Appendix I

entitled

Analysis report

in addendum to the thesis

The selection and conceptual design of a heavy lifting installation for the Damen decommissioning vessel

By

Marco Kouwenhoven

Damen Shipyards
January 2017

DAMEN

Analysis report

in addendum to the thesis

The selection and conceptual design of a heavy lifting installation for the Damen decommissioning vessel

Submitted to the university mentor in partial fulfillment of the requirements for

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At

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Version	2.1	**Company supervisor**	Mr. L. Zaat

Damen Shipyards
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Version management

Table 1 Version management

Version	Date	Description	Author	Provided to	
1.0	27-10-2016	Analysis report	Marco Kouwenhoven	/	
2.0	22-12-2016	Appendix B	Marco Kouwenhoven	Company supervisor	Mr. S. Utzon
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List of abbreviations

- **C.O.G.** Center of gravity
- **R.A.O**. Response amplitude operator
- **B.p.p.** Between perpendiculars
- **Mld** Molded
- **HLC** Heavy lifting crane

Glossary of terms

- **Transit draught**
  Draft of the vessel during transit
- **Summer draught**
  Fully loaded and maximum draught

Preface

This document contains several analyses and assessments in addendum to the thesis “The selection and conceptual design of a heavy lifting installation for the Damen decommissioning vessel”. In the thesis is referred to chapters in this appendix. This report is structured chronologically by the thesis.

For the development of the heavy lifting construction, the dimensions of the conceptual decommissioning vessel are listed and the dimensions of oil and gas platforms, installed offshore have been accessed. By this analysis the greatest dimensions of the platforms are determined (chapter 1&2).

Damen established three possible methods for the heavy lifting construction, which can be installed on the decommissioning vessel. In chapter 3 contains the analysis to all three methods. With the obtained knowledge and the results from the assessment to the dimensions of the decommissioning vessel and offshore platforms, a founded choice is made according the set of requirements.

The heavy lifting construction must comply with several rules and standards. For this study the document “Standard for offshore and platform lifting appliances” (DNV-GL, 2016) is analyzed . The rules and standards whish are of importance for the development of the heavy lifting construction are described in chapter 4.

A study is done over the ballast system of the decommissioning vessel and the contribution of this system to the decommissioning vessel is analyzed in chapter 5. In chapter 6 and 7, the diversity in airgap and tidal range is analyzed, required for the development of the heavy lifting construction.

The movements of the decommissioning vessel, which are of great importance for the development, have been analyzed. As established by the scope of this project, these movements are calculated by Damen Shipyards. The input Damen needs to calculate these movements are described chapter 8. In order to calculate the forces, the outline of the situation is determined for the calculation model(appendix II) in chapter 9.

The weight distribution of the topside to the heavy lifting construction is analyzed in chapter 10.

1. Dimensions decommissioning vessel

The heavy lifting construction must be developed for the conceptual decommissioning vessel. Therefore, the dimensions of this vessel must be known. The dimensions, necessary for this project, are shown in the table below, with figure 1 and 2 for clarification. The dimensions are obtained with the leaflet of the decommissioning vessel (Appendix IA) and the thesis “The development of an innovative solution for the offshore decommissioning industry” (Rietveld, 2016).

Table 2 Dimensions decommissioning vessel

Dimensions decommissioning vessel	
Length o.a.	89.89 m
Length b.p.p.	84.15 m
Beam mld.	32.00 m
Depth mld.	8.50 m
Draught transit (base)	5.18 m
Draught summer (base)	5.83 m
Cargo deck area	942 m^2
Gap length	24.60 m
Gap width	14.40 m

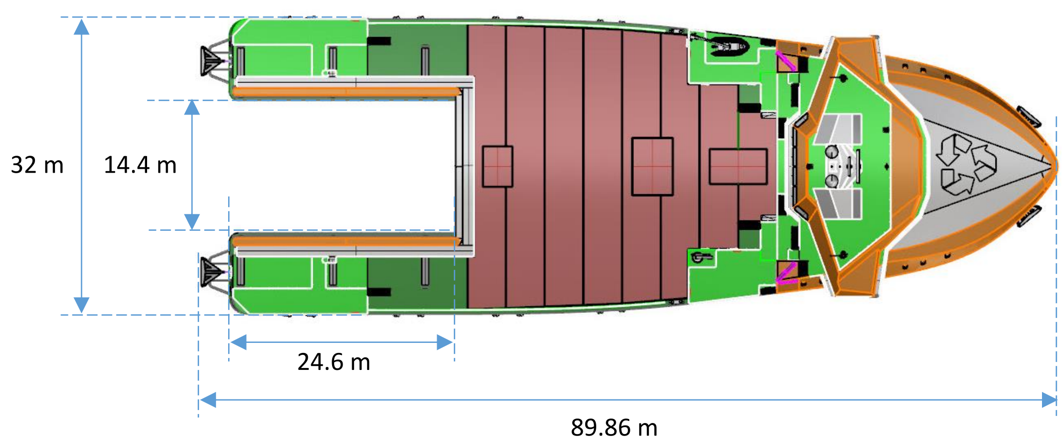


Figure 1 Dimensions decommissioning vessel (Top-view)

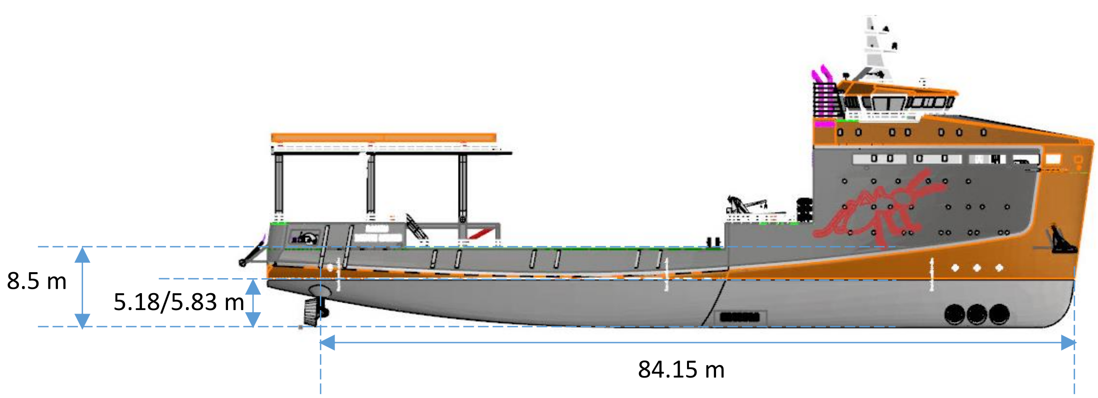


Figure 2 Dimensions decommissioning vessel (Side-view)

2. Offshore platforms

Oil and gas platforms are installed all over the world. The dimensions and weight of the platforms depends on the purpose and the region the platform is installed. For the development of the heavy lifting structure it is necessary to obtain knowledge of the dimensions.

2.1.1. Weight platforms

This study started with collecting information relating to the weight of platforms installed offshore. The Excel document ''Offshore Market Intelligence Module 1 Datafile Update'', Van Vlimmeren (2016), contains, among other things, information of the region, the purpose and weight of more than 11000 platforms installed all around the world. In order to get a knowledge of the distribution of the weight of platforms by region, the platforms are subdivided in weight classes per region (appendix IB). Damen Shipyards has established that the heavy lifting construction must be able to lift topsides with a maximum weight of 1600 tons. By the charts is concluded that according to topside weight, for each region at least 55% off all platforms can be decommissioned.

2.1.2. Dimensions platforms

For the development of the heavy lifting construction, research is carried out in order to obtain knowledge of the dimensions of offshore platforms. The research focused on collecting information of the height, width and length of the topside, length and width of the jacket and the airgap (figure 4). The weight and dimensions of the topside depends on the purpose of the platform. The width, length and height of the jacket are depending on the weight of the topside and the region in which the platform is installed. The airgap is the space between the bottom of the topside with the lowest astronomical tide, figure 3.

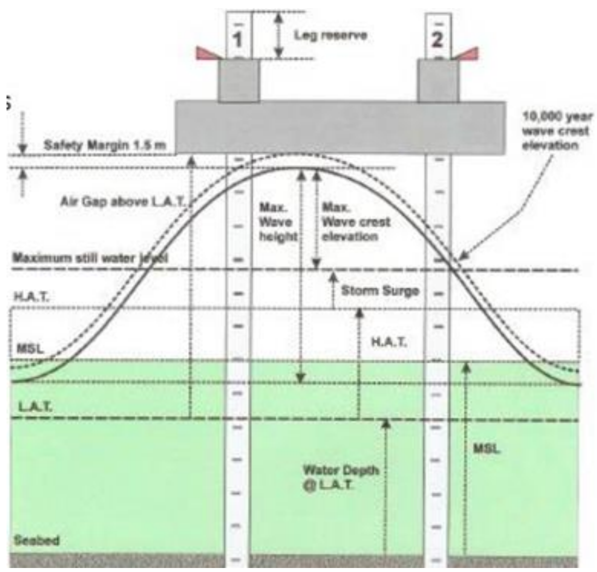


Figure 3 Airgap (lowest astronomical tide – bottom topside)

Information is collected by search on the internet and approaching companies managing the marine areas. Unfortunately it appeared that this information is only known by the operators of the platforms. Contacting the operators would be time consuming. On the internet information of 27 platforms is found, all installed in the North Sea.

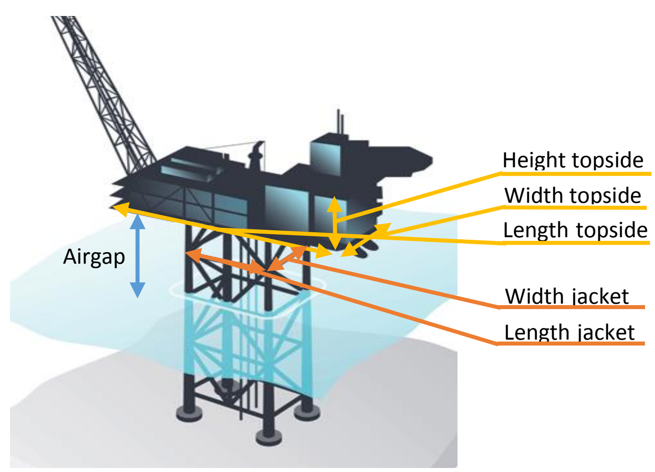


Figure 4 Dimensions platform

The collected information is registered in an excel document (appendix IC). The tables below summarizes the collected data, distributing the dimensions by ranges for topsides with a maximum weight of 1600 ton. The total amount of platforms differ by dimension because not all the dimensions are known for each platform.

Table 3 Topside height

Topside height	
Range	**Amount**
Height < 9	3
10 < Height < 14	7
15 < Height < 19	4
20 < Height < 24	2
25 < Height < 29	2
30 < Height	0

Table 4 Topside length

Topside length	
Range	**Amount**
Length < 10	0
10 < Length < 15	5
15 < Length < 20	4
20 < Length < 25	3
25 < Length < 30	3
30 < Length	0

Table 5 Jacket width

Jacket width	
Range	**Amount**
10 < Width < 10	6
10 < Width < 15	3
15 < Width < 20	1
20 < Width < 25	2
25 < Width < 30	1
30 < Width	0

Table 7 Airgap

Topside width	
Range	**Amount**
Width < 10	4
10 < Width < 15	6
15 < Width < 20	3
20 < Width < 25	2
25 < Width < 30	0
30 < Width	0

Table 8 Topside width

Airgap	
Range [m]	**Amount**
Airgap < 10	0
10 < Airgap < 15	0
15 < Airgap < 20	16
20 < Airgap < 25	0
25 < Airgap < 30	0
30 < Airgap	0

Table 6 Jacket length

Jacket length	
Range	**Amount**
Length < 10	1
10 < Length < 15	5
15 < Length < 20	15
20 < Length < 25	1
25 < Length < 30	3
30 < Length	0

Table 9 Minimal and maximal dimensions

Min/max dimensions		
Dimension	**Min [m]**	**Max [m]**
Topside Height	3.2	26.5
Topside Width	8.5	25
Topside Length	12	30
Airgap	15.5	20
Jacket width	7.5	26
Jacket length	10	27

3. Choosing method

In this chapter a choice among the three methods is made. First of all the functioning of the methods and the (dis)advantages in comparison to each other will be discussed. Then, with the use of the selection matrix and the set of requirements a method will be chosen.

3.1. Methods

Damen Shipyards established three possible methods in order to remove the topside from the jacket. The decommissioning can be done by the use of a heavy lifting crane mounted on the vessel, by a forklift construction or by a lifting frame. The three methods needs to be applied to the developed decommissioning vessel. However it is assumed for the forklift construction and the heavy lifting crane the opening at the back of the vessel is disregarded.

3.1.1. Decommissioning by forklift construction

This method of decommissioning is done by a forklift construction. The vessel positions two ‘forks’ at each side of the jacket. While in position the vessel will de-ballast and therefore generate upward force to lift the topside. After lifting the topside, the construction will slide towards the middle of the vessel on order to sea fasten the topside and ensure the stability of the vessel during transport to shore.

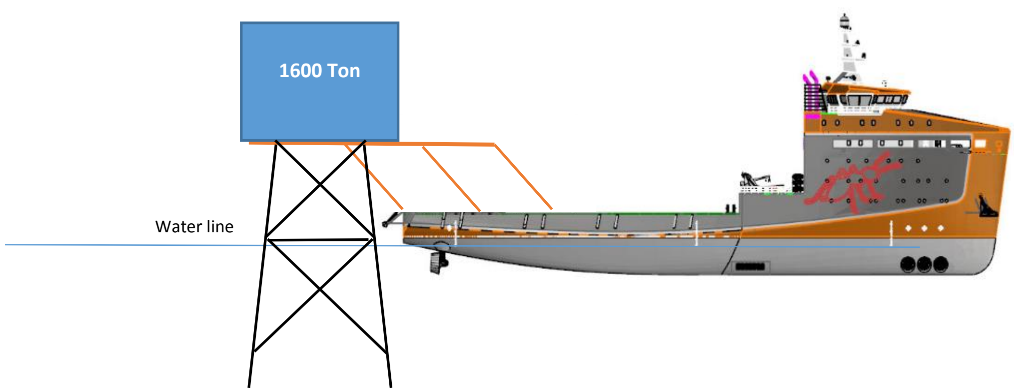


Figure 5 Forklift method

3.1.2. Decommissioning by crane

Lifting by a crane is a well-known method because the topsides are often installed by a crane. Picture 6 shows how a topside is installed with the use of a HLC. (Garus, 2013)

Figure 6 Topside lifting by crane

The vessel can be positioned side wards, or with the back next to the platform. The topside will be attached to the crane, then lifted and placed on the deck. The lifting operation can be carried out using one or two cranes. Three options are analyzed for applying a HLC to the decommissioning vessel.

Using a single crane to lift the topside, it is positioned at the portside or starboard, at the back of the vessel (figure 7, right image). This position ensures the lateral and longitudinal stability of the vessel when lifting and transporting the topside to the deck.

When lifting by two cranes, they both have to be positioned at the back of the vessel, each at one side (figure 7, middle image). If the two cranes are both placed at the side of the vessel (figure 7, left image), the lateral stability cannot be ensured. The topside can be transported to deck by first turning one crane towards main deck, followed by the other one. The advantage of using two cranes is the cranes only need to lift half of the weight of the topside and the weight of the topside is better distributed which is beneficial for the transversal stability of the vessel. Disadvantage is the topside needs to move in between the two cranes in order to place it on the deck, so the size of the topside is limited.

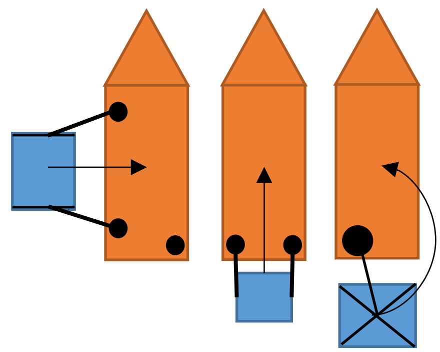


Figure 7 Placing crane on deck

The method of decommissioning needs to be applied to the designed decommissioning vessel which is only 32 meters wide (chapter 1). Research showed the base of the crane is usually four meters wide and the crane is lifting at about an angle of 70 degrees. Placing two cranes at the back leaves too little space at the back of the vessel for the topside to be transported to the main deck. For decommissioning with a crane by the designed decommissioning vessel is chosen for lifting by a single crane, placed on the back of the vessel, at the portside or starboard (Figure 8).

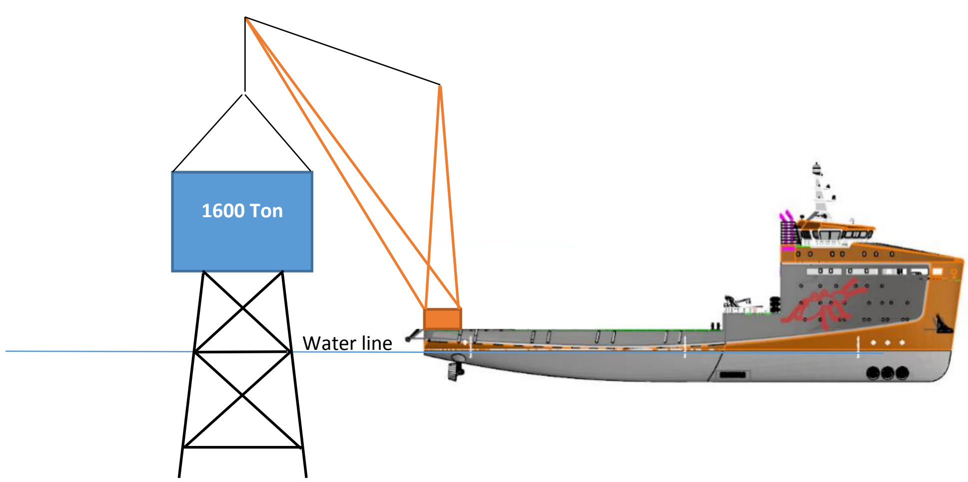


Figure 8 Lifting by heavy lifting crane

3.1.3. Method 3 Decommissioning by lifting frame

The designed decommissioning vessel is now equipped with a lifting frame (figure9,10). The lifting frame is mounted at the aft of the vessel around the gap. The vessel will be positioned backwards around the jacket. When positioned it will de-ballast in order to lift the topside from the jacket on to the lifting frame.

Figure 9 The decommissioning vessel, equipped with lifting frame

After the topside is lifted, before transported to shore, the lifting frame is lowered in order to sea fasten the topside. Sea fastening makes sure the topside is secured to the vessel and the drive components of the lifting frame are discharged by lowering the topside to another structure on deck.

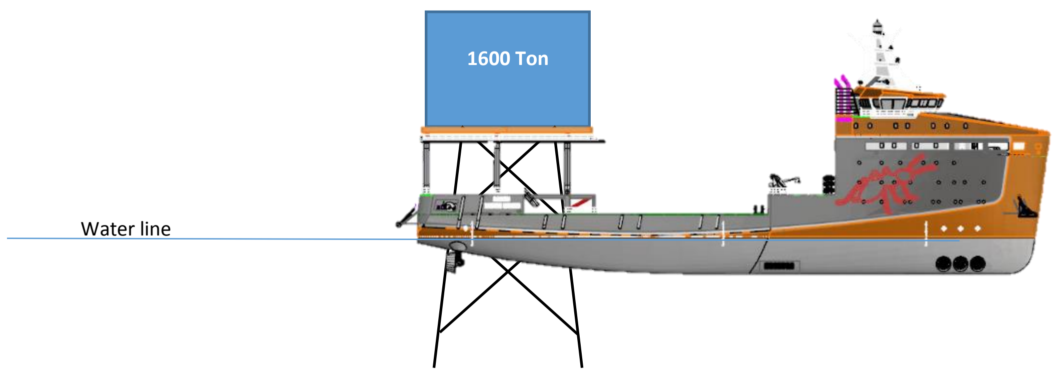


Figure 10 Lifting frame method

3.2. Choice of method

In this chapter a method will be chosen. As mentioned earlier this choice is based on the set of requirements which will be discussed. The requirements are used in a selection matrix. This selection matrix is used to make a well-founded choice and uses weight factors for each requirement in order to determine its importance.

3.2.1. Set of requirements

The choice among the three methods is based on the set of requirements, established in cooperation with Damen Shipyards. The requirements are displayed in the table below.

Table 10 Set of requirements

	Set of requirements
	Dimensions platform
1	Ability for lifting of topsides in a wide range
2	Adaptable to weight topside
3	Adaptable to width & length topside
4	Adaptable to height topside
5	Adaptable to width & length jacket
6	Adaptable to airgap (topside-sea level)
	Decommissioning vessel
7	Required modifications
8	Stability
	Costs
9	Material costs
10	Manufacturing costs
	Operational costs
11	Complexity (reliability)
12	Operating speed
13	Required preparations
	Operational window
14	Sensitivity to wave height
15	Sensitivity to wave period
16	Sensitivity to wind speed

Dimensions platform

As concluded from the assessment to the dimensions of platforms, the dimensions of the topside, jacket and airgap differ due to the purpose and weight of the platform and the region the platform is installed. The amount of platforms that can be decommissioned depends on the adaptability of the heavy lifting construction to these dimensions. This requirement rates the methods on the adaptability to:

- **The topside weight**
- **The topside width and length**
- **The topside height**
- **The jacket length and width**
- **The airgap**

The heavy lifting construction can, for example, be adaptable to all the heights of the topsides, but not to the airgap. In order to ensure that the heavy lifting construction is rated to its ability to decommission the most topsides, the requirement ‘ability for lifting of topsides in a wide range’ is also added.

Decommissioning vessel

The heavy lifting construction needs to be applied to the designed decommissioning vessel. In order to determine the applicability of the heavy lifting construction two requirements are set up.

Required modifications

For this requirement the developed decommissioning vessel is considered as a vessel without the gap. This requirement weights the methods on the required modifications to the vessel. Damen Shipyards is specified in in the standardization of ships. If the heavy lifting construction requires a lot of modifications to the vessel, standardization would be impossible. When ships are no longer needed for the work for which they were built, ships can be converted in order to fulfill other tasks. When the ship is complex due to the heavy lifting construction, it is difficult or even impossible to find a new purpose for this ship.

Stability

This requirement is set to determine the impact of the heavy lifting structure to the stability of the decommissioning vessel. The stability of the vessel may be adversely affected when the outreach of the heavy lifting construction is greater or requires modifications to the ballast capacity of the vessel. This stability has an effect on the number of various topsides that can be lifted by the decommissioning vessel.

Costs

Figure 11 is used to clarify what is the effect of the different requirements on the total costs.

$$\begin{array}{r} Operational\ window\ [\%] \\ Failure\ time\ [days] \\ \hline \boldsymbol{Downtime}\ [\boldsymbol{days}] \end{array} + \quad \Rightarrow \quad \begin{array}{r} Payback\ time[years] \\ Downtime\ [days] \\ \hline \boldsymbol{Payback}\ [\boldsymbol{days}] \end{array} -$$

$$\begin{array}{r} OPEX\ [€] \\ CAPEX\ [€] \\ \hline \boldsymbol{TCO}\ [€] \end{array} +$$

$$\frac{TCO[€]}{Payback\ [days]} = \boldsymbol{Dayrate}\ \left[{}^{€}/_{\boldsymbol{Day}}\right]$$

$$Dayrate\ \left[{}^{€}/_{Day}\right] * Operational\ time\ [Days] = \boldsymbol{Costs\ decommissioning}[€]$$

Figure 11 Calculating costs decommissioning

- **TCO (Total Costs of Ownership)**
  The total costs of ownership is the sum of the OPEX and CAPEX.
- **OPEX (Operating expenditures)**
  Operating expenditures, the recurring costs of the vessel. In this case these expenditures are; maintenance costs, staff on board, fuel costs, etc.
- **CAPEX (Capital expenditures)**
  The capital expenditures are in this case the total costs of a new decommissioning vessel.
- **Payback time**
  Is the total period in years the decommissioning vessel will be written off.

- **Downtime**
  The amount of days the decommissioning vessel cannot operate due to weather conditions or failure of systems onboard of the vessel.

Material and manufacturing costs

The material and manufacturing costs of the heavy lifting construction are of major influence on the TCO of the decommissioning vessel. These costs have to be kept as low as possible. These costs are included in the CAPEX.

Complexity (reliability)

The more complex the lifting construction, the lower the reliability. When the decommissioning vessel is out of use due to a defect on the heavy lifting structure it will contribute to the failure time and therefore increase the costs of decommissioning.

Operating speed

The operating speed contributes to the operating time in the calculation. The longer the operation for lifting the topside, the more it will cost the operator to remove the topside.

Required preparations

In order to carry out the lifting operation, several preparations have to be performed to the topside and/or the heavy lifting construction. The longer these preparations will take, the longer the decommissioning operation will take, what increases the costs.

Operational window

The operational window is of high importance in the contribution to the total costs of decommissioning. The decommissioning vessel must be able to sail from and to shore in most of the weather conditions. The operational window for lifting operation on the other hand, is determined by the heavy lifting construction. In the selection matrix the heavy lifting construction is rated by the sensitivity to: wave height, wave period and wind speed.

3.2.2. Selection matrix

The selection matrix rates the methods to the set of requirements. The requirements differ in importance so weight factors are given. These weight factors are determined in table 11.

Determining weight factors

In this table, every requirement is rated to each other. Comparing two requirements, the post important requirement is rated with 1, so the with other 0. The total is converted to a factor of 1 to a maximum of 3.

Table 11 The Determination of the weight factors for the selection matrix

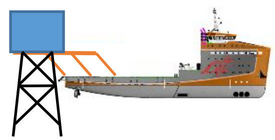
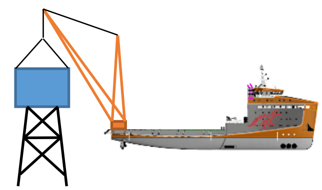
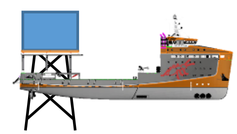
	Determining weight factors																	
	Set of requirements	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Total**	**Factor**
	Dimensions platform																	
1	Ability for lifting of topsides in a wide range	X	1	1	1	1	1	0	1	1	1	1	1	0	0	0	10	3
2	Adaptable to width & length topside	0	X	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1
3	Adaptable to height topside	0	1	X	1	1	1	0	1	1	1	0	1	0	0	0	8	2
4	Adaptable to width & length jacket	0	0	0	X	0	0	0	0	0	0	0	0	0	0	0	0	1
5	Adaptable to airgap (topside-sea level)	0	1	0	1	X	1	0	1	1	0	1	1	0	0	0	7	2
	Decommissioning vessel																	
6	Required modifications	0	1	0	1	0	X	0	1	1	0	0	0	0	0	0	4	1
7	Stability	1	1	1	1	1	1	X	1	1	1	1	1	1	1	1	14	3
	Costs																	
8	Material costs	0	1	0	1	0	0	0	X	1	0	0	0	0	0	0	3	1
9	Manufacturing costs	0	1	0	1	0	0	0	0	X	0	0	0	0	0	0	2	1
	Operational costs																	
10	Complexity (reliability)	0	1	0	1	1	1	0	1	1	X	0	0	0	0	0	6	2
11	Operating speed	0	1	1	1	0	1	0	1	1	1	X	1	0	0	0	8	2
12	Required preparations	0	1	0	1	0	1	0	1	1	1	0	X	0	0	0	6	2
	Operational window																	
13	Sensitivity to wave height	1	1	1	1	1	1	0	1	1	1	1	1	X	0	0	11	3
14	Sensitivity to wave period	1	1	1	1	1	1	0	1	1	1	1	1	1	X	0	12	3
15	Sensitivity to wind speed	1	1	1	1	1	1	0	1	1	1	1	1	1	1	X	13	3

In the table, every requirement is rated to each other, resulting in a weight factor. From this table it can be concluded that the operational window, the stability of the vessel and the ability of lifting topsides in a wide range are the most important requirements for the heavy lifting construction. All these factors are added to the selection matrix.

Selection matrix

By this table the method will be chosen. The method that meets the requirement the worst is rated with 1, the best with 3. If two methods meet the requirement equally, they are both rated with 2.

Table 12 Selection matrix

	Requirements	Factor (1t/m 3)			
	Dimensions platform				
1	Ability for lifting of topsides in a wide range	3	3	1	2
2	Adaptable to width & length topside	1	2	1	2
3	Adaptable to height topside	2	2	1	2
4	Adaptable to width & length jacket	1	2	3	1
5	Adaptable to airgap (topside-sea level)	2	1	2	1
	Decommissioning vessel				
6	Required modifications	1	2	3	1
7	Stability	3	2	1	3
	Costs				
8	Material costs	1	2	1	2
9	Manufacturing costs	1	2	3	1
	Operational costs				
10	Complexity (reliability)	2	1	2	1
11	Operating speed	2	2	1	3
12	Required preparations	2	1	3	1
	Operational window				
13	Sensitivity to wave height	3	2	1	3
14	Sensitivity to wave period	3	2	1	3
15	Sensitivity to wind speed	3	3	1	3
	Result without factor		**29**	**25**	**29**
	Result with factor		**60**	**44**	**65**

Selection accountability

In this chapter is accounted how the method are rated relative to each other for each requirement.

Dimensions platforms

For these requirements, the methods are rated using the knowledge from the analysis of dimensions of platforms and the analysis to the methods. The figures below shows the effects of the increasing dimensions of the topside, jacket and airgap for each method. Picture 12 shows the characteristics of the crane in relation to the dimensions of the platform. The second and third picture shows an increased width and length of the topside and a higher airgap. These increased dimensions are resulting in a bigger crane. The width and length of the jacket have no effect on the characteristics of the heavy lifting crane.

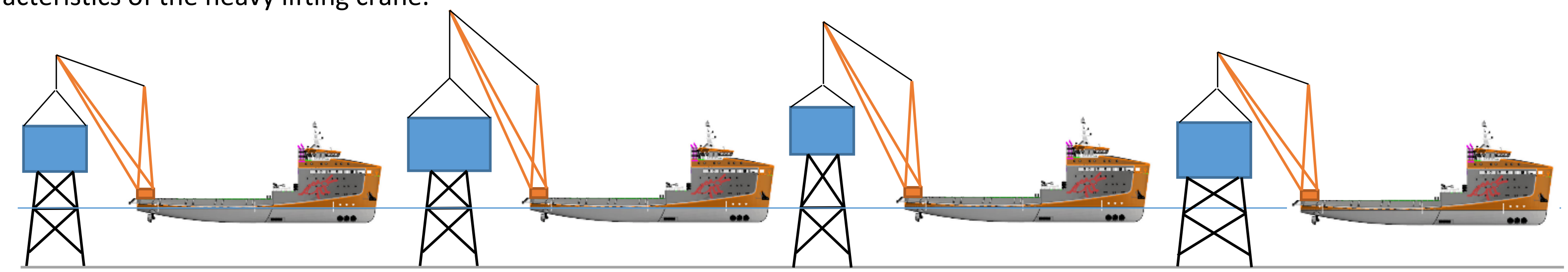


Figure 12 Changing dimensions of platform for heavy lifting crane

For both the forklift construction as the lifting frame, (picture 13 and 14) increasing dimensions of the topside do not affect the design. The increasing airgap however, has a great impact on the development of the lifting frame and forklift construction. The constructions will have to be adjustable to the difference in airgap height. Unlike the heavy lifting crane, the characteristics, so the possibility of picking up topsides, strongly depends on the dimensions of the jacket. In order to get a clear picture, for these dimensions a top view is sketched, figure 15 and 16.

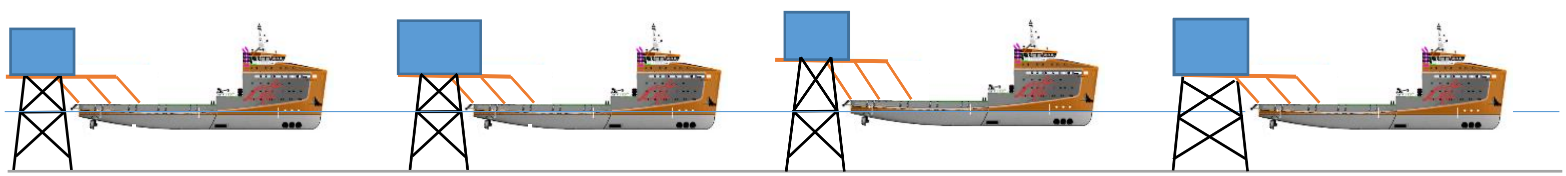


Figure 13 Changing dimensions of platform for the forklift construction

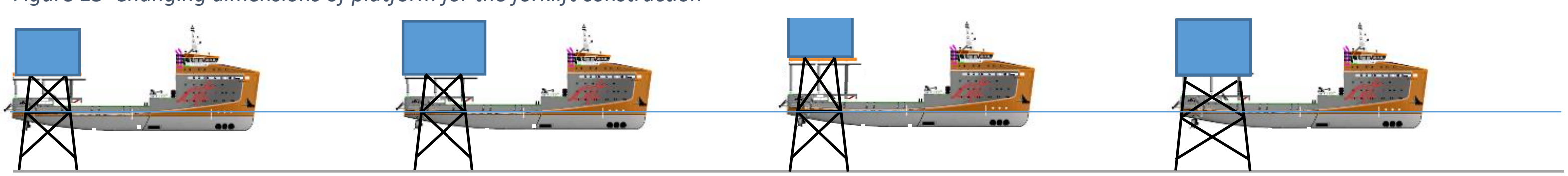


Figure 14 Changing dimensions of platform for the lifting frame

The width of the jacket is the limiting factor for both the forklift construction as the lifting frame. However, clarified by the figures, the lifting frame is more limited than the forklift construction. The lifting frame is limited to the width of the gap and this gap again is limited by the stability of the decommissioning vessel.

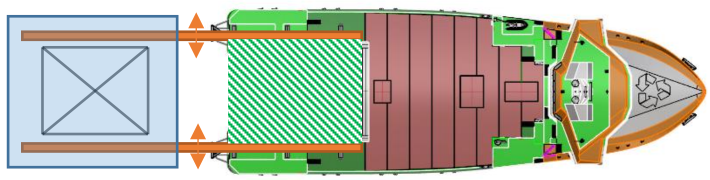


Figure 16 Top view, forklift construction

When the topsides is lifted, the vessel ensures the stability with, among others, ballast tanks placed at the back of the vessel. Increasing the width of the gap means decreasing ballast capacity. The 'forks' of the forklift construction can be placed more at the side of the decommissioning vessel which enables to decommission topsides with a wider jacket.

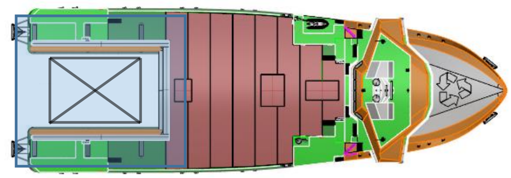


Figure 15 Top view, lifting frame

Decommissioning vessel

The methods are rated to the required modifications and the effect to the stability to the vessel. The lifting frame has the greatest impact on the decommissioning vessel. The vessel must be equipped with a gap at the aft which makes it more difficult to find a new purpose for the vessel after use for decommissioning. The modifications which are required using a heavy lifting crane are assumed as equal when the forklift construction is applied.

The figure below clarifies the effect of the methods to the stability of the decommissioning vessel after the topside is lifted.

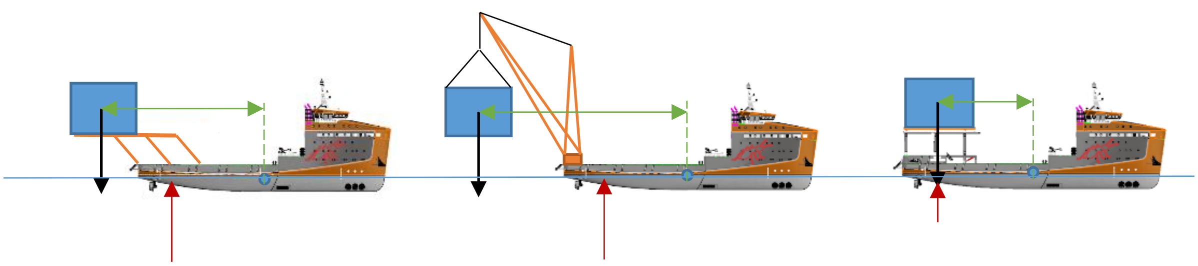


Figure 17 Stability of decommissioning vessel

The black arrow represents the force of gravity and the inertia forces of the topside due to the motions of the vessel. The red arrow represents the resulting force of the ballast in the back of the vessel. The force of ballast is less when using the lifting frame due to the gap at the aft of the vessel. The green arrow is the distance from the C.O.G. of the vessel to the C.O.G. of the topside. The greater this distance, the greater the moment force, and therefore more ballast capacity is require. Calculations, carried out by Damen Shipyards, have showed that if the heavy lifting crane is applied to this decommissioning vessel, the stability can only by guaranteed with topsides with less airgap and less weight. For the lifting frame and the forklift construction, the lifting frame has less impact on the stability, due to the fact that the greater moment force has a bigger impact than the less ballast at the back of the vessel.

Costs

The costs for both the material and manufacturing is difficult to determine in this phase. There is known that a heavy lifting crane is very expensive, but is easier to install to the decommission vessel. The material costs of the forklift construction and lifting frame are considered equivalent. The manufacturing costs for the lifting frame is considered higher than for the forklift construction because of the gap at the aft of the vessel.

Operational costs

The reliability partly depends on the complexity of the heavy lifting construction. All three methods are complex. However, the advantage of the heavy lifting crane is that there is a lot of knowledge, because the crane is already used for many different applications. By this knowledge the weaknesses are known so the heavy lifting crane is considered as most reliable.

The operating speed is the time needed for lifting until the topsides is placed on the deck. The time for lifting depends on the way of lifting of the heavy lifting construction, and the way of placing the topside to the deck. For the forklift construction and lifting frame, the lifting system is not determined yet. So for this requirement only the time for ballasting is considered. Using a crane, the ballasting will take a very long because of the great force extended by the crane to the decommissioning vessel. When the topside is picked up, the crane will rotate in order to place the topside on the deck. As the crane rotates, the force of the crane, caused by the weight of the topside, moves. To compensate the displacement of forces the decommissioning vessel needs to constantly change the ballast which is a slow process. The time needed for ballasting for both the forklift construction and lifting frame takes less time than when the crane is applied. The difference in time, needed for ballasting while lifting with the forklift construction or lifting frame cannot be determined in this phase. However, it can be assumed that the time needed for placing the topside at the deck is less when using a lifting frame. The topside have to move less when lifted by the lifting frame than with the forklift.

The required modifications are equal for the forklift construction as the lifting frame because both methods lifts the topside from below with a beam. When a crane is used, the preparations of the topside will take longer. The topsides are often installed by using a crane. However, after installation, the topsides are adjusted. Equipment is placed, a helicopter deck is installed and usually the mounting points of the crane are removed (NUTU, 2010). All these adjustments requires preparations to the topside for decommissioning.

Operational window

The operational window is determined with the sensitivity to the wave height, wave period and wind speed. The document 'floating crane response in sea waves' contains information about the effect of waves on the an offshore crane. According to this document, the boom accelerations depends on the movements of the vessel due to the wave height and period. The higher the boom accelerations, the more the topside will swing what results in a continuously changing load on the decommissioning vessel. The wave conditions have less influence on the forklift construction and lifting frame. However, the distance from the C.O.G. of the topside to the C.O.G. of the decommissioning vessel is more for the forklift construction than lifting frame. These greater distance results in greater accelerations and displacements due to roll and pitch. The forklift construction will be subjected to greater accelerations than for the lifting frame.

Because of the big dimensions of the topside, the wind can cause a variable load on the topside. When the topside is lifted by the forklift construction or lifting frame, these loads are eliminated by the structure. When lifting with a crane, this wind force results in moving the topside back and forth. The movements of the topside can result in a collision of the crane and the topside. In order to prevent this situation, for each crane is specified what is the maximum wind speed at which an lifting operation may be performed.

Conclusion

With the selection matrix is be concluded, with respect to the other methods, the lifting frame meets the requirements the best. The lifting frame is distinguished by the less sensitivity to weather conditions, the less negative impact on the stability and fastest operational speed. This method will be further developed.

4. Rules and standards

In order to develop the heavy lifting frame, the standards the design has to fit needs to be assessed. DNV-GL is a company which develops rules, standards and guidelines. The decommissioning vessel is out of the scope, so this study only focuses on the rules and standards the lifting frame has to meet. A standard for offshore heavy lifting constructions is not available. For this study the document standard 'Standards for offshore and platform lifting appliances' is analyzed (DNV-GL, 2016). This document describes, among others things, standards for cranes intended for load handling outside vessel at sea, what corresponds the most to the heavy lifting frame of the decommissioning vessel. The parts of this document which are related to the development of the lifting frame are cited in this chapter. The indicated page and chapter numbers are in accordance with the numbering of the document. In italics is added the way the rules are related to the lifting frame.

Standard DNVGL-ST-0378 – Edition May 2016

This standard provides requirements for certification and verification for cranes intended for load handling outside vessel while at sea (offshore cranes) and load handling onboard offshore units/installations (platform cranes).

4.1. Section 3 Materials and fabrication – Page 31

This section gives requirements for materials for structural members and equipment for lifting appliances. The necessary information for this project depends on the designed lifting frame.

This section contains information related to:

3.2 Rolled structural steel for welding
3.3 Rolled steel not for welding
3.4 Steel forgings
3.5 Steel castings
3.6 Iron castings
3.7 Steel tubes, pipes and fittings
3.8 Aluminium alloy structures
3.9 Composite materials
3.10 Steel wire ropes
3.11 Crane manufacturing and construction

4.2. Section 4 Structural design and strength – Page 49

The standards, according to the design and strength of the lifting frame, are described in this section. The relevant parts of this section are listed.

4.1 Design loads

The loads to be considered in the analysis of structures are divided into:

4.1.2 Principal loads
4.1.3 Vertical loads due to operational motions
4.1.4 Horizontal loads due to operational motions
4.1.5 Loads due motion of the vessel on which the crane is mounted
4.1.6 Loads due to climatic effect
4.1.7 Miscellaneous loads

4.1.2 Principal loads

The principal loads are:

- The loads due to dead weight of the components (S_G)
- The loads due to working load (S_L)
- The loads due to pre-stressing

All the principal loads are due to weight which always acts vertically (in the normal sense). This means that if the crane is mounted on an object which can obtain inclination (heel and/or trim) in any direction, the principal loads may have "horizontal" components when referred to a practical coordinate system of the crane. These components shall be taken into account, and shall be considered as principal loads, also if the angles are due to motions such as rolling and pitching of a vessel. Note that the simultaneous inertia forces are **not** considered as principal loads.

For cranes mounted on floating vessels the horizontal components of SG and SL shall be taken into account. The angles to be considered are the maximum angles expected during lifting operation with no wind and waves acting. Minimum values to be used, when decisive, are given in Table 4-1. These values are considered as minimum but may be especially considered provided statistically evidence or separate means/-operational conditions proving that list and trim could be assessed smaller.

Table 13 Minimum heel and trim angles, still water (Table 4-1 in the standard DNVGL-ST-0378)

Type of vessel	*Heel*	*Trim*
Ships and vessels having ship-shape hull properties	Min. 5˚	Min. 2˚
Barges of length less than 4 times breadth, and catamarans	Min. 3˚	Min. 2˚
Semi-submersibles	Min. 3˚	Min. 3˚
Submersibles and jack-ups	Min. 1˚	Min. 1˚

4.1.3 Vertical loads due to operational motions

Vertical refers to the coordinate system of the crane. For a crane onboard a floating unit it is assumed that vertical state is so defined that it corresponds to physical vertical state in the ideal position with zero heel and trim of the unit on which the crane is mounted.

The vertical loads due to operational motions shall be taken into account by multiplying the working load by a 'dynamic factor', Ψ. The dynamic factor covers inertia forces and shock.

$$\Psi = 1 + V_R \sqrt{\frac{C}{W * g}}$$

C = geometric stiffness coefficient

g = standard acceleration of gravity = 9.81 m/s^2

W = working load

V_R = relative velocity (m/s) between load and hook at the time of pick-up.

4.1.4 Horizontal loads due to operational motions

The horizontal loads (S_H) due operational motions are:

- Inertia forces due to acceleration or deceleration of horizontal motions.
- Centrifugal forces
- Forces transverse to rail resulting from reeling and skew motion.
- Buffer loads

These horizontal forces act in addition to possible simultaneously acting horizontal components of the principal loads.

For the lifting frame only 'inertia forces due to acceleration or declaration of horizontal motions' are relevant.

The inertia forces shall be determined on the basis of the maximum possible acceleration with the given machinery and on the basis of the maximum possible deceleration with the given brakes. Typically, the forces of this type occur by starting and stopping of travelling-, traversing- and slewing motions. The inertia due to angular acceleration (deceleration) of rotating machinery components shall be taken into account when this effect is significant.

4.1.5 Loads due to motion of vessel on which the crane is mounted

Inertia forces due to ship motion shall be calculated in accordance with **RU SHIP Pt.3 Ch.4 Sec.3 B *Ship motions and accelerations.*** The forces shall be combined to 10^{-8} probability level to correspond with safety factors as specified for Load Case III.

In the scope is established the movements of the decommissioning vessel, such as accelerations, are provided by Damen Shipyards.

4.1.6 Loads due to climatic effects

The possible loads due to climatic effects are:

- loads due to wind
- loads due to snow and ice
- loads due to temperature variations

For the lifting frame only loads due wind is relevant

Loads due wind shall be calculated in accordance with **appendix A.**

4.1.8 Loads for strength analysis of mechanisms

A mechanism will always have to transmit forces when it is in motion, i.e. it shall be considered for the most unfavorable motor or brake action. The loads of this type are those associated with:

- Vertical displacement of centers of gravity of load and parts moved by the mechanism.
- Friction between moving parts
- Acceleration (or braking) of the motion
- Effect of wind acting on the parts oved by the mechanism

4.2 Cases of loading

For the purpose of making the nominal safety dependent upon the probability of occurrence of the loading, three general cases of loading are defined, for which the required safety margins are different:

Case I: Working without wind
Includes the principal loads, vertical and horizontal loads due to operational motions.

Case II: Working with wind
Includes the same loads as Case I, with the addition of loads due to wind.

Case III Working subjected to exceptional loadings
Any loading condition where one or more exceptional loads are included belongs to Case III. The following loads are defined as exceptional loads:

- Buffer loads.
- Inertia forces due to motion of the vessel.
- Loads due to 'out of service' wind.

Strength calculations for the lifting frame includes the inertia forces due motion of vessel. So the lifting frame is in load case III.

4.3 Strength calculations

It shall be shown that the structures and components have the required safety against the following types of failure:

- Excessive yielding
- Buckling
- Fatigue fracture

The safety shall be evaluated for the three cases of loading. For each of these cases and for each member or cross section to be checked, the most unfavorable position and direction of the forces shall be considered.

The strength calculations shall be based on accepted principles of structural strength and strength of materials. When applicable, plastic analysis may be used. If elastic methods are not suitable to verify safety, for instance due to pre-stressing, plastic analysis may be required.

The verification of safety may be based on the permissible stresses method or the limit state method. With the factors given in this standard there will be only a formal difference between the two methods. The relation is:

Safety factor = load factor times material factor

$$S_F = \gamma_f \cdot \gamma_m$$

4.3.2 Checking with respect to excessive yielding

For members made of structural steel the requirements for the various cases of loading are given. With reference to method of analysis and method of verification of safety given in table 15, σ_y is the guaranteed minimum yield strength (or 0.2% proof stress). If σ_y is higher than 0.8 times the ultimate strength σ_u use in this connection 0.8* σ_u instead of σ_y

When using elastic analysis, the permissible stresses (or the required safety factors) given in table 14 refer in cases of combines stresses to the equivalent stress according to von Mises. Local peak stresses in areas with pronounced geometrical changes may be accepted by case by case evaluation.

Table 14 Criteria for checking with respect to excessive yielding (Table 4-2, standard DNVGL-ST-0378)

<table>
<tr><th colspan="3">Method of verification</th><th>Load Case I</th><th>Load Case II</th><th>Load Case III</th></tr>
<tr><td rowspan="2">Safety factor</td><td colspan="2">Elastic analysis</td><td>1.50</td><td>1.33</td><td>1.10</td></tr>
<tr><td colspan="2">Plastic (ult.str.) analysis</td><td>1.69</td><td>1.51</td><td>1.25</td></tr>
<tr><td>Permissible stresses</td><td colspan="2">Elastic analysis</td><td>$\sigma_y/1.50$</td><td>$\sigma_y/1.33$</td><td>$\sigma_y/1.10$</td></tr>
<tr><td rowspan="3">Limit state method</td><td colspan="2">Load factor</td><td>1.30</td><td>1.16</td><td>0.96</td></tr>
<tr><td rowspan="2">Material factor</td><td>Elastic analysis</td><td>1.15</td><td>1.15</td><td>1.15</td></tr>
<tr><td>Plastic analysis</td><td>1.30</td><td>1.30</td><td>1.30</td></tr>
</table>

4.3.3 Checking with respect to buckling

The guiding principle is that the safety against buckling shall be the same as the required safety against the yield limit load being exceeded. This principle indicates that the factors given in the second line of table 16 should represent the normal requirement. However, other values may be required or allowed, for instance due to uncertainty in the determination of the critical stresses (or load) or due to the post-buckling behavior. Required factors are given for various types of buckling in table 16.

The safety factors given in table 16 are based on the assumption that the critical stresses (or loads) are determined by recognized methods, taking possible effects of geometrical imperfections and initial stresses into account. Elastic buckling in table 15 means that elastic buckling stress does not exceed the yield strength.

Table 15 Safety factors for checking with respect to buckling (Table 4-3, the standard DNVGL-ST-0378)

<table>
<tr><th rowspan="2">Type of buckling</th><th colspan="3">S_F or $\gamma_f \cdot \gamma_m$</th></tr>
<tr><th>Load Case I</th><th>Load Case II</th><th>Load Case III</th></tr>
<tr><td>Elastic buckling</td><td>1.86</td><td>1.66</td><td>1.38</td></tr>
<tr><td>Elastic-plastic buckling</td><td>1.69</td><td>1.51</td><td>1.25</td></tr>
</table>

4.3. Section 5 Machinery and equipment

This section contains information of the standards machines and other equipment has to fit. It is not known yet which machines or equipment will be applied to the lifting frame so this section is not analyzed yet.

4.4. Appendix A Wind loads on cranes – page 118

A simplified method of wind load calculations is presented below. The method will be acceptable for all normal crane designs and applications where wind loads are of significant less importance than the other design loads.

In the design of cranes the distribution of wind pressure and suction around the structure need not be considered in detail, and wind loads may normally be determine in terms of resulting forces on each of the larger parts of the crane, or on each assembly of smaller members. A basic assumption is that wind pressure and suction will act normal to surfaces. As a consequence the resulting wind force on a prismatic member will act normal to axis of the member, irrespective of wind direction. This applies to long prismatic members and, if the ends are not exposed to wind, also to short prismatic members.

A.1.2 Wind force on flat surfaces

The wind force normal to a flat surface or area A is taken as:

$$P = A \cdot q \cdot C \cdot \sin \alpha$$

P = Wind force in [Newton]

A = Exposed area [m^2]

q = Air velocity pressure = $\rho v^2/2$

C = Average pressure coefficient for exposed surface. (Table 17)

α = Angle between the wind direction and the exposed surface

ρ = Mass density of the air (1.225 kg/m^3)

v = Wind velocity [m/s]

Table 16 Wind coefficient C (Table A-1, the standard DNVGL-ST-0378)

Type of member	Coefficient C		
	Pressure	Suction	Total
Flat-sided section			2.0
Tubular member:			
Diameter < 0.3 m			1.2
Diameter ≥ 0.3 m			0.7
Trusses of flat-sided sections			1.8
Trusses of tubular members			1.1
For leeward truss in case of two trusses behind each other			2/3 of above values
Machinery houses, cabins, counterweights and the like	Max: 1.0 Average: 0.7	Max: 1.0 Average: 0.7	1.2
Working load:			
Containers and similar shapes	(0.7)	(0.5)	1.2
Other shapes			1.0

A.1.5 Air velocity pressure

The velocity pressure q to be used as design parameter shall be based on expected conditions for each particular crane or part of the crane. The variation with height above ground (or sea level) may be taken as:

$$q = q_{10}(0.9 + 0.01 \cdot H)$$

q_{10} is the velocity pressure 10 meters above ground (or sea level) and H is the considered height in meters. General minimum values of q_{10} are given in Table A-2. The corresponding free-stream wind velocity v_{10} [m/s] is also given.

Table 17 Design velocity pressure [N/m²] (Table A-2, the standard DNVGL-ST-0378)

Location	Crane condition	V_{10}	q_{10}
Inland and sheltered conditions	''working''	≈ 20	250
Ship in harbor	''out of service''	≈ 36	800
Offshore and open areas	''working''	≈ 24	360
Ship at sea	''out of service''	≈ 44	1200

For the calculations for the lifting frame the location will be ''offshore and open areas'

5. The ballast system

Lifting the topside is the main function of the lifting frame. However, the force that is needed for the lift is generated by the ballast system of the decommissioning vessel. De-ballasting the vessel increases the load-bearing capacity and therefore the upward force. Exploratory research is done on the ballast system to gain some knowledge. For this study the document "Vessel and ballast water" is used (David, 2015). The most important parts are summarized in this chapter.

5.1.1. Ballast system

Commercial vessels are built for the transport of various cargoes or passengers. When a vessel is not fully loaded, additional weight is required to provide for the vessel's seaworthiness. The water used for adding weight to the vessel is referred to as ballast. Even when a vessel is fully laden it can require ballast due to a non-equal distributed load, weather conditions, approach to shallow waters and the consumption of fuel during transport.

The number, volume and distribution of ballast tanks are vessel type and size related. The ballast tanks can be in the vessels double bottom (DBT – double bottom tanks), port and starboard amount the sides (ST – side tanks), in the bow (FPT – forepeak tank), in the stern (APT – after peak tank), port and starboard underneath the main deck (TST – topside tanks or upper wing tanks), and other. (Figure 18)

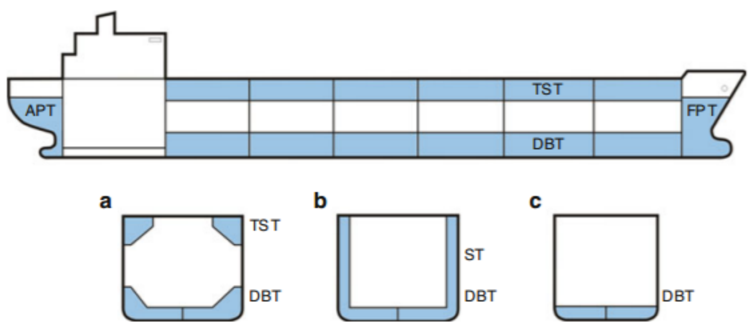


Figure 18 ballast tanks

Ballast tanks are connected with the ballast water pump(s) by a ballast pipeline. Water from the vessels surrounding area is loaded on the vessel through the vessel through the vessel sea-chest(s) and strainer(s) via the ballast pipeline to ballast tanks. Inside the ballast tanks water is loaded and discharged via the ballast water pipeline suction head. Vessels with greater ballast capacity are usually equipped with two ballast pumps in order to ensure ballast water operations are carried out even in case of a failure of one pump.

5.1.2. Ballast capacity

The vessel ballast capacity is mainly determined by the vessel cargo capacity in terms of cargo weight and the speed at which the cargo operations may be conducted. Generally the more tonnes of cargo a vessel is capable to carry, the more ballast may be needed when sailing without cargo on board and if the cargo operations on a vessel are very fast, the ballast uptake or discharge has to be correspondingly fast. The ballast water capacity of a vessel is given in terms of volume of spaces that are available for ballasting expressed in m^3 and in terms of the ballast pumps capacity expressed in m^3/h. the volumetric ballast water capacity mainly determines the vessels seaworthiness in different static and dynamic conditions.

5.1.3. Ballasting and de-ballasting process

vessels conduct ballast water operations usually in the port as opposite to the cargo operations, when a vessel would load cargo, ballast water would be discharged, and when more heavier cargo is loaded on one side, ballast water would be discharged from that side or loaded/moved to the other side. Ballasting and de-ballasting may also be conducted during navigation or at the anchorage, depending on the vessel type, weather and sea conditions and vessel operations.

Ballast water is taken onboard by:

- Gravity trough opening valves which enables a vessel to take on water into ballast tanks (or cargo holds used for ballast) below the water line;
- pumping water into ballast tanks (or cargo holds used for ballast) above the water line.

Nevertheless, all the water may be taken on board by pumping, instead of using the gravity method. The tanks are filled according to a predetermined sequence, depending on the type of vessel and current cargo operation. The ballast tanks are usually filled up to maximum capacity in order to prevent the free surface effects.

However, generally does nog apply to fore-peak and after-peak tanks since these are frequently filled partially because of trimming the vessel.

De-ballasting is conducted in the opposite sequence by:

- Gravity through opening the valves that enables a vessel to discharge ballast water into the surrounding environment from ballast tanks (or cargo holds used for ballast) above the water line;
- pumping out the ballast water from ballast tanks (or cargo holds used for ballast) below the water line.

When tanks are getting close to empty, ballast pumps start losing suction as they start getting air in the system. The remaining water in tanks after pumping with ballast umps is in general between 5% – 10% of tank volume. This depends on the trim of the vessel.

5.2. Decommissioning process

The decommissioning process due to the de-ballasting of the decommissioning vessel is disclosed in this chapter for static conditions, motions of the vessel are disregarded. In the figures, the orange arrow represents the force due to gravity of the topside, the red arrows the reactional forces from the jacket, the yellow the reactional forces from the lifting frame.

At the start of the lifting process the decommissioning vessel is full ballasted (figure 19). With the ballast enough space is created to position around the jacket. The vessel sails around the jacket in DP mode.

When positioned the vessel will activate DP mode. The ballast system will extract water from the ballast tanks so the draft of the vessel will decrease. Contact with the topside is created (Figure 20).

The decommissioning vessel will continue de-ballasting and therefore generate load bearing capacity. The load of the topside is gradually transferred from the jacket to the lifting frame. By the increasing load at the aft, the vessel will tilt. To prevent an unstable situation due to the tilt, the ballast water is not all discharged but also pumped to the front ballast tanks of the decommissioning vessel (figure 21).

Eventually the decommissioning vessel generated enough load bearing capacity and the topside is transferred to the lifting frame. (figure 22)

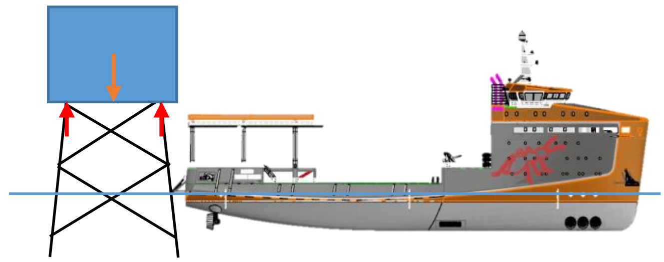


Figure 19 Positioning around jacket

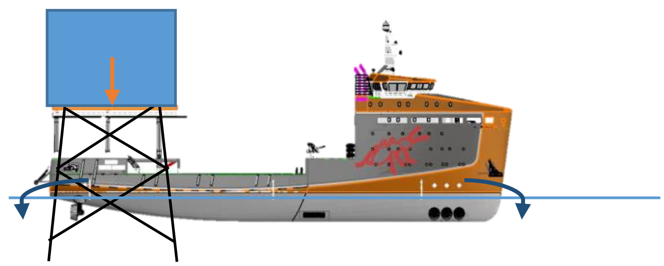


Figure 20 De-ballasting, make contact with topside

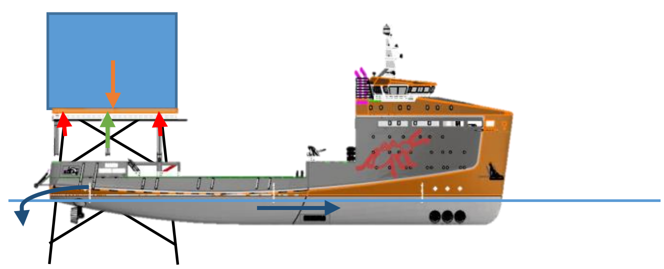


Figure 21 De-ballasting, transferring load from the jacket to the lifting frame.

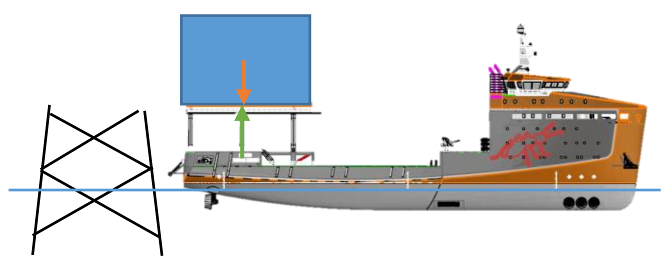


Figure 22 The topside is detached from the jacket and transferred to the lifting frame

6. Diversity height airgap

The airgap prevents waves to hit the topside and therefore serves as protection. The previous assessment to the platform dimensions (Chapter 2) has shown the airgap for platforms installed in the North Sea varies between 16 and 20 meters. However, this assessment only gathered information of platforms in the North Sea, for other regions to little information is available. As mentioned earlier, the height of the airgap depends to the weather conditions and therefore the region in which the platform is installed. In order to gain information of the airgap for other regions the scatter diagrams, used in order to calculate the weather window (Appendix II), are used. For every region the highest significant waves are listen in the table below.

Table 18 Maximum wave height by region

Region	Highest wave [Meter]
North Sea (Area 11)	10 - 11
Gulf of Mexico (Area 32)	7 - 8
West Africa (Area 36)	6 - 7
Gulf of Oman (Area 39)	6 - 7
South Chinese Sea (Area 40)	9 - 10
Bay of Bengal (1) (Area 51)	6 - 7
Bay of Bengal (2) (Area 61)	5 - 6
Gulf of Thailand (Aria 62)	8 - 9

The maximum wave height in the North Sea region is 11 meters with a registered highest airgap of 20 meters. The ratio for biggest airgap is 20/11 = 1.81 and for the smallest 16/11 = 1.45. Table 19 shows the results when these ratios are used for the other regions.

Table 19 Estimated airgap per region

Region	Estimated highest wave height [m]	Lowest airgap [m]	highest airgap [m]
North Sea (Area 11)	10 - 11	16	**20**
Gulf of Mexico (Area 32)	7 - 8	11.6	14.48
West Africa (Area 36)	6 - 7	10.15	12.67
Gulf of Oman (Area 39)	6 - 7	10.15	12.67
South Chinese Sea (Area 40)	9 - 10	14.5	18.1
Bay of Bengal (1) (Area 51)	6 - 7	10.15	12.67
Bay of Bengal (2) (Area 61)	5 - 6	**8.7**	10.86
Gulf of Thailand (Aria 62)	8 - 9	13.05	16.29

By the research is concluded the airgap height is in between 8.7 and 20 meters.

7. Tide

In addition to the vessel’s movements the tides must be taken into account during the development of the lifting frame.

7.1.1. Tidal

Tides are the rise and fall of sea levels caused by the combined effects of the gravitational forces exerted by the moon and sun and rotation of the earth. Spring tide, having the maximum range, occurs during the full moon and when the earth is in between the sun and moon and when the moon is in between earth and sun. The typical tidal range in the open ocean is 0.61 meter but increases near the coast. Tidal ranges vary around the world, some places are relatively tideless while the greatest tidal is 12 meters (Bay of Fundy, Canada). The average tidal range around the world is about 2 to 3 meters. Every day consists of two tidal periods (figure 23). Sea level rises over serval hours covering the intertidal zone, sea level falls over several ours revealing the intertidal zone.

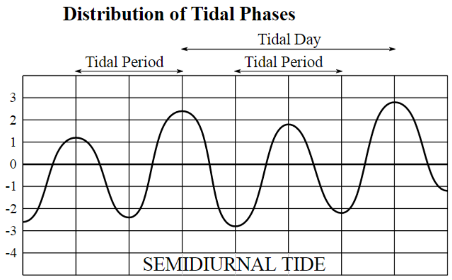


Figure 23 Distribution of tidal phases

7.1.2. Tide north sea

Figure 24 is the tidal range, measured at K13A platform. The K13A is a production platform located 100 kilometers from the Netherlands in the southern North Sea. The maximum tidal range at this location is 2.11 meters. 24 hours consists of two tidal periods, if assumed the tide rises and falls equally in one tidal period:

2.11 m / 6 hours = 0.35 m/h

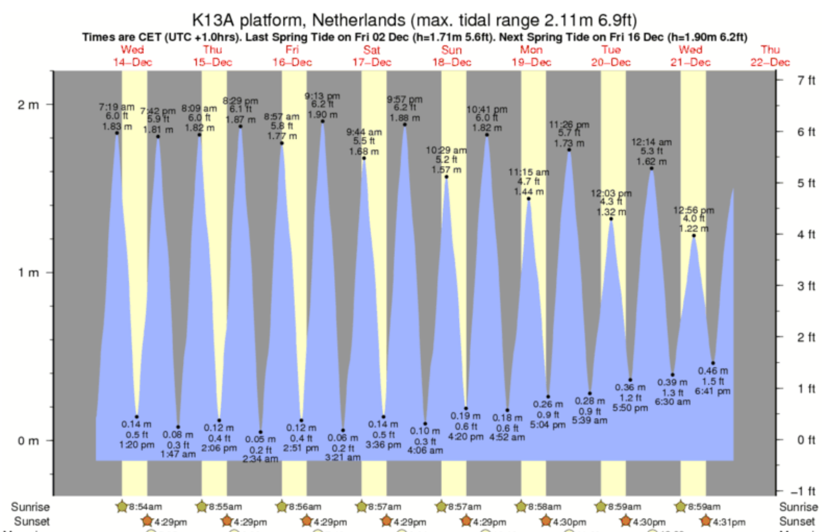


Figure 24 K13A platform, tidal lapse [14dec - 22dec]

The tidal range can be used for extra load bearing capacity by timing the lift operation. If the lifting operation is carried out during the rise of the sea-level, the decommissioning vessel is lifted relative to the topside, what generates an upward force. However, as mentioned earlier, some places are relatively tideless. For the development nor the negative as the positive influence of the tide is included in the calculations.

8. Movements vessel

In addition to static calculations, also dynamic calculations will be carried out for the heavy lifting construction. To calculate the dynamic forces, the movements of the vessel such as accelerations, pitch and roll needs to be determined. As defined in the scope of the project, this movements will be provided by Damen Shipyards. However, in order to calculate these movements, Damen Shipyards needs input which will be defined in this chapter.

8.1.1. Determining movements and reference points

The accelerations, created by roll and pitch, differ for every spot on the vessel. In order to calculate these accelerations, reference points must be defined. Figure 25 displays the decommissioning vessel with topside. The two orange dots represent the points where the movements of the vessel must be calculated.

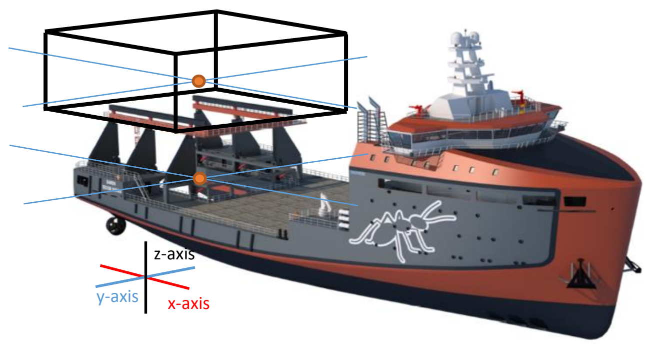


Figure 25 Reference points decommissioning vessel

The first reference point is placed in the C.O.G. of the topside. The topside has a high inertia which besides the static force, also exerts a great dynamic force on the lifting structure. When the accelerations are known at the C.O.G. of the topside, these can be calculated at the points where the lifting structure supports the topside.

The second reference point is placed at main deck level, in the center of the gap at the aft of the vessel. By this point, the accelerations caused by roll and pitch can be converted to the places where the supporting structure is fixed to the vessel.

In order to determine the coordinates of the two reference points, first a zero-point have to be defined. This zero-point is located at the intersection of the base line and the aft perpendicular. The following figures show the two reference points relative to the zero-point.

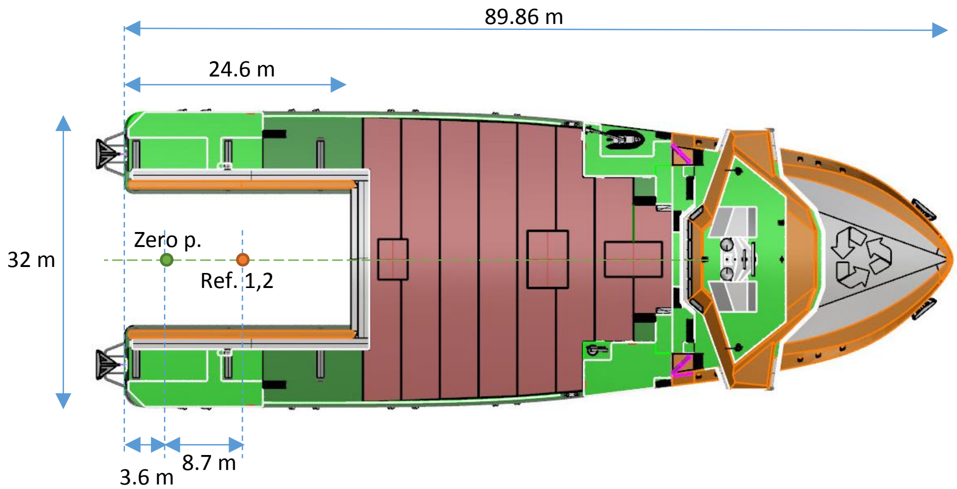


Figure 26 Top view decommissioning vessel with reference points

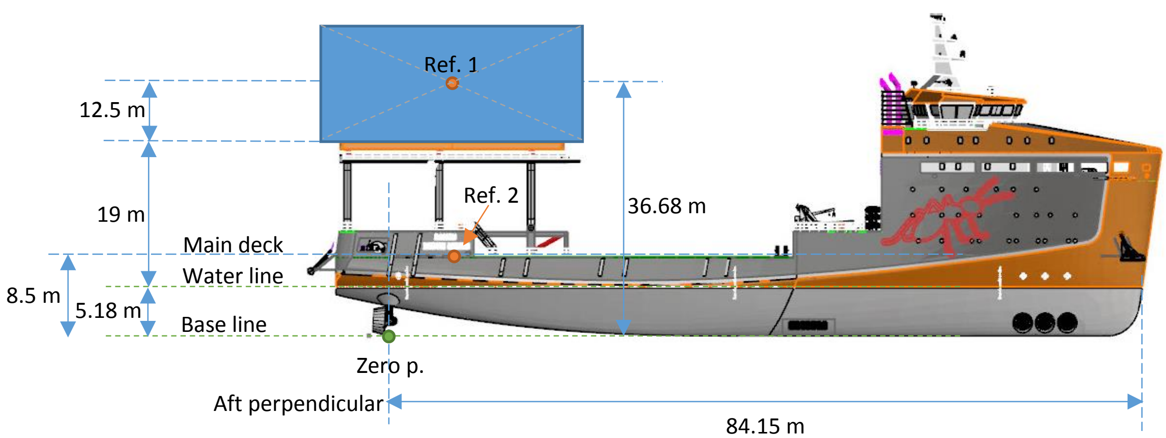


Figure 27 Side view decommissioning vessel with reference points

The coordinate of reference point 1: (8.7 ; 0 ; 36.68)

The coordinate of reference point 2: (8.7 ; 0 ; 8.50)

8.2. Center of gravity

The movements of a ship depends on the center of gravity. By picking up a topside, the mass and therefore the C.O.G. changes. In order to calculate the movements the combined C.O.G. of the topside with the supporting frame is calculated.

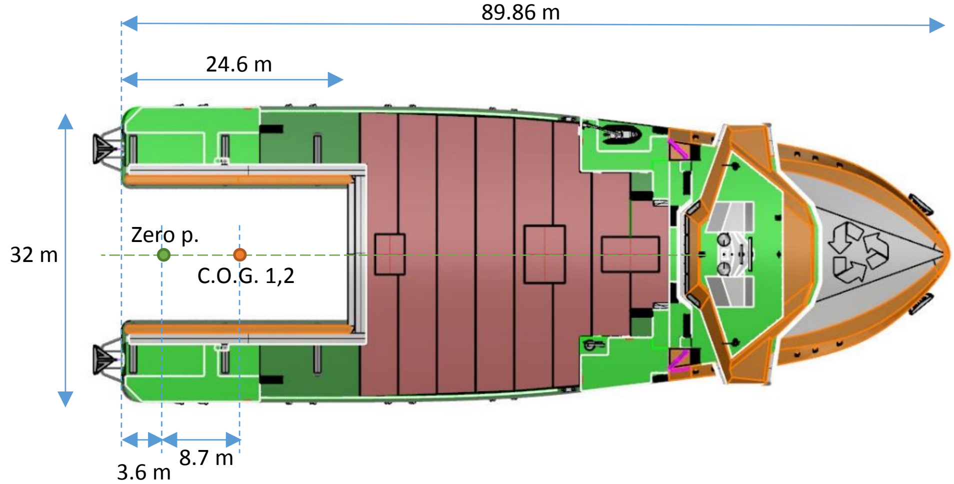


Figure 28 Top view decommissioning vessel with C.O.G.

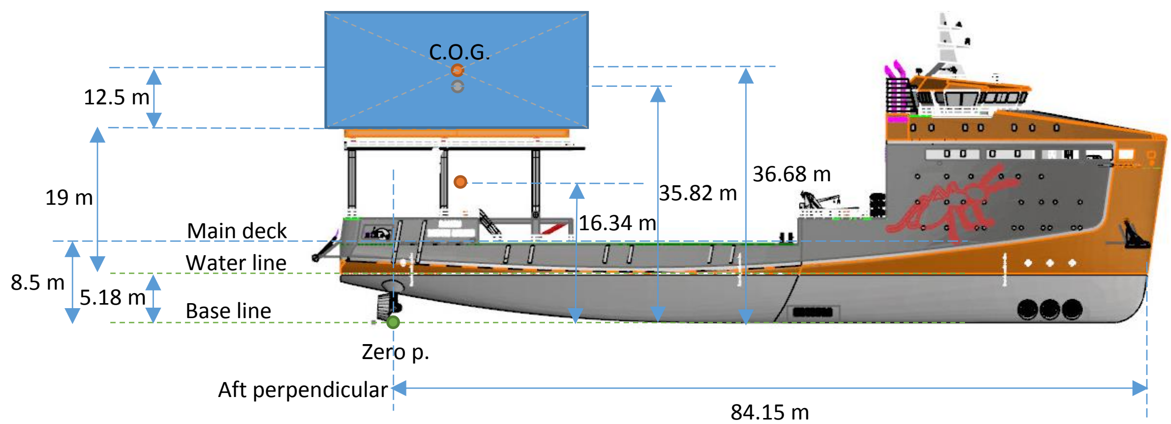


Figure 29 Side view decommissioning vessel with C.O.G.

Calculation:

Weight topside: 1600 Ton

Estimated weight of lifting frame: 35 Ton

Combined C.O.G. (lifting frame + topside) : $Y = \frac{m_1 * x_1 + m_2 * x_2}{m_1 + m_2} = \frac{800*36.68 + 35*16.34}{800 + 35} = \mathbf{35.82}$

As mentioned previously, the C.O.G. moves by adding weight from the topside to the vessel. The topside will not be lifted all at once but gradually. The movements of the vessel will be different for each stage of lifting. To determine the movements the lifting process is divided into two stages.

1. Without load of the topside.
2. When the vessel took over the weight of the topside from the jacket.

9. Occurring forces lifting frame

Prior to the development of the components of the lifting frame, the occurring forces from the topside to the lifting frame are determined for as well the operational conditions as the survival conditions. These calculations are carried out by the calculation model. The layout, functionality and calculations of the calculation model are described in appendix II. For the development of the lifting frame it is essential to determine the greatest forces occurring during survival and operational conditions. In order to calculate these forces, the worst conditions, determined by the input of the model, are defined.

9.1. Standard input model

The standard input of the model consists of the physical constants, the properties of the decommissioning vessel, properties of the platform and the rules and standards (set by the classification company DNV-GL). All the input is already completed in the model (described in appendix II), except for the properties of the platform.

9.1.1. Define greatest platform dimensions

Because the assessment only provided information of 27 platforms, no reasonable conclusion can be made. Further research would be time consuming and the project has to be continued, so in cooperation with Damen Shipyards is decided to define the dimensions by these 27 platforms and continue the project. The assessment of the dimensions is further carried out by Damen itself.

In cooperation with Damen Shipyards is decided to determine the dimensions for the biggest platform that can be decommissioned by the lifting frame. The width of the jacket is limited by the width of the gap at the aft of the decommissioning vessel which is 14.4 m. In order to keep distance between the jacket and the vessel the maximum width of the jacket is set at 14.2 meters. The jacket length is also limited by the gap. The other dimensions are determined by the known dimensions of the 27 platforms, displayed in the chart below.

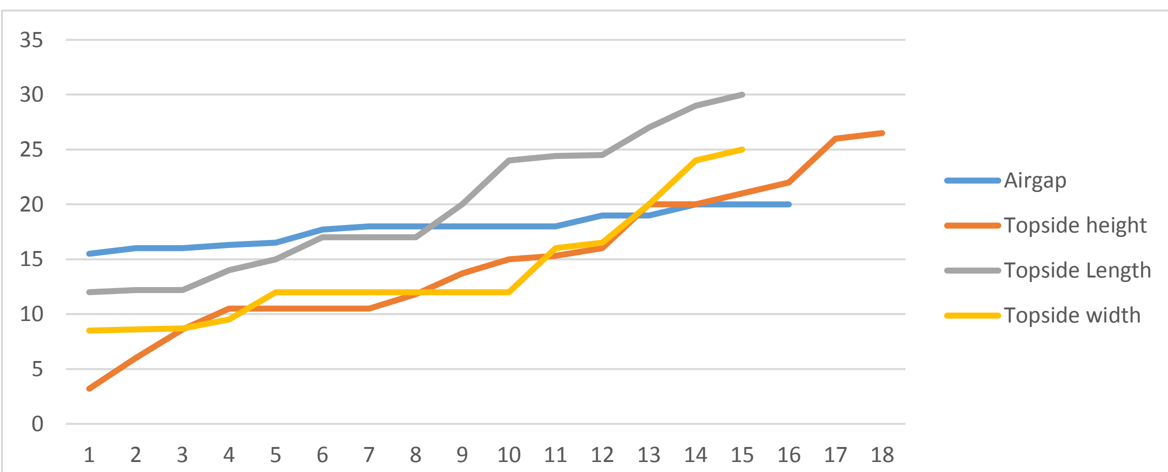


Figure 30 Dimensions platforms

The dimensions are determined by taking the maximum of every variable. The definitive dimensions, used for the development the lifting frame, are displayed below with figure 31 for clarification.

Table 20 Determined platform dimensions

Platform dimensions	
Dimension	**Value [m]**
Topside Height	26.5
Topside Width	25
Topside Length	30
Airgap	20
Jacket width	14.2
Jacket length	24.4

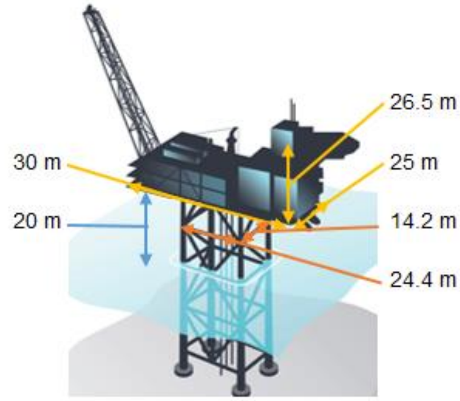


Figure 31 Platform dimensions

9.2. Movements decommissioning vessel

The movements are calculated for a wave height of 1.5 meter with period of 6 seconds. The survival conditions are calculated according to the DNV-GL rules. The movements are displayed in the table below.

Table 21 Movements decommissioning vessel for operational and survival conditions.

Movements decom. vessel	Operational conditions	Survival conditions
Vertical acceleration [m/s²]	0.6	2.93
Lateral acceleration [m/s²]	0.25	1.8
Longitudinal acceleration [m/s²]	0.25	1.34
Roll [˚]	3.4	8.6
Pitch [˚]	1.3	5
Vertical displacement [m]	2.4	
Lateral displacement [m]	1	
Longitudinal displacement [m]	1	

The accelerations by pitch and roll are included in the vertical, lateral and longitudinal accelerations.

9.3. Outline of the situation

The worst operational and survival conditions are defined by the outline of the situation. By this input, among other things, the movements can be turned on or off and the directions of the movements must be defined. Figure 33 represents the input in the model where to define the direction of the movements with figure 32 for clarification.

Determine in what direction the acceleration is active *define for each movement the direction using the figure below.*				
				Comment/Warning
Roll Φ	Roll to:	Starboard	Direction	
Pitch θ	Pitch to:	Front	Direction	
Gravity				***Gravity is fixed downwards.***
Vertical acceleration	Accelerate	Up	Direction	
Lateral acceleration	Accelerate to	Starboard	Direction	
Longitudinal acceleration	Accelerate	Forwards	Direction	
Fwind				***Already fixed in variables***

Figure 33 Input, outline of the situation

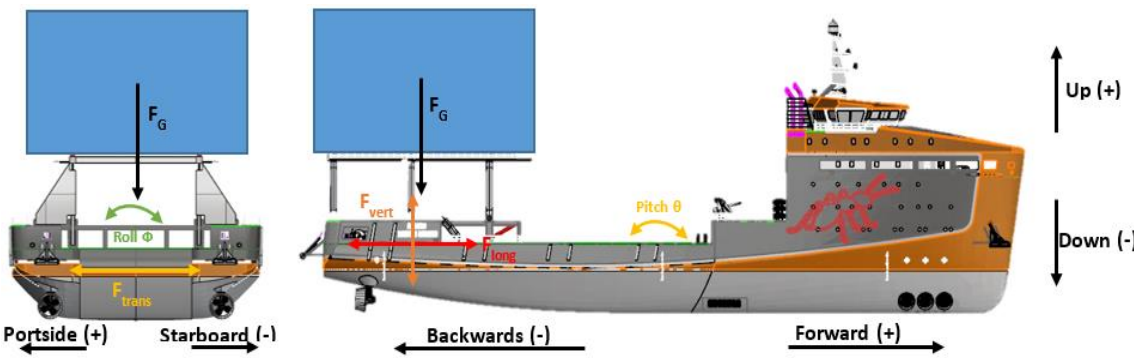


Figure 32 Figure for clarification of the movements

The model calculates the forces by the mass inertia of the topside according to the following formula.

$$F[KN] = a[m/s^2] * weight\ topside\ [Ton]$$

Calculations are carried out for each movement and due to pitch and roll these movements are not linear active in the direction of the acceleration, but consists of vectors in different directions. The model calculates the forces in x, y and z direction (figure 34) of the vessel for each acceleration. The occurring forces are presented without a safety factor, for calculations with respect to excessive yielding and for calculations with respect to buckling.

Figure 34 X,Y and Z axis vessel

9.3.1. Worst conditions

As mentioned, the forces are depending on the outline of the situation and are presented in x, y and z direction. For each direction the worst condition differs and therefore the worst condition is determined for as well the x, y and z direction. The forces are calculated assuming the topside completely lifted. The calculations, included in the excel model, are discussed in appendix II.

Worst conditions Z direction

The forces in the z direction of the vessel are mainly determined by the force of gravity and vertical acceleration. As the vessel is acceleration upwards the reacting force from the lifting frame operates in the same direction as the reactional force due to gravity (figure 36). In the figure the red arrow represents the direction of the acceleration, the black arrow the force due to gravity and the vertical acceleration and the purple arrows the reactional forces from the lifting frame to the topside.

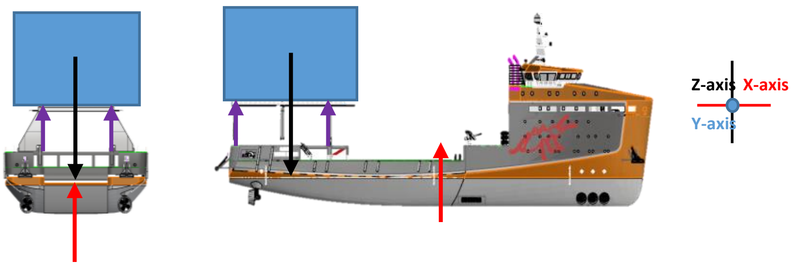


Figure 36 Worst condition Z direction

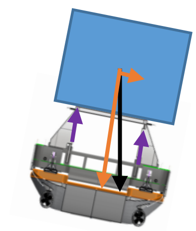


Figure 35 Vector gravity due to roll

As the vessel rolls and pitches, the lateral and longitudinal accelerations consists of vectors in the z direction. However, the force of gravity and vertical acceleration will also consist of vectors in the y and x direction whereby the resulting force in the z direction decreases. The contribution of the lateral and longitudinal accelerations by pitch and roll in z direction are less than the decreased force due to gravity and vertical acceleration. The worst condition with the associated reactional force of the lifting frame in z direction is displayed in the table below.

Table 22 Greatest reational forces in Z direction

Greatest reactional forces in Z direction		
Outline of the situation		
	Value	**Direction**
Roll	0˚	/
Pitch	0˚	/
Vertical acceleration	0.6 m/s^2	Up
Lateral acceleration	0 m/s^2	/
Longitudinal acceleration	0 m/s^2	/
Force in Z direction for operational conditions		
Without safety factor	16656 KN	
With respect to buckling	18321.6 KN	
With respect to excessive yielding	22985.3 KN	
Force in Z direction for survival conditions		
Without safety factor	20384 KN	
With respect to excessive yielding	22422.4 KN	
With respect to buckling	28129.9 KN	

Worst conditions X direction

The forces in the x direction of the vessel is mainly determined by the longitudinal acceleration. In figure 37 the red arrow represents the direction of the acceleration, the black arrow the mass inertia of the topside and the purple arrows the reactional forces from the lifting frame to the topside.

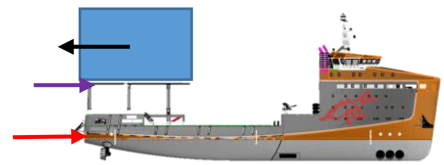


Figure 37 Longitudinal acceleration

By pitch the force due to gravity and vertical acceleration consists of a vector in the x direction as clarified by figure 38. With the vertical acceleration up and pitch backwards the forces in x direction operates in the same direction as the longitudinal acceleration forwards.

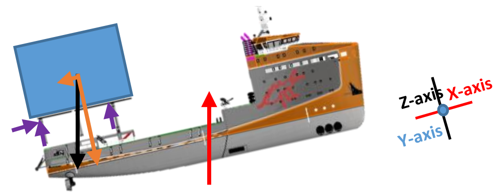


Figure 38 Gravity and vertical acceleration

As the vessel pitches the force due to longitudinal acceleration in x direction decreases, however, the additional force due to gravity and the vertical acceleration is greater.

The force due to wind creates a reactional force of the lifting frame in the same direction as the wind direction is set to North.

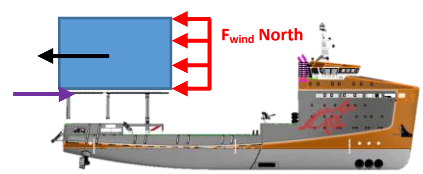


Figure 39 Wind direction North

Table 23 Greatest reactional forces in X direction

Greatest reactional forces in x direction		
Outline of the situation		
	Value	**Direction**
Roll	0˚	/
Pitch	1.3˚	Backwards
Vertical acceleration	0.6 m/s^2	Up
Lateral acceleration	0.25 m/s^2	/
Longitudinal acceleration	0.25 m/s^2	Forwards
F wind	357.5 KN	North
Force in x direction for operational conditions		
Without safety factor	1130.78 KN	
With respect to buckling	1243.85 KN	
With respect to excessive yielding	1560.47 KN	
Force in x direction for survival conditions		
Without safety factor	5083.42 KN	
With respect to excessive yielding	5591.77 KN	
With respect to buckling	7015.13 KN	

Worst conditions force Y direction

The forces in the y direction is mainly determined by the force due to the lateral acceleration. In figure 40 the red arrow represents the direction of the acceleration, the black arrow the mass inertia of the topside and the purple arrows the reactional forces from the lifting frame to the topside.

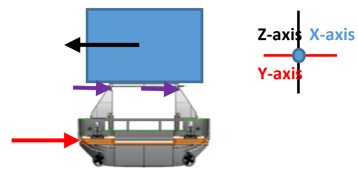


Figure 40 Lateral acceleration

By roll the force due to gravity and vertical acceleration consists of a vector in the y direction as clarified by figure 41. With the vertical acceleration up and roll to portside the reactional forces in y direction operates in the same direction as the reactional forces due to lateral acceleration to starboard.

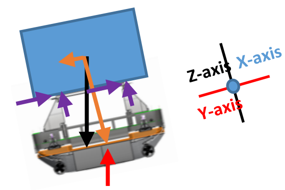


Figure 41 Gravity and vertical acceleration

As the vessel pitches the force due to lateral acceleration in y direction decreases, but the additional force due to gravity and the vertical acceleration is greater.

The force due to wind creates a reactional force of the lifting frame in the same direction as the wind direction is set to East.

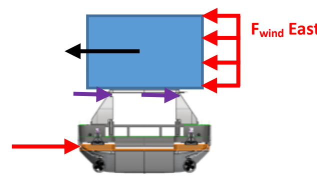


Figure 42 Wind direction East

Table 24 Greatest reactional force in Y direction

Greatest reactional forces in y direction		
Outline of the situation		
	Value	**Direction**
Roll	3.4˚	To portside
Pitch	0˚	/
Vertical acceleration	0.6 m/s^2	Up
Lateral acceleration	0.25 m/s^2	To starboard
Longitudinal acceleration	/ m/s^2	/
F wind	422.5 KN	East
Force in x direction for operational conditions		
Without safety factor	1810.1 KN	
With respect to buckling	1991.11 KN	
With respect to excessive yielding	2497.94 KN	
Force in x direction for survival conditions		
Without safety factor	7290.75 KN	
With respect to excessive yielding	8019.82 KN	
With respect to buckling	10061.2 KN	

10. Weight distribution topside

As defined in the scope, it is assumed the topside exerts an equal distributed load. However, the amount and place of the contact surfaces of the topside with the lifting frame must be defined. For this study the document by ESDEP Course, (n.d.) is used.

Figure 43 (top-view of topside) describes the basic structural grid for a jacked-based topside. The beams, indicated as main structure, transfers the forces from the topside to the jacket piles. The forces from the topside are transferred at the contact surfaces between main structure and lifting frame.

Since the figure indicates the standard structural design it can be concluded the amount of weight distribution points is equal to the amount of jacket piles and these points are located in line with the jacket piles.

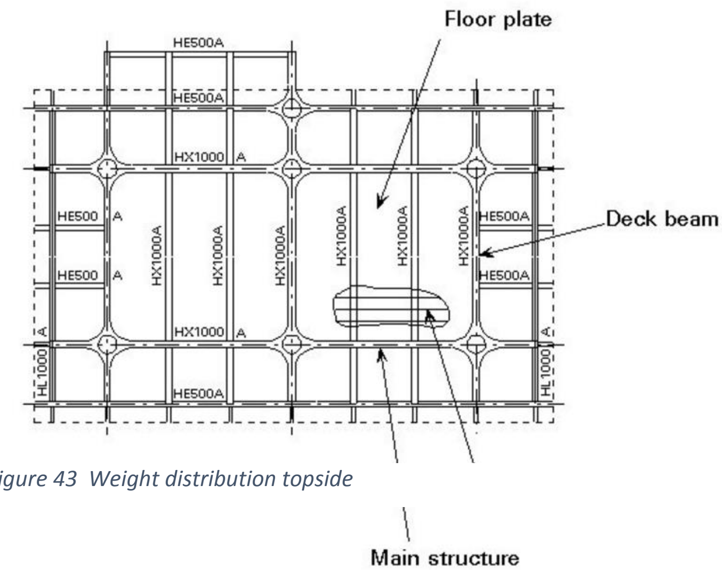


Figure 43 Weight distribution topside

The assessment on the dimensions of platforms chapter 2 showed the minimum amount of jacket piles is 4 for a single platform. The minimum distance between the jacket piles is 8.5 meters, however, this topside weights less than 200 ton. The topside with the narrowest distance between jacket piles with topside weight over 1000 ton is 12 meters. So for the development of the lifting frame is assumed, For a topside with maximum weight of 1600 ton the minimum distance between the jacket piles is 12 meters.

11. References

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12. Appendixes

The appendixes in addendum to the analysis report

Appendix IA

Leaflet decommissioning vessel

DAMEN OFFSHORE PLATFORM REMOVER

CONCEPT DESIGN

GENERAL

Yard number	-
Delivery date	-
Basic functions	Offshore Decommissioning Vessel with rotating lifting frame for topside removal and can be equipped with modular equipment
Classification	-
Flag	-
Owner	-

DIMENSIONS

Length o.a.	89.86	m
Length b.p.p.	84.15	m
Beam mld.	32.00	m
Depth mld.	8.50	m
Draught transit (base)	5.18	m
Draught summer (base)	5.83	m
Deadweight (Transit)	6480	t
Deadweight (summer)	7720	t
Cargo deck area	942	m^2

TANK CAPACITIES

Ballast water	5530	m^3
Fuel oil (service)	920	m^3
Potable water (service)	170	m^3
Liquid mud / Brine	835	m^3
Special products	200	m^3
Dry bulk	165	m^3

PERFORMANCES (APPROX.)

Speed (at transit draught)	12.00	kn
Speed (at summer draught)	10.00	kn

PROPULSION SYSTEM

Main engines	Diesel – Electric, 690V, 60 Hz
Propulsion power	2x electric motor of 1620 eKW
Propellers	2x 2150 mm, FPP propellers in nozzles
Bow thruster	3x 735 eKW, 1740 mm, FPP

AUXILIARY EQUIPMENT

Networks	690V, 440V and 230V – 60 Hz
Main generator sets	4x 1550 eKW at 1800 rpm
Emerg. generator set	1x 95 eKW at 1800 rpm
Shore supply	1x 400A

DECK LAY-OUT

4P mooring winch	4x 600 kN pull
Capstans	4x Electric, 10t pull
Deck crane	1X Knuckle boom 2.3t at 11m (harbour)
Tugger winches	4x Electric-hydraulic, 10t pull
Moon pool	1x 4.2 x 6.0 m

SPECIAL DECK EQUIPMENT

Rotating lifting frame	Up to 1600 ton lift capacity *(To be developed)*

PUMP SYSTEMS

Ballast pump	2x 2000 m^3/hr
Ballast pump (general)	2x 150 m^3/hr
Fuel oil pump	2x 150 m^3/hr
Potable water pump	1x 70 m^3/hr
Liquid mud / Brine pump	2x 150 m^3/hr
Special products pump	2x 75 m^3/hr
Dry bulk compressor	1x 60 t/hr
Liquid mud systems	Agitators, circulation system, hot water tank cleaning system

ACCOMMODATION

Crew	22 single person cabins
Special personnel	38 single person cabins

NAUTICAL AND COMMUNICATION EQUIPMENT

Radar systems	
DP – system	DP-2
GMDSS	Area A3

OPTIONS

Passive personnel transfer system
Active Heave Compensated subsea crane 100 ton @ 15m
Helideck D-factor 21m, take-off weight 12 ton
ROV support equipment
Air diving support equipment
Oil recovery equipment
Deep dredge equipment

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Appendix IB

Distribution of topside weight by region

The charts below show the distribution of the topside weight by region. The table, left to the chart, contains the total amount of topsides by weight class.

Table 25 Weight distribution topside global

Global	
Topside Weight (Ton)	**Amount**
1-500	5901
501-1000	1695
1001-1500	1509
1501-2000	446
> 2000	1965
Total	11516

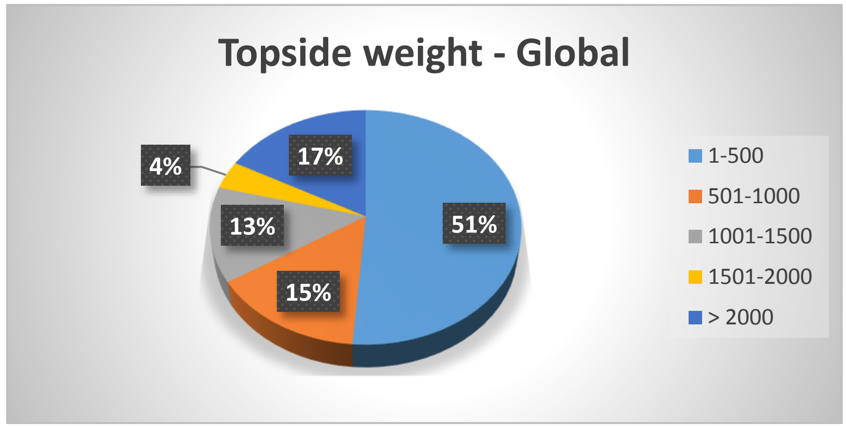

Figure 44 Weight distribution topside global

Table 26 Weight distribution topside Asia

Asia	
Topside Weight (Ton)	**Amount**
1-500	1214
500-1000	720
1000-1500	407
1500-2000	89
> 2000	497
Total	2927

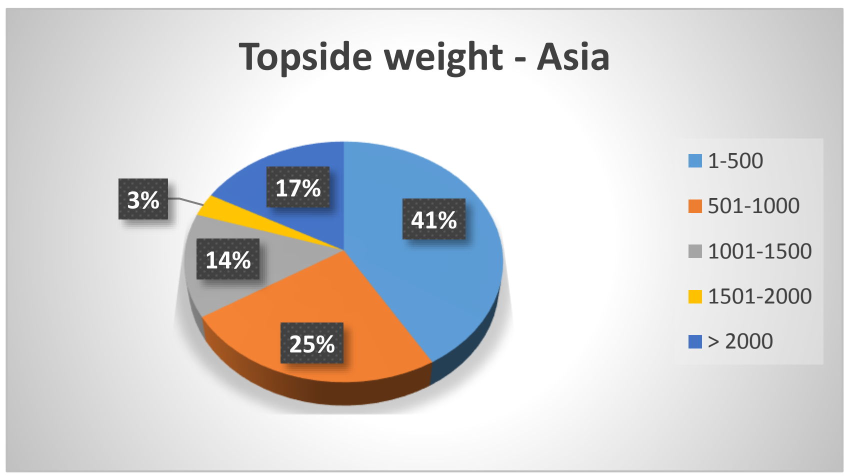

Figure 45 Weight distribution topside Asia

Table 27 Weight distribution topside North America

North America	
Topside Weight (Ton)	**Amount**
1-500	2114
501-1000	155
1001-1500	405
1501-2000	117
> 2000	225
Total	3016

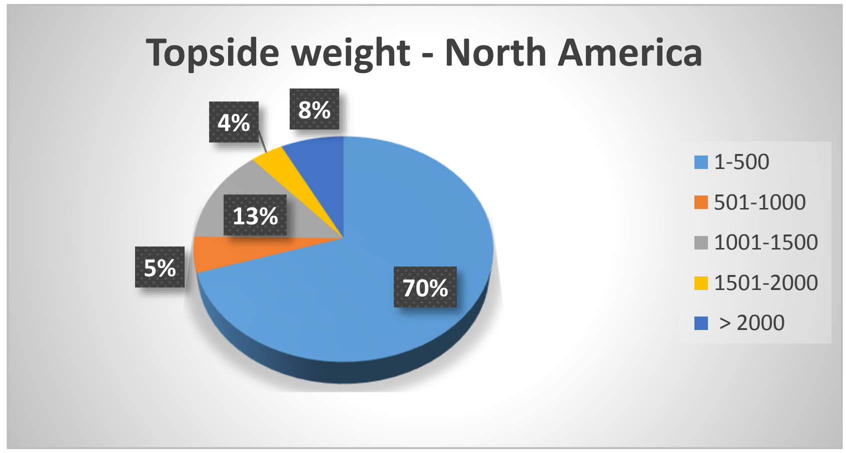

Figure 46 Weight distribution topside North America

Table 28 Weight distribution topside Latin America

Latin America	
Topside Weight (Ton)	**Amount**
1-500	416
501-1000	112
1001-1500	228
1501-2000	55
> 2000	308
Total	1119

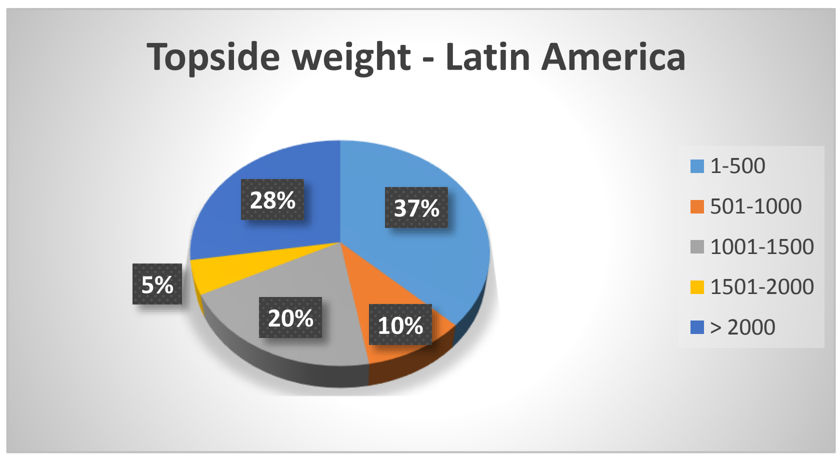

Figure 47 Weight distribution topside Latin America

Table 29 Weight distribution topside Europe

Europe	
Topside Weight (Ton)	**Amount**
1-500	221
501-1000	181
1001-1500	123
1501-2000	64
> 2000	368
Total	960

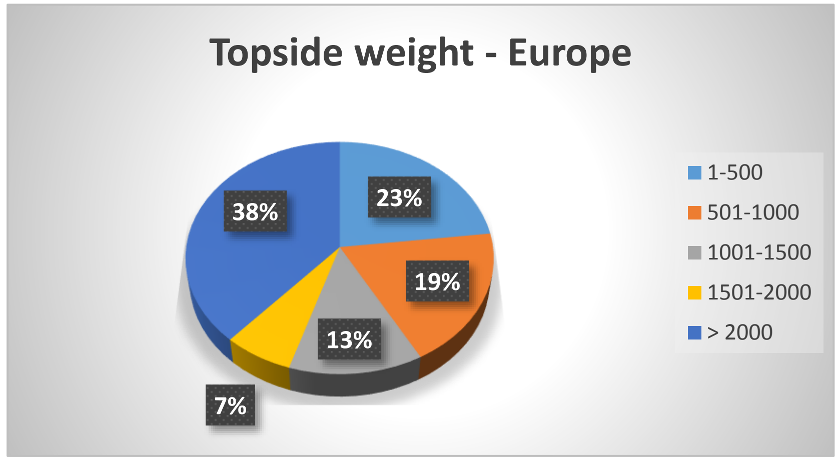

Figure 48 Weight distribution topside Europe

Table 30 Weight distribution topside Africa

Africa	
Topside Weight (Ton)	**Amount**
1-500	679
501-1000	228
1001-1500	167
1501-2000	59
> 2000	196
Total	1329

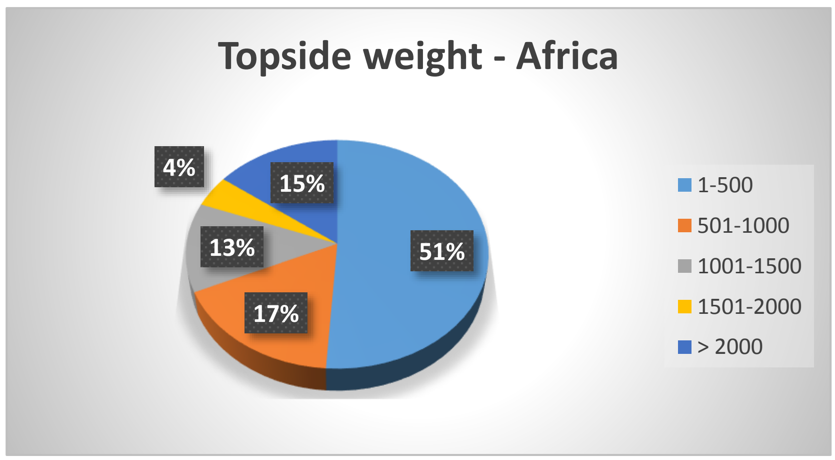

Figure 49 Weight distribution topside Africa

Table 31 Weight distribution topside Middle East & Caspian Sea

Middle East & Caspian Sea	
Topside Weight (Ton)	**Amount**
1-500	1220
501-1000	293
1001-1500	171
1501-2000	61
> 2000	320
Total	2068

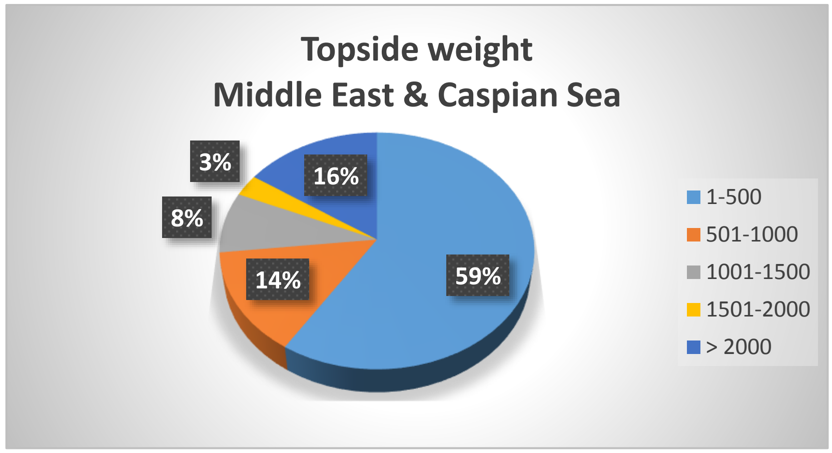

Figure 50 Weight distribution topside Middle East & Caspian Sea

Appendix IC

Platform dimensions

All the gathered information during the assessment to the dimensions of platforms are displayed in the table below. The resource numbers in the table are referring to the resources in table 33.

Table 32 Platform dimensions

	Platform name	**Region**	**Topside**					**Jacket**		**Source**
			Length [m]	width [m]	Height [m]	Airgap [m]	Weight [Ton]	Length [m]	Width [m]	
1	A18 satellite platform	North Sea	30	25	20	20	950	26	23	4
2	Conwy Wellhead Platform and Reception Module	Irish Sea	29	24	21	19	850	18	18	4
3	B13 satellite platform	North sea	38	20	20	16	2000	24	24	4
4	K6GT platform	North Sea	27	16	22	20	650	27	25	4
5	Borkum Riffgrund 2 Offshore High Voltage Substation	North Sea	40	25	20	20	2500	30	30	4
6	Horns Rev C Offshore High Voltage Substation	North Sea	41	34	25	26	2800			4
7	K4BE Satellite Platform	North Sea	24	12	26	20	680	26	26	4
8	Wintershall - L5-c	North Sea	17	12	10.5	18	660	12.3	7.5	1
9	Wintershall - Q4-c	North Sea	36	31.1	16	16.6	2226	15	15	1
10	Wintershall - P12 - SW	North Sea			16	16	500			1

	Platform name	Region	Topside					Jacket		Source
			Length [m]	width [m]	Height [m]	Airgap [m]	Weight [Ton]	Length [m]	Width [m]	
11	Wintershall P6-A	North sea			24.4	15	4730			1
12	Wintershall p6-B	North Sea	24.5	9.5	11.8	17.7	400	10	7.5	1
13	Wintershall Q4-a	North Sea			26.5	16.5	1081			1
14	Wintershall K13-A	North Sea	24.4	8.7	8.6	15.5	350	24.4	8.7	1
15	Wintershall L8-P	North Sea			15.3	16.3	963	13.6	12.1	1
16	Wintershall L8-A	North Sea			13.7	18	660	16.8	8.4	1
17	Wintershall L8 - P4	North Sea	45	28	25	18	3275	30	15	1
18	Wintershall L5-B	North Sea	17	12	10.5	18	479	12.3	7.5	1
19	Wintershall F16-A	North Sea	50.25	14	26	18	3600	32	16	1
20	Wintershall D12-A	North Sea	12	12	10.5	18	1220	12	12	1
21	Winstershall RAVN	North Sea	15	12	10.5		660			1
22	Winstershall A6-A	North Sea	43.7	32.2	32.2	19	3000	39.5	15.3	1
23	Abu Safah GOSP-1 TP	Gulf van Aden	17	12	20	9	408	11	11	4
24	AME-2	North Sea	14	20	15	18	350	18	9	2
25	Viking satellites DD	UK	12.2	8.6	3.2	19	171			3
26	Viking satellites CD	UK	12.2	8.5	6	16	172			3
27	Viking satellites ED	UK	20	16.5			409			3

Table 33 Recources dimensions platforms

Recourses	
1	De manenschijn. (n.d.). Noordzee. Retrieved from https://www.demanenschijn.nl/mijn-werk/noordzee/
2	NAM. (n.d.). NAM locaties - Ameland. Retrieved October 2, 2016, from http://www.nam.nl/nl/our-activities/ameland/nam-locaties-ameland.html
3	ConocoPhillips. (2015, September 16). Decommissioning Programmes. Retrieved from http://www.nam.nl/nl/our-activities/ameland/nam-locaties-ameland.html
4	Dimensions provided by Damen