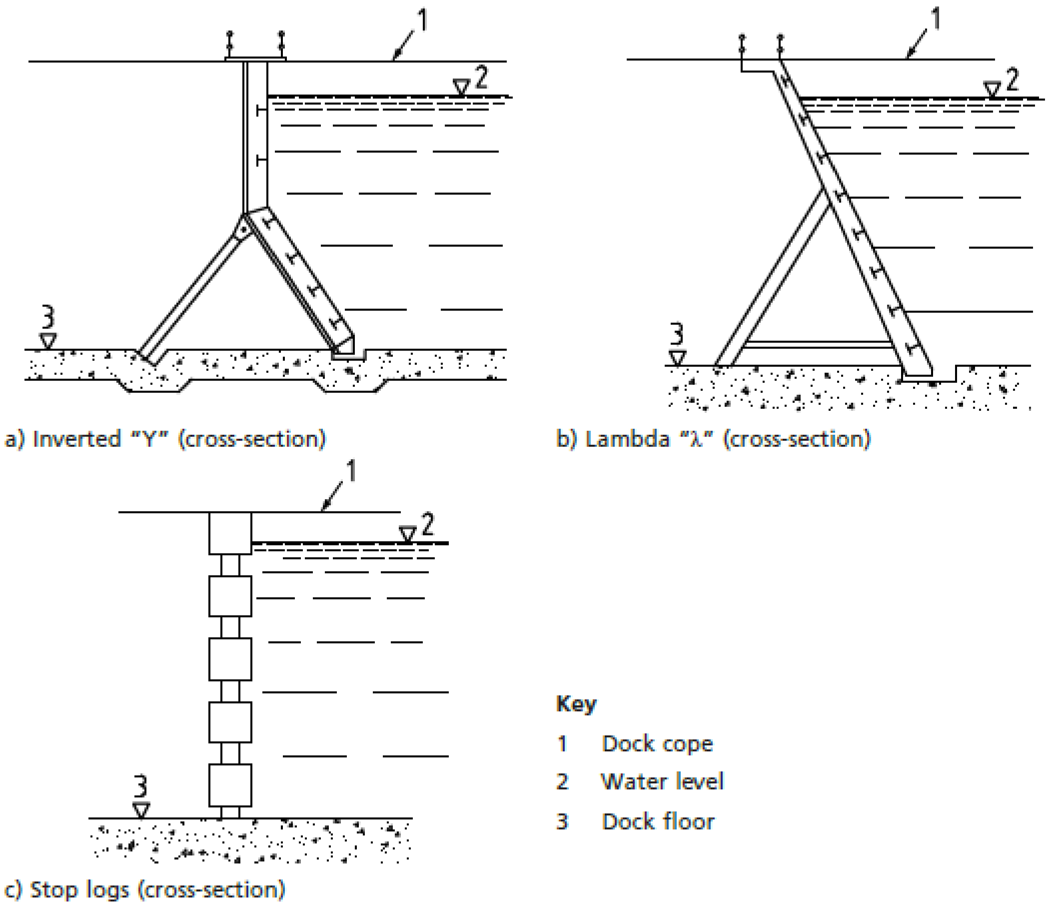


Figure 0.13: Modular units (British Standard 2013)

Appendix 5 System boundary

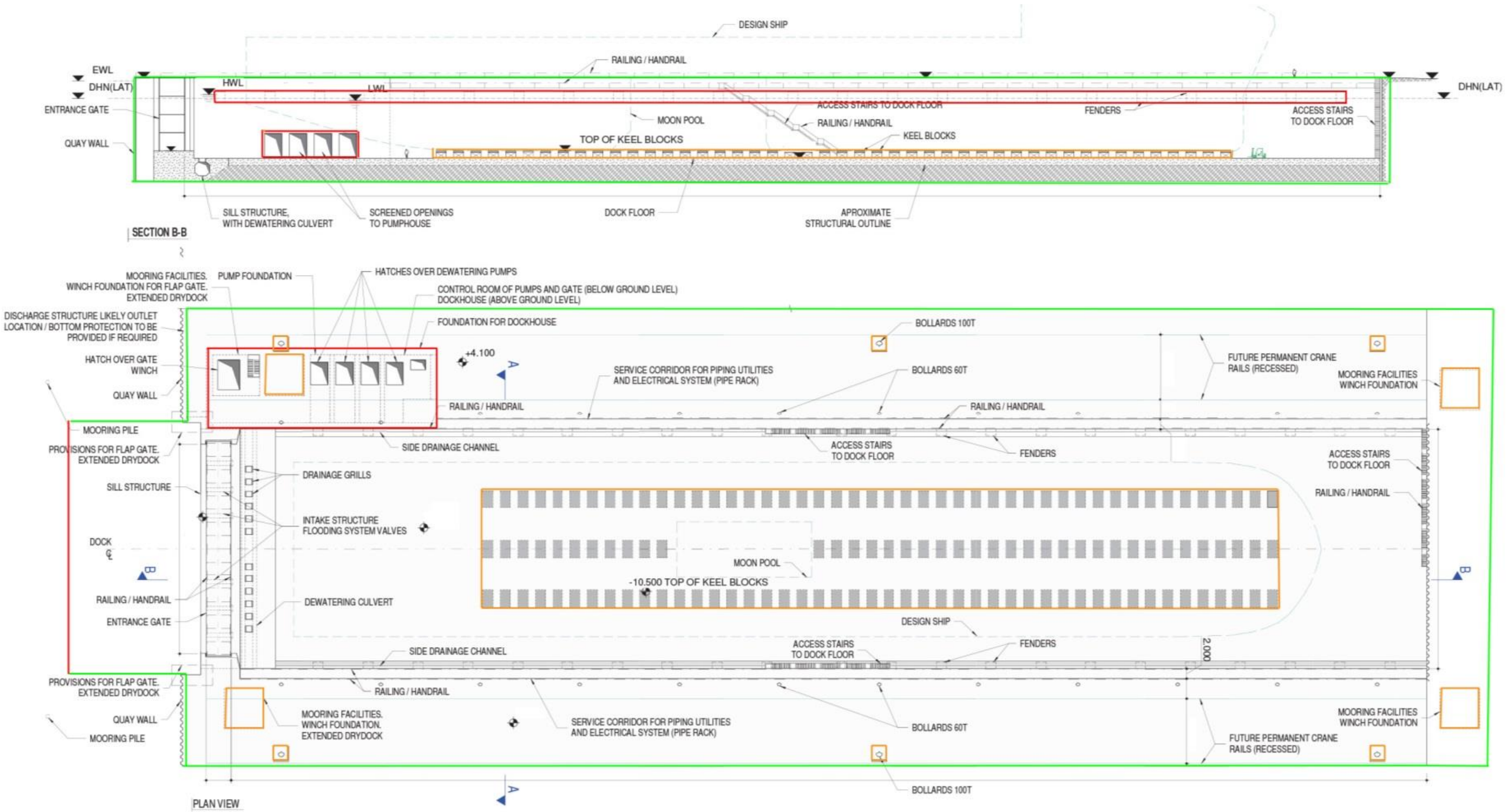


Figure 0.14: System boundry preliminary design of a dry dock (Arcaids)

Green = in scope
Red = out of scope
Orange = forces are taken into account, design of the structure falls out of the scope

Appendix 6 Parametric design formulas

This appendix give the formulas that are used in the parametric design in Paragraph 3.4.

Appendix 6.1 Forces on wall

To calculate the ground forces on the wall, Blums method is used. This is calculated by firstly calculating the effecitive vertical force, then the horizontal ground forces, shear forces and finally the momentum.

Mean cohesion, internal friction and volumetric weight:

$$c' = \frac{\sum_{i=1}^{i=n} c_i\, h_i}{\sum_{i=1}^{i=n} h_i}$$
$$\varphi' = \frac{\sum_{i=1}^{i=n} \varphi_i\, h_i}{\sum_{i=1}^{i=n} h_i}$$
$$\gamma' = \frac{\sum_{i=1}^{i=n} \gamma_i'\, h_i}{\sum_{i=1}^{i=n} h_i}$$

$c = cohesion$
$h = layer\ thickness\ [m]$
$\varphi = angle\ of\ internal\ friction\ [°]$
$\gamma = volumetric\ weight\ of\ soil\ layer\ [kn/m3]$

Effective vertical soil pressure:

$$\sigma_v' = \sigma_v - p = \sum_{i=1}^{n} \gamma_{d,i}\, d_i + \sum_{j=1}^{m} \gamma_{n,j}\, d_j - p$$

With:
$\sigma_v' = vertical\ inter - granular\ stress\ [kN/m2]$
$\sigma_v = total\ vertical\ stress\ \left[\frac{kN}{m2}\right]$
$\gamma_{d,i} = dry\ volumetric\ weight\ of\ soil\ layer\ i\ [kN/m3]$
$\gamma_{n,j} = wet\ volumetric\ weight\ of\ soil\ layer\ j\ [kN/m3]$
$d = thickness\ of\ soil\ layer\ [m]$
$p = water\ pressure\ in\ the\ considered\ plane\ [kN/m2]$

Horizontal ground pressure
In this case there is an active and passive part:

$$\sigma_{h,a}' = K_a * \sigma_v' - 2c * \sqrt{K_a}$$
$$\sigma_{h,p}' = K_p * \sigma_v' + 2c * \sqrt{K_p}$$
$$\sigma_{h,0}' = K_0 * \sigma_v'$$

$$K_a = \frac{1 - sin\varphi'}{1 + sin\varphi'}$$

$$K_p = \frac{1 + sin\varphi'}{1 - sin\varphi'}$$
$$K_0 = 1 - sin\varphi'$$

With:
$\sigma'_{h,a} = Active\ horizontal\ soil\ pressure\ [Pa]$
$\sigma'_{h,p} = Passive\ horizontal\ soil\ pressure\ [Pa]$
$\varphi' = Angle\ of\ internal\ friction\ [°]$
$c = cohesion$
$K_a = Active$
$K_p = Passive$
$K_0 = Neutral$

Shear stress and bending momentum
The horizontal soil and water force is calculated for each step of 10 cm. This is summarized to one force for each 10 cm. This force is then integrated over the length, given the shear force. The anchor force is then added to the shear force. The shear force is then integrated again over the length to find the momentum.

Appendix 6.2 Maximum anchor force

Maximum anchor force
The maximum force that an anchor can handle is given by the depth of the anchor. The force overview on an anchor is given in Figure 3.8.

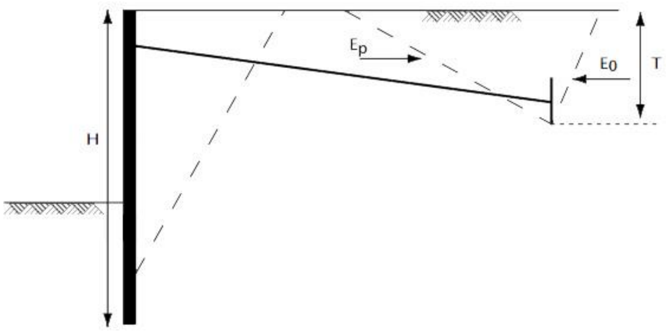


Figure 0.15: Stability of long anchors (Deltares 2010)

The maximum anchor force is than given by:

$$P = E_p - E_0$$

With:

$$E_p = \frac{1}{2} * K_p * \gamma * T^2 - 2 * c * \sqrt{K_p} - K_p * q * T$$
$$E_0 = \frac{1}{2} * K_a * \gamma * T^2 - 2 * c * \sqrt{K_a}$$

$E_p = Passive\ pressure\ on\ the\ anchor\ wall$
$E_0 = Active\ pressure\ on\ the\ anchor\ wall$

Appendix 6.3 Concrete thickness

Concrete wall

To calculate the concrete wall the dock is schematized as a U-shape dock. By doing this it is assumed that the walls and floor are stiffly connected and that the dock will not slip off. The maximum shear stress and momentum is determined on the bottom of the wall. From the maximum shear stress and momentum the height of the concrete can be calculated with the following equation (Molenaar, Baars et al. 2008):

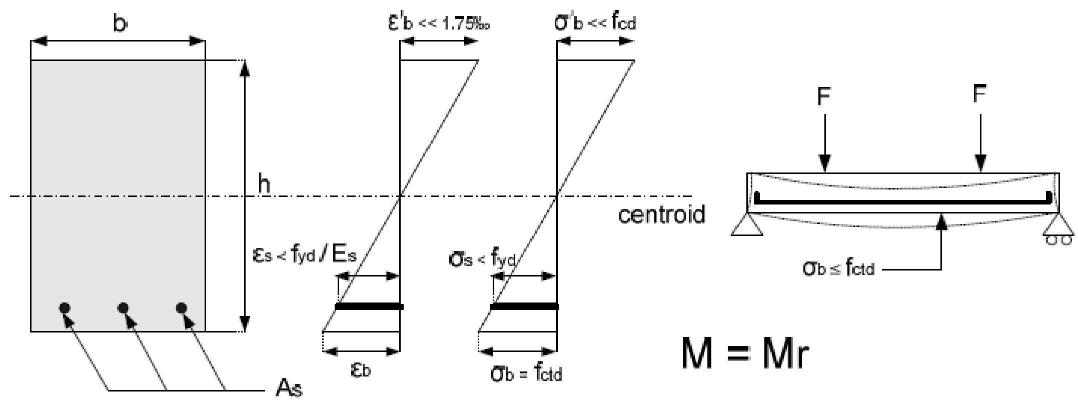


Figure 0.16: Deformation and stress diagram for non-cracked beam (Molenaar 2013)

Bending momentum:

$$M_{rd} = A_s * f_{yd} * z$$
$$z = d - \beta * x_u$$
$$x_u = N_s / N_c$$
$$N_s = A_s * f_{yd}$$
$$d = h - (c + \emptyset_{stirrups} + 0.5 * \emptyset_{longitudinal\ reinforcement})$$
$$N_c = \frac{3}{4} * x_u * f_{cd} * b$$

With:

$M_{rd} = design\ bending\ moment\ [Nm]$

$h = concrete\ height\ [mm]$

$A_s = total\ cross-sectional\ area\ of\ the\ reinforcement\ [mm^2]$

$f_{yd} = design\ yield\ strength\ of\ reinforcement$

$z = arm\ of\ internal\ leverage$

$N_s = tensile\ force\ in\ the\ reinforcement\ steel$

$N_c = desgin\ value\ of\ the\ compressions\ reulstant$

$d = distance\ between\ the\ tensile\ reinforcement\ and\ the\ edge\ with\ most\ compression$

$x_u = height\ of\ the\ concrete\ compression\ zone$

Shear force

$$V_{Rd,c} = (v_{min} + k_1 * \sigma_{cp}) * b_w * d$$

$$v_{min} = 0.035 * k^{\frac{3}{2}} * f_{ck}^{1/2}$$
$$k = 1 + \sqrt{\frac{200}{d}}$$

With:
$V_{Rd,c} = design\ value\ for\ shear\ resistance\ [N]$
$k_1 = coefficient, in\ the\ Netherlands: 0.15$
$\sigma_{cp} = compressive\ stress\ in\ the\ concrete\ from\ axial\ load\ or\ presstressing$
$b_w = the\ smallest\ width\ of\ the\ cross\_section\ in\ the\ tensile\ area\ [mm]$
$f_{ck} = characteristic\ compressive\ cylinder\ strenght\ of\ concrete\ at\ 28\ days\ [MPa]$

Appendix 6.4 Floor

Tensile force walls on floor

The maximum tensile force that a pile can resist without slipping is given by the following equation (Molenaar, Baars et al. 2008):

$$F_{r,tension,d} = \int_{z=o}^{L} q_{c,z,d} * f_1 * f_2 * O_{p,mean} * \alpha_t * dz$$

Where:
$F_{r,tension,d} = design\ value\ for\ the\ tensilte\ strength\ of\ the\ soil\ [kN]$
$q_{c,z,d} = design\ value\ of\ the\ cone\ resistance\ at\ depth\ z\ [{}^{kN}/_{m^2}]$
$f_1 = pile\ installation\ (f_1 \geq 1)\ [-]$
$f_2 = cone\ resistance\ reduction\ factor\ (f_2 \leq 1)[-]$
$O_{p,mean} = average\ circumference\ of\ the\ pile\ shaft\ [m]$
$\alpha_t = pile\ class\ factor$
$L = length\ over\ which\ shaft\ friction\ is\ computed\ [m]$
$dz = depth\ [m]$
$\alpha_t = 0{,}004\ for\ piles\ with\ little\ ground\ displacement; driven\ steel\ profiles$

Appendix 6.5 Costs

To give a first impression on how the costs of different objects can be added to the DSS, a cost indication is created for the sheet pile, combined and concrete walls and for the floors. These are the objects that are designed in more detail, therefore the amounts are available for these structures. In the Trade-Off Matrix for the objects the costs are also taken into account but in a quantitative manner. The different types are ranked by an Arcadis cost expert.

To get a first impression what the costs are for the different objects, unit rates are used from previous projects Arcadis has done on dry docks and quay walls. These unit rates can be per length, weight or volume unit. These unit rates are confidential and therefore they will not be reported in this thesis.

Appendix 7 Trade-Off Matrix

This appendix describes methods used in the Trade-Off Matrix (TOM). The TOM is described in the SE literature, in Paragraph 2.4.2, as a method that uses a table to weigh each option in order to make a rational choice between various alternatives. The criteria are the system requirements, these and the score per type are determined in the DSS.

In Appendix 7.1 the TOM for the construction method is described, in Appendix 7.2 for the wall, Appendix 7.3 the floor and finally in Appendix 7.4 the TOM for the gate is described.

The DSS helps the designer to choose four different objects, namely the construction method, wall type, floor type and gate type.

There are two types of requirements, functional and technical requirements. The technical requirements are object specific and the functional requirements are the same for the wall, floor and gate, these are shown in Figure 0.17. These functional requirements get a weighing factor. This factor should be discussed with the client, so that the client can give the preference for the particular project. This factor can be between the 1, not important, till 10, very important. Only for the availability of steel and concrete another distribution is given. If the material is widely available and preferred for the location it get a weight of 5, if the material is expensive or not preferred in the location a weight of -5 can be assigned.

Functional requirements	Weight	
Technical score	10	*1-10*
Reliability	8	*1-10*
Availability	8	*1-10*
Maintainability	7	*1-10*
Safety	8	*1-10*
Expandability	8	*1-10*
Availability of steel	-1	*-5 - 5*
Availability of concrete	-1	*-5 - 5*
Engineering cost	7	*1-10*
Building cost	9	*1-10*
Durability or CO2 footprint	7	*1-10*

Figure 0.17: Functional requirements

Appendix 7.1 Construction method

This Trade-Off Matrix indicates which construction method is possible with the information from the input sheet. These calculations are made with the information determined in Paragraph 3.4.1.1. The TOM calculates the safety factor, the upward force divided by the downward force, for the following construction methods:

- Open excavation with slopes
- Retaining walls till impermeable layer 1
- Retaining walls till impermeable layer 2
- Retaining walls till impermeable layer 3
- Retaining walls with underwater concrete

- Retaining walls with deep grouted layer

Appendix 7.2 Wall type

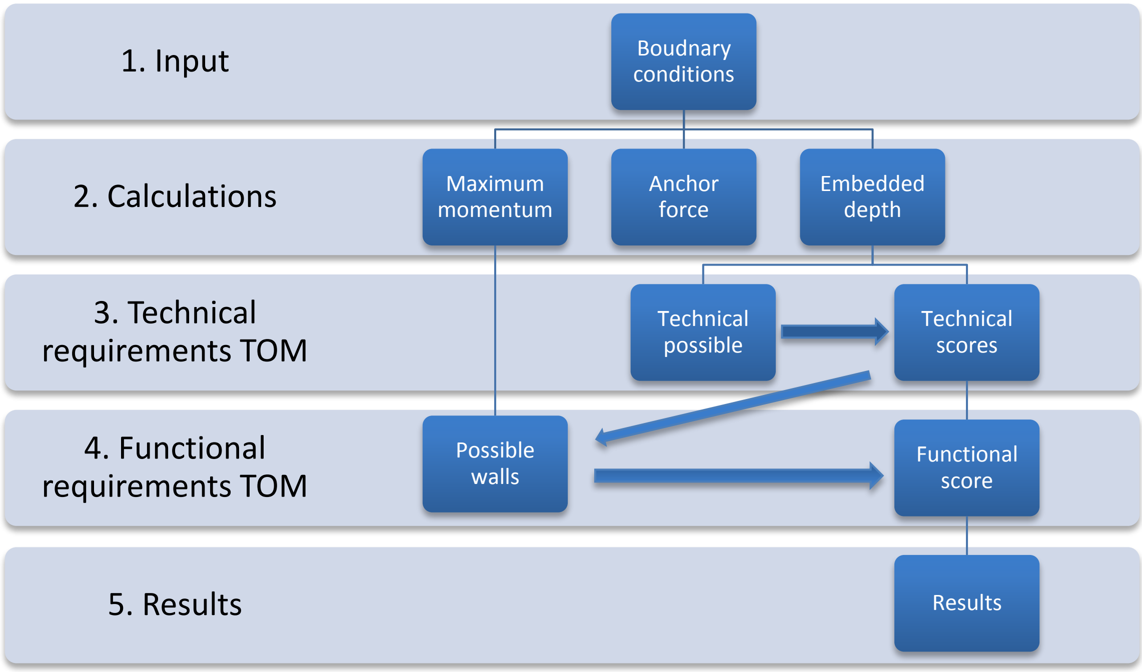


Figure 0.18: Flowchart wall Trade-Off Matrix

The wall Trade-Off Matrix consists of 5 steps to make an objective choice between the different wall types. The flowchart of these steps is described in Figure 0.18 and consists of the following steps:

1. Input
2. Calculations
3. Technical requirements floor TOM
4. Functional Requirements floor TOM
5. Result

1. Input

Step 1 is the part where the boundary conditions are fed in the system about the soil parameters, water levels and design vessel.

2. Calculations

Step 2 is where all the calculations are made for the walls. From these calculations the embedded depth, anchor force and maximum momentum are determined.

3. Technical requirements TOM

Step 3 is the first Trade-Off Matrix. This TOM determines which wall type is technical advised in the particular situation. This is done for the main wall types:

- Gravity dry dock walls (caissons / cellular)
- L-Shaped walls
- Embedded anchored walls
- Diaphragm wall
- Rock slope walls

The input for this Trade-Off Matrix is filled in the '*input sheet*', the information needed for the wall Trade-Off Matrix is shown in Figure 0.19. The TOM determines by the input parameters firstly which types are possible to use and secondly it gives a score on how technical feasible each type is.

	Technical requirements Wall	
1.0	Installation from ground level possible	yes
2.0	Building pit with natural slopes possible	no
2.1	Drainage needed	no
2.2	Sheet pile needed to close permeable layer	no
3.0	Building pit with retaining walls possible	yes
3.1	Drainage needed	no
3.2	Underwater concrete needed	yes
3.3	Grouting layer needed	no
4.0	Sufficient bearing capacity	no
4.1	Possible to improve bearing	indecisive
5.0	Dock created from the sea	no
6.0	Available space	>natural slope
7.0	Dock embedded in impervious rock	no
8.0	highest cone resistance	5-10
8.1	Installation depth [m]	<35

Figure 0.19: Technical wall requirement Trade-Off Matrix input

The questions 1 till 5 and 7, from Figure 0.19, can be answered with a dropdown menu with the following options: 'yes', 'no' or 'indecisive'. Question 7 gives the amount of available space, with a dropdown menu. From 8.0 the cone resistance range can be selected from a value with the dimensions [MPa]. From 8.1 the installation depth range can be selected. The combination of 8.0 and 8.1 indicates if it is possible to hammer a sheet pile wall (Regelgeving 2012).

After filling in the questions the Trade-Off Matrix gives a value between the 0 and 5 for the wall types, with 5 being the most technical preferred and 0 technically not possible. The value 3 is given when it has no influence on the process. The values are then summoned and the wall types are ranked.

For the questions with follow-up questions, such as 2.0 that has the follow-up questions 2.1 and 2.2, the values are averaged and added to the total score, by multiplying with the sub-score and divide with the score. An example of the outcome from the technical requirements for the wall types embedded anchored walls and L-shaped walls is given in Figure 0.20.

Score	Subscore	nr	Technical requirements Wall		Embedded anchored walls	L-shaped walls
			Wall type			
			Achievable		YES	YES
1		1.0	Installation from ground level possible	yes	5	0
4	2	2.0	Building pit with natural slopes possible	no	3	0
	1	2.1	Drainage needed	no	0	0
	1	2.2	Sheet pile needed to close permeable layer	no	0	0
7	3	3.0	Building pit with retaining walls possible	yes	5	3
	2	3.1	Drainage needed	no	3	3
	1	3.2	Underwater concrete needed	yes	2	4
	1	3.3	Grouting layer needed	no	3	3
2	1	4.0	Sufficient bearing capacity	no	5	0
	1	4.1	Possible to improve bearing	indecisive	3	3
1		5.0	Construction from waterside	no	3	3
1		6.0	Available space	>natural slope	5	5
1		7.0	Dock embedded in impervious rock	no	3	3
1		8.0	Pile-driving possible	5-10 / <35	5	5
			Total score		30,2	20,6
			Rank (5 is best)		5	3

Figure 0.20: Outcome technical requirements wall types: embedded anchor and L-shaed

Before the wall types get a rank on the score, it is checked if the different types are achievable. This is done by checking the answers from the technical requirements with the possibilities for building the wall types. For example the following requirements are given for the embedded anchor walls:

- The dry dock may not be situated in impervious rock
- The dry dock may not have a combination of a high cone resistance and installation depth as described in Table 3.4

These requirements are needed because it is otherwise not possible to place the sheet piles.

For the L-wall the following requirements must not occur:

- Both 2.0 and 3.0 may not be both answered with 'no', otherwise it is not possible to place a L-wall because it is impossible to create the building pit to place the walls. If the embedded anchor walls is not possible the Trade-Off Matrix will indicate that 3.0 is also not possible
- Both 4.0 and 4.1 may not be both be answered with 'no', otherwise it is not possible to place a L-wall without the soil settle to much
- 5.0 may not be answered with 'yes', because it is not possible to place the walls in the water
- 6.0 may not be answered with smaller than 'L-shaped wall', otherwise there is not enough space available

The wall types that are possible are then ranked on the score from the technical requirements. The wall type with a 5 is the preferred solution and with a 1 is the less preferred solution.

Technical score embedded anchor walls and L-shaped walls

1.0 Installation from ground level possible

For the embedded anchored walls it is preferred to install the piles from ground level, therefore it gets a score of 5. The L-shaped wall needs a building pit to place the wall, therefore it has no advantage of installation from ground level and it gets a score of 0.

2.0 Building pit with natural slopes possible

This is not possible, so there is no effect on the embedded anchor walls, thus a score of 3 is given. If it would have been possible to building pit with natural slopes it gives an advantage for the L-shaped walls.

2.1 Drainage needed

In this case the option of building pit is not possible and therefore the outcome is 0 for this question. When the option of building pit is possible and drainage is needed the embedded anchor wall scores a 5 and the L-shaped wall a 3. The embedded anchor walls scores higher because using a drainage system is expensive and it is easier to place an embedded anchor wall so that a building pit with natural slopes is not needed. If the drainage is not needed the embedded anchor wall scores a 3 and the L-shaped wall a 5, it makes it easy to place such a wall.

2.2 Sheet pile needed to close permeable layer

A sheet pile can be needed to enclose the soil till an impermeable layer. This has no effect on the drainage needed or not. If the building pit is possible and sheet piles needed to enclose it then the embedded anchor walls score a 5 and a L-shaped wall a 2 because it becomes a technically difficult option to create an building pit with natural slopes, sheet pile wall and drainage system to create room to place a L-shaped wall. When it is answered with a 0 then the L-shaped wall gets a score of 5 and embedded anchor wall a 3.

3.0 Building pit with retaining walls possible

When this is possible the embedded anchor walls get a score of 5, because in a way, when using this alternative, an embedded anchor wall is already used. The L-shaped wall gets a score of 3, because it is not preferred (building pit with natural slopes is preferred) but it is an option to use. When it is not possible 3.1 – 3.3 gets a score of 0. If it is not possible to use a building pit with retaining walls the embedded anchor walls get a score of 0, because it is not possible to use this type and the L-shape wall also get a score of 0, because it needs a building pit to be placed.

3.1 Drainage needed

This is the same as option 2.1

3.2 Underwater concrete needed

If yes, then the L-shaped wall gets a score of 4, the concrete walls help to retain the upward pressure better then the embedded anchor walls, causing the underwater concrete to be less thick in case of the L-shaped wall. Therefore the embedded anchor walls get a score of 2. If it is answered with no, it has no influence and both get a score of 3.

3.3 Grouting layer needed

When this is needed, the sheet piles must be placed till the depth of the grouting layer, therefore the embedded walls are favourite in this case and get a score of 5 when needed, the L-shaped wall get a score of 3. If not needed all get a score of 3, because it has no further influence.

4.0 Sufficient bearing capacity

If there is insufficient bearing capacity, the L-shaped walls need additional foundation and therefore it scores a 0. The embedded anchor walls do not need a foundation and score a 5. In case it is sufficient then the L-shaped walls score a 5 and the embedded anchor walls a 2.

4.1 Possible to improve bearing

If it is possible to improve the bearing layer in a way (e.g. soil improving, foundation) then it is possible to use the L-shaped wall and therefore it scores a 4 and embedded anchor wall a 3. This higher score for the L-shaped wall is added to compensate the 0 score from 4.0 a bit, however the embedded anchored wall is still preferred. In all other cases the score is 3.

5.0 Construction from waterside
In this case the option of construction from waterside is not possible, therefore it has no influence on the wall choice for embedded anchor and L-shaped wall, thus they get a score of 3. When it is possible to construct from waterside the L-shaped wall cannot be placed and therefore gets a score of 0. Embedded anchor walls can be placed in such situations and therefore get a 3.

6.0 Available space
If there is enough space available to place a wall type it scores 5, if not the score will be 0.

7.0 Dock embedded in impervious rock
If answered by *'no'*, the score for both wall types is 3, because it has no influence on the design. If answered with *'yes'*, embedded anchored wall scores a 0, because it is not possible to place the sheet piles, and L-shaped wall scores a 3. It is possible to use them if the soil needs further support but not the ideal situation.

8.0 Pile-driving possible
This question investigates the possibility to hammer a sheet pile wall in the soil. When it is possible all solutions score a 5 and when not possible they score a 0. The choice to give all the wall types the same technical score for this part is made because it does not check how preferred an option is, it only checks if it is technical possible to use embedded anchor walls.

4. Functional requirements TOM
The first step in the functional Trade-Off Matrix is to check which types are possible. This is done by checking which types are not possible from the technical requirements first and secondly it checks if the maximum moment that occurs is less than the maximum allowable moment of the sheet pile, combined and diaphragm wall.

Figure 0.21 describes the functional Trade-Off Matrix for the concrete and sheet pile wall. The total score is determined by multiplying the weight of each requirement against the requirements specific score. This requirement specific score is based on the literature on dry docks, as described in Paragraph 2.2.3 and in the manuals from quay walls (Gijt and Broeken 2013). This figure indicates that the functional requirements 'availability' and 'sustainability' are not used. Availability is not used because there is no difference between the availability of the different wall types. Sustainability is not used because the sustainability results are not available for all different wall types. This is because the dimensions of not all the different wall types are available. When this is known a CO2 footprint can be made.

For the sheet pile, combined and concrete wall the volumes and material is known. For these three types the CO2 footprint is calculated, described in

Table 0.6. The wall with the highest CO2 footprint will be ranked 1 and the type with the lowest CO2 footprint will get the highest score. The costs for the wall types as described in Paragraph 3.4.2 cannot be used because the quantities are not known for each wall type. The score for the two costs requirements per wall type are therefore determined in cooperation with Arcadis cost expert M.A. Deltrap in a qualitative manner.

Table 0.6: Sustainability rank wall types

Sustainability	C02 [ton]	Rank
Sheet pile	4.823	3
Combined	10.185	1
Concrete	7.912	2

Functional requirements	***Wall type***	Cantilever	Sheet-piled walls
	Total score	**196**	**0**
Maximum momentum			Not possible
Technical score	*Score*	3	5
	Weight	10	10
Reliability	*Score*	5	2
	Weight	8	8
Availability	*Score*		
	Weight	8	8
Maintainability	*Score*	5	2
	Weight	7	7
Safety	*Score*	5	2
	Weight	8	8
Expandability	*Score*	1	5
	Weight	8	8
Availability of steel	*Score*	0	5
	Weight	-1	-1
Availability of concrete	*Score*	5	0
	Weight	-1	-1
Engineering cost	*Score*	3	5
	Weight	7	7
Building cost	*Score*	3	7
	Weight	9	9
Sustainability	*Score*		
	Weight	7	7

Figure 0.21: Outcome functional requirements wall types: embedded anchor and L-shaped

Functional score embedded anchor walls and L-shaped walls

Reliability

The cantilever wall scores a 5 because the wall has less failure mechanisms then a sheet pile wall, which scores a 2. With a sheet pile wall the anchors can fail or the bottom part of the sheet piles can be deformed after hammering.

Maintainability

Concrete walls are less maintenance depended than sheet pile walls. Sheet pile walls need anti-corrosion measurements. Therefore the concrete walls score a 5 and sheet pile a 2.

Safety

Concrete wall (5) can handle collision forces better then sheet pile walls (2).

Expandability

It is possible to place another sheet pile wall behind the first wall, and then remove the first wall so that the dock can be expanded. For concrete wall this is a much more complicated operation. Therefore the concrete wall scores a 1 and embedded anchor walls a 5.

Availability of steel

Sheet piles walls need large amounts of steel therefore it scores a 5. Concrete walls only needs reinforcement bars and is not that depended on steel and scores a 0

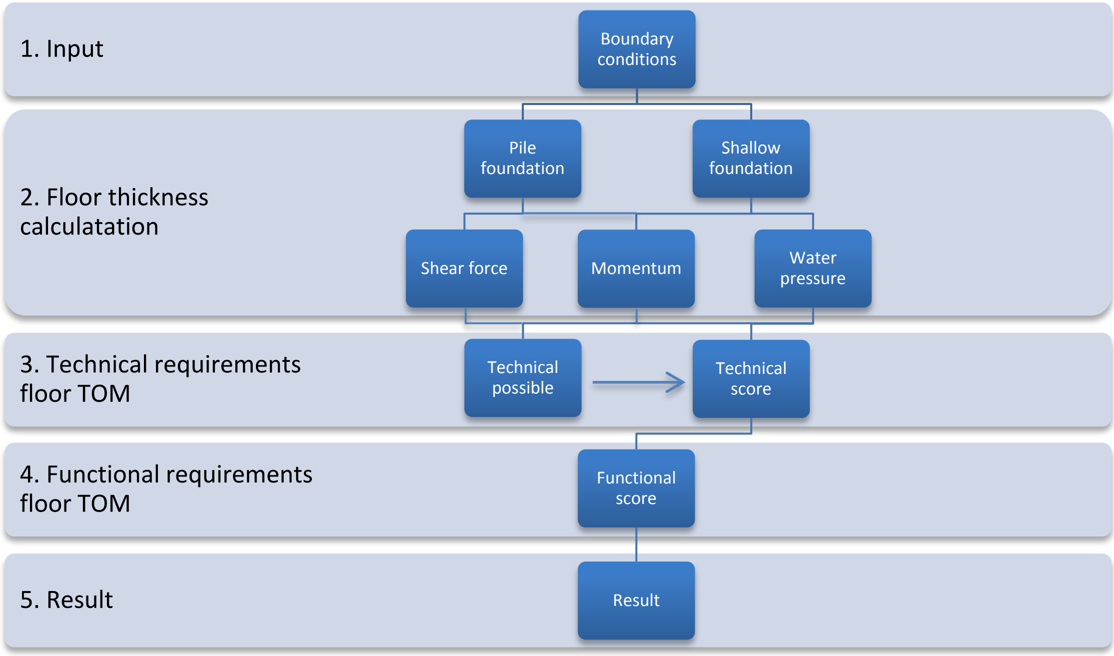
Availability of concrete

Concrete walls are depended on concrete therefore scores a 5, sheet pile wall does not use concrete and therefore scores a 0.

5. Results

From the functional requirements Trade-Off Matrix the score per wall type is determined. The type with the highest score is the preferred alternative in this design stage. It is advised to choose two wall types, from different head types, for the next design stage to investigate if the advantage determined in the preliminary design is still in effect for the next design stage.

Appendix 7.3 Floor type



The floor Trade-Off Matrix works mostly in the same manner as the wall Trade-Off Matrix. The outline of this methodology is described in 5 steps:

1. Input
2. Floor thickness calculations
3. Technical requirements floor TOM
4. Functional Requirements floor TOM
5. Result

With these steps the choice of what type of floor is advised in the preliminary design is made. To resist the uplift force the following types are available:

- Under-drained floors
- Gravity floors
- Tied floors

To resist the bearing force the following types are available:

- Floors bearing directly on the ground
- Floors supported on piling

1. Input

Step 1 is the part where the boundary conditions are fed in the system about the soil parameters, water levels and design vessel.

2. Floor thickness calculations

In this step the floor thickness is calculated for the floor with pile and shallow foundation. For these two types the thickness of the concrete floor is calculated in the case that the shear and moment forces determines the thickness and for the case that the upward water pressure must be resisted.

3. Technical requirements TOM

To check which types are technical possible, the questionnaire in Figure 0.22 has to be filled in.

	Technical requirements Floor			
1.0	Type of wall	L-Shaped walls		
2.0	Bearing capacity stronger than:	73,4	kN/m	yes
2.1	Bearing capacity stronger than:	111,4	kN/m	yes
3.0	Drainage possible	yes		
4.0	Possible to tie floor	yes		
5.0	Pile foudation possible	yes		

Figure 0.22: Technical floor requirement Trade-Off Matrix input

From question 1.0 the type of wall that will be used has to be selected. The wall type influences the downward force from the wall onto the floor; this affects the choice for a floor type in two ways. Firstly, this influences the soil bearing capacity that is needed. Secondly, it affects the resistance against the upward water pressure.

Question 2.0 describes the amount of downward force from the floor and wall in the case that the floor thickness is calculated by means of shear stress and momentum. The choice can than be made if there is enough bearing capacity. If this is answered by 'no' then it means that the downward force is too high for the soil to retain, therefore the foundation must be on piles. The uplift must be tied or under-drained.

Question 2.1 describes the amount of downward force from the floor and wall in case that the floor thickness is calculated to resist the upward water pressure. When this is answered by '*no*' the pile and shallow foundation are both possible, the uplift force can only be retained by under-drainage or tied, the gravity floor cannot be used. If the question is answered with 'yes' it is possible to use a gravity floor to retain the upward water pressure.

By answering questions 3.0 till 4.0 the designer indicates which options are possible and which are not.

Finally the technical possible solutions get ranked on which are preferred. The highest ranked gets a score of 10, the lowest ranked get a score of 5 and the technical not possible solution get a score of 0.

	Floor type	Uplift alternatives Under-drained floors	 Gravity floors
	Rank	10	0
	Result	19	0
2.0	Bearing capacity stronger than:	5	0
2.1	NVT	1	1
2.2	NVT	1	1
3.0	Drainage possible	5	3
4.0	Possible to tie floor	4	4
5.0	Pile foudation possible	3	3

Figure 0.23: Outcome technical requirements floor types: under-drained and gravity

Technical score under-drained and gravity floor

2.0 Bearing capacity stronger than …

The bearing capacity is not strong enough to withstand the gravity floor, therefore it scores a 0. The under-drainage floor is lighter and therefore ideal for this situation.

2.1 and 2.2 are not used because the bearing capacity is already not sufficient

3.0 Drainage possible

Drainage is possible therefore the under-drained floor scores best. It has no influence on the gravity floor, therefore this type scores a 3.

4.0 Possible to tie floor

Normally if a requirement has no influence a score of 3 is given, but because a tied floor is not favourable the score of 4 is given. This makes the tied floor a lower chance to be favourite.

5.0 Pile foundation possible

This has no influence on the two types and therefore it scores a 3.

4. *Functional requirements TOM*

The functional requirements for the floor types are described in the introduction of this appendix. In some of the requirements, the different floor types have the same score. Therefore these are neglected, as shown in Figure 0.24. These functional requirements are:

- Expandability
- Safety
- Availability of steel

Functional requirements floor trade-off		*Uplift alternatives*	
Entrance Floor Type		Under-drained floors	Gravity floors
Total score		239	0
Technical score	Score	10	0
	Weight	10	10
Reliability	Score	2	5
	Weight	8	8
Availability	Score	2	5
	Weight	8	8
Maintainability	Score	2	5
	Weight	7	7
Safety	Score		
	Weight	8	8
Expandability	Score		
	Weight	8	8
Availability of steel	Score		
	Weight	-1	-1
Availability of concrete	Score	5	5
	Weight	-1	-1
Engineering cost	Score	2	5
	Weight	7	7
Building cost	Score	7	5
	Weight	9	9
Sustainability	Score	3	1
	Weight	7	7

Figure 0.24: Functional floor Trade-Off Matrix

Functional score floors

Reliability, Availability and Maintainability

The under-drained floor scores lower on these points then the gravity floor. The gravity floor is a robust structure where there is no chance that it will not work and therefore always available. The maintenance on such a structure is also low. The under-drainage floor can have issues or needs maintenance on the pump or filter layer.

Engineering cost and building cost

The costs scores are determined with the professional opinion of the costs expert from Arcadis M.A. Deltrap.

Sustainability

The sustainability and availability of concrete functional scores are determined by the material usage per type.

5. Result

From the functional requirements Trade-Off Matrix the score per floor type is determined. The type with the highest score is the preferred alternative in this design stage.

Appendix 7.4 Gate type

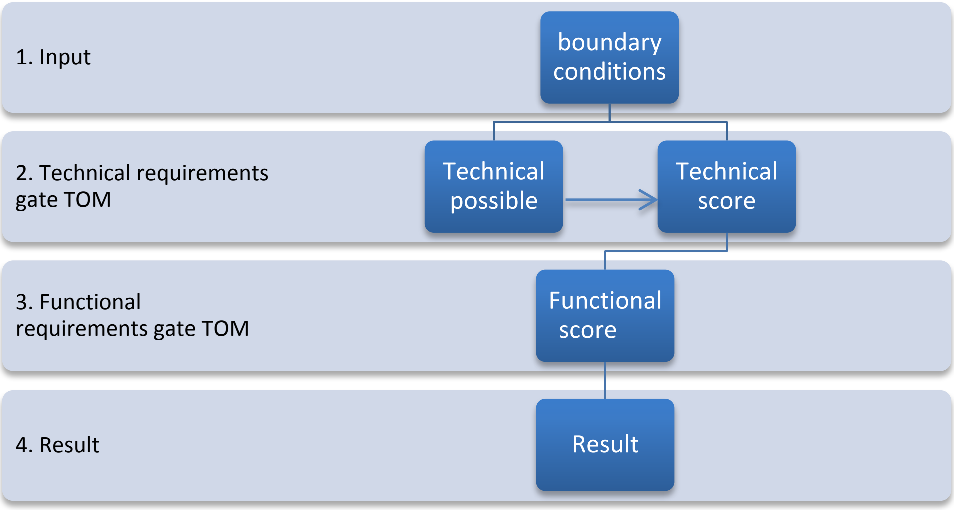


Figure 0.25: Flow chart gate Trade-Off Matrix

The Trade-Off Matrix for the gate consists of 4 steps. In Paragraph 3.4.1.4 it is discussed that the gate types are only made in a qualitative manner. Therefore the calculation step is not included. The flowchart of the gate TOM is described in Figure 0.25. The 4 steps of the gate TOM are:

1. Input
2. Technical requirements floor TOM
3. Functional requirements floor TOM
4. Result

1. Input
Step 1 is the part where the boundary conditions are fed in the system about the water levels and design vessel. The soil parameters are not of interest for the gate design.

2. Technical requirements TOM
To check which types are technically possible, the questionnaire has to be filled in; the questions are given in Figure 0.26.

	Technical requirements Gate	
1	Width of entrance	35,6
2	Speed of operation [min]	1 day
3	Labour force available for opening	>4
4	Available support for opening	Tug boat & crane
5	Reverse head capability	no
6	Ability to open against a head	no
7	Depth available outside dock	>Sill height
8	Provision of power	Available
9	Access across top of gate	Walking bridge

Figure 0.26: Technical gate requirement Trade-Off Matrix input

The maximum width each gate type can handle is described in Paragraph 3.4.1.4. and given in Table 3.5. The other scores are determined with the information from Appendix 3.3.

Question 1 is answered by the calculated entrance width. Question 2 indicates how fast the gate must operate, the choices are: '1 day', '0.5 day', '2-6 hours', '1-2 hours' or 'less than 10 minutes'. Question 3 has the following options available: '>4', '2-4', '1-2' and '1'. For question 4 'tug boat & crane', 'crane', 'tug boat' and 'none' can be selected. For question 5 and 6 'yes', 'no' and 'indecisive' can be chosen. Question 7 describes what depth is available outside the dock, this can be: 'more', 'less' or 'the same' as the sill height. For question 8 'available' or 'non-available' can be selected and finally question 9 describes how much room on top of the gate is needed to pass over the gate, the following options are available: 'walking bridge', 'forklift bridge', 'car bridge' or 'not needed'.

For each of the above questions the gate types get a score between the 0 and 5. A 0 means that the option is not possible, 1 means it is not preferred for this situation and 5 indicates that it is the ideal type for the answer. An example of the spanning box and free-floating caisson gate is given in Figure 0.27.

Entrance Gate Type	Spanning Box	Free caisson
Width of entrance	5	5
Speed of operation [min]	1	2
Labour	5	5
Reverse head capability	5	5
Ability to open against a head	3	3
Depth available outside dock	5	5
Provision of power	5	5
Access across top of gate	5	5
Total score	**34**	**35**
rank	**8**	**11**

Figure 0.27: Outcome functional requirements gate types: spanning box and free-floating caisson

The technical possible solutions get ranked to which are preferred. The highest ranked gets a score of 11 (11 types), the options that are not possible are ranked with a 0.

3. Functional requirements TOM

The functional requirements for the gate types are described in the introduction of this appendix. The weight of the functional requirements is determined with the following source:

- Technical score: Technical requirements TOM
- Reliability: *'Leidraad Kunstwerken'*
- Availability: *'Leidraad Kunstwerken'*
- Maintainability: British standard
- Safety: *'Leidraad Kunstwerken'*
- Expandability: British standard
- Availability of concrete Determined which material is used
- Availability of steel Determined which material is used
- Engineering costs Arcadis gate expert T.A. van Kooij
- Building costs Arcadis gate expert T.A. van Kooij

Sustainability is neglected, the material usage is not known at this design state.

From the *'Leidraad Kunstwerken'* page 130 a step-by-step plan is made to calculate three things of interest for this research, E2: mobilisation, E3: operating procedure during closing and E4: operating reliability closing system. The availability is determined to be E2, this determine if the dry dock and the users are available in case of an emergency. E3 and E4 determines the reliability of the dry dock gate. And the safety factor is determined by adding E2, E3 and E4 and divide these by 3, this is the mean of all the safety factors. An overview for the different gate types is given in Figure 0.28.

E2: Mobilastion

	Entrance Gate Type	a1	a2	a3	a4	a5	b1	b2	c	d1	d2	e
	Flap gate											
1	Spanning Box	4					1	0	5	4		**4**
2	Strutted	4					1	0	5	4		**4**
3	Cantilever	4					1	0	5	4		**4**
	Floating Caisson Gate											
4	Free	1	0,5			0,5	1	0	3	1	2	**3**
5	Hinged	4					1	0	5	4		**4**
6	Sliding or rolling caisson gate	4					1	0	5	4		**4**
	Sliding or rolling caisson gate (deballasting)	4							4	4		**4**
7	Mitre gates	4					1	0	5	4		**4**
8	Sector gates	4					1	0	5	4		**4**
	Intermediate gates											
	Modular units installed by crane											
9	Inverted "Y"	1	0,5			0,5	1	0	3	1	2	**3**
10	Lambda "λ"	1	0,5			0,5	1	0	3	1	2	**3**
11	Stop logs	1	0,5			0,5	1	0	3	1	2	**3**

E3: Operating procedure during closing

	Entrance Gate Type	a1	a2	a3	a4	b	c1	c2	c3	d	e
	Flap gate										
1	Spanning Box	4									**4**
2	Strutted	4									**4**
3	Cantilever	4									**4**
	Floating Caisson Gate										
4	Free	2	0,5	0	0,5	0,5	1	1	0,5	0,5	**3**
5	Hinged	2	0,5	0,5	0,5	1	1	1	0,5	0,5	**3**
6	Sliding or rolling caisson gate	4									**4**
	Sliding or rolling caisson gate (deballasting)	4									**4**
7	Mitre gates	4									**4**
8	Sector gates	4									**4**
	Intermediate gates										
	Modular units installed by crane										
9	Inverted "Y"	2	0,5	0	0,5	0,5	1	1	0,5	0,5	**3**
10	Lambda "λ"	2	0,5	0	0,5	0,5	1	1	0,5	0,5	**3**
11	Stop logs	2	0,5	0	0,5	0,5	1	1	0,5	0,5	**3**

E4: operating reliability closing system

	Entrance Gate Type	a1	a2	a3	b	c	d	e	f	g	h	i
	Flap gate											
1	Spanning Box	2	1	-1	4	2	0	1		1		**1**
2	Strutted	2	1	-1	4	2	0	1		1		**1**
3	Cantilever	2	1	-1	4	2	0	1		1		**1**
	Floating Caisson Gate											
4	Free	1	1	-1	2	1	1	2		2		**2**
5	Hinged	2	1	-1	4	2	1	1		1		**1**
6	Sliding or rolling caisson gate	2	1	-1	4	2	1	1		1		**1**
	Sliding or rolling caisson gate (deballasting)	2	1	-1	4	2	1	2		2		**2**
7	Mitre gates	2	1	-1	4	2	1	1		1		**1**
8	Sector gates	2	1	-1	4	2	1	1		1		**1**
	Intermediate gates											
	Modular units installed by crane											
9	Inverted "Y"	1	1	-1	2	1	1	2		2		**2**
10	Lambda "λ"	1	1	-1	2	1	1	2		2		**2**
11	Stop logs	1	1	-1	2	1	1	2		2		**2**

Figure 0.28: Outcome *'leidraad kunsterken'* functional requirements step-by-step plan

An overview of the outcome of the functional requirements Trade-Off Matrix for the gate types spanning box and free-floating caisson is described in Figure 0.29. The maintainability of the spanning box is a 3, this is a low score because it is not easy to get the gate out of the water for repair work. For the free floating caisson it is much easier, because it is not attached to the floor. The expendability of the flap gate is a 1. This gate cannot easily be extended for a wider entrance, because it is designed for the particular gate. The free-floating gate can be extended by adding another caisson to it and therefore it scores a 3.

Functional requirements gate trade-off			
	Entrance Gate Type	Spanning Box	Free-floating
	Total score	261	345
Technical score	*Score*	8	11
	Weight	10	10
Reliability	*Score*	5	5
	Weight	8	8
Availability	*Score*	4	3
	Weight	8	8
Maintainability	*Score*	3	9
	Weight	7	7
Safety	*Score*	3	2,7
	Weight	8	8
Expandability	*Score*	*1*	*3*
	Weight	*8*	*8*
Availability of steel	*Score*	5	0
	Weight	-1	-1
Availability of concrete	*Score*	0	5
	Weight	-1	-1
Engineering cost	*Score*	1	2
	Weight	7	7
Building cost	*Score*	6	6
	Weight	9	9
Sustainability	*Score*		
	Weight	7	7

Figure 0.29: Functional gate Trade-Off Matrix

4. Result

From the functional requirements Trade-Off Matrix the score per gate type is determined. The type with the highest score is the preferred alternative in this design stage. It is advised to also investigate the possibilities to use a type that has a faster opening and closing speed, this may be more expensive for the initial costs but makes the docking cycle shorter, making it cheaper to use.

Appendix 8 Verification

This appendix discusses the verification of the wall and floor calculations. These verifications are split into the embedded anchor walls and the concrete walls and floor. The embedded anchor wall calculations are verified with the program *D-sheet piling* and the concrete wall and floor calculations are verified with the *SCIA*.

Appendix 8.1 Embedded anchor walls

Boundary conditions

The DSS is programmed with the following boundary conditions. The first boundary condition is that the wall used is taken as a stiff wall. This wall has the thickness of 1 m and has one anchor connected to it. The option of a concrete floor that is used as a strut is not applied in this verification, this must be done in the future development of the DSS. For all the cases the surface and groundwater level are set at NAP. This means that the ground is actually swampy, but this has no effect on the calculations that are verified.

Initial conditions

This part describes the soil conditions set for the different cases.

Sand

In the case of sand there is one uniform soil consisting of sand with the parameters described in Table 0.7.

Table 0.7: Sand soil condition

Layer	Depth +NAP [m]	Density [kN/m3]	φ [degree]	Cohesion [kPa]
Sand	0	20	30	0

Clay

In the case of clay there is one uniform soil consisting of sand with the parameters described in Table 0.8.

Table 0.8: Clay soil condition

Layer	Depth +NAP [m]	Density [kN/m3]	φ [degree]	Cohesion [kPa]
Sand	0	18	23	10

Mixed

In the case of a mixed soil layer, the soil consists of multiple layers with different soil sorts. The mixed layer is not a random chosen type but is a soil structure as described in the case study. The soil conditions for this mixed layer can be described in Table 0.9.

Table 0.9: Mixed soil condition

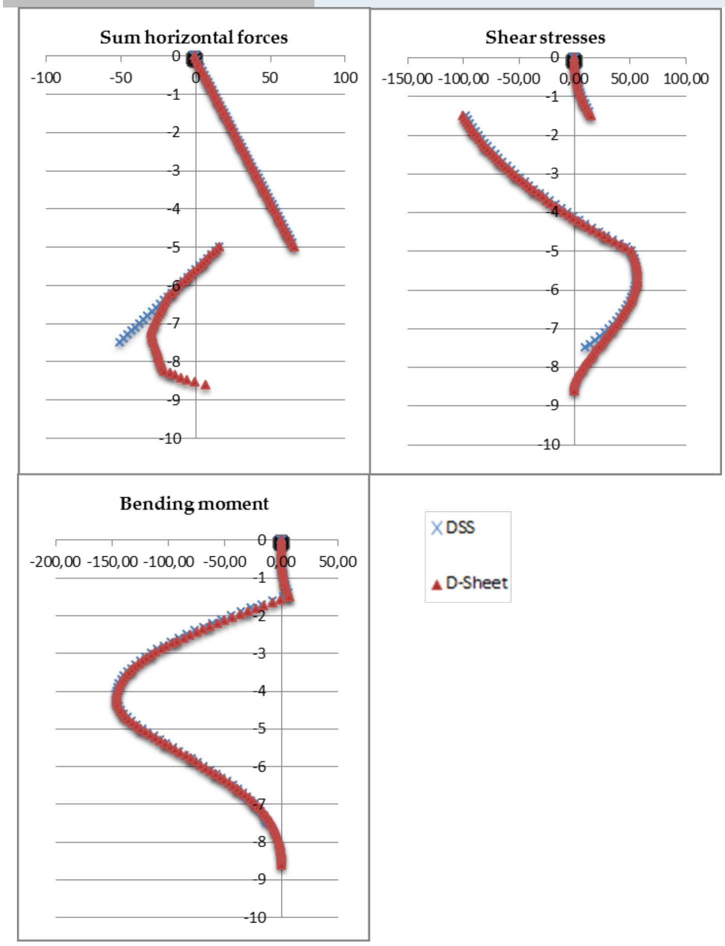
Layer	Depth +NAP [m]	Density [kN/m3]	φ [degree]	Cohesion [kPa]
Sand (landfill)	0	19	30	0
Clay (soft)	-3,8	14	18	5
Sand (loose)	-8,3	19	30	0
Clay (moderate)	-14,3	18	23	10
Sand (loose very silty)	-28,3	20	27	0
Sand (silty moderate)	-38,3	20	35	0
Sand (moderate)	-64	20	30	0

Case 1; 5m sand

A 5m retaining wall. Is used in this case

Table 0.10: Verification results case 1; 5m sand, anchor by DSS

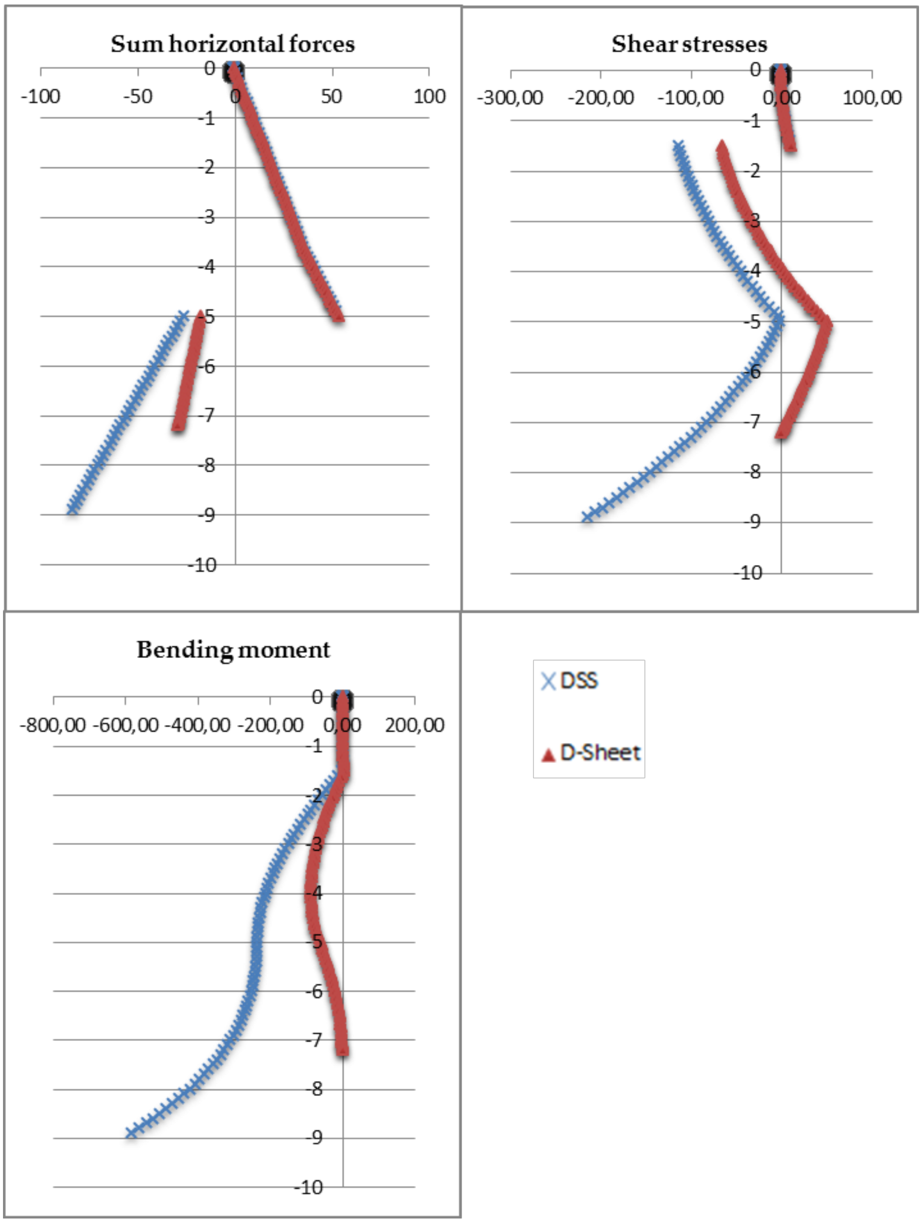
	Sheet pile	DSS	error [%]
Anchor force [kN]	115	113	-1,7
Depth [m]	-8,6	-7,5	-12,8
Max Shear stress [kN]	56,9	56,4	-0,9
Min shear stress [kN]	-100,0	-98,0	-2,0
Max Momentum [kNm]	7,5	6,1	-18,5
Min Momentum [kNm]	-145,9	-146,2	0,2



Case 2; 5m clay

Table 0.11: Verification results case 2; 5m clay, anchor by DSS

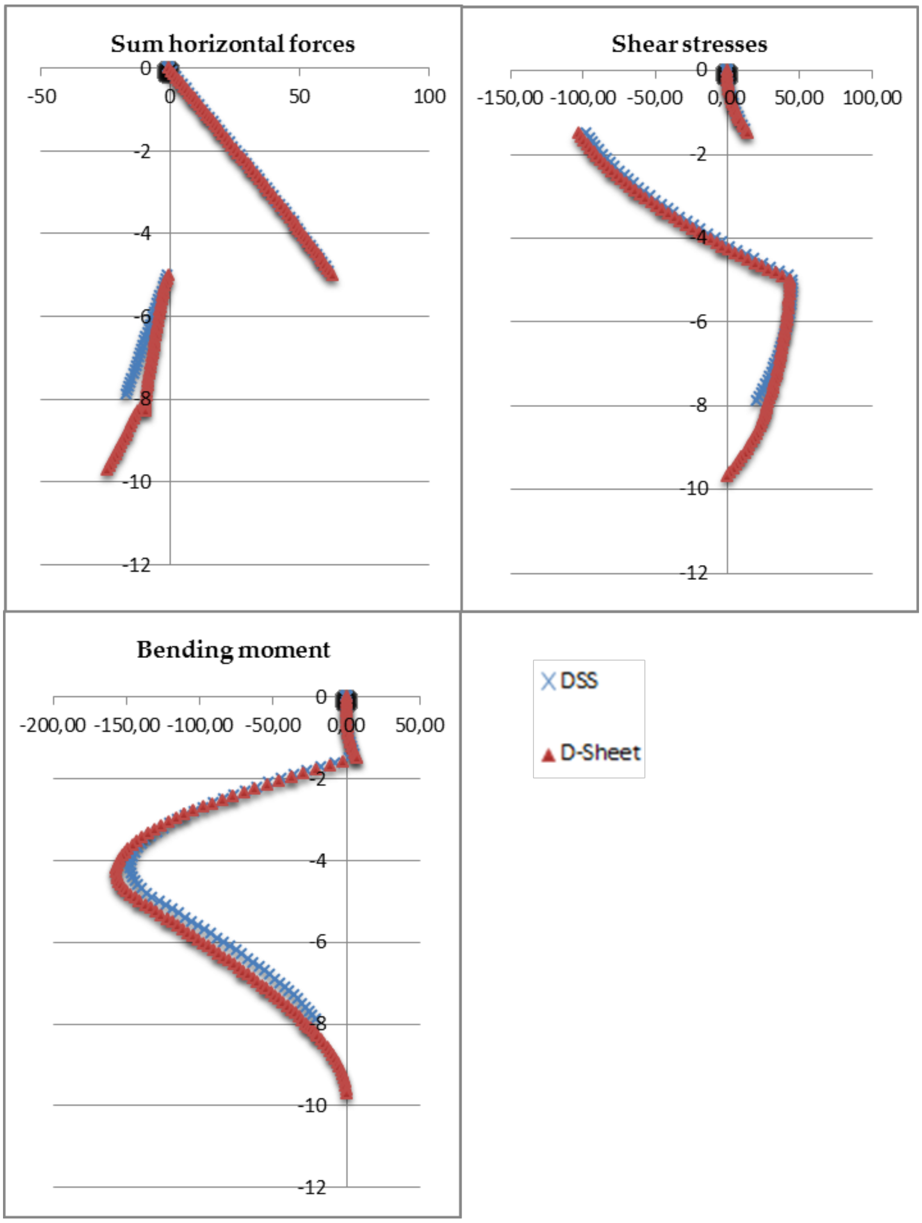
	Sheet pile	DSS	error [%]
Anchor force [kN]	77	125	62,3
Depth [m]	-7,2	-8,9	23,6
Max Shear stress [kN]	50,57	9,80135	80,6
Min shear stress [kN]	-65,8	-214,733	226,3
Max Momentum [kNm]	5,63	4,585913	18,5
Min Momentum [kNm]	-86,05	-583,017	577,5



Case 3; 5m mixed

Table 0.12: Verification results case 3; 5m mixed, anchor by DSS

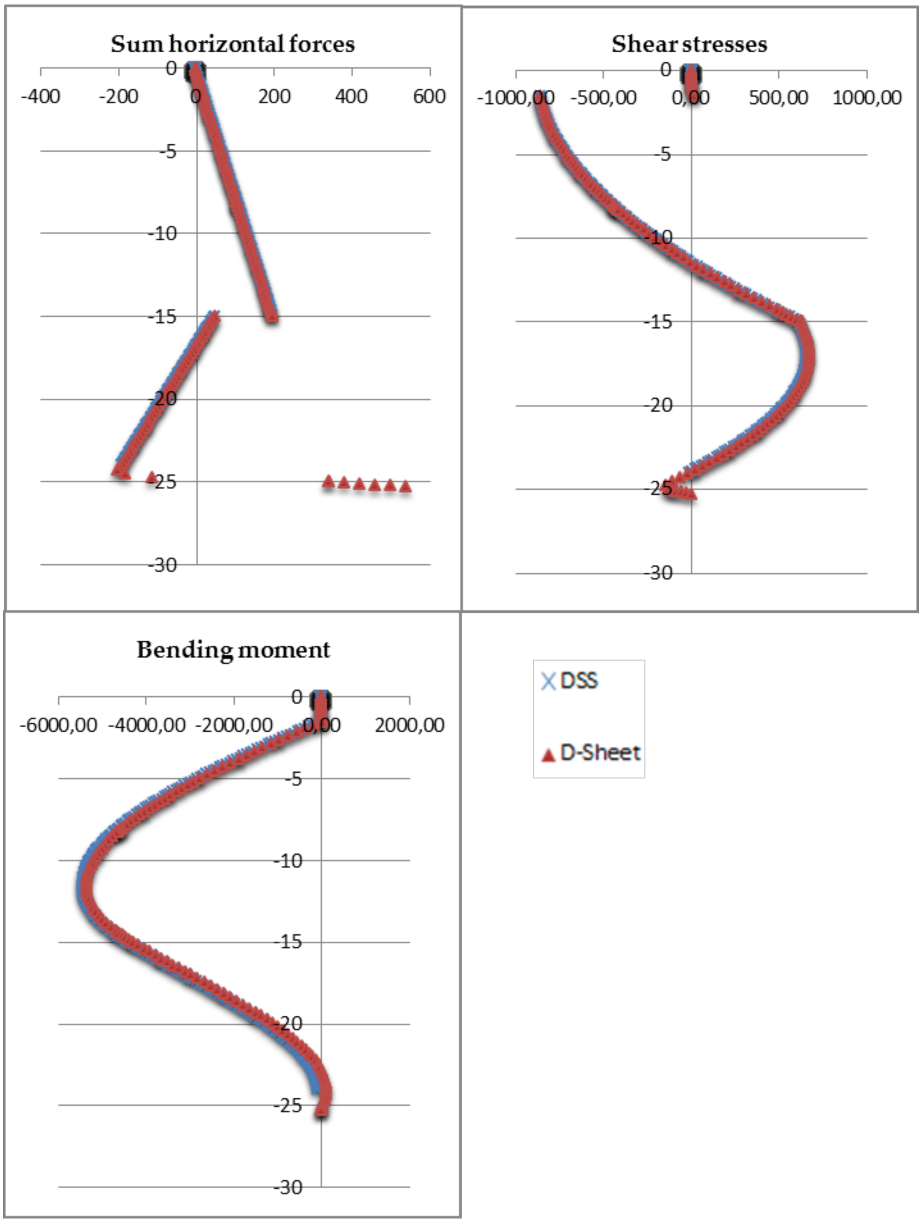
	Sheet pile	DSS	error [%]
Anchor force [kN]	117	112	4,3
Depth [m]	-9,7	-7,9	18,6
Max Shear stress [kN]	43,6	45,6	4,4
Min shear stress [kN]	-102,9	-97,4	5,3
Max Momentum [kNm]	7,3	6,0	18,4
Min Momentum [kNm]	-156,8	-147,5	5,9



Case 4; 15m sand

Table 0.13: Verification results case 4; 15m sand, anchor by DSS

	Sheet pile	DSS	error [%]
Anchor force [kN]	874	879	0,6
Depth [m]	-25,3	-24	-5,1
Max Shear stress [kN]	672,6	660,4	-1,8
Min shear stress [kN]	-859,2	-864,0	0,6
Max Momentum [kNm]	115,8	6,1	-94,7
Min Momentum [kNm]	-5362,0	-5454,0	1,7

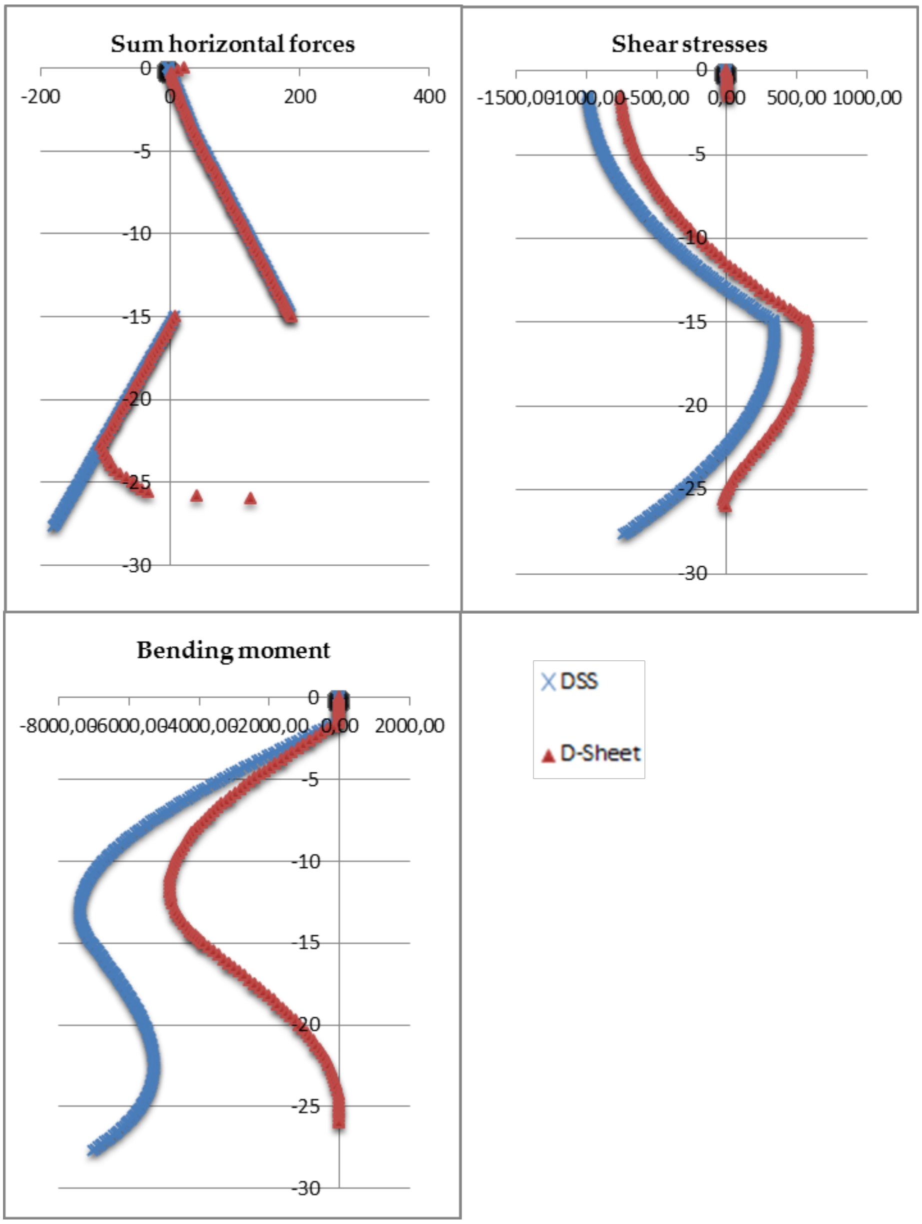


Case 5; 15m clay

Anchor by dss

Table 0.14: Verification results case 5; 15m clay, anchor by DSS

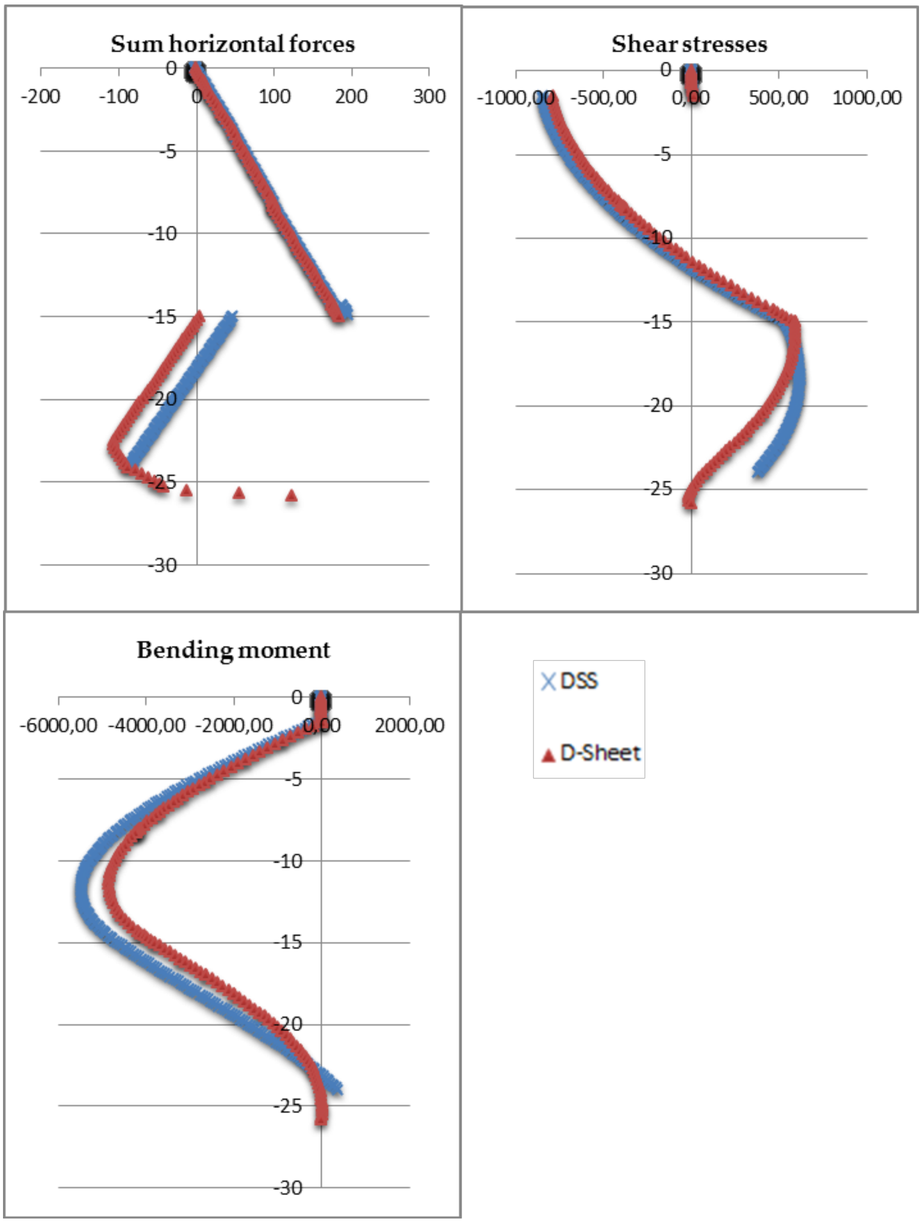
	Sheet pile	DSS	error [%]
Anchor force [kN]	767	996	29,9
Depth [m]	-26	-27,7	6,5
Max Shear stress [kN]	584,4	343,5	41,2
Min shear stress [kN]	-752,8	-984,7	30,8
Max Momentum [kNm]	10,1	4,6	54,8
Min Momentum [kNm]	-4831,5	-7383,6	52,8



Case 6; 15m mixed

Table 0.15: Verification results case 6; 15m mixed, anchor by DSS

	Sheet pile	DSS	error [%]
Anchor force [kN]	804	863	7,3
Depth [m]	-25,8	-24	-7,0
Max Shear stress [kN]	595,4	526,7	-11,6
Min shear stress [kN]	-790,1	-848,4	7,4
Max Momentum [kNm]	8,6	6,0	-30,3
Min Momentum [kNm]	-4848,9	-5486,4	13,1

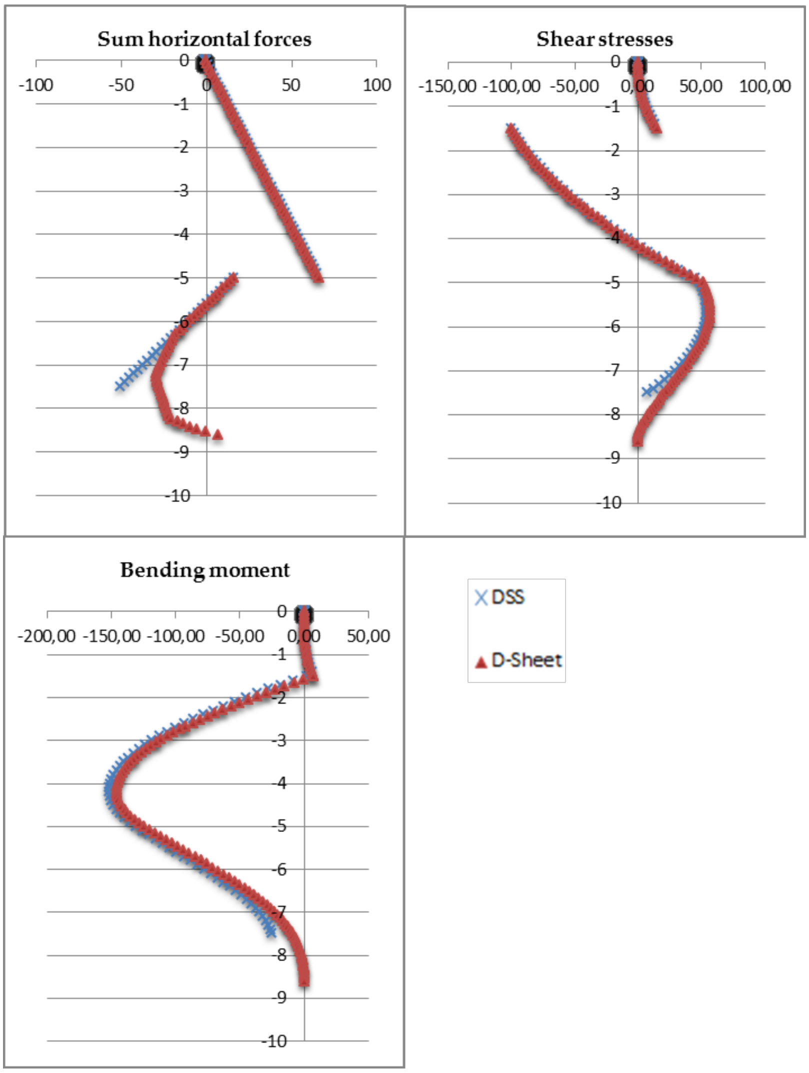


Appendix 8.2 Embedded anchor walls with D-Sheet anchor forces

Case 1; 5m sand, anchor force by D-Sheet

Table 0.16: Verification results case 1; 5m sand, anchor by D-Sheet

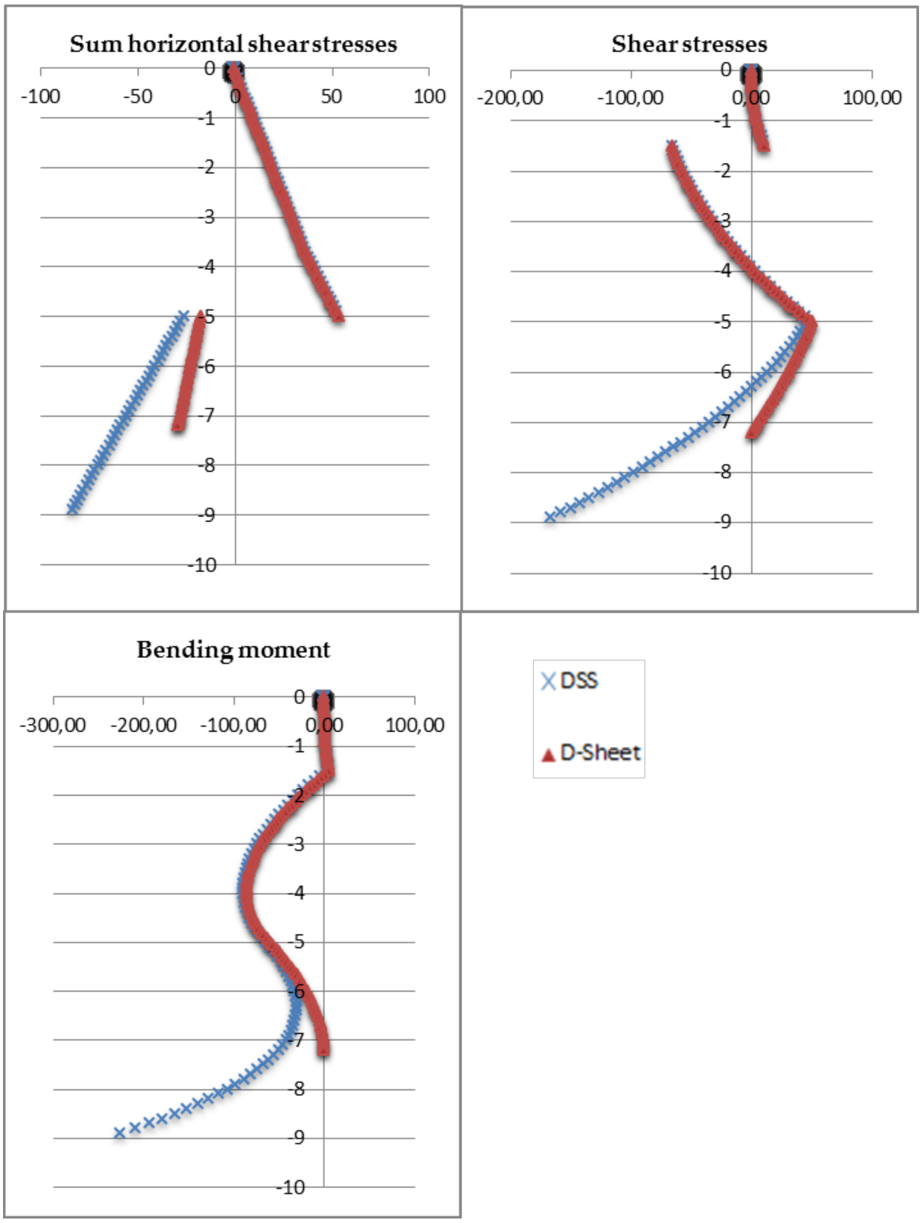
	Sheet pile	DSS	error [%]
Anchor force [kN]	115	115	0,0
Depth [m]	-8,6	-7,5	-12,8
Max Shear stress [kN]	56,9	54,4	-4,4
Min shear stress [kN]	-100,0	-100,0	0,0
Max Momentum [kNm]	7,5	6,1	-18,5
Min Momentum [kNm]	-145,9	-151,6	3,9



Case 2; 5m clay, anchor force by D-sheet

Table 0.17: Verification results case 2; 5m clay, anchor by D-Sheet

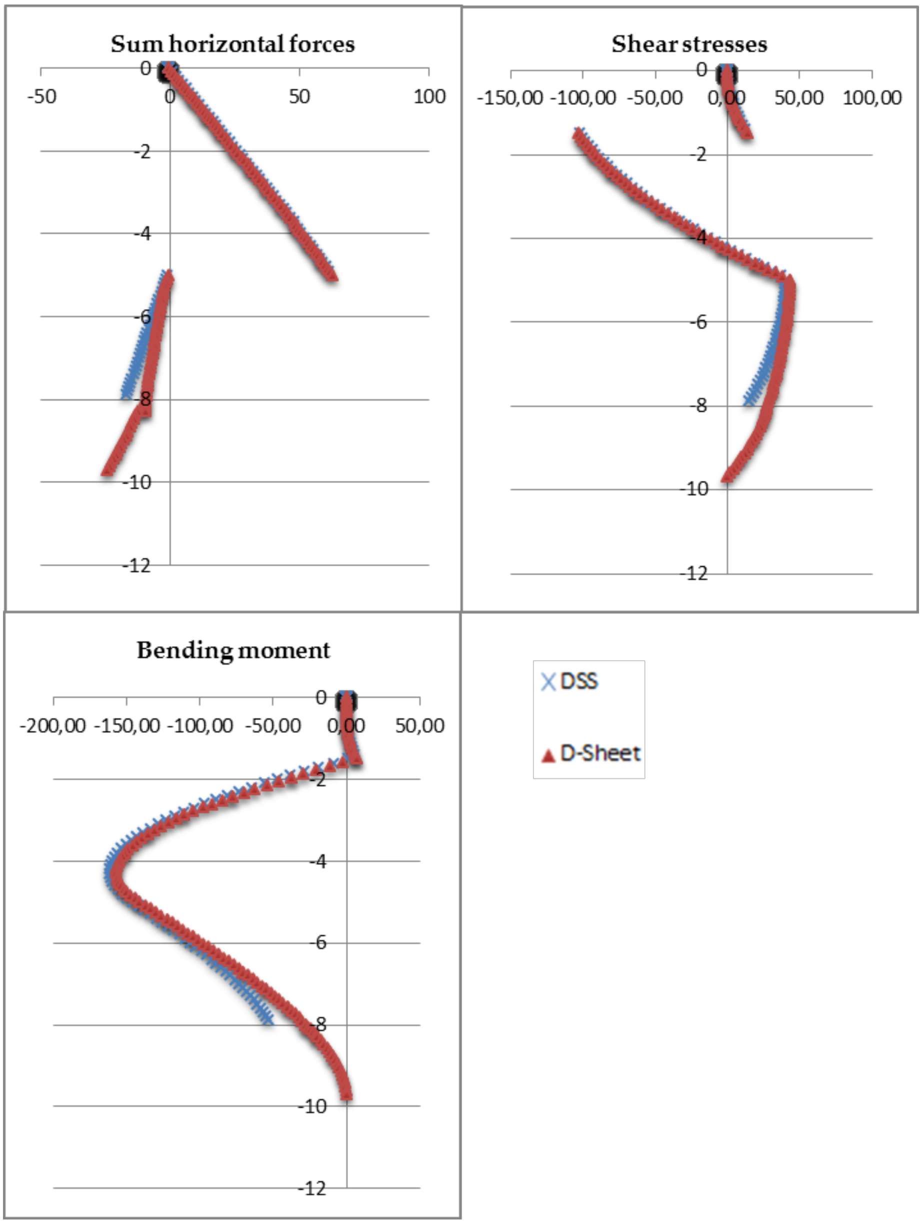
	Sheet pile	DSS	error [%]
Anchor force [kN]	77	77	0,0
Depth [m]	-7,2	-7	-2,8
Max Shear stress [kN]	50,6	46,6	-7,8
Min shear stress [kN]	-65,8	-65,7	0,1
Max Momentum [kNm]	5,6	4,6	-18,5
Min Momentum [kNm]	-86,1	-89,7	4,3



Case 3; 5m mixed, anchor force by D-Sheet

Table 0.18: Verification results case 3; 5m mixed, anchor by D-Sheet

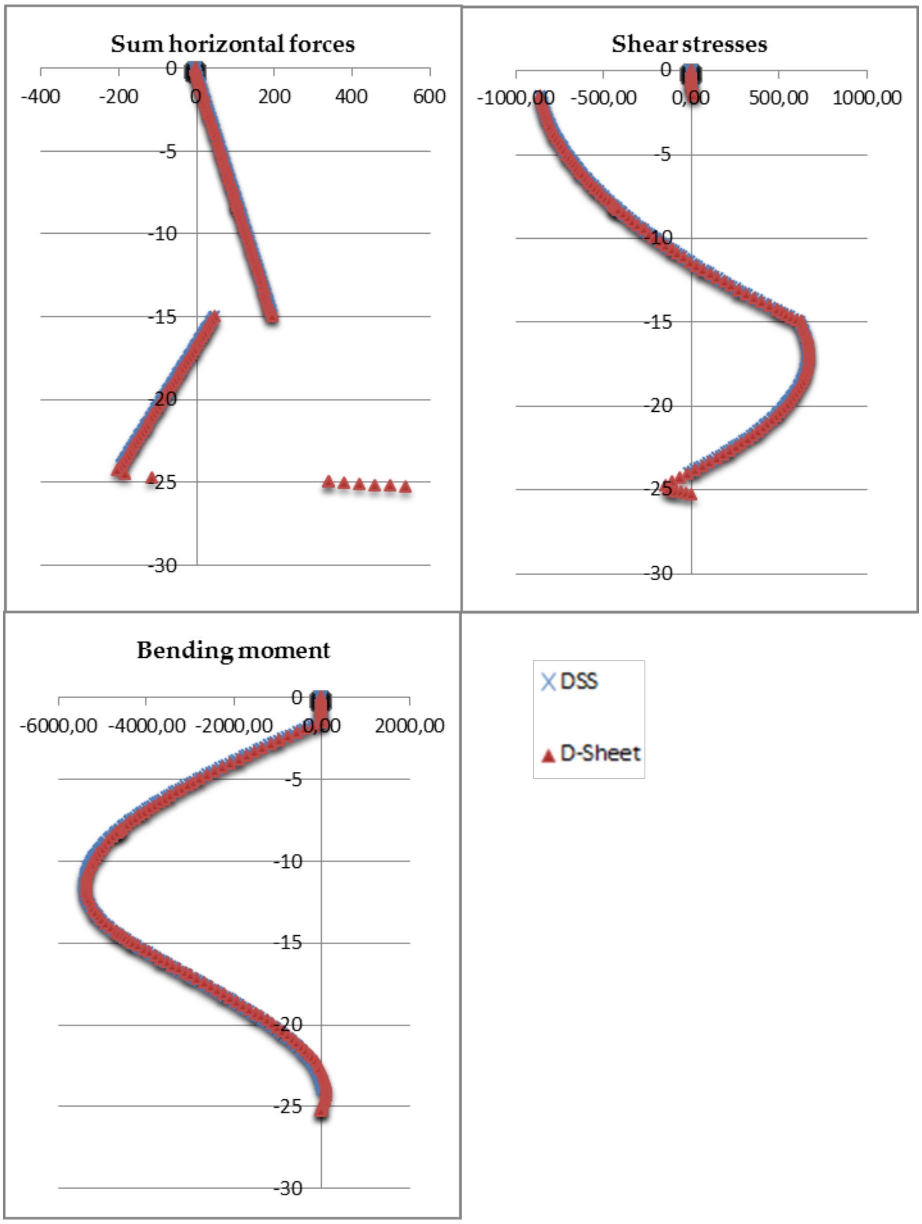
	Sheet pile	DSS	error [%]
Anchor force [kN]	117	117	0,0
Depth [m]	-9,7	-7,9	-18,6
Max Shear stress [kN]	43,6	40,6	-7,0
Min shear stress [kN]	-102,9	-102,4	-0,5
Max Momentum [kNm]	7,3	6,0	-18,5
Min Momentum [kNm]	-156,8	-161,3	2,8



Case 4; 15m sand, anchor force by D-Sheet

Table 0.19: Verification results case 5; 15m clay, anchor by D-Sheet

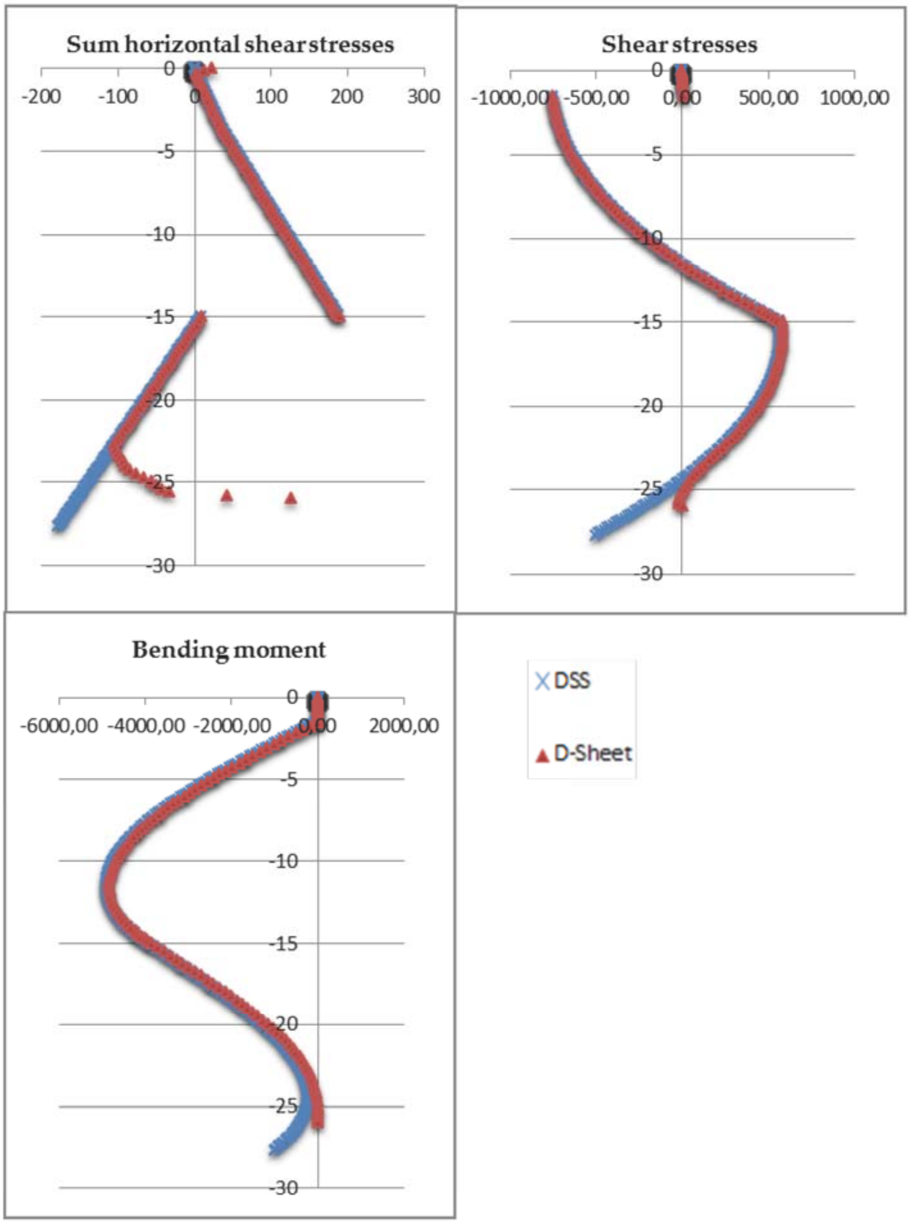
	Sheet pile	DSS	error [%]
Anchor force [kN]	874	874	0
Depth [m]	-25,3	-24	-5,1
Max Shear stress [kN]	672,6	665,4	-1,1
Min shear stress [kN]	-859,2	-859,0	0,0
Max Momentum [kNm]	115,8	8,8	-92,4
Min Momentum [kNm]	-5362,0	-5403,8	0,8



Case 5; 15m clay, anchor force by D-Sheet

Table 0.20: Verification results case 5; 15m clay, anchor by D-Sheet

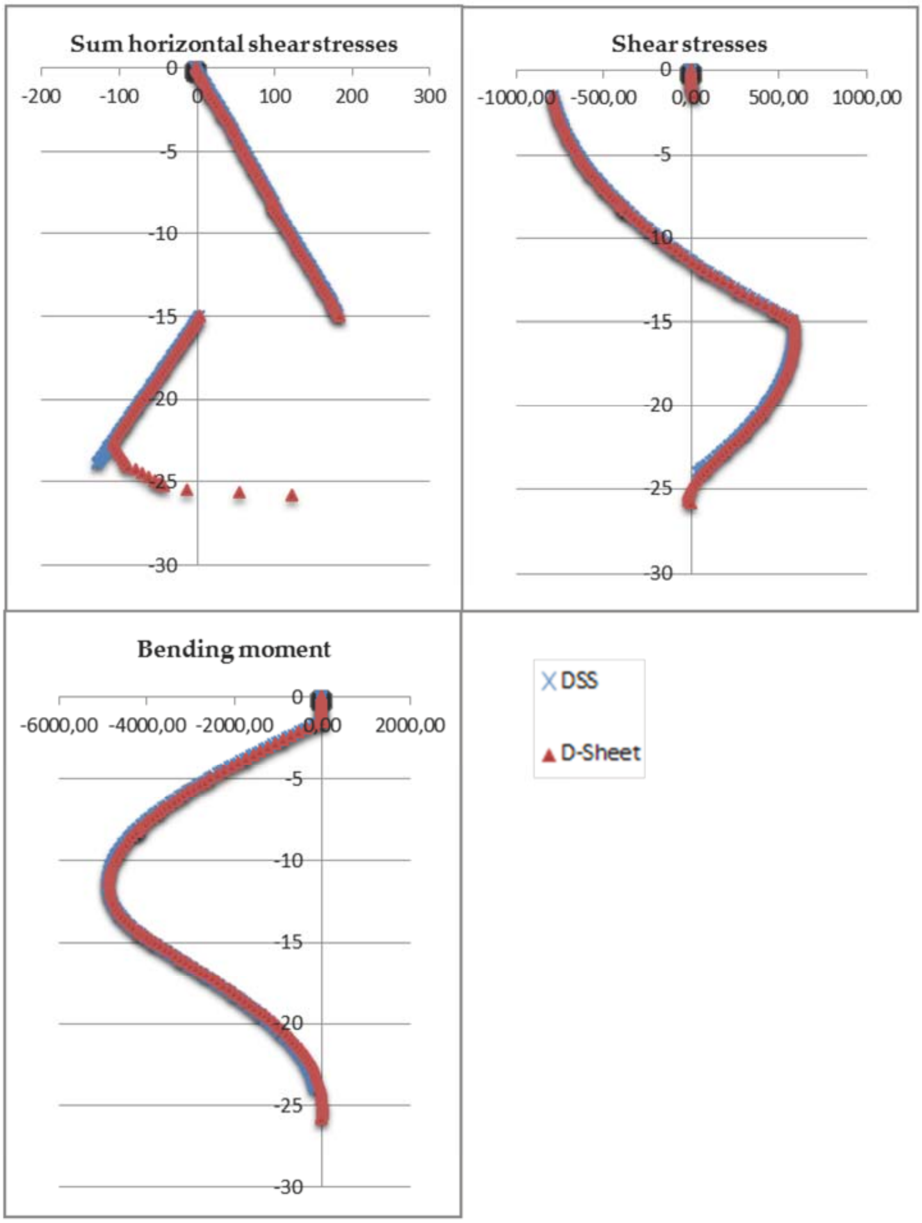
	Sheet pile	DSS	error [%]
Anchor force [kN]	767	767	0,0
Depth [m]	-26	-27,7	6,5
Max Shear stress [kN]	584,4	572,5	-2,0
Min shear stress [kN]	-752,8	-755,7	0,4
Max Momentum [kNm]	10,1	4,6	-54,8
Min Momentum [kNm]	-4831,5	-4904,3	1,5



Case 6; 15m mixed, anchor force by D-Sheet

Table 0.21: Verification results case 6; 15m mixed, anchor by D-Sheet

	Sheet pile	DSS	error [%]
Anchor force [kN]	804	804	0,0
Depth [m]	-25,8	-24	-7,0
Max Shear stress [kN]	595,4	585,7	-1,6
Min shear stress [kN]	-790,1	-789,4	-0,1
Max Momentum [kNm]	8,6	6,0	-30,3
Min Momentum [kNm]	-4848,9	-4888,9	0,8



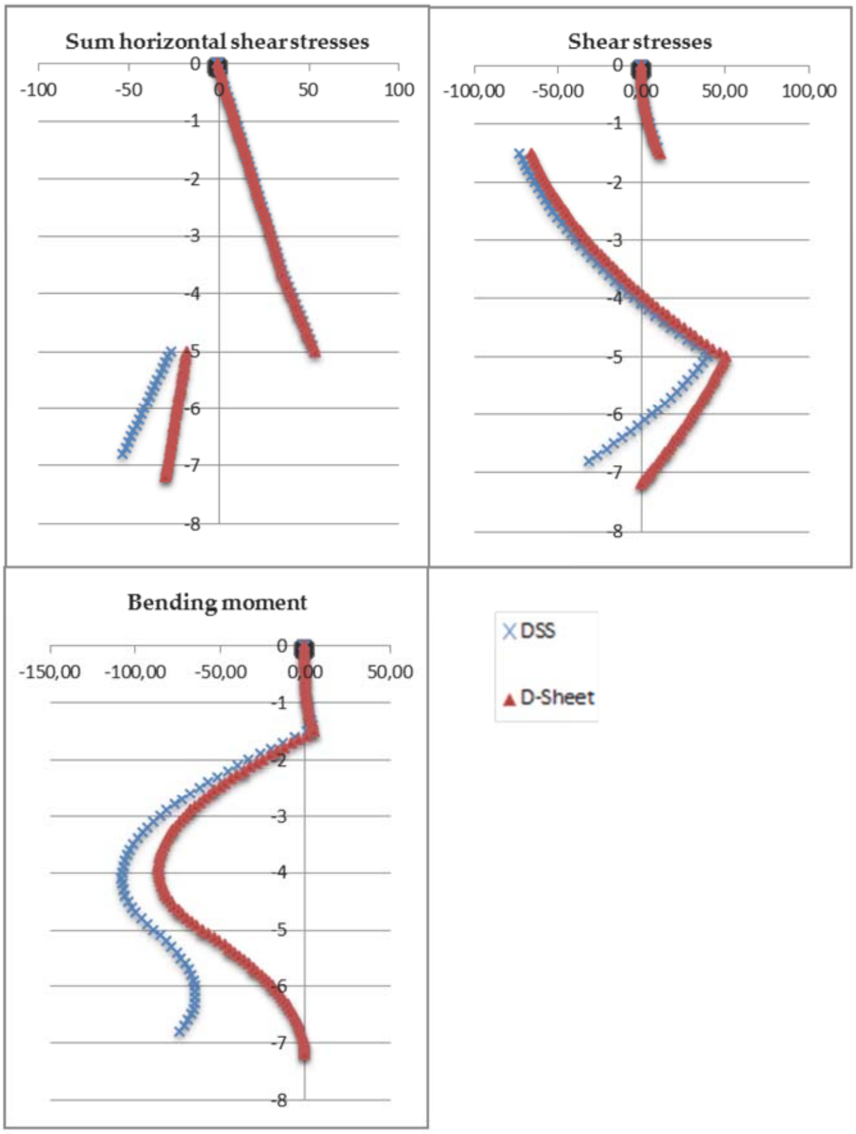
asdf

Appendix 8.3 Embedded anchor walls with manual anchor forces

Case 2; 5m clay, manual anchor force

Table 0.22: Verification results case 2; 5m clay, anchor manual calculation

	Sheet pile	DSS	error [%]
Anchor force [kN]	77	84	9,1
Depth [m]	-7,2	-6,8	5,6
Max Shear stress [kN]	50,6	39,6	21,7
Min shear stress [kN]	-65,8	-72,7	10,6
Max Momentum [kNm]	5,6	4,6	18,5
Min Momentum [kNm]	-86,1	-107,7	25,1



Appendix 8.4 Concrete results cases

Case 1			DSS		SCIA		Error	
			Max shear stress [kN/m]	Max momentum [kNm]	Max shear stress [kN/m]	Max momentum [kNm]	Max shear stress [%]	Max momentum [%]
Wall			2430	14580	2430	14580	0	0
Floor	shallow foundation	without vessel	958	17972	895	18093	-7,0	0,7
		with vessel	947	21728	895	18093	-5,8	-20,1
	pile foundation	without vessel	962	17972	1609	18093	40,2	0,7
		with vessel	896	21397	1202	18093	25,5	-18,3

Case 2			DSS		SCIA		Error	
			Max shear stress [kN/m]	Max momentum [kNm]	Max shear stress [kN/m]	Max momentum [kNm]	Max shear stress [%]	Max momentum [%]
Wall			2430	14580	2430	14580	0	0
Floor	shallow foundation	without vessel	958	17973	895	18093	-7,0	0,7
		with vessel	947	21730	895	18093	-5,8	-20,1
	pile foundation	without vessel	962	17973	2795	18093	65,6	0,7
		with vessel	896	20834	1473	18093	39,2	-15,1

Case 3			DSS		SCIA		Error	
			Max shear stress [kN/m]	Max momentum [kNm]	Max shear stress [kN/m]	Max momentum [kNm]	Max shear stress [%]	Max momentum [%]
Wall			188	313	188	313	0	0
Floor	shallow foundation	without vessel	266	1294	257	821	-3,5	-57,6
		with vessel	1383	9482	916	6225	-51,0	-52,3
	pile foundation	without vessel	277	1396	303	636	8,6	-119,5
		with vessel	1257	7470	919	4591	-36,8	-62,7

Case 4			DSS		SCIA		Error	
			Max shear stress [kN/m]	Max momentum [kNm]	Max shear stress [kN/m]	Max momentum [kNm]	Max shear stress [%]	Max momentum [%]
Wall			188	313	188	313	0	0
Floor	shallow foundation	without vessel	266	1294	257	821	-3,5	-57,6
		with vessel	351	2302	230	1526	-52,6	-50,9
	pile foundation	without vessel	277	1396	303	792	8,6	-76,3
		with vessel	306	1595	303	1001	-1,0	-59,3

Case 5			DSS		SCIA		Error	
			Max shear stress [kN/m]	Max momentum [kNm]	Max shear stress [kN/m]	Max momentum [kNm]	Max shear stress [%]	Max momentum [%]
Wall			2430	14580	2430	14580	0	0
Floor	shallow foundation	without vessel	829	17973	1047	18093	20,8	0,7
		with vessel	555	20023	556	18225	0,2	-9,9
	pile foundation	without vessel	800	17973	1000	18093	20,0	0,7
		with vessel	835	18613	963	18093	13,3	-2,9

Case 6			DSS		SCIA		Error	
			Max shear stress [kN/m]	Max momentum [kNm]	Max shear stress [kN/m]	Max momentum [kNm]	Max shear stress [%]	Max momentum [%]
Wall			2430	14580	2430	14580	0	0
Floor	shallow foundation	without vessel	829	17973	1047	18093	20,8	0,7
		with vessel	519	17973	899	18093	42,3	0,7
	pile foundation	without vessel	800	17973	1000	18093	20,0	0,7
		with vessel	835	18613	963	18093	13,3	-2,9

Case 7			DSS		SCIA		Error	
			Max shear stress [kN/m]	Max momentum [kNm]	Max shear stress [kN/m]	Max momentum [kNm]	Max shear stress [%]	Max momentum [%]
Wall			188	313	188	312.5	0	0
Floor	shallow foundation	without vessel	230	655	255	657	9,8	0,3
		with vessel	225	1552	177	1407	-27,1	-10,3
	pile foundation	without vessel	296	655	303	636	2,3	-3,0
		with vessel	299	705	303	636	1,3	-10,8

Case 8			DSS		SCIA		Error	
			Max shear stress [kN/m]	Max momentum [kNm]	Max shear stress [kN/m]	Max momentum [kNm]	Max shear stress [%]	Max momentum [%]
Wall			188	313	188	313	0	0
Floor	shallow foundation	without vessel	230	655	255	657	9,8	0,3
		with vessel	1061	5452	919	4993	-15,5	-9,2
	pile foundation	without vessel	296	655	303	636	2,3	-3,0
		with vessel	1092	2499	1058	2326	-3,2	-7,4

Appendix 8.5 Concrete case 1

Shallow foundation results SCIA case 1

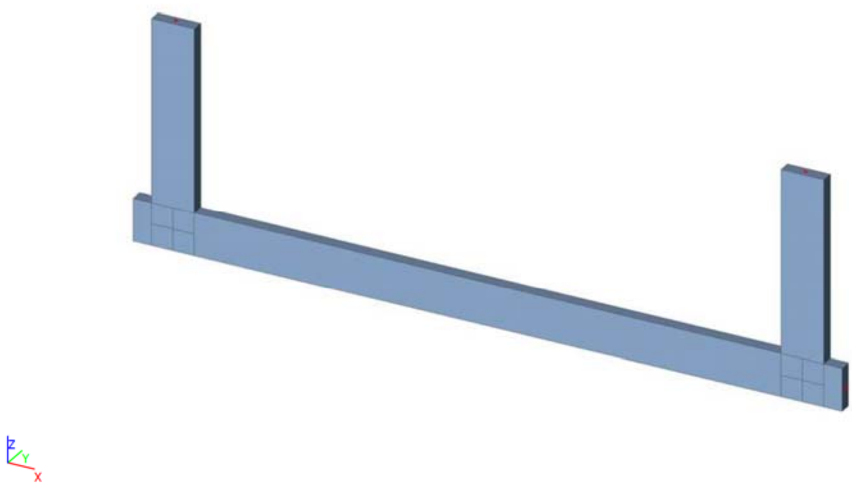
ARCADIS	Project	Case study dry dock	Author	J. Treffers
	Part	Conceptual design	Date	17-6-2015
	Description	Dry Dock shallow foundation		

1. Project

1.1. Project

Licence name	ARCADIS
Project	Case study dry dock
Part	Conceptual design
Description	Dry Dock shallow foundation
Author	J. Treffers
Date	17-6-2015
Structure	Frame XZ
No. of nodes :	8
No. of beams :	5
No. of slabs :	0
No. of solids :	0
No. of used profiles :	3
No. of load cases :	4
No. of used materials :	2
Acceleration of gravity [m/s^2]	9,810
National code	NEN

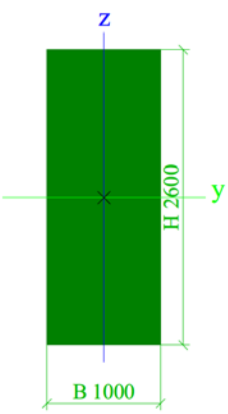
1.1.1. Analysis model



2. Cross-sections

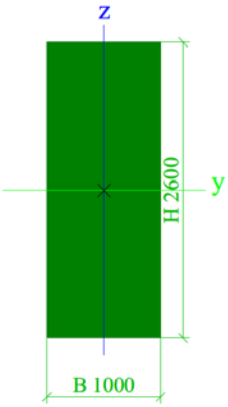
vloer		
Type	Rechthoek	
Detailed	2600; 1000	
Shape type	Thick-walled	
Item material	C45/55	
Fabrication	concrete	
A [m²]	2,6000e+00	
Ay [m²], Az [m²]	2,1667e+00	2,1667e+00
AL [m²/m], AD [m²/m]	7,2000e+00	7,2000e+00
cYUCS [mm], cZUCS [mm]	500	1300
α [deg]	0,00	
Iy [m⁴], Iz [m⁴]	1,4647e+00	2,1667e-01
iy [mm], iz [mm]	751	289
Wely [m³], Welz [m³]	1,1267e+00	4,3333e-01
Wply [m³], Wplz [m³]	0,0000e+00	0,0000e+00
Mply+ [Nm], Mply- [Nm]	0,00e+00	0,00e+00
Mplz+ [Nm], Mplz- [Nm]	0,00e+00	0,00e+00
dy [mm], dz [mm]	0	0
It [m⁴], Iw [m⁶]	6,5679e-01	0,0000e+00
β y [mm], β z [mm]	0	0

Picture



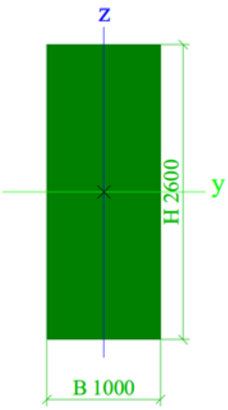
Wand oo		
Type	Rechthoek	
Detailed	2600; 1000	
Shape type	Thick-walled	
Item material	C45/55 oo	
Fabrication	concrete	
A [m²]	2,6000e+00	
Ay [m²], Az [m²]	2,1667e+00	2,1667e+00
AL [m²/m], AD [m²/m]	7,2000e+00	7,2000e+00
cYUCS [mm], cZUCS [mm]	500	1300
α [deg]	0,00	
Iy [m⁴], Iz [m⁴]	1,4647e+00	2,1667e-01
iy [mm], iz [mm]	751	289
Wely [m³], Welz [m³]	1,1267e+00	4,3333e-01
Wply [m³], Wplz [m³]	0,0000e+00	0,0000e+00
Mply+ [Nm], Mply- [Nm]	0,00e+00	0,00e+00
Mplz+ [Nm], Mplz- [Nm]	0,00e+00	0,00e+00
dy [mm], dz [mm]	0	0
It [m⁴], Iw [m⁶]	6,5679e-01	0,0000e+00
β y [mm], β z [mm]	0	0

Picture



Wand		
Type	Rechthoek	
Detailed	2600; 1000	
Shape type	Thick-walled	
Item material	C45/55	
Fabrication	concrete	
A [m^2]	2,6000e+00	
Ay [m^2], Az [m^2]	2,1667e+00	2,1667e+00
AL [m^2/m], AD [m^2/m]	7,2000e+00	7,2000e+00
cYUCS [mm], cZUCS [mm]	500	1300
α [deg]	0,00	
Iy [m^4], Iz [m^4]	1,4647e+00	2,1667e-01
iy [mm], iz [mm]	751	289
Wely [m^3], Welz [m^3]	1,1267e+00	4,3333e-01
Wply [m^3], Wplz [m^3]	0,0000e+00	0,0000e+00
Mply+ [Nm], Mply- [Nm]	0,00e+00	0,00e+00
Mplz+ [Nm], Mplz- [Nm]	0,00e+00	0,00e+00
dy [mm], dz [mm]	0	0
It [m^4], Iw [m^6]	6,5679e-01	0,0000e+00
β y [mm], β z [mm]	0	0

Picture



Explanations of symbols	
A	Area
Ay	Shear Area in principal y-direction
Az	Shear Area in principal z-direction
AL	Circumference per unit length
AD	Drying surface per unit length
cYUCS	Centroid coordinate in Y-direction of Input axis system
cZUCS	Centroid coordinate in Z-direction of Input axis system

Explanations of symbols	
IYLCS	Second moment of area about the YLCS axis
IZLCS	Second moment of area about the ZLCS axis
IYZLCS	Product moment of area in the LCS system
α	Rotation angle of the principal axis system
Iy	Second moment of area about the

Explanations of symbols	
	principal y-axis
Iz	Second moment of area about the principal z-axis
iy	Radius of gyration about the principal y-axis
iz	Radius of gyration about the principal z-axis
Wely	Elastic section modulus about the principal y-axis
Welz	Elastic section modulus about the principal z-axis
Wply	Plastic section modulus about the principal y-axis
Wplz	Plastic section modulus about the principal z-axis

Explanations of symbols	
Mply+	Plastic moment about the principal y-axis for a positive My moment
Mply-	Plastic moment about the principal y-axis for a negative My moment
Mplz+	Plastic moment about the principal z-axis for a positive Mz moment
Mplz-	Plastic moment about the principal z-axis for a negative Mz moment
dy	Shear center coordinate in principal y-direction measured from the centroid - Not calculated or simplified
dz	Shear center coordinate in principal z-direction measured from the centroid - Not calculated or simplified
It	Torsional constant - Not calculated or simplified
Iw	Warping constant - Not calculated or simplified
β y	Mono-symmetry constant about the principal y-axis
β z	Mono-symmetry constant about the principal z-axis

3. Materials

Concrete NEN 6720

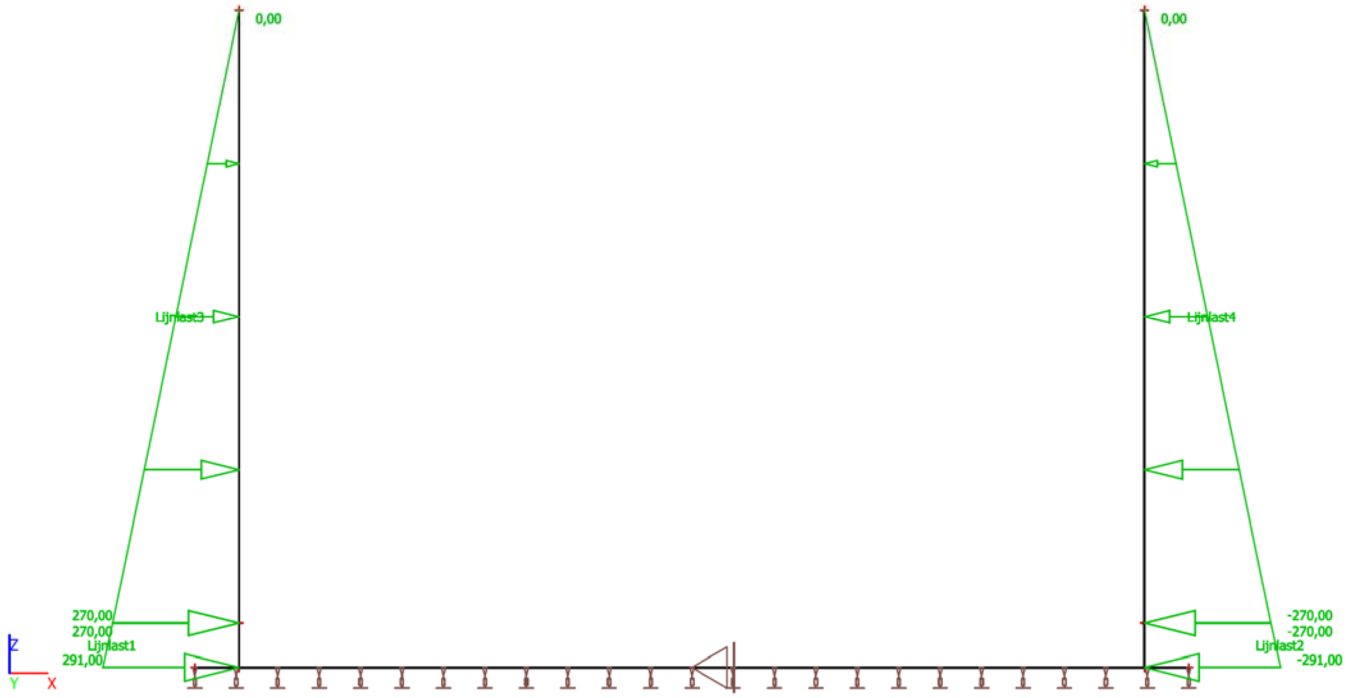
Type	Unit mass [kg/m^3]	E-mod [MPa]	Poisson - nu	G mod [MPa]	Characteristic cube compression strength (f'ck) [MPa]
Name					Design compression strength (f'b) [MPa]
Beton C45/55	2500,0	3,6000e+04	0.2	1,5000e+04	55,00
					33,00
Beton C45/55 oo	0,0	3,6000e+12	0.2	1,5000e+12	55,00
					33,00

4. Load cases

4.1. Load cases - grond

Name	Description Spec	Action type Load type	LoadGroup
grond		Permanent Standard	LG1

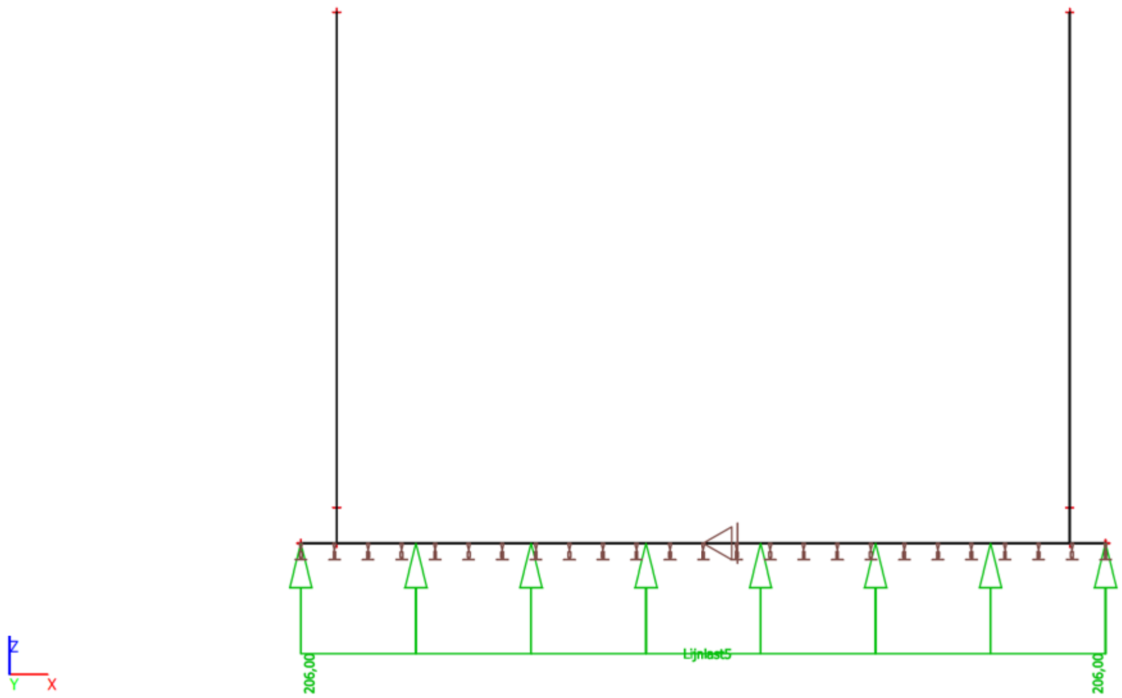
4.1.1. Load case



4.2. Load cases - water

Name	Description Spec	Action type Load type	LoadGroup
water		Permanent Standard	LG1

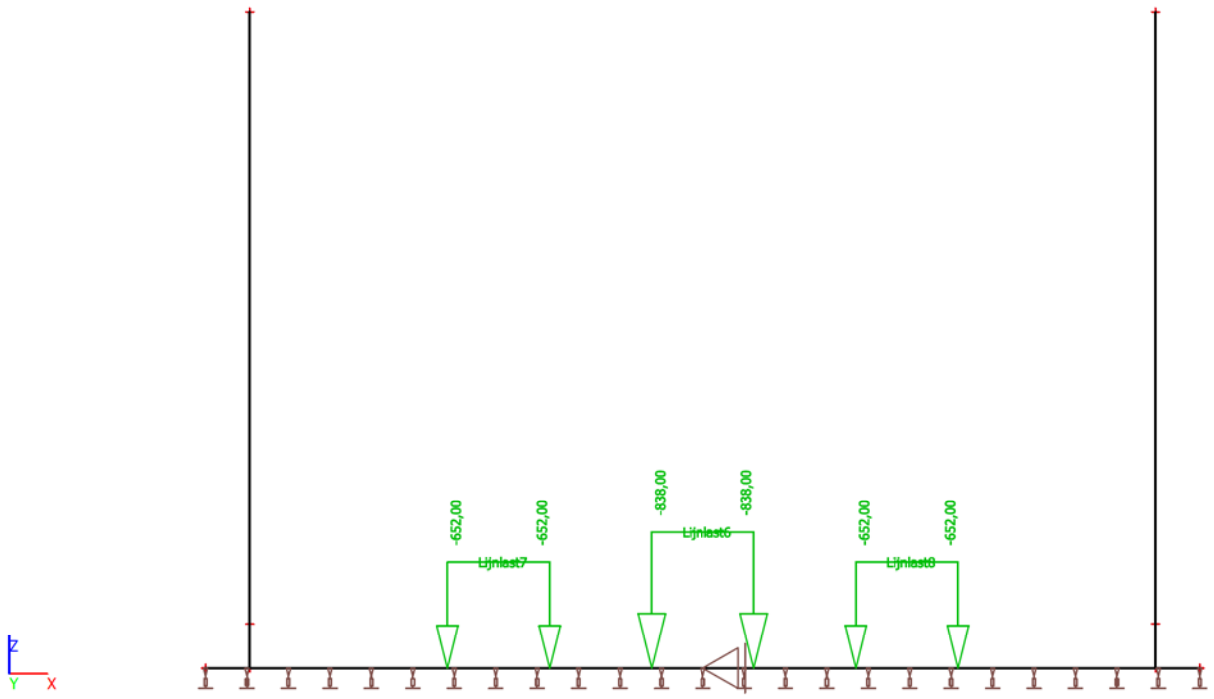
4.2.1. Load case



4.3. Load cases - vessel

Name	Description Spec	Action type Load type	LoadGroup
vessel		Permanent Standard	LG1

4.3.1. Load case



5. Weight structure

Weight of structure is defined by program

6. Members

Name	CrossSection	Layer	Length [m]	Shape	Beg. node	Type
					End node	FEM type
B36	vloer - Rechthoek (2600; 1000)	Layer1	29,200	Line	N48	beam (80)
					N49	standard
B42	Wand - Rechthoek (2600; 1000)	Layer1	18,000	Line	N53	column (100)
					N50	standard
B43	Wand - Rechthoek (2600; 1000)	Layer1	18,000	Line	N52	column (100)
					N51	standard
B44	Wand oo - Rechthoek (2600; 1000)	Layer1	1,300	Line	N56	column (100)
					N53	standard
B45	Wand oo - Rechthoek (2600; 1000)	Layer1	1,300	Line	N57	column (100)
					N52	standard

7. Nonlinear combinations

Name	Type	Load cases	Coeff. [-]
NL with vessel	Ultimate	grond	1,00
		water	1,00
		vessel	1,00
		eigengewicht	1,00
NL no vessel	Ultimate	grond	1,00
		water	1,00
		eigengewicht	1,00

8. Nonlinear combinations

8.1. Nonlinear combinations - NL with vessel

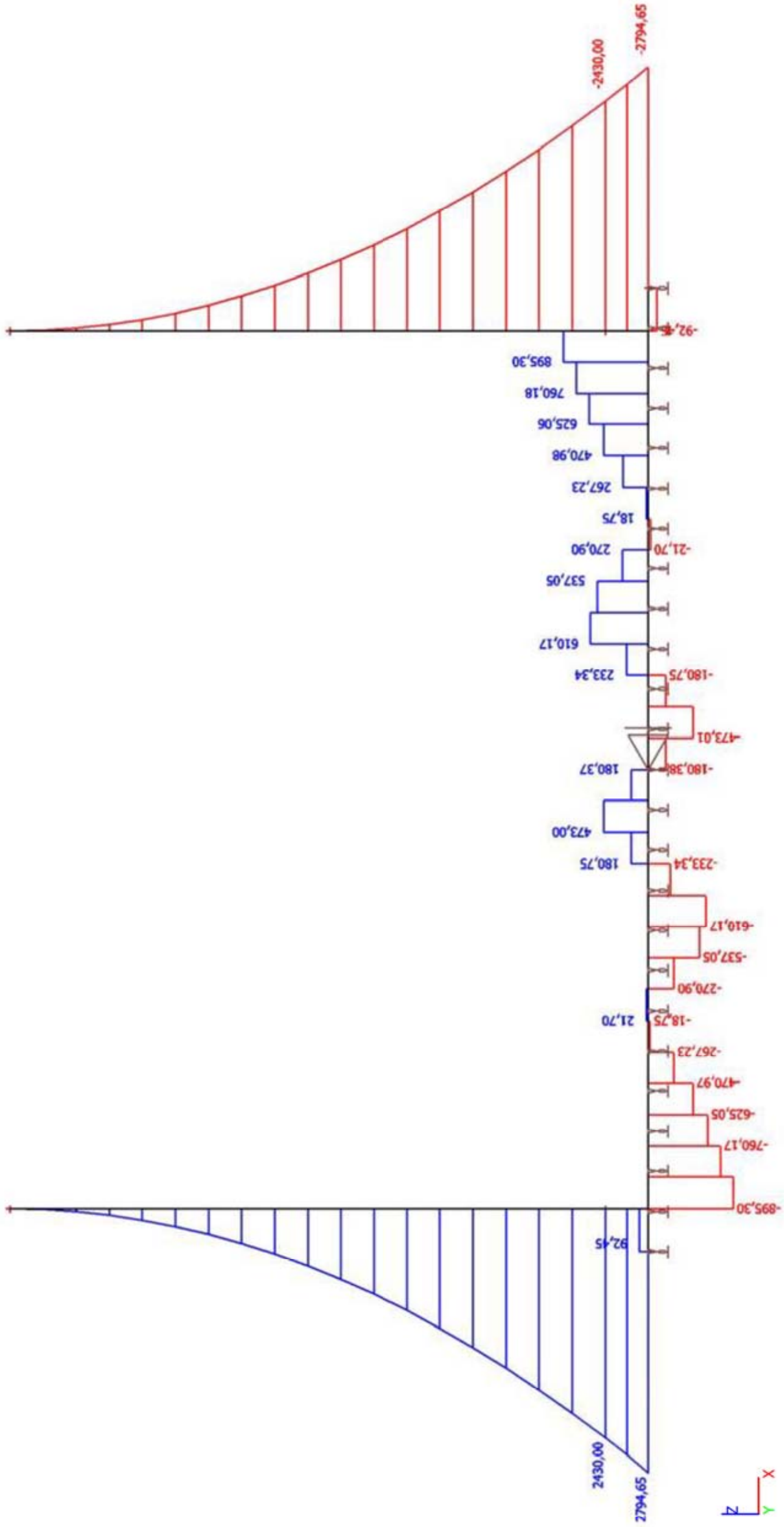
Name	Type	Load cases	Coeff. [-]
NL with vessel	Ultimate	grond	1,00
		water	1,00
		vessel	1,00
		eigengewicht	1,00

8.1.1. Internal forces on member

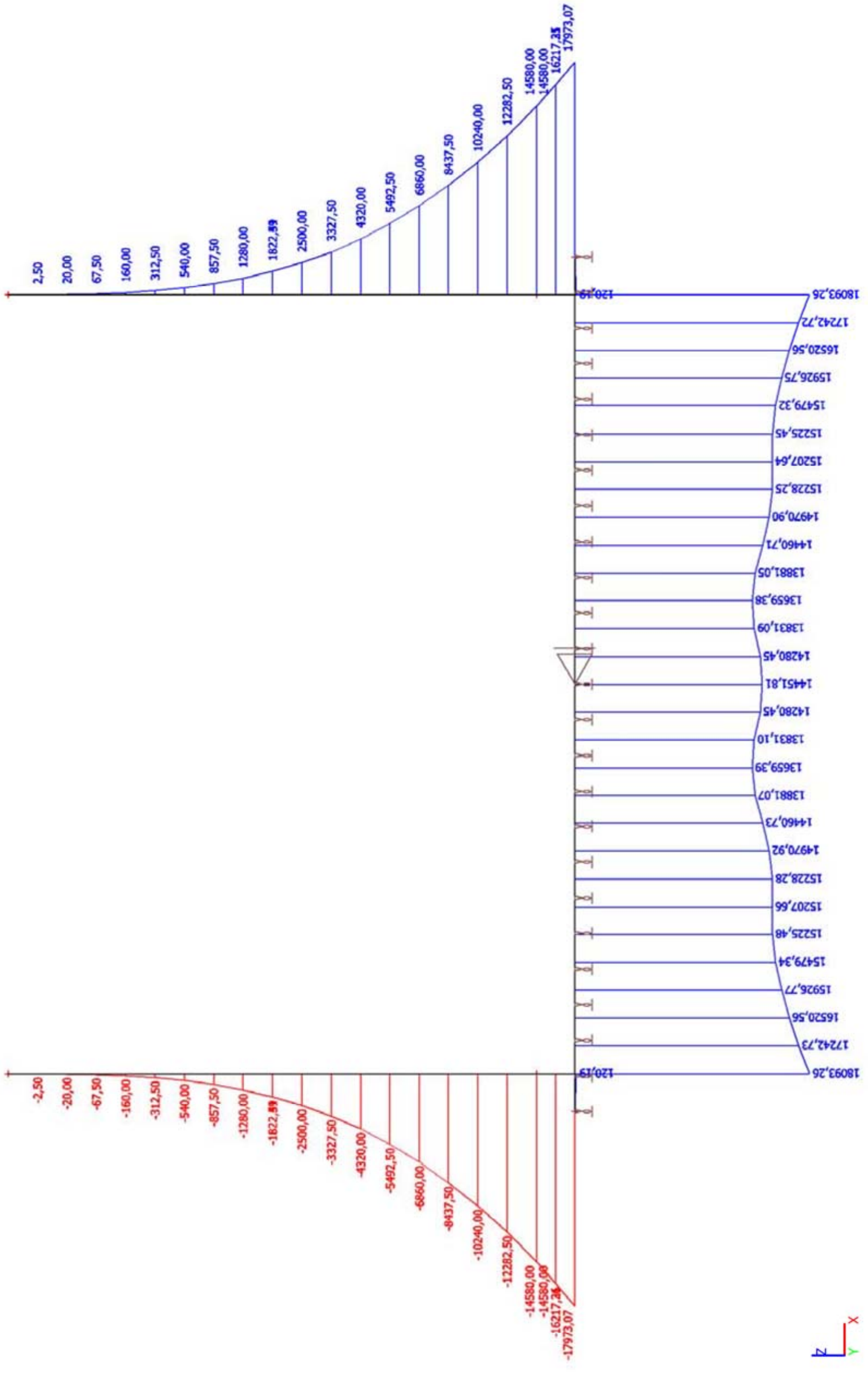
Nonlinear calculation, Extreme : Member, System : LCS
Selection : All
Nonlinear combinations : NL with vessel

Member	css	dx [m]	Case	N [kN]	Vz [kN]	My [kNm]
B36	vloer - Rechthoek	1,300	NL with vessel	**-2794,65**	-895,30	18093,26
B36	vloer - Rechthoek	0,000	NL with vessel	**0,00**	92,45	0,00
B36	vloer - Rechthoek	26,950	NL with vessel	-2794,65	895,30	17242,72
B36	vloer - Rechthoek	27,900	NL with vessel	-2794,65	895,30	**18093,26**
B42	Wand - Rechthoek	0,000	NL with vessel	-1147,77	2430,00	-14580,00
B42	Wand - Rechthoek	18,000	NL with vessel	0,00	0,00	0,00
B43	Wand - Rechthoek	0,000	NL with vessel	-1147,77	-2430,00	14580,00
B43	Wand - Rechthoek	18,000	NL with vessel	0,00	0,00	0,00
B44	Wand oo - Rechthoek	0,000	NL with vessel	-1147,78	**2794,65**	**-17973,07**
B44	Wand oo - Rechthoek	1,300	NL with vessel	-1147,78	2430,00	-14580,00
B45	Wand oo - Rechthoek	0,000	NL with vessel	-1147,77	**-2794,65**	17973,07
B45	Wand oo - Rechthoek	1,300	NL with vessel	-1147,77	-2430,00	14580,00

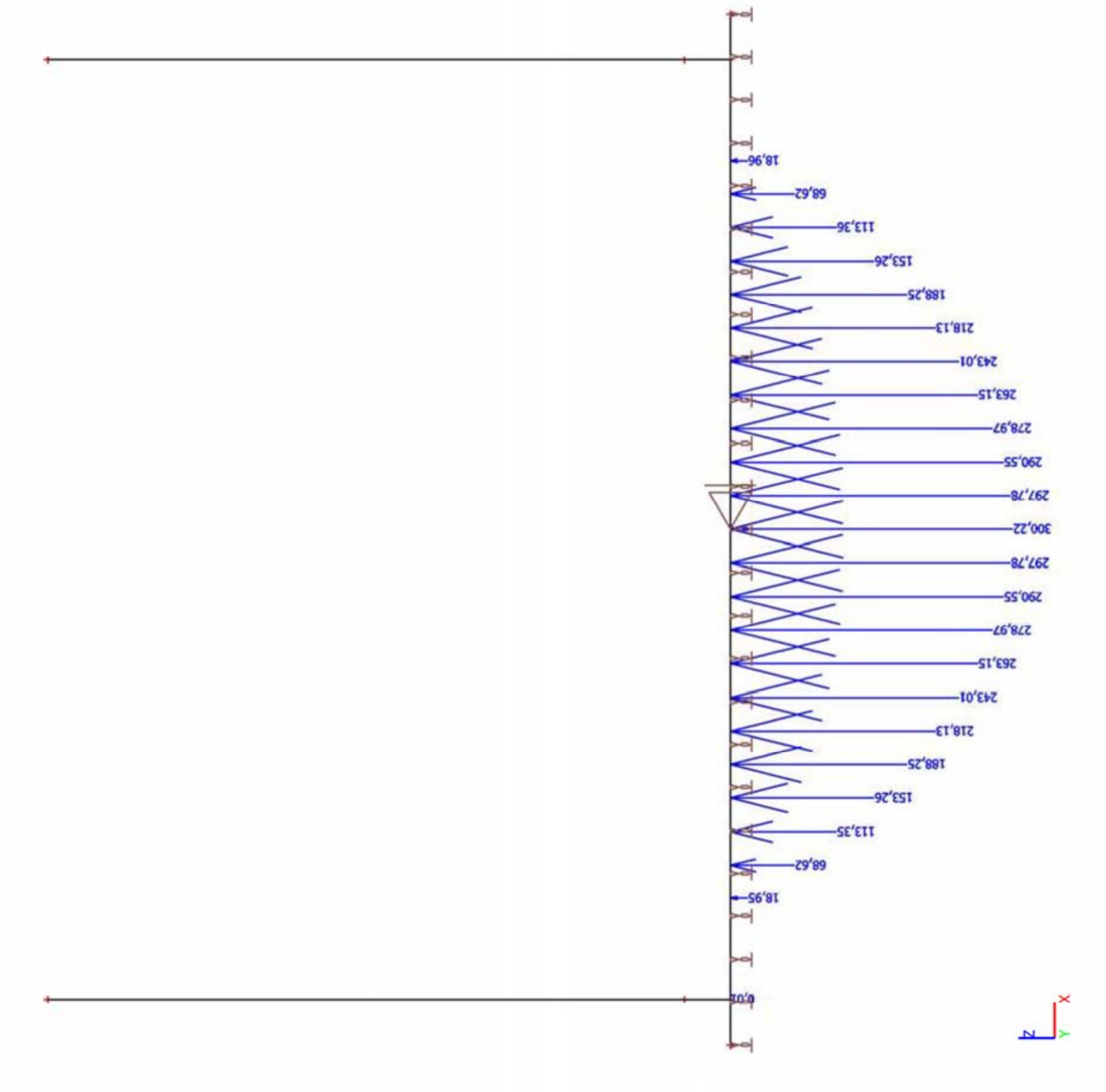
8.1.2. Internal forces on member; Vz



8.1.3. Internal forces on member; My



8.1.4. Reaction force; Rz

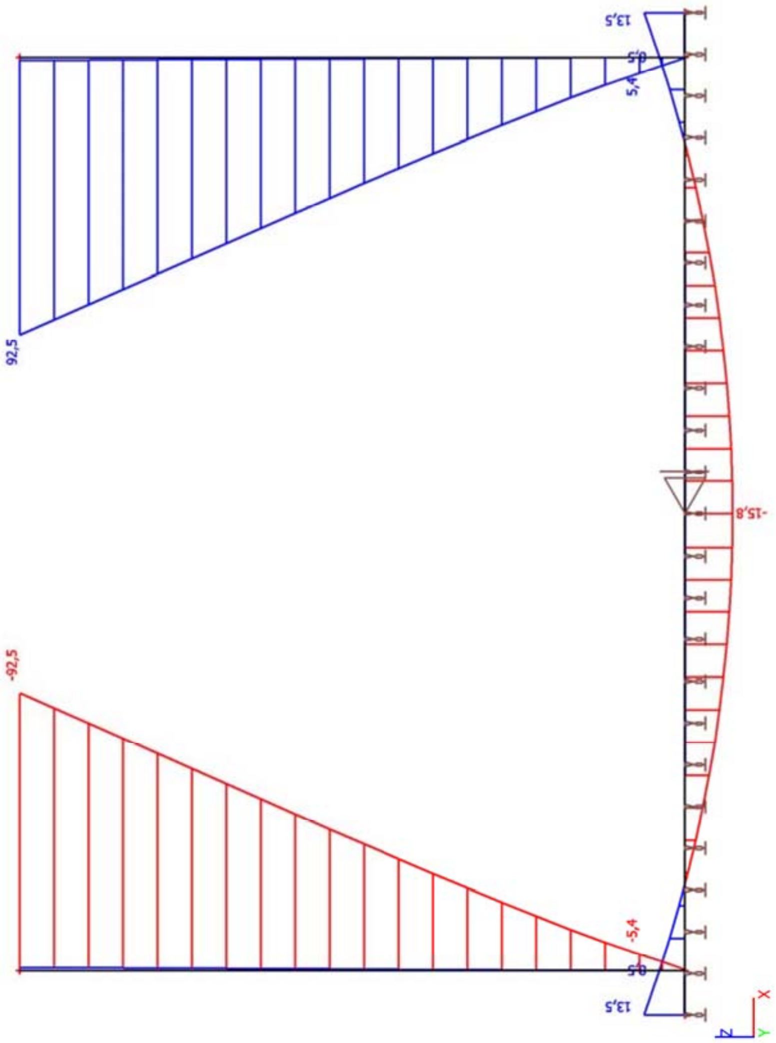


8.1.5. Deformations on member

Nonlinear calculation, Extreme : Global
Selection : All
Nonlinear combinations : NL with vessel

Member	dx [m]	Case	ux [mm]	uz [mm]	fiy [mrad]	Resultant [mm]
B36	27,900	NL with vessel	**-0,4**	8,5	-3,8	**8,5**
B42	0,000	NL with vessel	**8,5**	-5,4	3,8	10,1
B42	18,000	NL with vessel	8,4	**-92,5**	**5,1**	**92,9**
B43	18,000	NL with vessel	8,4	**92,5**	**-5,1**	92,9

8.1.6. Deformations on member; uz



8.2. Nonlinear combinations - NL no vessel

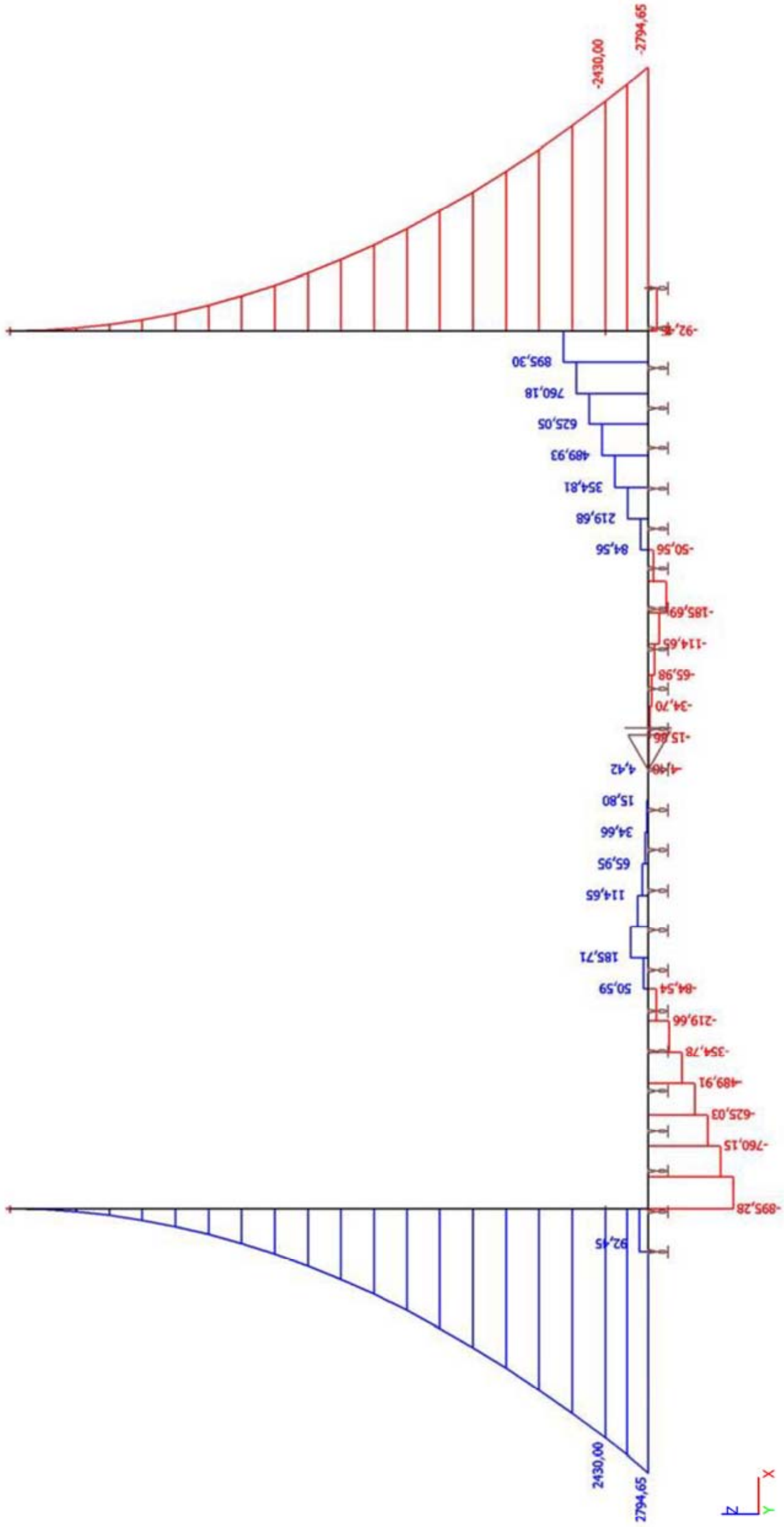
Name	Type	Load cases	Coeff. [-]
NL no vessel	Ultimate	grond	1,00
		water	1,00
		eigengewicht	1,00

8.2.1. Internal forces on member

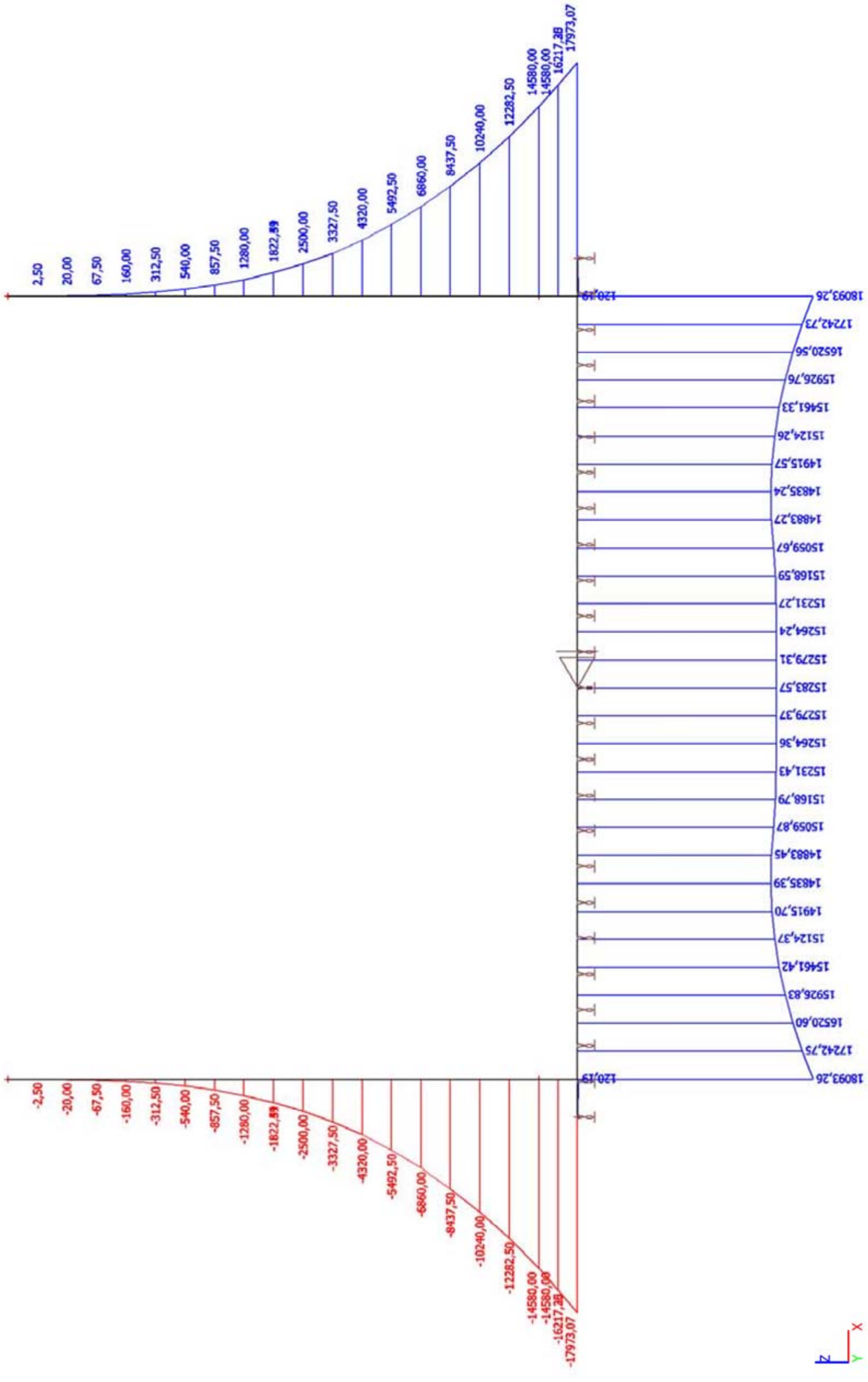
Nonlinear calculation, Extreme : Member, System : LCS
Selection : All
Nonlinear combinations : NL no vessel

Member	css	dx [m]	Case	N [kN]	Vz [kN]	My [kNm]
B36	vloer - Rechthoek	1,300	NL no vessel	**-2794,65**	-895,28	18093,26
B36	vloer - Rechthoek	0,000	NL no vessel	**0,00**	92,45	0,00
B36	vloer - Rechthoek	26,950	NL no vessel	-2794,65	895,30	17242,73
B36	vloer - Rechthoek	27,900	NL no vessel	-2794,65	895,30	**18093,26**
B42	Wand - Rechthoek	0,000	NL no vessel	-1147,77	2430,00	-14580,00
B42	Wand - Rechthoek	18,000	NL no vessel	0,00	0,00	0,00
B43	Wand - Rechthoek	0,000	NL no vessel	-1147,77	-2430,00	14580,00
B43	Wand - Rechthoek	18,000	NL no vessel	0,00	0,00	0,00
B44	Wand oo - Rechthoek	0,000	NL no vessel	-1147,81	**2794,65**	**-17973,07**
B44	Wand oo - Rechthoek	1,300	NL no vessel	-1147,81	2430,00	-14580,00
B45	Wand oo - Rechthoek	0,000	NL no vessel	-1147,81	**-2794,65**	17973,07
B45	Wand oo - Rechthoek	1,300	NL no vessel	-1147,81	-2430,00	14580,00

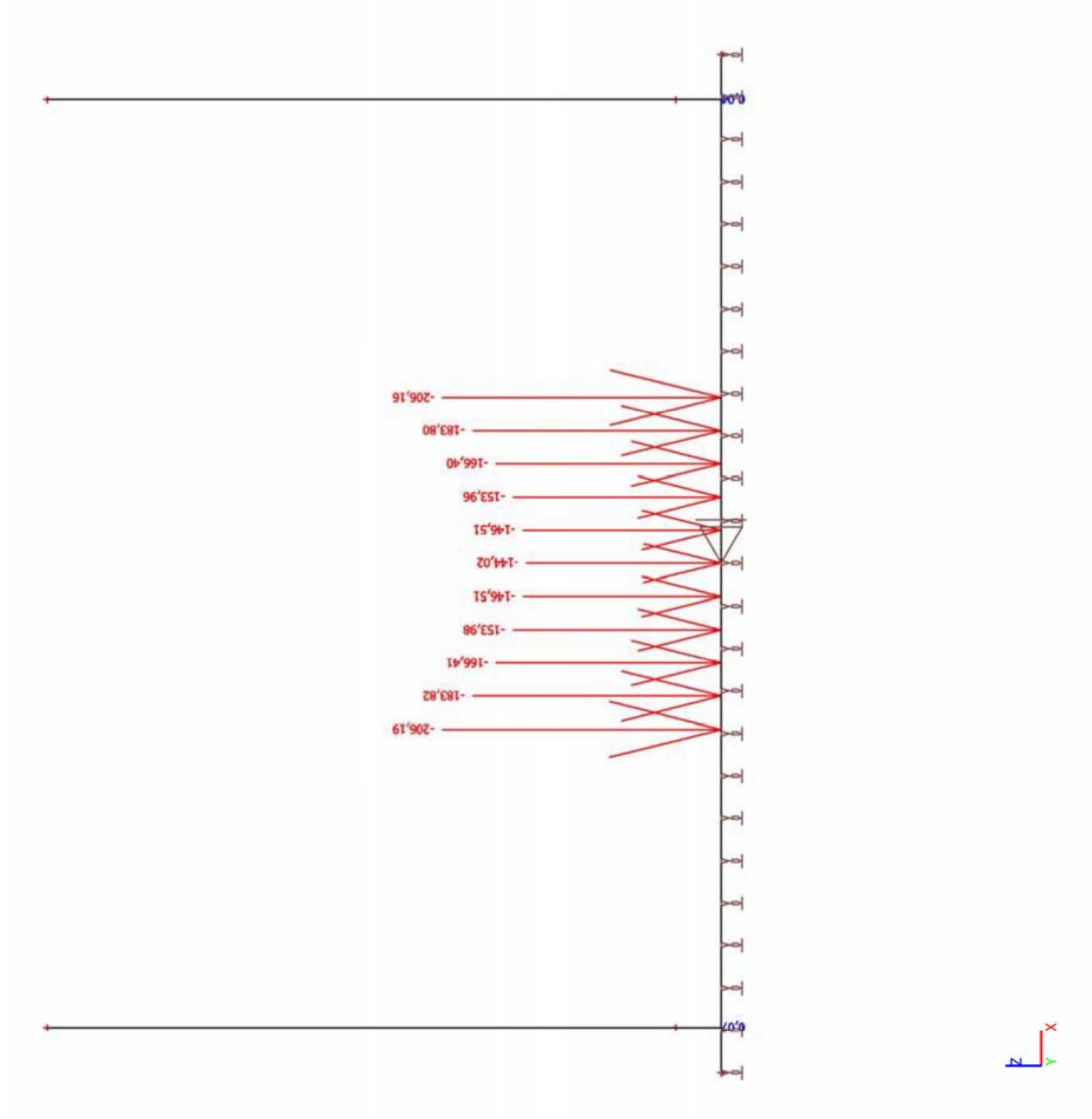
8.2.2. Internal forces on member; Vz



8.2.3. Internal forces on member; My



8.2.4. Reaction force; Rz

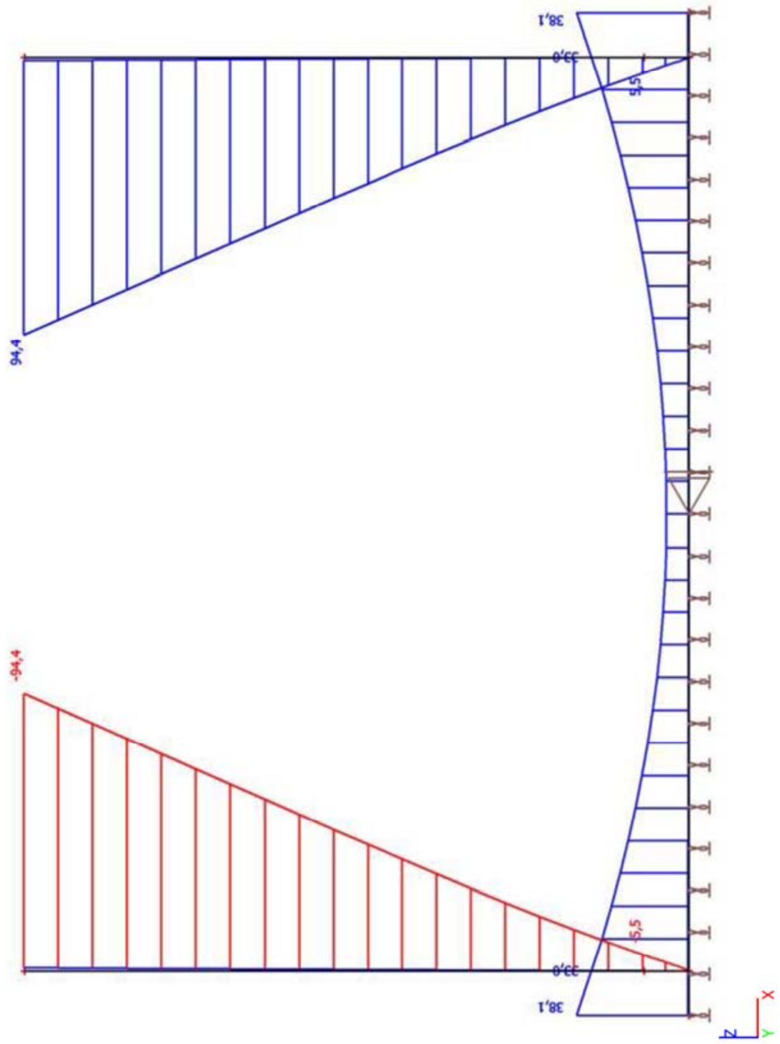


8.2.5. Deformations on member

Nonlinear calculation, Extreme : Global
Selection : All
Nonlinear combinations : NL no vessel

Member	dx [m]	Case	ux [mm]	uz [mm]	fiy [mrad]	Resultant [mm]
B36	27,900	NL no vessel	**-0,4**	33,0	-3,9	**33,0**
B42	0,000	NL no vessel	**33,0**	-5,5	3,9	33,5
B42	18,000	NL no vessel	32,9	**-94,4**	**5,2**	**100,0**
B43	18,000	NL no vessel	32,9	**94,4**	**-5,2**	100,0

8.2.6. Deformations on member; uz



Shallow foundation results DSS

Table 0.23: Concrete results DSS; shallow foundation

	Without vessel	With vessel
Dock internal width	24m	24m
Dock internal height	18m	18m
Wall thickness	2,6m	2,6m
Floor thickness	2,6m	2,6m
Maximum shear stress floor	958kN/m	947kN/m
Maximum momentum floor	17972kNm/m	21728kNm/m
Maximum shear stress wall	2430kN	2430kN
Maximum momentum wall	14580kNm	14580kNm

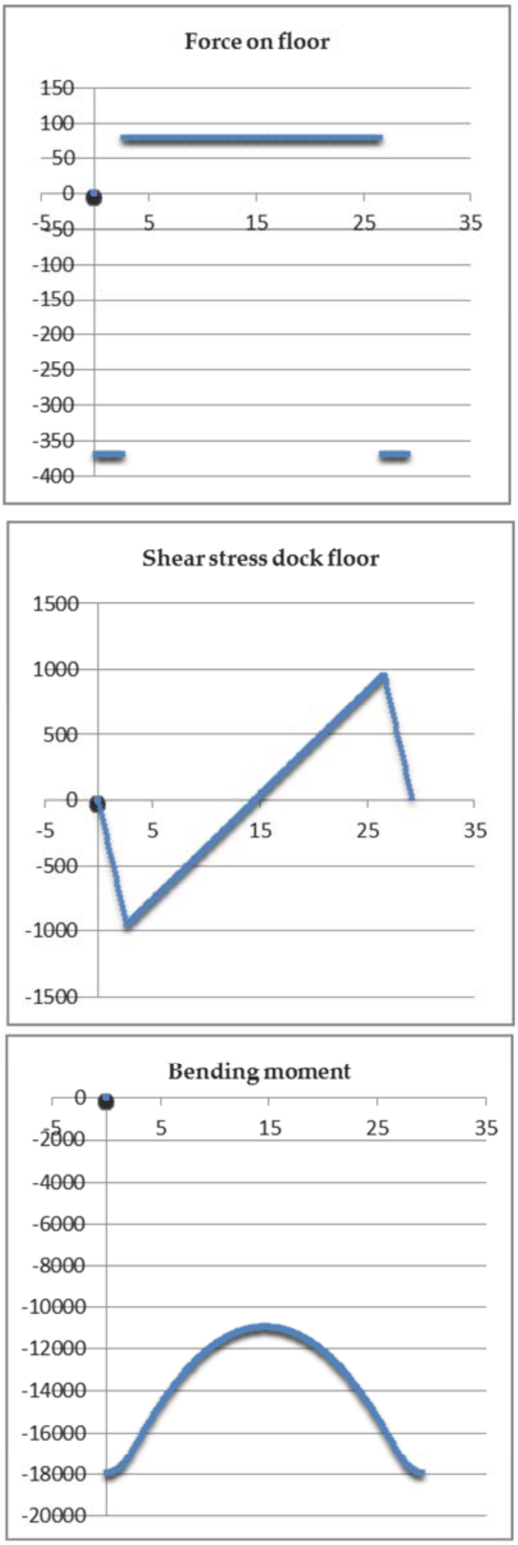


Figure 0.31: Floor results DSS, shallow foundation, Without Vessel

Y-axis: forces [kN/m2], stresses [kN/m], moment [kNm/m]; X-axis: Width [m]

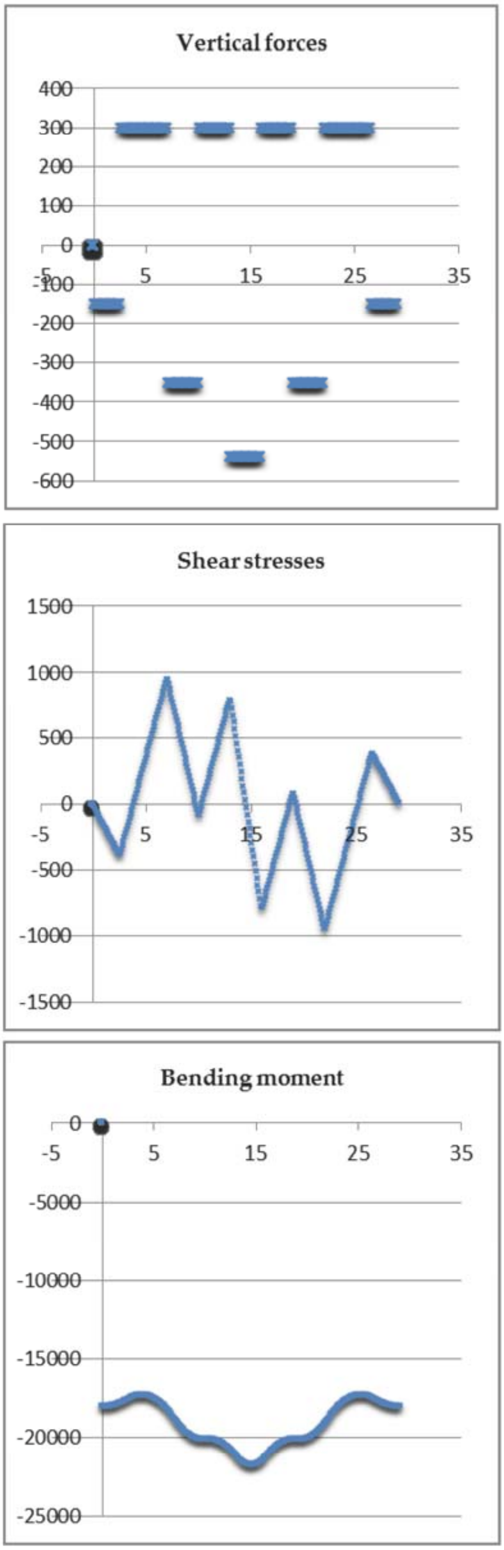


Figure 0.31: Floor results DSS, shallow foundation, With Vessel

Y-axis: forces [kN/m2], stresses [kN/m], moment [kNm/m]; X-axis: Width [m]

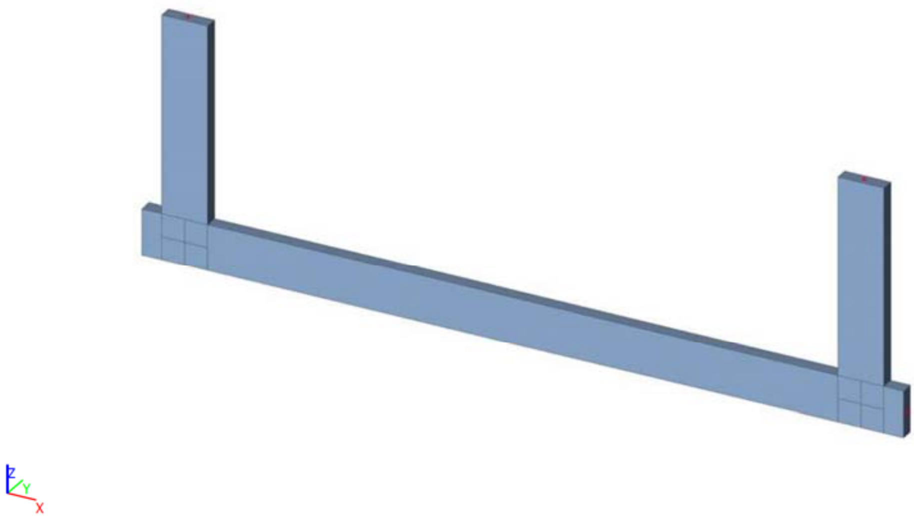
Pile foundation results SCIA case 1

1. Project

1.1. Project

Licence name	ARCADIS
Project	Case study dry dock
Part	Conceptual design
Description	Dry Dock pile foundation
Author	J. Treffers
Date	17-6-2015
Structure	Frame XZ
No. of nodes :	8
No. of beams :	5
No. of slabs :	0
No. of solids :	0
No. of used profiles :	3
No. of load cases :	4
No. of used materials :	2
Acceleration of gravity [m/s^2]	9,810
National code	NEN

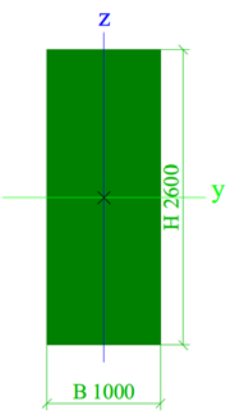
1.1.1. Analysis model



2. Cross-sections

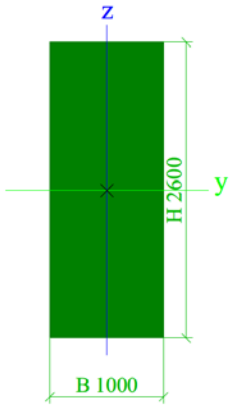
vloer		
Type	Rechthoek	
Detailed	2600; 1000	
Shape type	Thick-walled	
Item material	C45/55	
Fabrication	concrete	
A [m^2]	2,6000e+00	
Ay [m^2], Az [m^2]	2,1667e+00	2,1667e+00
AL [m^2/m], AD [m^2/m]	7,2000e+00	7,2000e+00
cYUCS [mm], cZUCS [mm]	500	1300
α [deg]	0,00	
Iy [m^4], Iz [m^4]	1,4647e+00	2,1667e-01
iy [mm], iz [mm]	751	289
Wely [m^3], Welz [m^3]	1,1267e+00	4,3333e-01
Wply [m^3], Wplz [m^3]	0,0000e+00	0,0000e+00
Mply+ [Nm], Mply- [Nm]	0,00e+00	0,00e+00
Mplz+ [Nm], Mplz- [Nm]	0,00e+00	0,00e+00
dy [mm], dz [mm]	0	0
It [m^4], Iw [m^6]	6,5679e-01	0,0000e+00
β y [mm], β z [mm]	0	0

Picture



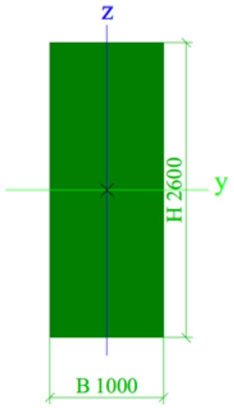
Wand oo		
Type	Rechthoek	
Detailed	2600; 1000	
Shape type	Thick-walled	
Item material	C45/55 oo	
Fabrication	concrete	
A [m^2]	2,6000e+00	
Ay [m^2], Az [m^2]	2,1667e+00	2,1667e+00
AL [m^2/m], AD [m^2/m]	7,2000e+00	7,2000e+00
cYUCS [mm], cZUCS [mm]	500	1300
α [deg]	0,00	
Iy [m^4], Iz [m^4]	1,4647e+00	2,1667e-01
iy [mm], iz [mm]	751	289
Wely [m^3], Welz [m^3]	1,1267e+00	4,3333e-01
Wply [m^3], Wplz [m^3]	0,0000e+00	0,0000e+00
Mply+ [Nm], Mply- [Nm]	0,00e+00	0,00e+00
Mplz+ [Nm], Mplz- [Nm]	0,00e+00	0,00e+00
dy [mm], dz [mm]	0	0
It [m^4], Iw [m^6]	6,5679e-01	0,0000e+00
β y [mm], β z [mm]	0	0

Picture



Wand		
Type	Rechthoek	
Detailed	2600; 1000	
Shape type	Thick-walled	
Item material	C45/55	
Fabrication	concrete	
A [m^2]	2,6000e+00	
Ay [m^2], Az [m^2]	2,1667e+00	2,1667e+00
AL [m^2/m], AD [m^2/m]	7,2000e+00	7,2000e+00
cYUCS [mm], cZUCS [mm]	500	1300
α [deg]	0,00	
Iy [m^4], Iz [m^4]	1,4647e+00	2,1667e-01
iy [mm], iz [mm]	751	289
Wely [m^3], Welz [m^3]	1,1267e+00	4,3333e-01
Wply [m^3], Wplz [m^3]	0,0000e+00	0,0000e+00
Mply+ [Nm], Mply- [Nm]	0,00e+00	0,00e+00
Mplz+ [Nm], Mplz- [Nm]	0,00e+00	0,00e+00
dy [mm], dz [mm]	0	0
It [m^4], Iw [m^6]	6,5679e-01	0,0000e+00
β y [mm], β z [mm]	0	0

Picture



Explanations of symbols	
A	Area
Ay	Shear Area in principal y-direction
Az	Shear Area in principal z-direction
AL	Circumference per unit length
AD	Drying surface per unit length
cYUCS	Centroid coordinate in Y-direction of Input axis system
cZUCS	Centroid coordinate in Z-direction of Input axis system

Explanations of symbols	
IYLCS	Second moment of area about the YLCS axis
IZLCS	Second moment of area about the ZLCS axis
IYZLCS	Product moment of area in the LCS system
α	Rotation angle of the principal axis system
Iy	Second moment of area about the

Explanations of symbols	
	principal y-axis
Iz	Second moment of area about the principal z-axis
iy	Radius of gyration about the principal y-axis
iz	Radius of gyration about the principal z-axis
Wely	Elastic section modulus about the principal y-axis
Welz	Elastic section modulus about the principal z-axis
Wply	Plastic section modulus about the principal y-axis
Wplz	Plastic section modulus about the principal z-axis

Explanations of symbols	
Mply+	Plastic moment about the principal y-axis for a positive My moment
Mply-	Plastic moment about the principal y-axis for a negative My moment
Mplz+	Plastic moment about the principal z-axis for a positive Mz moment
Mplz-	Plastic moment about the principal z-axis for a negative Mz moment
dy	Shear center coordinate in principal y-direction measured from the centroid - Not calculated or simplified
dz	Shear center coordinate in principal z-direction measured from the centroid - Not calculated or simplified
It	Torsional constant - Not calculated or simplified
Iw	Warping constant - Not calculated or simplified
β y	Mono-symmetry constant about the principal y-axis
β z	Mono-symmetry constant about the principal z-axis

3. Materials

Concrete NEN 6720

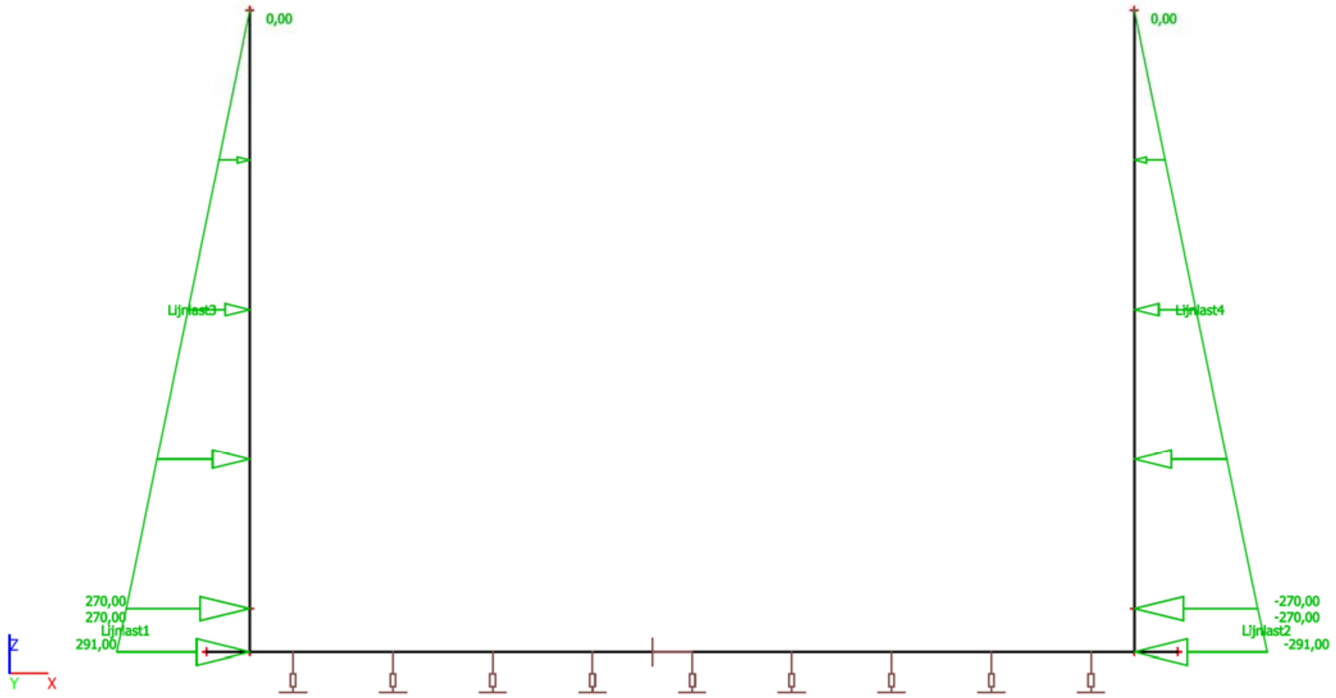
Type	Unit mass [kg/m^3]	E-mod [MPa]	Poisson - nu	G mod [MPa]	Characteristic cube compression strength (f'ck) [MPa]
Name					**Design compression strength (f'b) [MPa]**
Beton	2500,0	3,6000e+04	0.2	1,5000e+04	55,00
C45/55					33,00
Beton	0,0	3,6000e+12	0.2	1,5000e+12	55,00
C45/55 oo					33,00

4. Load cases

4.1. Load cases - grond

Name	Description Spec	Action type Load type	LoadGroup
grond		Permanent Standard	LG1

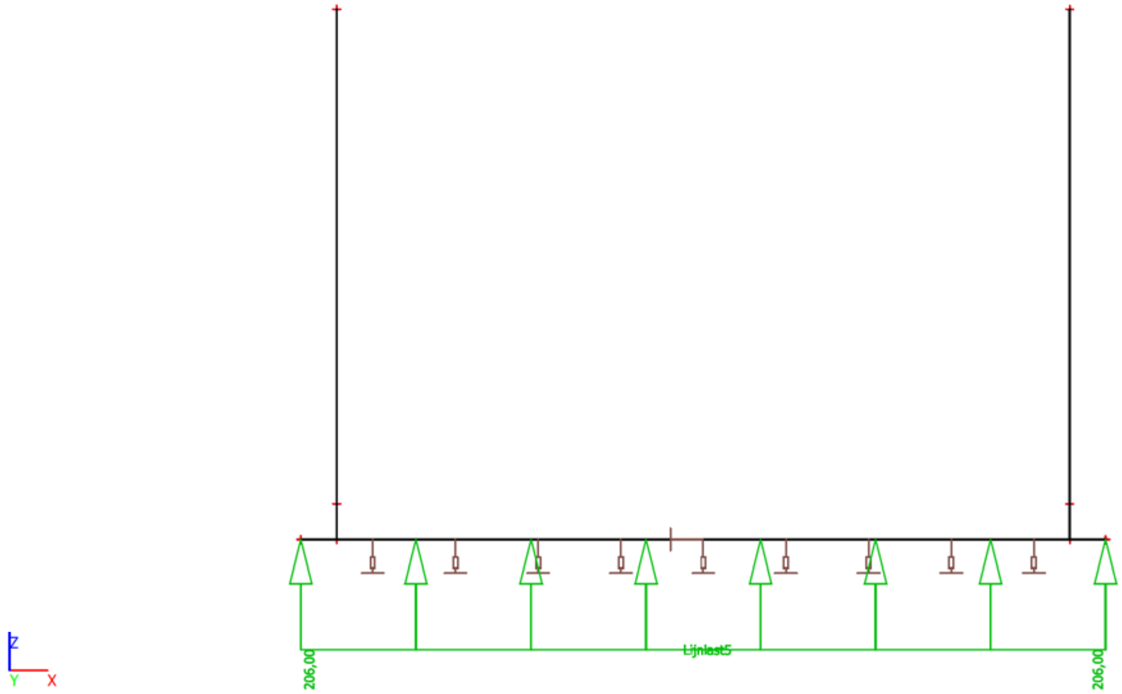
4.1.1. Load case



4.2. Load cases - water

Name	Description Spec	Action type Load type	LoadGroup
water		Permanent Standard	LG1

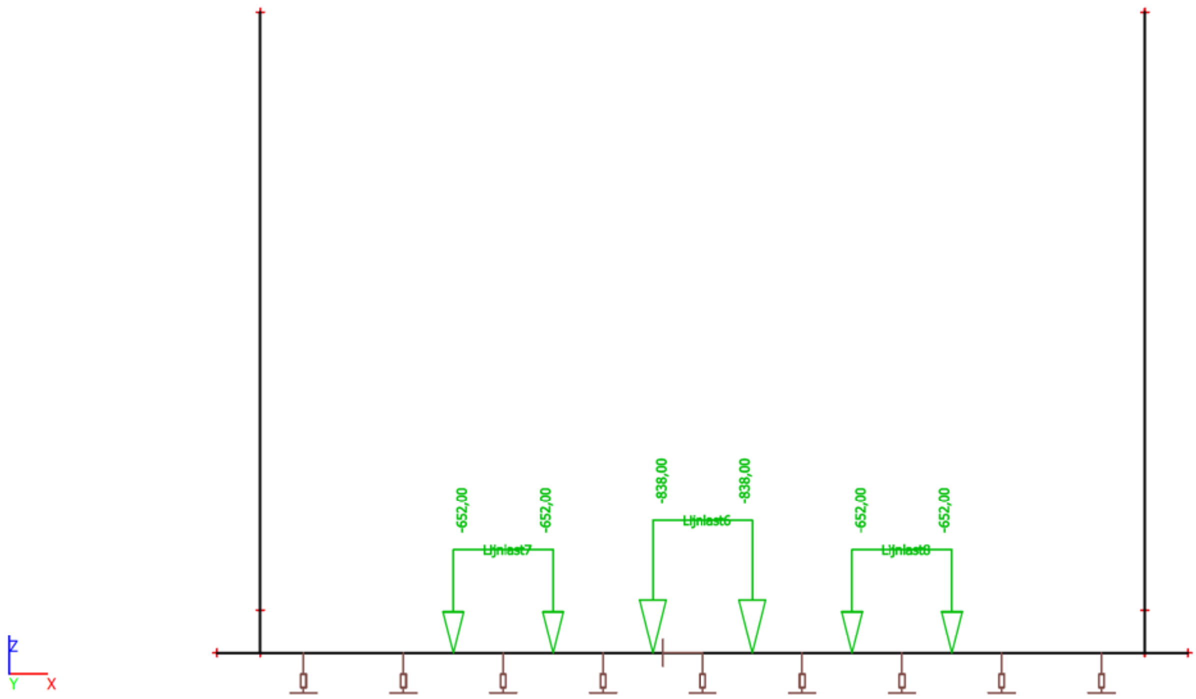
4.2.1. Load case



4.3. Load cases - vessel

Name	Description Spec	Action type Load type	LoadGroup
vessel		Permanent Standard	LG1

4.3.1. Load case



5. Weight structure

Weight of structure is defined by program

6. Members

Name	CrossSection	Layer	Length [m]	Shape	Beg. node	Type
					End node	FEM type
B36	vloer - Rechthoek (2600; 1000)	Layer1	29,200	Line	N48	beam (80)
					N49	standard
B42	Wand - Rechthoek (2600; 1000)	Layer1	18,000	Line	N53	column (100)
					N50	standard
B43	Wand - Rechthoek (2600; 1000)	Layer1	18,000	Line	N52	column (100)
					N51	standard
B44	Wand oo - Rechthoek (2600; 1000)	Layer1	1,300	Line	N56	column (100)
					N53	standard
B45	Wand oo - Rechthoek (2600; 1000)	Layer1	1,300	Line	N57	column (100)
					N52	standard

7. Combinations

Name	Description	Type	Load cases	Coeff. [-]
no vessel		Envelope - ultimate	grond	1,00
			water	1,00
			eigengewicht	1,00
With vessel		Envelope - ultimate	grond	1,00
			water	1,00
			vessel	1,00
			eigengewicht	1,00

8. Combinations

8.1. Combinations - no vessel

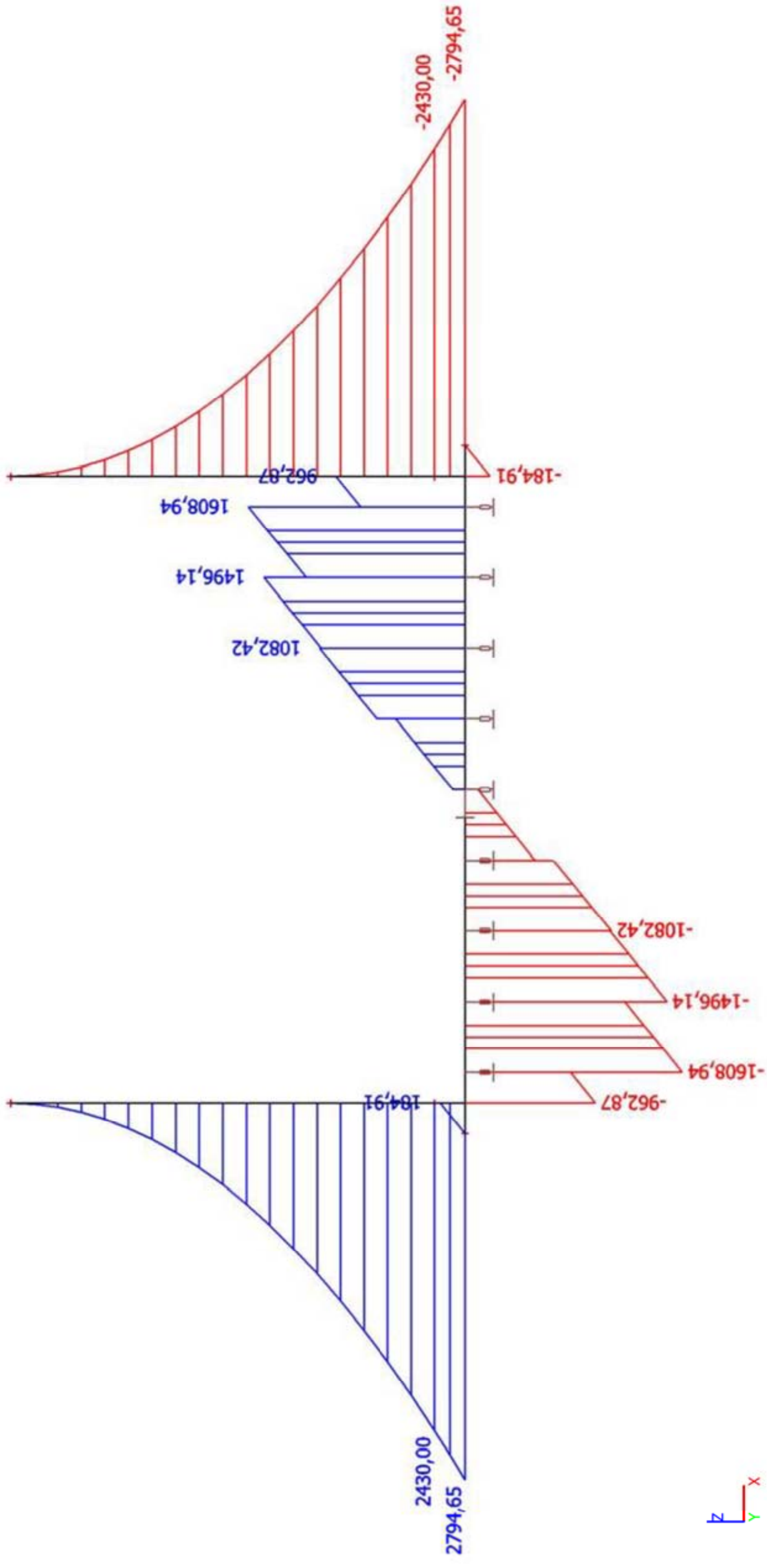
Name	Description	Type	Load cases	Coeff. [-]
no vessel		Envelope - ultimate	grond	1,00
			water	1,00
			eigengewicht	1,00

8.1.1. Internal forces on member

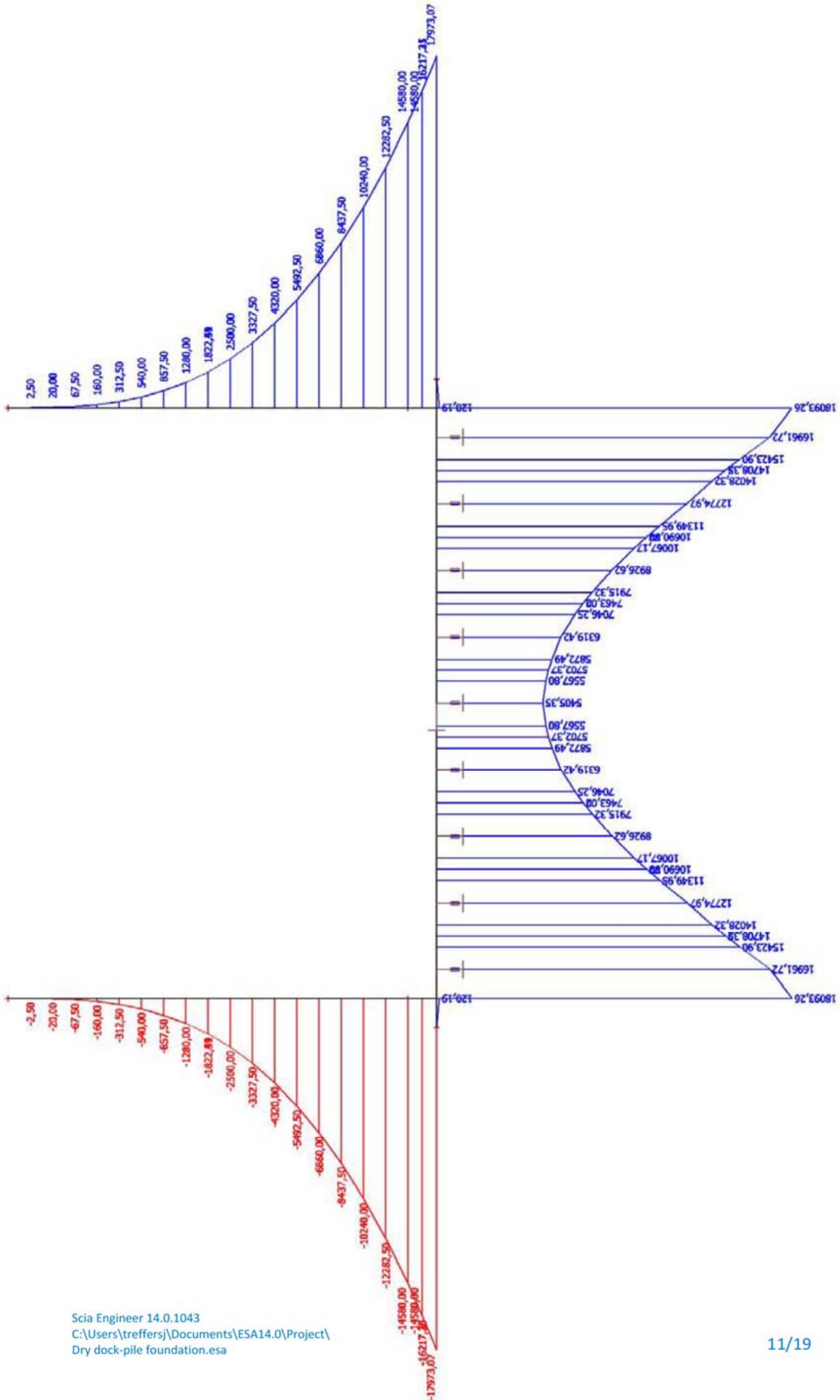
Linear calculation, Extreme : Member, System : LCS
Selection : All
Combinations : no vessel

Member	css	dx [m]	Case	N [kN]	Vz [kN]	My [kNm]
B36	vloer - Rechthoek	1,300	no vessel/1	**-2794,65**	-962,87	**18093,26**
B36	vloer - Rechthoek	0,000	no vessel/1	**0,00**	0,00	0,00
B36	vloer - Rechthoek	2,600	no vessel/1	-2794,65	-1608,94	16961,72
B36	vloer - Rechthoek	26,600	no vessel/1	-2794,65	1608,94	16961,72
B36	vloer - Rechthoek	29,200	no vessel/1	0,00	0,00	0,00
B42	Wand - Rechthoek	0,000	no vessel/1	-1147,77	2430,00	-14580,00
B42	Wand - Rechthoek	18,000	no vessel/1	0,00	0,00	0,00
B43	Wand - Rechthoek	0,000	no vessel/1	-1147,77	-2430,00	14580,00
B43	Wand - Rechthoek	18,000	no vessel/1	0,00	0,00	0,00
B44	Wand oo - Rechthoek	0,000	no vessel/1	-1147,77	**2794,65**	**-17973,07**
B44	Wand oo - Rechthoek	1,300	no vessel/1	-1147,77	2430,00	-14580,00
B45	Wand oo - Rechthoek	0,000	no vessel/1	-1147,77	**-2794,65**	17973,07
B45	Wand oo - Rechthoek	1,300	no vessel/1	-1147,77	-2430,00	14580,00

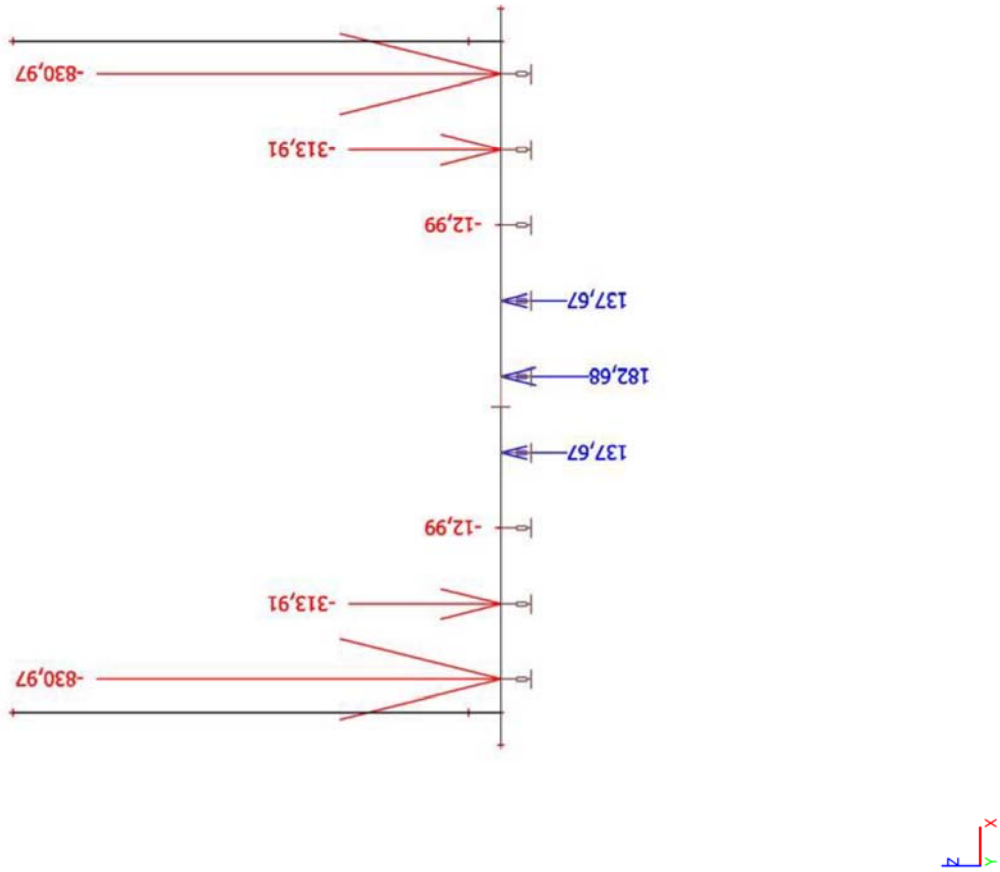
8.1.2. Internal forces on member; Vz



8.1.3. Internal forces on member; My



8.1.4. Reaction forces; Rz

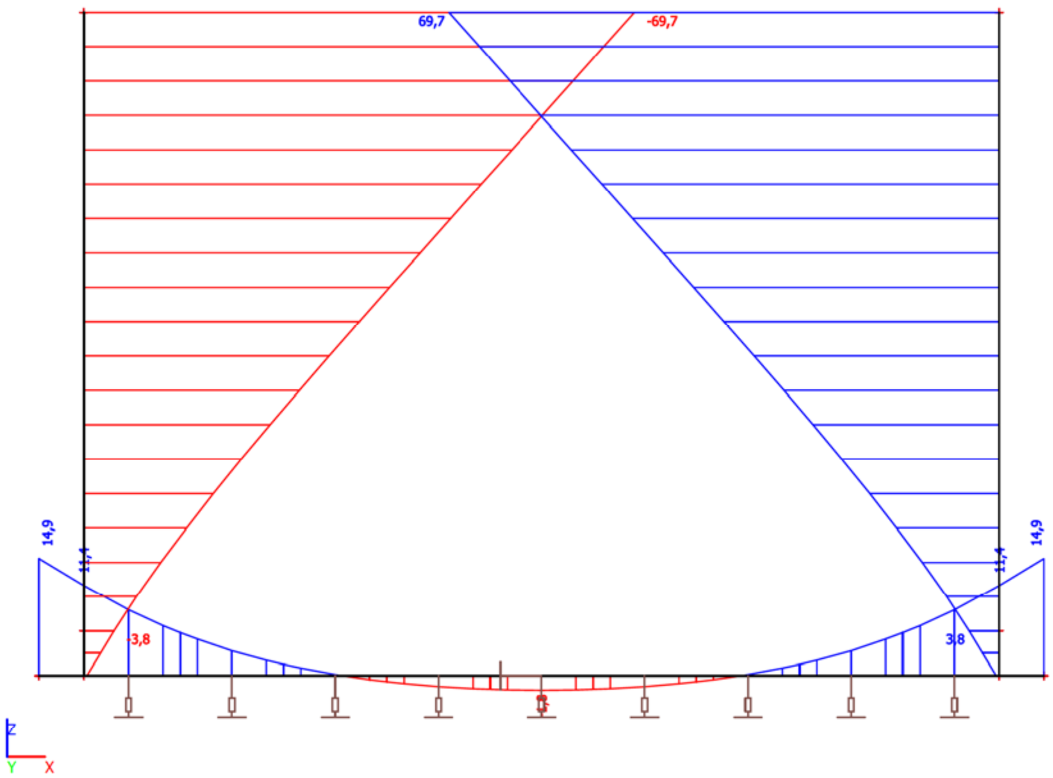


8.1.5. Deformations on member

Linear calculation, Extreme : Global
Selection : All
Combinations : no vessel

Member	dx [m]	Case	ux [mm]	uz [mm]	fiy [mrad]	Resultant [mm]
B36	27,900	no vessel/1	**-0,4**	11,4	-2,6	**11,4**
B42	0,000	no vessel/1	**11,4**	-3,8	2,6	12,0
B42	18,000	no vessel/1	11,3	**-69,7**	**3,9**	**70,6**
B43	18,000	no vessel/1	11,3	**69,7**	**-3,9**	70,6

8.1.6. Deformation on members; uz



8.2. Combinations - With vessel

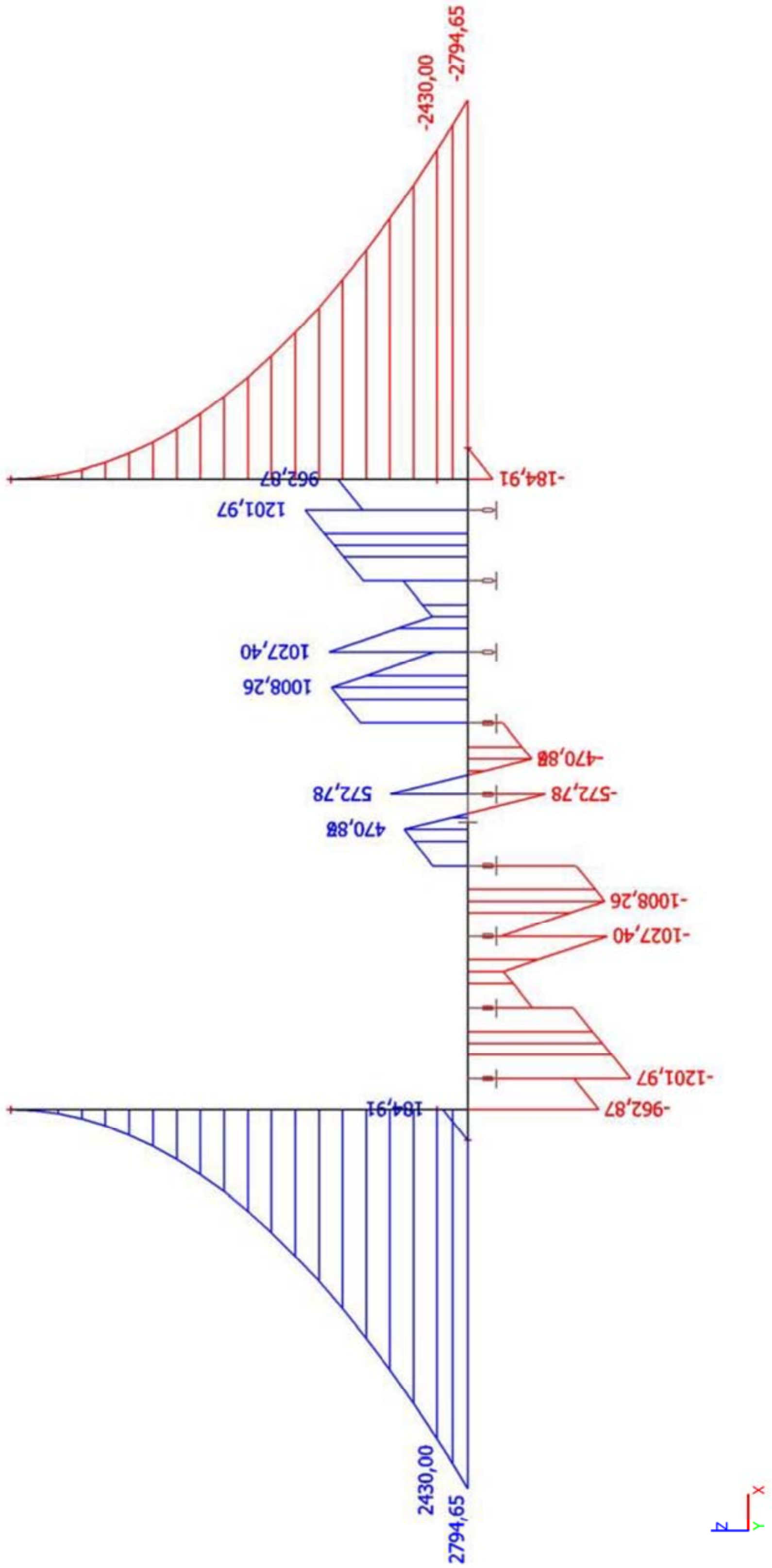
Name	Description	Type	Load cases	Coeff. [-]
With vessel		Envelope - ultimate	grond	1,00
			water	1,00
			vessel	1,00
			eigengewicht	1,00

8.2.1. Internal forces on member

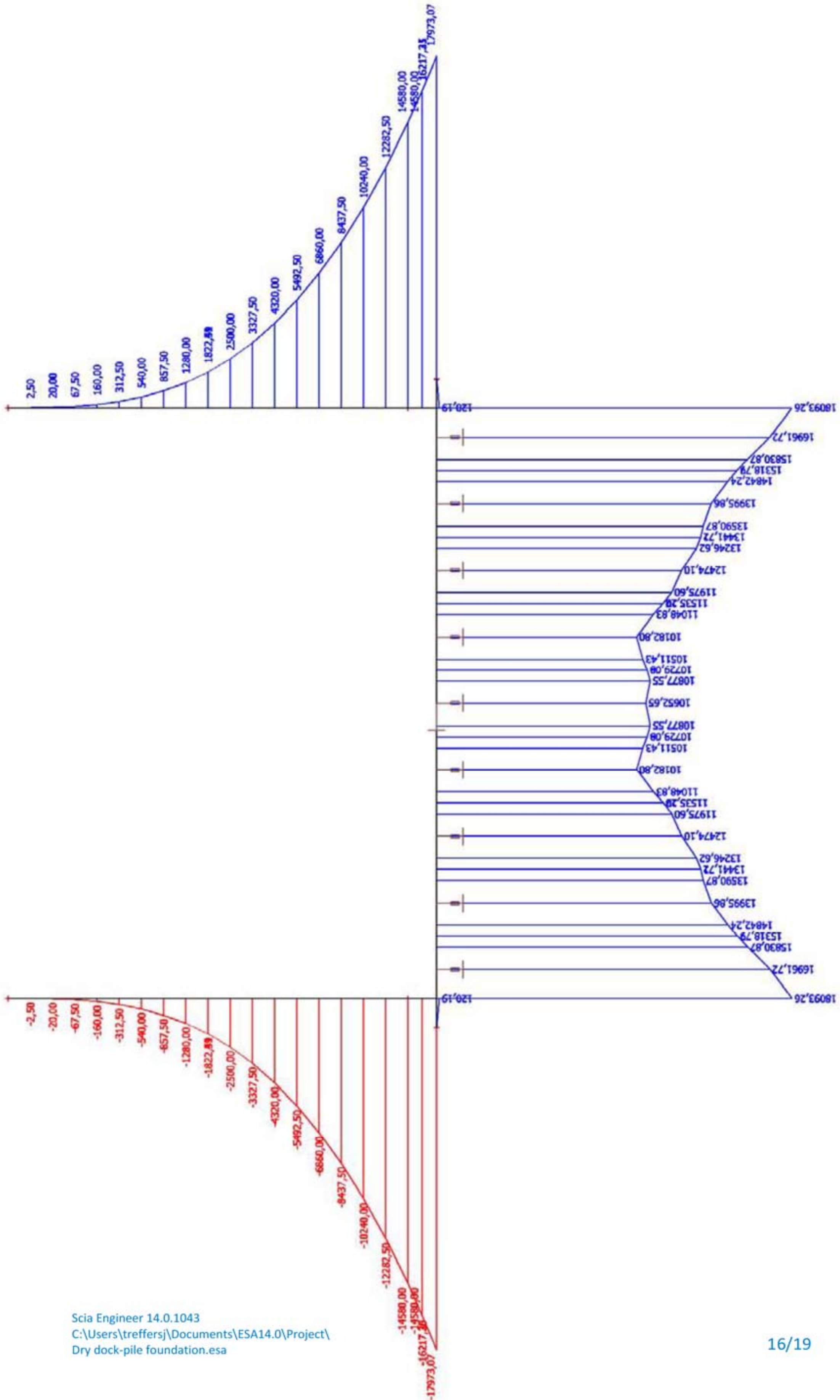
Linear calculation, Extreme : Member, System : LCS
Selection : All
Combinations : With vessel

Member	css	dx [m]	Case	N [kN]	Vz [kN]	My [kNm]
B36	vloer - Rechthoek	1,300	With vessel/2	**-2794,65**	-962,87	**18093,26**
B36	vloer - Rechthoek	0,000	With vessel/2	**0,00**	0,00	0,00
B36	vloer - Rechthoek	2,600	With vessel/2	-2794,65	-1201,97	16961,72
B36	vloer - Rechthoek	26,600	With vessel/2	-2794,65	1201,97	16961,72
B36	vloer - Rechthoek	29,200	With vessel/2	0,00	0,00	0,00
B42	Wand - Rechthoek	0,000	With vessel/2	-1147,77	2430,00	-14580,00
B42	Wand - Rechthoek	18,000	With vessel/2	0,00	0,00	0,00
B43	Wand - Rechthoek	0,000	With vessel/2	-1147,77	-2430,00	14580,00
B43	Wand - Rechthoek	18,000	With vessel/2	0,00	0,00	0,00
B44	Wand oo - Rechthoek	0,000	With vessel/2	-1147,77	**2794,65**	**-17973,07**
B44	Wand oo - Rechthoek	1,300	With vessel/2	-1147,77	2430,00	-14580,00
B45	Wand oo - Rechthoek	0,000	With vessel/2	-1147,77	**-2794,65**	17973,07
B45	Wand oo - Rechthoek	1,300	With vessel/2	-1147,77	-2430,00	14580,00

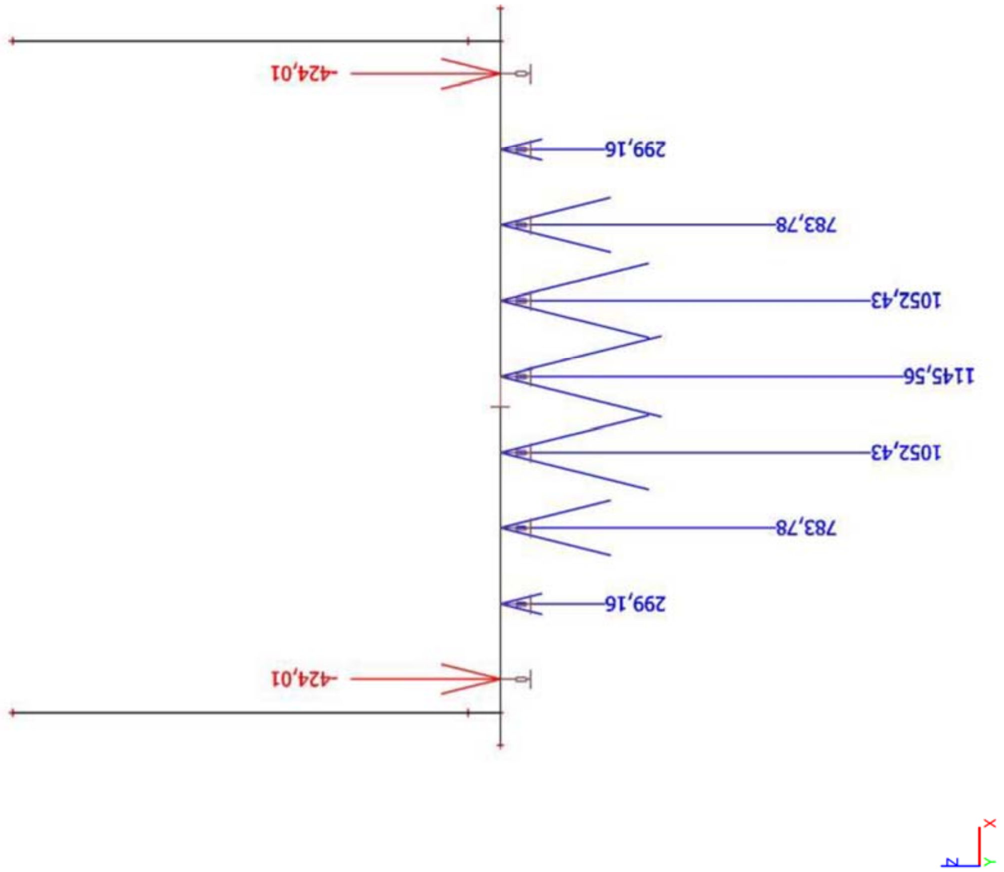
8.2.2. Internal forces on member; Vz



8.2.3. Internal forces on member; My



8.2.4. Reaction forces; Rz

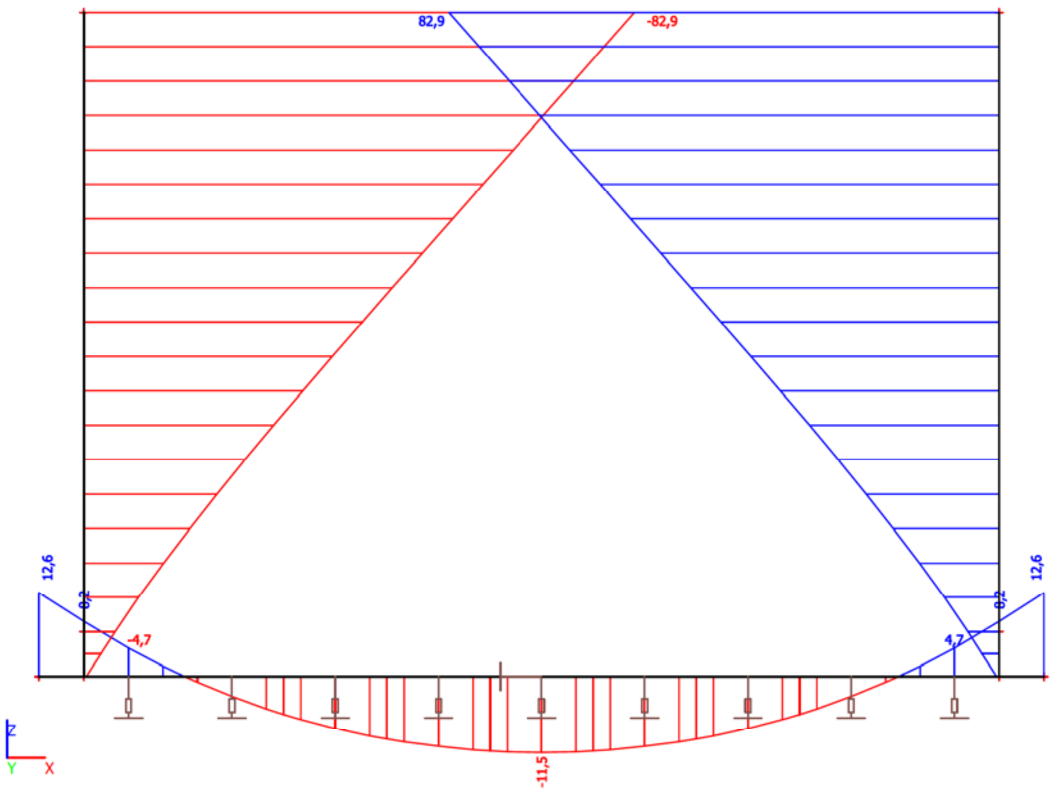


8.2.5. Deformations on member

Linear calculation, Extreme : Global
Selection : All
Combinations : With vessel

Member	dx [m]	Case	ux [mm]	uz [mm]	fiy [mrad]	Resultant [mm]
B36	27,900	With vessel/2	**-0,4**	8,2	-3,3	**8,3**
B42	0,000	With vessel/2	**8,2**	-4,7	3,3	9,5
B42	18,000	With vessel/2	8,1	**-82,9**	**4,6**	**83,3**
B43	18,000	With vessel/2	8,1	**82,9**	**-4,6**	83,3

8.2.6. Deformation on members; uz



Pile foundation results DSS case 1

Table 0.24: Concrete results DSS; pile foundation

	Without vessel	With vessel
Dock internal width	24m	24m
Dock internal height	18m	18m
Wall thickness	2,6m	2,6m
Floor thickness	2,6m	2,6m
Maximum shear stress floor	962kN/m	896kN/m
Maximum momentum floor	18253kNm/m	21397kNm/m
Maximum shear stress wall	2430kN	2430kN
Maximum momentum wall	14580kNm	14580kNm

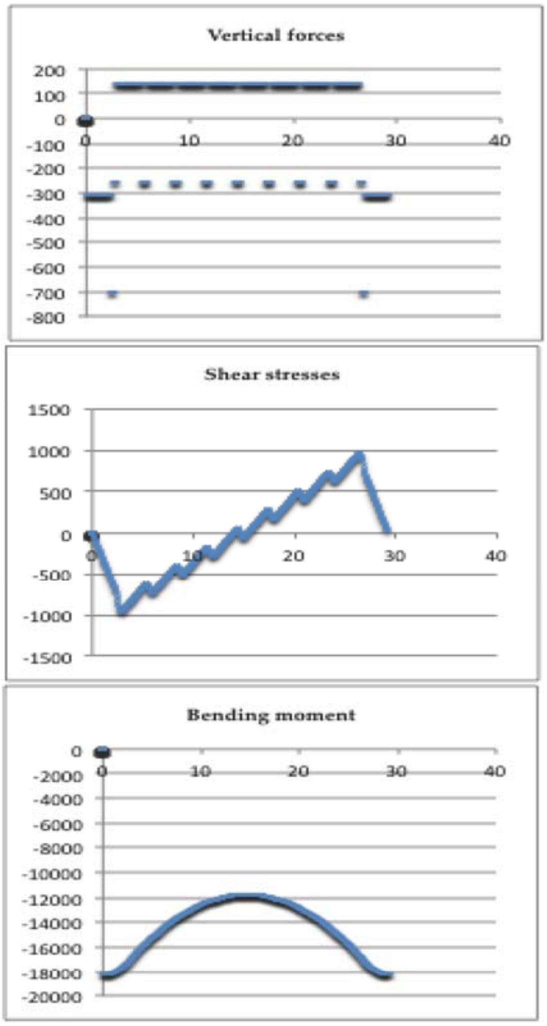


Figure 0.33: Floor results DSS, Pile foundation, Without Vessel

Y-axis: forces [kN/m2], stresses [kN/m], moment [kNm/m]; X-axis: Width [m]

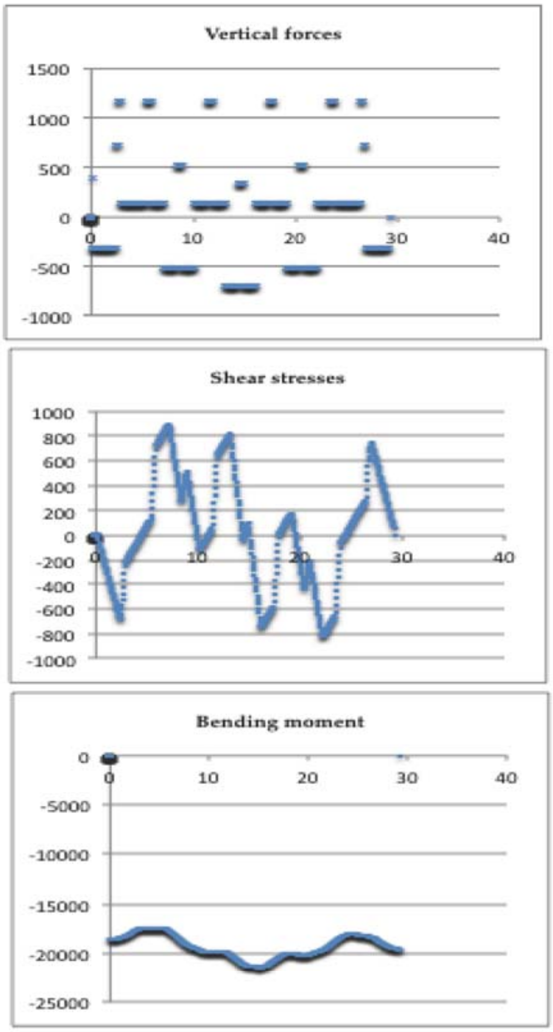


Figure 0.33: Floor results DSS, Pile foundation, With Vessel

Y-axis: forces [kN/m2], stresses [kN/m], moment [kNm/m]; X-axis: Width [m]

Appendix 9 Validation

Appendix 9.1 Input

MHWN	0,1	m+NAP
ground water level	-0,6	m+NAP
Concrete width	3	m
Boven belasting	0	kn/m2
Density concrete	25	kN/m^3
Density water	10	kN/m^3
safety margin upward pressure	1,1	[-]

Vessel

Vessel type	Design vessel	
Length	206,4	m
Width	35	m
Depth	12	m
LWT	60000	ton

	permeable/impermeable	Depth +NAP	top	bottom	Density		Cone resistance	Phi	Cohesion
1	permeable	4	air	sand	17	kN/m^3		30	0
2	impermeable1	1,8	sand	clay	14	kN/m^3		18	5
3	impermeable1	-0,6	sand	clay	14	kN/m^3		18	5
4	permeable1	-4,3	sand	sand	19	kN/m^3		30	0
5	impermeable2	-10,3	sand	clay	18	kN/m^3		23	10
6	permeable2	-23,3	sand	sand (sitly)	20	kN/m^3		27	0
7	impermeable3	-23,3	sand	sand (sitly)	20	kN/m^3		27	0
8	permeable3	-33,3		sand	20			35	0
9		-60							

Long anchors	Depth below surface [m]	Angle β (degrees)	Length [m]	Force	Diameter [m]
anchor 1	1,5	35	63	1335,5	0
anchor 2				1094	
anchor 3					

Struts	Depth below surface	Force [kN]
Concrete	19,5	0

Functional requirements	Weight	
Technical score	10	*1-10*
Reliability	8	*1-10*
Availability	8	*1-10*
Maintainability	7	*1-10*
Safety	8	*1-10*
Expandability	8	*1-10*
Availability of steel	-1	*-5 - 5Give minus score*
Availability of concrete	-1	*-5 - 5Give minus score*
Engineering cost	7	*1-10*
Building cost	9	*1-10*
Durability or CO2 footprint	7	*1-10*

	Technical requirements Wall	
1.0	Installation from ground level possible	yes
2.0	Building pit with natural slopes possible	no
2.1	Drainage needed	no
2.2	Sheet pile needed to close permeable layer	no
3.0	Building pit with retaining walls possible	yes
3.1	Drainage needed	no
3.2	Underwater concrete needed	yes
3.3	Grouting layer needed	no
4.0	Sufficient bearing capacity	no
4.1	Possible to improve bearing	indecisive
5.0	Drainage dock	yes
5.1	Possible to close of	yes
6.0	Dock created from the sea	no
7.0	Available space	>natural slope
8.0	Dock embedded in impervious rock	no
9.0	highest cone resistance	5-10
9.1	Installation depth [m]	<35

	Technical requirements Floor			
1.0	Type of wall	L-Shaped walls		
2.0	Bearing capacity stronger than:	73,7	kN/m	no
2.1	NVT		kN/m	no
2.2	NVT	no		
3.0	Drainage possible	yes		
4.0	Possible to tie floor	yes		
5.0	Pile foudation possible	yes		

	Technical requirements Gate	
1	Width of entrance	35,6
2	Speed of operation [min]	1 day
3	Labour force available for opening	>4
4	Available support for opening	Tug boat & crane
5	Reverse head capability	no
6	Ability to open against a head	no
7	Depth available outside dock	>Sill height
8	Provision of power	Available
9	Access across top of gate	Walking bridge

Appendix 9.2 Results; input DSS

Decision Support Results

Dry Dock dimension		
Length	221,6	m
Internal width	41	m
Depth	-14	m + NAP
Sill level	-12,4	m +NAP
Level top gate	1,6	m +NAP
Entrance width	35,6	m

Vessel dimension		
Vessel type	Design vessel	
Length	206,4	m
Width	35	m
Depth	12	m
LWT	60000	ton

Functional requirements	Weight	
Technical score	10	1-10
Reliability	8	1-10
Availability	8	1-10
Maintainability	7	1-10
Safety	8	1-10
Expandability	8	1-10
Availability of steel	-1	-5 - 5
Availability of concrete	-1	-5 - 5
Engineering cost	7	1-10
Building cost	9	1-10
Durability or CO2 footprint	7	1-10

Technical requirements Wall		
1.0	Installation from ground level possible	yes
2.0	Building pit with natural slopes possible	no
2.1	Drainage needed	no
2.2	Sheet pile needed to close permeable layer	no
3.0	Building pit with retaining walls possible	yes
3.1	Drainage needed	no
3.2	Underwater concrete needed	yes
3.3	Grouting layer needed	no
4.0	Sufficient bearing capacity	no
4.1	Possible to improve bearing	indecisive
5.0	Drainage dock	yes
5.1	Possible to close of	yes
6.0	Dock created from the sea	no
7.0	Available space	>natural slope
8.0	Dock embedded in impervious rock	no
9.0	highest cone resistance	5-10
9.1	Installation depth [m]	<35

Technical requirements Floor		
1.0	Type of wall	L-Shaped walls
2.0	Bearing capacity stronger than:	73,37 kN/m no
2.1	NVT	kN/m no
2.2	NVT	no
3.0	Drainage possible	yes
4.0	Possible to tie floor	yes
5.0	Pile foudation possible	yes

Technical requirements Gate		
1	Width of entrance	35,6
2	Speed of operation [min]	1 day
3	Labour force available for opening	>4
4	Available support for opening	Tug boat & crane
5	Reverse head capability	no
6	Ability to open against a head	no
7	Depth available outside dock	>Sill height
8	Provision of power	Available
9	Access across top of gate	Walking bridge

Trade-off

	Construction method			
	Method	**Safety factor**		
1	Open excavation with slopes	2,1		
2	Retaining walls (impermeable1)	N.A.		
3	Retaining walls (impermeable2)	2,1		
4	Retaining walls (impermeable3)	1,1		
5	Retaining walls with underwater concrete	1,0	9,99	meter concrete
6	Retaining walls with deep grouted layer	1,0	-120,6545555	m+NAP

	Wall trade-off			
	Wall type	***Technical score***	***Total score***	***Cost***
	Gravity dry dock walls	*22,6*		
1	Caissons walls		139	
2	Cellular walls		103	
	L-Shaped walls	23,1		€ 10.343.288
3	Cantilever		196	
4	Counterfort		183	
	Embedded anchor walls	31,2		
5	Sheet-piled walls		X	€ 6.583.769
6	Combined walls		X	€ 9.777.939
7	Embedded cofferdam walls		X	
8	**Diaphragm walls**	25,5	X	
9	**Soil or rock slope walls**	X	X	

	Gate trade-off		
	Entrance Gate Type	**Technical score**	**Total score**
	Flap gate		
1	Spanning Box	34	253
2	Strutted	34	239
3	Cantilever	34	230
	Floating Caisson Gate		
4	Free	35	321
5	Hinged	32	272
6	Sliding or rolling caisson gate	X	X
	Sliding or rolling caisson gate (deballasting)	35	285
7	Mitre gates	X	X
8	Sector gates	X	X
	Intermediate gates		
	Modular units installed by crane		
9	Inverted "Y"	X	X
10	Lambda "λ"	X	X
11	Stop logs	X	X

Trade-off

	Floor trade-off		
	Entrance Gate Type	***Technical score***	***Total score***
	Uplift alternatives		
1	Under-drained floors	10	279
2	Gravity floors	0	0
3	Tied floors	5	237
	Bearing alternatives		
4	Shallow foundation	0	0
5	Pile foundation	10	355

Under-drained with shallow foundation	€	4.525.603,16	+under draining cost
Under-drained with pile foundation	€	12.613.331,99	+under draining cost
Gravity with shallow foundation	€	11.642.816,45	
Gravity with pile foundation	€	18.245.772,87	
Tied with shallow foundation	€	12.613.331,99	
Tied with pile foundation	€	12.613.331,99	

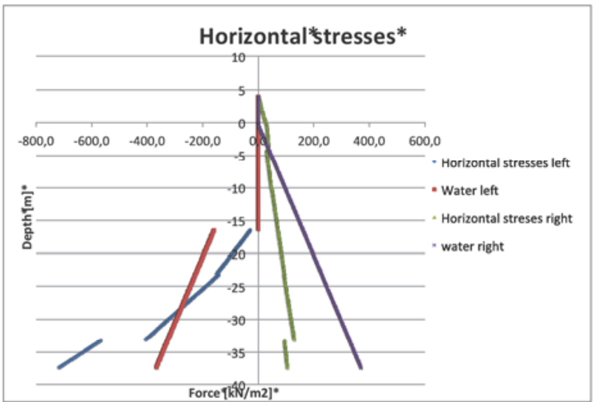
Embedded anchor walls

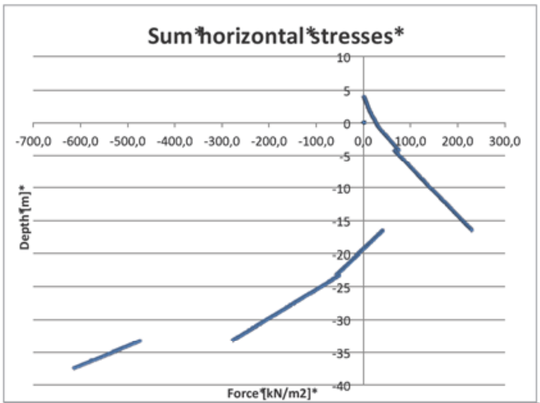
Max*embedded*wall*forces		
Max*moment	Min*moment	Absolute*maximum*momentum
2544,1 kNm/m' -30,2 m	-9926,0 knm/m -11,7 m	9926,0 kNm/m' -11,7 m
Max*shear*stress	Max*horizontal*stress	
1009,9 kN/m2' -19,3 m	228,8 kN/m'	

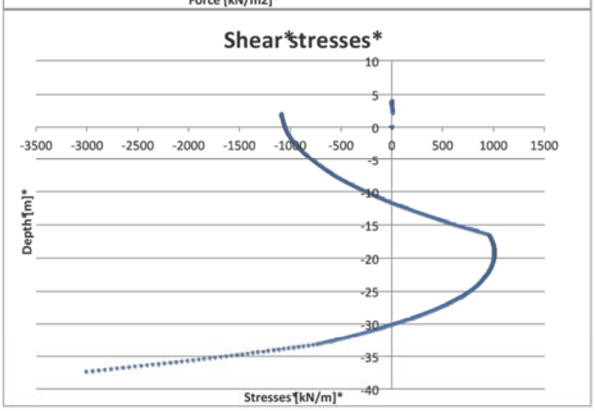
Long*anchors*	Depth	Angle β (degrees)	Length [m]	Force	Allowable force
anchor 1	2	35	63	1343	1203,9
anchor 2				0	0

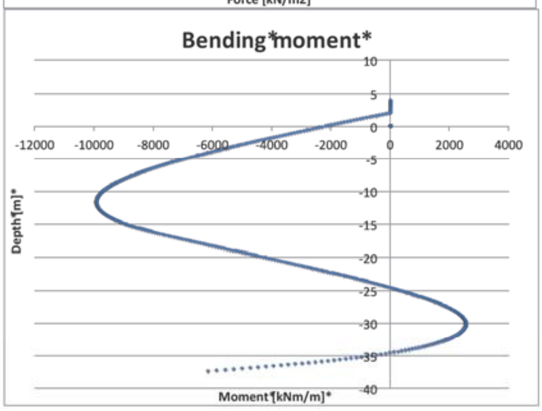
Struts	Depth below surface	Force [kN]
Concrete	18	0

Profile	Max Momentum	Steel quality	Profile	Max Momentum	Steel quality
AZ12	NVT	NVT	AZ25	NVT	NVT
AZ13	NVT	NVT	AZ26	NVT	NVT
AZ14	NVT	NVT	AZ28	NVT	NVT
AZ17	NVT	NVT	AZ46	NVT	NVT
AZ18	NVT	NVT	AZ48	NVT	NVT
AZ19	NVT	NVT	AZ50	NVT	NVT









Concrete wall

Forces on wall			
Max horizontal	Max shear stresses	Max bending moment	length wall
237,3 kN/m	1895,5 kN/m2	10754,3 kNm/m	18,0 m

Concrete information	
Concrete	c45/55
fck	55 n/mm2
fyk	500 n/mm2
b	18000 mm
h	2300 mm
As	11259,47 mm2

Volumes	
wall	20236,32 m3
steel	99,065304 m3
concrete	20137,255 m3

Allowable forces on concrete	
Vrd,c	1990,404 kN
mrd	11020,29 kNm

wall check		
shear ok?	0,9523049	OK
Momentum ok?	0,9758635	OK
Steel ok?	0,4895421	%

Shallow foundation floor

condition	Width [mm] no vessel	vessel
- Shear	1620	1554
- resist water	5907	

	q ground [kN/m]	
No vessel	2603,99544	upward resistance
Vessel	-3345,6633	downward resistance

Whitout vessel

Forces on floor		
max momentum	0	kNm/m
min momentum	-12986,18266	kNm/m
max shear	928,3223684	kN/m
min shear	-928,3223684	kN/m

Concrete information		
Concrete	c35/45	
fck	45	n/mm2
fyk	500	n/mm2
b	41000	mm
h	2100	mm
As	19301,94526	mm2

Allowable forces on concrete		
Vrd,c	1500,069475	kN
mrd	16905,58441	kNm

Floor check		
shear ok?	0,62	OK
Momentum ok?	0,77	OK
Steel ok?	0,92	%

Volumes (shear)		
Floor	19985,1	m3
Steel	183,7	m3
Concrete	19801,4	m3

Volumes (water pressure)		
Floor	56215,4	m2
Steel	516,7	m3
Concrete	55698,7	m3

With vessel

Forces on floor		
max momentum	0	kNm/m
min momentum	-16232,24685	kNm/m
max shear	860,3163	kN/m
min shear	-860,3163	kN/m

Concrete information		
Concrete	c35/45	
fck	45	n/mm2
fyk	500	n/mm2
b	41000	mm
h	2100	mm
As	19301,94526	mm2

Allowable forces on concrete		
Vrd,c	1500,069475	kN
mrd	16905,58441	kNm

Floor check		
shear ok?	0,57	OK
Momentum ok?	0,96	OK
Steel ok?	0,92	%

Volumes (shear)		
Floor	19079,8	m3
Steel	175,4	m3
Concrete	18904,4	m3

Pile foundation floor

condition	Width [mm] no vesse	vessel
- Shear	1267	2311
- resist water	5907	

	q ground [kN/m]	
No vessel	2261,995	upward resistance
Vessel	-4058,96	downward resistance

Whitout vessel

Forces on floor		
max momentum	-3234,88	kNm/m
min momentum	-13647,3	kNm/m
max shear	571,8249	kN/m
min shear	-964,925	kN/m

Concrete information			
Concrete	c35/45		0
fck	45	n/mm2	
fyk	500	n/mm2	
b	41000	mm	
h	2600	mm	
As	24931,68	mm2	

Allowable forces on concrete		
Vrd,c	2230,74	kN
mrd	27245,09	kNm

Floor check		
shear ok?	0,26	OK
Momentum ok?	0,50	OK
Steel ok?	0,96	%

Volumes (shear)		
Floor	24743,5	m3
Steel	237,3	m3
Concrete	24506,2	m3

Volumes (water pressure)		
Floor	56215,4	m2
Steel	539,1	m3
Concrete	55676,3	m3

With vessel

Forces on floor		
max moment	-11888,8	kNm/m
min moment	-26751,4	kNm/m
max shear	1792,859	kN/m
min shear	-1745,36	kN/m

Concrete information			
Concrete	c35/45		0
fck	45	n/mm2	
fyk	500	n/mm2	
b	41000	mm	
h	2600	mm	
As	24931,68	mm2	

Allowable forces on concrete		
Vrd,c	2230,74	N
mrd	27245,09	kNm

Floor check		
shear ok?	0,80	OK
Momentum ok?	0,98	OK
Steel ok?	0,96	%

Volumes (shear)		
Floor	24743,5	m3
Steel	237,3	m3
Concrete	24506,2	m3

Appendix 9.3 Results; input DSS (anchor +strut force D-Sheet)

	Wall trade-off			
	Wall type	***Technical score***	***Total score***	***Cost***
	Gravity dry dock walls	*22,6*		
1	Caissons walls		139	
2	Cellular walls		103	
	L-Shaped walls	23,1		€ 10.343.288
3	Cantilever		196	
4	Counterfort		183	
	Embedded anchor walls	31,2		
5	Sheet-piled walls		X	€ 6.583.769
6	Combined walls		213	€ 9.777.939
7	Embedded cofferdam walls		204	
8	**Diaphragm walls**	25,5	160	
9	**Soil or rock slope walls**	X	X	

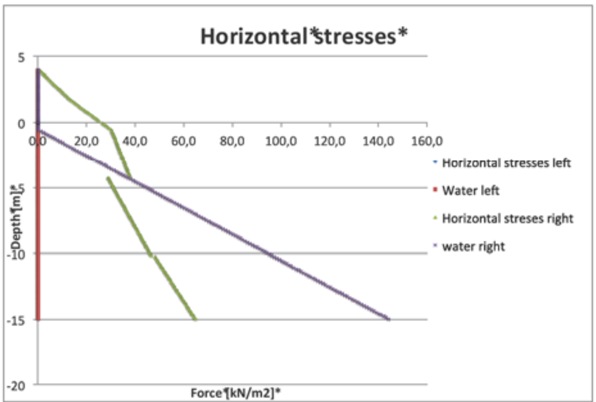
Embedded anchor walls

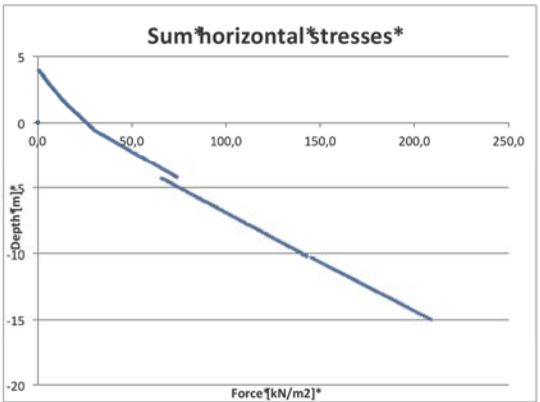
Max*embedded*wall*forces		
Max*moment	Min*moment	Absolute*maximum*momentum
568,0 kNm/m' -13,9 m	-2637,6 knm/m -6,9 m	2637,6 kNm/m' -6,9 m
Max*shear*stress	Max*horizontal*stress	
1024,8 kN/m2' -13,9 m	208,5 kN/m'	

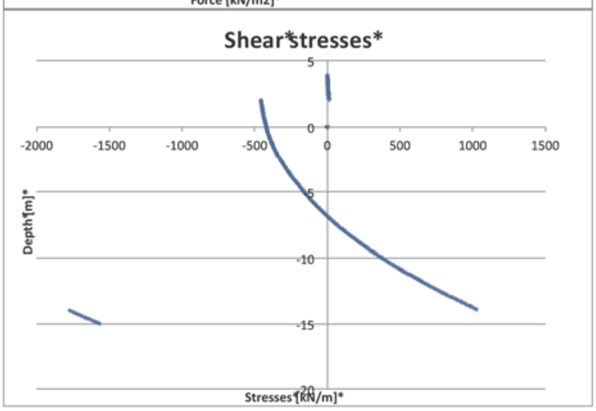
Long*anchors*	Depth	Angle β (degrees)	Length [m]	Force	Allowable force
anchor 1	2	35	63	572	1203,9
anchor 2				0	0

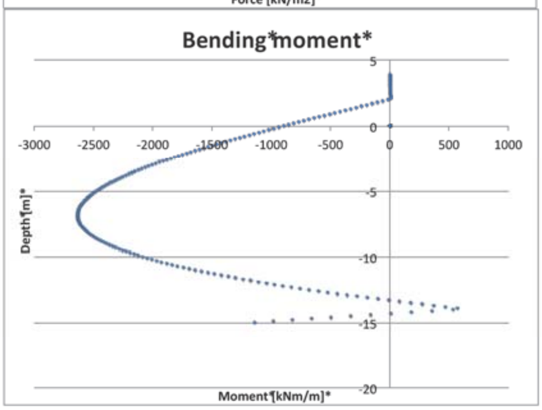
Struts	Depth below surface	Force [kN]
Concrete	18	2817

Profile	Max Momentum	Steel quality	Profile	Max Momentum	Steel quality
AZ12	NVT	NVT	AZ25	NVT	NVT
AZ13	NVT	NVT	AZ26	NVT	NVT
AZ14	NVT	NVT	AZ28	NVT	NVT
AZ17	NVT	NVT	AZ46	NVT	NVT
AZ18	NVT	NVT	AZ48	NVT	NVT
AZ19	NVT	NVT	AZ50	NVT	NVT









Appendix 9.4 Results; input Client

Decision Support Results

Dry Dock dimension		
Length	221,6	m
Internal width	41	m
Depth	-14	m + NAP
Sill level	-12,4	m +NAP
Level top gate	1,6	m +NAP
Entrance width	35,6	m

Vessel dimension		
Vessel type	Design vessel	
Length	206,4	m
Width	35	m
Depth	12	m
LWT	60000	ton

Functional requirements	Weight	
Technical score	10	1-10
Reliability	8	1-10
Availability	8	1-10
Maintainability	7	1-10
Safety	8	1-10
Expandability	8	1-10
Availability of steel	-1	-5 - 5
Availability of concrete	-1	-5 - 5
Engineering cost	7	1-10
Building cost	9	1-10
Sustainability or CO2 footprint	7	1-10

Technical requirements Wall		
1.0	Installation from ground level possible	yes
2.0	Building pit with natural slopes possible	no
2.1	Drainage needed	no
2.2	Sheet pile needed to close permeable layer	no
3.0	Building pit with retaining walls possible	yes
3.1	Drainage needed	no
3.2	Underwater concrete needed	yes
3.3	Grouting layer needed	no
4.0	Sufficient bearing capacity	no
4.1	Possible to improve bearing	indecisive
5.0	Dock created from the sea	no
6.0	Available space	>natural slope
7.0	Dock embedded in impervious rock	no
8.0	highest cone resistance	5-10
8.1	Installation depth [m]	<35

Technical requirements Floor		
1.0	Type of wall	L-Shaped walls
2.0	Bearing capacity stronger than:	73,37 kN/m no
2.1	NVT	kN/m no
2.2	NVT	no
3.0	Drainage possible	yes
4.0	Possible to tie floor	yes
5.0	Pile foudation possible	yes

Technical requirements Gate		
1	Width of entrance	35,6
2	Speed of operation [min]	1 day
3	Labour force available for opening	>4
4	Available support for opening	Tug boat & crane
5	Reverse head capability	no
6	Ability to open against a head	no
7	Depth available outside dock	>Sill height
8	Provision of power	Available
9	Access across top of gate	Walking bridge

Trade-off

	Construction method			
	Method	**Safety factor**		
1	Open excavation with slopes	1,5		
2	Retaining walls (impermeable1)	N.A.		
3	Retaining walls (impermeable2)	1,5		
4	Retaining walls (impermeable3)	1,0		
5	Retaining walls with underwater concrete	1,0	9,99	meter concrete
6	Retaining walls with deep grouted layer	1,0	-120,6545555	m+NAP

	Wall trade-off			
	Wall type	***Technical score***	***Total score***	***Cost***
	Gravity dry dock walls	*22,6*		
1	Caissons walls		139	
2	Cellular walls		103	
	L-Shaped walls	23,1		€ 9.589.886
3	Cantilever		196	
4	Counterfort		183	
	Embedded anchor walls	31,2		
5	Sheet-piled walls		X	€ 6.801.048
6	Combined walls		X	€ 9.917.515
7	Embedded cofferdam walls		X	
8	**Diaphragm walls**	25,5	X	
9	**Soil or rock slope walls**	X	X	

	Gate trade-off		
	Entrance Gate Type	**Technical score**	**Total score**
	Flap gate		
1	Spanning Box	34	253
2	Strutted	34	239
3	Cantilever	34	230
	Floating Caisson Gate		
4	Free	35	321
5	Hinged	32	272
6	Sliding or rolling caisson gate	X	X
	Sliding or rolling caisson gate (deballasting)	35	285
7	Mitre gates	X	X
8	Sector gates	X	X
	Intermediate gates		
	Modular units installed by crane		
9	Inverted "Y"	X	X
10	Lambda “λ”	X	X
11	Stop logs	X	X

Trade-off

	Floor trade-off		
	Entrance Gate Type	***Technical score***	***Total score***
	Uplift alternatives		
1	Under-drained floors	10	279
2	Gravity floors	0	0
3	Tied floors	5	237
	Bearing alternatives		
4	Shallow foundation	0	0
5	Pile foundation	10	355

Under-drained with shallow foundation	€	5.290.145,62	+under draining cost
Under-drained with pile foundation	€	14.853.205,63	+under draining cost
Gravity with shallow foundation	€	12.831.528,24	
Gravity with pile foundation	€	20.587.905,46	
Tied with shallow foundation	€	14.853.205,63	
Tied with pile foundation	€	14.853.205,63	

Embedded anchor walls

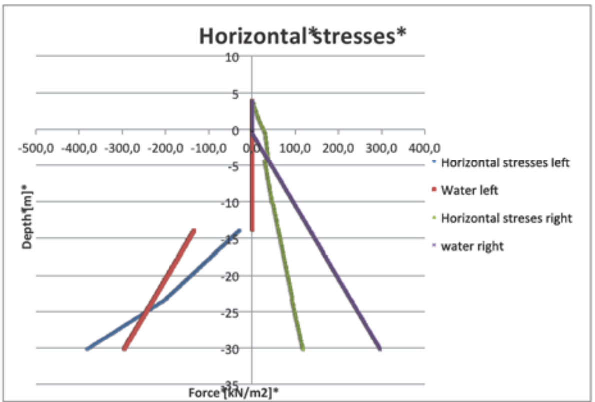
Max*embedded*wall*forces		
Max*moment	Min*moment	Absolute*maximum*momentum
1692,5 kNm/m'	-6112,5 knm/m	6112,5 kNm/m'
-25,9 m	-9,7 m	-9,7 m

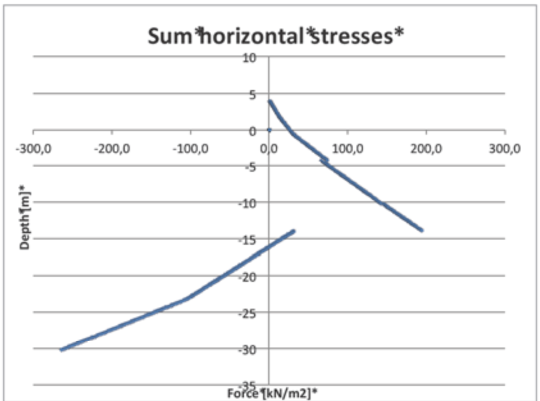
Max*shear*stress	Max*horizontal*stress
734,8 kN/m2'	193,7 kN/m'
-16,1 m	

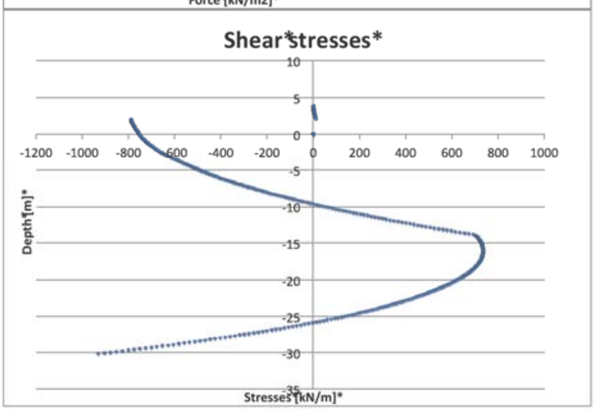
Long*anchors*	Depth	Angle β (degrees)	Length [m]	Force	Allowable force
anchor 1	2	35	63	979	1203,9
anchor 2				0	0

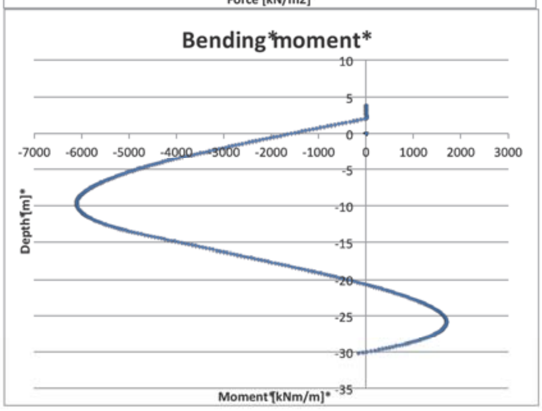
Struts	Depth below surface	Force [kN]
Concrete	18	0

Profile	Max Momentum	Steel quality	Profile	Max Momentum	Steel quality
AZ12	NVT	NVT	AZ25	NVT	NVT
AZ13	NVT	NVT	AZ26	NVT	NVT
AZ14	NVT	NVT	AZ28	NVT	NVT
AZ17	NVT	NVT	AZ46	NVT	NVT
AZ18	NVT	NVT	AZ48	NVT	NVT
AZ19	NVT	NVT	AZ50	NVT	NVT









Concrete wall

Forces on wall			
Max horizontal	Max shear stresses	Max bending moment	length wall
207,5 kN/m	1450,7 kN/m2	7418,0 kNm/m	16,0 m

Concrete information		
Concrete	c45/55	
fck	55	n/mm2
fyk	500	n/mm2
b	16000	mm
h	1950	mm
As	9650,973	mm2

Volumes		
wall	16595,28	m3
steel	82,133637	m3
concrete	16513,146	m3

Allowable forces on concrete		
Vrd,c	1468,991	kN
mrd	7977,917	kNm

wall check		
shear ok?	0,9875334	OK
Momentum ok?	0,9298221	OK
Steel ok?	0,4949217	%

Shallow foundation floor

condition	Width [mm] no vessel	vessel
- Shear	1431	1873
- resist water	5596	

	q ground [kN/m]	
No vessel	2721,74481	upward resistance
Vessel	-3078,164	downward resistance

Whitout vessel

Forces on floor		
max momentum	0	kNm/m
min momentum	-10101,72873	kNm/m
max shear	738,3815029	kN/m
min shear	-701,3872832	kN/m

Concrete information		
Concrete	c35/45	
fck	45	n/mm2
fyk	500	n/mm2
b	48000	mm
h	2100	mm
As	20910,4407	mm2

Allowable forces on concrete		
Vrd,c	1500,069475	kN
mrd	18316,7911	kNm

Floor check		
shear ok?	0,49	OK
Momentum ok?	0,55	OK
Steel ok?	1,00	%

Volumes (shear)		
Floor	22708,1	m3
Steel	226,1	m3
Concrete	22482,0	m3

Volumes (water pressure)		
Floor	60513,1	m2
Steel	602,6	m3
Concrete	59910,6	m3

With vessel

Forces on floor		
max momentum	0	kNm/m
min momentum	-18294,81988	kNm/m
max shear	1213,125567	kN/m
min shear	-1186,686567	kN/m

Concrete information		
Concrete	c35/45	
fck	45	n/mm2
fyk	500	n/mm2
b	48000	mm
h	2100	mm
As	20910,4407	mm2

Allowable forces on concrete		
Vrd,c	1500,069475	kN
mrd	18316,7911	kNm

Floor check		
shear ok?	0,81	OK
Momentum ok?	1,00	OK
Steel ok?	1,00	%

Volumes (shear)		
Floor	24192,0	m3
Steel	240,9	m3
Concrete	23951,1	m3

Pile foundation floor

condition	Width [mm] no vesse	vessel
- Shear	890	2470
- resist water	5596	

	q ground [kN/m]	
No vessel	2332,495	upward resistance
Vessel	-3988,46	downward resistance

Whitout vessel

Forces on floor		
max momentum	-581,694	kNm/m
min momentum	-9659,18	kNm/m
max shear	288,8602	kN/m
min shear	-750,331	kN/m

Concrete information			
Concrete	c35/45		0
fck	45	n/mm2	
fyk	500	n/mm2	
b	48000	mm	
h	2600	mm	
As	26540,17	mm2	

Allowable forces on concrete		
Vrd,c	2230,74	kN
mrd	29007,64	kNm

Floor check		
shear ok?	0,13	OK
Momentum ok?	0,33	OK
Steel ok?	1,02	%

Volumes (shear)		
Floor	28114,7	m3
Steel	287,0	m3
Concrete	27827,8	m3

Volumes (water pressure)		
Floor	60513,1	m2
Steel	617,7	m3
Concrete	59895,4	m3

With vessel

Forces on floor		
max moment	-8287,22	kNm/m
min moment	-28801	kNm/m
max shear	2028,314	kN/m
min shear	-1990,81	kN/m

Concrete information			
Concrete	c35/45		0
fck	45	n/mm2	
fyk	500	n/mm2	
b	48000	mm	
h	2600	mm	
As	26540,17	mm2	

Allowable forces on concrete		
Vrd,c	2230,74	N
mrd	29007,64	kNm

Floor check		
shear ok?	0,91	OK
Momentum c	0,99	OK
Steel ok?	1,02	%

Volumes (shear)		
Floor	28114,7	m3
Steel	287,0	m3
Concrete	27827,8	m3

Appendix 9.5 Results; input client (anchor +strut force D-Sheet)

	Wall trade-off			
	Wall type	***Technical score***	***Total score***	***Cost***
	Gravity dry dock walls	*22,6*		
1	Caissons walls		139	
2	Cellular walls		103	
	L-Shaped walls	23,1		€ 9.589.886
3	Cantilever		196	
4	Counterfort		183	
	Embedded anchor walls	31,2		
5	Sheet-piled walls		X	€ 6.801.048
6	Combined walls		213	€ 9.917.515
7	Embedded cofferdam walls		204	
8	**Diaphragm walls**	25,5	160	
9	**Soil or rock slope walls**	X	X	

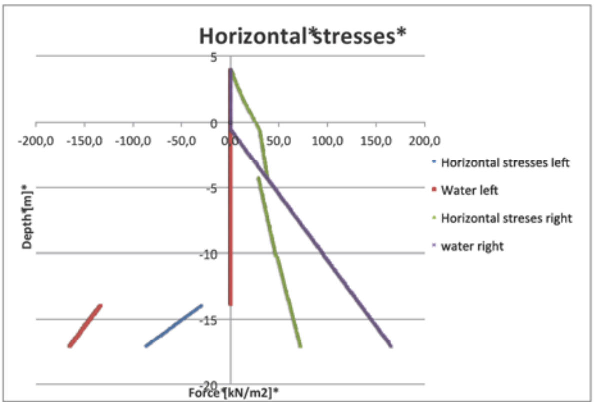
Embedded anchor walls

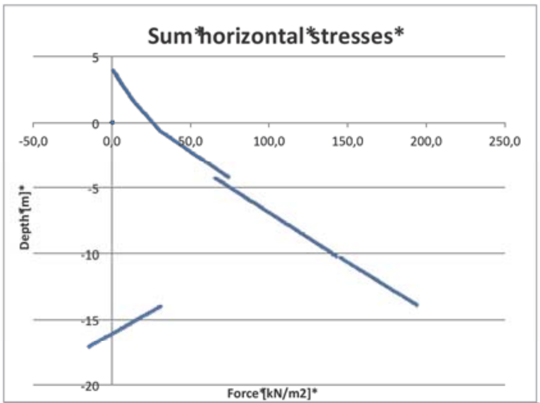
Max*embedded*wall*forces		
Max*moment	Min*moment	Absolute*maximum*momentum
2514,8 kNm/m' -14 m	-1633,2 knm/m -5,5 m	2514,8 kNm/m' -14 m
Max*shear*stress	Max*horizontal*stress	
1146,1 kN/m2' -13,9 m	193,7 kN/m'	

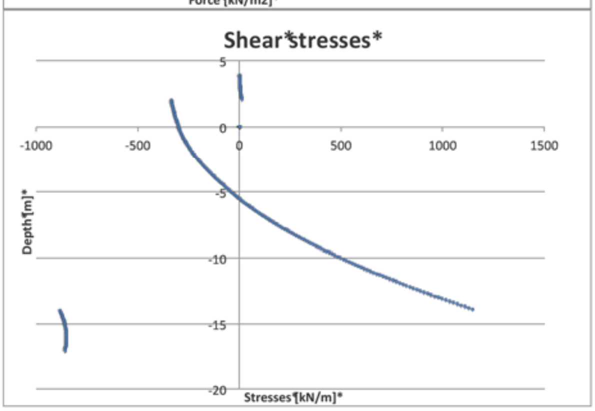
Long*anchors*	Depth	Angle β (degrees)	Length [m]	Force	Allowable force
anchor 1	2	35	63	424	1203,9
anchor 2				0	0

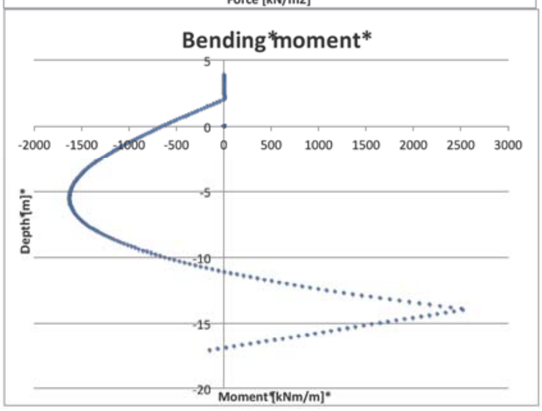
Struts	Depth below surface	Force [kN]
Concrete	18	2042

Profile	Max Momentum	Steel quality	Profile	Max Momentum	Steel quality
AZ12	NVT	NVT	AZ25	NVT	NVT
AZ13	NVT	NVT	AZ26	NVT	NVT
AZ14	NVT	NVT	AZ28	NVT	NVT
AZ17	NVT	NVT	AZ46	NVT	NVT
AZ18	NVT	NVT	AZ48	NVT	NVT
AZ19	NVT	NVT	AZ50	NVT	NVT









Appendix 10 BIM Ready

The macro used to export the information from the DSS to a Notepad file is given by the following formulas:

```
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' ExportToTextFile
' This exports a sheet or range to a text file, using a
' user-defined separator character.
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
Public Sub ExportToTextFile(FName As String, _
    Sep As String, SelectionOnly As Boolean, _
    AppendData As Boolean)

Dim WholeLine As String
Dim FNum As Integer
Dim RowNdx As Long
Dim ColNdx As Integer
Dim StartRow As Long
Dim EndRow As Long
Dim StartCol As Integer
Dim EndCol As Integer
Dim CellValue As String

Application.ScreenUpdating = False
On Error GoTo EndMacro:
FNum = FreeFile

If SelectionOnly = True Then
    With Selection
        StartRow = .Cells(1).Row
        StartCol = .Cells(1).Column
        EndRow = .Cells(.Cells.Count).Row
        EndCol = .Cells(.Cells.Count).Column
    End With
Else
    With ActiveSheet.UsedRange
        StartRow = .Cells(1).Row
        StartCol = .Cells(1).Column
        EndRow = .Cells(.Cells.Count).Row
        EndCol = .Cells(.Cells.Count).Column
    End With
End If

If AppendData = True Then
    Open FName For Append Access Write As #FNum
Else
    Open FName For Output Access Write As #FNum
End If

For RowNdx = StartRow To EndRow
    WholeLine = ""
    For ColNdx = StartCol To EndCol
        If Cells(RowNdx, ColNdx).Value = "" Then
            CellValue = Chr(34) & Chr(34)
        Else
            CellValue = Cells(RowNdx, ColNdx).Value
        End If
        WholeLine = WholeLine & CellValue & Sep
    Next ColNdx
    WholeLine = Left(WholeLine, Len(WholeLine) - Len(Sep))
    Print #FNum, WholeLine
Next RowNdx

EndMacro:
On Error GoTo 0
Application.ScreenUpdating = True
Close #FNum

Application.Goto ActiveWorkbook.Sheets("BIM").Range("B7")

End Sub
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' END ExportTextFile
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''

''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' DoTheExport
' This prompts the user for the FileName and the separtor
' character and then calls the ExportToTextFile procedure.
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
Sub BIM()
    Dim FileName As Variant
    Dim Separator As Variant
    Dim Sep As String
    Sep = ","
    Application.Goto ActiveWorkbook.Sheets("BIM").Range("A2:D2")
    FileName = ThisWorkbook.Path & "\" & "simple wall.txt"
        If FileName = False Then
        ''''''''''''''''''''''''''
        ' user cancelled, get out
        ''''''''''''''''''''''''''
        Exit Sub
    End If
    Debug.Print "FileName: " & FileName, "Separator:" & Sep
    ExportToTextFile FName:=CStr(FileName), Sep:=CStr(Sep), _
        SelectionOnly:=True, AppendData:=True
End Sub
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' END DoTheExport
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
```

Appendix 11 List of figures and tables

Appendix 11.1 List of figures

Appendix 11.2 List of tables