NEXT GENERATION OF TOPSIDE LIFTING

The most cost effective modification to extend the platform capabilities of the Pioneering Spirit

B.C. Den Haan

TU Delft

Department of Ship Design, Production and Operation
SDPO.16.006.m

Next generation of topside lifting

The most cost effective modification to extend the platform capabilities of the Pioneering Spirit

By

B.C. Den Haan

in partial fulfilment of the requirements for the degree of

Master of Science

in Applied Physics

at the Delft University of Technology,

to be defended publicly on Wednesday March 30, 2016 at 10:00 AM.

Supervisor:	Prof. ir. J.J. Hopman	
Thesis committee:	Ir. R.G. Hekkenberg,	TU Delft
	Dr. ing. A Romeijn,	TU Delft
	Ir. M. Dijk,	Allseas

Department of Ship Design, Production and Operation
SDPO.16.006.m

Preface

Before you lies the thesis “Next Generation of Topside Lifting”. I wrote this thesis for my graduation from the Delft University of Technology, completing my master degree in Ship Design. Working on the largest ship in the world has certainly been challenging and exiting.

As is, in my opinion, unavoidable when writing a master thesis, there were off course some bumps in the road. However, in the end I have managed this achievement, but not without the help of a number of people.

More in particular I would like to thank Robert Hekkenberg of the Delft University of Technology, for his profound guidance and support during this thesis. I would also like to express my gratitude towards Marijn Dijk of Allseas, for providing this design thesis about one of the most remarkable vessels ever built. I also want to thank my colleagues at Allseas for all the help and support during period. Furthermore I would like to thank Hans Hopman for his guidance as my supervisor at the university. In addition my gratitude goes to Arie Romeijn, for his time and effort as member of my graduation committee.

In addition, I have really appreciated all help and support I received from my fellow students, who have, are or will undergo the same process I went through. Thank you for reading my thesis and I hope you will enjoy.

B.C. den Haan

Delft, March 2016

Abstract

In the last decades a lot of oil platforms have been built. According to Infield (Infield, 2015), there are over 800 oil platforms out in the ocean. These platforms need to be decommissioned at the end of their lifetime. The Pioneering Spirit (PS), is a state-of-the-art multi-purpose twin hull vessel with the capability to decommission and install oil and gas platforms. To lift these platforms, the vessel is equipped with the so called Topside Lift System (TLS). This system enables the vessel to decommission or install complete topsides, up to a weight of 48,000 tonnes, in one single action.

During the design of the PS, limited detailed information on platforms was available. With more information revealed by various tenders, the widening procedure during the new-build-phase was initiated. However, even after this widening, the vessel is not able to handle all existing platforms. The extreme dimensions of several platforms makes it challenging to design a ship which is suitable for all platforms. In this research, the most cost effective modification to extend the topside lifting capabilities of the Pioneering Spirit is investigated.

To find this modification, first the performance limiting factors, with respect to topside lifting, of the vessel are identified. Research indicates that the performance limiting factors of the vessel, are influenced by five topside characteristics. These characteristics describe the topside and its location; the weight of the topside, the length of the platform, the width of the platform, the air gap under the topside and the water-depth.

The performance limiting factors are used to identify the group of platforms which cannot be lifted by the PS. This group of platforms forms the potential market for the modified vessel. For this potential market, Allseas' platform database is used. The database is based on data of Infield (Infield, 2015) and contains over 750 platforms worldwide. For the PS, topsides with a weight of less than 10,000 tonnes are not relevant. Unfortunately, the information in the database is not complete for each platform. Platforms that lack essential information are not taken into account. The known potential market for the PS contains 37 platforms, with a topside weight range between 18,000 and 52,000 tonnes. Many of these platforms suffer from more than one limitation of the vessel.

The potential platforms are used as a guideline to assess viable modification concepts. For instance, the maximum liftable weight does not need to be higher than the heaviest potential platform. There are four viable concepts generated to overcome the performance limiting factors. These are: adding additional TLS beams, extending the vessel's bows, widening the slot and use connection bridges. These concepts are combined in several different modifications to extend the lifting capability.

To be able to compare the modifications, on a ratio between the investment, running costs and income, two key figures are used. The return on investment (RoI), which indicates the efficiency of the investment (Investopedia, n.d.) and the financial result. In case the RoI of multiple modifications are equal, the financial result will be decisive.

The most cost effective modification is a small modification with only the connection bridge. This modification enables the system to lift 4 additional platforms. However, the calculated removal rate turned out to be too low to cover all the costs.

A sensitivity study is performed to identify the influence of the assumed input parameters. With an increase of the removal rate of approximately 20%, to €2,800, the financial result of more than 50 modifications turns positive. The return of investment would also be positively influenced, if the potential market increases. The weighted average cost of capital, steel price and the duration would need to be unreasonably reduced to turn a modification into a positive financial result.

Abbreviations

CoB	Centre of buoyancy
CoG	Centre of gravity
CPT	Compliant Piled Tower
CTC	Centre To Centre
D	Depth
D_i	Depth inside slot
D_o	Depth outside hull
DP	Dynamic positioning
IBS/IS	Inboard support
JLS	Jacket lift system
LCT	Loading Condition Tool
L_{oa}	Length overall
L_{pp}	Length perpendicular
LR	Lloyd's Register
L_s	Slot Length
MDO	Marine Diesel Oil
MGO	Marine Gas Oil
OBS/OS	Outboard support
PS	Pioneering Spirit
T	Draught
TLS	Topsides Lift System
T_{max}	Maximum draught
W	Width
W_s	Slot Width

Glossary

Outreach	Outreach is defined as the distance from the centre of the inboard support to the clamp/yoke hinge at the tip of the lever (Soetens, 2014).
Tonne	Metric Ton, 1000 kilograms
Outreach	Distance form centre of IBS to hinge of the lifting beam.
Bow	One of the protruding structures at the fore end of the vessel (Figure 1-1).
Slot	The area between the bows, which leaves a space for the substructure to fit in (Figure 1-1)
Beam	One of the 16 TLS lifting arms
Fork-lift	Two TLS beams, which are coupled for a clamp or yoke

Platform related terms

Platform	Complete structure
Substructure / Jacket	Foundation of the platform, see Figure 0-1
Topside	Oil and/or gaps producing part of the platform
Air gap	Height from water level to topside

Figure 0-1: Gullfaks C - (Subsea World news, n.d.)

Contents

List of Figures

List of Tables

1. Introduction

In the last decades a lot of oil platforms have been built. According to Infield (Infield, 2015), there are over 800 oil platforms out in the ocean. In 1996 an act is adopted that states that these platforms should be removed at the end of their lifetime (Norwegian Petroleum Directorate, 2011). This act entered into force on 9 February 1999, while the majority of the current platforms were already installed. It is not likely that decommissioning, according to this regulation, was already taken into account, during the installation of these platforms. This regulation requires an impact assessment that provides an overview of the consequences that are expected from the disposal, e.g. for the environment and a disposal section, for a final disposal solution (Norwegian Petroleum Directorate, 2011).

The Pioneering Spirit (PS), is a state-of-the-art oil and gas platform decommissioning and installation vessel. To lift these platforms, the vessel is equipped with the so called Topside Lift System (TLS). This system enables the vessel to remove or install complete topsides, up to a weight of 48,000 tonnes, in one single action. Allseas intention with the PS is to provide an attractive solution for the oil and gas industry. By removing and installing the topsides in a single action, the operational time at sea will be reduced compared to removal by offshore cranes which requires more lifts. The topside also can remain in one piece, this reduces the amount of expensive work performed off shore and the potential environmental pollution.

A Short description of the Pioneering Spirit is given. The PS is designed to perform three tasks; pipe-laying, jacket lifting and topside lifting. To understand which parts of the vessel will be used for each task, the vessel can be divided into four parts; main deck aft, - middle, - fore and the centreline below the main deck. A graphical representation of the main deck is provided in Figure 1-1 and schematic drawings of all decks and the vessels main dimensions are included in 0.

The aft part of the main deck is characterized by the large A-frame. This frame is designed to lift up jackets up to a weight of 25,000 tonnes. Amidships, on the main deck, the pipe storage and the accommodation are located. The first floors of the accommodation are used for the first welding process of the pipe fabrication. At the fore end of the vessel, the Topside Lifting System (TLS) is situated on the bows. Along the complete length of the bows, rails are installed to make the beams move freely over the length of the bows. Below the main deck, the pipe fabrication line is situated. From the aft of the vessel to the aft of the slot multiple welding- and coating stations are positioned.

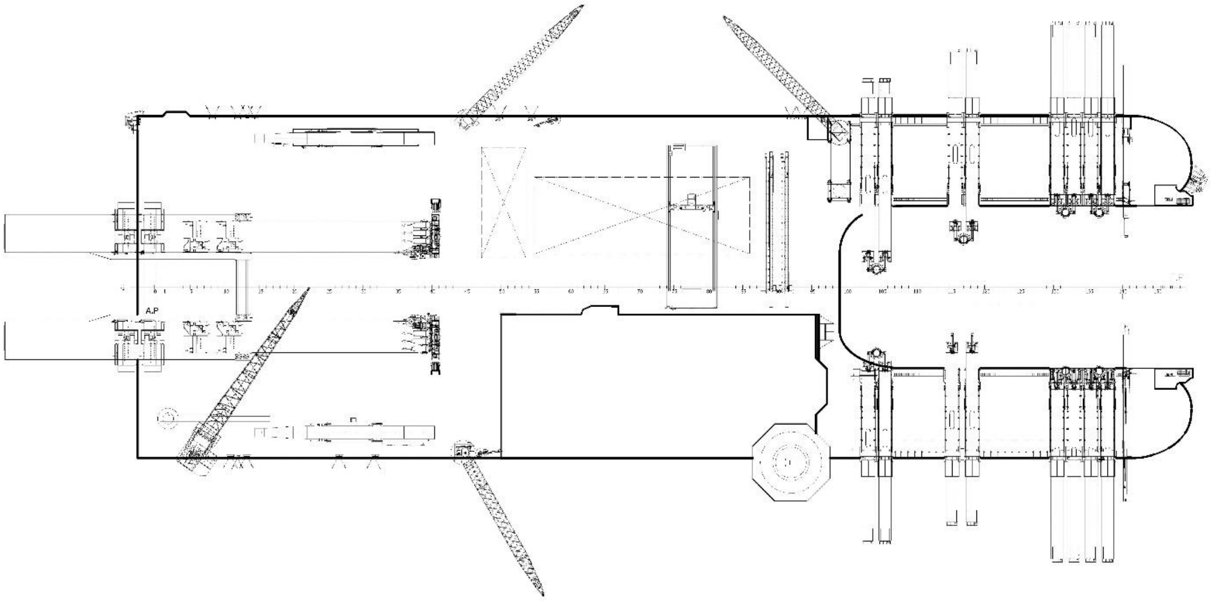


Figure 1-1: Mapping of Pioneering Spirit

Description	Abbreviation	Value (m)
Length over all	L_{oa}	382
Length perpendicular	L_{pp}	370
Width	W	123.75
Depth inside	D_i	30
Depth outside	D_o	29
Maximum draught	T_{max}	27
Slot length	L_s	122
Slot width	W_s	58.75

Table 1-1: Vessel dimensions

During the design of the PS, limited detailed information on platforms was available. By the time a tender was evaluated with the detailed information about a platform, the vessel turned out to be too small. This initiated the widening of the PS. However, even after this widening, the vessel is not able to handle all existing platforms. The extreme dimensions of a few platforms makes it challenging to design a ship which is suitable for all platforms.

Allseas is aware of the problem that the Pioneering Spirit is not capable of lifting all installed platforms. To ensure Allseas is able to remove all platforms, they announced an even larger vessel, also known as the Pieter Schelte II or Pioneering Spirit II. This concept does not only have a bigger slot for the platforms, it also has more lifting capacity. With this vessel Allseas will have the opportunity to handle topsides which are too heavy or too large for the PS. Besides the capacity, Allseas would also have the benefit of having two vessels for an enhanced operational ability.

The goal of this research is to find a modification to the original vessel in order to enable the vessel to lift more platforms. This is of interest because of the high expected investment for a second vessel.

The aim of this survey is to study the feasibility to modify the Pioneering Spirit (PS) to extend its topside lifting capacity, without compromising the other functionalities. The feasibility is assessed by a cost benefit analysis. The benefit for the PS consists of the total weight of the additional platforms, which the vessel will be able to lift after the conversion, and the rate per tonne topside. The financial performance of the modification will be defined by the return of investment and the financial result of the modification.

1.1. Main question

What is financially the best performing modification to extend the topside lifting capabilities of the Pioneering Spirit?

1.2. Sub question

- What are the performance limiting factors of the Pioneering Spirit?
- What existing platforms are beyond the limiting factors, thus composing the potential market for the modified vessel?
- Which modifications are feasible, to solve the performing limiting factors?
- Which modification of the Pioneering Spirit is most cost-effective?

1.3. Research boundaries

Only topsides with a weight of 10,000 tonnes and more will be taken into account. According to Allseas, topside removal under 10,000 tonnes has a significant amount of competition. The equipment of the competition is more suitable and less expensive for these lighter platforms than the PS is.

A second limitation to this research is the difference between decommissioning and installation. Although the vessel is capable of installing the same kind of topsides as it will be able to remove, the installation market will not be taken into account. There is not as much information known about the new platforms, which have to be built or installed, as there is for topside decommissioning. Besides, where the designers of new platforms can take the maximum capacity of the PS into account, the already installed platforms cannot be adapted.

The third limitation of this research is concerning the vessel itself. While the focus of this research will be towards the decommissioning of topsides, the other vessel capabilities, such as jacket lifting and pipe lay, must not be negatively affected. However, the level of detail whether these capabilities are affected will be low. For each modification, the best effort will be carried out to compensate for these capabilities. However, it is inevitable that these details will need to be reviewed.

1.4. Research set-up

In the initial phase, the performance limiting factors of the Pioneering Spirit are identified in chapter 2. In this chapter the boundaries of the vessel are described to be able to make a distinction in the platform database which platforms the vessel cannot handle.

With the boundaries of the vessel set in the performance limiting factors, the database of the market can be compared with these limitations to generate the potential market in chapter 3. The database will be examined for every platform property which will be limited by the vessel. The extend of the modification will be based on the group of platforms the vessel is not capable to decommission.

Chapter 4 will discuss the exploration of viable modification concepts. For every limiting factor a modification concept will be proposed to extend the capabilities of the vessel. The non-feasible modifications are eliminated with respect to the practicability and an indication of the modification costs. The modifications are first described on a basic level including a description of the implementation procedure. Based on this basic outline, the required equipment and changes to the vessel are specified for each modification, which are of importance for the complete cost of the modification. To provide a clear understanding of the effect, and later also costs, of a modification, a modification concept will be restricted to extend the limitations of the vessel for only one platform property at the time. In the cost-benefit comparison, all viable modification concepts will be combined into a complete modification.

The detailed analysis of each viable modification concept, chapter 5, will be performed based on four items:

- Additional equipment
- Hull blocks for changes to the size of the hull
- Structural integrity
- Duration of modification

The additional weight of the structure and the hull will be determined using a software tool of Allseas, the Loading Control Tool. This tool calculates acting bending moments and contains a detailed weight distribution of the hull and all tanks within the vessel.

The next step to find the most cost effective modification will be to define all costs of a modification and the vessel in chapter 6. The costs are divided into two categories: costs which apply to all modifications and modification specific costs. Both these categories are divided into direct costs and running costs. The direct cost are the total costs until the vessel will be operational again. The running costs are the daily expenses to operate the vessel and in case of the modification, also the daily costs involved with the modification.

The final step, performed in chapter 7, is to estimate the income from the potential market for the modified vessel. Then all the costs and revenue together form the profit of the modification. The optimal point for the modifications will be determined by return on investment and the financial performance. In case the return on investment is equal for multiple modifications, the performance will also be based on the financial result of the modification.

Chapter 8 describes a sensitivity study performed to identify the influence of the assumed input parameters. Closing, chapter 9 contains the conclusions and discussion of the research, while chapter 10 provides some recommendations.

2. Performance limiting factors of the Pioneering Spirit

In this chapter, the performance limiting factors of the Pioneering Spirit, regarding topside lifting will be identified. The maximum values of these factors are used in chapter 3.2, in order to determine the group of platforms the vessel is not able to lift.

The performance limiting factors are the vessel properties which are limiting the vessel to lift all topsides. These factors are related to the topside properties, like: topside weight, topside- and substructure length, substructure width, air gap (Figure 0-1) and water depth. All performance limitations will be expressed in terms of these topside properties in order to obtain a better insight into which limiting factor prohibits the current PS from decommissioning a specific platform.

In this chapter the following performance limiting factors of the vessel are discussed:

- Topside Lifting System (TLS) (paragraph 2.1)
- Slot- and TLS rail length (paragraph 2.2)
- Slot width (paragraph 2.3)
- Draught (paragraph 2.4)
- Length position of deckhouse (paragraph 2.5)
- Vessel structure (paragraph 2.6)
- Vessel motions (paragraph 2.7)

The details of the relations with the topside properties will be discussed in the paragraphs concerning the performance limiting factors. Figure 2-1 gives an overview of the relations between the performance limiting factors and the topside properties.

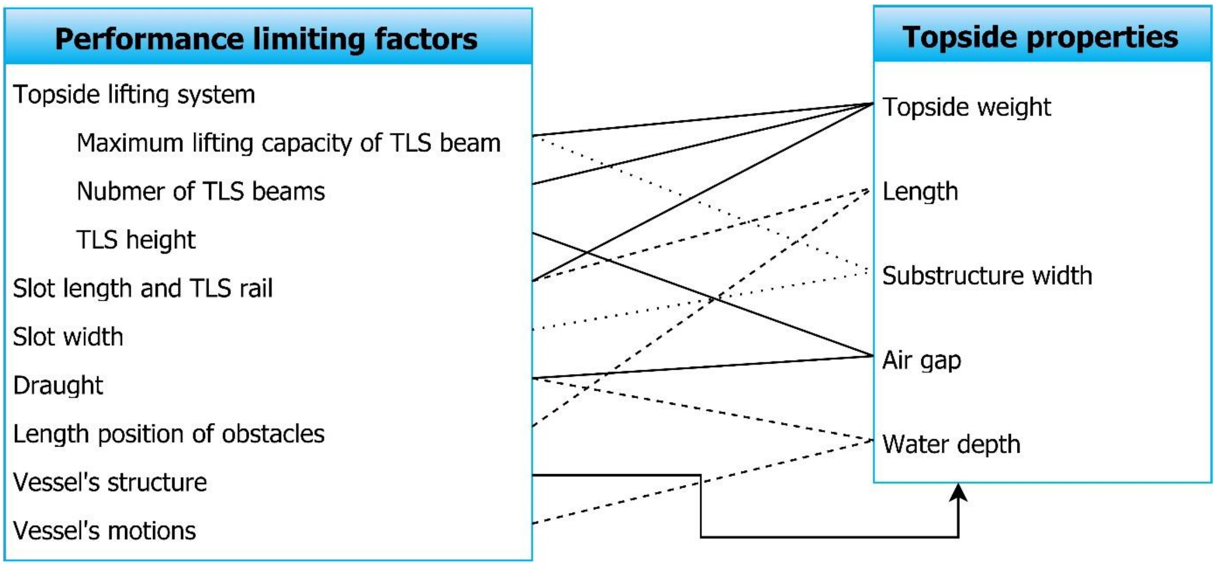


Figure 2-1: Relation between performance limiting factors and topside properties

2.1. Topside lifting system

The TLS is located at the bows of the vessel. These lifting beams enable the PS to decommission and install topsides and at the same time compensate for the vessel motions. The TLS system consists of 16 lifting beams. A coupled set of lifting beams is called a forklift unit. In Figure 2-2 an example of two units is shown. The beams have a length of 65m and are about 6m wide. The system is able to compensate, all the motions of the vessel; by riding on the TLS rails, extending or withdrawing the beam and moving the red lifting lever up and down.

Currently, 12 beams are built and installed in the first half of 2015. The remainder four beams are different, also to improve the maximum lifting load. They will be longer and stronger than the existing beams. More detailed information is not available at this moment, because Allseas is currently still working on these beams.

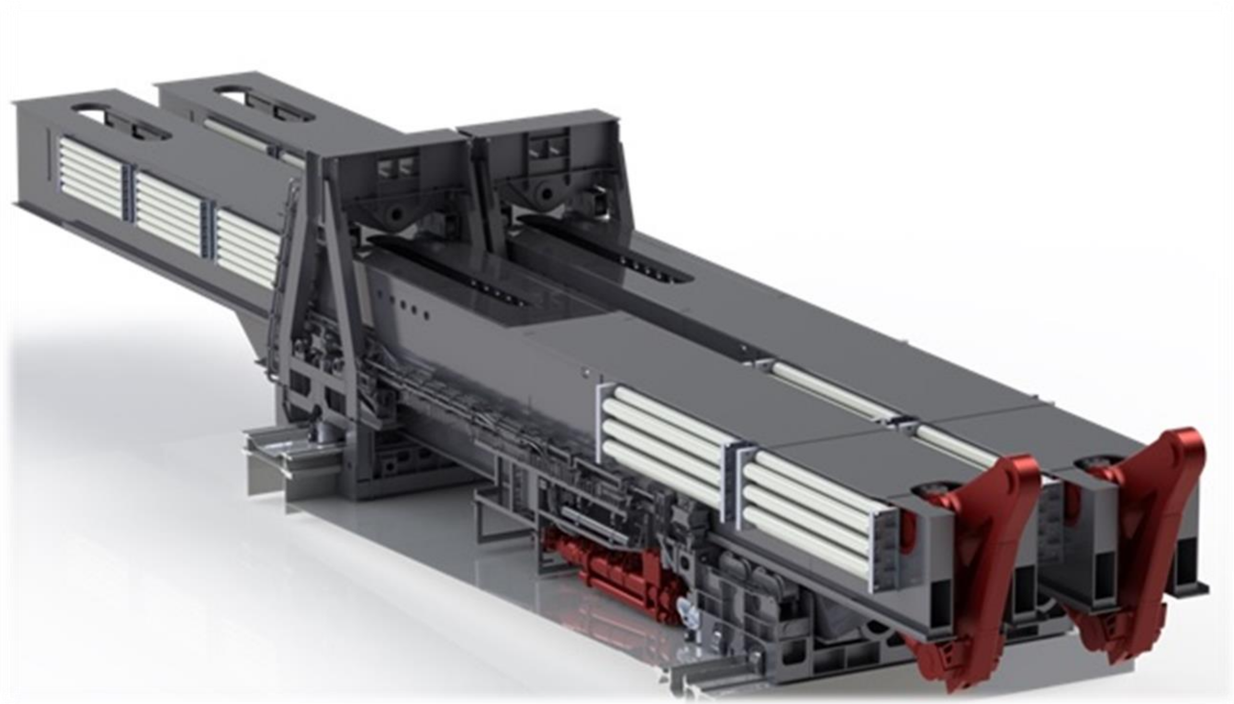


Figure 2-2: Render of topside lifting system

The document "TOPSIDES LIFT SYSTEM – TECHNICAL & FUNCTIONAL DESCRIPTION (TFD)" (Emmerik & Kuiper, 2015) can be consulted for the complete understanding of all components of the TLS.

In this thesis we will focus on three aspects of this system; the maximum lifting capacity, the number of Topside Lifting System beams and the height of the beams. These three aspects characterize the lifting capability range of the lifting system.

2.1.1. Maximum lifting capacity of TLS beam

All the TLS lifting beams combined have a theoretical lifting capacity of 48,000 tonnes. This lifting capacity only applies under the ideal circumstances, such as no wind and no motions of the vessel. In reality, this lifting capacity is reduced, amongst others by the accelerations of the vessel and wind force on the topside, to a total lifting capacity of 30,000 tonnes or 1,875 tonnes per beam (Soetens, 2014). The ideal circumstances almost never occur, therefore during this report, the dynamic maximum lifting capacity of 30,000 tonnes will be used.

The structure of the beam is able to withstand a certain maximum bending moment. Therefore the maximum load at the tip of the beam is related to the outreach of the beam (Soetens, 2014). The TLS beams can lift their maximum capacity from an outreach (Figure 2-7) of 4.723m up to 18.600m in lifting mode, after this point the lifting capacity drops to about 40% of the maximum lifting capacity on a full outreach of 25.373m. Below the minimum outreach the lifting beam cannot lift any load. The load curve of a single beam, as a function of the outreach, is defined in Figure 2-3. The data is based on the information of the document "TLS – System Load Curve (Soetens, 2014). The outreach of the beam is defined as the distance from the IBS to the hinge of the TLS beam. The IBS is the last supporting system of the TLS beam on the vessel. Figure 2-5 and Figure 2-7 provide a graphical reproduction of the IBS and the length of the outreach.

The outreach of the lifting beams is dependent on the platform's substructure location. The topsides have different substructure formations, but in general the most likely location of the strongest structure is between the substructure's pillars. Therefore the outreach is taken to the centreline of the substructure's pillar.

The width of the substructure and the outreach are related to each other, this means that the load curve can also be expressed in relation to the substructure width. This relation is defined in Equation 2-1. The system can lift topsides at its full capacity from a substructure width of 26.16m up to the maximum allowable width (2.3). When the substructure is smaller, the load drops to about 40% of the maximum capacity at a substructure width of 12.62m. The load curve of a single beam, as a function of the substructure width, is displayed in Figure 2-3.

$$Outreach = \left(\frac{slot\ width}{2} + IBS\ to\ inner\ slot - \frac{pillar\ width}{2}\right) \quad \text{Equation 2-1}$$

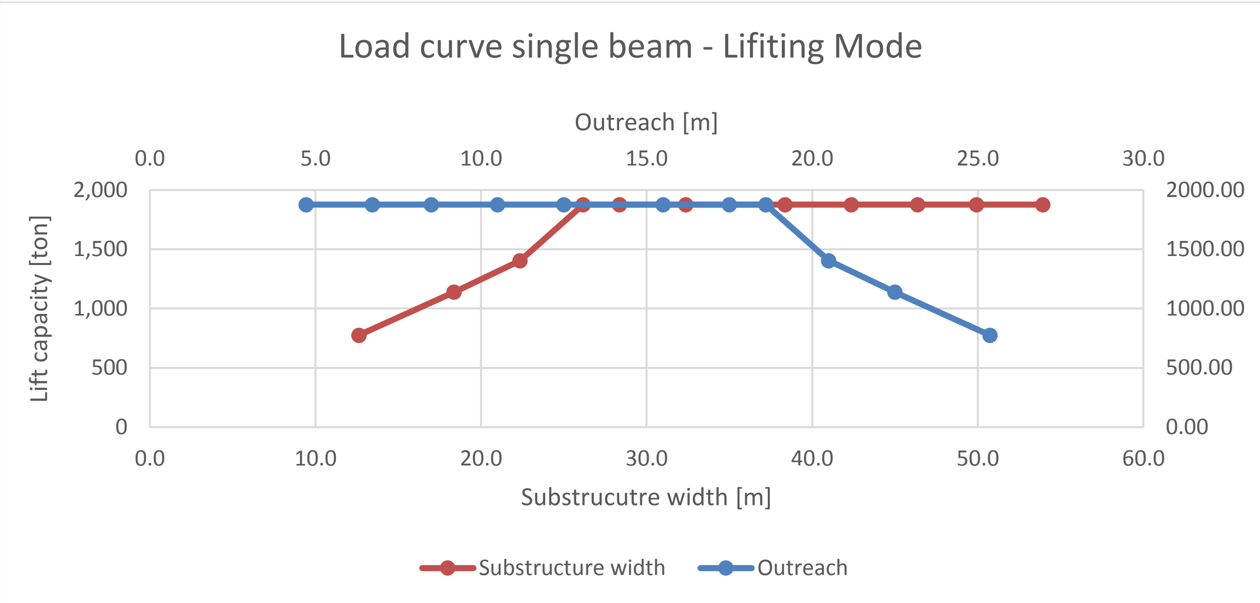


Figure 2-3: Load curve

The lifting capacity starts at 1,875 tonnes with a minimum outreach, after which the capacity decreases by the increase of the outreach. The lifting capacity increases for an increase in substructure width.

2.1.2. Number of Topside Lifting System beams

The total number of lifting beams is a limiting factor for the total lifting capacity. In total 16 beams will be installed on-board of the vessel. Allseas is currently redesigning the last four beams, due to lack of information about the new beams, for the remainder of this thesis all beam will be assumed to be similar to the original 12 beams. As mentioned before, the dynamic lifting capacity of a single beam is limited to 1,875 tonnes. The maximum lifting capacity of the system for a specific configuration is defined by the load curve and the dynamic lifting capacity.

Assuming a uniform load, the maximum combined lifting capacity is 30,000 tonnes.

2.1.3. TLS height

The TLS height is part of the total height, required to be moved under the topside. This “air gap” under these topsides can be too high or too low for the vessel to cope with.

The height is dependent on the lifting method. To lift, the system uses yokes and friction clamps, see Figure 2-4 and Figure B-6. These parts are both installed on the lifting levers of two lifting beams. The friction clamps can only be used for platforms with legs up to a diameter of 2.25m (Kuiper, 2014). Use of the yokes allows for removal of, for instance, gravity based structures. The minimum lifting height is higher with the use of yokes rather than the friction clamps. This restriction will be taken into account when determining the group of platforms the vessel is not able to lift.

The minimum height of a clamp is 9.5m above the deck line and a yoke rises 11.5m above the deck line, a section of these heights are depicted in Figure 2-5. The TLS height is not a self-contained limitation, these heights will be used to determine the minimum and maximum air gap in chapter 2.8.

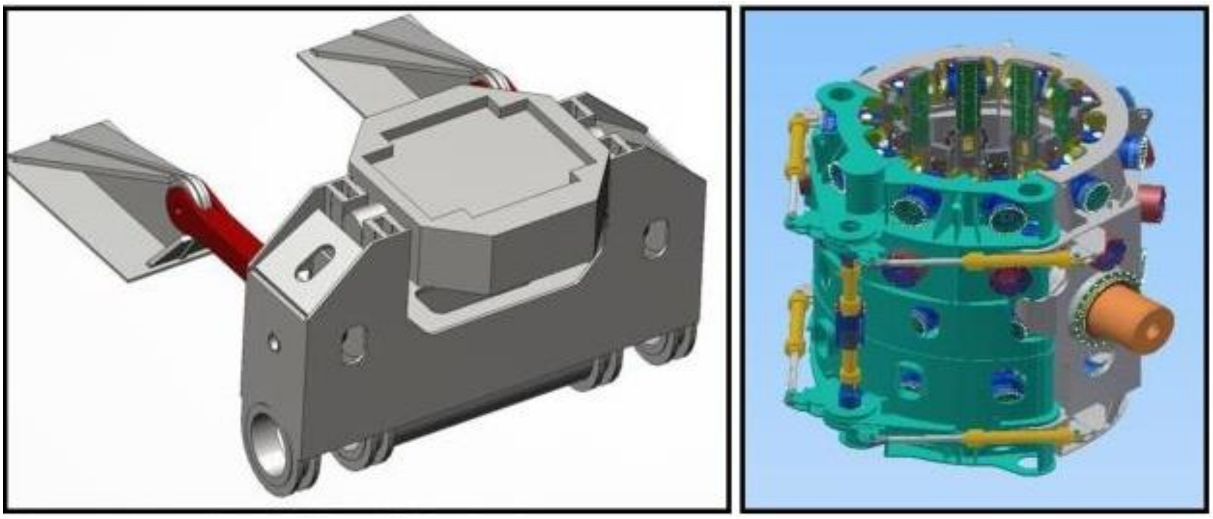


Figure 2-4: Yoke and friction clamp - (Emmerik & Kuiper, 2015)

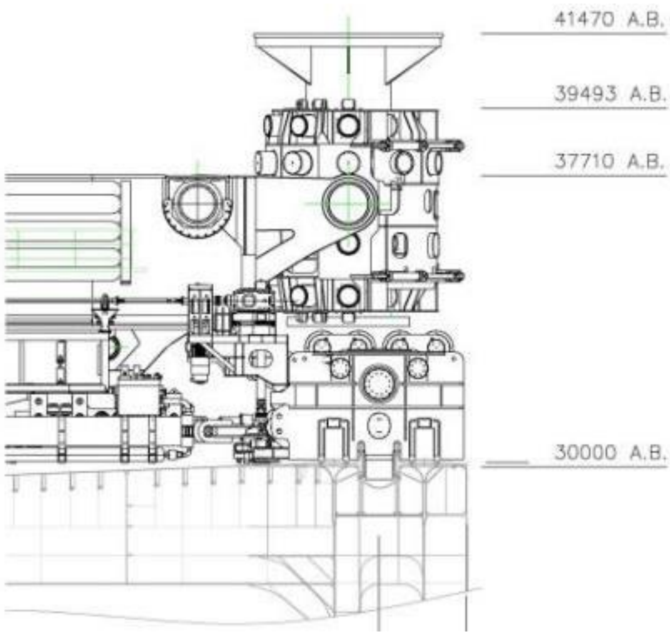


Figure 2-5: Height of TLS (Allseas, 2015)

2.2. Slot length and TLS rail

The length of the slot and the TLS rail are highly related to each other. Therefore these two will be discussed together.

The slot length is related to the sub-structure length due to the length of the TLS rails. The topside has to be supported by the TLS and needs to be positioned at the strongest points of the topside. As discussed in 2.1.3, this is near the substructure piles for gravity based structures. For piled structures, these topside will be lifted by their piles.

The rail length is related to the substructure length by the TLS lifting beams. To define the maximum substructure length, the limitations of the system are based on the technical and functional description of the TLS (Emmerik & Kuiper, 2015). The maximum substructure length can be characterized by the following two criteria:

- Piled substructures – For piled structures, the distance between the centres of the piles, from now on referred as the centre to centre length of the substructure, may not exceed the maximum TLS centre to centre offset between fore and aft clamps. Otherwise the substructure is to long for the system. In Equation 2-2 the maximum length for piled substructures is defined.

$$\begin{aligned} &Maximum\ Centre\ to\ centre\ length\ substurcture \\ &= \ Max\ TLS\ offset = 80.6m \end{aligned} \quad \text{Equation 2-2}$$

- Other substructures – For all other substructures the lift will be carried out with yokes. To distribute the load evenly, there has to be a yoke lifting point fore and aft of the pillars. Therefore the maximum substructure length is the defined by the maximum distance between the centres of the clamps, from now on referred as the TLS centre to centre offset, minus the two times the TLS lifting beam width. In Equation 2-3 the maximum length for other than piled substructures is defined.

$$\begin{aligned} &Maximum\ substructure\ lenght \\ &= max\ TLS\ offset - 2 \cdot TLS\ width \\ &= 80.6 - 2 * 6.1 = 68.4m \end{aligned} \quad \text{Equation 2-3}$$

The mapping of the TLS rail is graphically pictured in Figure 2-6.

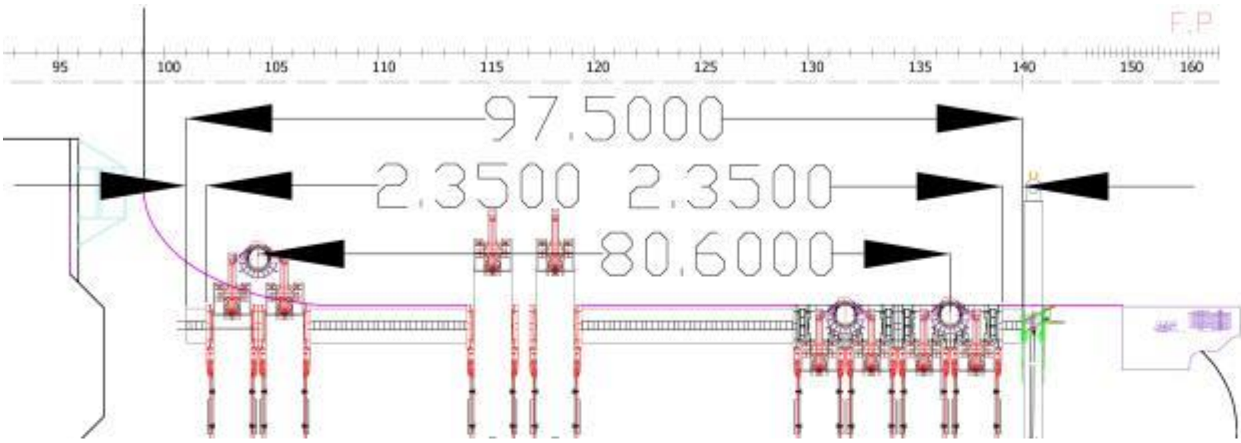


Figure 2-6: TLS length restrictions

The topsides rises above the TLS beams, therefore there would be no direct relation between the topside length and the slot length. Although, the maximum liftable topside length is, without hitting any obstacles on the PS, limited by the maximum offset between the fore and aft TLS lifting beam plus the maximum unsupported length the structure of the topside can handle. The maximum offset is limited by the rail length, while the rail length is limited to the length of the slot.

With an evenly distributed weight and an evenly distributed load on the TLS, the maximum unsupported length is calculated by Equation 2-4.

$$Max\ unsupported\ length = \frac{\left(\frac{\frac{max\ TLS\ offset}{No.TLS\ forklifts} - 1}{2}\right)}{2} \approx 13.45m \qquad \text{Equation 2-4}$$

The maximum topside length may not exceed the maximum TLS offset plus two times the maximum unsupported length, which results in a maximum topside length ~107.5m.

2.3. Slot width

The slot width of the vessel limits only the width of the substructure of the platform, since the topside itself will rise above the TLS beams. There are two types of width restriction; the first restriction is that the substructure has to physically be able to fit in the slot of the PS, taking into account the margin between the vessel and the substructure. The second restriction deals with the minimum outreach of the TLS before they can take any loads.

All the required dimensions are provided in Table 1-1, some of these dimensions are graphically represented in Figure 2-7. The width restriction is calculated by Equation 2-5.

$$Max\ extreme\ pillar\ width = slot\ width - 2 \cdot margin = 53.35m \qquad \text{Equation 2-5}$$

The second restriction only applies if the clamps are used. The minimum required outreach of the TLS beams and the safety margin, defines the maximum centre to centre width of the substructure (Figure 2-7). The minimum outreach of the lifting beam, including the margin is calculated by Equation 2-6. The required dimensions are also provided in Table 1-1.

$$Max\ center\ to\ center\ pillar\ width = slot\ width + 2 \cdot IBS\ to\ inner\ slot - 2 \cdot (minmum\ outreach + margin) \approx 48.52m \qquad \text{Equation 2-6}$$

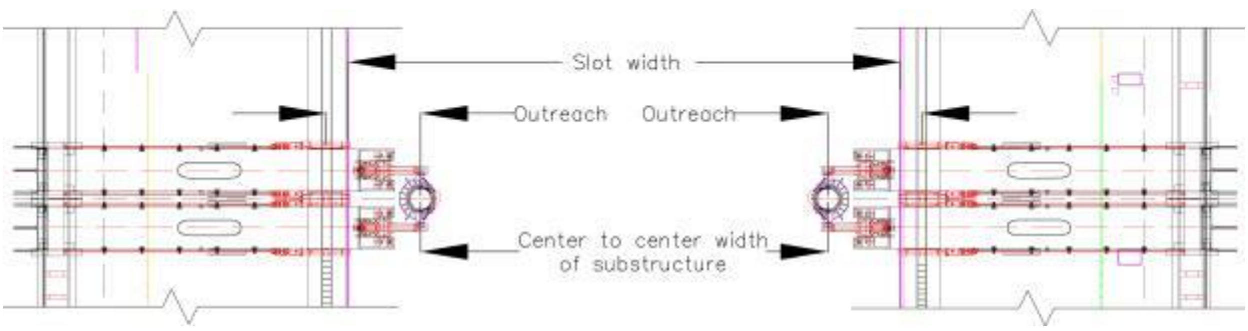


Figure 2-7: Top view of TLS

Description	Value
Slot width	58.75 m
Minimum outreach from inner slot	2.416 m
Safety margin to jacket	2.700 m
IBS to inside vessels slot	2.307 m

Table 2-1: General width information - (Soetens, 2015)

A completely different group of platforms, which are in a way limited by the width of the slot, are the low air gap platforms. These platforms requires the slot to be wide enough to provide enough width for the complete topside plus an additional structure to lift the topside. This would give the vessel the opportunity to decommission platforms which have an air gap too low to fit under. An example is sketched in Figure 2-8.

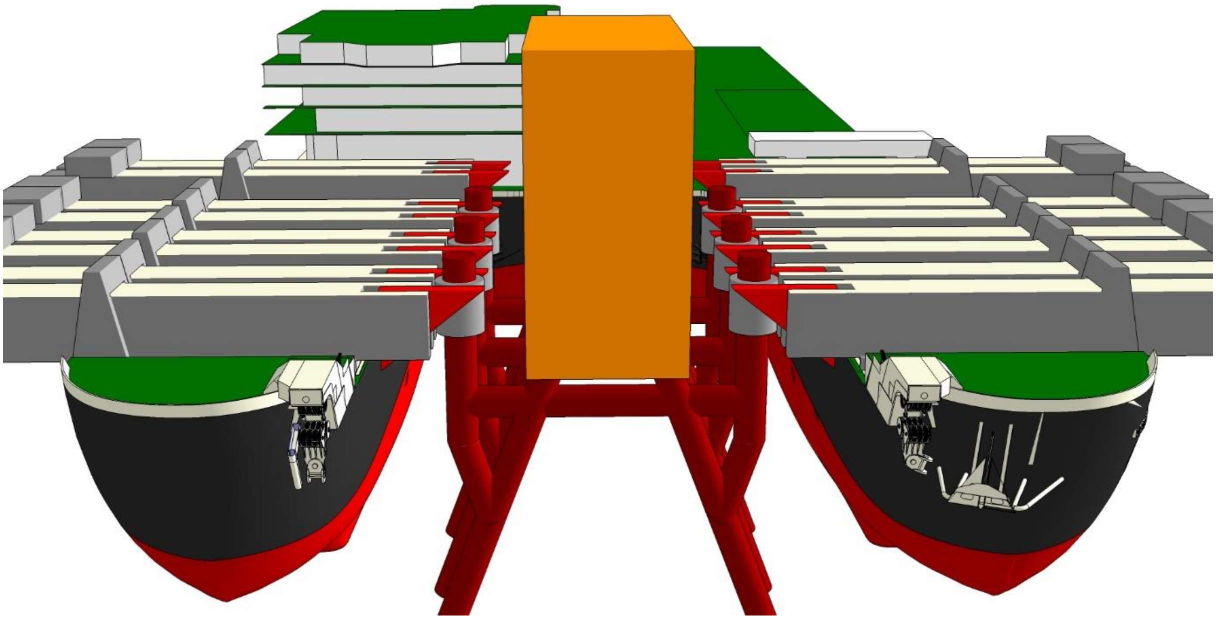


Figure 2-8: Lifting of a low air gap topside

The maximum width of these topsides, including lifting structure, may not exceed the maximum extreme pillar width as described in Equation 2-7. The additional structure is based on a pipe of 2m in diameter, which is 1m outward of the topside itself.

$$Max\ topside\ width = slot\ width - 2 \cdot margin - 2 \cdot additional\ structure = 47.35m \quad \text{Equation 2-7}$$

2.4. Draught

The minimum draught of the vessel is limited when the vessel is operating in shallow waters. The draught of the vessel is dependent on the topside weight and the use of ballast water. The use of ballast water is needed to reduce the bending moments and shear forces in the vessel.

To obtain the minimum draught of the vessel in all topside loading conditions, four scenarios with different topside loads are examined. These corresponding minimum draughts are obtained by the Loading Condition Tool (LCT, Appendix H) for these topside loads. The precondition in this case was that the structure may not be overloaded. The output from the LCT is given in Appendix D. An empirical formula can be generated from these loading conditions, this formula is represented in Equation 2-8.

$$D = 1.3 \cdot 10^{-4} \cdot Topside\ weight + 10.8 \qquad \text{Equation 2-8}$$

Although the draught is the most important value to estimate the minimum water depth, there are more properties influencing the water depth. The absolute minimum water depth is determined in chapter 2.8.

2.5. Length position of obstacles

Directly at the aft of the TLS rail, large items are placed. A crane on portside and the accommodation on the starboard side are directly at the aft of the slot. Of these two, the accommodation is the less (re)movable object. This obstructs long topsides to protrude backwards and limits the maximum topside length. Since the accommodation cannot compensate for the surge motion, the minimum margin between the accommodation and the topside is equal to the maximum distance the TLS can compensate for in surge motion of the vessel (2.1). The accommodation is located 9.5m aft of the TLS rail. With the dimensions from Figure 2-6, the accommodation is located about 18m aft of the lifting position of the most aft positioned lifting beam. The minimum distance between the accommodation and the topside is 3.35m. This contains the maximum longitudinal freedom of the TLS on the rails of 2.35m to compensate for the vessel motion and an additional margin of 1m. This leaves a maximum protruding topside length of 14.60m. To distribute the load evenly, the same length will protrude at the fore end of the TLS.

The maximum topside length, defined by the protruding parts and the maximum TLS offset (Equation 2-2) may not exceed 109.80m. In Figure 2-9 the dimensions are graphically presented.

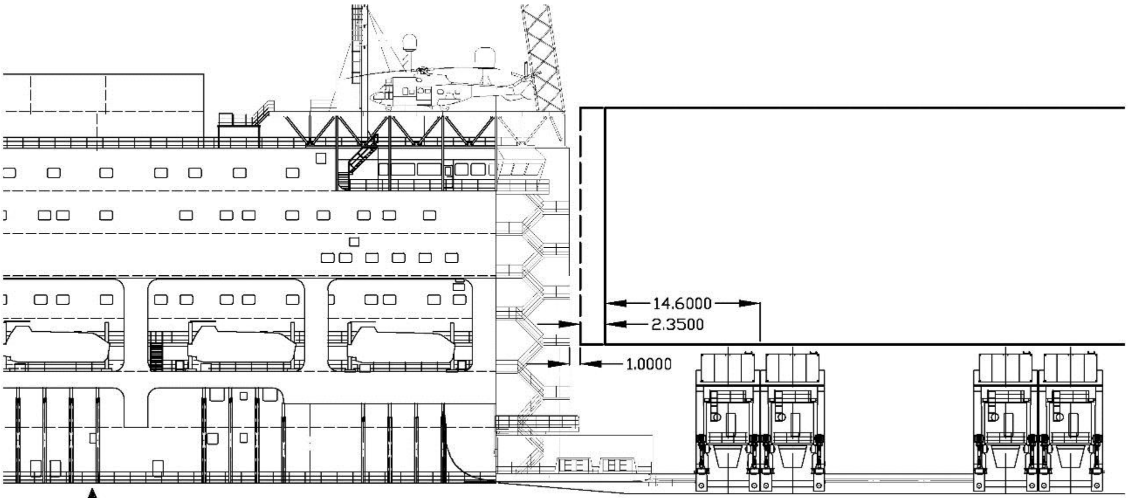


Figure 2-9: Maximum topside length due to obstacles

At this moment the maximum unsupported length of a topside is limited to only 13.45m (Equation 2-5). In case the maximum unsupported length is increased, the maximum distance to the accommodation need to be taken into account.

2.6. Vessel's structure

The maximum allowable stresses in the structure may not be exceeded. While the structure of the vessel is not a limitation for the current vessel, the stresses are almost at their maximum values. Without getting into a high level of detail, the following structural components are taken into account during this project:

- Longitudinal strength
  - Longitudinal bending moment
  - Longitudinal shear stress
- Transverse strength
  - Transverse bending moment
  - Transverse shear stress
- Torque in vessel's bows

The torque, caused by the lifting beams, at the bow of the vessel is a highly limiting factor and is already critical for the most heavy topsides. The values of these stresses will be determined by the Loading condition Tool (LCT, Appendix H).

2.7. Vessel's motions

The vessel is subjected to motions due to waves. The TLS is able to compensate for heave motions by moving the tip of the lifting beam up and down. All items fixed to the vessel, as the TLS beam itself, are still moved by the wave motions. The vessel itself is able to compensate for the surge, sway and yaw motions by its propulsion system, which only leaves the heave, roll and pitch motion of all items fixed to the vessel uncompensated. These three motions can be merged into a heave motion at a specific point on the vessel. This heave motion is of influence on the minimum keel clearance and the minimum clearance between the lifting beams and the topside. The specific roll and pitch motions are not required for this assessment.

For this project, the removal/installation operation will be used to calculate the motions. This operation is considered to be most the severe condition in the topside lifting sequence. The operation conditions are limited to a significant wave height (H_z) of 2.5m with a wave period (T_s) of 6 seconds. More allowable environmental conditions during this operation are stated in the Basis of Design of the vessel (Berg, 2010).

The maximum combined heave motion is located at the maximum forward position of the TLS beams, this is about the same longitudinal position as the forward thruster. This position is obtained by checking multiple locations on the vessel with Ansys – Aqwa (Ansys, 2016). This software uses the hull-shape and wave motion to calculate the motions of the vessel. In Appendix E the motions of all checked locations are presented. The Y-location is taken at the position of the OutBoard Support (OBS). The OBS structure is the highest point, but it is not likely that the system is able to lift such wide topsides because of the unsupported width of the topsides. Therefore the Z-location will be the height of the TLS beam itself (Figure 2-5). This is the highest not heave compensated object, relevant for topside lifting.

The heave amplitude is dependent on the wave. Since this project is focussed at the time the vessel is lifting the topside, the maximum prescribed wave condition for this procedure will be used to calculate the heave motion. According to this software the maximum heave amplitude is 1.57m at the specified location.

Position	Measured from	Location
Length	Frame 0	350.5m
Width	Centre line	60.4m
Height	Keel	38.0m

Table 2-2: Heave location

2.8. Air gap limitation

The ability of the vessel to lift a topside with a certain air gap is dependent on the depth and draught of the vessel and the height of the lifting beams. There are two types of limitations for the air gap of the platform, the air gap can be too large or too small. Both of these limitations will be assessed.

2.8.1. Minimum air gap limitation

The minimum air gap limitation is a combination of the depth of the vessel (Table 1-1), the height of the TLS (2.1.3), the maximum draught of the vessel (Table 1-1), and the vessel motions (2.7). This leaves a minimum air gap of 15.1m for lifting with clamps and 17.1m for lifting wit yokes, taking 1.0m margin into account when the vessel is manoeuvring under the topside. In Table 2-3 an overview of these items is listed.

Description	Clamp (m)	Yoke (m)
Depth	30.0	30.0
Height of TLS	9.5	11.5
Maximum draught	-27.0	-27.0
Vessel wave motion	1.6	1.6
Height margin	1.0	1.0
Minimum air gap	**15.1**	**17.1**

Table 2-3: Minimum air gap limitation

2.8.2. Maximum air gap limitation

The maximum air gap depends on the topside weight, the depth of the vessel (Table 1-1), the height of the TLS (2.1.3) and the minimum draught of the vessel (2.4). The topside weight, based on the database with a maximum air gap limitation, ranges from 22,000 up to 52,000 tonnes. An indication for the relation between the topside weight and the minimum draught of the vessel is given in Equation 2-8. In Table 2-4 an overview of these items is listed, for the case the topside is lifted with yokes.

Description	22,000 Tonne topside	52,000 Tonne topside
Depth	30.0m	30.0m
Height of TLS (yokes)	11.5	11.5
Minimum draught	-13.70m	-17.60m
Minimum clearance for lifting of topside	-2.0m	-2.0m
Maximum air gap	**25.8m**	**21.9m**

Table 2-4: Maximum air gap limitation – lifting with Yokes

The draught function is a linear function, this indicates that the maximum air gap will also be a linear function. In Equation 2-9 the function is provided which gives the maximum air gap, depending on the topside weight.

Yoke $$Max\ air\ gap = 28.7 - 1.3 \cdot 10^{-4} \cdot topside\ weight$$ Equation 2-9

The maximum air gap limitation is not applicable when the topside is lifted with clamps. The system can also lift piled topsides by their piles several meters below the bottom of the topside itself. For this project we assume that the maximum air gap for clamps is unlimited. In reality, this could lead to stability issues of the vessel. This is however not included in this research.

2.9. Minimum water depth

The minimum air gap limitation is a combination of the draught of the vessel (2.4) and the vessel motions (2.7). In Table 2-5 an overview of these items is listed.

Description	[m]
Topside weight and the corresponding draft	$1.3 \cdot 10^{-4} \cdot topside\ weight + 10.795$
Additional draft to manoeuvre under the topside	2.0
Vessel motions	1.6
Minimum keel clearance	5.0

Table 2-5: Water depth

The minimum keel clearance is an additional water depth below the keel for phenomena that are not included in the above components. This water depth is required for, for instance, suction forces. Due to the higher velocities of the water under the vessel, the water pressure will drop. This will draw the vessel to the seabed and increases the draught. Also when the propeller is near the seabed, the high water velocities can damage the seabed. The low keel clearance also has a second downside concerning the interaction with the sea bed. The propellers mix the loose sand and mud of the sea bed with the water, this mixture flows through the propellers and leads to faster wear of the propellers.

Information about minimum required keel clearance for this vessel was not directly available, therefore a minimum required keel clearance of 5m is assumed.

The draught function is a linear function, this indicates that the minimum water depth will also be a linear function. In Equation 2-10 the function is provided which gives the minimum required water depth, depending on the topside weight.

$$Minimum\ water\ dept = 1.3 \cdot 10^{-4} \cdot topside\ weight + 19.4 \qquad \text{Equation 2-10}$$

2.10. Summary

This chapter started with the five topside properties; topside weight, topside length, substructure width, air gap and water depth. Based on the interaction of the topsides with the vessel, the performance limiting factors of the vessel are identified. In Table 2-6, the complete overview of the limitations of the performance limiting factors, related to the topside properties, are provided.

Topside property	Limitation	Performance limiting factor
Weight	Load curve 30.000 tonnes with 16 beams	Topside lifting system Topside lifting system / structure
Length	For use with clamps / piled structures the maximum centre to centre length of substructure is 80.6m	Slot length / rail length
	For use with yokes / gravity based structures the maximum overall length of substructure is 68.4m	Slot length / rail length
	The maximum topside length is 107.5m The topside may not protrude more than 14.60m aft wards	Slot length / rail length / TLS Length position of obstacles / structure
Width	Yokes – The maximum width overall inside the slot is 53.35m	Slot width / structure
	Clamps – The maximum centre to centre width of the substructure is 48.52m	Slot width / structure
Air gap	Clamp: $Min.\,air\ gap = 15.1(m)$ $Max.\,air\ gap = non\ applicable$ Yoke: $Min.\,air\ gap = 17.1\ (m)$ $Max.\,air\ gap = 28.7 - 1.3 \cdot 10^{-4} \cdot topside\ weight\ (m)$	Vessel's dimensions Vessel's draught / structure Topside lifting system Vessel's motions
Water depth	Minimum water depth: $1.3 \cdot 10^{-4} \cdot topside\ weight + 19.4$	Vessel's draught / structure Vessel's motions

Table 2-6: Overview of limitations

These limitations will be used in chapter 3 to identify the group of platforms which cannot be lifted by the PS. This group of platforms forms the potential market for the modified vessel. This potential market will generate the revenue for the modification. The revenue is a parameter to estimate the performance of the modification.

3. Potential market

In this chapter, the market of oil and gas platforms will be mapped. The market used in this thesis is based on Allseas' platform database provided by Infield. Based on the information in this database, the potential market for the modified PS will be obtained. The chapter starts with a familiarization of the database, followed by categorizing the platforms of the database and applying the performance limiting factors.

The database will be divided into the five platform categories. For each of these categories the limitations caused by the performance limiting factors of the vessel will be applied. The platforms which do not comply with the limitations, are the platforms the vessel cannot remove. These platforms will form the potential market for the modified vessel. In a later stage this potential market will form the revenue in the financial comparison.

The market will be inventoried for every platform category by themselves. Instead of reviewing the complete market at once, this approach will create a more clear view on the market per category, in terms of number of platforms and their combined topside weight. Also the range to modify the vessel will be more clear when only one category is reviewed at once.

3.1. Platform database

The Allseas platform database contains 755 platforms positioned all around the world. This database is based on information from Infield and Allseas own additions (Infield, 2015). In this survey, only the platforms with a topside weight over 10,000 tonnes are taken into account. Allseas presumes that for topsides with a weight under 10,000 tonnes, the competition will be cheaper than the PS. In the complete database, only 193 platforms have a topside weight over 10,000 tonnes.

3.1.1. Database distribution

To get an understanding of the distribution of the topside weight in the database, Figure 3-1 presents the number of platform within a topside weight group.

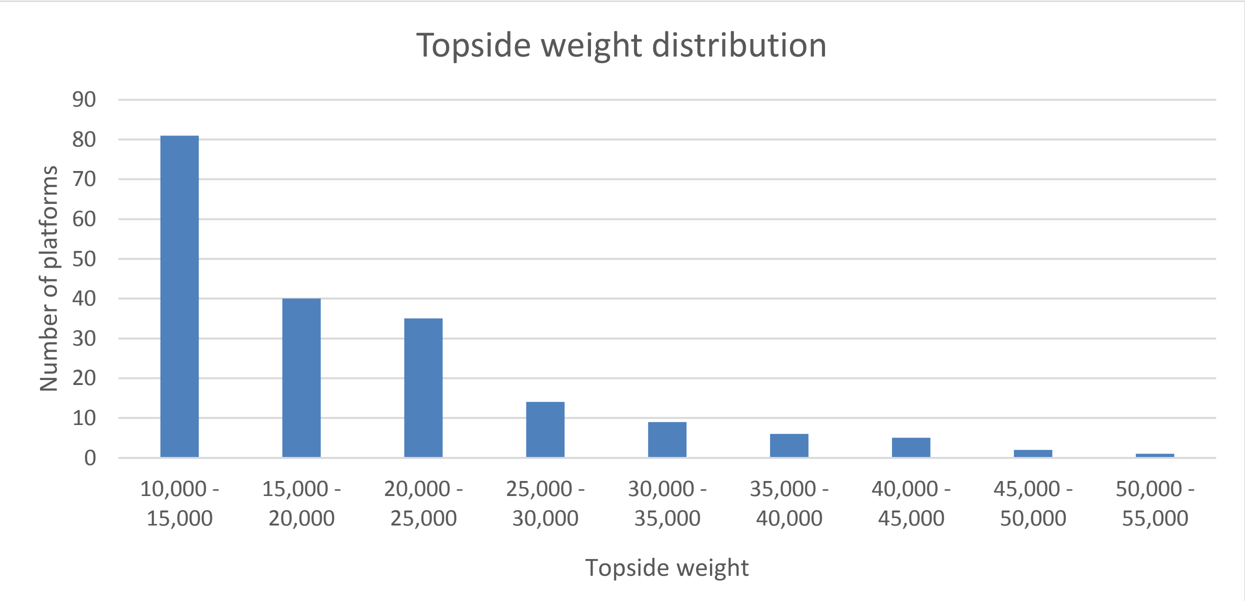


Figure 3-1: Platform weight distribution

The distribution of the platforms over the years of removal are presented in Figure 3-2. These platforms are also categorized by location, provided by the database.

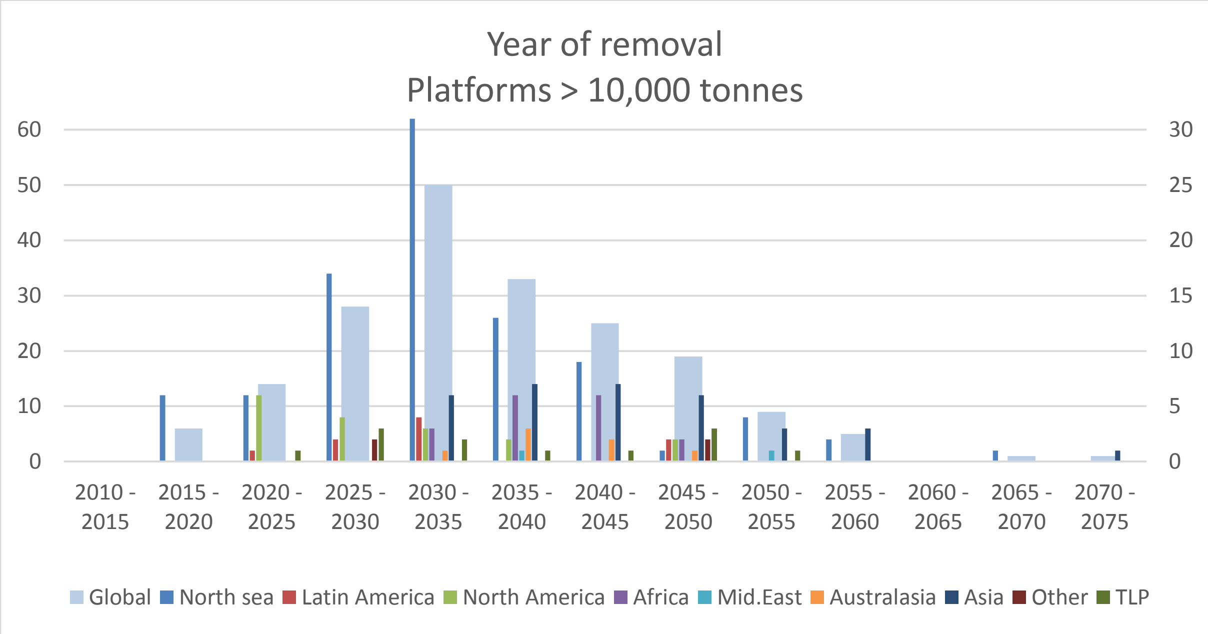


Figure 3-2: Year of removal

There would be no limitation on the year of removal due to the vessel's age. The PS is only recently built and the economic lifetime of the vessel is more important for the company than the age of the vessel. This sort of specialized vessels will last longer than cargo vessels in general, for instance the hull of Allseas Lorelay is built in 1974 (Scheepvaartwest, 2014), the Solitaire origins from 1972 (Wikipedia, 2015) and Heerema's Thialf is built in 1985 (Wikipedia, 2016).

3.1.2. Missing information

Unfortunately, the database does not contain all the necessary information. This lack of data makes it more difficult to make a statement about the number of platforms. For this project, only the information of the platforms which are related to the vessel are of importance. This information can be limited to the platform categories. The missing information of this database is listed in Table 3-1. The complete market with a topside weight of 10,000 tonnes and more, consists of 193 platforms.

Category	Sub group	No. known values	No. missing values
Weight		193	0
Length			
	Overall length topside	60	133
	Extreme length substructure	61	132
	Centre to centre length substructure	72	121
	Derivation of CTC from extreme length substructure	85	108
Width			
	Extreme width of substructure	61	132
	Centre to centre width of substructure	72	121
	Derivation of CTC from extreme width of substructure	85	108
Air gap		78	115
Water depth		192	1
	Overall missing items	**44.1% available**	**55.9% missing**

Table 3-1: Available information

The data also does not allow to predict the missing information, based on the provided information. This data can only be obtained by measuring the platforms in the field, or have drawings delivered by the platform owners. For this project the first option will be much too expensive, the second brings up confidentially problems. Platform owners are not open handed to provide this information for these basic studies. The same problem was experienced while initiating the building process of this vessel, the data is not freely accessible. Even the values of this database are not 100% reliable, for instance the topside weight can be different due to the adding of new systems or the replacement of old ones.

Using this database will bring along uncertainties about the total number of platforms which forms the potential market. Therefore, the sensitivity of the database will be looked into in chapter 8

3.2. Quantifying platforms per topside category

The potential market is defined as the group of platforms which the vessel is not able to remove. These platforms will generate an additional income for the modified vessel. To indicate the size of this market, the limiting values of the performance limiting factors are applied to the database. These limitations are divided into five topside categories;

- Topside weight paragraph 3.2.1
- Length paragraph 3.2.2
- Width paragraph 3.2.3
- Air gap paragraph 3.2.4
- Water depth paragraph 3.2.5

The groups of platforms, which form the potential market, are expressed in a number of platforms and total combined weight of these platforms. The revenue created by removing a topside will be estimated as an income per tonne topside weight, therefore the weight is an important figure. These two values will be used to establish the costs and revenue of this potential market.

3.2.1. Topside weight restricted platforms

The first property concerns the topside weight. The maximum liftable topside weight is dependent on the lift-curve of the lifting system (2.1.1) and the maximum lifting capacity, 30,000 tonnes with 16 beams, of the lifting system (2.1.2).

The weight of the topsides is assumed to be uniformly distributed over the length and width of the topside. The database does not contain any information about the location of the centre of gravity (CoG). An off-centre position of the CoG can influence multiple platform categories. The weight to be lifted by the TLS beams can be exceeded at one end of the platform and still have remaining lifting capacity on the other end. Or a topside which is in theory too long, can actually protrude more forward because one end of the platform has a low weight and does not need to be supported.

This assumption needs to be taken into account during further research to this topic, because it could influence the number of potential platforms suitable for decommissioning by the PS.

There are in total 25 platforms, with a combined weight of 844,883 tonnes, which do not comply with the weight restrictions. In Figure 3-3, an overview of these platforms, which are too heavy for the current vessel, is provided. The red dots are the number of platforms and the blue diamonds are representing the combined weight of the corresponding platforms.

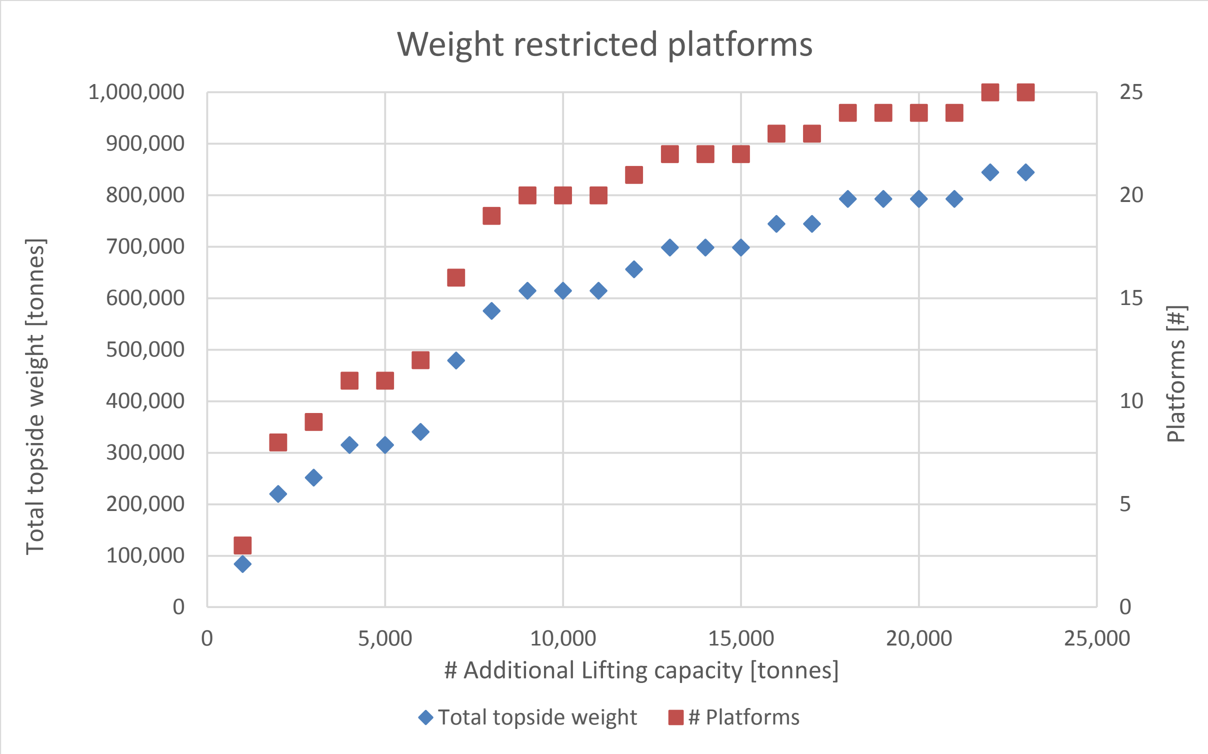


Figure 3-3: Potential market weight restricted platforms

This graph contains all platforms which are too heavy for the vessel. It can be concluded, that adding more lifting capacity than 22,000 tonnes does not add more potential topsides. The optimal point, based on this graph, is expected to be at 13,000 tonnes. Above this point, the number of platforms and their corresponding combined weight increases significantly slower.

These two values are the guidelines for the modification concepts. These concepts should be capable of adding a maximum of 22,000 tonnes lifting capacity, but the modification should at least be capable of adding about 13,000 tonnes.

3.2.2. Length restricted platforms

The second property concerns the maximum length of the platform. The length restriction does not only apply to the length of the topside, the length of the substructure is just as important. The maximum liftable topside length is dependent on the rail length (2.1) and the position of obstacles (2.5). The maximum liftable substructure length is dependent on the length of the rail and the slot length (2.1).

- For use with clamps / piled structures the maximum centre to centre length of substructure is 80.6m
- For use with yokes / gravity based structures the maximum overall length of substructure is 68.4m
- The maximum topside length is 107.5m
- The topside may not protrude more than 14.60m aft wards, measured from last TLS beam

The number of platforms, that do not comply with these criteria for the PS, is:

Centre to centre length of substructure	0	Equation 2-2
Extreme length substructure	5	Equation 2-3
Topside length	11	Equation 2-4

There are in total 12 individual platforms, with a combined weight of 415,249 tonnes, that do not comply with the length restrictions. In Figure 3-4 an overview of platforms, that are too long for the current vessel is provided.

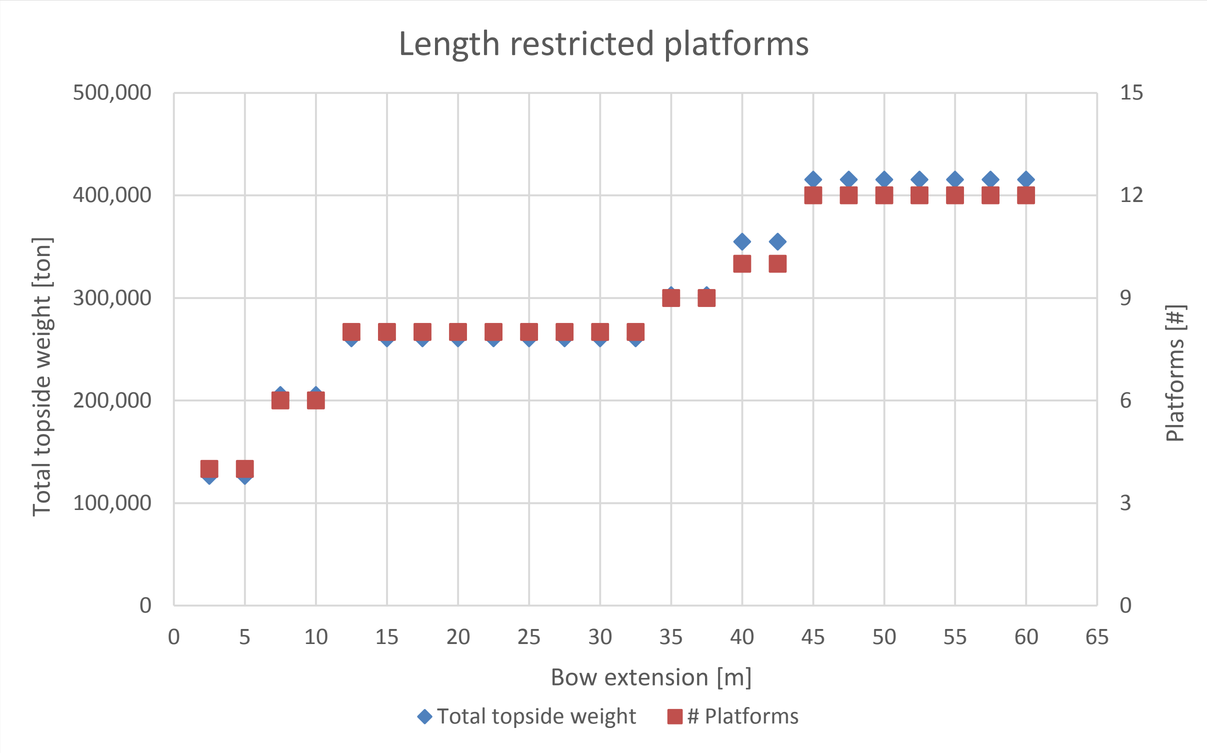


Figure 3-4: Potential market length restricted platforms

From this graph we can conclude, that increasing the length with more than 45m does not add more potential topsides. The optimal point, based on this graph, is expected to be at a length increase of 12.5m.

These two values are the guidelines for the modification concepts. These concepts should be capable of adding a maximum of 45 meters of length, but the modification should at least be capable of adding 12,5m of length.

3.2.3. Width restricted platforms

As there are no performance limiting factors influencing the width of the topside, this part will only look at the width of the substructures of the platforms. The maximum substructure width is dependent on the width of the slot (2.3) for both lifting types.

- Yokes – The maximum width overall inside the slot is 53.35m
- Clamps – The maximum centre to centre width of the substructure is 48.52m

The number of platforms, which do not comply with these criteria for the PS, is:

Based on extreme width of substructure, piled only	6	Equation 2-5
Based on centre to centre width of substructure	11	Equation 2-6

There are in total 13 individual platforms, with a combined weight of 413,520 tonnes, which do not comply with the width restrictions. In addition to this group, there are 6 platforms with a very low air gap. The combined weight of these platforms are 167,025 tonnes. In Figure 3-5, an overview of platforms, which are too wide for the current vessel, is provided.

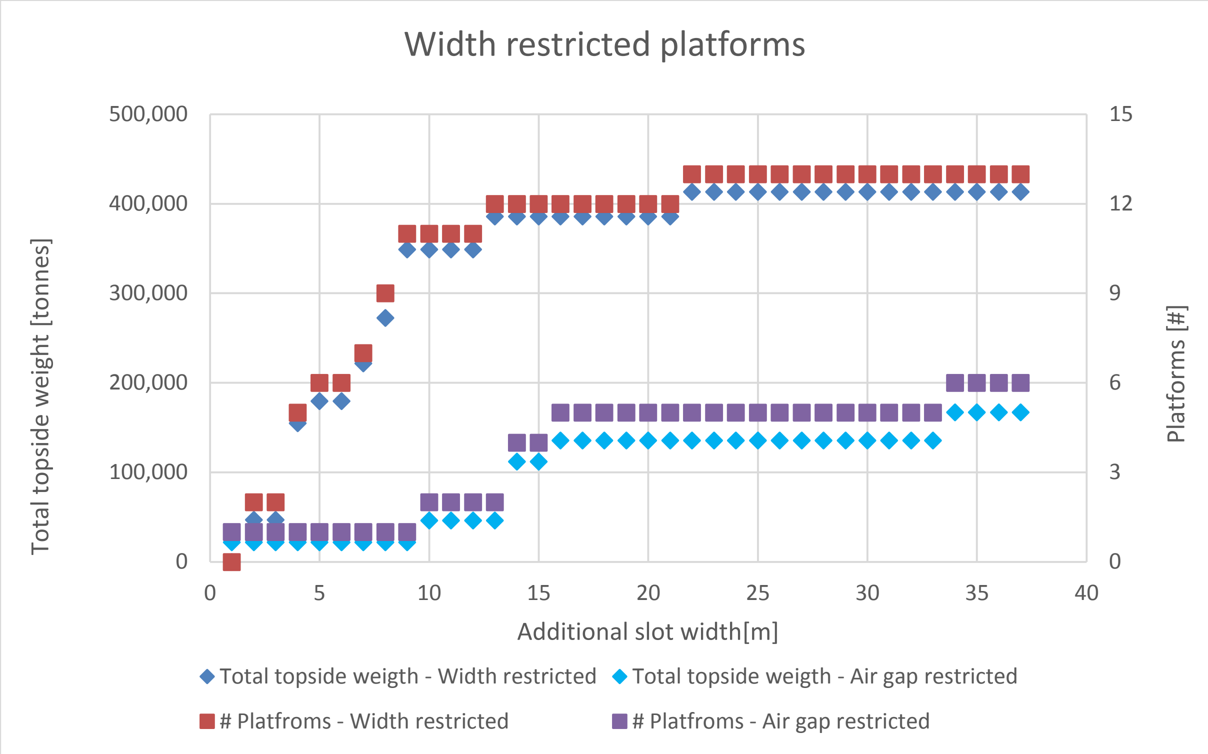


Figure 3-5: Potential market width restricted platforms

From this graph we can conclude, that with an increase of the vessel's width of 16m, most of the platforms are within the capabilities of the vessel. The last two platforms contain one extremely wide platform and one with a very low air gap with a wider topside.

It is assumed that widening the vessel to an extend where the PS can decommission even these two remaining platforms is not possible without affecting other capabilities of the vessel. For instance, during pipe-lay operations the stinger needs to be placed inside the slot, which won't be possible if the vessel becomes more than 16m wider.

3.2.4. Topside air gap restricted platforms

The air gap under the topside is dependent on the vessel's depth, the vessel's draught (2.4), the topside lifting system (2.1) and the vessel's motions (2.7). These performance limiting factors combined results in these restrictions:

- Clamps:

$$Min\ air\ gap = 15.1(m) \qquad \text{Equation 3-1}$$

$$Max\ air\ gap = unlimited \qquad \text{Equation 3-2}$$

- Yokes:

$$Min\ air\ gap = 17.1(m) \qquad \text{Equation 3-3}$$

$$Max\ air\ gap = 28.7 - 1.3 \cdot 10^{-4} \cdot topside\ weight \qquad \text{Equation 3-4}$$

The number of platforms that does not comply with these criteria for the PS is:

High air gap	10
Low air gap	6

There are in total 16 individual platforms, with a combined weight of 561,839 tonnes, that do not comply with the air gap restrictions. In Figure 3-6 an overview of platforms of which the air gap is not suitable for the current vessel is provided.

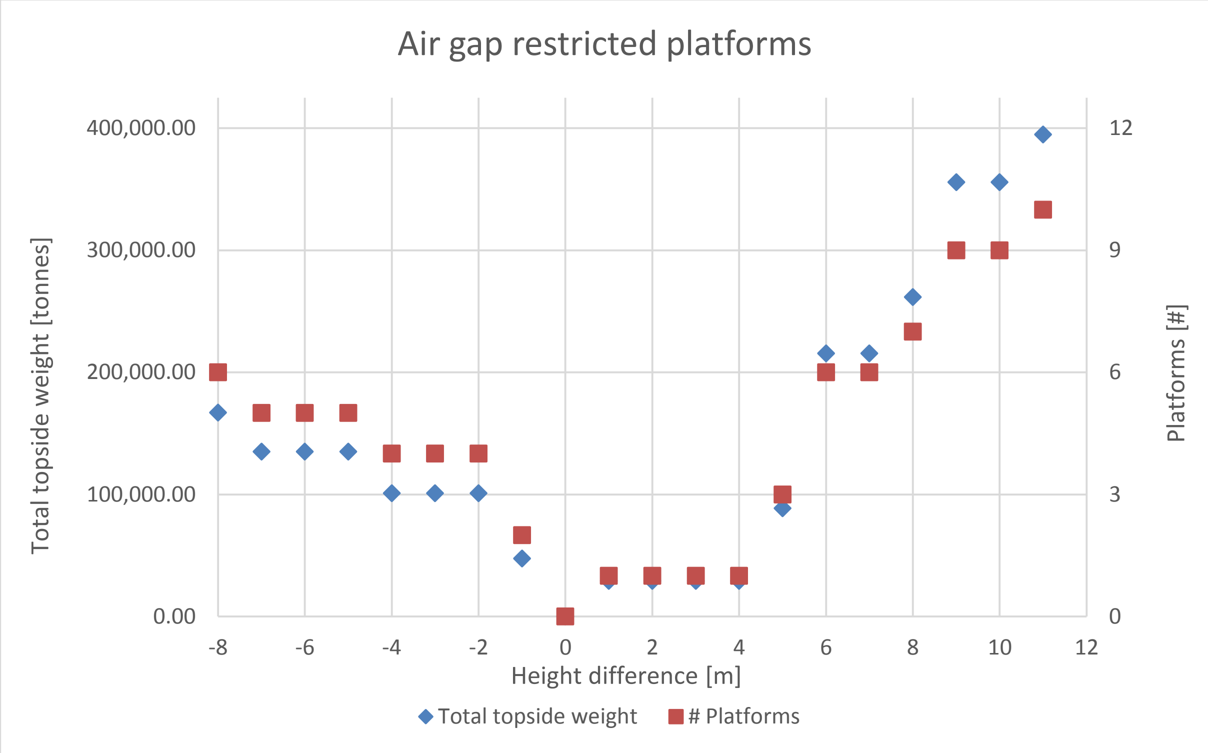


Figure 3-6: Potential market air gap restricted platforms

From this graph we can deduct the guidelines for the modification concepts. To be able to reach to the highest topsides, a height of 11 meters need to be overcome. On the other side, minimum air gap restricted platforms requires a reduction of the air gap by 8m to be able to service the entire market.

3.2.5. Water depth

The water depth at the location of the platform, is a limitation for the vessel. The water depth is dependent on two criteria; the vessel's draught (2.4) and the vessel motions (2.7).

- The minimum water depth is prescribed in Equation 3-5.

$$Minimum\ water\ depth = 1.3 \cdot 10^{-4} \cdot topside\ weight + 19.4 \qquad \text{Equation 3-5}$$

The sum of the minimal clearance, the depth of the hull and the height of the TLS are about 50m with clamps and 52m with yokes, including the vessel motions. The database does not provide any information about the height of the air gap for the very low water depth topsides, which could be critical on this point.

There are in total 7 individual platforms, that do not comply with the water depth restrictions. One platform has such extreme dimensions, over 100m of substructure width, that it is not likely that the vessel can be widened to this extend. The other 6 platforms lack all of the information about the size of the substructure and topside. Therefore it is not possible to say if these platforms are only limited by the water depth and not by another restriction. Without this information these platforms cannot be added to the potential market of platforms, which eliminates the water depth as a limiting factor for this research.

3.2.6. Combination of market overview

A large part of the platforms, which are out of the scope of the PS, are limited by more than one design limitation on more than one topside property. Therefore, these platforms will only come into the scope of the modified PS with a combination of modifications. The overview of all platforms, with all their limitations, is provided in Appendix F.

3.3. Summary

The Allseas platform database contains 755 platforms. In this research the focus is on platforms with a topside weight of 10,000 tonnes and over, due to the financial advantage of the competition.

Although a significant part of the required information is missing, completing the database in any other way is too expensive or is counteracted by the platform owners. To see what influence the database has, a sensitivity analysis has to be carried out.

The market is inventoried for every platform category by themselves. Contrary to reviewing the complete market at once, this approach creates a more clear view on the market per category, in terms of number of platforms and their combined topside weight. Also the range to modify the vessel is more clear when only one category is reviewed at once.

From chapter 2, the performance limiting factors are applied to this database. In chapter 3.2, an impression of the potential topside market is obtained. This potential market consists of platforms the vessel is not capable of lifting in its current state. The number of platforms, for every category, and their total weight are provided in Table 3-2.

Category	Number of platforms	Total topside weight [tonnes]	Required Increase	Performance limiting factor
Topside weight	25	844,883	22,000 tonnes	Topside lifting system
Length	12	415,249	45m	Slot length / rail length Length position of obstacles
Width	13	413,520	16m	Slot width
Air gap	16	561,839	-6 / 11m	Vessel's dimensions Vessel's draught Topside lifting system Vessel's motions
Water depth	-	-	-	Vessel's draught Vessel's motions

Table 3-2: Bandwidth overview

This data only represents the total number of platforms within a specific category. Since a large part of the platforms are limited in multiple categories, the sum of the different categories does not match with the total number and weight of all platforms the vessel cannot lift.

All of the water depth restricted platforms lack all of the information about the size of the substructure and topside. Therefore it is not possible to say if these platforms are only limited by the water depth and not by another restriction. Without this information these platforms cannot be added to the potential market of platforms, which eliminates the water depth as a limiting factor for this research.

The bandwidth in the above table will be used as a guideline for the following chapter where the viable modifications are assessed. The modifications have to be able to fulfil these bandwidths in order to be viable. These platforms are the potential market, which provides the additional revenue of the modified vessel in the later cost analysis.

4. Exploration of viable modification concepts

In chapter 2, the limitations of the Pioneering Spirit are identified. These limiting factors are withholding the vessel to handle a group of platforms. In chapter 3 the size of these groups and the range of the limitation are determined. The modification has to be applicable for this range. With this information, this chapter will come up with modifications to overcome the limitations that are suitable for the range.

As indicated in chapter 3.2.6, about half of all platforms are limited by more than one property. To provide a clear understanding of the effect, and later also costs of a modification, a modification concept will be restricted to extend the limitations of the vessel for only one platform property at the time. In a later stage, the most reasonable modifications of this chapter will be combined to form the most cost effective modification.

This chapter will initiate with some basic design requirements the modifications need to meet. These requirements prevent the modification from undesired side effects, which could cancel out the benefits of the modification.

To prevent lots of unnecessary detailed work, the concept ideas are compared on a very low detailed information basis, just the basics of a concept. In these basics, the concepts are evaluated on functionality, quantity of work to perform the modification, implementation difficulty of the modification and the potential impact on the number of platforms the vessel can lift. Based on these points the most reasonable modifications will be further developed in chapter 5.

This chapter starts with the modifications requirements in chapter 4.1. The first concept is to increase the maximum lifting capacity in chapter 4.2. This is followed by a concept to extend the length of the slot in chapter 4.3 and in chapter 4.4 a concept to widen the slot will be examined. The last concept is to overcome the high air gap limitation in chapter 4.5.

Two limiting factors, the vessel structure and its motions, are not considered as limiting factors which directly translate to a number of platforms. The structure of the vessel needs to meet the technical requirements and if not, it has to be reinforced. The effect to the motion of the vessel, by the modification, will be neglected. The motion is, with excluding of the water depth limitation, only of influence on the air gap limiting factor. The difference in heave motion is expected to be less than the margin taken into account for this performance limiting factor.

4.1. Design modification requirements

The design limitations are the guidelines for all modifications. To make sure the modification does not have an undesired side effect, these guidelines have to describe the conditions the modification has to comply with.

4.1.1. Technical requirements

A modification shall not cause the vessel structure to be overloaded.

> The used material shall have a yield stress of 355MPa. According to Lloyds (Lloyd's Register, 2013), the highest steel-grade to be used in the structure of ships, is a material with a yield stress of 390MPa.
>
> The original hull is also built from steel with a yield stress of 355MPa. Another benefit, by not choosing for a material with the highest yield stress, is the ability to increase the strength of the material without having an increase in structure weight. This project is the first concept to find a profitable modification for the vessel. Calculating the cost and additional weight is

required for this project, but is not the primary focus. This margin is taken into account for imperfections in the design.

The specific weight of steel is about 7,85 gr/cm^3 (Azom, 2014). To include uncertain factors like welding, the specific weight of structures is estimated at 8,000 kg/m^3

4.1.2. Functional requirements:

All safety margins, like bottom clearance and jacket margin have to be taken into account.

To protect the vessel from colliding with platforms and substructures, these safety margins are implemented in the procedures of the vessel.

The lifting procedure of the PS shall not be adjusted.

If topsides can be removed by adjusting the procedure, the vessel is not the limiting factor.

The lifting method of the PS shall be a single lift.

Removing the topside in a single lift is the key-selling point of the PS. Decommissioning a platform piece by piece is not the approach of the PS, other vessels are specialized and optimized in this kind of lifting methods.

Modifications shall not cause a reduction in any of the existing vessel capabilities.

Besides topside lifting, the vessel is also capable of lifting jackets, laying pipe and has an accurate DP system. All these qualities may not be negatively affected by the modification.

TLS is used as a system and would not be investigated onto component basis.

The TLS beam is a very complicated piece of equipment. The parts on component level of the beam are too detailed for this research.

The load of the topsides is assumed to be static.

There is no use of a model over time, to determine the dynamic topside load during the complete topside lifting procedure. A topside is modelled, held up by the TLS, in the final position after the fast lift procedure. While the load is taken as static, the maximum liftable load of the system is reduced by the dynamic factors (2.1).

4.2. Increasing the maximum lifting capacity

The largest group of platforms is restricted by the maximum lifting capacity of the vessel. In total there are 25 platforms with a weight restriction with a combined weight of 844,883 tonnes. This restriction is foremost limited by the maximum capacity of the TLS system. To generate more lifting force, three concepts are examined; placing buoyancy tanks under the TLS beams (Figure 4-1), adding lift systems which contain one beam over the complete width of the slot (Figure 4-2) and expanding the TLS with additional beams. Allseas is already researching and developing an improved version of the TLS beam, therefore that modification will not be taken into account in this project. At this moment, the final specifications of these modified beams are not known. Therefore the original characteristics of the beams are used, if more TLS beams are added.

The buoyancy tanks are tanks which can be placed under two TLS beams, a forklift, and will generate a lifting force under the lifting system. These tanks are positioned at the inside of the slot, as shown in Figure 4-1.

To install the tanks, the vessel needs to be ballasted at its maximum draught. This allows the tanks to be ballasted as well to become stable in an upright position, in order to manoeuvre them under the TLS beams. The positioning will be executed by small tugs, which fit in the slot. To keep the tanks in their location, some temporary guidance rails are attached to the vessel to secure the length position of the tanks. These guidance rails allow to adjust the draught levels of the tanks. On top of the tanks the connection with the beams is situated. This connection consist out of rollers which allow the TLS beams to extend and retract and also allow for a small correction in length direction of the vessel. The tanks are not a permanent item on the vessel, but will be installed once needed and removed after the job.

The upward force of the buoyancy tank reduces the bending moment in the beam, the torque in the vessel's bows and the longitudinal bending moment. This allows the topside load to increase, before the same stresses occur in the vessel's structure as before the modification.

Given that a forklift is 12.2m wide, the tank will also have a length of 12.2m. This withholds the tanks of interfering with the length positions of the TLS beams. The width of the tanks is affecting the remaining width of the slot, therefore the width and the length of these tanks are the degrees of freedom to generate the most optimal solution.

In Appendix G, a first attempt to calculate the effect of the buoyancy tanks is carried out. These tanks have a width of 7m, a height of 30m and will weigh 450 tonnes each. Depending on the draught of the vessel and tanks, the lift each tank can generate is up to 1,800 tonnes.

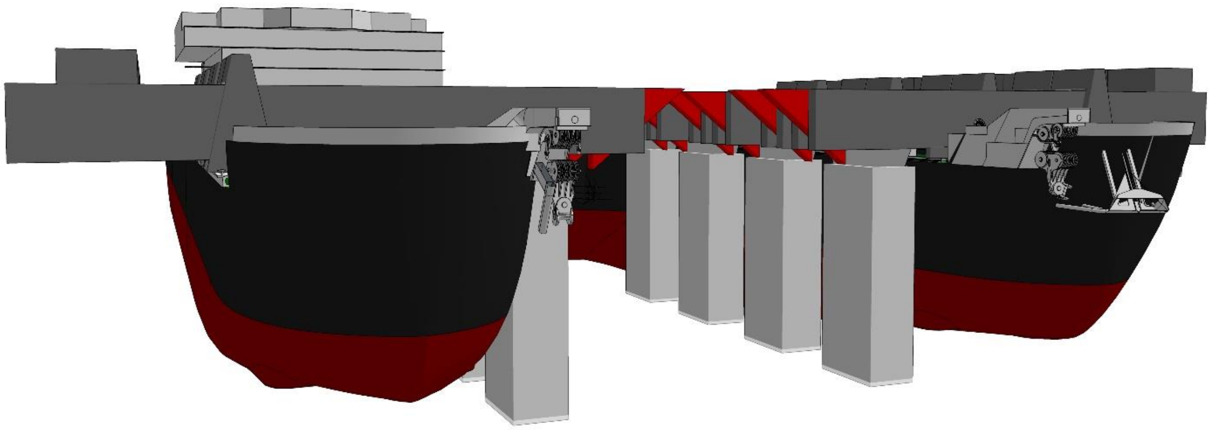


Figure 4-1: Artist impression of buoyancy tanks

The second concept is a transverse beam from starboard to the portside of the vessel. This concept consists of 2 beams, which interconnect at the centreline of the vessel and act like one beam.

The beams are a permanent modification to the vessel. They are installed on a sliding device which is supported by the inboard and outboard rail. These sliding devices are installed by an external crane and the beams are placed into position on self-propelled modular transporters and a barge in a sheltered area.

Once the beams are installed, the beam will be supported by a sliding device which is placed on the inside and outside TLS rail, on the vessel's bows. These two points on the rail are simply supported. The beam is connected in the middle of the sliding device, which is situated at the centreline of the vessel's bow. With this lifting position, this concept does not increase the torque on the vessel's bows, because the lifting force acts at the centreline of the bow. The reaction forces on the vessel's bows are only a vertical force on the rail. A graphical interpretation of this concept is provided in Figure 4-2.

When the vessel enters the topside, the beam is fully retracted like the TLS beams. In this stage the beam is supported by rollers at both ends, to prevent the beam from tipping over. Once the vessel is in position the beams are extended towards each other and connected to perform the lift. The system is capable to correct for vessel movements. Surge movements are eliminated by relocating on the TLS rail and sway by extending or retracting the beam. For heave the sliding devices will have heave compensating cylinders which lift the complete beam. These cylinders will also be used to perform the lift, so the beams are lifted as well.

The length of half a beam, is about 65m. This length makes it possible to be supported on both the inboard as the outboard rail, while both beams are connected. To be able to fit within the other systems, the height of the beam may not exceed the height of the TLS beams. Since the beam is about similar as the TLS beams, the weight can be assumed to be in the same order. Two TLS beams weigh about 5,100 tonnes, therefore a complete set of starboard and portside beam will weigh about 10,200 tonnes. Since the beams also have about the same size as four TLS beams, the lifting performance is assumed to be equal to 4 TLS beams, 7,500 tonnes.

This modification is only applicable for topsides which can be supported at the bottom. This system is not able to lift platforms which needs to be lifted on their legs.

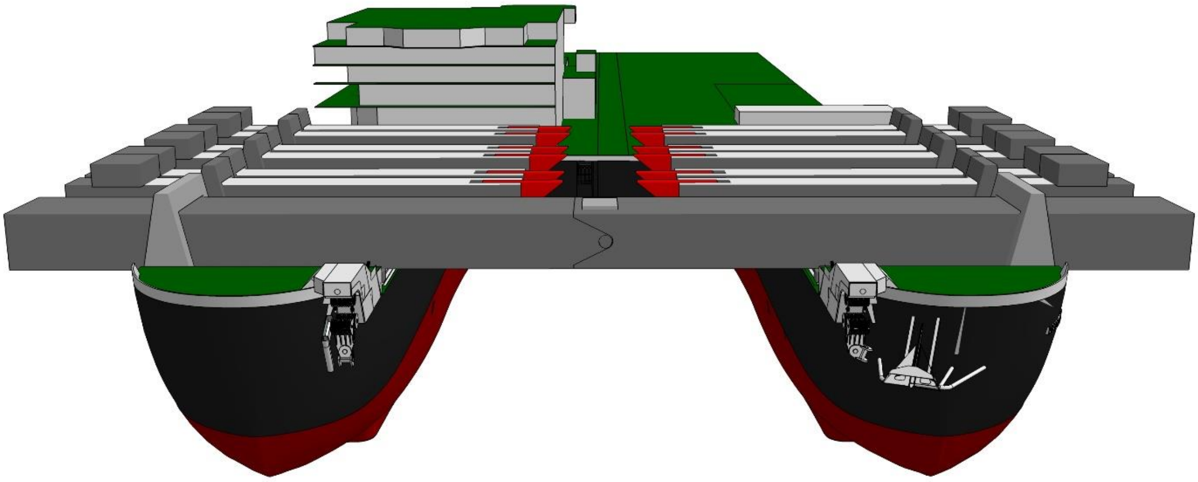


Figure 4-2: Transverse beam

The third concept is to extend the lifting capacity by adding more TLS beams. These additional TLS beams will be installed in the same way as the current beams are placed on board of the vessel. The beams, the inboard support and the outboard support are skidded on a barge, this barge is manoeuvred in the slot of the vessel. The vessel will be ballasted to a draught, so both supports can be installed by cranes and the beams can be skidded on board of the PS.

4.2.1. Evaluation of increasing weight concepts

The buoyancy tanks are a simple addition to improve the lifting capacity of the vessel. But compared to the two other concepts, these tanks are limiting the applicability. The implementation of the solution depends on the substructure formation and its width. The slot width is reduced between the buoyancy tanks, therefore it is only applicable at the location where the substructures are small, types like triangle and Jesus cross substructures, with a high topside load. In this project, the aim is to find the most cost effective solution. With the substructure limitation, it is doubtful whether this solution will be cost effective. There are only three platforms with this substructure type and a too high topside weight. Therefore this modification will not be applied to the vessel as a modification to solve the topside load limitation, but this solution will be kept in mind if the load limitation has to be pushed a little higher and is applicable to the substructure.

The other two systems are much more alike and have common downsides. Both modifications will need structural reinforcement to compensate for the increase in topside lifting capacity. Also the original TLS rail length will not be long enough to accommodate an infinite number of additional lifting systems. There will be a point where adding a lifting device requires an increase of the length of the TLS rail (4.3). Besides the similarities, both modification have their own benefits and downsides. A benefit of the transverse beam is that it does not lead to an addition in torque in the vessels bows. However, with a combination of transverse beams and the already installed TLS beams, the flexibility of this system is much lower than by using additional TLS beams. Once the transverse beams are placed between the TLS beams, the configuration of the original TLS beams and the new transverse beams cannot be adapter easily. It is possible that due to the substructure size, the transverse beam is located opposite a substructure leg and cannot be used. In contrast to the TLS beams, which are all the same and all combinations are possible.

The TLS is a very familiar system for Allseas, this implies that the engineering costs for this system is likely to be much lower than with a new system. This combined with the previous pros and cons, the benefits are in favour of installing additional TLS beams. The high flexibility in employability and the familiarity with the system are of high importance for a good working system. By choosing this system, the strength of the vessel's structure has to be evaluated to see if it still meets the maximum allowable stresses.

4.3. Increasing maximum topside and substructure length

The length of the topside and its substructure are limited by the obstacles direct aft of the slot (2.5) and the length of the slot (2.2). In total there are 12 platforms with a length restriction with a combined weight of 415,249 tonnes.

The accommodation of the PS is indicated as the least movable object right behind the slot. Relocating the accommodation is not considered an option, due to the required aft deck space. Shortening the accommodation affects the pipe-lay capabilities due to the pipe welding facilities in the lower part of the accommodation. Due to these impossibilities, the accommodation is taken as a fixed object.

The slot length and the length of the TLS rail are highly related to each other, since the TLS rail is positioned on top of the vessel's bows. Extending the slot aft wards is not an option because the pipe lay fabrication line ends directly at the aft of the slot and cannot be moved without influencing the performance of the vessel for pipe lay. Therefore extending the TLS rail aft is not a valid option.

For topsides which are only restricted by the length of the topside or the substructure, the rail can be extended forward. This requires the raised foredeck to be removed, so a stinger-like structure can be added in the front of the vessel. This modification will increase the bending moments, because the length of the rails is extended forward. The bending moment can be dealt with by increasing the structural strength. Due to the lowering of the foredeck, the vessel will be more vulnerable to green water at maximum draught. This would imply that the working scope of the vessel will be affected or the maximum draught. The wide work scope is a key selling point of the vessel and by decreasing the maximum draught, the group of platforms with a low air gap which the vessel is capable to lift, will be affected.

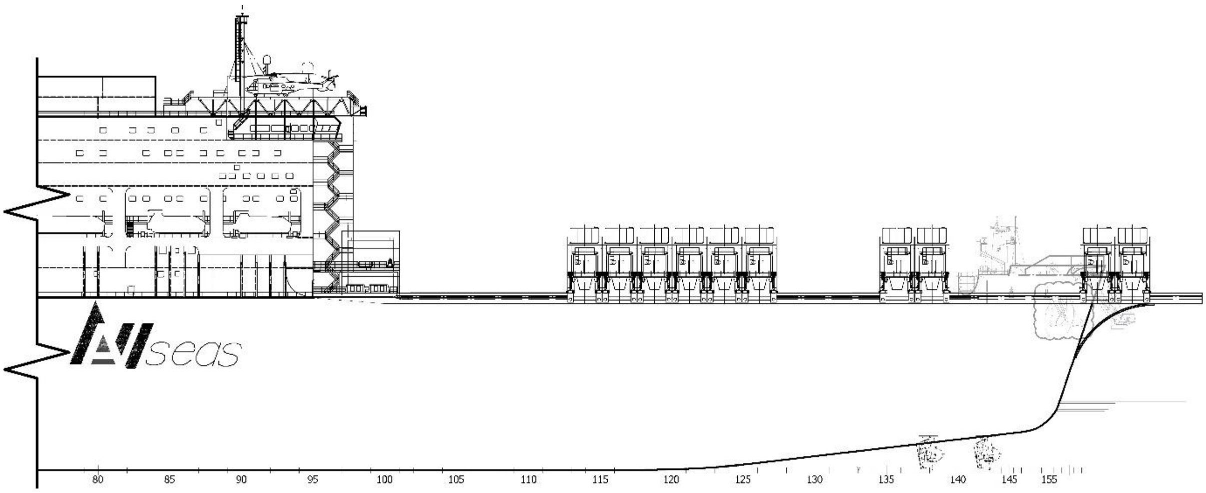


Figure 4-3: Extending the TLS rail

By increasing the length of the bows, the length of the rail can be extended as well. This enables the TLS system to position on a longer rail to position around longer substructures. Also the system can have a better lift distribution on the larger topsides, which allows the system to lift larger topsides. Lifting longer topsides could increase the acting longitudinal bending moment. Although the longer bows will also generate additional buoyancy. This will negate, at least some of, the increase in structural load. This structural analysis will be dealt with at a later stage.

The installation procedure to extend the bows of the vessel will take place while the vessel is still afloat. Due to the shape of the bows, there will most likely be remaining acting stresses in the bow sections. Therefore additional barges will be connected to the bow, before the bow will be removed, to compensate with additional buoyancy. The extension hull blocks will be added to the bows when the bows are put into a dock.

Considering the web frame space of 2.500m of the vessel, the vessel will be extended with a step size of 2.500m. This will complicate the structure as little as possible and the step-size is assumed to be small enough for an accurate length increase estimation. Based on the weight of the hull and the total top view deck area of the vessel (0) a rough estimation of the weight per square meter is derived. A block of 2,5m will weigh about 275 tonnes for each side.

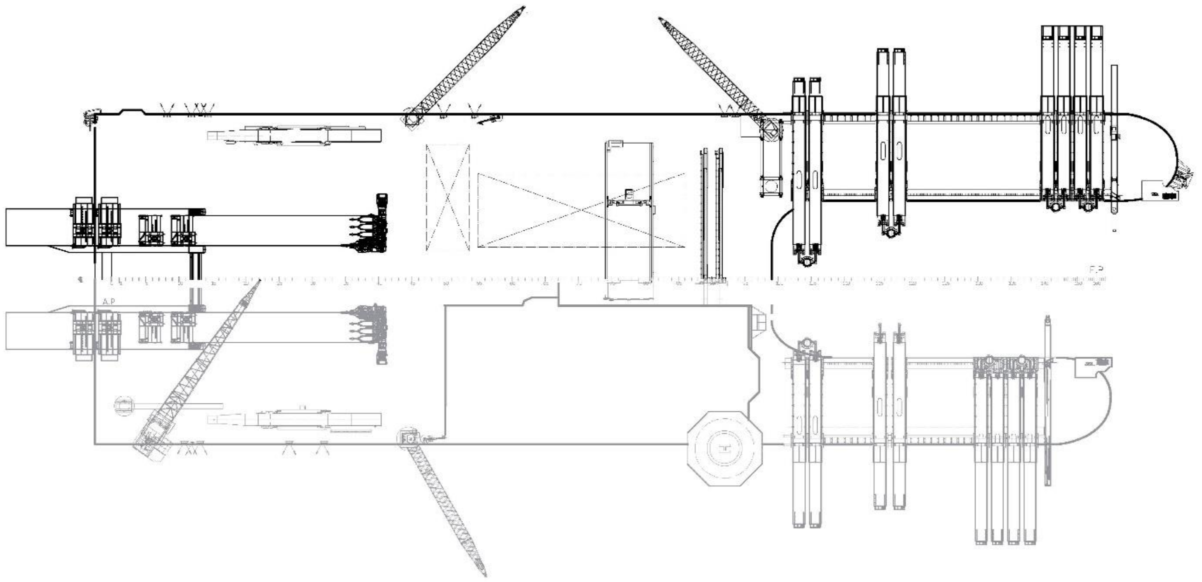


Figure 4-4: Extending the bows

4.3.1. Evaluation of extension concepts

The main differences between only increasing the length of the rail and extending the length of the bow, are the additional buoyancy and the possibility of affecting the work scope by lowering the foredeck. Inserting an extending part in the bows is most likely more costly than only extending the rail, but taking into account that the structure requires less reinforcement, a significant part of the cost difference will be cancelled. Extending only the TLS rail is also less limited in terms of maximum additional length, which makes extending the bows a more robust and better suitable for this research.

By extending the bows, the structural capacity needs to be checked and if necessary reinforced. Secondly, by increasing the displacement of the vessel, the ballast capacity increases as well. To compensate for the additional ballast capacity, additional pumping capacity needs to be installed.

4.4. Increasing the slot width

The second largest group of platforms is limited by the maximum allowable width of the substructure. In total there are 13 platforms with a width restriction with a combined weight of 413,520 tonnes. The substructure width is restricted by the width of the slot. A second group of platforms which are in a way limited by the slot width, is the group with a low air gap. These platforms can be lifted once the complete topside fits into the slot. This will require an additional structure, to be able to lift these topsides with the TLS. This additional structure provides lifting piles at the side of the topside, so the system can lift them with clamps.

To make way for the wider substructures and topsides, the slot of the vessel needs to be widened. There are three ways to implement this;

- Widening of the vessel at the centreline
- Widening of the vessel at one side
- Widening of the vessel at both sides

Widening the vessel at the centreline, requires the vessel to be split in half like during the building process. In Figure 4-5 a top view of this modification is presented. One of the halves has to be widened in a dry-dock and then reassembled.

The installation procedure to widen the vessel, will follow the procedure of widening during construction phase. The vessel will be cut into two parts, while the vessel is afloat. Cutting the vessel at the same width location as the vessel is cut the first time, will leave the pipe-lay equipment untouched, this saves money and time during the implementation. The cutting results in a part of the vessel with a width of 65.25m which will be widened in the dry-dock.

A block of 1m will weigh about 930 tonnes for each side. This is deduced by the weight of the steel hull of the vessel and its corresponding top view deck area (0), which is interpolated to the deck area of this block.

As a secondary side effect, the vessel generates more buoyancy, which could improve the ability to lift platforms with a high air gap.

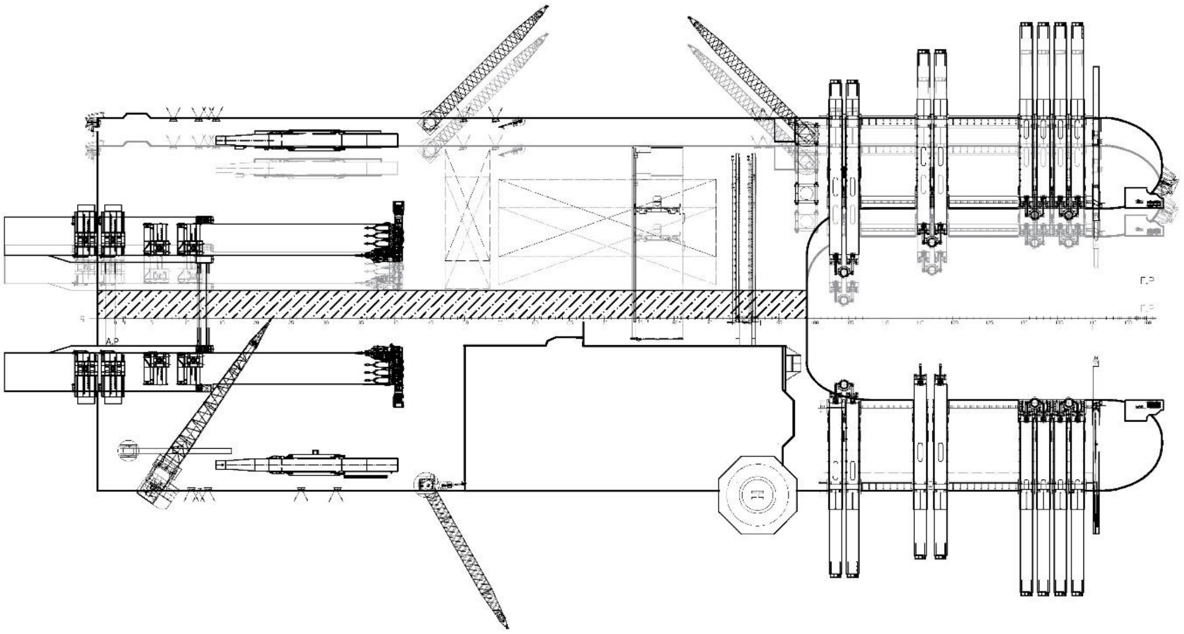


Figure 4-5: Widening at centreline

Widening the vessel at one side, requires the portside bow to be cut-off. This bow will be moved to the new desired width-location. The rest of the length of the vessel obtains a new block to make the vessel symmetric again. In Figure 4-6 a top view of this modification is presented.

The installation procedure to widen the vessel, will initiate with cutting off the portside bow. Due to the shape of the bow, it is not possible to ballast the bow in such way, that the bow has no tension at the cutting line. Therefore additional barges will be connected to the bow, as is explained in chapter 4.3, before the bow will be removed. With the bow positioned at a new location, the vessel is not symmetric anymore. To overcome this, additional sections are added at the portside. These sections are not floating on their own, so they have to be installed by a crane.

A block of 1m will be about the same size as for widening at the centreline. But due to the new shell of the new blocks, these blocks will be a little more heavy and thus, more costly.

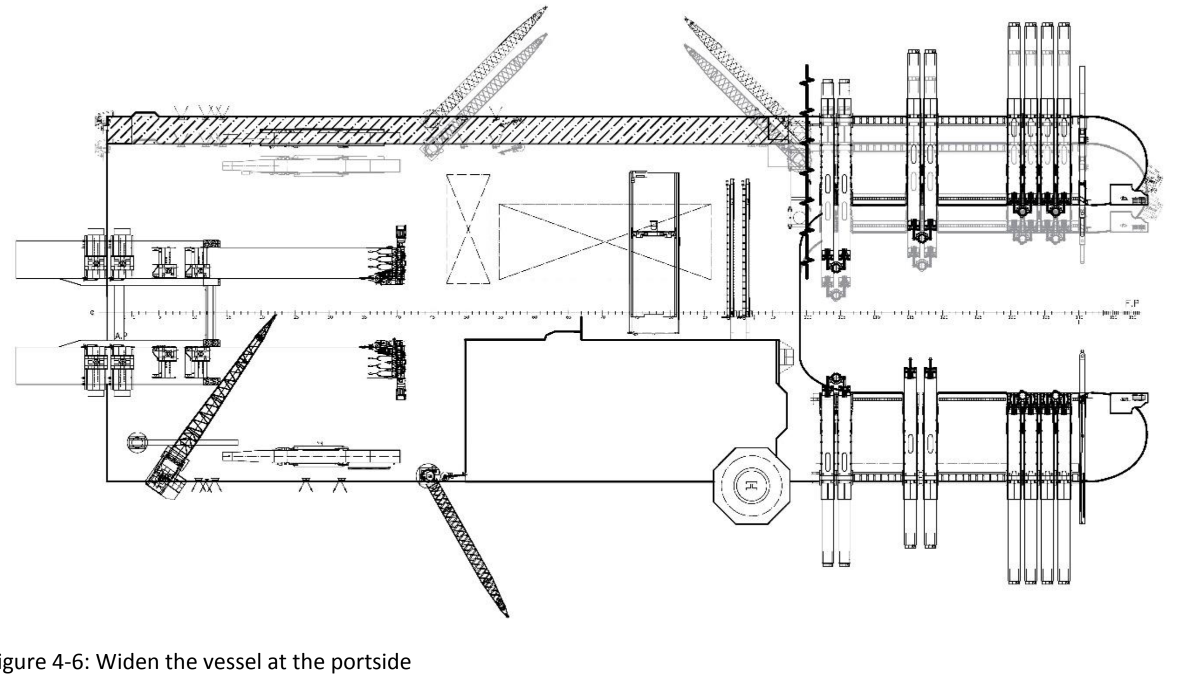


Figure 4-6: Widen the vessel at the portside

The last method is to widen both bows equally, this keeps the vessel symmetric as well. This modification is presented in Figure 4-7. This modification is assumed to require less weight and a relocation of equipment at the side of the vessel is not needed.

To perform this modification, both bows are cut off with assistance of additional barges and placed on their new desired width positions. To provide a smooth transition of the stresses, triangle blocks are installed at the aft of the bows and the side of the vessel. These blocks are not floating, so they have to be installed in a dock.

By changing the width location of the bows, no additional material is needed. Only smoothening the sides of the vessel with two triangular blocks is required. The weight of these steel blocks is deduced by the weight of the steel hull of the vessel and its corresponding top view deck area (0), which is interpolated to the deck area of this block. Because the size of this triangular block is not known at this moment, an exact number cannot be provided at this moment. As an educated guess, the weight is about 15% of widening along the centreline for small modifications, up to 25% for larger modifications. This is including the structural reinforcements.

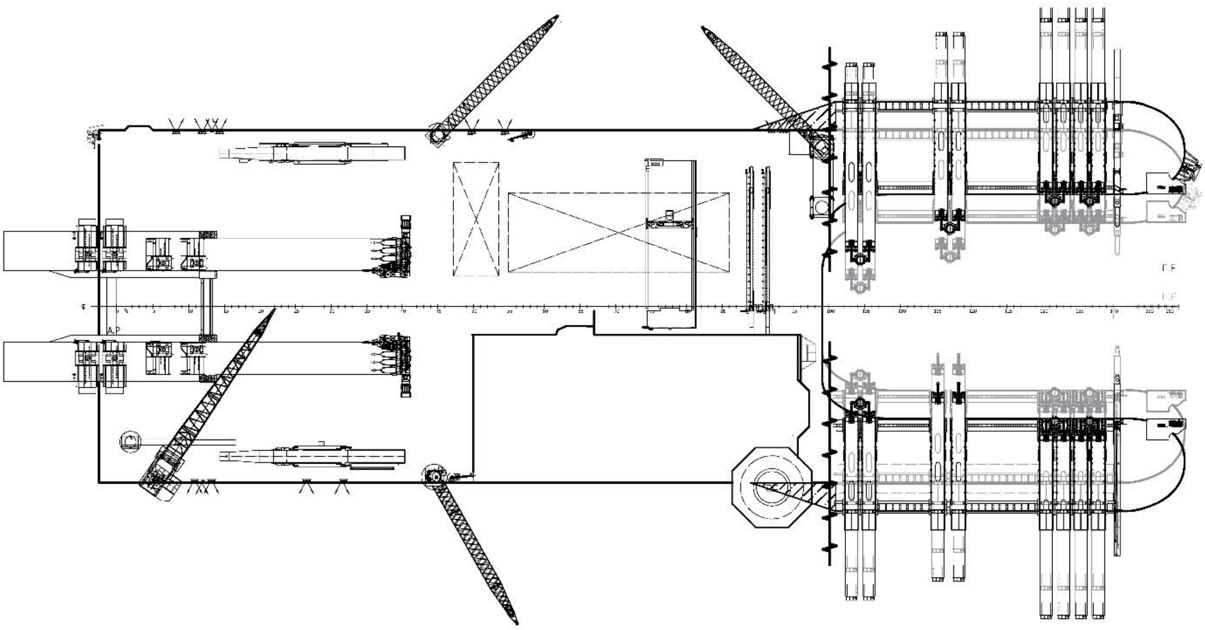


Figure 4-7: Widening at both sides

An alternative approach is to lift topsides with a too wide substructure in a different way. Allseas is already looking into the possibility to lift platforms on one bow. Although this could also be a solution these platforms, this is an indication that not the vessel but the procedure is the limiting factor of the vessel. In this project, the focus is to identify the limiting performance factors of the vessel and propose a cost effective modification to lift larger platforms. Changing the procedure of lifting topsides can be a solution for some topsides, but is very dependent on the substructure. Therefore this alternative improvement is not a general solution for all platforms regarding the width limitation and is not taken into account.

4.4.1. Evaluation of widening concepts

The modifications are very much alike; they all have the same out-come, only the implementation is different. Seeing as for all modifications the slot becomes wider, they suffer from the same complications. With a wider slot, the lifting beams will have a higher outreach for the same topsides. A higher outreach results in less lifting capacity. This has to be taken into account by adding more lifting beams or increasing the strength of the beams. Also the wider vessel and the higher outreach will result in a higher transverse bending moment in the vessel and torque in the vessel's bows. Taking into account that the structure is already loaded at its maximum allowable stress, the structure needs to be strengthened as well. For the modifications with a significant increase in displacement of the vessel, the ballast capacity has to be increased as well.

The impact of the additional work which has to be done, and with that the costs, is higher if the vessel is widened at one side. All existing equipment, which is situated at the P.S. of the vessel, has to be relocated. Also the accessibility of the transverse structure, for reinforcement, is more difficult than widening along the centreline. This modification is more expensive and has no additional benefits, therefore it will no longer be an option.

The difference, with the highest influence on the cost, between the other two is the ability to reinforce the structure of the vessel. At the centreline high transverse bending moments are occurring. By increasing the width of the slot, these moments increase together with the torque in the bows, due to the higher outreach for the same topsides. When the vessel is cut in half, it is easier to reinforce the vessel along the centreline. This easier implementation can be expressed in time and also costs.

Where the widening at the centreline will be an easier solution to reinforce the vessel, repositioning the bows seems a less impactful modification. Although, with the need to reinforce the complete centreline area of the vessel, it seems more logical to widen the vessel at the centreline. Based on this information, no modification can be selected. Therefore both modifications will be examined more thoroughly on a cost basis in chapter 5. Based on the costs of the modification, one will be selected to be combined with the other modifications.

4.5. Increasing the maximum air gap

The maximum height of the combination of the vessel and the TLS reach is limited. In total there are 10 platforms with a width restriction with a combined weight of 394,814 tonnes. This leaves some platforms with a high air gap untouched. To overcome this gap between the topside and the TLS, a "Connection Bridge" between them can be installed. By placing a bridge between both the SB and PS TLS beams, some meters of height can be overcome.

A second benefit is that this system can also be used for topsides which requires to be supported in the middle of the topside, which causes a high outreach of the TLS. This bridge will reduce the outreach of the TLS beams and according to the load curve, the maximum lift capacity of the beam will increase with a lower outreach.

This equipment is not permanently fixed to the vessel. If necessary the bridge can be installed, but if the topside does not require this piece, the bridge can be stored on board or on shore. This installation will be performed with an external crane, since the vessel does not disposes of a crane that reaches to all beams. In this concept only one side of the bridge will be connected to a forklift and pointed to the outside of the vessel. When the vessel is in position to lift a platform, the bridge will be turned and the opposite forklift will also be connected.

An impression of the connection bridge is provided in Figure 4-8. The structure will be about 30m long and 4m wide. The weight of the bridge will be about 1000 tonnes, for a 7m high bridge (Appendix J). This weight will be subtracted from the lift capacity of 4 TLS beams.

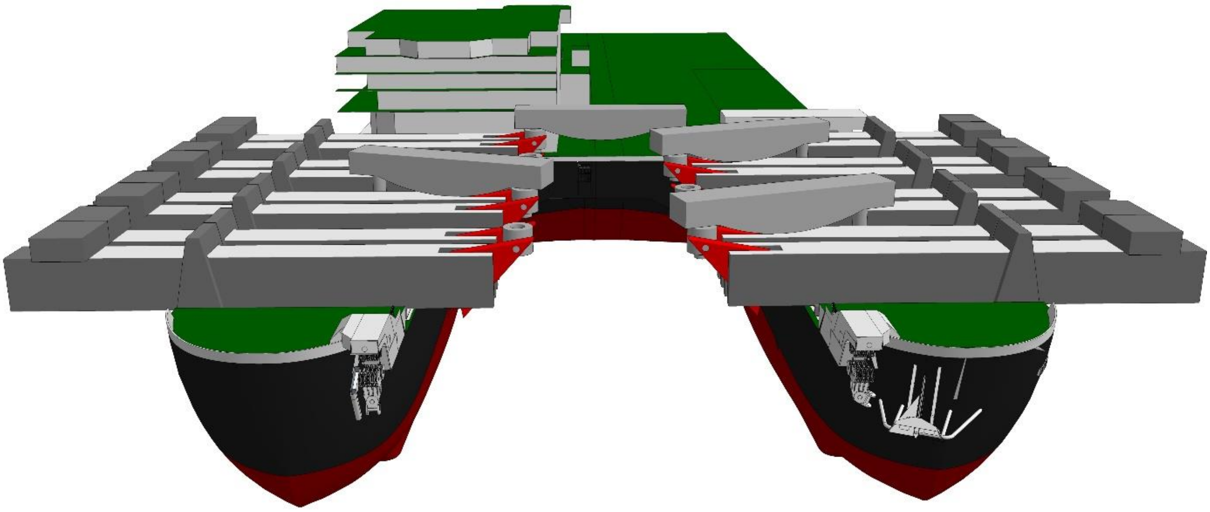


Figure 4-8: Connection bridge

A different approach will be to increase the depth of the vessel. This modification will, most likely, come with higher cost, but above all, eliminate the topsides with a low air gap. Every meter the depth of the vessel increases, the minimum air gap the vessel requires increases as well. Therefore the first modification with a module which does not have to be permanently installed is a better solution.

4.6. Summary of concepts

From previous chapters, we learned the limitations of the vessel. These performance limiting factors are used as input for the platform database. The required modification for the platforms the vessel is not able to remove, is set in chapter 3.

In this chapter some ideas are introduced about how to modify the Pioneering Spirit. For each limiting factor one or more concepts were derived. These concepts have to fulfil the required increase for each of the platform categories stated in 3. In Table 4-1, an overview of the bandwidths for every category and the corresponding limiting factor are presented.

Category	Required Increase	Performance limiting factor	Modifiable
Topside weight	22,000 tonnes	Topside lifting system	Yes
Length	45m	Slot length / rail length	Yes
		Length position of accommodation	No
Width	14m	Slot width	Yes
Air gap	-6 / 11m	Vessel's depth	No
		Vessel's draught	No
		Topside lifting system	Yes

Table 4-1: Modification requirements overview

Based on the implementation of the modification, the size, lifting force, impact on the vessel and an indication of the costs, various modification are examined. For some performance limiting factors, no modifications were directly applicable. The length position of the accommodation is one of these limiting factors. The accommodation cannot be moved aft wards, the JLS is positioned here and requires this deck space, the accommodation cannot be shortened because the pipe fabrication facilities on the main deck in the accommodation.

For the other performance limiting factors, different modifications can be applied in order to extend the capabilities of the vessel. These modifications can be summarized by:

- Adding additional TLS beams (4.2).
  With more lifting devices, the system can lift heavier loads. By applying this modification, the load on the structure will increase as well, which requires some reinforcement of the structure. A second problem with adding additional TLS beams, is the total number of TLS units the original TLS rail can accommodate. At a certain point, adding additional beams requires an extension of the TLS rail.
- Extending the vessel's bows (4.3).
  By extending the bows, the vessel can accommodate longer substructures and topsides. This modification can require some increase in the structural strength of the vessel, although some of the increase in bending moment will be cancelled out by the additional buoyancy. The additional buoyancy comes with additional ballast capacity. In order not to affect the ballast time, the pumping capacity needs to be increased as well.
- Widen the vessel's slot (4.4).
  By widening the slot, the vessel can accommodate wider substructures. Widening the vessel's slot has two modification possibilities, which have the same outcome based on this level of detail. These two will be investigated on a deeper cost level, in order to apply the most cost efficient modification to the vessel. For both modifications, the structural load increases on the transverse structure and the outreach of the TLS beams will increase.
- Connection bridge (4.5).
  These connection bridges are blocks, which will be lifted by the TLS and increase the height of the system. This allows the system to lift topsides with a higher air gap. The weight of the connection bridge will reduce the maximum lifting capacity of the TLS.

These four concepts will eventually be combined into one modification, but to improve the understanding of each concept, these concepts are discussed separately until chapter 7.

In the next chapter, the costs and impact of these four modifications are worked out in more detail. All possible combinations will be formed with these four modifications. Based on the costs and the income of a combined modification, the most cost effective modification will be selected in the final stage.

5. Detailed analysis of modification concepts

The previous chapter was about finding viable modification concepts for the PS. In this chapter the viable modifications will be looked into more detail, with respect to cost items. All costs items of these modifications will be explained and quantified in this chapter, for the estimated cost will be referred to chapter 6. For each modification, these details are divided into three parts;

- An overview of new equipment
- The required structural modification
- The duration of the modification

For each modification various activities are scheduled which form the complete duration of the modification. The duration of the structural reinforcement of the vessel, will be based on the total weight of the structure which needs to be added to the vessel. Based on the input of two other naval architects, about the duration of the structural modification, a function is introduced which fitted these points as best as possible. Their input was based on their estimation of duration for different added construction weights. This function is described in Equation 5-1. Their main notes were about the influence of the accessibility of the location which needed to be reinforced in relation to the duration.

$$Construction\ days = 9.66 \cdot 10^{-11}x^3 - 2.43 \cdot 10^{-6}x^2 + 2.42 \cdot 10^{-2}x + 12.1$$ Equation 5-1

The duration required for other items can be divided into;

- Transport to facility
- Construction block installation
- Docking period, if needed
- Beam installation, if needed
- Test of modified vessel

Apart from the structural duration of the modification, the vessel will need to sail from its last destination to the shipyard or a modification facility. The cost for this trip will be based on the daily cost of the vessel and the time the vessel needs to sail to the shipyard. The location and thus the sailing time is dependent on the type of modification. For each modification a suitable transport period will be included.

After the modification, the modified system will have to be tested. In this research, it is assumed that the test procedure will take about 15 days to complete (Table 5-1). This duration is added to the duration of each modification. The duration is based on the basis of design data of the PS (Berg, 2010). During the testing operation, the daily costs of the vessel are equal to when the vessel is fully operational.

Procedure	Design (days/job)	Test (days/job)
Inshore preparation	7	-
Transit	3.5	1
Offshore preparation	4	1
Operation (removal or installation)	8	8
Transport	4	2
Load –off/-on	3	2
De-mobilization	1	1
Total	**30.5**	**15**

Table 5-1: Test duration

5.1. Increasing the maximum lifting capacity with additional TLS beams

To increase the total lifting capacity of the system, additional TLS beam will be added, as concluded in chapter 4.2. Adding more TLS beams will increase the total lifting capacity of the system. Besides only adding TLS beams, various other details need to be taken into account. The most obvious is the increase of the load on the vessel's structure as well as the duration of the modification. Another problem, which needs to be dealt with, is the length of the TLS rail.

The TLS rail has a length of 97.5m, which limits the maximum number of TLS beams without extending the rail. To provide a minimum of 8m of space between two forklifts, the vessel can accommodate 4 additional beams (two forklifts), without a modification to the rail. This minimum space is required to be able to position around large substructures. To calculate the minimum rail extension, all TLS beams are grouped into a forklift with an even number of beams. In case of an odd number of beams on one bow, only one beam will be a single. With the width of a TLS beam of 6.10m and a forklift of 12.20m (Kuiper, 2014), the additional length of the TLS rail can be determined. In Table 5-2 the minimum extension of the rail is provided together with the modified lifting capacity and the corresponding minimum draught of the vessel.

Additional TLS beams	Total beams per side	Minimum extension of TLS rail [m]	New maximum lifting capacity [tonnes]	Minimum draught [m]
2	9	-	33,750	15.18
4	10	-	37,500	15.67
6	11	14.30	41,250	15.16
8	12	20.40	45,000	16.45
10	13	34.50	48,750	17.13
12	14	40.60	52,500	17.62
14	15	54.70	56,250	18.11
16	16	60.80	60,000	18.60

Table 5-2: Minimum extension for TLS beams

The extension itself will not be discussed as a part of the additional TLS beams modification. Extending the TLS rail and vessel's bows is a modification on its own and will be discussed in chapter 5.2.

5.1.1. Equipment

For this modification only one component will be added to the vessel, the TLS beam. This component consists of the beam itself, the inboard support, the outboard support and the connection with the controls. This component will be quantified in terms of costs in the next chapter.

5.1.2. Structural reinforcement

The original performance of the vessel, in this case the minimum criteria of lifting a topside, may not be negatively influenced by the modification. With additional TLS beams and higher topside loads, the load on the structure of the vessel will increase. In order to fulfil the requirement, the modified vessel needs to be able to lift at least a 30,000 tonnes topside with a minimum draught of 14.70m (Equation 2-8) or the maximum lifting capacity with the corresponding draught according to Equation 2-8, as is displayed in Table 5-2.

To indicate the structural loads, the Loading Condition Tool (LCT, appendix Appendix H) is modified to see how the structural loads are developing by changing the vessel and the load. In Appendix I, the method of calculating the additional required structural reinforcement is explained in more detail. In Table 5-3 an overview of the structural load is provided as well as the increase in section area to meet the material limitations.

The longitudinal reinforcement is not necessary over the complete length of the vessel. Only at the location where the load exceeds the maximum allowable stress of the original vessel, the structure needs to be reinforced. Therefore Table 5-3 will also provide a length specification on which the structural modification applies. Using the increase of the section areas and lengths, the weight of the structural modification will be calculated.

The transverse bending moments and shear forces are showing a more gradual increase in the Loading condition Tool, than for longitudinal. However, as stated in Appendix I, the transverse strength of the vessel has much more margin in its maximum values than the longitudinal strength. Also the stresses have a much lower absolute value while the strength of the structure abeam is about the same as for along ships. By increasing the structural loads, some local problems would come up which cannot be identified with the LCT. Therefore a fixed additional weight will be included for local modifications to the structure, in order to meet the allowable stresses.

The torque in the vessel’s bows increases with the increased load of the topsides. The reinforcement for torque is not necessary for the complete length of the vessel as well. In the table, a length specification on which the structural modification applies is provided as well. Using the increase of the section area of the bow section and lengths, the weight of the structural modification to compensate for torque will be calculated.

The total weight of the structural modification will be used in the next chapter to come up with the cost for the structural reinforcement.

# Beams		16		20	24	28
Extension		0		0	20	40
Long. Bend. Mom		2,527,700	ton*m	+35%	+35%	+14%
Trans. Bend. Mom		338,600	ton*m	+9%	+28%	+48%
Long. shear		28,900	ton	+29%	+1%	-3%
Trans. Shear		25,300	ton	+4%	+27%	+39%
Torque		625,000	ton*m	+24%	+48%	+73%
Transverse section area		20.60	m^2	+31%	+24%	+9%
Transverse bow section area (torque – one bow)		8.99	m^2	+20%	+33%	+46%
Length for longitudinal reinforcement	[m]	-		150	170	190
Length for bow reinforcement (torque)	[m]	-		14	34	54
Longitudinal reinforcement weight	[ton]	-		7,650	6,600	2,750
Transverse reinforcement weight	[ton]	-		1,050	1,700	2,500
Torque reinforcement weight	[ton]	-		600	2,450	5,400
Total weight of structural modification	**[ton]**	**-**		**9,300**	**10,750**	**10,650**

Table 5-3: Structural change

With an increase in length of the vessel's bows, at a certain point the longitudinal bending moment and shear stress start to decrease. The vessel has a high hogging bending moment, due to the higher load at the fore and aft parts of the vessel. By increasing the length in the front, additional buoyancy is generated at the location of the load which reduces the bending moment.

5.1.3. Duration

The duration for this modification consists of four parts;

- Transport to facility
- Beam installation
- Structural reinforcement
- Test of modified vessel

It is supposed the modification can be performed all around the world, there are no indications that this modification requires a specific shipyard. A transport period of 10 days will be included.

For each beam, a five day installation time will be scheduled. Installing the IBS, OBS and the beam itself can be performed in 2 days, other activities can run simultaneously.

During the installation of the beams, the ballast tanks needs to be filled to provide the needed draught to skid the beams in place from a pontoon. This obstructs the work of reinforcing the structure, therefore time required for installing the structure parts are added to the installation period of the additional TLS beams. The duration for applying the structural reinforcement is defined by the total weight of the structural modification and Equation 5-1.

A duration of 15 days is added to accommodate for testing.

5.2. Increasing maximum topside and substructure length by extending the vessel's bows

To enable the vessel to lift longer topsides, the bows with the rail will be extended as concluded in chapter 4.3. Extending the bows will also provide more rail length for additional TLS beams and will generate a higher displacement. When extending the bow's length, the modification requires additional construction blocks, pumping capacity and the strength of the structure needs to be checked.

5.2.1. Equipment and hull

For this modification, additional construction blocks are required. In chapter 4.3, the weight is calculated based on the total weight of the hull and the deck area of the vessel. The weight is at this stage also estimated with the Loading Condition Tool. Both weights are provided in Table 5-4.

Steel block weight	Area based	LCT Based
Increase 2.5m length	550 tonnes	695 tonnes

Table 5-4: Weight construction blocks

The LCT has a very detailed weight description, the weight of the equipment is included in the weight distribution of the vessel. For extending the bows, only the weight of the hull is required. At the location the vessel is extended, not much equipment is expected to influence the weight estimation of the LCT. Therefore the weight estimation of the LCT will be used to calculate the costs.

If both sides are extended equally and the extension step is 2.5m, the weight increase is about 695 tonnes per extension step.

Another important parameter is the pumping capacity. With extending the water ballast capacity, the pumping capacity needs to be expanded as well in order to maintain an equal pumping time. The ballast capacity of the vessel increases with 1,735m^3 for every meter of bow extension, according to the LCT.

5.2.2. Structural reinforcement

As stated earlier, the original performance of the vessel, in this case the minimum criteria of lifting a topside, may not be influenced by the modification. The modified vessel needs to be able to lift at least a 30,000 tonne topside, with the corresponding draught of 14.70m. By extending the vessel, every increased meter of length produces more buoyancy than the additional weight of the construction, according to the LCT.

To indicate the structural loads, the LCT (Appendix H) is modified to see how the structural loads are developing by changing the vessel and the load. In Appendix I, the method to calculate the additional required structural reinforcement is explained in more detail. In Table 5-3 an overview of the structural load is provided as well as the increase in section area to meet the material limitations.

By increasing the vessel's length, the longitudinal stresses of the structure decrease, while the transverse stresses increase. Some parts of the structure are used both longitudinal and transverse, like decks and bottom plating. According to the theory of the Mohr's Circle (Hibbeler, 2007), as the longitudinal stresses decrease, the transverse stress can increase. For the stresses due to the bending moment, these will cancel out. The longitudinal and transverse shear stress has much less corresponding structural pieces, so the Mohr's circle does not apply. Therefore the structure will be modified in accordance with the transverse shear stress.

The transverse reinforcement of the vessel does not relate to the increase in load on the structure, as for longitudinal. As stated in Appendix I, the transverse strength of the vessel has much more margin to their maximum values than the longitudinal strength. While the stresses are much lower the strength of the structure is comparable. By increasing the structural loads, some local problems would come up which cannot be identified with the LCT. Therefore fixed additional weights will be included for local modifications to the structure, in order to meet the allowable stresses. These weights are related to the increase needed, to reduce the transverse shear stress within their allowable range.

The total weight of the structural modification will be used in the next chapter to come up with the cost for the structural reinforcement.

Extension [m]		0		20	40
# Beams		16		16	16
Long. Bend. Mom		2,527,700	ton*m	-35%	-49%
Trans. Bend. Mom		338,600	ton*m	+7%	+14%
Long. shear		28,900	ton	-9%	-9%
Trans. Shear		25,300	ton	+3%	+12%
Torque		625,000	ton*m	0%	-9%
Length for longitudinal reinforcement	[m]	-		170	190
Transverse reinforcement weight	[ton]	-		700	1,400
Total weight of structural modification	[ton]	-		700	1,400

Table 5-5: Structural change

With an increase in length of the vessel's bows, the longitudinal bending moment and shear stress decrease. The vessel has a high hogging bending moment, due to the higher load at the fore and aft parts of the vessel. By increasing the length in the front, additional buoyancy is generated at the location of the load which reduces the bending moment.

5.2.3. Duration

The duration for this modification consists of five parts;

- Transport to facility
- Construction block installation
- Structural reinforcement
- Docking period
- Test of modified vessel

It is supposed the modification can be performed all around the world; the bows of the vessel have no extreme dimensions compared to other merchant vessels. A transport period of 10 days will be included.

The modification requires the bows to be cut off, extended and reconnected. The duration of the complete modification will be led by the required time in the dock plus the period that includes the time required to cut off the vessels bows and reconnect them to the vessel. The structural reinforcement of the vessel will mainly be executed during one of these operations. Taking into account the structural added weight (5.2.2) and the corresponding duration, the structural reinforcement is not considered to be on the critical path of the modification. The complete modification will take 90 days including the docking period.

The cut-off bows are extended in a dock, this simplifies the extension. The duration these parts needs to be in a dock are discussed with an employee of Keppel Verolme. Based on my input, the total period a dock needs to be available for this project would be about 50 days for both sides. The costs to make use of a dock will be based on the duration and the day-rate of the dock.

A duration of 15 days is added to accommodate for testing.

5.3. Increasing the slot width by widening the vessel's slot

To enable the vessel to lift wider topsides, there are two options to widen the vessel, as concluded in chapter 4. The cost identification of both options are discussed at once, which makes it easier to compare the different approaches.

Widening the vessel's slot affects many other things. Within the vessel the load on the transverse structure will increase and the outreach of the TLS beams will increase as well. Other equipment as the stinger and the barges will also be affected by the change of the slot's width.

5.3.1. Equipment and hull

Widening the vessel's slot affects many different components. In this project the five main components, which are required to widen the slot, are investigated;

- Weight of construction blocks
- Modification to TLS beam
- Modification to stinger
- Modification to barges
- Modification for pumping capacity

For both modifications, additional construction blocks are required. For the modification at the centreline of the vessel, the weight of 1m increase in width is estimated in two different ways; based on the deck area and the total weight of the hull and based on the LCT. Both of the weight are listed in Table 5-6.

Steel block weight	Area based	LCT Based
Widening at the centreline (1m)	930 tonnes	2,150 tonnes

Table 5-6: Steel weight – Widening at the centreline

The LCT has a very detailed weight description, but the weight of the equipment is processed in the weight distribution. Lots of equipment for pipe-lay is installed at the centreline of the vessel, therefore the weight of the LCT does not provide the correct information. Based on the weight estimation for extending the bows and the layout of the structure at the centreline of the vessel, the increase in weight is estimated at 1,300 tonnes per increased meter of width.

For relocating the vessels bows, much less steel is required. Unfortunately, the LCT does not allow to provide information about the weight of the additional triangles. This weight will be based on a shell plate and the corresponding weight of the additional deck area of the triangle. The angle of the triangle will be 10 degrees, to provide a smooth envelope for both structural purposes as for the water resistance. Besides the triangle at the side of the vessel, a transition block needs to be inserted to align the longitudinal stiffeners of the vessel with the bows. The transition block will follow a 30 degree envelope, which is a commonly used angle for structural transitions. The weight of this modification is not linear, due to the use of triangles. The weight of the modification can be expressed by Equation 5-2 as a function of the width increase. The complete weight built up for this modification is provided in Appendix K.

$$Weight = 5.29x^2 + 637x + 9.45 \text{ [tonnes]} \quad \text{Equation 5-2}$$

Not only new parts are needed for this modification. Due to the widening of the slot, the TLS beams need to extend further for the same topside. This lowers the maximum lifting capacity of the beam and with that the total lifting capacity. In order to compensate for this, the beams needs to be strengthened. The method to determine the additional weight will be explained in Appendix L. In

Equation 5-3 the weight function is provided as a function of the increase in slot width. This weight is for one single beam.

$$Weight = 0.4x^2 + 14.5x \text{ [tonnes]} \qquad \text{Equation 5-3}$$

One of the most important boundaries of the project, is that the modification may not have any influence on the pipe-lay capacity. For Pipe lay, the vessel uses a stinger. A stinger is a steel structure to support a pipe to bend gradually into the water onto the seabed. This structure is positioned between the vessels arms and with an increase of this width, the structure needs to be widened as well. Because the stinger is already widened once before, the structure of the stinger cannot easily be widened again. The complete stinger will be replaced to deal with the new loads. The weight of the new part is based on the original weight of the stinger. The total structure weight of the stinger is about 3,400 tonnes. Allseas, advises to increase the strength, if possible. Therefore, the weight of the new half of the stinger starts at 4,000 tonnes. Based on the bending moment increased by widening the structure, Table 5-7 provides an estimation of the new weight.

Stinger Width increase [m]	-	4	8	12
Weight new stinger [tonnes]	4,000	4,500	5,000	5,500

Table 5-7: Stinger weight

The PS is supported by two barges, one barge for the stinger and one for the topsides. When widening the slot of the vessel, the barges are smaller than the slot itself. The size of the barges is designed so that it fits neatly in the slot, not only for buoyancy but also to reduce the motions of the barge. Therefore the barges need some small modifications. For stability issues of the barge, the best solution will be to widen the barge equally with the width of the slot. Because this procedure needs to be carried out in a dry dock the costs for this additional modification are not only based on the steel work. Also without detailed information about these barges, the exact additional weight is hard to calculate. In Table 5-8 an estimated combined steel weight for both barges is provided.

Width increase [m]	4	8	12
Combined modification weight barges [ton]	2,500	5,000	7,500

Table 5-8: Modification barges

An important parameter for the vessels' operation, is the pumping capacity. With extending the water ballast capacity, the pumping capacity needs to be expanded as well in order to maintain an equal pumping time. The ballast capacity of the vessel increases with 3,325m^3 for every meter of widening at centreline. For relocating the vessels' bows this increase can be neglected.

5.3.2. Structural reinforcement

As for the previous modifications, the original performance of the vessel may not be influenced by the modification. When widening the vessel's slot, with the same topside, the beams need to be extended further in order to grab the topside. Other characteristics as the topside weight of 30,000 tonnes and the draught of the vessel of 14.70m, remain the same for the modified vessel.

To indicate the structural loads, the LCT (Appendix H) is modified to see how the structural loads are developing by changing the vessel and the load. The approach to come to these values is explained in more detail in Appendix I. In Table 5-9 and Table 5-10 overviews of the structural loads are provided with the increase in section area.

By increasing the width of the vessel over the complete length, the longitudinal bending moment and shear stresses are both within their maximum allowable range, the shear stress even shows a slight reduction due to the relocating of the water ballast. The transverse bending moment and shear force are also slightly reduced by the modification. Only the torque in the vessel's bows shows an increase. The trend seems to be almost linear, which follows the assumptions of the reason of the increase.

The torque of in the vessel's bows increases with the increased moment due to the extension of the beams. The reinforcement for torque is not necessary over the complete length of the vessel, the table will also provide a length specification on which the structural modification applies. These section areas and lengths will be converted to the weight of the structural modification.

Widening [m]		**-**		**4**	**8**	**12**
# Beams		16		16	16	16
Long. Bend. Mom		2,527,700	ton*m	0%	+1%	+2%
Trans. Bend. Mom		338,600	ton*m	-1%	-3%	-4%
Long. shear		28,900	ton	0%	-5%	-4%
Trans. Shear		25,300	ton	-5%	-4%	-2%
Torque		625,000	ton*m	+9%	+19%	+29%
Transverse bow section area (torque – one bow)		8.99	m^2	+13%	+18%	+23%
Length for longitudinal reinforcement	[m]	-		8	12	14
Torque reinforcement weight	[ton]	-		200	450	700
Total weight of structural modification	**[ton]**	**-**		**200**	**450**	**700**

Table 5-9: Structural change – widening at centreline

When increasing the slot width by repositioning the vessel's bows, the longitudinal bending moments and shear forces show about the same values as the original vessel. Only the transverse shear stress and bending moments increase by widening the slot. Where at the previous modification the ballast water was moved further of the centreline, this modification does not have these benefits.

The torque in the vessel's bows are comparable for both modifications. The slight increase is also an effect of missing the additional width at the aft of the vessel.

Widening [m]	**-**		**4**	**8**	**12**
# Beams	16		16	16	16
Long. Bend. Mom	2,527,700	ton*m	0%	-1%	0%
Trans. Bend. Mom	338,600	ton*m	+10%	+40%	+61%
Long. shear	28,900	ton	-1%	-1%	-2%
Trans. Shear	25,300	ton	+24%	+36%	+46%
Torque	625,000	ton*m	+11%	+22%	+34%
Transverse bow section area (torque – one bow)	8.99	m^2	+15%	+21%	+27%
Length for bow reinforcement (torque)	-		8 m	12 m	22 m
Transverse reinforcement weight	-		1,250 Ton	2,200 Ton	3,100 Ton
Torque reinforcement weight	-		250 Ton	550 Ton	1,250 ton
Total weight of structural modification	**-**		**1,500 Ton**	**2,750 Ton**	**4,350 Ton**

Table 5-10: Structural change – relocating the vessels' bows

The total weight of the structural modification will be used in the next chapter to come up with the cost for the structural reinforcement.

5.3.3. Duration

The duration for this modification consists of five parts;

- Transport to facility
- Construction block installation
- Structural reinforcement
- Docking period
- Test of modified vessel

The widening procedure at the centreline of the vessel requires a large dock, which are mainly available in Asia (Korean Register, n.d.). To include that the vessel will have to sail from its last working location to the specific location for the modification, a transport period of 38 days will be included in the cost analysis. This period is about the same as the vessel needs to reach the port of Rotterdam from its building site.

The widening procedure to relocate the bows, requires a much smaller dock. These kind of dry docks are available in Europe. To include that the vessel will have to sail from its last working location to the specific location for the modification, a transport period of 10 days will be included in the cost analysis.

The widening procedure at the centreline requires the vessel to be cut in half, widened in a dock and reconnected again. The duration of these procedures will take about 90 days, about the same as for extending the vessels bows, although this modification has much more structural work. This amount of structural work will not all be performed during the other activities. To be consistent with the other modifications, all construction work within 40 days can be performed during the other activities. The remaining time will be added to the 90 days of modification. The complete duration for applying the structural reinforcement is defined by the total weight of the structural modification and Equation 5-1.

The duration of the modification to relocate the vessel's bows will take 90 days as well. This modification procedure is very similar to extending the vessel's bows, only the reinforcement of the structure is much more significant. To be consistent with the other modifications, all construction work within 40 days can be performed during the other activities. The remaining time will be added to the 90 days of modification.

Both modifications will need a dock, the centreline widening procedure takes more time to be widened and requires a larger dock than the bow repositioning. The duration for the widening procedure is estimated, based on the duration of extending the bows.

The centreline widening will contain a longer duration for the welding and painting activities. However, with a large working area, more people can work simultaneously on the same activities. Compared with extending the bows, this modification requires more blocks which need to be connected with the original vessel, therefore this duration is assumed to take about 75 days.

Repositioning the vessel's bows is very similar to extending the vessel's bows. The duration of this modifications is assumed to be the same as for extending the bows, 50 days.

After the modification, a duration of 15 days is added to accommodate for testing.

5.4. Increasing the maximum air gap with a connection bridge

To be able to reach for the highest topsides, an additional bridge will be placed on the TLS beams (chapter 4.5). Adding these bridges will reduce the total lifting capacity of the system, this will be taken into account by adding more TLS beams (5.1).

5.4.1. Equipment

For this modification only one component will be added to the vessel, the Connection Bridge. This component has to withstand a static load of 7,500 tonnes and a dynamic load of 12,000 tonnes.

The price of this component is based on the weight of the steel. The weight calculation is described in Appendix J including the calculation method and formulas. Using this data, the weight of this bridge is approached by Equation 5-4. The weight of the beam is expressed as a function of the height of the beam.

$$Weight = -1.543x^3 + 44.44x^2 - 419.4x + 2100 \text{ [tonnes]} \qquad \text{Equation 5-4}$$

5.4.2. Duration

The modification is an easy to install piece within a day these pieces can be lifted by a crane and be installed. This fast installation method makes it easier to remove and install this piece of equipment for a specific project.

It is supposed the modification can be performed all around the world, there are no indications that this modification requires a specific shipyard. A transport period of 10 days will be included.

The vessel needs to sail from its last destination to the testing facility. At this location the bridges will be installed and the system will be tested. The cost for this trip will be based on the daily cost of the vessel and the time the vessel has to sail. A transport period of 10 days will be included.

After the modification, a duration of 15 days is added to accommodate for testing.

5.5. Summary

The goal of this chapter is to obtain more details of the most viable modification concepts from chapter 4. The details concern the duration in days, equipment in units or tonnes of steel and the required structural modification in tonnes of steel. The costs per unit will be estimated in the next chapter. Combined with the quantity of this chapter, the total costs of a modification can be calculated in chapter 7.

In this chapter, four limiting factors are investigated and the required quantity for the corresponding modification is listed in the corresponding tables;

- Increasing the maximum lifting capacity (Table 5-11)
- Increasing maximum topside and substructure length (Table 5-15)
- Increasing the slot width (Table 5-12 & Table 5-13)
- Increasing the maximum air gap (Table 5-14)

Increasing the slot width contains two modification concepts. These two concepts seem, at first sight, very similar with regard to costs.

Additional TLS beams	0	4	8	12
Dynamic lift capacity [tonnes]	30,000	37,500	45,000	52,500
Minimum required bow extension [m]	-	-	20.20	40.40
TLS installation [days]	-	20	40	60
Structural modification [days]	-	105	111	111
Structural modification [tonnes]	-	9,300	10,750	10,650
Total modification period [days]	**-**	**125**	**151**	**171**

Table 5-11: Requirements additional TLS beams

Extending vessel's bows	[m]	0	20	40
Dynamic lift capacity [tonnes]		30,000	30,000	30,000
Extension block weight [tonnes]		-	5,551	11,102
Docking period [days]		-	50	50
Structural modification [days]		-	28	41
Structural modification [tonnes]		-	700	1400
Total modification period [days]		**-**	**90**	**90**

Table 5-12: Requirements extending vessel's bows

Widening vessel's slot - centreline	[m]	0	4	8	12
Dynamic lift capacity [tonnes]		30,000	30,000	30,000	30,000
Widening block weight [tonnes]		-	5,200	10,400	15,600
Docking period [days]		-	75	75	75
Structural modification [days]		-	17	23	28
Structural modification [tonnes]		-	200	450	700
Total modification period [days]		**-**	**90**	**90**	**90**

Table 5-13: Requirements widening vessel's slot - centreline

Widening vessel's slot - bow	[m]	0	4	8	12
Dynamic lift capacity [tonnes]		30,000	30,000	30,000	30,000
Widening block weight [tonnes]		-	2,630	5,420	8,380
TLS beam strengthening [tonnes/beam]		-	22.625	66.761	110.897
Docking period [days]		-	50	50	50
Structural modification [days]		-	43	62	79
Structural modification [tonnes]		-	1,500	2,750	4,350
Total modification period [days]		**-**	**93**	**112**	**129**

Table 5-14: Requirements widening vessel's slot - relocating bows

Connection bridge	Height [m]	0	3	6	9	12
Dynamic lift capacity per bridge [tonnes]		7,500	7,500	7,500	7,500	7,500
Weight connection bridge [tonnes]		-	1,200	850	800	800
Bridge installation [days]		-	1	1	1	1
Structural modification [days]		-	-	-	-	-
Structural modification [tones]		-	-	-	-	-
Total modification period [days]		**-**	**1**	**1**	**1**	**1**

Table 5-15: Requirements connection bridge

6. Income and costs of modifications

In the previous chapters, the viable modification concepts are explored. These concepts are introduced on a low level of detail. Later on more details, related to the costs, are introduced. In this chapter more information about the income and costs itself are looked into. These costs are divided into two parts, general costs and modification specific costs.

These costs are the input parameters for the modification comparison chapter, where all modifications are combined and the optimum of these combinations of modifications, based on the costs and benefit, is established.

In chapter 4 and chapter 5, two modification concepts for widening the vessel are considered to be viable based on the known information. In this chapter all unit costs are determined, which enables us to make a financial distinction between the two concepts. Based on this financial comparison, one concept will be selected as the most cost effective modification.

6.1. Cash Flow approach

In this research we will simplify the reality, in terms of costs and income. Normally we should make a distinction between future costs and income and current costs and income, by making use of the net present value (NPV). Where future costs and income are discounted by the extend they are in the future.

For this approach we lack too much information, the discount rate for Allseas and the dates of removal of all platforms are unknown. Guessing both of these items will cause more inaccuracies, than it will clarify the most cost effective modification.

The cash flow approach does not need all this information. Although this approach lacks, financially speaking, some important information, at this stage, in search of a cost effective modification, the cash flow approach is considered appropriate.

6.2. Topside removal rate

The most influential parameter, to determine the most cost efficient modification, is the income from topside removal. In order to be able to calculate the income of all platforms, a generalised income needs to be assumed. In this research the income for topside lifting is based on the weight of the topside.

The weight, to calculate a generalised income, will be based on the median topside weight of the database, starting with topsides at 10,000 tonnes. The distribution of the database is provided in Figure 3-1. The median of all topside weights will not suffer from the few very high weight topsides, which the vessel currently cannot lift. Therefore in this case the median will provide a suitable indication for the most probable topside weight compared to the average topside weight of the database. The median topside weight is 17,000 tonnes.

The PS is supposed to remove 6 platforms each half year (Berg, 2010). Combined with the daily costs of the vessel in heavy lift mode, as stated in paragraph 6.3.1, this, on average, means that the vessel has about €39,850,000 of total expenses during the removal of one platform.

To set the income per ton topside weight, there are three different possible scenarios;

- The removal price per ton increases with an increase in total topside weight. The number of contractors which are capable of removing the high weight topsides decreases with an increase in topside weight. With less competition the removal price could be higher.

- The removal price per tonne decreases with an increase in total topside weight. Based on the PS, the vessel does not have significant higher cost when the topside weight increases. This could result in a lower price per tonne but the total removal price will increase if the topside weight increases.
- A fixed rate per tonne topside weight. If both arguments of the previous two scenarios are combined, the increase and decrease of the price per tonne could cancel out.

Unfortunately no information is known about the market removal prices. Which makes it impossible to investigate if there is a relation between removal prices and the topside weight. To find a well-founded market price for platform removal, an individual removal price for all topsides need to be estimated. Secondly, the income is only a tool to find the most cost effective solution. Therefore the removal price is taken, in this project, as a fixed price per tonne topside weight. The price is set as the average cost of the vessel per tonne topside weight. This gives an estimated removal price per tonne topside weight of €2,350. The effect of the price per tonne will be assessed in the sensitivity analysis in chapter 8.

6.3. General costs

The general costs are cost items which are applicable for multiple or all modifications. These are items as the costs of the vessel, the increase of the costs of the vessel by the modification, shipyard costs and the price for construction steel.

6.3.1. Vessel costs

The costs of the vessel are used for two parts during the complete modification process. First the vessel will have to sail to the modification facility and second the vessel will be laid up for a certain period and at last the modified vessel need to be tested again. During this time the vessel will cost money on a daily basis, the daily costs of the vessel. To determine these costs, this paragraph starts with the operational profile of the vessel followed by the cost build-up of the vessel.

The operational profile of the vessel will be used to determine the costs of the vessel for topside lifting. The vessel has two purposes, heavy lift operations and pipe-lay. The prospectus is that the work will be divided in 50% platform handling and 50% pipe-lay. More information about the operational profile of the vessel can be consulted in Basis of Design document (Berg, 2010).

The daily costs of the PS are estimated, based on publications of analysts and educated guesses. At this stage it will be emphasised that these numbers are not provided by Allseas and are only used for an indication in this thesis. To calculate the daily costs of the vessel, the key-figures of Table 6-1 are used, together with the cost breakdown of the vessel's new building price from Table 6-2.

To be able to calculate the costs for the mortgage, but also for Allseas' own capital a Weighted Average Cost of Capital (WACC) (Investopedia, n.d.) is used. In this WACC, the tax is not taken into account.

$$WACC = \frac{Shareholders\ equity}{Total\ capital} \cdot cost\ of\ equity + \frac{Total\ debt}{Total\ capital} \cdot cost\ of\ debt$$

Equation 6-1

As mentioned, the exact distribution between shareholder equity and mortgage is not known. For this thesis the WACC is assumed to be 5%. The effect of the WACC will be assessed in the sensitivity analysis in chapter 8.

Description	
Lifetime	25 years
Weighted Average Cost of Capital	5,00%
Regular maintenance	1,0% of new value
Repair and replacement parts	1,5% of new value
Fuel price	€450/tonne
Scrap value	€88,000,000

Table 6-1: Key figures for daily costs of PS

Vessel part	Cost
Ship hull	€ 700,000,000
Heavy lift	€ 1,000,000,000
Pipe-lay	€ 600,000,000
Total	**€ 2,300,000,000**

Table 6-2: Estimated new building price

The daily cost of the PS consists of three parts; capital expenditures (CAPEX), operational expenditures (OPEX) and non-operational expenditures. These three parts covers most of the costs, relevant for the PS. A more detailed calculation is provided in Appendix C.

Capital expenditures	Cost [M€/year]
Repayment Ship	€ 28,000,000
Repayment heavy lift	€ 40,000,000
Repayment Pipe-lay	€ 24,000,000
Maintenance ship	€ 10,500,000
Maintenance Heavy lift	€ 15,000,000
Maintenance Pipe-lay	€ 9,000,000
Total annual expenses	**€ 126,500,000**

Table 6-3: Capex overview

Operational expenditures	Cost [€/year]
Fuel	€ 23,300,000
Personnel Heavy lift	€ 6,500,000
Personnel pipe-lay	€ 13,000,000
Maintenance ship	€ 7,000,000
Maintenance Heavy lift	€ 10,000,000
Maintenance Pipe-lay	€ 6,000,000
Depreciation	€ 88,500,000
Total annual expenses	**€ 154,300,000**

Table 6-4: Opex overview

Non-operational expenditures	Cost [€/year]
Interest Ship	€ 35,000,000
Interest heavy lift	€ 50,000,000
Interest Pipe-lay	€ 30,000,000
Total annual expenses	**€ 115,000,000**

Table 6-5: Other costs overview

In this daily cost calculation of the PS, not everything is included. For instance insurance and food for the crew are not listed. To cover for these excluded items, the daily cost of the vessel is increased by 10%.

With a division between heavy lift and pipe-lay of 50-50%, the daily cost for the PS is described in Table 6-6.

Daily cost of Pioneering Spirit	Cost [€/day]
Heavy lift – mode	€ 1,310,000
Pipe-lay – mode	€ 1,070,000
Average daily costs of the vessel	**€ 1,190,000**

Table 6-6: PS daily costs overview

When the vessel is laid-up, the fuel consumption of the vessel will be close to zero. Also the maintenance of the equipment can be neglected while unused and the regular maintenance to the hull will also be expected to be lower. In this case, the maintenance will be taken as 50% of the operational mode. Also a part of the crew is not needed when the vessel is laid-up. These reductions lower the average daily costs of the vessel to €940,000.00 when the vessel is laid-up.

The total duration of a modification is based on many things, which are all presented in this chapter. When multiple modifications are performed at once, the duration of these modifications cannot simply be added together. Some modifications can be performed simultaneously. To approach the total days of modification the following formula is introduced.

$$Days = longest\ duration\ of\ modification + \frac{\sum(duration\ of\ modificaton) - longest\ duration\ of\ modification}{2}$$

Equation 6-2

6.3.2. Increase of the vessels costs

During the modification of the vessel, equipment and steel work are added to the vessel. These components will increase the daily costs of the vessel. These costs are estimated within three categories; depreciation, financing costs and maintenance.

The standard expected lifetime of a vessel is about 25 years. The lifetime of the PS, as stated in chapter 3.1.1, is assumed to be longer, for topside removal purposes. This implies that the vessel requires a lifetime extending program if topsides are scheduled after this expected lifetime of 25 years. This lifetime extending program is not included in this analysis, but it is assumed that Allseas will use this vessel for more than 25 years, based on their current vessels and those of competitors.

For the costs of the modification, the modification will be assumed to take place around 2030. About 80% of the removal dates of the topsides, which currently cannot be decommissioned, are scheduled after 2030. It is also assumed that the lenders do not accept a longer period than the expected lifetime of the vessel. Without a lifetime extending program, this leaves a remaining 10 year to depreciate the vessel and repay the mortgage. Therefore, for these parts the period is assumed to be 10 years.

The costs of the total modification will be calculated in the same way as the cost for the hull itself (Chapter 6.3.1). For the financial costs of the modification a WACC of 5% is used. This cost will be added to the non-operational expenditures of the vessel.

The new installed components and steel will also need maintenance and repair. These costs are considered equal to the rest of the vessel, therefore the total maintenance is estimated on an annual 2.5% over the component costs, structural reinforcement costs and other costs which are not related to the modification itself, like facility costs (chapter 6.3.1).

These operational costs are only made to be able to remove some specific topsides. To recoup these expenses on only these additional topsides, the complete operational costs over a period of 10 years are divided over these additional topsides. These costs will be added to the daily costs of the vessel. This will prevent the vessel becoming more expensive for its current capabilities.

6.3.3. Labour costs

The modification needs to be carried out by shipyard workers, therefore a daily cost for this personnel is estimated at €30,000/day. This day-rate is based on 200 man, €150/day. The quantity of these workers is an educated guess.

The daily wages of the personnel is based on the average incomes in the Netherlands for shipyard personnel. According to Loonwijzer (Loonwijzer, 2015), a steel-worker earns about €2,350 a month, this would be for an employer about €35,500 per year (Berekenhet, 2015). Other specialized personnel is incorporated in the unit price.

In case multiple modifications are performed, each modification will have €30,000/day of labour costs, for their own duration.

6.3.4. Docking costs

The docking cost are taken into account for the modifications which require a dry-dock. For the cost of a dry-dock, two different scenarios are outlined; one for only the bow sections and a large one for at least half of the vessel. For reference prices the medium (275x40x10.30m) and the large dock (405x90x11.06m) of Keppel Verolme (Keppel Verolme, 2013) are used. These docks are too shallow for these operations, but will provide an adequate indication for the price.

	Small	Large
Daily costs		
Dock costs	€ 25,000	€ 120,000
General services	€ 20,000	€ 25,000
Daily total	€ 45,000	€ 145,000
Fixed costs		
Docking costs	€ 40,000	€ 60,000
Engineering docking	€ 25,000	€ 75,000
General services	€ 10,000	€ 10,000
Total initial costs	€ 75,000	€ 145,000

Table 6-7: Docking costs

When multiple modifications are performed at once, the duration of dock usage of these modifications cannot always simply be added together. Repositioning the bows and extending the bows both take place in a small dock. Therefore if these modifications are combined, the longest duration will be used as dock duration in this case. Widening the vessel along centreline will require a large dock. If this modification is combined with extending the bows, the extending the bows will also be performed in this large dock.

6.3.5. Construction steel

As concluded in chapter 4.1.1, the used material has a yield stress of 355MPa. In the previous chapter the total mass of additional steel is determined. For these large kinds of steel constructed blocks, an advised (by Allseas and field experts) fixed price of €2,500/tonne will be used to estimate the cost of the new blocks.

This type of steel will also be used to strengthen the structure of the vessel or TLS beam. The total price of the steel and the fabrication when strengthening will be higher than for new built blocks. The accessibility is a major factor in this price difference. To bring steel and welding equipment inside a structure, will take more time and with that higher cost per tonne. To cover the slower working progress, the price is assumed to be 50% higher, €3,750/tonne.

6.4. Modification specific costs

Some of the modification concepts require special components or modifications to components. These are the components which cannot be expressed only by the weight of the unit. Items which consist only out of steel, will be calculated by the steel price. The specific costs for items used in the four concepts, can be divided into;

- Topside lifting beam costs
- Pumping capacity costs
- Barges modification costs

6.4.1. Topside lifting beam

For the additional lifting beams, a price will be estimated. Allseas was not able to provide a fixed price for a TLS beam. Based on the known parameters and components, a price will be calculated. The price consists of two parts, start-up cost and costs per beam. The costs are provided in Table 6-8. The start-up costs concern amongst others the modification to the controls of the system.

The main component of the TLS beam is steel. The costs for this component are based on the weight of this steel. The total weight of the lifting beam, including the inboard and outboard support, is 2,550 tonnes. The total steel weight is estimated at 2,000 tonnes and the lever weight at 200 tonnes (Appendix L), which leaves a 350 tonnes for other equipment. The price of the construction steel will be based on chapter 6.3.5. The lever is a special casted item, therefore the normal construction price is not suitable for this component and a €5,000/tonnes rate is used.

Component	Price per beam
Construction steel	€ 5,000,000
Lever	€ 1,000,000
Cylinders / (pumping) equipment / cabling	€ 6,500,000
Installation	€ 200,000
Total per beam	€ 12,700,000
Start-up costs	€ 2,500,000

Table 6-8: Topside Lifting Beam price built-up

For the widening modification of the vessel, the beams need to be removed from the vessel in order to be extended and reinforced. This procedure requires additional equipment;

- Barge
- Tug
- Crane
- Self-Propelled Modular Transporter (SPMT)

The cost of this kind of equipment is estimated at €200,000 for off-loading and on-loading the TLS beam. This price is based on an educated guess.

6.4.2. Pumping Capacity

The vessel has a large volume of ballast water. To make sure the pumping capacity is adequate for the modified vessel, additional pumping capacity will be added if the tank volume is increased. This will prevent the pumping time to be unnecessarily extended during the pumping procedure. The additional expenses for pumping installations are estimated at be €100,000 for every 1000m^3.

The price for installing additional pumping capacity is based the price for a pump of online suppliers (Aliexpress, 2015). The complete installation of the pump, pipes, valves and electronics is assumed to be a multiple of the price of a pump.

6.4.3. Widening barges

As stated in chapter 5.3.1, if the vessel is widened, the barges needs to be widened as well. Without going into too much detail for this additional modification, only the cost for steel, the docking costs and the labour costs are included into the costs overview, see Table 6-9. The docking costs are based on the large dock, so both barges can fit simultaneously. The duration is estimated at 30 days for all modifications, because only the new block needs to be added to the barges.

Width increase [m]	4	8	12
Combined modification weight barges [ton]	2,500	5,000	7,500
Steel costs	€ 6,250,000	€ 12,500,000	€ 18,750,000
Docking costs	€ 4,500,000	€ 4,500,000	€ 4,500,000
Labour costs	€ 1,000,000	€ 1,000,000	€ 1,000,000
Total modification costs	**€ 11,750,000**	**€ 18,000,000**	**€ 24,250,000**

Table 6-9: Modification costs of the barges

6.5. Consideration of widening method

As stated in earlier chapters, the choice of widening procedure, would be based on costs. The modification with the lowest costs will be selected. With all costs known, this consideration can now be made. For an overview of the costs, only the costs which are different for both modifications are presented in Table 6-10 and Table 6-11.

Slot width increase	4m	8m	12m
Dock	€ 10,875,000	€ 10,875,000	€ 10,875,000
Transport	€ 28,500,000	€ 28,500,000	€ 28,500,000
Weight increase	€ 13,000,000	€ 26,000,000	€ 39,000,000
Pumping	€ 1,330,000	€ 2,660,000	€ 3,990,000
Structure	€ 825,000	€ 1,765,000	€ 2,625,000
Total	**€ 54,530,000**	**€ 69,800,000**	**€ 84,990,000**

Table 6-10: Total costs for widen the vessel along centreline

Slot width increase	4m	8m	12m
Dock	€ 3,750,000	€ 3,750,000	€ 3,750,000
Transport	€ 7,500,000	€ 7,500,000	€ 7,500,000
Weight increase	€ 6,575,000	€ 13,555,000	€ 20,955,000
Pumping	€ -	€ -	€ -
Structure	€ 5,665,000	€ 10,315,000	€ 16,295,00
Total	**€ 23,490,000**	**€ 35,120,000**	**€ 48,500,000**

Table 6-11: Total costs for widen the vessel by relocating the bows

As the difference in modification costs shows, relocating the vessels bows costs less than widening the vessel along the centreline. A significant difference is introduced by the transport cost of the vessel. Although even when discounting this item from the equation, the financial benefit is still in favour of relocating the bows of the vessel. Therefore this widening procedure will be used in further costs analysis.

6.6. Summary

In this research we simplified the finances by not taking into account the future cost and income with a discount rate with a net present value (NPV). Here we only look at the cash flow of the costs and income of the modification. To implement a NPV, a discount rate would have to be estimated as well as the moment the topsides would be removed. This will implement many uncertainties, which the cash flow method does not suffer from.

The income from topside removal activities is based on the daily costs of the vessel and the average weight of a platform. In this calculation, the time per topside is based on the information that the vessel is supposed to remove 6 platforms in half a year. To be able to convert the daily costs of the vessel to a price per tonne, a topside weight needs to be used. The weight, to calculate a generalised income, is based on the median topside weight of the database, starting with a topside weight of 10,000 tonnes. This gives an estimated removal price per tonne topside weight of €2,350.

In this chapter, all relevant cost items for the modification concepts are estimated. The most common items are summarized in Table 6-12. Based on these costs and the corresponding quantity of chapter 5, the costs for every single modification can be calculated. In the next chapter these costs will be combined with the possible income from the expansion of the range of topsides.

Cost item	Cost / unit	Application
Daily costs		
Heavy lift mode	€ 1,310,000/day	Test of modified vessel
Average daily costs	€ 1,190,000/day	Sailing costs
Lay-up costs	€ 940,000/day	Vessel costs while modified
Labour costs	€ 30,000/day	
Steel building blocks	€ 2,500/tonnes	
Reinforcement steel	€ 3,750/tonnes	
TLS beam	€ 12,700,000/unit	

Table 6-12: Summary cost items

In chapter 4 and chapter 5, two modification concepts to widening the vessel are considered to be viable based on the known information. Based in the cost information of this chapter, the benefit over the complete range of slot width increase is in favour of widening the vessel by relocating the bows.

7. The most cost effective modification

With all the information of the previous chapters the most cost effective conversion of the Pioneering Spirit can be calculated. From chapter 3, all platforms the vessel is currently unable to lift are identified. The conversion and the associated costs of the vessel, are examined in the chapters 4 to 6. From this chapter, all four modification concepts are combined into one modification which is applied to the vessel.

In this chapter the income from the additional market is key parameter. Based on the income and the costs form previous chapters, the financial result of the modification and the return on investment will be calculated. These parameters are calculated for different combinations of modifications and based on these parameters the most cost effective modification will be specified.

7.1. Comparison parameters

The modifications need to be compared to each other, based on their income, modification costs and costs in operation. The modifications cannot only be compared on their profit, this will not take the costs proportional to the income into account, but only the summation. A large modification with high conversion cost, is most likely to have a high turnover. The profit of this modification could possibly turn out higher than for a small modification. However, proportionally to the investment, a smaller modification could perform better. Therefore the primary comparison will not be based on the total profit.

The comparison between the modifications is based on two parameters; the return on investment (RoI) and the financial result. The RoI indicates the efficiency of the investment (Investopedia, n.d.). Value's lower than 1.00 are an indication that the conversion will cost more than it will bring in. The value can be interpreted as a factor that is to be applied over the invested capital to obtain the total return.

$$Return\ on\ Investment\ (RoI) = \frac{Income - cost\ during\ operation}{Investment} \qquad \text{Equation 7-1}$$

In case the RoI is equal for different modifications, the financial result of the modification will be the decisive factor. Based on these two parameters, the most cost effective modification will be selected.

A break even in the total costs of the modification and the income does not indicate that Allseas will not have any financial benefits. In the daily costs of the vessel, the WACC is inserted. This WACC does include the margin on Allseas own equity.

7.2. Modification combinations

There are four modification concepts, which will be combined into one combination of modifications. The boundaries of these concepts are based on the extreme requirements of the platforms (chapter 3.2), which the vessel is currently not able to remove. The combination of all possibilities will also contain modification which could not be possible, like no extension of the bows with 16 additional TLS beams. Also some modifications will not lead to additional potential platforms and are not meaningful at this moment. These modifications are removed to reduce the total number of modifications to compare. In Table 7-1 the boundaries of each modification is listed. This results in 46,800 possible modification combinations. Only 317 different combinations of topsides can be identified, which all require a unique modification.

Topside property	Modification	Maximum value	Step value	Possibilities
Topside weight	Additional TLS beams	16	2	9
Length	Extension	60m	2.5m	25
Width	Widening	15m	1.0m	16
Air gap	connection bridge	12m	1.0m	13
Total combinations*				**317**

Table 7-1: Database boundaries

7.3. Financial performance of modifications

For all 317 modifications, the costs and income are calculated. In Figure 7-1 the investment and income are plotted against each other. The most striking aspect of this picture is the diversity of the income for each investment. There are modifications which have an over four times higher income with the same investment as other modifications. Based on these two parameters, the better performing modification are the upper dots of the group.

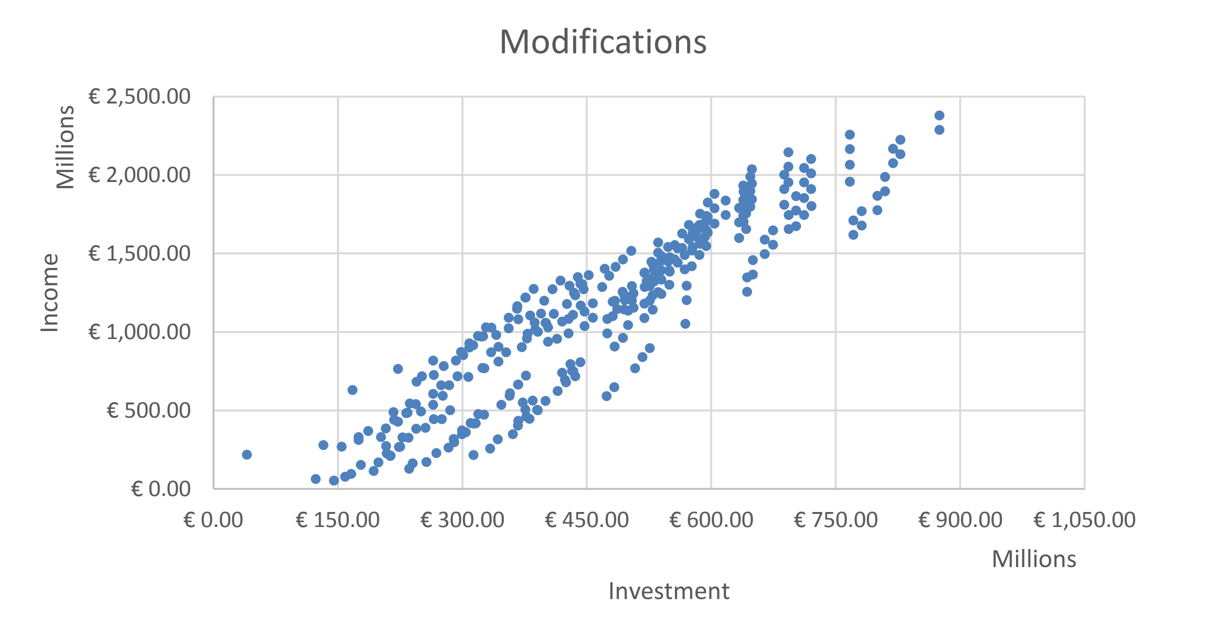


Figure 7-1: Financial performance of modifications - Income

The overview in Figure 7-1 does not include future costs. For a complete overview of all costs of a modification, the future costs need to be included to gather the return on investment (RoI) and financial result of the modification. When the investment is plotted against the RoI, a more clear indication of the financial performance is obtained. In Figure 7-2, two groups can be identified, based on the RoI.

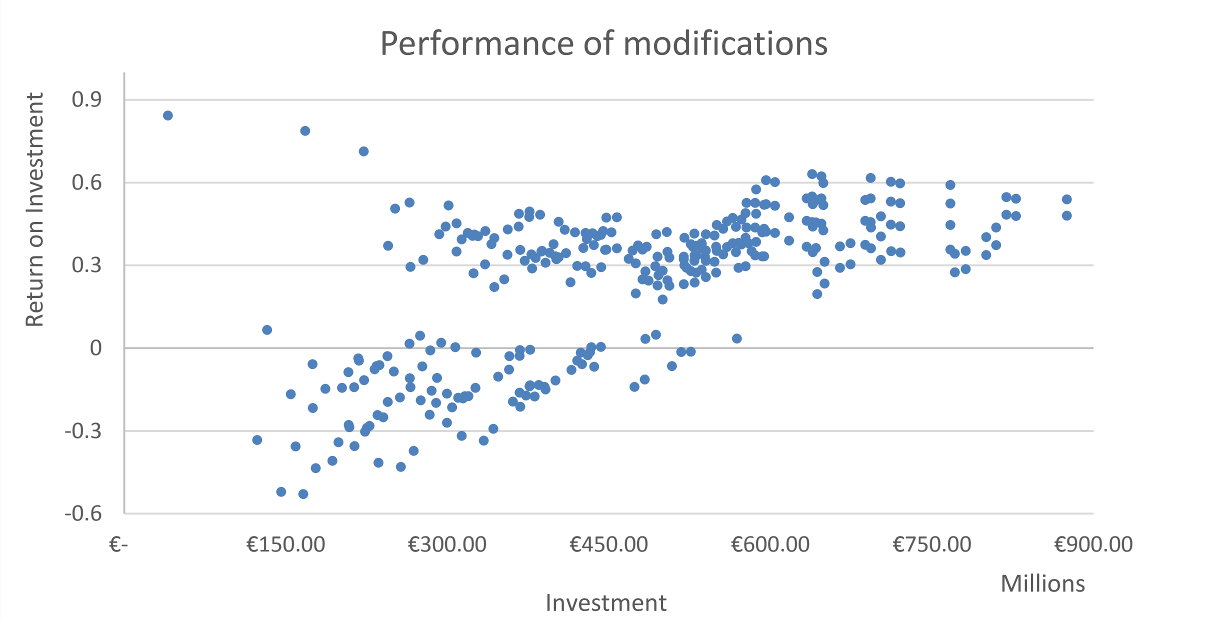


Figure 7-2: Financial performance of modifications - RoI

Figure 7-1 and Figure 7-2 do not provide information about the composition of the modification. This paragraph will elaborate on which modifications are within a certain region. To start, an overview of the occurrence of each modification step within all 317 modifications is provided. For additional TLS beams, a step contains two beams and for extending the bows is performed in steps of 2.5m while widening is per meter. The occurrence is followed by an indication which modification concept represents each point within Figure 7-2 and Figure 7-1.

Although the future costs are not taken into account in Figure 7-1, the upper dots, or modifications, are in general still the better performing modifications in terms of RoI and vice versa. Some modifications are highly affected by the vessel's daily costs, during the removal of the topsides. This influences on the RoI.

7.3.1. Occurrence of adding topside lifting beams

The first modification concept is to add additional TLS beams to increase the topside lifting capacity. In Table 7-2 the occurrence of each step of adding TLS beams is presented.

TLS beams	Occurrence	% Occurrence
0	42	13%
2	57	18%
4	57	18%
6	18	6%
8	36	11%
10	48	15%
12	18	6%
14	27	9%
16	14	4%

Table 7-2: Occurrence of TLS beams steps

In Figure 7-3 all modifications which contain additional TLS beams are indicated. This graph shows that additional TLS beams do not occur quite often in the cheapest modifications. A TLS beam is an expensive piece of equipment, it also requires a bow extension which explains the presence of this modification in the high investment ranges. Overall, the modifications with additional TLS beams perform better than without.

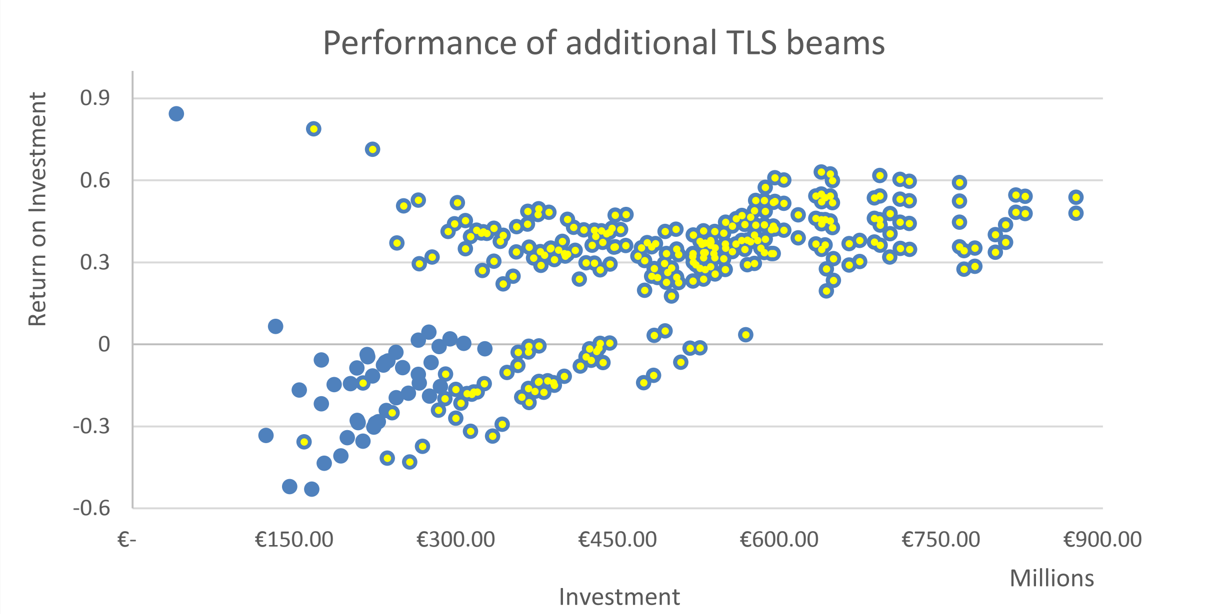


Figure 7-3: Performance of additional TLS beams

In Table 7-3 the occurrence of most common TLS beam modification is presented. All 317 modifications are grouped into groups of 50 modifications, starting with the best performing modification, based on the RoI. The most common modification step per group is highlighted in this table.

Modification group	Lowest number of additional beams	Highest number of additional beams	Most common number of additional beams	Occurrence of most common value	% Occurrence of most common value
0 - 50	0	16	10	15	30%
50 - 100	2	16	2	13	26%
100 - 150	2	16	10	12	24%
150 - 200	2	16	8	12	24%
200 - 250	0	16	4	12	24%
>250	0	6	0	29	12%

Table 7-3: Occurrence of the most common TLS beam modification within modification groups

From the above tables and figure it can be concluded that over 85% of all modifications include adding TLS beams. Also, within almost all modification groups of 50 platforms, based on the RoI, between 0 or 2 and 16 TLS beams are added.

Based on this information, it can be concluded that in the 50 financially best performing modifications, 10 additional beams is most common. The occurrence of 10 additional beams in this best performing group is almost twice as high as it is in the overall database.

For the modifications with low RoI, no additional TLS beam is most common. This occurrence is about the same as it is in the overall database. Although, it cannot be concluded that adding more TLS beams will increase the financial performance of the modification.

7.3.2. Occurrence of slot length extension

The second modification concept is to increase the slot length to make room for larger topsides and more lifting beams. In Table 7-4 the occurrence of length steps is presented.

Extension [m]	Occurrence	% Occurrence
0.0	43	14%
2.5	50	16%
12.5	38	12%
20.0	18	6%
35.0	24	8%
40.0	9	3%
45.0	94	30%
55.0	27	9%
60.0	14	4%

Table 7-4: Occurrence of length steps

In Figure 7-4 all modifications which contain the extension are indicated. This graph shows that additional extension is less common in the cheapest modifications. Also the RoI is quite low for low investments with a length extension. This effect could be explained by the fact that topsides which require a small length modification are quite light and are low in number, while the larger and more expensive modifications contain multiple concepts and contain more and more heavy topsides.

Figure 7-4: Performance of extension

In Table 7-5 the occurrence of most common extension is presented. All 317 modifications are grouped into groups of 50 modifications, starting with the best performing modification, based on the RoI. The most common modification step per group is highlighted in this table.

Modification group			Lowest extension [m]	Highest extension [m]	Most common extension [m]	Occurrence of most common value	% Occurrence of most common value
0	-	50	0	60	45	20	40%
50	-	100	0	60	45	15	30%
100	-	150	0	60	45	20	40%
150	-	200	0	60	45	19	38%
200	-	250	0	60	45	13	26%
>250			0	45	0	24	10%

Table 7-5: Occurrence of the most common length modification within modification groups

From the above tables and figure it can be concluded that over 85% of all modifications contains an increase of slot and rail length. Also, within almost all modification groups of 50 platforms between 0 and 45 or 60 meters of length is added.

Based on this information, the most common value is 45m extension, in both over all modification as in almost all modification groups. The occurrence of 45m extension in this best performing group is even 10% higher as it is in the overall database. However, no conclusion can be drawn about the existence of a relation between the increase of length of the slot and the financial performance of a certain modification.

7.3.3. Occurrence of slot widening

The third modification concept is to increase the slot width. In Table 7-6 the occurrence of width steps is presented.

Widening [m]	Occurrence	% Occurrence
0	24	8%
1	25	8%
2	25	8%
4	36	11%
5	36	11%
7	8	3%
8	39	12%
9	39	12%
10	46	15%
14	39	12%

Table 7-6: Occurrence of width steps

In Figure 7-5 all modifications which contain widening of the slot are indicated. This graph shows that an increase in slot width is present over almost the complete range of modifications. There is also no relation between the RoI and the presence of widening.

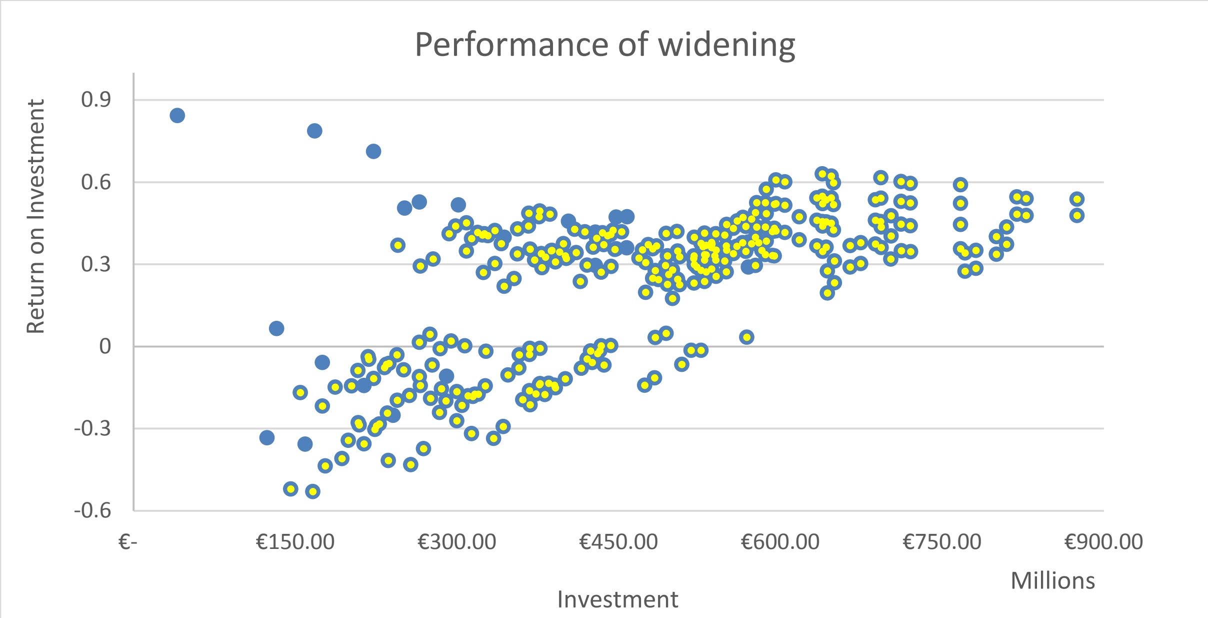


Figure 7-5: Performance of widening

In Table 7-7 the occurrence of the most common width step modifications within a group of modifications is presented. All 317 modifications are grouped into groups of 50 modifications, starting with the best performing modification, based on the RoI. The most common modification step per group is highlighted in this table.

Modification group	Lowest widening [m]	Highest widening [m]	Most common widening [m]	Occurrence of most common value	% Occurrence of most common value
0 - 50	0	14	9	13	26%
50 - 100	0	14	9	10	20%
100 - 150	0	14	14	10	20%
150 - 200	0	14	4	9	18%
200 - 250	0	14	10	9	18%
>250	0	14	4	14	6%

Table 7-7: Occurrence of the most common width modification within modification groups

From the above two tables it can be concluded that over 90% of all modifications contains an increase of slot and rail length. Also, within all modification groups of 50 platforms between 0 and 14 meters of width is added.

Based on this information, the most common value is between 8 and 14m, 50% of all modifications contains these widening concepts. However, no conclusion can be drawn about the existence of a relation between the increase of the slot width and the financial performance of a certain modification.

7.3.4. Occurrence of use of Connection Bridge

The last modification concept is to increase the maximum height of the TLS system, in order to remove topsides with a high air gap. Over 75% of all modifications contain a connection bridge. In Figure 7-6 all modifications which contain the connection bridge are indicated. This graph shows that all modifications with a connection bridge are in the higher region of RoI, independent of the investment. This indicates that use of the connection bridge will always positively influence the performance of the modification.

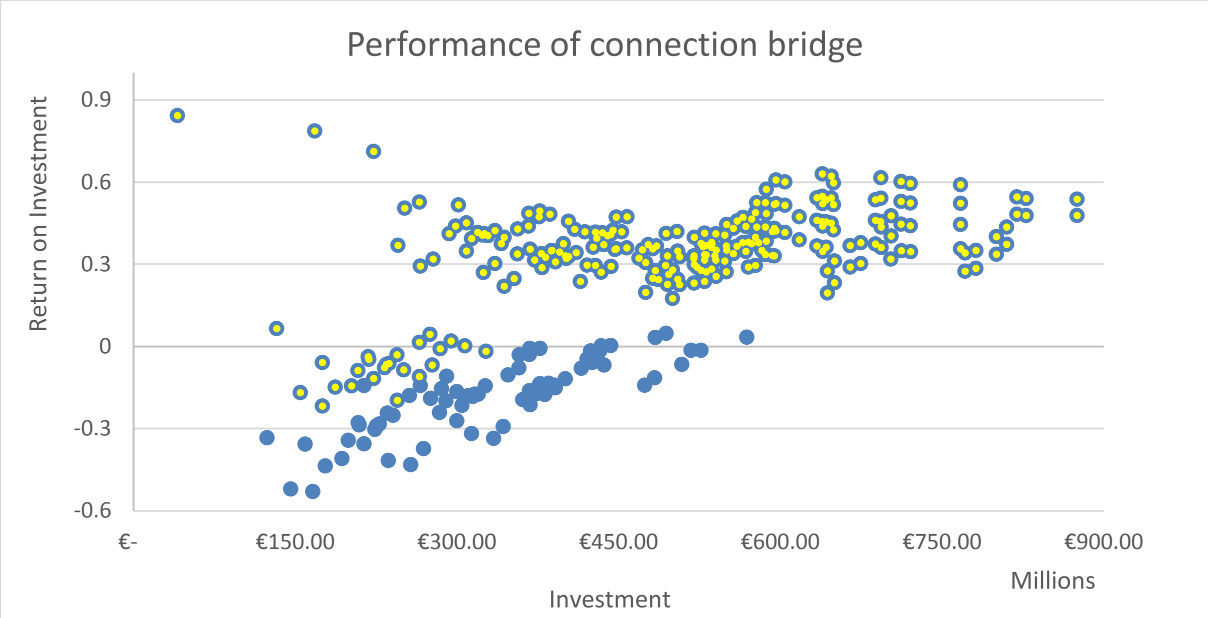


Figure 7-6: Performance of connection bridge

In Table 7-8 the occurrence of applying a connection bridge within a group of modifications is presented. The distinction between use of a connection bridge or not is denoted with "Yes" and "No" in this table. All 318 modifications are grouped into groups of 50 modifications, starting with the best performing modification, based on the RoI. The most common modification step per group is highlighted in this table.

Modification group			Most common use of connection bridge [m]	Occurrence of most common value	% Occurrence of most common value
0	-	50	Yes	50	100%
50	-	100	Yes	50	100%
100	-	150	Yes	50	100%
150	-	200	Yes	50	100%
200	-	250	Yes	33	66%
>250			No	55	82%

Table 7-8: Occurrence of the most common width modification within modification groups

As shown in Table 7-8, based on this information, all 200 best performing modifications contain a connection bridge. Below that, the modifications perform much less, based on their RoI. This can also be seen in Figure 7-6.

7.3.5. Top five most cost efficient modifications

In the previous paragraph it is concluded that there is not always a direct relation between a modification and its extend to the financial performance. In this paragraph the composition of the top five most cost efficient modifications will be looked into on a deeper level.

The specifications of all five modifications are provided in Table 7-9 and their performance in Table 7-10. A detailed cost calculation of modification five is provided in appendix 0 to provide more insight in the calculation method and modification application.

Modification			# Additional platforms	Investment	Total costs
1	Extension	-	4	€ 40,500,000	€ 222,100,000
	Widening	-			
	Additional TLS beams	-			
	Connection bridge	Yes			
2	Extension	-	10	€ 168,000,000	€ 664,900,000
	Widening	-			
	Additional TLS beams	2			
	Connection bridge	8m			
3	Extension	2.5m	12	€ 222,500,000	€ 827,000,000
	Widening	-			
	Additional TLS beams	2			
	Connection bridge	Yes			
4	Extension	45.0m	28	€ 638,800,000	€ 2,166,300,00
	Widening	9.0m			
	Additional TLS beams	12			
	Connection bridge	Yes			
5	Extension	45.0m	29	€ 647,300,000	€ 2,230,700,000
	Widening	10.0m			
	Additional TLS beams	12			
	Connection bridge	Yes			

Table 7-9: Top-5 most cost efficient modifications

Modification	Income	Financial result	RoI
1	€ 215,800,000	- € 6,300,000	0.84
2	€ 629,300,000	- € 35,600,000	0.79
3	€ 763,300,000	- € 63,800,000	0.71
4	€ 1,930,400,000	- € 235,900,000	0.63
5	€ 1,986,800,000	- € 243,900,000	0.62

Table 7-10: Performance most cost efficient modifications

7.3.6. Required topside removal rate

At the start of chapter 7.3, it was already clear that the calculated removal rate of 2,350 per tonne topside weight, is not enough to cover all the costs of the modifications. The minimum required removal rate can be calculated by dividing the total costs by the total topside weight for each modification. This shows that the best performing modification, with only connection beams installed, required about €2,420 per tonne topside to break even. In Figure 7-7 all 317 modifications and their minimum removal rates to break even are plotted. These modifications are ordered by their original RoI, starting with the best performing modification. There are in total over 50 modifications that requires less than €2,800 per tonne topside weight to break even, which is about 20% more than the original €2,350.

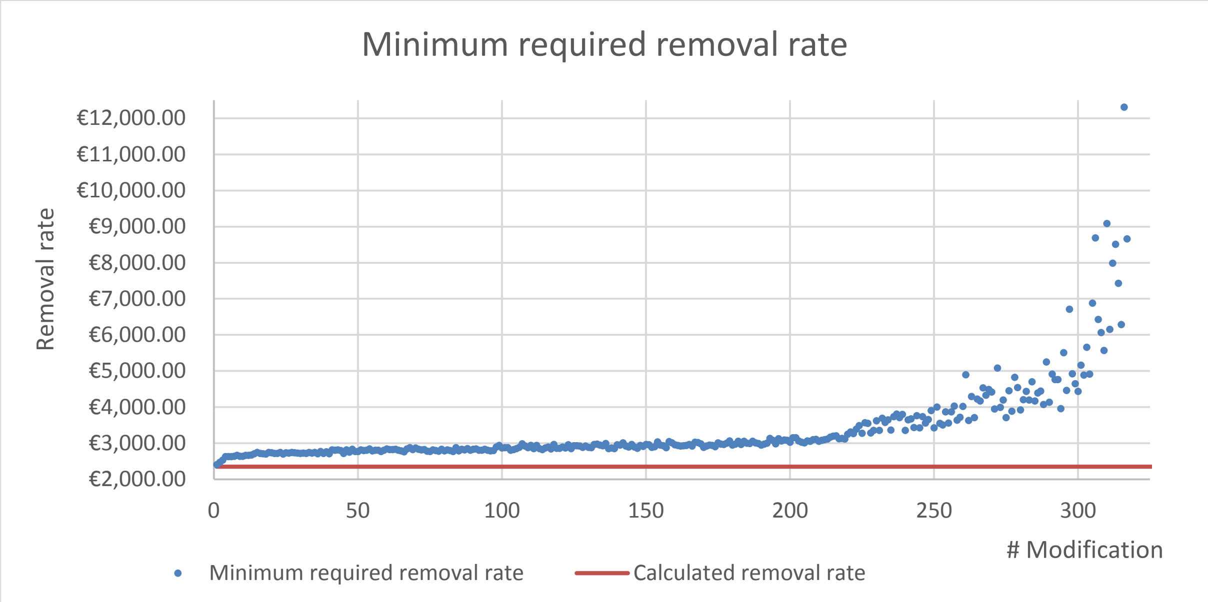


Figure 7-7: Minimum required removal rate

7.4. Summary

To be able to compare the modifications on a ratio between the investment, running costs and income, two key figures are used. The return on investment (RoI) (Equation 7-2), which indicates the efficiency of the investment and the financial result. In case the RoI is equal for two modifications, the financial result will be decisive.

$$\text{Return on Investment (RoI)} = \frac{\text{Income} - \text{cost during operation}}{\text{Investment}} \qquad \text{Equation 7-2}$$

To obtain the total number of combinations of modifications, the bandwidth for each modification is based on the extreme requirements by the platforms. This provides about 46,800 individual combinations, although some of these combinations are physically impossible and thus the actual number of modification will be lower. Combining all possible modifications with the database of potential topsides, only 317 different combinations of topsides can be identified, which all require a unique modification.

The most clear relation between financial performance and applying a concept is for the connection bridge. All modifications which contain a connection bridge perform better than without. For additional TLS beams, modifications with additional beams perform, in general, better than without. However, there is a group with additional beams which perform significantly less that the others. The last relation can be found by extending the bows, these modification perform better when the total investment increases. For widening the slot, no relation could be found.

Based on the input parameters, costs and income, the calculated removal rate turned out to be too low to cover all the costs. With an increase of 20%, the financial result of more than 50 modifications turns positive.

The most cost effective modification is a small modification with only the connection bridge. This bridge has a height of 8m, which is the most cost effective height to carry the load. This modification enables the system to lift four additional platforms. With a minimum removal rate of €2,420 per tonne topside weight, the financial result will be positive.

8. Sensitivity analysis

In this project, various values are estimated. These values are of influence on the results as presented in chapter 7. To understand the influence of these assumptions, a sensitivity analysis will be performed to the most influential factors of the equation. In total there are four major parameters which have a severe influence on the financial performance of a modification. This chapter provides information about the robustness of the results. Also, the recommendations will be based on these results.

The four parameters which are expected to have a severe influence on the result are:

- Weighted Average Cost of Capital — Income and costs
- Database — Income
- Steel price and steel weight — Costs
- Modification duration and lay-up costs — Costs

In this chapter, these four parameters will be varied to see the influence of each. To indicate the robustness of the sequence of best performing modifications, the return on investment (RoI) for all modifications is compared for different values of each of these four parameters. Secondly, three modifications are used to provide an indication of the influence of each parameter on the minimum required removal rate. The first modification is the best performing modification of chapter 7, it only contains connection bridges. The second modification is the third best modification from chapter 7. The third best is chosen over the second best because the second best is very similar to the first modification. The third modification analysed is the largest modification of the of the top five best performing modifications. The three modifications that are analysed are displayed in Table 8-1.

Modification	Extension [m]	Widening [m]	Additional beams	TLS	Connection bridge
1	-	-	-		Yes
2	2.5	-	2		Yes
3	45.0	10.0	12		Yes

Table 8-1: Modification overview for sensitivity analysis

8.1. Weighted Average Cost of Capital

The Weighted Average Cost of Capital (WACC) is used to indicate the cost of the total capital invested in the Pioneering Spirit. This capital is a combination of Allseas' own equity and third parties. This cost is a significant portion of the daily costs of the vessel. The daily cost is, as will be presented in paragraph 8.4, in its turn a significant part of the total modification costs.

The daily cost of the vessel is an input parameter of the removal rate. Therefore, by changing the WACC, the income will change as well. In Figure 8-1 the RoI of all modifications are presented for four different WACC rates. A WACC of 5% is used in the previous calculations. With a change of the WACC, the costs will rise faster than the income. In this graph some shifts in the RoI ranking can be identified. The large drop of the RoI of the first modification, the best performing modification with only connection beams, is very noticeable. With a 10% WACC, this modification would not reach the top-10 best performing modifications. This modification is quite small as well as the group of topsides, therefore the daily costs of the vessel are a significant part of the complete costs.

The impact of a change in the WACC, to the RoI, increases by worst performing modifications. The worse a modification performs, the higher the relative loss. The increase of the WACC has more effect on modifications with a high relative loss, because it increases the costs more than the income.

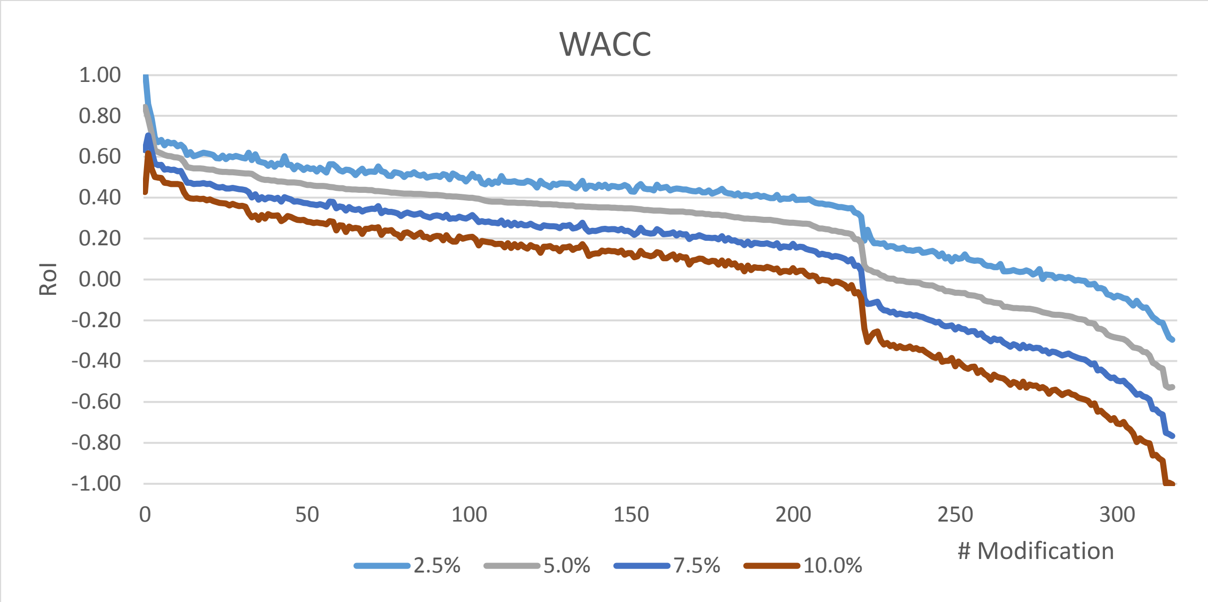


Figure 8-1: Weighted Average Cost of Capital

8.2. Database

As stated in paragraph 3.1.2, over 50% of the required information was not available in the platform database. The missing platforms could also contain potential platforms for the modifications. The influence of the total number of platforms is not only related to the amount of platforms, the topside weight is even more important.

Given the information of the database, it cannot be predicted in which group the platforms that miss information will be. Therefore, the influence of the completeness of the database is examined by applying a factor to the total topside weight a modification is able to remove. Because the removal costs, approximately €39,850,000, also need to be included proportionally to the increase in platforms, are they multiplied by the same factor.

The range, to multiply the total potential market for each modification, is taken between an additional -25% and 100%. Since the total database lacks over 50% of the required data, it seems to be an appropriate start. It is also possible that not all platform owners choose for the Pioneering Spirit, the effect is displayed by a reduction of 25% of the potential platforms.

In Figure 8-2 the RoI of all modifications is presented for five different changes of the potential market. The baseline, 0% change, is used in the previous calculations. With an in- or decrease, all RoI's change as expected over the complete range of modifications. There are only a few modification with a deviating character. At about modification 40 there are some modifications which scale significantly less with an increase of the potential market. In general, the sequence of the modification, based on RoI performance, remains the same independent to the change of potential market.

The impact of a change of the potential market, to the RoI, decreases by worst performing modifications. The costs, used in the RoI, consists of removal cost based on the original vessel and costs concerning the modification. The removal costs scales with the change of the group of potential platforms, which equals the income. A small result of the income minus the removal cost, compared to the investment, results in a low RoI. Doubling this low value will have less impact than doubling a high value.

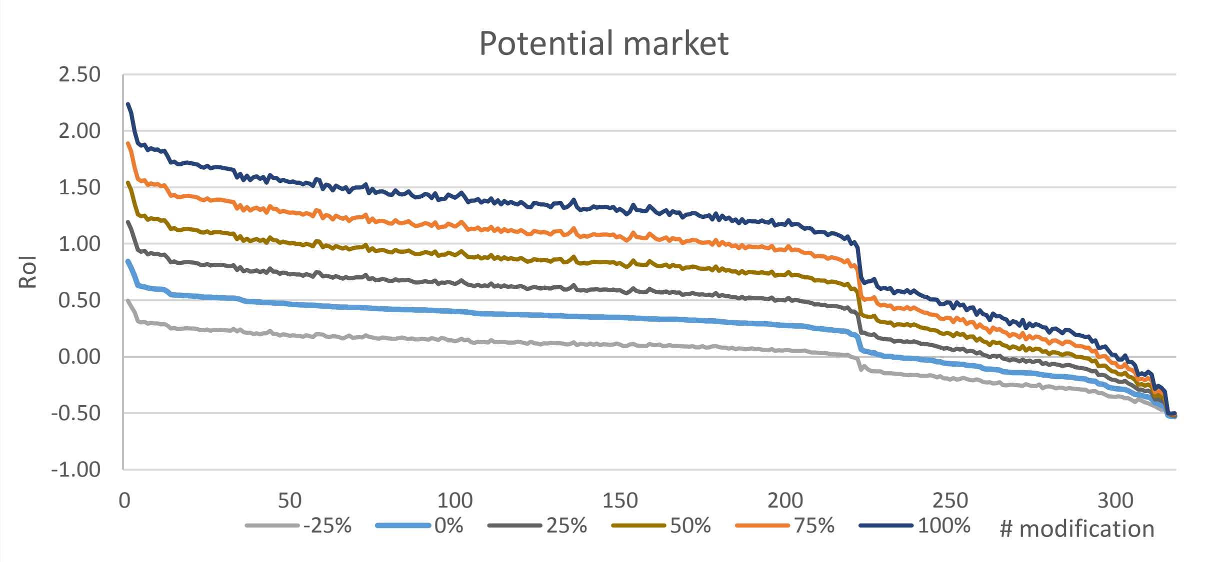


Figure 8-2: Potential market

In Figure 8-3, the impact of the potential market to the three highlighted modifications is shown. In this graph the lines represent the minimum required removal rate per tonne for a modification to break even. With an increase of between 10% and 30% of the potential market all three modifications are at their break-even point with the original removal rate of €2,350 per tonne. For all modifications the removal rate can be reduced by increasing the potential market. Although there are large differences between the sizes of modification 2 and modification 3, with a market increase of about 50% the minimal removal rate of both modifications is equal.

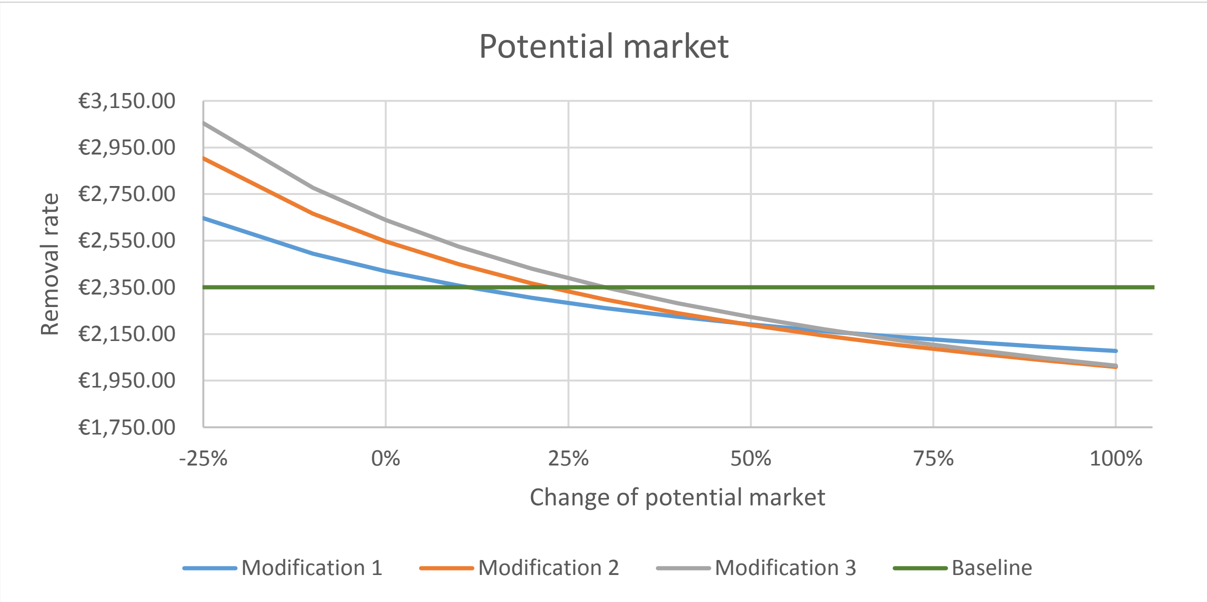


Figure 8-3: Potential market – minimum required removal rate

8.3. Steel price

Every modification requires additional steel, some to modify the hull and others to increase the hull's strength. This makes the price of steel per tonne a very important parameter. This part also tests the influence of the amount of required steel. By applying a factor to the complete price of all steel parts, this can be interpreted as an increase of the steel price, or as an increase of the amount of steel.

In Figure 8-4 the RoI of all modifications is presented for five different steel prices. The baseline, €2,500 per tonne, is used in the previous calculations. With an in- or decrease, all RoI's change as expected over the complete range of modifications. However, there is a remarkable difference in the performance of the modifications, based on RoI. The difference is usage of the amount of steel. Modifications with a low portion of steel on the total modification costs, are less influenced than modifications with a high portion of steel.

The impact of a change of the steel price, to the RoI, decreases by worst performing modifications. This phenomenon cannot be assigned to the input parameters or modifications, but is the effect of the calculation method used for the RoI. A lower RoI means a low fraction, an increase of the steel price leads to more increase of the investment than the running costs which has less effect on smaller RoI's. In case the RoI is negative, the upper part of the fraction is negative. Increasing the investment will increase the running cost. Because the income minus the running costs is already negative, the upper part of the fraction will, in absolute numbers, increase. This results in a very small or almost no influence on the negative RoI.

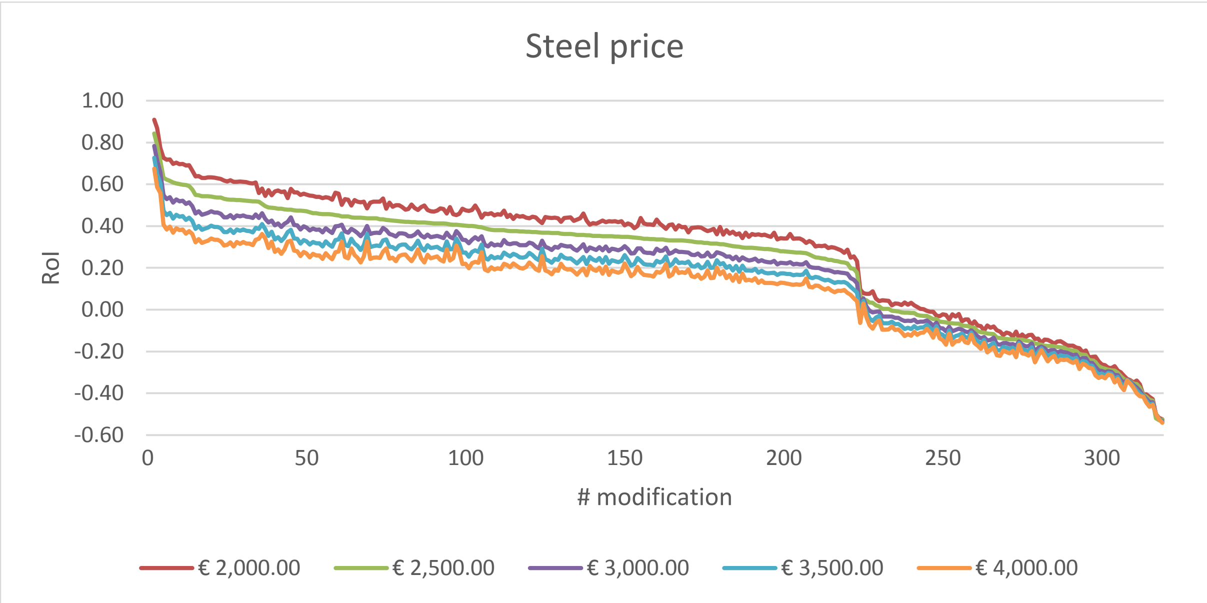


Figure 8-4: Steel price

In Figure 8-5, the impact of the steel price to the three highlighted modifications is presented. In this graph the lines represent the minimum required removal rate per tonne for a modification to break even. As the graph shows, the steel price needs to be unreasonably low before a modification will be at its break-even point with the original removal rate of €2,350. On the other hand, the modification result is greatly affected by an increase of the steel price. The slope of the lines are an indication of the amount of steel used in each modifications.

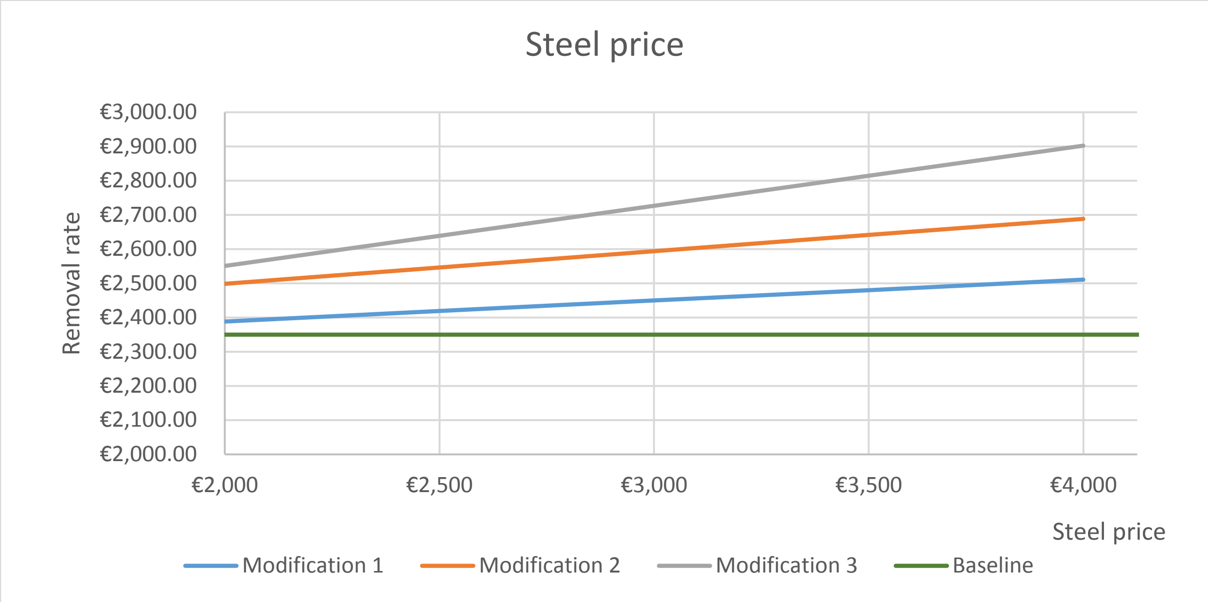


Figure 8-5: Steel price - minimum required removal rate

8.4. Modification duration

The duration of the lay-up time of the vessel is an influential parameter as well. Sometimes the lay-up costs of the vessel take up almost 50% of the total modification costs. The influence of this parameter will be more significant on larger modifications than on smaller modifications.

In Figure 8-6, the impact to the RoI of the modification is presented for all modifications. The RoI of the baseline, 0% change, is used in the previous calculations. With an in- or decrease, all RoI's change as expected over the complete range of modifications. But, there is a remarkable difference in the performance of the modifications, based on RoI. This can be appointed to the duration of the original modification. Modifications with a long duration are more sensitive to a change in duration than others.

The impact of a change of the duration, to the RoI, decreases by worst performing modifications. This phenomenon cannot be assigned to the input parameters or modifications, but is the effect of the calculation method used for the RoI. A lower RoI means a low fraction, an increase of the duration leads to a higher increase of the investment than the running costs which has less effect on smaller RoI's. In case the RoI is negative, the upper part of the fraction is negative. Increasing the investment will, increase the running cost. Because the income minus the running costs is already negative, the upper part of the fraction will, in absolute numbers, increase. This results in a very small or almost no influence on the negative RoI.

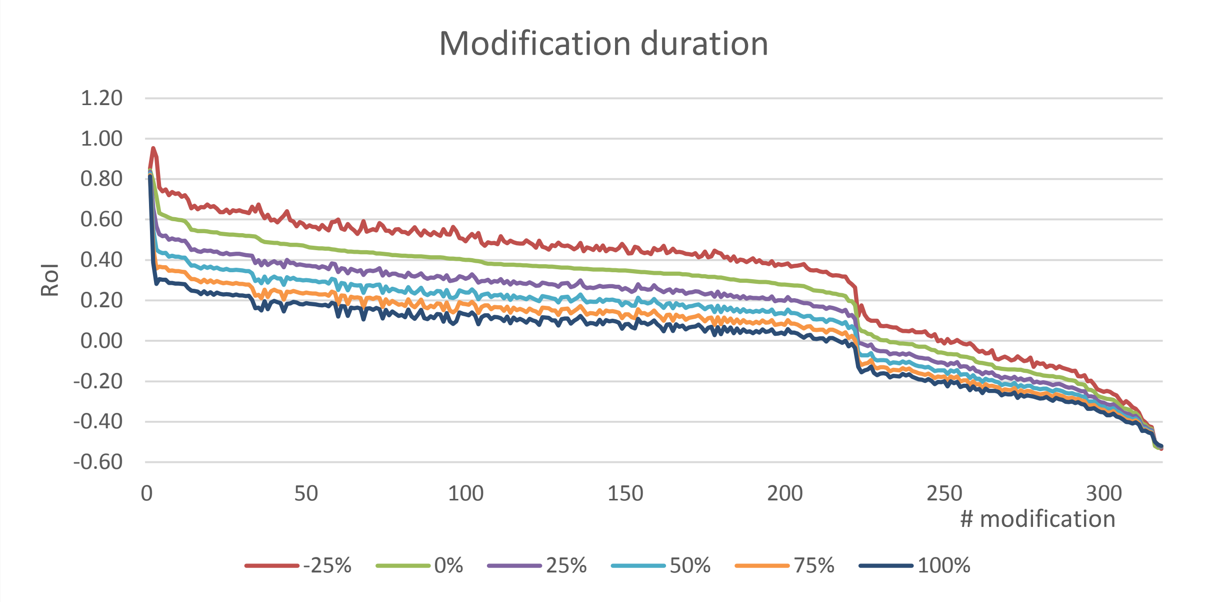


Figure 8-6: Modification duration

In Figure 8-7, the impact of the duration of the modification to the three highlighted modifications is presented. In this graph the lines represent the minimum required removal rate per tonne for a modification to break even. As can be seen in the graph, the duration needs to be unreasonably low before the modification will be at its break-even point with the original removal rate. The smallest modification (1), with only the connection bridge has almost no change in removal rate if the duration is doubled. This is because the duration of installing the connection bridges is very short. The increase of the removal rate of modification 3 is lower than for modification 2, while the duration is more than twice as long. This is due to the significant larger group of topsides of modification 3. The costs, influenced by the duration is divided over a large total topside weight.

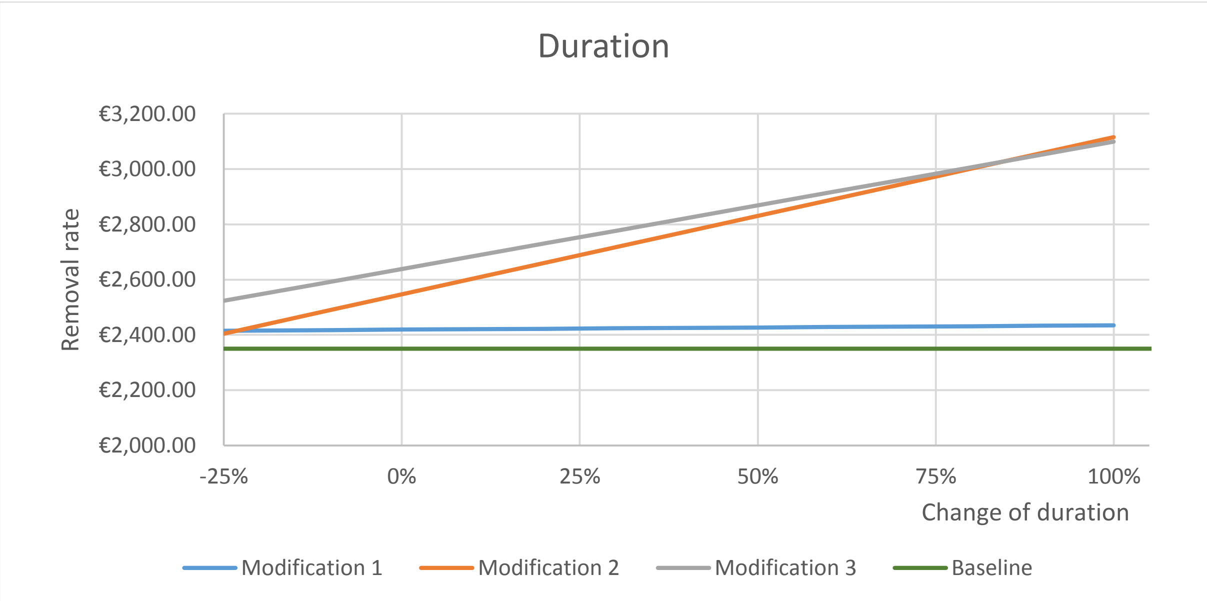


Figure 8-7: Duration - minimum required removal rate

8.5. Summary

In this project, various values are estimated. These values are of influence of the results as presented in chapter 7. To understand the influence of these assumptions, the four major parameters are adjusted to see the severity of the influence on the performance of a modification. The information, obtained in this chapter, provides information for recommendations for future research.

The four parameters which are expected to have a severe influence on the result, are;

- Weighted Average Cost of Capital — Income and costs
- Database — Income
- Steel price and steel weight — Costs
- Modification duration and lay-up costs — Costs

An increase of the WACC leads to lower RoI values of the modifications. The WACC is of influence on the daily costs of the vessel and the removal rate is based on the daily costs. Therefore income, investment and removal costs are all influenced by the RoI. The best performing modification is quite dependent on the WACC. With a WACC of 5% it is not even in the top-10 with a WACC of 10%.

The change of the group of potential platforms rapidly changes the modification results. In general, the sequence of the modification, based on RoI performance, remains the same independent of the change of potential market. With an increase of 50% of the potential group, more than 50 modifications are above their break-even point. Combining the increase of the potential market with the minimum required removal rate, shows a strong reduction of the removal rate with an increase of the potential market. The minimum removal rate of two modifications were almost even, while the modifications were completely different.

The change of the steel price per tonne had an expected effect on the result of the modifications. The portion of steel differs between all the modifications, this results in different impacts by changing the steel price. The result is that the best performing modification is dependent on the steel price.

The change of the duration of a modification had a similar effect as the steel price. The portion is affecting the change of the financial result.

9. Conclusions and discussion

The financially best performing modification to the Pioneering Spirit in order to extend its topside lifting capabilities is sought, where financially best performing is defined by the highest return of investment.

The topside lifting capabilities of the Pioneering Spirit are limited firstly by the topside lifting system and its rail length. They are also limited by the dimensions of the vessel and its components: the slot length and width, the draught of the vessel and the length position of the deckhouse. Last but not least, the topside lifting capabilities are limited by the vessel's structure and motions.

Of the 46,800 combinations of modifications to extend these limitations, 317 are actually feasible and have a unique group of potential platforms to lift.

The most cost effective modification is installing connecting beams on the TLS.

Based on the input parameters, costs and income, the calculated removal rate turned out to be too low to cover all the costs. With an increase of the removal rate to €2800, about 20%, the financial result of more than 50 modifications turns positive.

The sensitivity study shows that the weighted average combined costs of capital has a higher impact to modifications with a lower return on investment (RoI). The completeness of the database, the steel price and the duration of the modification each have a significant influence on the financial performance with a higher RoI. However, the sequence of the modifications, based on their RoI performance, show only small changes within all four parameters. Except for the WACC, the best performing modification, based on a WACC of 5%, did not reach the top 10 best performing modifications with a WACC of 10%.

For the best performing modification, installation of the connection bridges, decreasing the WACC with 2,5% would result in no financial benefit or loss, a return of investment of 1.0. The return of investment would also be positively influenced, if the potential market increases. With an increase of 20%, over 50 modifications will have a positive financial result. A reduction of the steel price, or needed steel weight, can positively influence the financial performance. However, the steel price needs to be unreasonably low to turn modifications into a positive financial result. The duration of the lay-up does not have a significant influence on the best performing modification, however for most modifications the influence of the duration is a significant factor for the performance, but is unlikely to turn any financial result into positive.

9.1. Discussion

The outcome of this thesis is based on various assumptions. The usefulness can be improved by applying more accurate figures.

9.1.1. Performance limiting factors

The performance limiting factors are identified so they could be applied to the platform database. These required fixed values do not take the specific shape of the topside or substructure into account. Some topsides might be categorized as potential topsides, however, when looking into detail, it is possible that these topsides can be decommissioned without any modifications, merely by changing the removal procedure.

The maximum lifting capacity is determined at 30,000 tonnes. With the ongoing modifications to the TLS beams, the maximum lifting capacity is likely to change. An alteration in the maximum lifting capacity will have a significant impact on both the potential market as well as the proposed modifications.

9.1.2. Potential market

As concluded in paragraph 3.1.2, over 50% of the relevant information about topsides and their substructures is not available. As shown in chapter 8.2, the influence of the total number of potential platforms on the financial performance of a modification is very large. A complete database could result in a different outcome of this research.

Also the accuracy of the topside weight is doubtful, there was no information available to verify the accuracy of the topside weight. If the topside weight of the potential topsides differ from the values in the database, different financial results are expected.

In this thesis the focus is on removing topsides. However, the vessel is built to install topsides as well. As has been previously shown in other markets, if the supplier can handle larger object the new build units will be larger as well. The possibility to install larger platforms as well is not included in this thesis, because of the high uncertainty. That does not mean that it is not a potential market for the vessel.

9.1.3. Daily costs of the Pioneering Spirit

The daily costs of the Pioneering Spirit are calculated based on various assumptions. The daily costs have a significant impact on the outcome of the modifications. If these assumptions turn out different in reality, the financial performance of a modification will differ.

9.1.4. Income

To be able to weigh the different modifications on their financial performance, the income from topside removal needs to be available. The income is obtained by implementing a fixed removal rate per tonne topside weight (Chapter 6.2). This generalisation of all platforms was necessary to simplify the research and have a workable income parameter.

For future research, better results can be obtained by applying a unique removal price for each individual topside. In this removal price estimation, the costs of the use of the Pioneering Spirit need to be taken into account as well as the competitor prices. This will provide a more realistic removal price for each topside.

9.1.5. Influence of other vessel capabilities by modifications

As stated in the introduction, the other vessel capabilities, such as jacket lifting and pipe lay, may not be negatively be affected by these modifications. Although the functionality of these systems are looked into, the modifications and additional adjustments for these systems and equipment may not be sufficient.

For future research, specialists concerning this equipment need join this research to provide adequate information about these systems and how they should be modified if necessary.

10. Recommendations

Based on the input parameters as chosen in this research, the most cost effective modification is installing connecting beams on the TLS. However, it is recommended to expand the research, in order to eliminate some uncertainties, before making any modification decisions. Apart from that, a recommendation is given to compare the financials with the possibilities of building a second ship and a time frame to complete the modifications is recommended.

10.1. Uncertainties

In order to be able to recommend any specific modifications, the uncertainties need to be reduced. As discussed in the previous chapter, the performance limiting factors, the potential marked, daily costs and income all contain uncertainties that could influence the outcome of this research. Therefore the first recommendation is to clarify these parameters.

Especially more accurate performing limiting factors and potential market would be beneficial to the accuracy of the financial performance of the modifications.

10.2. Modification to Pioneering Spirit or second vessel

At the same time as this research started, Allseas also initiated to look into the possibilities of building a second vessel. This research is focussed on the modification of the Pioneering Spirit.

It is recommended for Allseas to compare the modifications to the Pioneering Spirit with a new concept vessel. This comparison should not only contain the performance limiting factors of each vessel, or number of topsides the vessel can lift. Cost and income should be included in the comparison in order to find the most optimal financial solution.

Besides the performance of the vessels, the benefits of having two vessels need to be taken into account.

10.3. Time of modification

The provided database also contains an indication of the expected removal date of the topsides. In Figure 10-1 a timetable of the removal period of all topsides is provided.

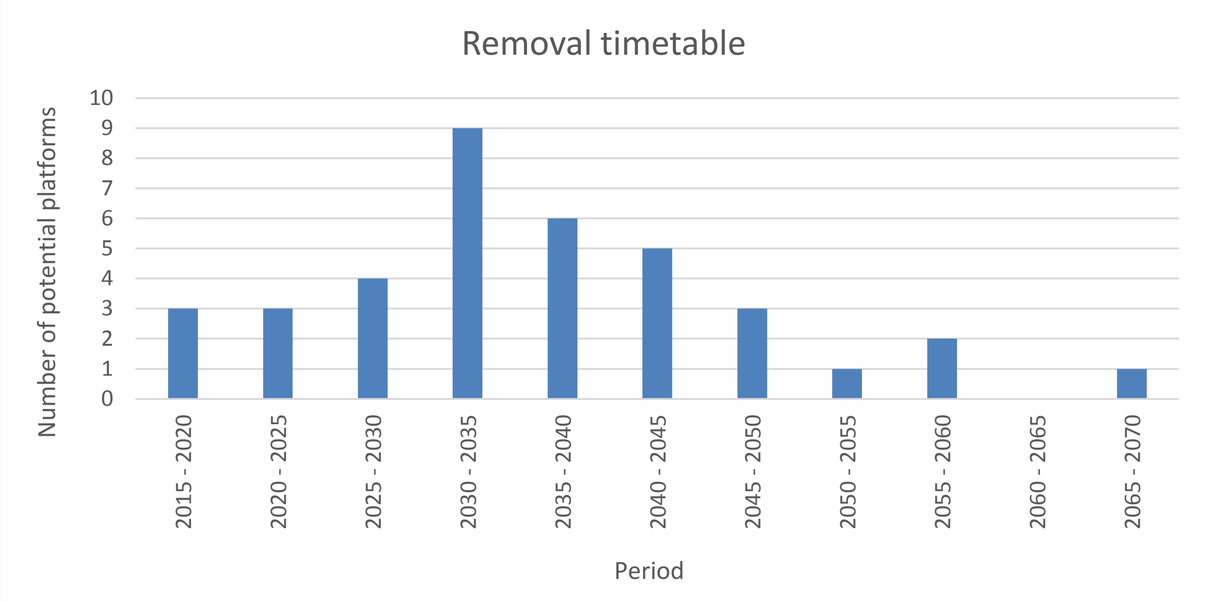


Figure 10-1: Removal timetable

The platform owners have the possibility to extend this removal date, the Norwegian Petroleum Directorate provided this information for some platforms. In Figure 10-2 this information is presented.

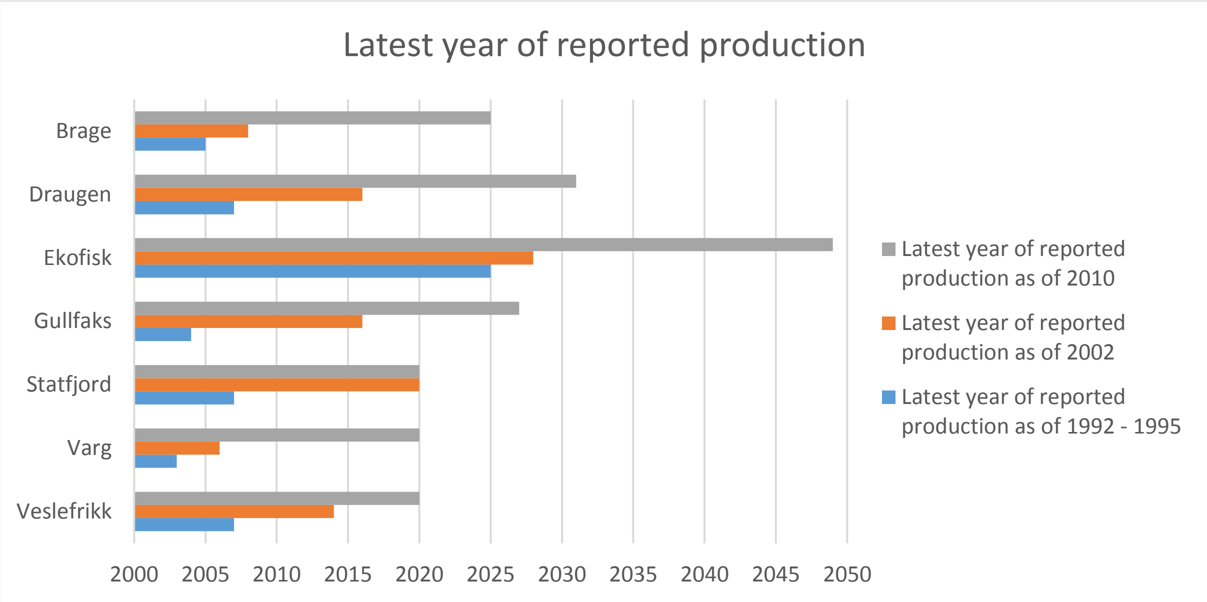


Figure 10-2: Change of latest year of reported production (Norwegian Petroleum Directorate, 2011)

At this moment the best indication can be obtained by the database. However, it should be taken into account that this information is subject to change.

Although the year of removal of the first topside of a modification is highly dependent on the modification itself and the corresponding group of potential platforms, about 75% of all platforms needs to be decommissioned after 2030. Based on this information it is recommended to complete any modification before this date.

Bibliography

Aliexpress, 2015. *Aliexpress.* [Online]
Available at: nl.aliexpress.com
[Accessed 10 12 2015].

Allseas, 2013. *TLS - Extreme positions minimum outreach (Loaded condition), PI-321V1-112-M-G-001 Rev. wA,* s.l.: s.n.

Allseas, 2014. *General Arrangement,* sl: DSME.

Allseas, 2014. *Pieter Schelte - TLS- LCA Module, PI-323v8-610-S-G-026 Rev.01.* s.l.:s.n.

Allseas, 2015. *PI-321V1-112-M-G-007 Rev.wA.* [Illustraties] (Allseas).

Ansys, 2016. *Ansys Aqwa.* [Online]
Available at: http://www.ansys.com/Products/Other+Products/ANSYS+AQWA
[Accessed 13 04 2015].

Azom, 2014. *A36 steel.* [Online]
Available at: http://www.azom.com/article.aspx?ArticleID=6117
[Accessed 29 02 2016].

Berekenhet, 2015. *Loonkosten voor de werkgever.* [Online]
Available at: http://www.berekenhet.nl/ondernemen/loonkosten-werkgever.html
[Accessed 25 10 2015].

Berg, E. v. d., 2010. Design citeria. In: *Pieter Schelte - Basis of Design, PI-10110-021-N-F-001 Rev. F.* s.l.:Allseas, p. 30.

DSME, 2014. *General Arrangement - PI-10130-103-N-A-001 Rev.Z1,* sl: DSME.

DSME, 2014. *General Arrangement - PI-10130-103-N-A-002 Rev.Z1,* sl: DSME.

Emmerik, M. V. & Kuiper, P., 2015. *Pieter Schelte - TLS - Technical description, PI-321V1-022-M-F-001 Rev.k,* s.l.: Allseas.

Hibbeler, R., 2007. Mohr's circle. In: *Engineering Mechanics Statics.* Singapore: Pearson Education, p. 658.

Infield, 2015. *Infield The Energy Analysts,* London, UK: Infield.

Investopedia, n.d. *Depreciation.* [Online]
Available at: http://www.investopedia.com/terms/d/depreciation.asp
[Accessed 04 2015].

Investopedia, n.d. *Return on Investment - RoI.* [Online]
Available at: http://www.investopedia.com/terms/r/returnoninvestment.asp
[Accessed 24 09 2015].

Investopedia, n.d. *Weigthed Average Cost of Capital - WACC.* [Online]
Available at: http://www.investopedia.com/terms/w/wacc.asp
[Accessed 27 11 2015].

Keppel Verolme, 2013. *Werffaciliteiten.* [Online]
Available at: http://www.keppelverolme.nl/nl/over-ons/werffaciliteiten
[Accessed 25 10 2015].

Korean Register, n.d. *Shipyards in Korea,* s.l.: s.n.

Kuiper, M., 2014. *Pieter Schelte - TLS - Technical description, PI-321V1-022-M-F-001 Rev.F,* s.l.: Allseas.

Lammeren, J. v., 2014. *PS Loading Condition Tool, HL-106-120-PE-EG-0102-LCT.* [Illustraties] (Allseas).

Lloyd's Register, 2013. Hull strucutral steel. In: *Rulefinder version 9.20.* s.l.:Lloyd's.

Loonwijzer, 2015. *Salaris check.* [Online]
Available at: www.loonwijzer.nl/home/salaris/salarischeck
[Accessed 25 10 2015].

Metalprices, 2015. *Steel/Iron scrap.* [Online]
Available at: http://www.metalprices.com/metal/steel-iron-scrap/fe-eastern-no-1-heavy-melt
[Accessed 04 2014].

Norwegian Petroleum Directorate, 2011. Development and Operation. *Facts,* p. 150.

Scheepvaartwest, 2014. *Lorelay - IMO 7349807.* [Online]
Available at: http://www.scheepvaartwest.be/CMS/index.php/dredgers-workboats/4761-lorelay-imo-7349807
[Accessed 29 02 2016].

Ship and Bunker, 2015. *IFO380 in Rotterdam.* [Online]
Available at: http://shipandbunker.com/prices/emea/nwe/nl-rtm-rotterdam#IFO380
[Accessed 04 2015].

Soetens, M., 2014. *TLS - System load curve, PI-321V1-020-M-R-003 Rev.A,* s.l.: Allseas.

Soetens, M., 2015. *TLS - System load curve, PI-321V1-020-M-R-003 Rev. B,* s.l.: Allseas.

Subsea World news, n.d. *www.subseaworldnews.com.* [Online]
Available at: http://subseaworldnews.com/wp-content/uploads/2012/07/Norway-Apply-S%C3%B8rco-Bags-Subsea-Modifications-Contract-from-Statoil.jpg
[Accessed 15 01 2016].

Vogelaar, M., 2015. *Overview Yoke foundation and stabilisatoin frame - PI-321V1-100-Z-Z-008 Rev.A.* [Illustraties] (Allseas).

Wikipedia, 2015. *Solitaire (schip, 1972).* [Online]
Available at: https://nl.wikipedia.org/wiki/Solitaire_(schip,_1972)
[Accessed 29 02 2016].

Wikipedia, 2016. *Thialf (schip, 1985).* [Online]
Available at: https://nl.wikipedia.org/wiki/Thialf_(schip,_1985)
[Accessed 29 02 2016].

Yeo, J. B., 2014. *Detailed weight calculation report, PI-10120-400-W-R-001 Rev.wQ,* s.l.: DSME.

Appendix A. The Pioneering Spirit

Lay-out of Pioneering Spirit

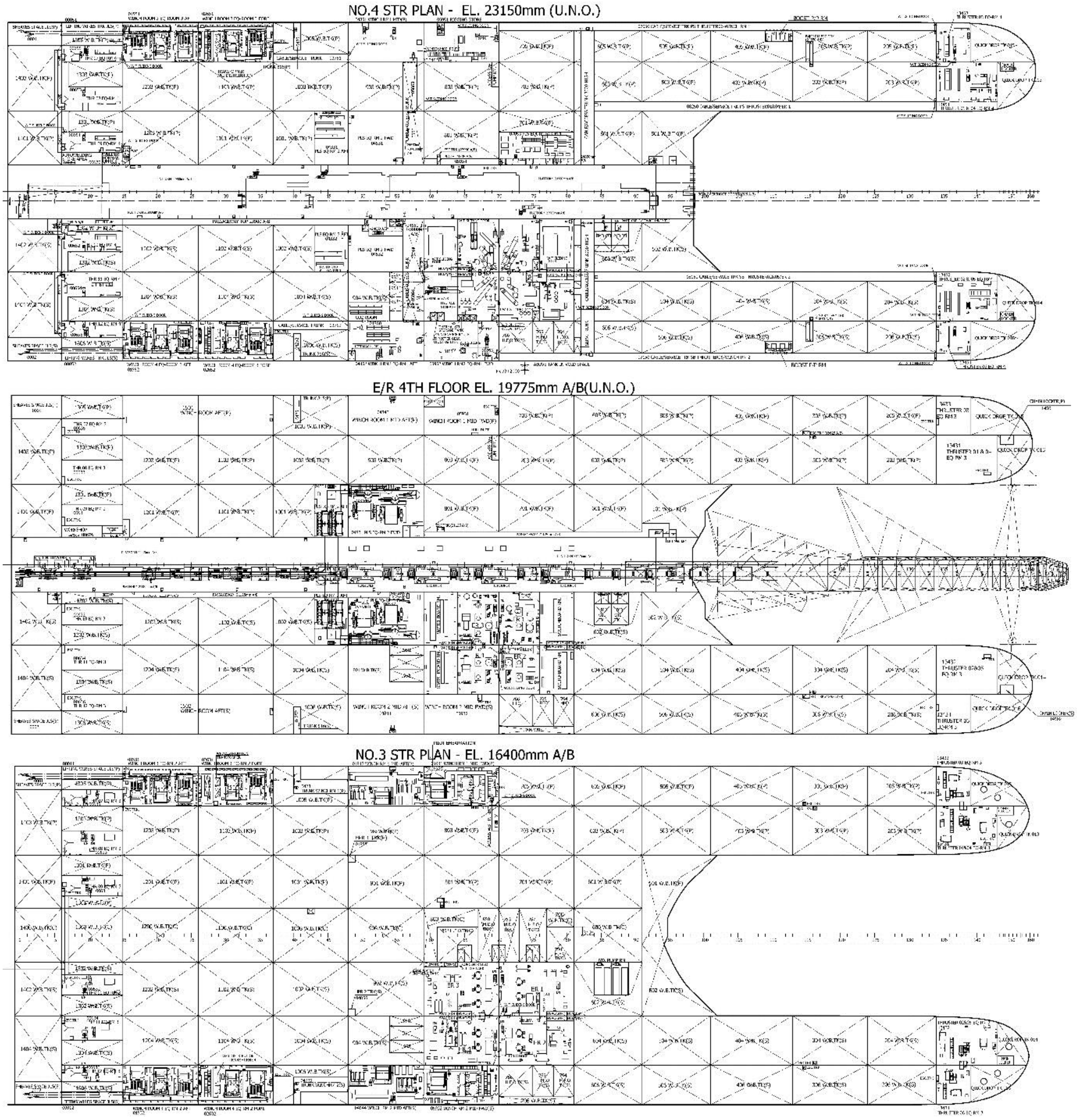


Figure A-1: General arrangement, decks 16400/19775/2315 of Pioneering Spirit (DSME, 2014)

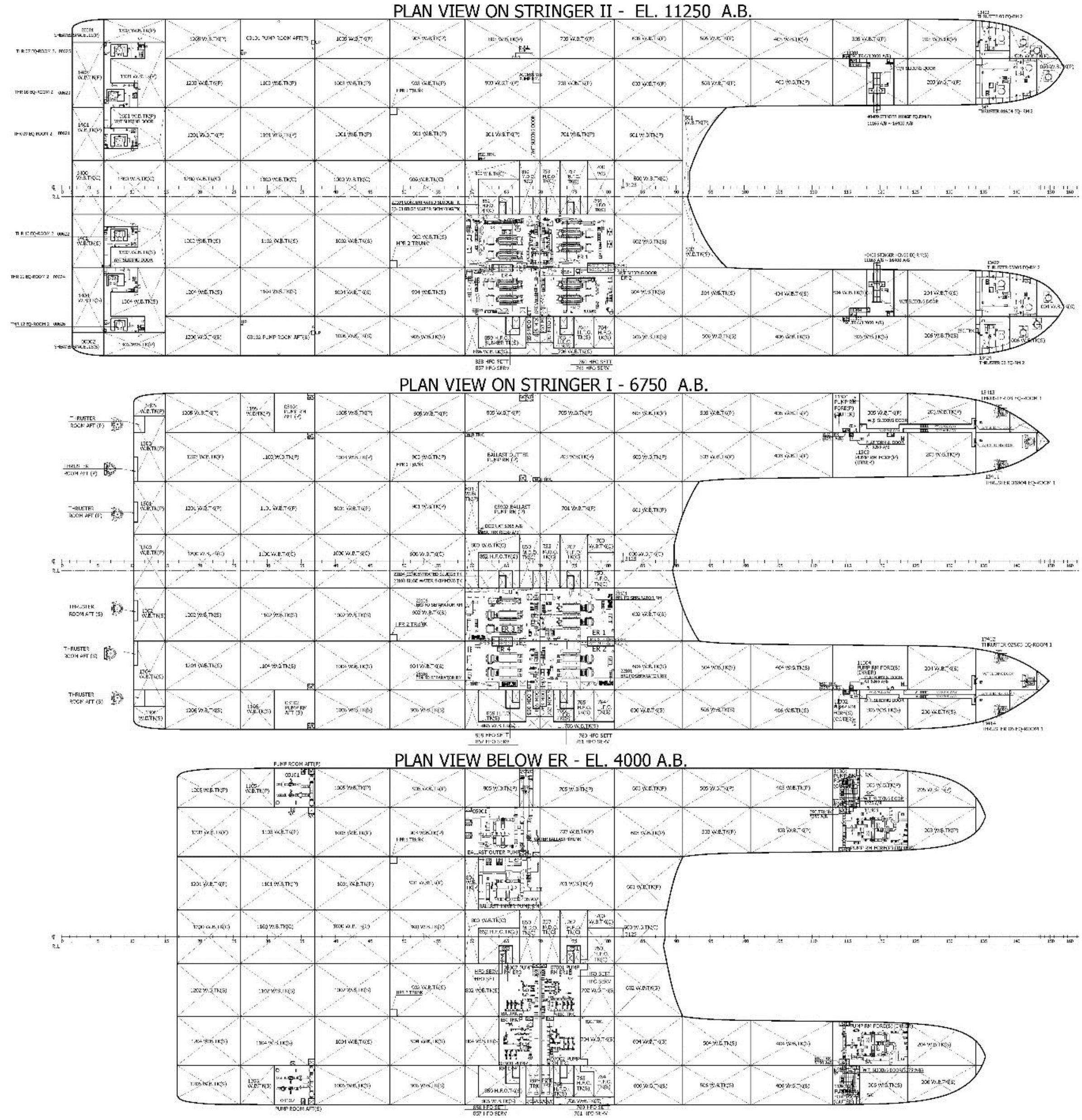


Figure A-2: General arrangement, decks 4000/6750/11250 of Pioneering Spirit (DSME, 2014)

Vessel specifications

The size of the vessel is the result of the need to lift large and heavy topsides and the long pipe-lay fabrication line. The detailed dimensions of the vessel are given in Table A-1.

Description	Abbreviation	Value (m)
Length over all	L_{oa}	382.00
Length perpendicular	L_{pp}	370.00
Width	W	123.75
Depth inside	D_i	30.00
Depth outside	D_o	29.00
Maximum draught	T_{max}	27.00
Slot length	L_s	122.00
Slot width	W_s	58.75
Deck area	A_{Deck}	39,600m^2

Table A-1: Vessel dimensions

Lightship weight summary Pioneering Spirit

Assembly	Weight (T)	Rolling Margin (T)	% of the Lightship
Hull and Tanks	143743.9	4312.3	58.20
Lifting Appliance	68431.3		27.71
Navigation and Nautical Equipment	2268.5		0.92
Equipment for Crew	7840.3		3.17
Machinery Main Components	3071.0		1.24
System for Machinery Main Components	2291.5		0.93
Ship Common Systems	9922.3		4.02
Production Equipment	8477.2		3.43
Welding	945.0		0.38
Nominal weight (N)	246991.0	4312.3	100
Building Margin (N*0.01)	2469.9		
Lightship Weight	**249460.9**		

Table A-2: Lightship weight of Pioneering Spirit

Appendix B. TLS describing figures

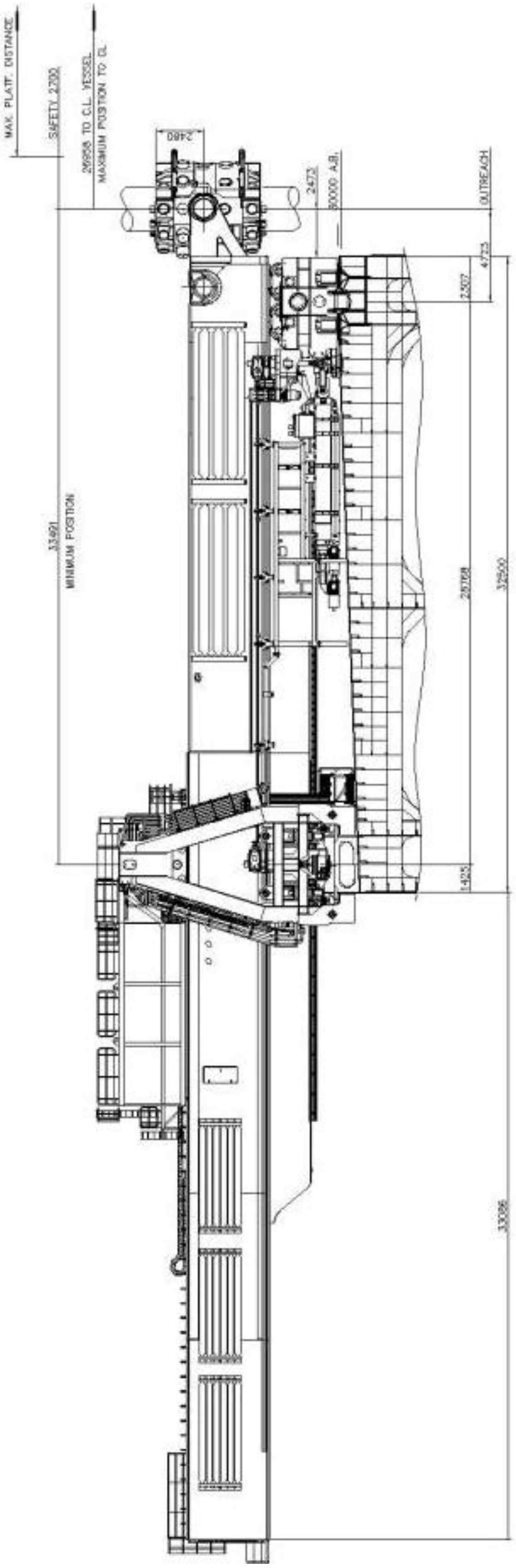


Figure B-1: TLS on transverse bow-section (Allseas, 2013)

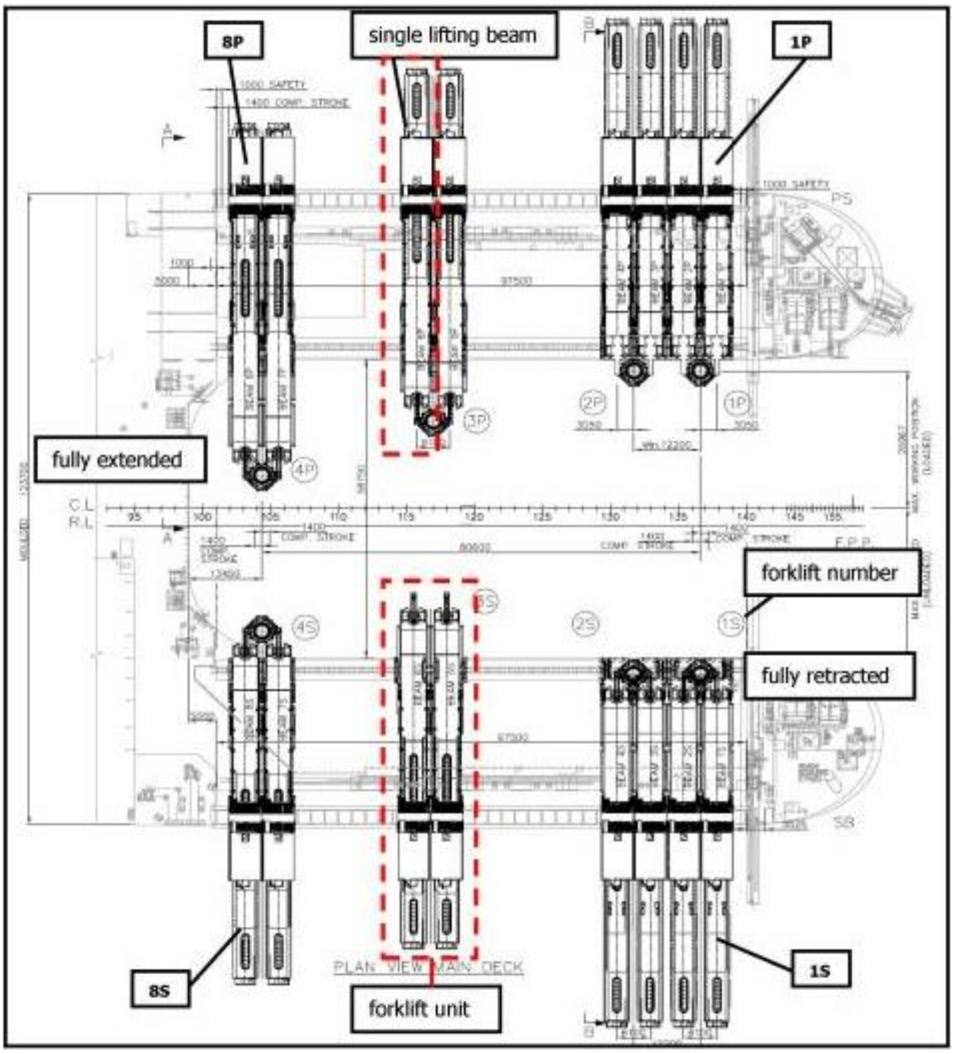


Figure B-2: 16 lifting beams installed on the bows (Emmerik & Kuiper, 2015)

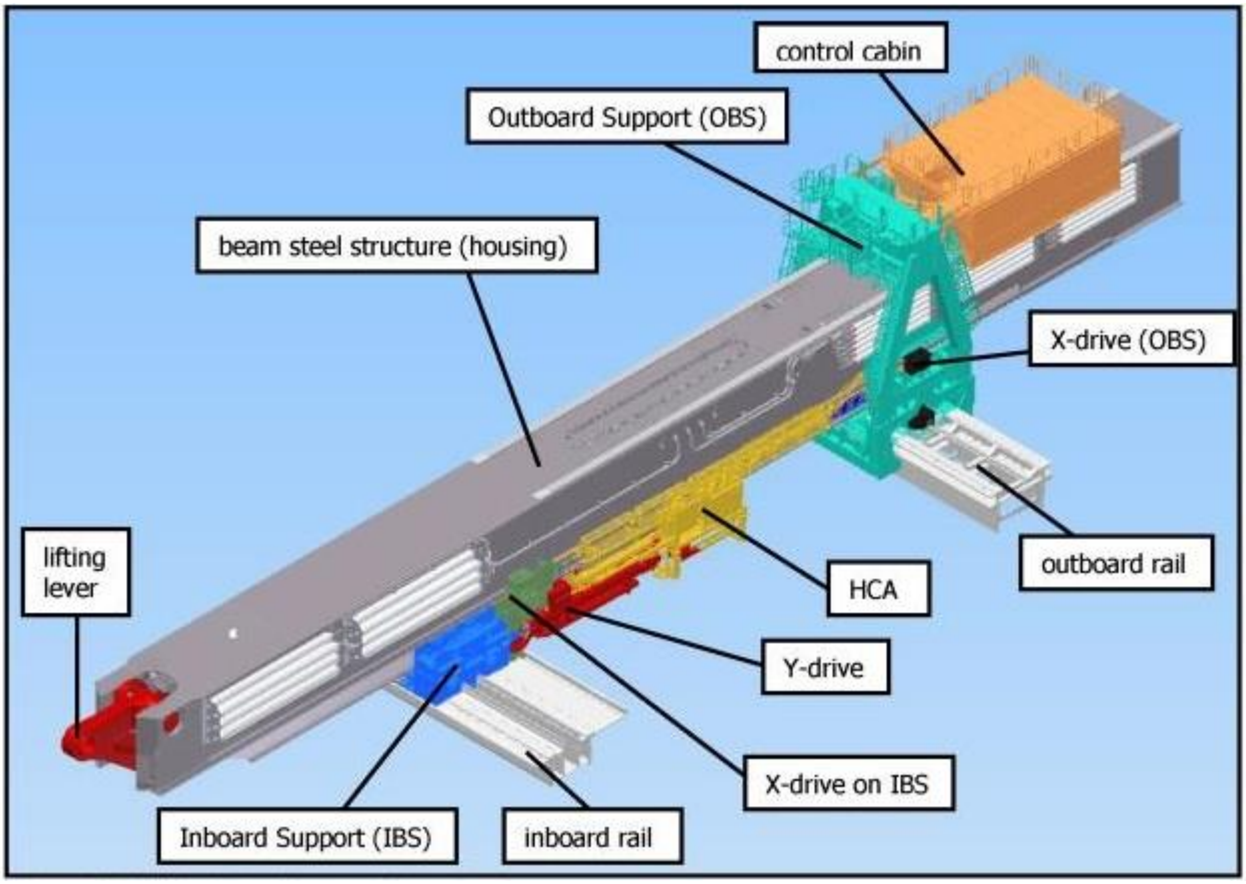


Figure B-3: General layout TLS beam (Emmerik & Kuiper, 2015)

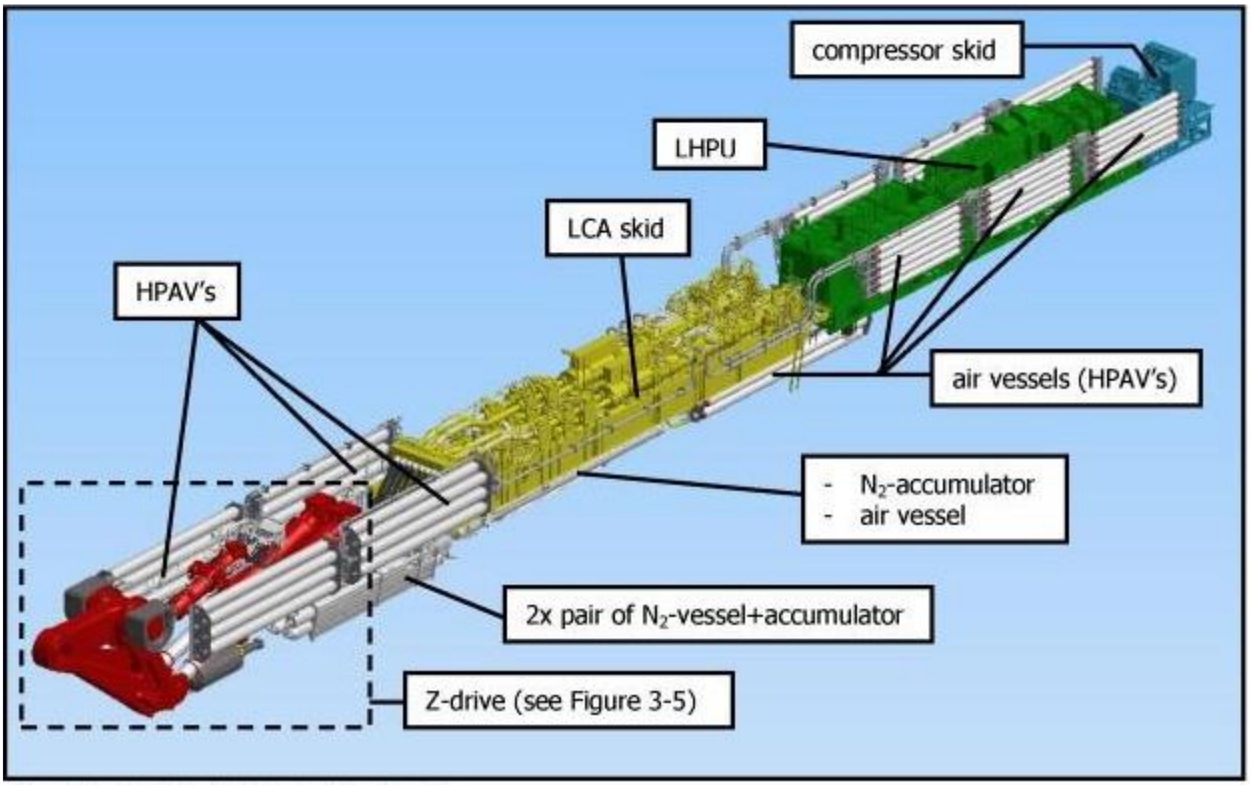


Figure B-4: Internal components of TLS beam (Emmerik & Kuiper, 2015)

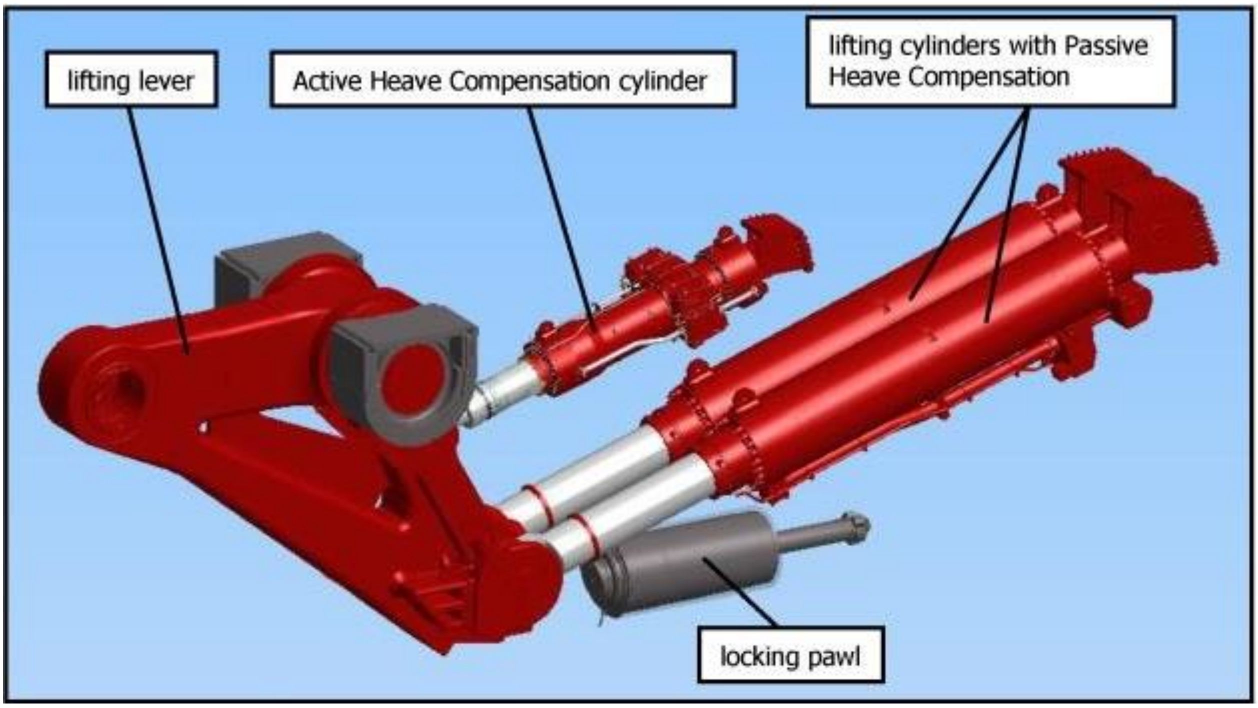


Figure B-5: Detail of lifting lever with lifting cylinder layout (Emmerik & Kuiper, 2015)

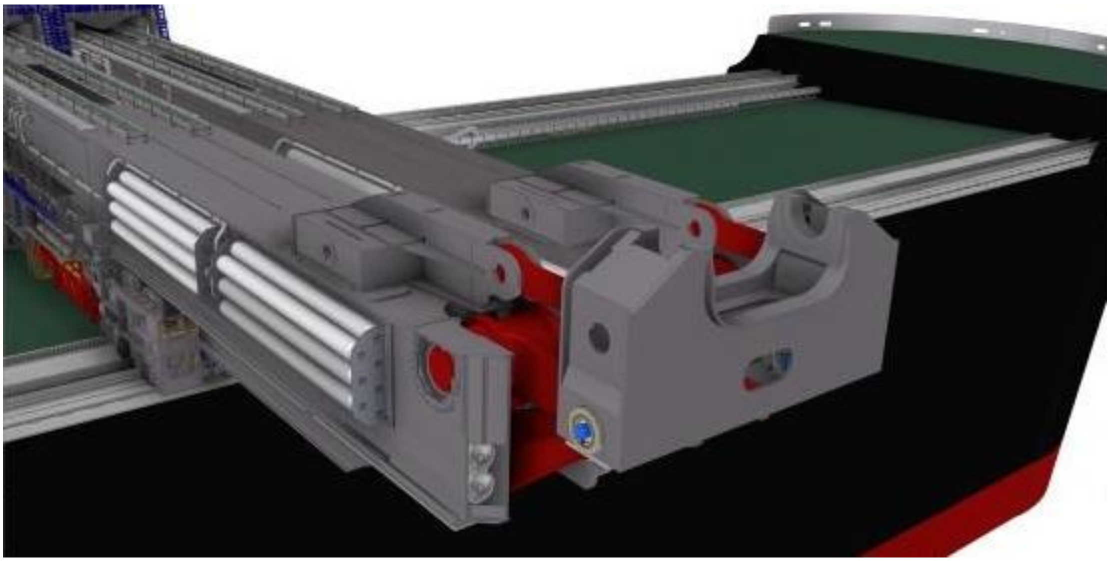


Figure B-6: Artist impression installed yoke (Vogelaar, 2015)

Appendix C. Daily cost of the Pioneering Spirit

In this appendix, the daily costs of the PS are estimated. To determine the cost of the vessel, the cost breakdown of the vessels new building price (Table C-1) will be used. The vessel is divided in heavy lift and pipe-lay capabilities to distinguish these two day rates.

Vessel part	Cost
Ship hull	€ 700,000,000
Heavy lift	€ 1,000,000,000
Pipe-lay	€ 600,000,000
Total	**€ 2,300,000,000**

Table C-1: Estimated new building price

To keep things manageable, in this more detailed daily cost estimation, all final prices are rounded to a plural of €25,000.

Investment costs

To calculate the costs of the invested capital to finance the vessel, the Weighted Average Cost of Capital (WACC) (Investopedia, n.d.) is used. The WACC includes the cost for the shareholders equity as well as the cost for the total mortgage. In Equation C-1, the formula is provided which is used to calculate the WACC. In this WACC, the tax is not taken into account.

$$WACC = \frac{Shareholders\ equity}{Total\ capital} \cdot cost\ of\ equity + \frac{Total\ debt}{Total\ capital} \cdot cost\ of\ debt$$

Equation C-1

The exact distribution between shareholder equity and mortgage is not known. For this thesis the WACC is assumed to be 5% of the new building price. The WACC for each part of the vessel is in proportion with the new-building cost of the different vessel parts, therefore the WACC is categorized in the same categories as the cost breakdown of the vessels new building price.

Part	Annual interest
Ship hull	€ 35,000,000
Heavy lift	€ 50,000,000
Pipe-lay	€ 30,000,000
Average annual WACC	**€ 115,000,000**

Table C-2: WACC break-down

The expected lifetime of the vessel is not known at this time. Therefore the depreciation of the vessel is taken over a more general lifetime of a vessel of 25 years. The repayment is in proportion with the new-building cost of the different vessel parts, therefore the interest is categorized in the same categories as the cost breakdown of the vessels new building price.

Part	Annual repayment
Ship hull	€ 28,000,000
Heavy lift	€ 40,000,000
Pipe-lay	€ 24,000,000
Annual repayment	**€ 92,000,000**

Table C-3: Repayment break-down

Maintenance

Maintenance can be divided into both CAPEX and OPEX. The CAPEX part covers the regular maintenance of the vessel and its equipment. The OPEX part covers the repairs and replacements. For regular maintenance, the annual cost are estimated at 1.50% of the new building price and for repair and replacements 1,00%. In Table C-4 an overview of the specific costs is provided.

	CAPEX	OPEX
Percentage over new-value	1.50%	1.00%
Ship hull	€ 10,500,000	€ 7,000,000
Heavy lift	€ 15,000,000	€ 10,000,000
Pipe-lay	€ 9,000,000	€ 6,000,000
Total	**€ 34,500,000**	**€ 23,000,000**

Table C-4: Maintenance and repair

Fuel consumption

A detailed fuel consumption estimation has been made by Allseas. To calculate the fuel costs for the PS, the fuel price will be taken into account. At the end of 2014, the fuel price dropped from ~$580 to a price of ~$300 in the beginning of 2015 (Ship and Bunker, 2015). The fuel price is likely to establish on a higher level than at this moment, therefore a fuel price is taken on a rate of $450 per tonne.

Fuel Consumption	Duration		Power		Energy	Fuel consumption	
	% of time	[hrs/yr]	% of total	[kW]	[kWh]	g/kWh	[ton/yr]
Transit	10%	876	80%	71,680	62,791,680	175	10,989
Pipe lay (DP)	35%	3,066	25%	22,400	68,678,400	190	13,049
Platform Removal on location (DP)	25%	2,190	25%	22,400	49,056,000	190	9,321
Platform Removal transit	10%	876	80%	71,680	62,791,680	175	10,989
Standby	10%	876	40%	35,840	31,395,840	190	5,965
Harbour/ sheltered waters	10%	876	10%	8,960	7,848,960	190	1,491
Total per year	***100%***	***8,760***			***282,562,560***		***51,803***

Table C-5: Fuel consumption Pioneering Spirit

The annual fuel costs of the vessel is estimated at €23,300,000.00.

Crew cost

The crew is divided into two parts, for both of the work scenarios for the vessel. The work of both parts takes about 50-50% of the time. For the heavy lift operations, ~200 people are supposed to be working on-board, while in pipe lay mode there are more like ~400 people from Allseas working on the vessel.

On average, the costs of a crewmember on-board is intended to be €65.000 per year.

Vessel mode	Crew cost
Personnel Heavy lift	€ 6,500,000
Personnel pipe lay	€ 13,000,000
Total	**€ 19,500,000**

Table C-6: Crew costs

Depreciation

The depreciation of the vessel is taken over the same time span as the expected lifetime of the vessel, 25 years (Investopedia, n.d.). The vessel is depreciated to the scrap value of the steel of the vessel.

The scrap value of the vessel is based on the scrap price for steel (Metalprices, 2015) and the lightweight of the vessel (Yeo, 2014).

	Value
Scrap price	€350/tonne
Lightweight	250,000 tonnes
Scrap value	**€ 87,500,000**

Table C-7: Scrap price

This results in an annual depreciation of the vessel of €88,500,000.00.

Daily cost

With a division between heavy lift and pipe-lay of 50-50%, the daily cost for the PS is described in Table 6-6.

Daily cost of Pioneering Spirit	Cost [€/day]
Heavy lift – mode	€ 1,310,000.00
Pipe-lay – mode	€ 1,070,000.00
Average daily costs of the vessel	**€ 1,190,000.00**

Table C-8: PS daily costs overview

Appendix D. Determination of draught function

To be able to set up a function for the draught of the vessel, fixed dimensions of the topside have been chosen for all topside weights. This eliminates the change in centre of gravity, or locations of the TLS beams. The centre of gravity and the vessel coordinates are both relative to the point at the aft and centreline of the topside.

	Size [m]	COG [m]	Vessel coordinate COG [m]
Length [m]	100	50	301.8
Width [m]	50	0	0
Height [m]	40	15	65

Table D-1: Topside position

The draught of the vessel is determined in the Loading Condition tool (LCT, Appendix H). For each loading situation, the lowest possible amount of water ballast is used to obtain the lowest draught for each topside load. The minimum water ballast is chosen as such, that the longitudinal and transverse shear and bending moments are still within the capacity of the structure.

The topside load is varied between 15,000 and 45,000 tonnes, with steps of 10,000 tonnes.

15,000 Tonnes topside

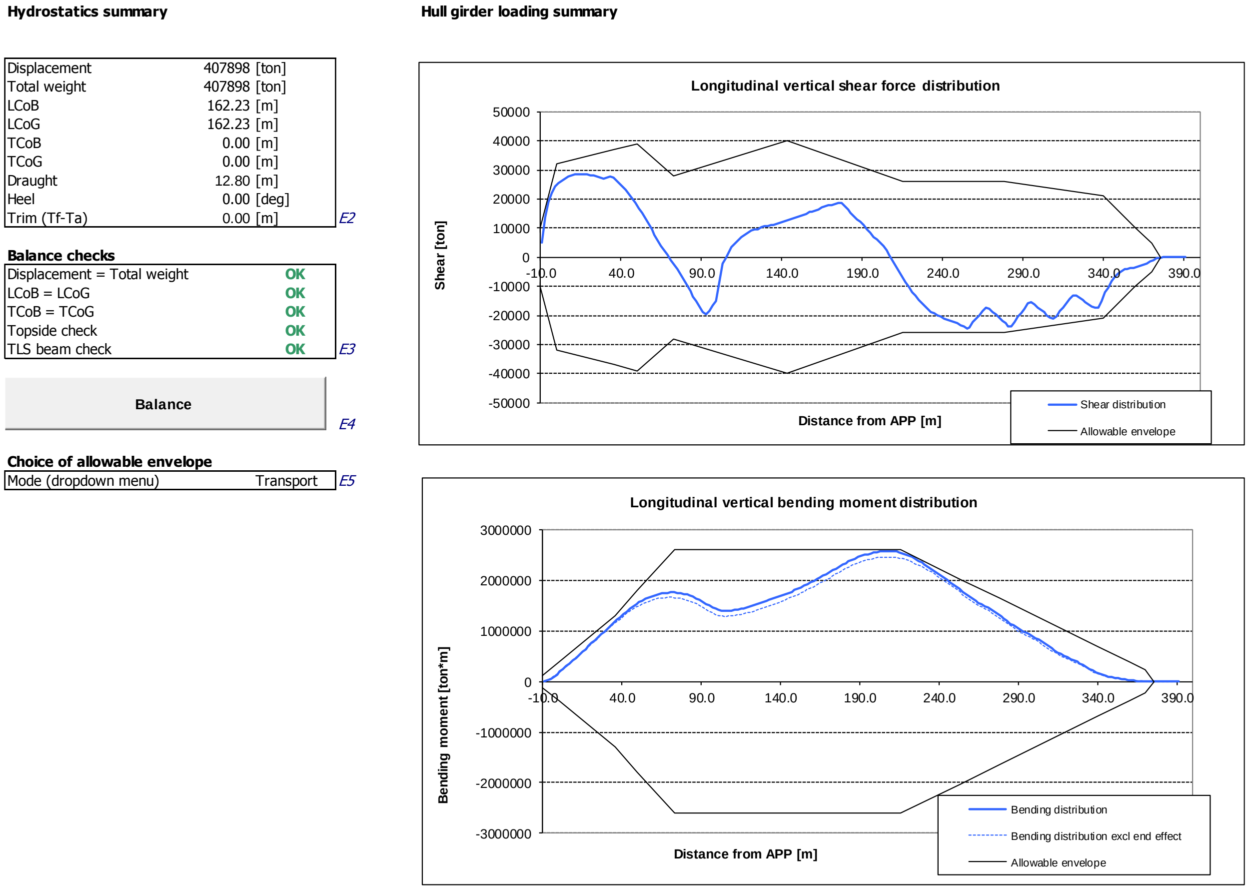


Figure D-1: Output 15,000 tonnes topside

Mass summary			
Total water ballast			
	Total mass	108805	[ton]
	LCG	124.44	[m]
	TCG	10.61	[m]
	VCG	11.79	[m]
Other tanks			
	Total mass	9437	[ton]
	LCG	173.70	[m]
	TCG	-28.85	[m]
	VCG	9.31	[m]
Fixed weights			
	Total mass	185505	[ton]
	LCG	166.96	[m]
	TCG	-4.10	[m]
	VCG	20.21	[m]
TLS (including topside)			
	Total mass	55871	[ton]
	LCG	301.75	[m]
	TCG	0.00	[m]
	VCG	41.56	[m]
Topside			
	Total mass	15000	[ton]
	LCG	301.75	[m]
	TCG	0.00	[m]
	VCG	60.00	[m]
JLS (including jacket)			
	Total mass	40165	[ton]
	LCG	40.83	[m]
	TCG	0.08	[m]
	VCG	37.56	[m]
HCB			
	Total mass	1010	[ton]
	LCG	351.75	[m]
	TCG	-8.15	[m]
	VCG	33.20	[m]
Other loads			
	Total mass	7111	[ton]
	LCG	164.56	[m]
	TCG	-16.04	[m]
	VCG	31.38	[m]
Vessel total			
	Total mass	407903	[ton]
	LCG	162.23	[m]
	TCG	0.00	[m]
	VCG	22.57	[m]

Table D-2: Detailed mass information with 15,000 tonnes topside weight, at 12,8m draught

25,000 Tonnes topside

Hydrostatics summary

Displacement	453575	[ton]
Total weight	453575	[ton]
LCoB	161.72	[m]
LCoG	161.72	[m]
TCoB	0.00	[m]
TCoG	-0.01	[m]
Draught	14.00	[m]
Heel	0.00	[deg]
Trim (Tf-Ta)	0.00	[m]

E2

Balance checks

Displacement = Total weight	OK
LCoB = LCoG	OK
TCoB = TCoG	OK
Topside check	OK
TLS beam check	OK

E3

Balance

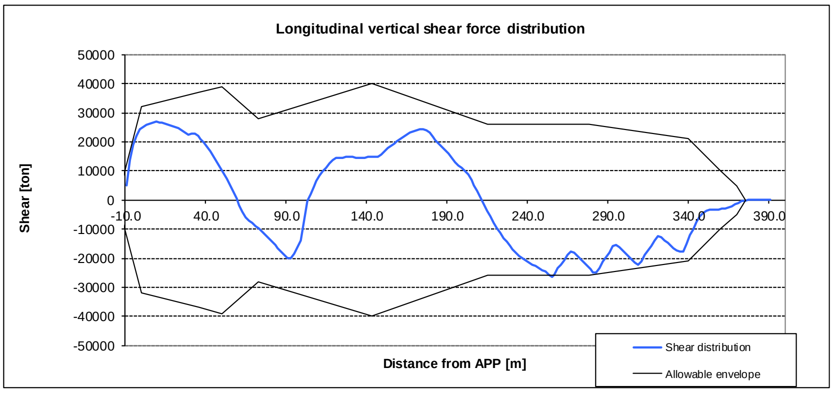
E4

Choice of allowable envelope

Mode (dropdown menu)	Transport

E5

Hull girder loading summary



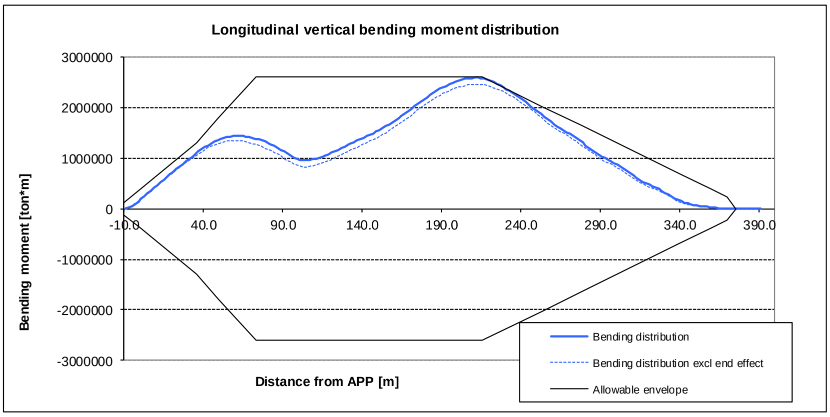


Figure D-2: Output 25,000 tonnes topside

35,000 Tonnes topside

Hydrostatics summary

Displacement	507901	[ton]
Total weight	507901	[ton]
LCoB	161.26	[m]
LCoG	161.26	[m]
TCoB	0.00	[m]
TCoG	0.00	[m]
Draught	15.40	[m]
Heel	0.00	[deg]
Trim (Tf-Ta)	0.00	[m]

E2

Balance checks

Displacement = Total weight	OK
LCoB = LCoG	OK
TCoB = TCoG	OK
Topside check	OK
TLS beam check	OK

E3

Balance

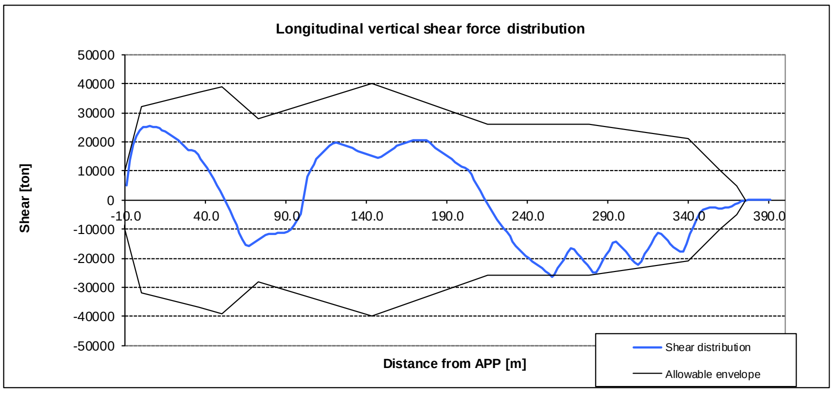
E4

Choice of allowable envelope

Mode (dropdown menu)	Transport

E5

Hull girder loading summary



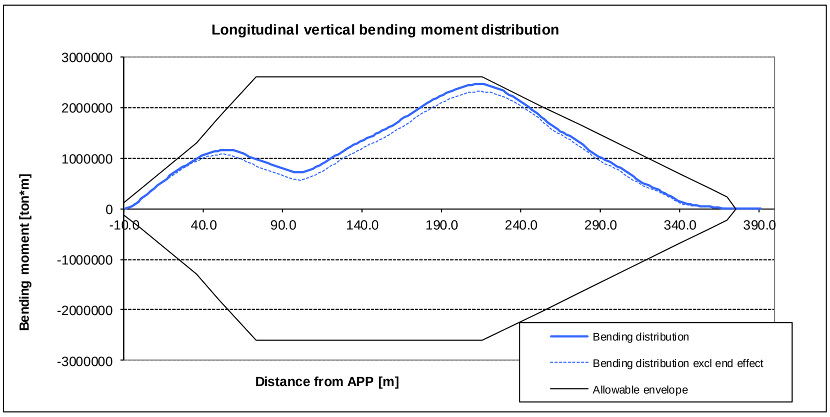


Figure D-3: Output 35,000 tonnes topside

45,000 Tonnes topside

Hydrostatics summary

Displacement	558859	[ton]
Total weight	558859	[ton]
LCoB	160.95	[m]
LCoG	160.95	[m]
TCoB	0.00	[m]
TCoG	0.01	[m]
Draught	16.71	[m]
Heel	0.00	[deg]
Trim (Tf-Ta)	0.01	[m]

E2

Balance checks

Displacement = Total weight	OK
LCoB = LCoG	OK
TCoB = TCoG	OK
Topside check	OK
TLS beam check	OK

E3

Balance

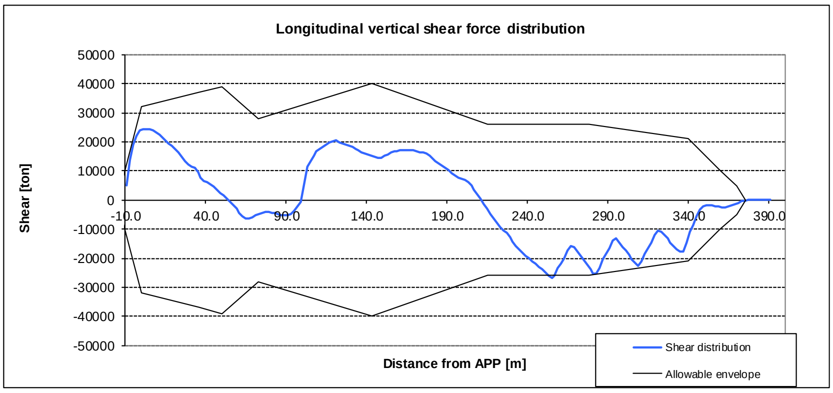
E4

Choice of allowable envelope

Mode (dropdown menu)	Transport

E5

Hull girder loading summary



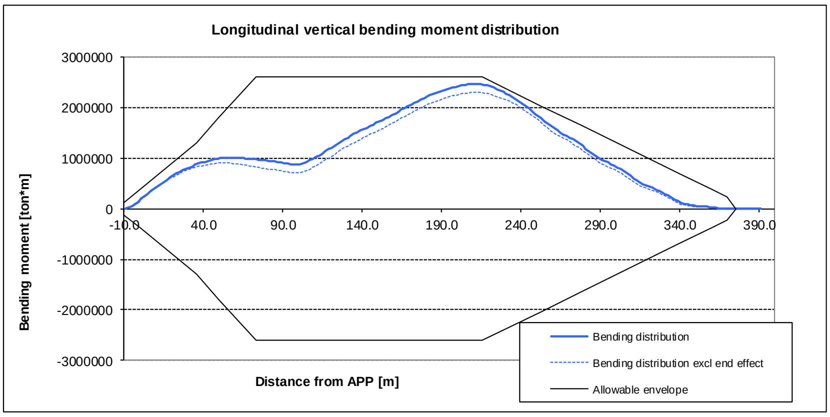


Figure D-4: Output 45,000 tonnes topside

Draught line graph

Table D-3 and Figure D-5 show the draughts of the four calculated loading conditions. The result indicates that there is a linear relation between topside weigh and the draught of the vessel. The extrapolated minimum draught, without topside load, is very close to the specifications of the vessel. The cause of the small deviation can be due to the manual distribution of the water ballast within the LCT.

Topside Weight [tonnes]	Draught [m]
15000	12.8
25000	14.0
35000	15.4
45000	16.7

Table D-3: Draught overview

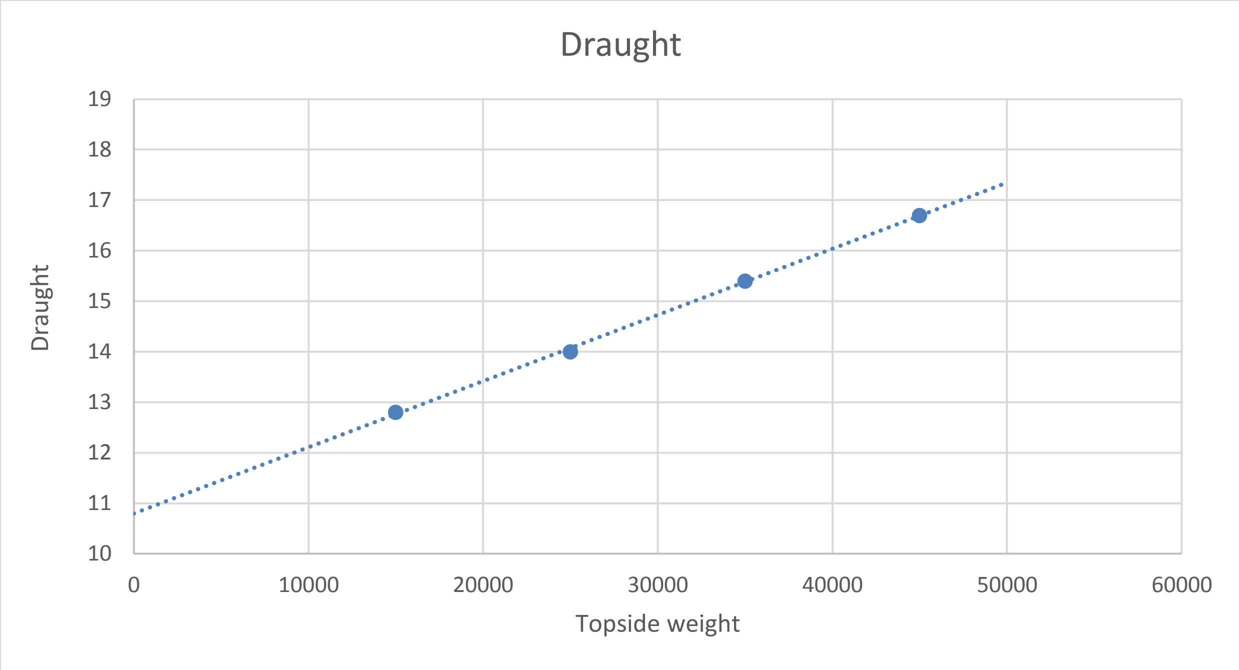


Figure D-5: Relation between draught and topside weight

$$D = 1.3 \cdot 10^{-4} \cdot Topside\ weight + 10.795 \qquad \text{Equation D-1}$$

Appendix E. Vessel motion report

Centre of gravity of vessel

Motion Response Calculator - results form

Allseas

General		
Date	15-Apr-2015	
Project	Next Generation of Topside Lifting	
Specification	-	
Originator	JLn	
Revision	01	
Vessel	*Pieter Schelte*	[-]
Draft	*17.02*	[m]
AQWA *.lis file	*_WIDE_T=17M_TRANSIT.*	[-]
Water depth	100	[m]
Operational / survival condition	Operational	[-]
Wave spectrum	Jonswap	[-]
Wave directions	[0:15:345]	[deg]
Peakedness factor (γ)	DNV notation	[-]
Significant wave height	[2.5]	[m]
Wave period	[6]	[s]
Wave period type	Tz	[-]
Wave height reduction applied?	no (default)	[-]

Location of interest*			
	x-Coor	y-Coor	z-Coor
	[m]	[m]	[m]
center of gravity	160.70	0.00	20.00

Remarks

***Coordinate system**

- positive x-axis points from the APP towards the bow
- positive y-axis points from CL towards PS
- positive z-axis points from the keelline orthogonal upwards
- 0 degree wave direction coming form the stern, positive defined anti-clockwise.

3 hours maximum, single amplitude motions and corresponding environmental conditions

Position**		x	y	z	rx	ry	rz	Hs [m]	Tz [s]	γ [-]	Wave Dir. [deg]
Surge	[m]	**0.06**	0.18	0.36	0.67	0.28	0.12	2.5	6	1.0	75
Sway	[m]	0.04	**0.39**	0.31	1.20	0.24	0.07	2.5	6	1.0	90
Heave	[m]	0.06	0.18	**0.36**	0.67	0.28	0.12	2.5	6	1.0	75
Roll	[deg]	0.04	0.39	0.31	**1.20**	0.24	0.07	2.5	6	1.0	90
Pitch	[deg]	0.06	0.18	0.36	0.67	**0.28**	0.12	2.5	6	1.0	75
Yaw	[deg]	0.05	0.17	0.20	0.68	0.26	**0.12**	2.5	6	1.0	105

Velocity**		x	y	z	rx	ry	rz	Hs [m]	Tz [s]	γ [-]	Wave Dir. [deg]
Surge	[m/s]	**0.04**	0.12	0.22	0.38	0.18	0.09	2.5	6	1.0	75
Sway	[m/s]	0.03	**0.28**	0.20	0.71	0.15	0.05	2.5	6	1.0	90
Heave	[m/s]	0.04	0.12	**0.22**	0.38	0.18	0.09	2.5	6	1.0	75
Roll	[deg/s]	0.03	0.28	0.20	**0.71**	0.15	0.05	2.5	6	1.0	90
Pitch	[deg/s]	0.04	0.12	0.22	0.38	**0.18**	0.09	2.5	6	1.0	75
Yaw	[deg/s]	0.03	0.12	0.12	0.39	0.17	**0.09**	2.5	6	1.0	105

Acceleration**		x	y	z	rx	ry	rz	Hs [m]	Tz [s]	γ [-]	Wave Dir. [deg]
Surge	[m/s^2]	**0.05**	0.00	0.07	0.00	0.10	0.00	2.5	6	1.0	0
Sway	[m/s^2]	0.02	**0.36**	0.13	0.43	0.10	0.05	2.5	6	1.0	90
Heave	[m/s^2]	0.03	0.16	**0.14**	0.22	0.12	0.07	2.5	6	1.0	75
Roll	[deg/s^2]	0.02	0.36	0.13	**0.43**	0.10	0.05	2.5	6	1.0	90
Pitch	[deg/s^2]	0.03	0.16	0.14	0.22	**0.12**	0.07	2.5	6	1.0	75
Yaw	[deg/s^2]	0.03	0.15	0.07	0.23	0.11	**0.07**	2.5	6	1.0	105

****Remarks**

- listed values for motions,velocities and accelerations are single amplitudes
- all values are related to 3 hours maxima
- for a complete description of the model and calculation method see the motion report.
- the gravity contribution [g*sin(phi)] is incorporated in all affected values
- Motion analyzer rev. 11

Centreline of vessel at 253m length, 38m height

Motion Response Calculator - results form

General			
Date	05-Jan-2015		
Project	Next Generation of Topside Lifting		
Specification	_		
Originator	JLn		
Revision	01		
Vessel	*Pieter Schelte*		[-]
Draft	*17.02*		[m]
AQWA *.lis file	*_WIDE_T=17M_TRANSIT.l*		[-]
Water depth	100		[m]
Operational / survival condition	Operational		[-]
Wave spectrum	Jonswap		[-]
Wave directions	[0:15:345]		[deg]
Peakedness factor (γ)	DNV notation		[-]
Significant wave height	[2.5]		[m]
Wave period	[6]		[s]
Wave period type	Tz		[-]
Wave height reduction applied?	no (default)		[-]

Location of interest*	x-Coor	y-Coor	z-Coor
	[m]	[m]	[m]
Centreline Fr. 101	253.00	0.00	38.00

Remarks

***Coordinate system**
- positive x-axis points from the APP tow ards the bow
- positive y-axis points from CL tow ards PS
- positive z-axis points from the keelline orthogonal upw ards
- 0 degree w ave direction coming form the stern, positive defined anti-clock w ise.

3 hours maximum, single amplitude motions and corresponding environmental conditions

Position**		x	y	z	rx	ry	rz	Hs [m]	Tz [s]	γ [-]	Wave Dir. [deg]
Surge	[m]	**0.09**	0.00	0.44	0.00	0.21	0.00	2.5	6	1.0	0
Sway	[m]	0.04	**0.71**	0.59	1.20	0.24	0.07	2.5	6	1.0	90
Heave	[m]	0.04	0.32	**0.76**	0.67	0.28	0.12	2.5	6	1.0	75
Roll	[deg]	0.04	0.71	0.59	**1.20**	0.24	0.07	2.5	6	1.0	90
Pitch	[deg]	0.04	0.32	0.76	0.67	**0.28**	0.12	2.5	6	1.0	75
Yaw	[deg]	0.05	0.41	0.56	0.68	0.26	**0.12**	2.5	6	1.0	105

Velocity**		x	y	z	rx	ry	rz	Hs [m]	Tz [s]	γ [-]	Wave Dir. [deg]
Surge	[m/s]	**0.06**	0.00	0.29	0.00	0.14	0.00	2.5	6	1.0	0
Sway	[m/s]	0.02	**0.48**	0.39	0.71	0.15	0.05	2.5	6	1.0	270
Heave	[m/s]	0.02	0.21	**0.48**	0.38	0.18	0.09	2.5	6	1.0	75
Roll	[deg/s]	0.02	0.48	0.39	**0.71**	0.15	0.05	2.5	6	1.0	90
Pitch	[deg/s]	0.02	0.21	0.48	0.38	**0.18**	0.09	2.5	6	1.0	75
Yaw	[deg/s]	0.03	0.26	0.36	0.39	0.17	**0.09**	2.5	6	1.0	105

Acceleration**		x	y	z	rx	ry	rz	Hs [m]	Tz [s]	γ [-]	Wave Dir. [deg]
Surge	[m/s^2]	**0.08**	0.00	0.19	0.00	0.10	0.00	2.5	6	1.0	0
Sway	[m/s^2]	0.05	**0.51**	0.26	0.43	0.10	0.05	2.5	6	1.0	270
Heave	[m/s^2]	0.06	0.22	**0.31**	0.22	0.12	0.07	2.5	6	1.0	75
Roll	[deg/s^2]	0.05	0.51	0.26	**0.43**	0.10	0.05	2.5	6	1.0	90
Pitch	[deg/s^2]	0.06	0.22	0.31	0.22	**0.12**	0.07	2.5	6	1.0	75
Yaw	[deg/s^2]	0.06	0.26	0.24	0.23	0.11	**0.07**	2.5	6	1.0	105

****Remarks**
- listed values for motions,velocities and accelerations are single amplitudes
- all values are related to 3 hours maxima
- for a complete description of the model and calculation method see the motion report.
- the gravity contribution [g*sin(phi)] is incorporated in all affected values
- Motion analyzer rev. 11

Centreline of vessel at 300.5m length, 38m height

Motion Response Calculator - results form

General			
Date	05-Jan-2015		
Project	Next Generation of Topside Lifting		
Specification	_		
Originator	JLn		
Revision	01		
Vessel	*Pieter Schelte*	[-]	
Draft	*17.02*	[m]	
AQWA *.lis file	*_WIDE_T=17M_TRANSIT.l*	[-]	
Water depth	100	[m]	
Operational / survival condition	Operational	[-]	
Wave spectrum	Jonswap	[-]	
Wave directions	[0:15:345]	[deg]	
Peakedness factor (γ)	DNV notation	[-]	
Significant wave height	[2.5]	[m]	
Wave period	[6]	[s]	
Wave period type	Tz	[-]	
Wave height reduction applied?	no (default)	[-]	

Location of interest*

	x-Coor	y-Coor	z-Coor
	[m]	[m]	[m]
Centreline Fr. 120	300.50	0.00	38.00

Remarks

***Coordinate system**
- positive x-axis points from the APP towards the bow
- positive y-axis points from CL towards PS
- positive z-axis points from the keelline orthogonal upwards
- 0 degree wave direction coming form the stern, positive defined anti-clockwise.

3 hours maximum, single amplitude motions and corresponding environmental conditions

Position**		x	y	z	rx	ry	rz	Hs [m]	Tz [s]	γ [-]	Wave Dir. [deg]
Surge	[m]	**0.09**	0.00	0.61	0.00	0.21	0.00	2.5	6	1.0	0
Sway	[m]	0.04	**0.74**	0.77	1.20	0.24	0.07	2.5	6	1.0	90
Heave	[m]	0.04	0.36	**0.98**	0.67	0.28	0.12	2.5	6	1.0	75
Roll	[deg]	0.04	0.74	0.77	**1.20**	0.24	0.07	2.5	6	1.0	90
Pitch	[deg]	0.04	0.36	0.98	0.67	**0.28**	0.12	2.5	6	1.0	75
Yaw	[deg]	0.05	0.49	0.77	0.68	0.26	**0.12**	2.5	6	1.0	105

Velocity**		x	y	z	rx	ry	rz	Hs [m]	Tz [s]	γ [-]	Wave Dir. [deg]
Surge	[m/s]	**0.06**	0.00	0.40	0.00	0.14	0.00	2.5	6	1.0	0
Sway	[m/s]	0.02	**0.50**	0.50	0.71	0.15	0.05	2.5	6	1.0	90
Heave	[m/s]	0.02	0.25	**0.63**	0.38	0.18	0.09	2.5	6	1.0	75
Roll	[deg/s]	0.02	0.50	0.50	**0.71**	0.15	0.05	2.5	6	1.0	90
Pitch	[deg/s]	0.02	0.25	0.63	0.38	**0.18**	0.09	2.5	6	1.0	75
Yaw	[deg/s]	0.03	0.32	0.50	0.39	0.17	**0.09**	2.5	6	1.0	105

Acceleration**		x	y	z	rx	ry	rz	Hs [m]	Tz [s]	γ [-]	Wave Dir. [deg]
Surge	[m/s^2]	**0.08**	0.00	0.27	0.00	0.10	0.00	2.5	6	1.0	0
Sway	[m/s^2]	0.05	**0.52**	0.33	0.43	0.10	0.05	2.5	6	1.0	90
Heave	[m/s^2]	0.06	0.24	**0.41**	0.22	0.12	0.07	2.5	6	1.0	75
Roll	[deg/s^2]	0.05	0.52	0.33	**0.43**	0.10	0.05	2.5	6	1.0	90
Pitch	[deg/s^2]	0.06	0.24	0.41	0.22	**0.12**	0.07	2.5	6	1.0	75
Yaw	[deg/s^2]	0.06	0.30	0.33	0.23	0.11	**0.07**	2.5	6	1.0	105

****Remarks**
- listed values for motions,velocities and accelerations are single amplitudes
- all values are related to 3 hours maxima
- for a complete description of the model and calculation method see the motion report.
- the gravity contribution [g*sin(phi)] is incorporated in all affected values
- Motion analyzer rev. 11

Centreline of vessel at 350.5m length, 38m height

Motion Response Calculator - results form

General			
Date	05-Jan-2015		
Project	Next Generation of Topside Lifting		
Specification	_		
Originator	JLn		
Revision	01		
Vessel	*Pieter Schelte*		[-]
Draft	*17.02*		[m]
AQWA*.lis file	*_WIDE_T=17M_TRANSIT.*		[-]
Water depth	100		[m]
Operational / survival condition	Operational		[-]
Wave spectrum	Jonswap		[-]
Wave directions	[0:15:345]		[deg]
Peakedness factor (γ)	DNV notation		[-]
Significant wave height	[2.5]		[m]
Wave period	[6]		[s]
Wave period type	Tz		[-]
Wave height reduction applied?	no (default)		[-]
Location of interest*			
	x-Coor	y-Coor	z-Coor
	[m]	[m]	[m]
Centreline Fr. 140	350.50	0.00	38.00
Remarks			
***Coordinate system**			
- positive x-axis points from the APP towards the bow			
- positive y-axis points from CL towards PS			
- positive z-axis points from the keelline orthogonal upwards			
- 0 degree wave direction coming form the stern, positive defined anti-clockwise.			

3 hours maximum, single amplitude motions and corresponding environmental conditions											
Position**								Hs	Tz	γ	Wave Dir.
		x	y	z	rx	ry	rz	[m]	[s]	[-]	[deg]
Surge	[m]	**0.09**	0.00	0.79	0.00	0.21	0.00	2.5	6	1.0	0
Sway	[m]	0.04	**0.77**	0.97	1.20	0.24	0.07	2.5	6	1.0	90
Heave	[m]	0.04	0.42	**1.22**	0.67	0.28	0.12	2.5	6	1.0	75
Roll	[deg]	0.04	0.77	0.97	**1.20**	0.24	0.07	2.5	6	1.0	90
Pitch	[deg]	0.04	0.42	1.22	0.67	**0.28**	0.12	2.5	6	1.0	75
Yaw	[deg]	0.05	0.59	0.99	0.68	0.26	**0.12**	2.5	6	1.0	105
Velocity**								Hs	Tz	γ	Wave Dir.
		x	y	z	rx	ry	rz	[m]	[s]	[-]	[deg]
Surge	[m/s]	**0.06**	0.00	0.52	0.00	0.14	0.00	2.5	6	1.0	0
Sway	[m/s]	0.02	**0.53**	0.63	0.71	0.15	0.05	2.5	6	1.0	90
Heave	[m/s]	0.02	0.31	**0.79**	0.38	0.18	0.09	2.5	6	1.0	75
Roll	[deg/s]	0.02	0.53	0.63	**0.71**	0.15	0.05	2.5	6	1.0	90
Pitch	[deg/s]	0.02	0.31	0.79	0.38	**0.18**	0.09	2.5	6	1.0	75
Yaw	[deg/s]	0.03	0.39	0.64	0.39	0.17	**0.09**	2.5	6	1.0	105
Acceleration**								Hs	Tz	γ	Wave Dir.
		x	y	z	rx	ry	rz	[m]	[s]	[-]	[deg]
Surge	[m/s^2]	**0.08**	0.00	0.35	0.00	0.10	0.00	2.5	6	1.0	0
Sway	[m/s^2]	0.05	**0.54**	0.41	0.43	0.10	0.05	2.5	6	1.0	90
Heave	[m/s^2]	0.06	0.27	**0.51**	0.22	0.12	0.07	2.5	6	1.0	75
Roll	[deg/s^2]	0.05	0.54	0.41	**0.43**	0.10	0.05	2.5	6	1.0	90
Pitch	[deg/s^2]	0.06	0.27	0.51	0.22	**0.12**	0.07	2.5	6	1.0	75
Yaw	[deg/s^2]	0.06	0.35	0.42	0.23	0.11	**0.07**	2.5	6	1.0	105

****Remarks**
- listed values for motions,velocities and accelerations are single amplitudes
- all values are related to 3 hours maxima
- for a complete description of the model and calculation method see the motion report.
- the gravity contribution [g*sin(phi)] is incorporated in all affected values
- Motion analyzer rev. 11

31.2m width, 253m length, 38m height

Motion Response Calculator - results form

General			
Date	15-Apr-2015		
Project	Next Generation of Topside Lifting		
Specification	-		
Originator	JLn		
Revision	01		
Vessel	*Pieter Schelte*		[-]
Draft	*17.02*		[m]
AQWA *.lis file	*_WIDE_T=17M_TRANSIT.*		[-]
Water depth	100		[m]
Operational / survival condition	Operational		[-]
Wave spectrum	Jonswap		[-]
Wave directions	5:75 105:15:255 285:15:3		[deg]
Peakedness factor (γ)	DNV notation		[-]
Significant wave height	[2.5]		[m]
Wave period	[6]		[s]
Wave period type	Tz		[-]
Wave height reduction applied?	no (default)		[-]

Location of interest*

	x-Coor	y-Coor	z-Coor
	[m]	[m]	[m]
IBS Fr. 101	253.00	31.70	38.00

Remarks

***Coordinate system**
- positive x-axis points from the APP towards the bow
- positive y-axis points from CL towards PS
- positive z-axis points from the keelline orthogonal upwards
- 0 degree wave direction coming form the stern, positive defined anti-clockwise.

3 hours maximum, single amplitude motions and corresponding environmental conditions

Position**								Hs	Tz	γ	Wave Dir.
		x	y	z	rx	ry	rz	[m]	[s]	[-]	[deg]
Surge	[m]	**0.09**	0.41	0.71	0.68	0.26	0.12	2.5	6	1.0	105
Sway	[m]	0.09	**0.41**	0.71	0.68	0.26	0.12	2.5	6	1.0	105
Heave	[m]	0.07	0.32	**0.96**	0.67	0.28	0.12	2.5	6	1.0	285
Roll	[deg]	0.09	0.41	0.71	**0.68**	0.26	0.12	2.5	6	1.0	105
Pitch	[deg]	0.08	0.32	0.70	0.67	**0.28**	0.12	2.5	6	1.0	75
Yaw	[deg]	0.09	0.41	0.71	0.68	0.26	**0.12**	2.5	6	1.0	105

Velocity**								Hs	Tz	γ	Wave Dir.
		x	y	z	rx	ry	rz	[m]	[s]	[-]	[deg]
Surge	[m/s]	**0.07**	0.26	0.44	0.39	0.17	0.09	2.5	6	1.0	105
Sway	[m/s]	0.07	**0.26**	0.44	0.39	0.17	0.09	2.5	6	1.0	105
Heave	[m/s]	0.05	0.21	**0.60**	0.38	0.18	0.09	2.5	6	1.0	285
Roll	[deg/s]	0.07	0.26	0.44	**0.39**	0.17	0.09	2.5	6	1.0	105
Pitch	[deg/s]	0.06	0.21	0.44	0.38	**0.18**	0.09	2.5	6	1.0	75
Yaw	[deg/s]	0.07	0.26	0.44	0.39	0.17	**0.09**	2.5	6	1.0	105

Acceleration**								Hs	Tz	γ	Wave Dir.
		x	y	z	rx	ry	rz	[m]	[s]	[-]	[deg]
Surge	[m/s^2]	**0.09**	0.26	0.28	0.23	0.11	0.07	2.5	6	1.0	105
Sway	[m/s^2]	0.09	**0.26**	0.28	0.23	0.11	0.07	2.5	6	1.0	105
Heave	[m/s^2]	0.06	0.22	**0.38**	0.22	0.12	0.07	2.5	6	1.0	285
Roll	[deg/s^2]	0.06	0.26	0.26	**0.23**	0.11	0.07	2.5	6	1.0	255
Pitch	[deg/s^2]	0.08	0.22	0.29	0.22	**0.12**	0.07	2.5	6	1.0	75
Yaw	[deg/s^2]	0.09	0.26	0.28	0.23	0.11	**0.07**	2.5	6	1.0	105

****Remarks**
- listed values for motions,velocities and accelerations are single amplitudes
- all values are related to 3 hours maxima
- for a complete description of the model and calculation method see the motion report.
- the gravity contribution [g*sin(phi)] is incorporated in all affected values
- Motion analyzer rev. 11

31.2m width, 300.5m length, 38m height

Motion Response Calculator - results form

General			
Date	15-Apr-2015		
Project	Next Generation of Topside Lifting		
Specification	-		
Originator	JLn		
Revision	01		
Vessel	*Pieter Schelte*		[-]
Draft	*17.02*		[m]
AQWA *.lis file	*_WIDE_T=17M_TRANSIT.*		[-]
Water depth	100		[m]
Operational / survival condition	Operational		[-]
Wave spectrum	Jonswap		[-]
Wave directions	.5:75 105:15:255 285:15:3		[deg]
Peakedness factor (γ)	DNV notation		[-]
Significant wave height	[2.5]		[m]
Wave period	[6]		[s]
Wave period type	Tz		[-]
Wave height reduction applied?	no (default)		[-]

Location of interest*			
	x-Coor	y-Coor	z-Coor
	[m]	[m]	[m]
IBS Fr. 120	300.50	31.70	38.00

Remarks

***Coordinate system**

- positive x-axis points from the APP towards the bow
- positive y-axis points from CL towards PS
- positive z-axis points from the keelline orthogonal upwards
- 0 degree wave direction coming form the stern, positive defined anti-clockwise.

3 hours maximum, single amplitude motions and corresponding environmental conditions

Position**								Hs	Tz	γ	Wave Dir.
		x	y	z	rx	ry	rz	[m]	[s]	[-]	[deg]
Surge	[m]	**0.09**	0.49	0.89	0.68	0.26	0.12	2.5	6	1.0	105
Sway	[m]	0.09	**0.49**	0.89	0.68	0.26	0.12	2.5	6	1.0	105
Heave	[m]	0.07	0.36	**1.15**	0.67	0.28	0.12	2.5	6	1.0	285
Roll	[deg]	0.09	0.49	0.89	**0.68**	0.26	0.12	2.5	6	1.0	105
Pitch	[deg]	0.08	0.36	0.93	0.67	**0.28**	0.12	2.5	6	1.0	75
Yaw	[deg]	0.09	0.49	0.89	0.68	0.26	**0.12**	2.5	6	1.0	105

Velocity**								Hs	Tz	γ	Wave Dir.
		x	y	z	rx	ry	rz	[m]	[s]	[-]	[deg]
Surge	[m/s]	**0.07**	0.32	0.56	0.39	0.17	0.09	2.5	6	1.0	105
Sway	[m/s]	0.07	**0.32**	0.56	0.39	0.17	0.09	2.5	6	1.0	105
Heave	[m/s]	0.05	0.25	**0.73**	0.38	0.18	0.09	2.5	6	1.0	285
Roll	[deg/s]	0.07	0.32	0.56	**0.39**	0.17	0.09	2.5	6	1.0	105
Pitch	[deg/s]	0.06	0.25	0.59	0.38	**0.18**	0.09	2.5	6	1.0	75
Yaw	[deg/s]	0.07	0.32	0.56	0.39	0.17	**0.09**	2.5	6	1.0	105

Acceleration**								Hs	Tz	γ	Wave Dir.
		x	y	z	rx	ry	rz	[m]	[s]	[-]	[deg]
Surge	[m/s^2]	**0.09**	0.30	0.36	0.23	0.11	0.07	2.5	6	1.0	105
Sway	[m/s^2]	0.06	**0.30**	0.34	0.23	0.11	0.07	2.5	6	1.0	255
Heave	[m/s^2]	0.06	0.24	**0.46**	0.22	0.12	0.07	2.5	6	1.0	285
Roll	[deg/s^2]	0.06	0.30	0.34	**0.23**	0.11	0.07	2.5	6	1.0	255
Pitch	[deg/s^2]	0.08	0.24	0.38	0.22	**0.12**	0.07	2.5	6	1.0	75
Yaw	[deg/s^2]	0.09	0.30	0.36	0.23	0.11	**0.07**	2.5	6	1.0	105

****Remarks**

- listed values for motions,velocities and accelerations are single amplitudes
- all values are related to 3 hours maxima
- for a complete description of the model and calculation method see the motion report.
- the gravity contribution [g*sin(phi)] is incorporated in all affected values
- Motion analyzer rev. 11

31.2m width, 350.5m length, 38m height

Motion Response Calculator - results form

General			
Date	15-Apr-2015		
Project	Next Generation of Topside Lifting		
Specification	-		
Originator	JLn		
Revision	01		
Vessel	*Pieter Schelte*		[-]
Draft	*17.02*		[m]
AQWA *.lis file	*_WIDE_T=17M_TRANSIT.*		[-]
Water depth	100		[m]
Operational / survival condition	Operational		[-]
Wave spectrum	Jonswap		[-]
Wave directions	5:75 105:15:255 285:15:3		[deg]
Peakedness factor (γ)	DNV notation		[-]
Significant wave height	[2.5]		[m]
Wave period	[6]		[s]
Wave period type	Tz		[-]
Wave height reduction applied?	no (default)		[-]

Location of interest*			
	x-Coor	y-Coor	z-Coor
	[m]	[m]	[m]
IBS Fr. 140	350.50	31.70	38.00

Remarks

***Coordinate system**
- positive x-axis points from the APP towards the bow
- positive y-axis points from CL towards PS
- positive z-axis points from the keelline orthogonal upwards
- 0 degree wave direction coming form the stern, positive defined anti-clockwise.

3 hours maximum, single amplitude motions and corresponding environmental conditions

Position**								Hs	Tz	γ	Wave Dir.
		x	y	z	rx	ry	rz	[m]	[s]	[-]	[deg]
Surge	[m]	**0.09**	0.59	1.09	0.68	0.26	0.12	2.5	6	1.0	105
Sway	[m]	0.07	**0.59**	1.03	0.68	0.26	0.12	2.5	6	1.0	255
Heave	[m]	0.07	0.42	**1.37**	0.67	0.28	0.12	2.5	6	1.0	285
Roll	[deg]	0.09	0.59	1.09	**0.68**	0.26	0.12	2.5	6	1.0	105
Pitch	[deg]	0.08	0.42	1.17	0.67	**0.28**	0.12	2.5	6	1.0	75
Yaw	[deg]	0.09	0.59	1.09	0.68	0.26	**0.12**	2.5	6	1.0	105

Velocity**								Hs	Tz	γ	Wave Dir.
		x	y	z	rx	ry	rz	[m]	[s]	[-]	[deg]
Surge	[m/s]	**0.07**	0.39	0.69	0.39	0.17	0.09	2.5	6	1.0	105
Sway	[m/s]	0.07	**0.39**	0.69	0.39	0.17	0.09	2.5	6	1.0	105
Heave	[m/s]	0.05	0.31	**0.87**	0.38	0.18	0.09	2.5	6	1.0	285
Roll	[deg/s]	0.07	0.39	0.69	**0.39**	0.17	0.09	2.5	6	1.0	105
Pitch	[deg/s]	0.06	0.31	0.75	0.38	**0.18**	0.09	2.5	6	1.0	75
Yaw	[deg/s]	0.07	0.39	0.69	0.39	0.17	**0.09**	2.5	6	1.0	105

Acceleration**								Hs	Tz	γ	Wave Dir.
		x	y	z	rx	ry	rz	[m]	[s]	[-]	[deg]
Surge	[m/s^2]	**0.09**	0.35	0.45	0.23	0.11	0.07	2.5	6	1.0	105
Sway	[m/s^2]	0.09	**0.35**	0.45	0.23	0.11	0.07	2.5	6	1.0	105
Heave	[m/s^2]	0.06	0.27	**0.56**	0.22	0.12	0.07	2.5	6	1.0	285
Roll	[deg/s^2]	0.06	0.35	0.44	**0.23**	0.11	0.07	2.5	6	1.0	255
Pitch	[deg/s^2]	0.08	0.27	0.49	0.22	**0.12**	0.07	2.5	6	1.0	75
Yaw	[deg/s^2]	0.09	0.35	0.45	0.23	0.11	**0.07**	2.5	6	1.0	105

****Remarks**
- listed values for motions,velocities and accelerations are single amplitudes
- all values are related to 3 hours maxima
- for a complete description of the model and calculation method see the motion report.
- the gravity contribution [g*sin(phi)] is incorporated in all affected values
- Motion analyzer rev. 11

60.4m width, 253m length, 38m height

Motion Response Calculator - results form

Allseas

General			
Date	15-Apr-2015		
Project	Next Generation of Topside Lifting		
Specification	-		
Originator	JLn		
Revision	01		
Vessel	*Pieter Schelte*	[-]	
Draft	*17.02*	[m]	
AQWA *.lis file	*_WIDE_T=17M_TRANSIT.*	[-]	
Water depth	100	[m]	
Operational / survival condition	Operational	[-]	
Wave spectrum	Jonswap	[-]	
Wave directions	.5:75 105:15:255 285:15:3	[deg]	
Peakedness factor (γ)	DNV notation	[-]	
Significant wave height	[2.5]	[m]	
Wave period	[6]	[s]	
Wave period type	Tz	[-]	
Wave height reduction applied?	no (default)	[-]	

Location of interest*	x-Coor	y-Coor	z-Coor
	[m]	[m]	[m]
OBS Fr. 101	253.00	60.40	38.00

Remarks

***Coordinate system**

- positive x-axis points from the APP tow ards the bow
- positive y-axis points from CL tow ards PS
- positive z-axis points from the keelline orthogonal upw ards
- 0 degree w ave direction coming form the stern, positive defined anti-clock w ise.

3 hours maximum, single amplitude motions and corresponding environmental conditions

Position**		x	y	z	rx	ry	rz	Hs [m]	Tz [s]	γ [-]	Wave Dir. [deg]
Surge	[m]	**0.15**	0.41	0.96	0.68	0.26	0.12	2.5	6	1.0	105
Sway	[m]	0.15	**0.41**	0.96	0.68	0.26	0.12	2.5	6	1.0	105
Heave	[m]	0.12	0.32	**1.21**	0.67	0.28	0.12	2.5	6	1.0	285
Roll	[deg]	0.15	0.41	0.96	**0.68**	0.26	0.12	2.5	6	1.0	105
Pitch	[deg]	0.14	0.32	0.81	0.67	**0.28**	0.12	2.5	6	1.0	75
Yaw	[deg]	0.15	0.41	0.96	0.68	0.26	**0.12**	2.5	6	1.0	105

Velocity**		x	y	z	rx	ry	rz	Hs [m]	Tz [s]	γ [-]	Wave Dir. [deg]
Surge	[m/s]	**0.11**	0.26	0.57	0.39	0.17	0.09	2.5	6	1.0	105
Sway	[m/s]	0.11	**0.26**	0.57	0.39	0.17	0.09	2.5	6	1.0	105
Heave	[m/s]	0.09	0.21	**0.74**	0.38	0.18	0.09	2.5	6	1.0	285
Roll	[deg/s]	0.11	0.26	0.57	**0.39**	0.17	0.09	2.5	6	1.0	105
Pitch	[deg/s]	0.10	0.21	0.49	0.38	**0.18**	0.09	2.5	6	1.0	75
Yaw	[deg/s]	0.11	0.26	0.57	0.39	0.17	**0.09**	2.5	6	1.0	105

Acceleration**		x	y	z	rx	ry	rz	Hs [m]	Tz [s]	γ [-]	Wave Dir. [deg]
Surge	[m/s^2]	**0.11**	0.26	0.35	0.23	0.11	0.07	2.5	6	1.0	105
Sway	[m/s^2]	0.11	**0.26**	0.35	0.23	0.11	0.07	2.5	6	1.0	105
Heave	[m/s^2]	0.08	0.22	**0.46**	0.22	0.12	0.07	2.5	6	1.0	285
Roll	[deg/s^2]	0.08	0.26	0.33	**0.23**	0.11	0.07	2.5	6	1.0	255
Pitch	[deg/s^2]	0.11	0.22	0.31	0.22	**0.12**	0.07	2.5	6	1.0	75
Yaw	[deg/s^2]	0.11	0.26	0.35	0.23	0.11	**0.07**	2.5	6	1.0	105

****Remarks**

- listed values for motions,velocities and accelerations are single amplitudes
- all values are related to 3 hours maxima
- for a complete description of the model and calculation method see the motion report.
- the gravity contribution [g*sin(phi)] is incorporated in all affected values
- Motion analyzer rev. 11

60.4m width, 300.5m length, 38m height

Motion Response Calculator - results form

General			
Date	15-Apr-2015		
Project	Next Generation of Topside Lifting		
Specification	-		
Originator	JLn		
Revision	01		
Vessel	*Pieter Schelte*		[-]
Draft	*17.02*		[m]
AQWA *.lis file	*_WIDE_T=17M_TRANSIT.*		[-]
Water depth	100		[m]
Operational / survival condition	Operational		[-]
Wave spectrum	Jonswap		[-]
Wave directions	5:75 105:15:255 285:15:3		[deg]
Peakedness factor (γ)	DNV notation		[-]
Significant wave height	[2.5]		[m]
Wave period	[6]		[s]
Wave period type	Tz		[-]
Wave height reduction applied?	no (default)		[-]

Location of interest*	x-Coor [m]	y-Coor [m]	z-Coor [m]
OBS Fr. 120	300.50	60.40	38.00

Remarks

***Coordinate system**
- positive x-axis points from the APP towards the bow
- positive y-axis points from CL towards PS
- positive z-axis points from the keelline orthogonal upwards
- 0 degree wave direction coming form the stern, positive defined anti-clockwise.

3 hours maximum, single amplitude motions and corresponding environmental conditions

Position**		x	y	z	rx	ry	rz	Hs [m]	Tz [s]	γ [-]	Wave Dir. [deg]
Surge	[m]	**0.15**	0.49	1.10	0.68	0.26	0.12	2.5	6	1.0	105
Sway	[m]	0.15	**0.49**	1.10	0.68	0.26	0.12	2.5	6	1.0	105
Heave	[m]	0.12	0.36	**1.38**	0.67	0.28	0.12	2.5	6	1.0	285
Roll	[deg]	0.15	0.49	1.10	**0.68**	0.26	0.12	2.5	6	1.0	105
Pitch	[deg]	0.14	0.36	1.01	0.67	**0.28**	0.12	2.5	6	1.0	75
Yaw	[deg]	0.15	0.49	1.10	0.68	0.26	**0.12**	2.5	6	1.0	105

Velocity**		x	y	z	rx	ry	rz	Hs [m]	Tz [s]	γ [-]	Wave Dir. [deg]
Surge	[m/s]	**0.11**	0.32	0.67	0.39	0.17	0.09	2.5	6	1.0	105
Sway	[m/s]	0.11	**0.32**	0.67	0.39	0.17	0.09	2.5	6	1.0	105
Heave	[m/s]	0.09	0.25	**0.85**	0.38	0.18	0.09	2.5	6	1.0	285
Roll	[deg/s]	0.11	0.32	0.67	**0.39**	0.17	0.09	2.5	6	1.0	105
Pitch	[deg/s]	0.10	0.25	0.62	0.38	**0.18**	0.09	2.5	6	1.0	75
Yaw	[deg/s]	0.11	0.32	0.67	0.39	0.17	**0.09**	2.5	6	1.0	105

Acceleration**		x	y	z	rx	ry	rz	Hs [m]	Tz [s]	γ [-]	Wave Dir. [deg]
Surge	[m/s^2]	**0.11**	0.30	0.42	0.23	0.11	0.07	2.5	6	1.0	105
Sway	[m/s^2]	0.08	**0.30**	0.39	0.23	0.11	0.07	2.5	6	1.0	255
Heave	[m/s^2]	0.08	0.24	**0.54**	0.22	0.12	0.07	2.5	6	1.0	285
Roll	[deg/s^2]	0.08	0.30	0.39	**0.23**	0.11	0.07	2.5	6	1.0	255
Pitch	[deg/s^2]	0.11	0.24	0.39	0.22	**0.12**	0.07	2.5	6	1.0	75
Yaw	[deg/s^2]	0.11	0.30	0.42	0.23	0.11	**0.07**	2.5	6	1.0	105

****Remarks**
- listed values for motions,velocities and accelerations are single amplitudes
- all values are related to 3 hours maxima
- for a complete description of the model and calculation method see the motion report.
- the gravity contribution [g*sin(phi)] is incorporated in all affected values
- Motion analyzer rev. 11

60.4m width, 350.5m length, 38m height

Motion Response Calculator - results form

Allseas

General			
Date	15-Apr-2015		
Project	Next Generation of Topside Lifting		
Specification	-		
Originator	JLn		
Revision	01		

Vessel	*Pieter Schelte*	[-]
Draft	*17.02*	[m]
AQWA *.lis file	*_WIDE_T=17M_TRANSIT.*	[-]
Water depth	100	[m]
Operational / survival condition	Operational	[-]
Wave spectrum	Jonswap	[-]
Wave directions	5:75 105:15:255 285:15:3	[deg]
Peakedness factor (γ)	DNV notation	[-]
Significant wave height	[2.5]	[m]
Wave period	[6]	[s]
Wave period type	Tz	[-]
Wave height reduction applied?	no (default)	[-]

Location of interest*	x-Coor	y-Coor	z-Coor
	[m]	[m]	[m]
OBS Fr. 140	350.50	60.40	38.00

Remarks

***Coordinate system**
- positive x-axis points from the APP towards the bow
- positive y-axis points from CL towards PS
- positive z-axis points from the keelline orthogonal upwards
- 0 degree wave direction coming form the stern, positive defined anti-clockwise.

3 hours maximum, single amplitude motions and corresponding environmental conditions

Position**		x	y	z	rx	ry	rz	Hs [m]	Tz [s]	γ [-]	Wave Dir. [deg]
Surge	[m]	**0.15**	0.59	1.27	0.68	0.26	0.12	2.5	6	1.0	105
Sway	[m]	0.13	**0.59**	1.17	0.68	0.26	0.12	2.5	6	1.0	255
Heave	[m]	0.12	0.42	**1.57**	0.67	0.28	0.12	2.5	6	1.0	285
Roll	[deg]	0.15	0.59	1.27	**0.68**	0.26	0.12	2.5	6	1.0	105
Pitch	[deg]	0.14	0.42	1.22	0.67	**0.28**	0.12	2.5	6	1.0	75
Yaw	[deg]	0.15	0.59	1.27	0.68	0.26	**0.12**	2.5	6	1.0	105

Velocity**		x	y	z	rx	ry	rz	Hs [m]	Tz [s]	γ [-]	Wave Dir. [deg]
Surge	[m/s]	**0.11**	0.39	0.79	0.39	0.17	0.09	2.5	6	1.0	105
Sway	[m/s]	0.11	**0.39**	0.79	0.39	0.17	0.09	2.5	6	1.0	105
Heave	[m/s]	0.09	0.31	**0.98**	0.38	0.18	0.09	2.5	6	1.0	285
Roll	[deg/s]	0.11	0.39	0.79	**0.39**	0.17	0.09	2.5	6	1.0	105
Pitch	[deg/s]	0.10	0.31	0.77	0.38	**0.18**	0.09	2.5	6	1.0	75
Yaw	[deg/s]	0.11	0.39	0.79	0.39	0.17	**0.09**	2.5	6	1.0	105

Acceleration**		x	y	z	rx	ry	rz	Hs [m]	Tz [s]	γ [-]	Wave Dir. [deg]
Surge	[m/s^2]	**0.11**	0.35	0.50	0.23	0.11	0.07	2.5	6	1.0	105
Sway	[m/s^2]	0.11	**0.35**	0.50	0.23	0.11	0.07	2.5	6	1.0	105
Heave	[m/s^2]	0.08	0.27	**0.62**	0.22	0.12	0.07	2.5	6	1.0	285
Roll	[deg/s^2]	0.08	0.35	0.48	**0.23**	0.11	0.07	2.5	6	1.0	255
Pitch	[deg/s^2]	0.11	0.27	0.49	0.22	**0.12**	0.07	2.5	6	1.0	75
Yaw	[deg/s^2]	0.11	0.35	0.50	0.23	0.11	**0.07**	2.5	6	1.0	105

****Remarks**
- listed values for motions,velocities and accelerations are single amplitudes
- all values are related to 3 hours maxima
- for a complete description of the model and calculation method see the motion report.
- the gravity contribution [g*sin(phi)] is incorporated in all affected values
- Motion analyzer rev. 11

Appendix F. Combined market overview

Platform name	Topside Weight [Tonnes]	Length [m]	Width [m]	Weight [Tonnes]	Air Gap [m]
Alaminos Canyon 025-A DDCV Hoover	23400				-0.30
Alba North	23800			1723	
Benguela/Belize (BBLT) CPT	34000			4000	-4.10
Beryl A	29150			16759	
Brae A	32000			2000	
Brae B	36813			6813	
Brent B	29014			16623	0.11
Brent D	22433			10042	
Bressay A	31000	2.50		1000	
Britannia PDQ	28900			1202	
Clair DP (Clair Ridge)	26000	2.50			
Dunlin A	25112		7.65		
Ekofisk 2/4J	25600			5653	
Goodwyn A	23500	2.50	1.48		
Green Canyon 645-A T-Spar Holstein	23990				-0.30
Green Canyon 782-A T-Spar Mad Dog	22226				-1.90
Gullfaks A	42300	28.10	6.65	12300	8.44
Gullfaks B	28000			15609	
Gullfaks C	52000	28.60	3.85	22000	8.10
Liwan LW 03-1-1 PUQ	31385	12.50		1385	-1.10
Lunskoye LUN-A (Sakhalin 2)	27400		21.65		
Magnus	30600		7.48	600	
Main Pass 299 (Sulphur) STO	20000			1860	
Murchison	24544		4.48		
Ninian Central	39000			9000	10.41
Ninian South	25500		6.48		
North Rankin B	23600	12.50	1.48		
Oseberg A	46000	0.10	8.65	16000	7.32
Piper B	28900			3186	
Sleipner SLA	37964	53.00	3.85	7964	
Statfjord A	48000			18000	5.58
Statfjord B	37000	6.50		7000	5.15
Statfjord C	42000	6.50		12000	5.80
Thistle A	18000		3.08		
Tombua-Landana CPT	32024			2024	-7.10
Troll A	22500	42.00			4.27
Wheatstone	37000		13.15	7000	4.15

Table F-1: Potential topside market

In Table F-1 the complete potential market is listed by with all topside limitations. The number of platforms given in tables Table F-2 to Table F-5 for two and more solutions are cumulative. The number of platforms are the total platforms limited by the indicated conditions, including the platforms for each limitation separately.

	Number	Total weight (tonnes)
Weight	10	275,596
Length	1	26,000
Width	5	120,556
Water depth	3	69,616
Air Gap	10	275,596

Table F-2: Summary of additional platforms for one condition

Two modifications combined	Number	Total weight (tonnes)
Weight & Length	12	332,596
Weight & Width	16	426,752
Weight & Air gap	18	527,250
Length & Width	8	193,656
Length & Air gap	5	118,116
Width & Air gap	8	190,172

Table F-3: Additional platforms for two combined conditions

Three modifications combined	Number	Total weight (tonnes)
Weight & Length & Width	21	568,816
Weight & Length & Air gap	24	717,135
Weight & Width & Air gap	25	715,406
Length & Width & Air gap	12	285,772

Table F-4: Additional platforms for three combined conditions

Four modifications combined	Number	Total weight (tonnes)
Weight & Length & Width & Air gap	37	1,130,655

Table F-5: Additional platforms for all conditions

Appendix G. Buoyancy tanks

One of the benefits of using buoyancy tanks is that the lifting capacity can be increase, while the maximum torque in the bows is kept constant. This also ensures that the structure does not need to be reinforced. The outreach of the beam is taken at the maximum outreach (18.75m), whereby the system is still able to lift at its full capacity, and at 10m.

The dimensions of the buoyancy tanks are;

- 7m wide
- 12.2m long
- 30m high

Description	Outreach – 10.00m	Outreach – 18.75m
Length	12.2 m	
Width	7 m	
Height	30 m	
Maximum vessel draught	27 m	
Max. displacement buoyancy tank	2306 m^3 – 2250 tonnes	
Structure weight (est.)	450 tonnes	
Max. buoyancy	1800 tonnes	
Distance IBS to outer vessel	2.307m	2.307m
Lift position buoyancy-tank to outer vessel	3.600m	3.600m
Distance lift location of buoyancy tank from hinge of TLS beam	4.093 m	12.843 m
Original TLS lifting capacity	1,875 tonne per beam	1,875 tonne per beam
TLS lifting capacity at T=27m	3,350 tonne per beam	2,975 tonne per beam
TLS lifting capacity at T=16m	3,025 tonne per beam	2,700 tonne per beam

Table G-1: Buoyancy tank calculations

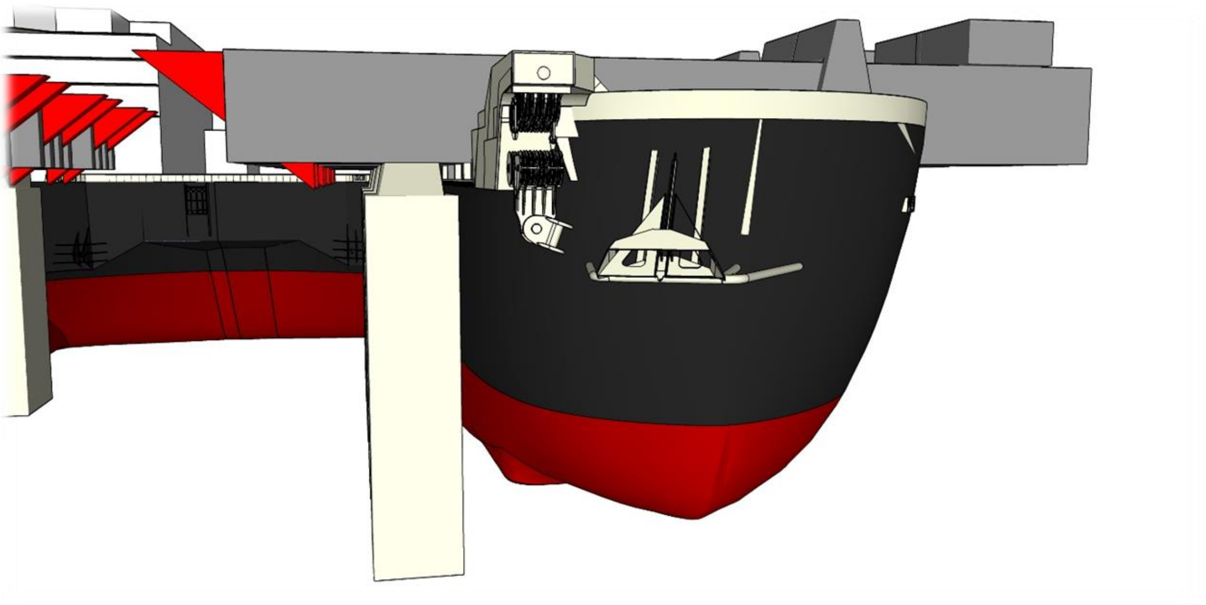


Figure G-1: Buoyancy tank installed on PS

As stated in chapter 4.2.1, this concept is only applicable for small substructures. In Figure G-2 a triangle-shaped substructure drawn inside the slot of the vessel is displayed. The aft three TLS beams could be outfitted with these buoyancy tanks in this case.

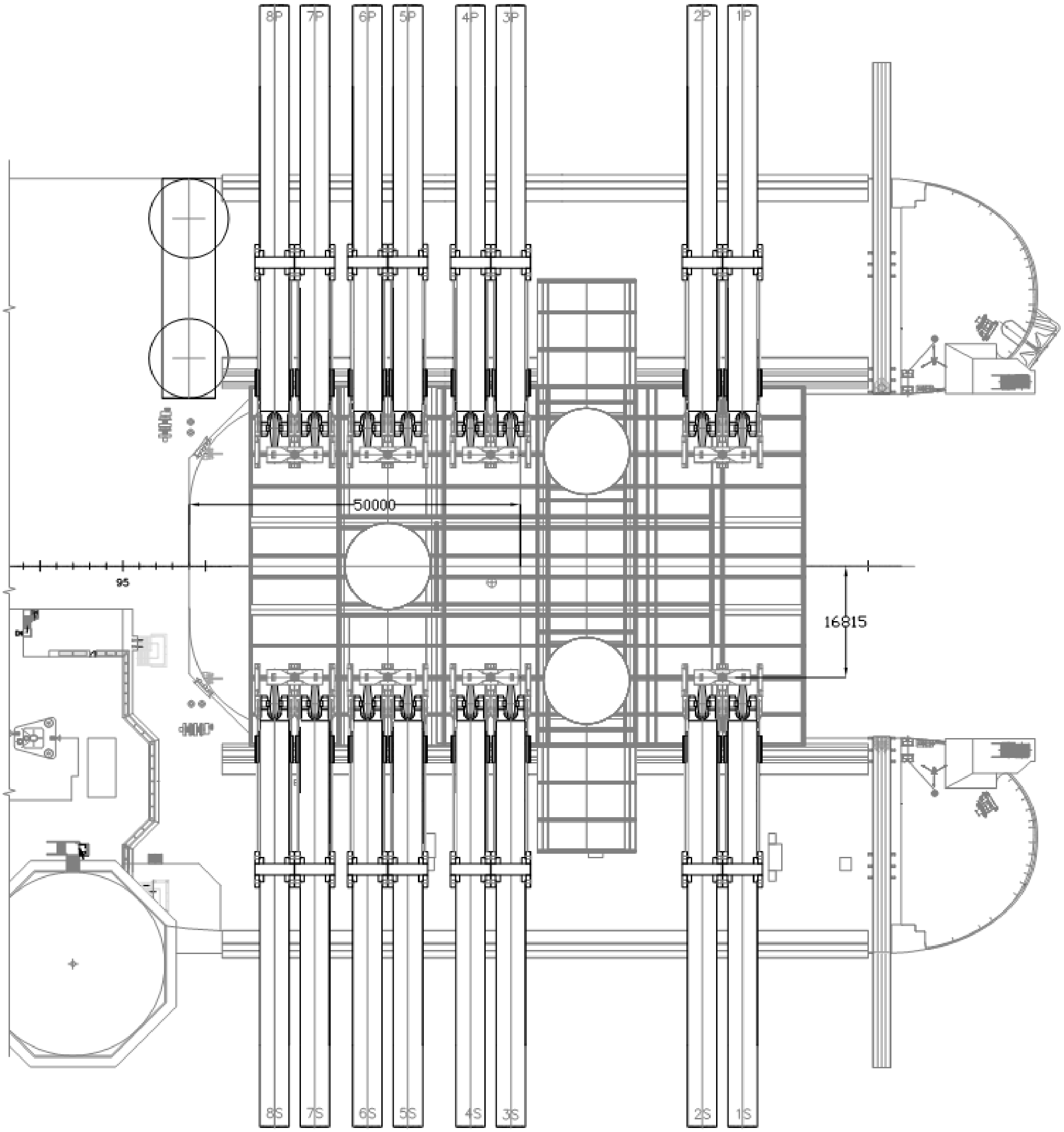


Figure G-2: Topview of triangle substructure removal

Appendix H. Loading Condition Tool

The Loading Condition Tool (LCT) is a piece of software, specially designed for the PS. The LCT is capable of calculating the bending moments and shear forces, both longitudinal and transverse, as well as the torsion in the vessels bows. To be able to modify the tool, the tool is partially simplified. Input parameters that do not influence the modifications and their results, regarding bending moments and shear forces, are deleted from the tool. This makes it easier to modify the tool. The original tool is used to verify the functionality of the simplified tool, by checking various loading conditions. Once the simplified tool is verified, the tool can be modified to match the modified vessel. From this part on, only the simplified tool will be discussed.

Functionality

The functionality of the tool can be described by the following parts:

- Ballast tanks definition
- Tank filling input
- Vessel model and buoyancy
- Longitudinal bending moments and shear forces
- Transverse bending moments, shear forces and torsion

Other and more detailed functionality are described in (Lammeren, 2014).

Ballast tanks definition

The arrangement of all ballast tanks is defined by fixed values;

- Aft and fore length position
- SB and BB width position
- Floor height
- Top height
- Centre of gravity, both longitudinal and transverse
- Tank volume
- Moment of inertia, on all three axis of the vessel

The filling of these tanks generates a weight and vertical centre of gravity for the particular tank.

Tank filling input

All water ballast tanks of the vessel are displayed in an overview. By setting a filling value of each tank, the tool translates this filling percentage, on the basis of the tank definition (0), to the weight of the tank. This weight will be included in the complete weight distribution of the vessel. In Figure H-1, the input form is shown.

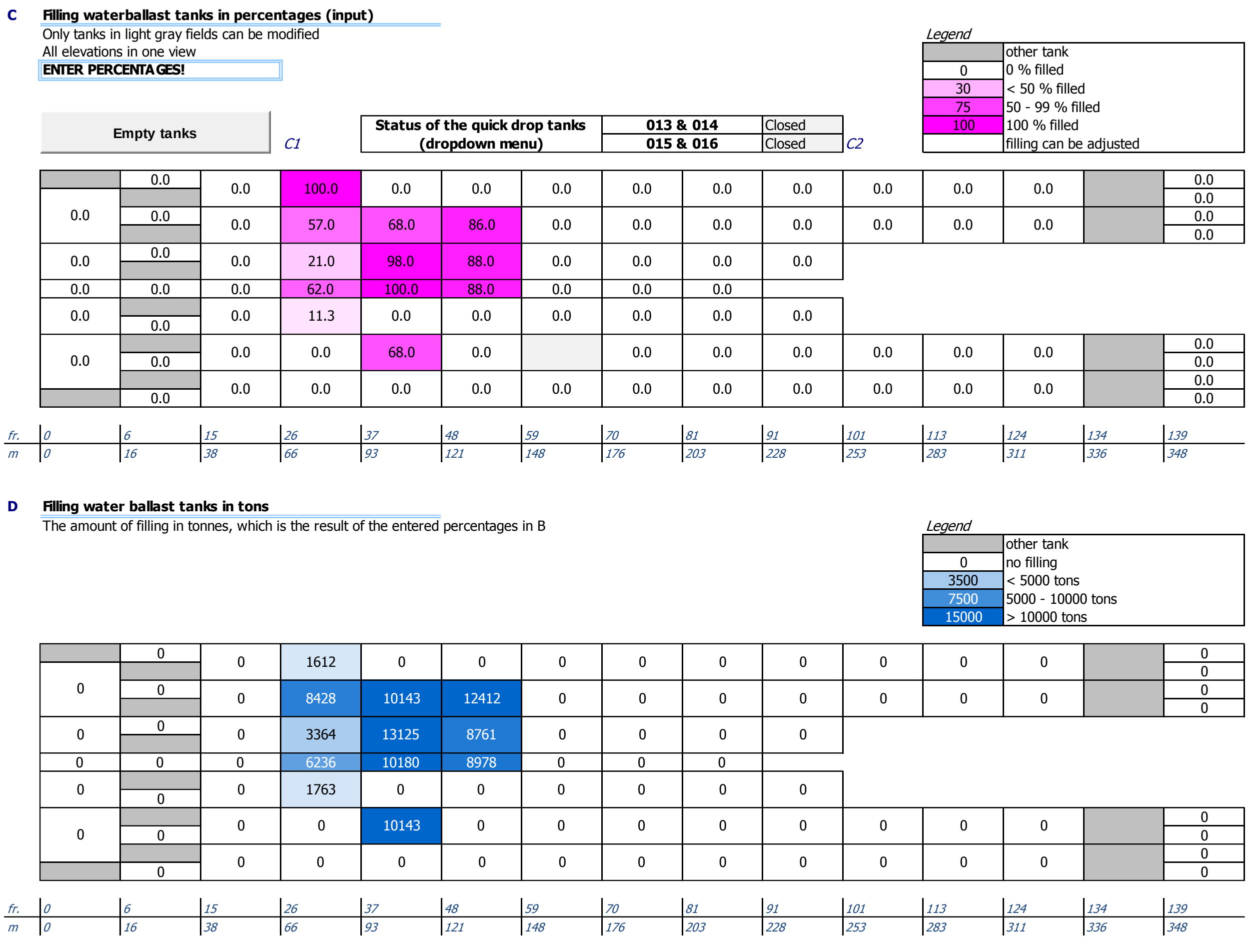


Figure H-1: Preview of input form

For quick adjustments and checks of the loading condition, the hydrostatic output and structural loading is also provided in this overview. This hydrostatic output contains the total weight, longitudinal centre of gravity, draught, list and trim.

Vessel model and buoyancy

In order to be able to calculate the draught, the complete hull of the vessel is modelled in the tool, see Figure H-2. The vessel is divided into panels of 2 by 2 meter. For every panel the average distance from the keel is estimated.

With the vessel modelled, the draught of each panel is calculated by the draught of the vessel. The summation of the volume above all these panels is the displacement of the hull.

The tool estimates the draught of the vessel by comparing the total weight of the vessel and the displacement calculated with the modelled vessel. The draught will be chosen as the one where the displacement equals the total weight. This estimation also includes the trim of the vessel by comparing the longitudinal CoG and the longitudinal Cob.

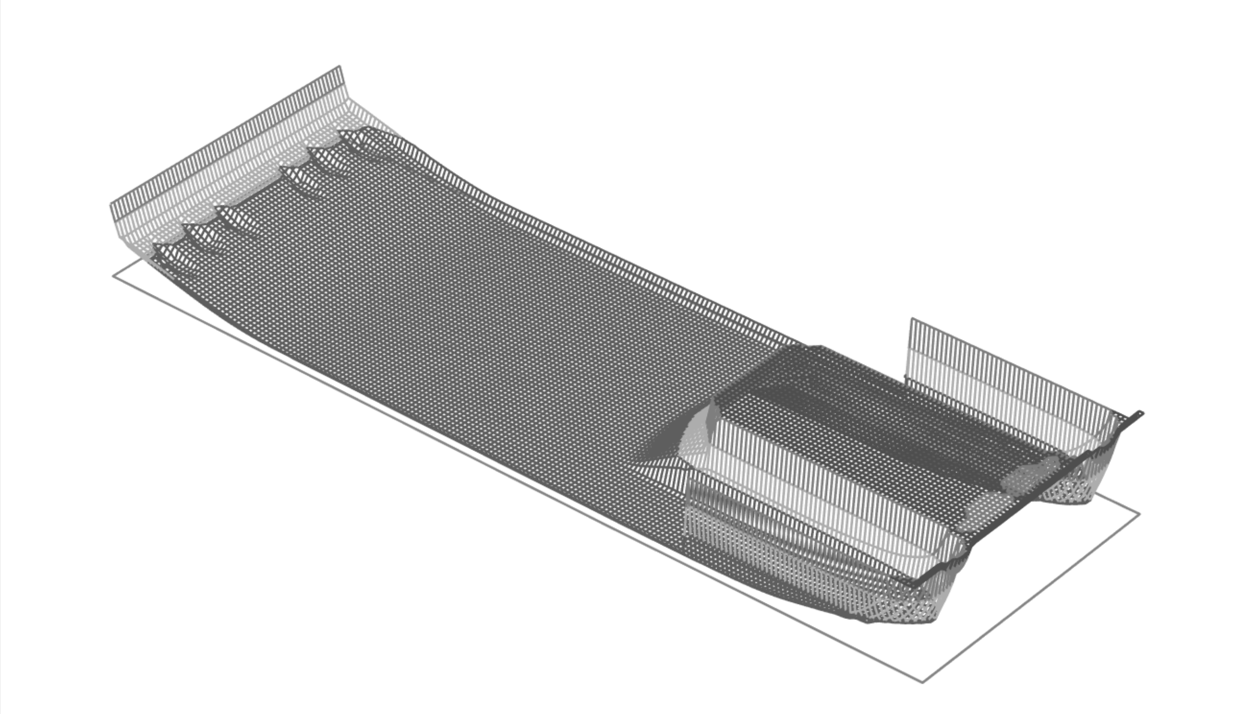


Figure H-2: Model of PS

Longitudinal bending moments and shear forces

All loads on the vessel, including the topside load and water ballast are listed in a weight list, see Figure H-3. The topside load is included in the reaction loads of the TLS beams. To estimate the load distribution, each load input contains a start position and an end position in length and a longitudinal CoG. Each load is longitudinally divided in steps of 2m, in accordance with these input parameters, to calculate the load distribution on the vessel.

The longitudinal bending moment and shear force is calculated with the load distribution and the buoyancy.

The reaction forces of the TLS beams are obtained from the original LCT. In the original tool the outreach and topside load are input parameters which calculate the reaction forces of the TLS beam to the IBS and OBS on the vessel. In this is tool, these simplifications were made to make the tool more manageable for vessel modifications. The positions of the TLS beams are manually calculated.

Tank no/description	Weight	xmin	xmax	LCoG	LCoG	Distribution
				Target	Verification	Mean
	[ton]	[m]	[m]	[m]	[m]	[ton/m]
	AG1	*AG1*	*AG1*	*AG1*	*AG5*	*AG2*
Fixed weights						
111	239.0538597	-5.7	0.839	-2.4305	-2.40	37
12A	2397.649241	145.095	175.875	160.485	160.47	78
12C	465.2640549	144.887	175.522	160.2045	160.20	15
13A	1763.666046	145.095	175.875	160.485	160.47	57
13B	2617.006051	144.7	175.688	160.194	160.19	84
13C	1469.487598	144.807	175.511	160.159	160.16	48
16A	2368.412119	175.693	207.256	191.4745	191.48	75
16C	593.2963047	175.665	207.369	191.517	191.52	19

Figure H-3: Weight list

Transverse bending moments, shear forces and torsion

For the transverse part of the tool, a similar calculation, as for longitudinal, has been carried out to calculate the shear forces and bending moments.

In addition to that, this part will also calculate the torsion in the vessels bows.

Limitations

The tool also has its limitations, for optimal functionality the vessel has to comply with the following:

- Displacement may not differ more than 50 tonnes compared to the total weight.
- Trim < 5cm
- List < 4cm

Modifications

The tool is simplified to be able to apply modifications to modelled vessel. Therefore the limitations of the tool are still valid. Three modifications will be discussed, adding more TLS beams, extending the vessel's bows and widening the vessel's slot.

Adding additional TLS load points

Of all modifications, additional TLS load points is the most easy modification to the tool. Only both the longitudinal and transverse weight lists needs to be extended with the additional TLS load points. The distributed dimensions of these load points are equal to the existing TLS beams.

Extension of the vessel's bows

For extending the vessel's bows, the modelled hull needs to be modified. To start this modification to the tool, the hull length needs to be updated with the new dimensions of the vessel. These dimensions are used to calculate the load distributions.

Second, the model needs to be adjusted. To minimize the impact on the curves of the vessel, the vessel is extended at the location of the parallel bow. This is at a length of 271m, measured from APP. The extended hull sections have the exact same dimensions as the modelled panels, corresponding to 271m.

Then, the newly generated sections need to be inserted in the tank filling input sheet. The extended insertion consists of new tanks. These new tanks need to be inserted into the ballast tank list as well, in accordance with the fore and aft locations of the new tanks. The data of all existing tanks in front of the extension, have to be moved to their new location.

The next part is to update the weight list with the new tanks on the longitudinal weight list as well as the transverse weight list. All weights in front of the extension length have to be moved forward and the weight of the inserted tanks needs to be added. The weight of the hull is also included in load distribution. All weight items, which start before 271m and end after 271m, are increased, proportional to their extension. At last, the database with the longitudinal load distribution needs to be extended for the longer vessel.

The last action is to reallocate the TLS load points. These points can be chosen according to the user but need to be within the range of the TLS rail.

Widening of the vessel

For widening the vessel's slot, the modelled hull needs to be modified. To start the modification to the tool, the maximum hull width needs to be updated with the new dimensions of the vessel. These dimensions are used to calculate the load distributions.

Second, the model needs to be adjusted. To minimize the impact on the curves of the vessel, the vessel needs to be widened evenly at centre line. This will also introduce a new limitation. Because of the basic step of 2m in width, the vessel can only be widened for 4m or a multiple thereof. The widened hull sections have the exact same dimensions as the modelled panels, corresponding to the centreline.

The tank filling input sheet does not need any modification. The widened centre line tanks are updated in the ballast tank list, in accordance with their new width positions and volumes. All tanks which are not on centre line, also need to be moved to their new locations.

The weight list needs to be updated, with the new tank width positions, on the longitudinal weight list as well as the transverse weight list. The weight of the hull is also included in load distribution. All weight items, which have one boundary to the centreline or which are located over the centreline, are increased, proportional to their extension. At last, the database with the transverse load distribution needs to be updated with the right references.

The last action is to change the TLS load values. These points can be chosen according to the user.

Appendix I. Structural reinforcement

The construction of the vessel is examined in five different ways; longitudinal bending moment, longitudinal shear force, transverse bending moment, transverse shear force and torque in the bows. Based on these five parts, the original vessel is used as a benchmark to check the modified options.

The values of the load on the structure are taken from the LCT.

Longitudinal

For comparison of the longitudinal strength of the vessel, a typical transverse web frame is used. All modifications are compared based on two items, the longitudinal bending moment and the longitudinal shear stress. These values are obtained from the LCT.

The structure of the vessel needs to be reinforced, in order to deal with the increase of these moments and stresses. The maximum allowable bending moment and shear stress of this typical web frame of the original vessel is calculated. To maintain the same reserve in structural strength, the web frame is modified as such, that the increase in bending moment and shear stress, according to the LCT, equals the increase of the maximum allowable bending moment and shear stress.

Transverse

For comparison of the transverse strength of the vessel, a typical longitudinal section is used. All modifications are compared based on two items, the transverse bending moment and the transverse shear stress. These values are obtained from the LCT.

The transverse strength of the vessel has much more margin to their maximum values than longitudinal. The stresses are much lower and the strength of the structure is about the same. By increasing the structural loads, some local problems would come up which are cannot be identified with the LCT. Therefore a fixed weight will be included for local modifications to the structure, in order to meet the allowable stresses.

Torque

For comparison of the torque of the vessel's bows, a typical transverse web frame of the bow is used. All modifications are compared based on the torque. These values are obtained from the LCT.

The structure of the bow needs to be reinforced, in order to deal with the increase of the torque. The maximum allowable torque (Equation I-1) in the bow of the original vessel is calculated. To maintain the same reserve, the web frame is modified as such, that the increase in torque, according to the LCT, equals the increase of the maximum allowable torque.

To deal with the torque (Equation I-1), the area or the thickness of the structure is modified. By widening the bow at the aft part of the slot of the vessel, the area of the bow cross section will increase and with that the maximum allowable torque. Narrowing the slot in the aft of the vessel would not directly be a problem, but at some point there will be not enough clearance between the substructure and the vessel. At this point the thickness of the shell-plating will increase to increase the allowable torque of the bows.

This modification only applies over the length where the torque of the modified vessel is higher than the torque of the original vessel. This torque envelope is derived from the LCT.

$$Torque = 2 \cdot A \cdot t \cdot \tau \qquad \text{Equation I-1}$$

Appendix J. Weight estimation of Connection Bridge

To calculate the weight of a connection bridge, the formulas of Equation J-1 to Equation J-5are used.

$$Max\ bending\ moment = \frac{F \cdot l}{4} \quad \text{Equation J-1}$$

$$Bending\ moment\ due\ to\ own\ weight = \frac{beam\ weight\ (N)}{l} \cdot \frac{span}{2} \cdot 0.5 - \frac{beam\ weight(N)}{l} \cdot \frac{l - span}{2} \cdot 0.5 \quad \text{Equation J-2}$$

$$\sigma = \frac{M \cdot y}{I} \quad \text{Equation J-3}$$

$$\tau_{max} = \frac{\sigma_{max}}{2}\ (\text{Hibbeler}, 2007) \quad \text{Equation J-4}$$

$$Max. allowable\ shearforce\ (V) = \frac{\tau_{max} \cdot I \cdot t}{Q} \quad \text{Equation J-5}$$

In Table J-1 the weights of different heights of the connection bridges are calculated. In Figure J-1 a section of the 3m heigh connection beam is illustrated. In Equation J-6, a function of the weight of the connection bridge is described.

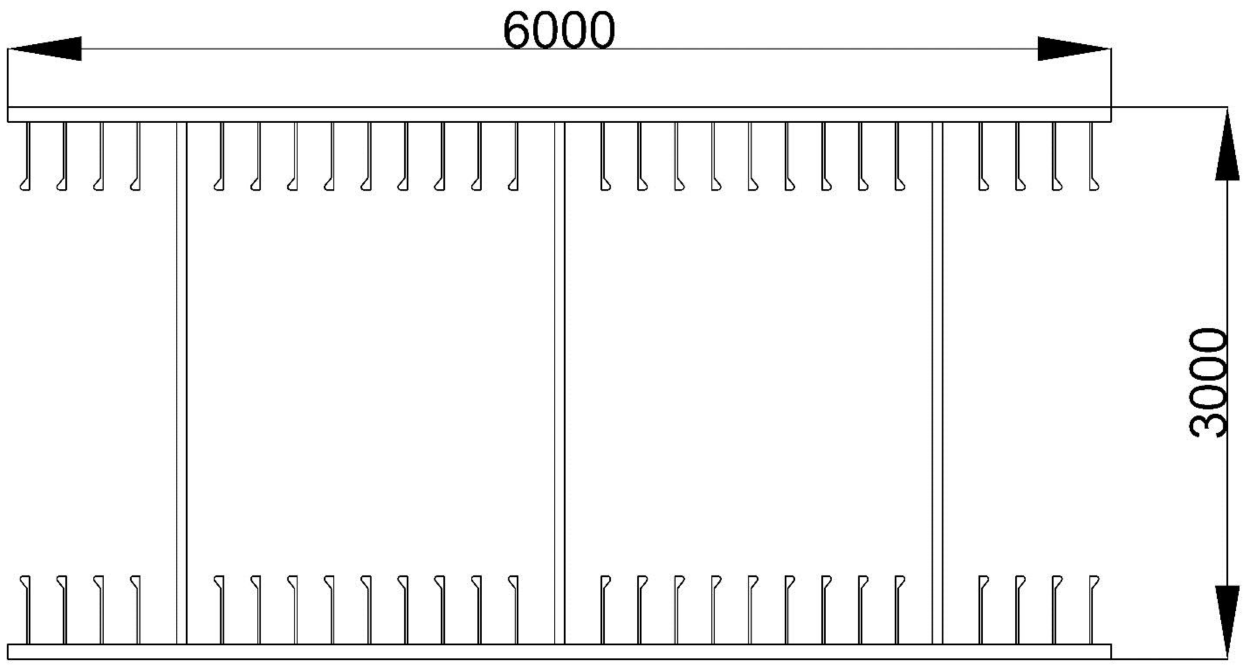


Figure J-1: Section 3m connection beam

		3m	6m	9m	12m
Slot width	m	58.75	58.75	58.75	58.75
Outreach of TLS	m	18.60	18.60	18.60	18.60
Span of Connection bridge	m	26.20	26.20	26.20	26.20
Total beam length	m	30.00	30.00	30.00	30.00
Maximum load	tonnes	12,000	12,000	12,000	12,000
Maximum bending moment	kNm	771,066	771,066	771,066	771,066
Max bending moment due to own weight	kNm	33,062	23,400	21,758	22,490
Total bending moment	Nm	804,128	794,466	792,824	793,556
σ [maximum]	MPa	355.0	355.0	355.0	355.0
Safety factor		0.7	0.7	0.7	0.7
σ [maximum allowable]	MPa	248.5	248.5	248.5	248.5
σ [maximum occurring]	MPa	247.5	245.8	205.8	161.8
τ_{max}	MN/m^2	124.25	124.25	124.25	124.25
τ [maximum allowable]	kN	81,611	68,414	115,529	136,666
τ [maximum occurring]	kN	58,860	58,860	58,860	58,860
Weight	**Tonnes**	**1,204**	**852**	**792**	**819**

Table J-1: Weight calculation of Connection bridge

$$Weight = -1.54321x^3 + 44.4444x^2 - 419.4444x + 2100 \quad \text{Equation J-6}$$

Appendix K. Weight estimation relocating vessels' bows

Additional width [m]	Triangle length [m]	Shell length [m]	Transition Length [m]	Triangle weight (deck area) [tonnes]	Shell weight [tonnes]	Transition block weigh [tonnes]	Weight per side [tonnes]	Total weight [tonnes]
0.00	0.00	0.00	0.00	0	0	0	0	0
1.00	2.84	2.88	0.87	3	33	303	338	677
2.00	5.67	5.76	1.73	11	33	606	649	1,299
3.00	8.51	8.64	2.60	24	49	909	982	1,964
4.00	11.34	11.52	3.46	42	65	1,212	1,319	2,639
5.00	14.18	14.40	4.33	65	82	1,516	1,662	3,325
6.00	17.01	17.28	5.20	94	98	1,819	2,011	4,021
7.00	19.85	20.16	6.06	128	114	2,122	2,364	4,728
8.00	22.69	23.04	6.93	167	131	2,425	2,723	5,445
9.00	25.52	25.91	7.79	212	147	2,728	3,086	6,173
10.00	28.36	28.79	8.66	261	163	3,031	3,456	6,911
11.00	31.19	31.67	9.53	316	179	3,334	3,830	7,660
12.00	34.03	34.55	10.39	376	196	3,637	4,209	8,419
13.00	36.86	37.43	11.26	442	212	3,940	4,594	9,188
14.00	39.70	40.31	12.12	512	228	4,244	4,984	9,968
15.00	42.53	43.19	12.99	588	245	4,547	5,379	10,759
16.00	45.37	46.07	13.86	669	261	4,850	5,780	11,559
17.00	48.21	48.95	14.72	755	277	5,153	6,185	12,371
18.00	51.04	51.83	15.59	847	294	5,456	6,596	13,192
19.00	53.88	54.71	16.45	943	310	5,759	7,012	14,025
20.00	56.71	57.59	17.32	1,045	326	6,062	7,434	14,867

Table K-1: Weight estimation for relocating vessels' bows

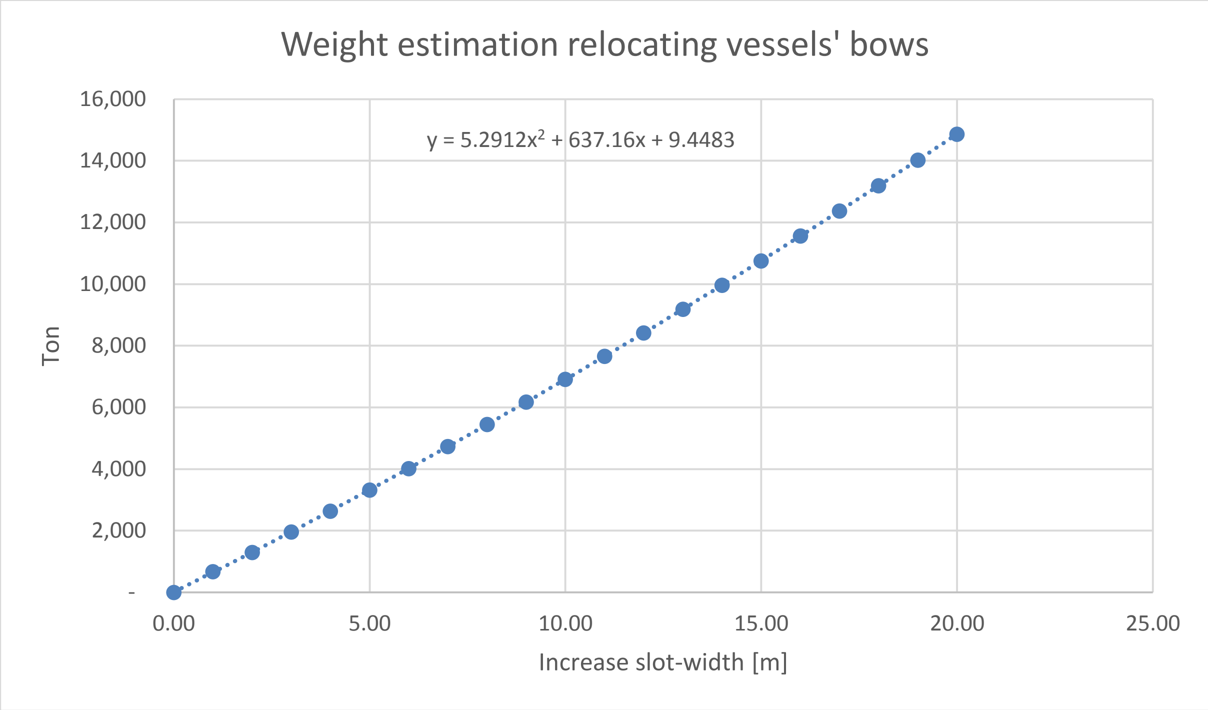


Figure K-1: Weight estimation curve

Appendix L. Strengthening of TLS beams

The strength of the beam needs to be increased, due to the higher extension with an increased slot width. The amount of increase in strength of the beam is based on two characteristics of the beam; the bending moment and the shear stress in longitudinal direction. For four widening scenario's these characteristics are calculated. To maintain an equal margin to the maximum limit of the beam, without the exact knowledge of this maximum limit, the increase of structural strength of the beam is scaled linear with the bending moment and shear stress.

The base scenario is with an 18,60m outreach, measured from the IBS to the hinge of the beam. According to the TLS defined load curve (Soetens, 2014), at 18,60m outreach the maximum allowable load may still be applied to the TLS beam. Taking into account the weight of the beam itself, the highest bending moment and shear force acting on the beam is with an outreach of 18,60m and with a load of 35,215MN (3,589.7 tonnes) (Soetens, 2014).

This appendix starts with the formulas to calculate the acting bending moments and shear stress. The next step is to calculate the additional weight of the beam due to the extension and the additional weight to reinforce the extended TLS beams.

Forces

To define the bending moment and the shear stress, all acting forces on the TLS beam are needed. The forces of the beam are listed in Table L-1.

	Indicator	Weight [tonnes]	Weight [N]	Start position [m]	End position [m]	N/m
Load	t	3589.7	35,215,000	65.000	65.000	NA
Beam weight	b	1600.0	15,696,000	0.000	65.000	241,477
Machinery weight	m	350.0	3,433,500	0.000	20.000	171,675
Lever weight incl. cylinders	l	200.0	1,962,000	50.000	65.000	130,800
IBS	IBS	NA	NA	46.400	46.400	NA
OBS	OBS	NA	NA	17.632	17.632	NA

Table L-1: weight list TLS beam

The reaction forces in both IBS and OBS are to be calculated for each configuration. The reaction forces are determined by Equation L-3 and Equation L-4. These equations follow from the equation of motions of the TLS beam (Equation L-1 and Equation L-2). The origin is located at the left side of the TLS beam, as pictured in Figure L-1.

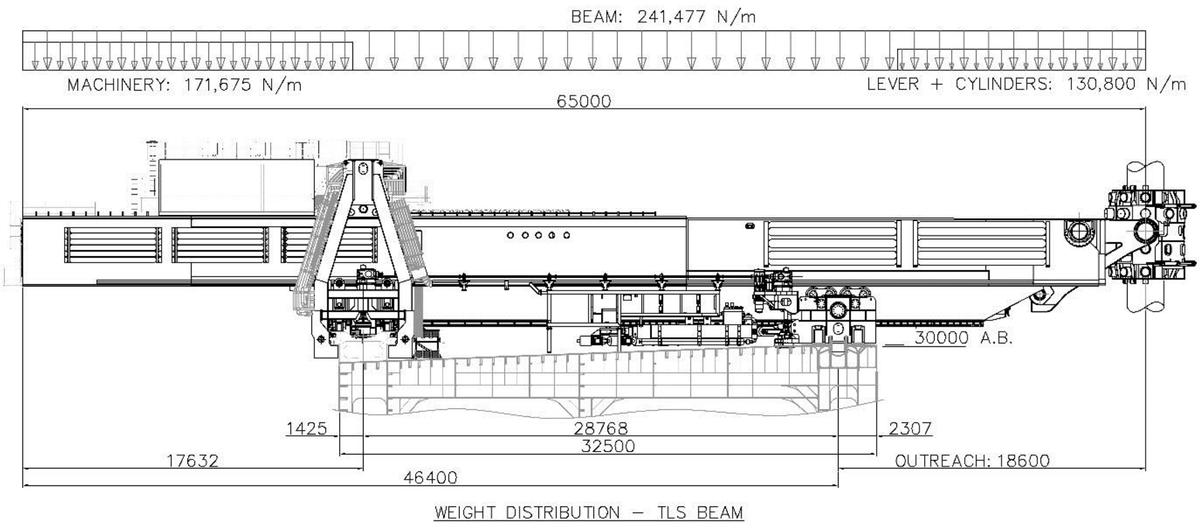


Figure L-1: TLS dimensions and weight distribution

Abbreviations	Description	Value	
F_{IBS}	Reaction force of IBS on the beam		
F_{OBS}	Reaction force of OBS on the beam		
F_t	Load of the topside	35,215,000	N
$L_{b\text{-}end}$	End position of beam	65.0	m
$L_{b\text{-}start}$	Start position of beam	0.0	m
$L_{l\text{-}end}$	End position of lever and cylinder weight	50.0	m
$L_{l\text{-}start}$	Start position of lever and cylinder weight	65.0	m
$L_{m\text{-}end}$	End position of machinery	0.0	m
$L_{m\text{-}start}$	Start position of machinery	20.0	m
L_{IBS}	Position IBS	46.5	m
L_{OBS}	Position OBS	17.8	m
L_t	Position of topside load	65.0	m
q_b	Distributed load of beam	15,696,000	N/m
q_l	Distributed load of lever and cylinder	1,962,000	N/m
q_m	Distributed load of machinery	3,433,500	N/m

Table L-2: list of abbreviations

$$force:$$

$$\begin{aligned}&-F_t + F_{IBS} - F_{OBS} - q_m \cdot (L_{m-end} - L_{m-start})\\ &-q_b \cdot (L_{b-end} - L_{b-start}) - q_l \cdot (L_{l-end} - L_{l-start}) = 0\end{aligned}$$

Equation L-1

$$Bending\ moment:$$

$$\begin{aligned}&-F_t \cdot L_t + F_{IBS} \cdot L_{IBS} - F_{OBS} \cdot L_{OBS}\\ &-q_m \cdot (L_{m-end} - L_{m-start}) \cdot \left(L_{m-start} + \frac{L_{m-end} - L_{m-start}}{2}\right)\\ &-q_b \cdot (L_{b-end} - L_{b-start}) \cdot \left(L_{b-start} + \frac{L_{b-end} - L_{b-start}}{2}\right)\\ &-q_l \cdot (L_{l-end} - L_{l-start}) \cdot \left(L_{l-start} + \frac{L_{l-end} - L_{l-start}}{2}\right) = 0\end{aligned}$$

Equation L-2

$$Load\ IBS\ [N]:$$

$$f_{OBS} = \frac{\left(\begin{matrix}\left(\begin{matrix}F_t + q_m \cdot (L_{m-end} - L_{m-start}) + q_b \cdot (L_{b-end} - L_{b-start}) \\ +q_l \cdot (L_{l-end} - L_{l-start})\end{matrix}\right) \cdot L_{IBS} \\ -F_t \cdot L_t \\ -q_m \cdot (L_{m-end} - L_{m-start}) \cdot \left(L_{m-start} + \frac{L_{m-end} - L_{m-start}}{2}\right) \\ -q_b \cdot (L_{b-end} - L_{b-start}) \cdot \left(L_{b-start} + \frac{L_{b-end} - L_{b-start}}{2}\right) \\ -q_l \cdot (L_{l-end} - L_{l-start}) \cdot \left(L_{l-start} + \frac{L_{l-end} - L_{l-start}}{2}\right)\end{matrix}\right)}{(L_{OBS} - L_{IBS})}$$ Equation L-3

$$Load\ OBS\ [N]:$$

$$F_{IBS} = +F_t - F_{OBS} + q_m \cdot (L_{m-end} - L_{m-start}) + q_b \cdot (L_{b-end} - L_{b-start}) + q_l \cdot (L_{l-end} - L_{l-start})$$ Equation L-4

Shear stress

To define the shear stress in the beam, Equation L-5 is used.

$$V(x) = \int w\,(x)\,dx$$ Equation L-5

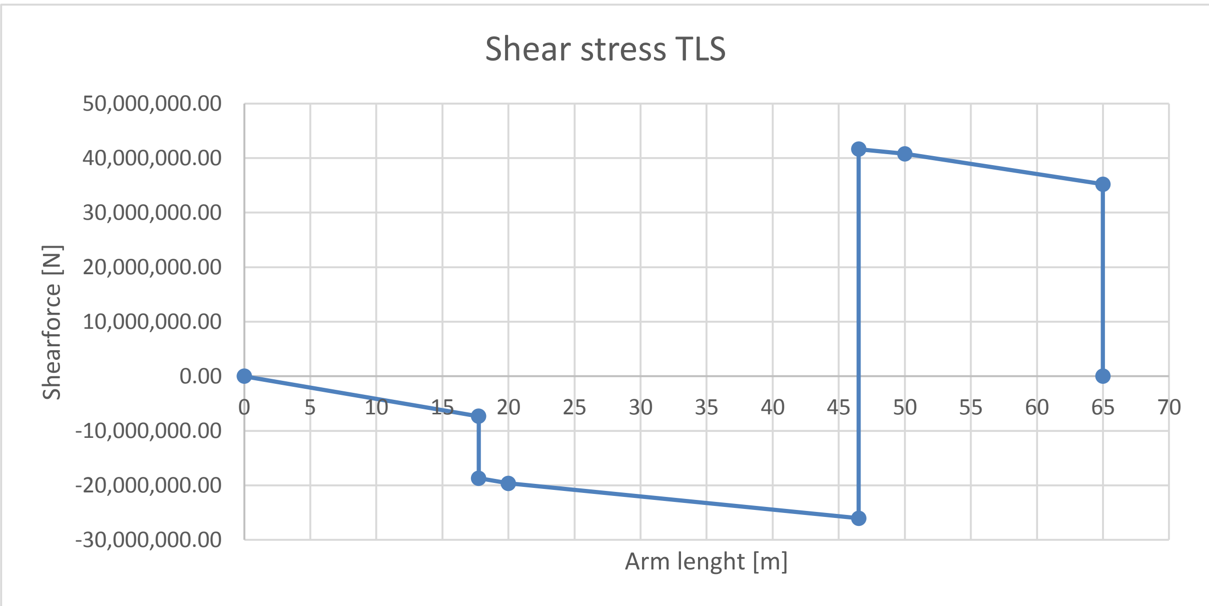


Figure L-2: Shear stress envelope of original TLS beam

Bending moment

To define the bending moment in the beam, Equation L-6 is used.

$$M(x) = \int V\,(x)\,dx$$ Equation L-6

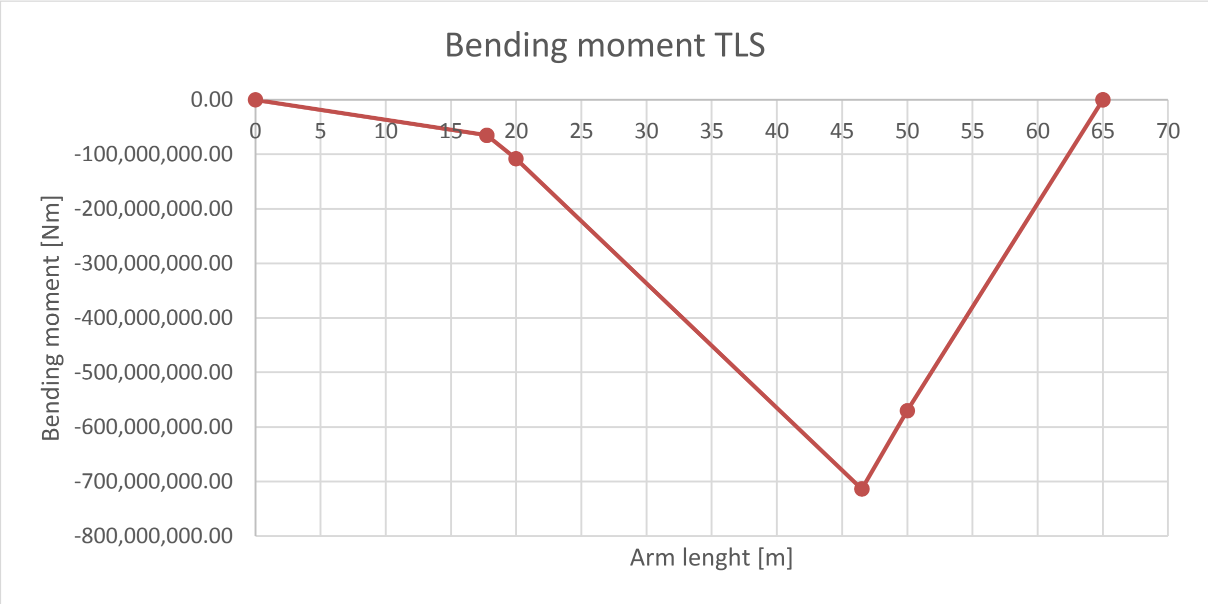


Figure L-3: Bending moment envelope of original TLS beam

Overview of modified TLS beams

With the previous information the modified beam with the new outreach has been calculated. These calculated values are compared to the values of the original beam to determine the increase in shear stress and bending moment.

The next step is to modify the section of the TLS beam, in order to meet these new values. The maximum allowable shear stress and bending moment of the TLS beam, are calculated based on section drawings (Allseas, 2014). These maximum allowable values are compared with the acting bending moment and shear stress. The ratio between these two, is maintained to keep the same margin. In other words, if the acting bending moment increases with 10%, the allowable bending moment needs to increase 10% as well. This is achieved by increasing the beam's structural strength.

The beam will also be increased in length if the slot width is increased. This will be at the position of the highest bending moment for better access to reinforce the beam. The weight of the extension is based on the section area of the beam and the additional length, which is half the widening of the slot. This weight only includes the longitudinal plates and stiffeners, therefore a factor 2 is applied to cover all transverse stiffeners, welding, paint and others.

Increasing the strength of the complete beam, would be exaggerating. Therefore only the length over which the bending moment and shear stress exceed the values of the original beam will be reinforced. The calculated weight, needed to reinforce the beam, will be multiplied by 2, due to welding and additional construction to support the added construction.

In Table L-3, an overview of all necessary parameters is provided to calculate the added weight of the modified TLS beam.

Widening [m]	0	4	8	12	20
Outreach [m]	18.5	20.5	22.5	24.5	28.5
Beam length [m]	65.0	67.0	69.0	71.0	75.0
Shear stress [kN]	-41,640	-42,123	-42,606	-43,089	-44,055
Bending moment [kNm]	-728,350	-812,120	-896,850	-982,540	-1,156,800
Location [m]	18.482	20.482	22.482	24.482	28.482
Increase shear stress [%]	0%	1%	2%	3%	6%
Increase bending moment [%]	0%	12%	23%	35%	59%
Length increase [m]	-	2.00	4.00	6.00	10.00
Sectional area [m²]	1.58	1.70	1.80	1.95	2.16
Reinforced length [m]		8.0	10.0	14.0	21.0
Added weight [tonnes]	**0**	**66**	**137**	**234**	**449**

Table L-3: Beam weight

The added weight to increase the length of the beam and reinforce a part, can be expressed in a linear function, which is presented in Equation L-7.

$$Weight = 0.4x^2 + 14.5x \text{ [tonnes]} \qquad \text{Equation L-7}$$

Appendix M. Detailed cost calculation of modification

For a clear understanding of the cost built-up of a modification, a cost estimation of a large modification which contains all four concepts is provided. The details of the modification are presented in Table M-1. The cost built-up is divided into building costs, material costs and vessel costs. At last, an overview of the topsides the vessel can decommission with this modification is provided.

Modification		# Additional platforms
Extension	45.0m	29
Widening	10.0m	
Additional TLS beams	12	
Connection bridge	12.0m	

Table M-1: Modification details

Building costs

Labour

Modification	Units	Duration (days)
Additional TLS beams	12	171
Extension	45.0 m	90
Widening	10.0 m	119
Connection bridge	12.0 m	1
		381

The labour cost, based on 381 working days and a daily costs for labour of €30,000, is €11,430,000

Lay up

As stated in Equation 6-2, the total duration is not equal to the summation of the four different modification parts.

According to Equation 6-2, the total lay-up time of the vessel is 276 days. Combined with the daily cost of the vessel (Chapter 6.3.1) of €940,000, the total lay-up costs are €259,440,000

Transport

The transport time of each modification is maximum 10 days (Chapter 5). In Chapter 6.3.1 it is calculated that the average daily cost of the vessel is €1,190,000.00. The total transport cost of the vessel to reach the modification facility is €11,900,000.

Docking

For this modification a dock is used for both extension as widening. The total duration of dock usage is 50 days for a relative small dock.

	Day-rate	Total
Variable costs	€45,000.00	€2,250,000
Fixed costs		€75,000
Total		**€2,325,000**

Table M-2: Docking costs

Test

As stated in chapter 5, the testing period of each modification will be 15 days. In Chapter 6.3.1 is calculated that the daily cost of the vessel in heavy lift mode is €1,310,000. The total cost for testing of the vessel is €19,650,000

TLS beam modification

For widening the slot, the TLS beams need to be modified. To be able to modify these beams, they need to be removed and later reinstalled on-board the vessel. The total cost of this procedure is estimated at €5,600,000

Total building costs

Building costs	
Labour	€11,425,000
Lay up	€259,450,000
Transport	€11,900,000
Docking	€2,325,000
Testing	€19,650,000
TLS beam modification	€5,600,000
	€310,350,000

Table M-3: Building costs

Material costs

Hull

Extension

As stated in chapter 5.2, the weight of the extension of the hull will weigh 695 tonnes for each 2.5m length for both bows. A 45m extension will weigh 12,510 tonnes and cost €31,275,000

Widening

According to Equation 5-2, the additional weight of widening the slot by relocating the vessel's bows for 10 meters is 6,910 tonnes and costs €17,275,000

Equipment

New TLS Beams

For this modification 12 additional TLS beams are required. The price of each beams is estimated at €12,700,000 with an additional cost of €2,500,000 for updating the system. In total the additional TLS beams cost €154,900,000.

Connection Bridge

With the installation of 12 additional TLS beams, 7 connection bridges are required. Each of the beams will weigh, according to Equation 5-4, 800 tonnes and will cost €2,000,000. All connection bridges together will cost €14,000,000

Pumping

For each meter of extension of the vessel's bows, an additional 1,735m^3 of water ballast volume will be created. The costs for updating the pumping capacity is €7,800,000

Other equipment

When widening the slot, the barges, stinger and the TLS beams need to be modified. These costs are specified in Table M-4. When widening the slot, the TLS beams need to be modified. They need to be reinforced and extended. The modification weight is estimated in Appendix L. The total costs for other equipment is estimated at €19,425,000

Equipment	
Barges	€20,950,000
Stinger	€13,125,000
TLS beams	€19,425,000
Total	**€53,500,000**

Table M-4: Cost of other equipment

Construction

Extension

Extending the vessel requires structural reinforcements to deal with the increased loads. In total for 45m extension, 1,575 tonnes of additional steel is required. The cost for this reinforcement is €5,900,000.

Widening

Widening the vessel requires structural reinforcement to deal with the increased loads. In total for 10m widening, 3,465 tonnes of additional steel is required. The cost for this reinforcement is €13,000,000.

Additional lifting capacity

Adding TLS beams increases the maximum liftable topside weight. Due to this higher load, the vessel requires structural reinforcement. For adding 12 TLS beams, 10,650 tonnes of additional steel is required. The cost for this reinforcement is €39,950,000.

Total material costs

Material costs	
Hull	
Extension	€31,275,000
Widening	€17,275,000
Equipment	
New TLS beams	€154,900,000
Connection bridge	€14,000,000
Pumping	€7,800,000
Other equipment	€53,500,000
Construction	
Extension	€5,900,000
Widening	€13,000,000
Additional lifting capacity	€39,350,000
	€337,000,000

Table M-5: Material costs

Vessel costs

Unmodified vessel costs

For removing a topside, the vessel is deployed for approximately 30 days. During these days the daily cost of the vessel in heavy lift mode needs to be taken into account. For each topside this equals about €39,850,000. For two topsides, an additional cost of €10,000,000 is included to cover for an additional construction to lift these topsides. These topsides are very close to the waterline, which requires this kind of additional structure.

Increased vessel costs

All new items installed on the vessel during the modification are not taken into account in the daily costs of the vessel. For these items the maintenance and interest needs to be taken into account. Maintenance is only applicable to new material installed on-board of the vessel. Maintenance as well as interest is a summation over the indicated 10 year lifetime.

	Maintenance	Interest (WACC)
Building cost	€-	€155,175,000
Material cost	€84,250,000	€168,500,000
Total	**€84,250,000**	**€323,675,000**

Table M-6: Maintenance and interest - values are summation over 10 year

Total costs

Total costs	
Building cost	€310,350,000
Material cost	€337,000,000
Vessel cost	€1,583,575,000
Total	**€2,230,925,000**

Table M-7: Total cost overview

Income

Name	Topside weight (tonnes)	Income
Alba North	23,800	€ 55,930,000
Beryl A	29,150	€ 68,502,500
Brae A	32,000	€ 75,200,000
Brae B	36,813	€ 86,510,550
Brent B	29,014	€ 68,182,900
Brent D	22,433	€ 52,717,550
Bressay A	31,000	€ 72,850,000
Britannia PDQ	28,900	€ 67,915,000
Clair DP (Clair Ridge)	26,000	€ 61,100,000
Dunlin A	25,112	€ 59,013,200
Ekofisk 2/4J	25,600	€ 60,160,000
Goodwyn A	23,500	€ 55,225,000
Green Canyon 645-A T-Spar Holstein	23,990	€ 56,376,500
Green Canyon 782-A T-Spar Mad Dog	22,226	€ 52,231,100
Gullfaks A	42,300	€ 99,405,000
Gullfaks B	28,000	€ 65,800,000
Magnus	30,600	€ 71,910,000
Main Pass 299 (Sulphur) STO	20,000	€ 47,000,000
Murchison	24,544	€ 57,678,400
Ninian Central	39,000	€ 91,650,000
Ninian South	25,500	€ 59,925,000
North Rankin B	23,600	€ 55,460,000
Oseberg A	46,000	€ 108,100,000
Piper B	28,900	€ 67,915,000
Sleipner SLA	37,964	€ 89,215,400
Statfjord B	37,000	€ 86,950,000
Statfjord C	42,000	€ 98,700,000
Thistle A	18,000	€ 42,300,000
Troll A	22,500	€ 52,875,000
Total		**€ 1,986,798,100**

Table M-8: Total income

Artist impressions

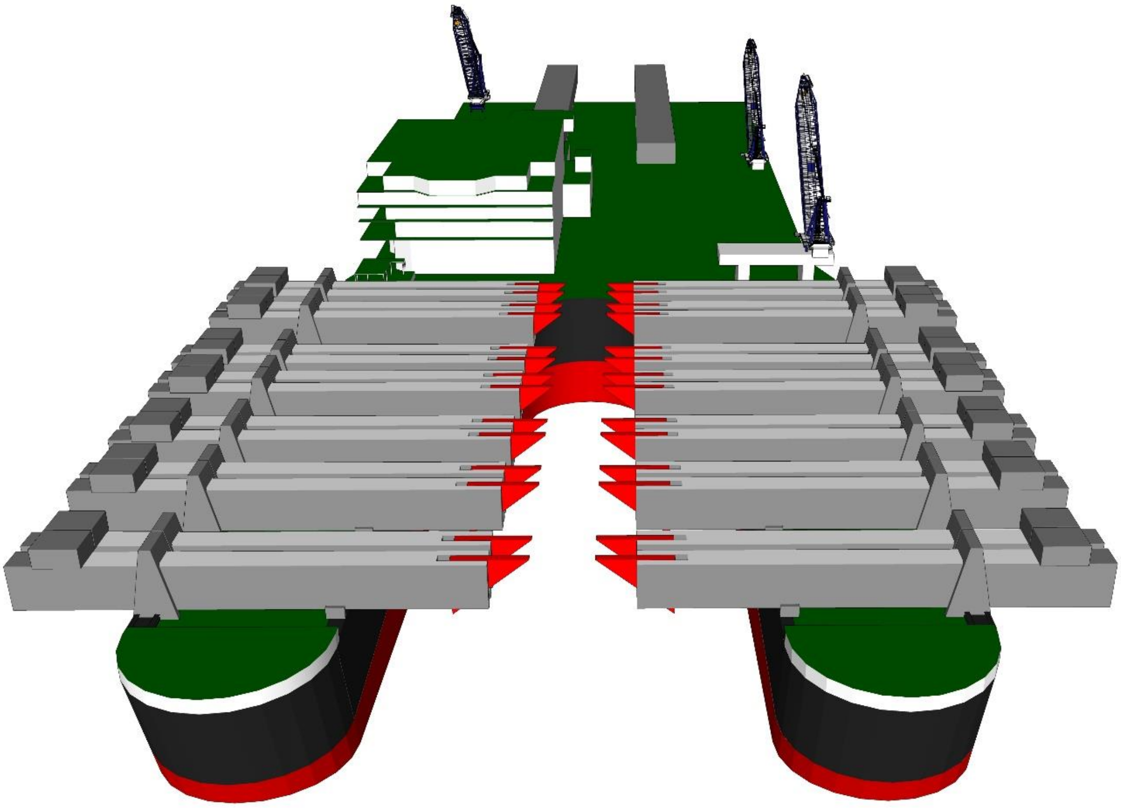


Figure M-1: Artists impression of modified Pioneering Spirit - with TLS

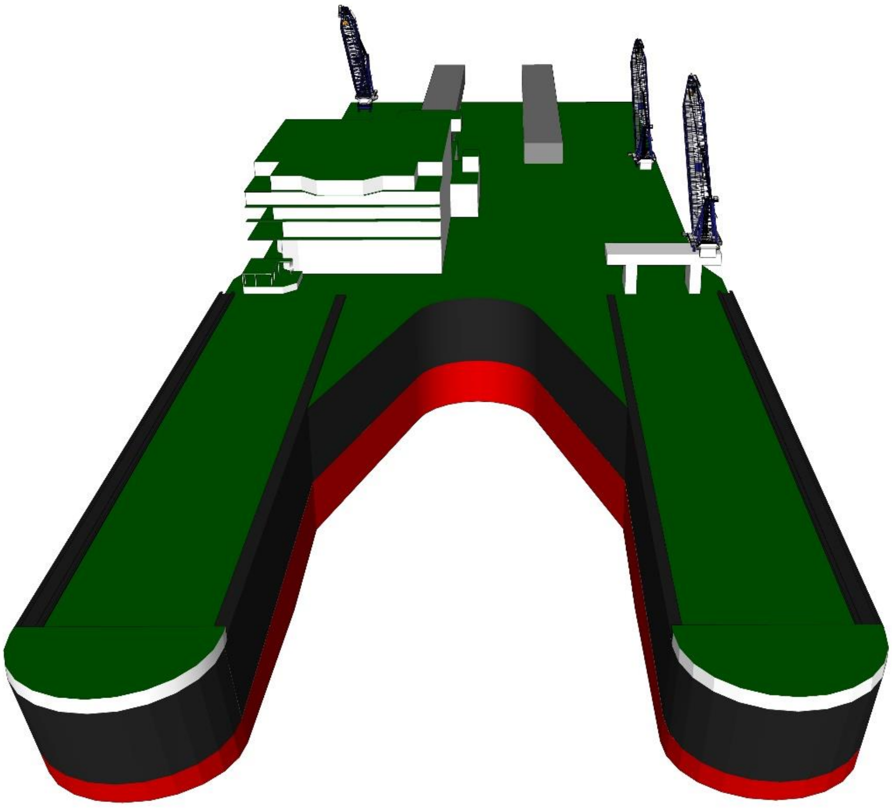


Figure M-2: Artist impression of modified Pioneering Spirit - without TLS

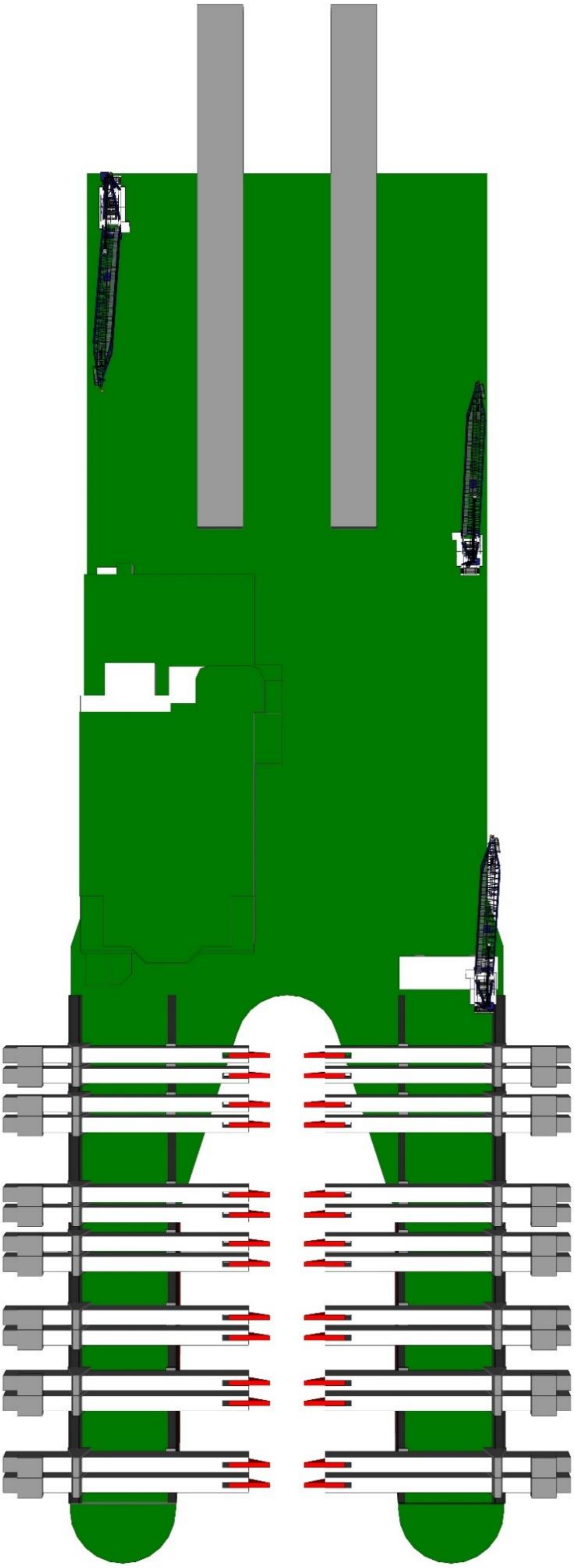


Figure M-3: Artists impression of modified Pioneering Spirit - Topview with TLS

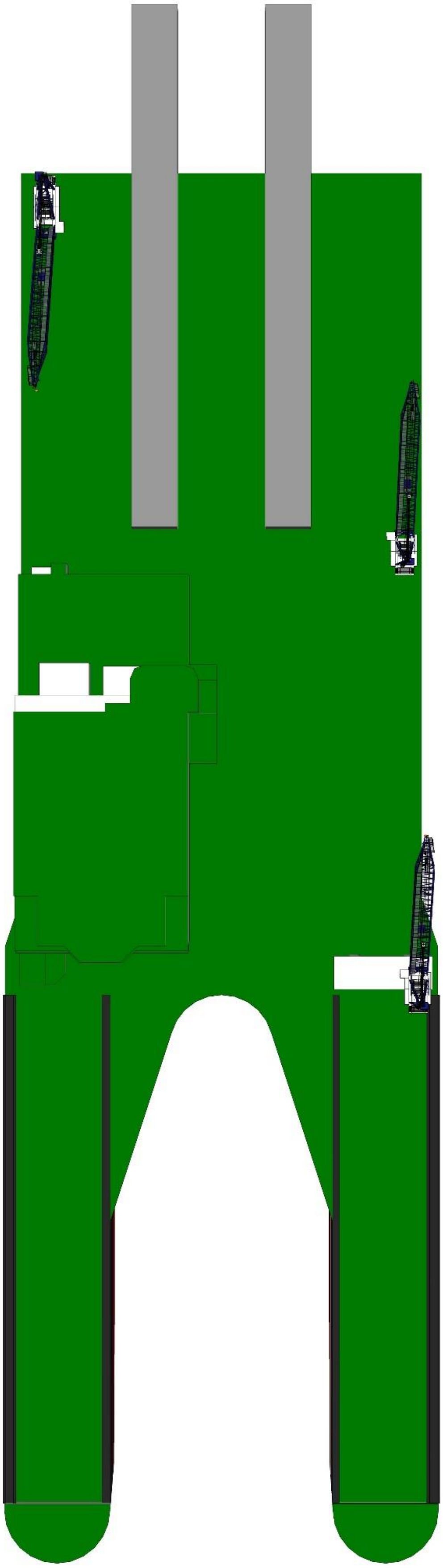


Figure M-4: Artists impression of modified Pioneering Spirit - Topview without TLS