DAMEN

Thesis

entitled

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

By

M. Kouwenhoven

Damen Shipyards
January 2017

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

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Author	Marco Kouwenhoven	**University mentor**	Mr. F.M. de Wit
Student number	12060070	**University supervisor**	Mr. A. Van der Vlugt
University	The Hague University	**University accessor**	Mr. J.P.M. Tromp
Bachelor	Mechanical engineering		
Date	1/8/2017	**Company mentor**	Mr. S. Utzon
Version	2.0	**Company supervisor**	Mr. L. Zaat

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Version management

Table 1 Version management

Version	Date	Description	Author	Provided to	
1.0	29-12-2016	Thesis	Marco Kouwenhoven	Company mentor	Mr. S. Utzon
2.0	9-1-2017	Thesis	Marco Kouwenhoven	Company mentor Company supervisor University mentor University supervisor University accessor	Mr. S. Utzon Mr. L. Zaat Mr. F.M. de Wit Mr. A. v.d. Vlugt Mr. J.P.M. Tromp

Abstract

Damen Shipyards is always on the lookout for new emerging niche markets. It appeared one of the most promising emerging niche markets is the offshore oil and gas infrastructure decommissioning industry. Therefore Damen produced a preliminary design of an offshore oil and gas infrastructure decommissioning vessel.

This decommissioning vessel is designed for the decommissioning of topsides from fixed steel platforms installed offshore. The vessel is equipped with a heavy lifting construction in order to be able to lift the topside. The method for heavy lifting is not defined yet, and therefore the functionality of the decommissioning vessel is not proven. By this thesis, the method of the heavy lifting construction will be defined and the functionality is proven according to the requirements of Damen Shipyards.

In cooperation with Damen, three methods for decommissioning have been established;

- decommissioning by a heavy lifting crane;
- decommissioning by a forklift construction;
- and decommissioning by a lifting frame.

By an analysis to the three methods and the assessment to the dimensions of offshore platforms, a choice is made among the three methods according to the set of requirements by a selection matrix which rates the methods with respect to each other. By this analysis occurred the lifting frame meets the requirements the best and is distinguished by the less sensitivity to weather conditions, the less negative impact on the stability and fastest operational speed. This method is further developed.

The functions of the lifting frame have been accessed and by this assessment several studies are carried out according to;

- the diversity in airgap;
- the tidal range;
- the motion compensation systems;
- the weight distribution of the topside;
- and the occurring forces for operational and survival conditions.

By this results a lifting frame is developed which consists of active compensation by cylinders, a height adjustable frame in order to adapt to the airgap and the ability of lowering the topside in order to discharge the drive components and sea fasten the topside before transport. The function is proven and the design complies with the set of requirements.

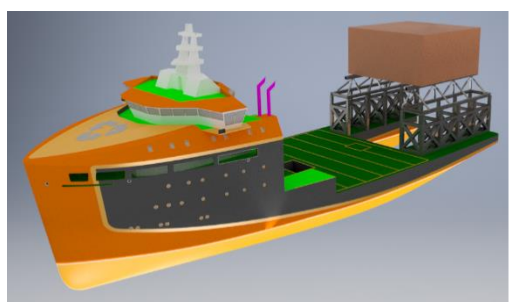

Figure 1 Final design lifting frame

The final design is developed at conceptual level and the functionality is proven in general. It is of importance a next design iteration is done for this concept. However, it is of importance the specific movements of the decommissioning vessel and dimensions of platforms is determined, which is not complied by this project. It is also recommended to study the applicability of stamps instead of lifting beams in order to reduce preparations to the topside before decommissioning.

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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

1. Preface

Damen is a client-focused, international and family-owned shipbuilder with Dutch roots. Damen designs and build innovative ships of excellent quality, supported by a worldwide network of sales and services including maintenance and repair & conversion facilities.

Damen aims to become a global market leader in the niche markets of shipbuilding, shiprepair & conversion and related services, growing step by step developing quality vessels and services. Damen wants to exceed their clients' expectations in terms of quality, innovation and reliability. Building successful relationships with customers, partners and employees in a safe environment."

Following their mission and vision, Damen is always on the lookout for new emerging niche markets. According to the business intelligence of Damen, one of the most promising emerging niche markets is the offshore oil and gas infrastructure decommissioning industry.

Damen has a Design and proposal department for the development of new ship designs. The department produced a preliminary design of an offshore oil and gas infrastructure decommissioning vessel.

The decommissioning process consists of lifting the topside from the jacket (figure 2),(Offshore-technology, (n.d.)). This is done by a heavy lifting installation which has not been defined and therefore the functionality of the decommissioning vessel is not proven. The goal of this project is to determine which method for decommissioning provides the best solution and develop this method in order to prove its functionality.

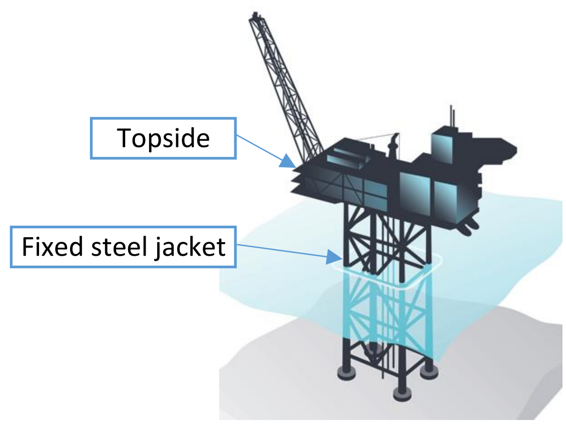

Figure 2 Offshore platform

1.1. Scope

The scope determines which activities are included and excluded for the project.

- All the calculations made during this project assume an equally distributed load by the topside to the heavy lift installation;
- the force calculations, made in the detail phase, will be carried out with both the dynamic and static forces. The static forces includes the weight of the topside and heavy lift construction. The dynamic forces includes the roll, pitch and accelerations of the vessel and the force exerted by the wind on the topside;
- the reactional forces from the vessel to the lifting installation will not be calculated;
- the calculations, are calculated for a maximum wave height of 1,5 meters.
- the heavy lifting structure will be designed for decommissioning of the topside with a fixed steel jacket;
- the heavy lifting installation will be designed for lifting topsides with a maximum weight of 1600 ton;
- this project includes lifting and positioning the topside on to the decommissioning vessel. All previous activities and activities after the topside is positioned are **out** of the scope;
- the project will be carried out within sixteen weeks of which weekly five days, nine hours a day.
- the 3D model will be drawn up in the program Autodesk Inventor 2016;
- the method for decommissioning will be chosen according to the variable requirements.

1.2. Preconditions

Several preconditions are required for the project.

- The properties of the decommissioning vessel, necessary during this project, will be provided by Damen Shipyards;
- Damen Shipyards provides coaching for the student at least once a week;
- Damen Shipyards will provide the student with a work desk and a laptop;
- after this report is approved, the project will not be expanded by other activities;
- the transfer of knowledge and results is done by the thesis and 3D model.
- The movements of the vessel will be provided by Damen Shipyards.

1.3. Set of requirements

The heavy lifting construction, placed at the decommissioning vessel, must comply with several requirements. The requirements are subdivided by fixed requirements and variable requirements.

Fixed requirements

- The heavy lifting installation needs to be able to lift topsides with a maximum weight of 1600 ton.
- The heavy lifting installation needs to be applicable to the designed decommissioning vessel.
- The heavy lifting installation needs to be able to decommission the topside of platforms with a fixed steel structure.
- The heavy lifting installation must be able to operate with a wave height of 1.5 meters and a wave period of 6 seconds.
- The heavy lifting installation must ensure the topside can be sea fastened after lifting, before transport to shore.
- The heavy lifting installation must not cause damage to the topside whereby the lifting operation is negative influenced.
- The heavy lifting installation must ensure the stability of the vessel during the lifting operation.
- The heavy lifting installation must position at the vessel so the stability remains ensured during transport to shore.
- The heavy lifting installation needs to be adaptable to four meters height difference of the airgap.

Variable requirements

- The dimensions of the fixed steel jacket and topside vary in a wide range, the heavy lifting installation needs to be able to decommission topsides in a wide range of dimensions.
- The heavy lifting installation should have as little as possible negative influence on the vessel.
- The heavy lifting installation should require as little as possible modification to the decommissioning vessel.
- The costs of the heavy lifting installation should be kept as low as possible.

1.4. Thesis outline

In this thesis, first a choice is made between three by Damen Shipyards established methods for decommissioning; decommissioning by a heavy lifting crane, by a forklift construction or lifting frame. By the chosen method an analysis is done by the functions of the heavy lifting construction in chapter 3. This analysis contains the rules and standards which must be complied by the design, analysis to required information for every function of the design in advance of the development, movements of the vessel and the calculation of the occurring forces. Chapter 4 describes the development for every function of the heavy lifting construction and the final design. By the final design the functionality is described and the design is proven to the set of requirements (chapter 5&6&7). Several recommendations are arranged by the results from the analysis and the final design, which is described in chapter 8.

2. Choose method

Damen established three methods for the heavy lifting construction; decommissioning by a heavy lifting crane, forklift construction and lifting frame. A choice is made among these three methods which needs to be applied to the designed decommissioning vessel. In advance, the dimensions of the decommissioning vessel are listed and research is done to the dimensions of the oil and gas platforms installed offshore (appendix I, chapter 1 & 2). By these analysis and a study to the different methods, a choice is made, based on the set of variable requirements. The analysis to the three methods, interpretations of the variable requirements, choice of the method and choice accountability is described in appendix I, chapter 3.

2.1. 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.

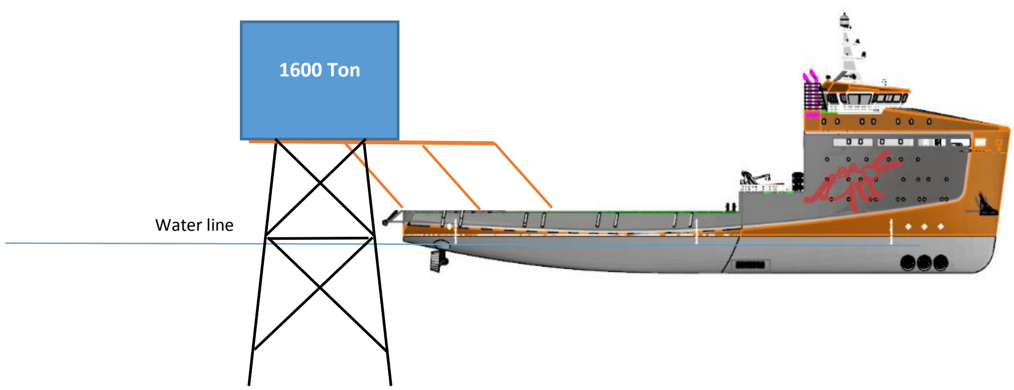

Figure 3 Forklift method

2.2. Decommissioning by heavy lifting crane

Lifting by a crane is a well-known method because the topsides are often installed by a crane. Picture 4 shows how a topside is installed with the use of a HLC. (Garus, 2013)

Figure 4 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 5, 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 5, middle image). If the two cranes are both placed at the side of the vessel (figure 5, 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.

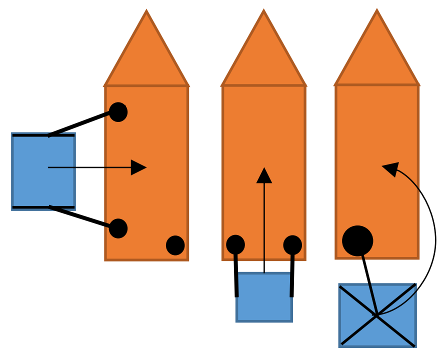

Figure 5 Placing crane on deck

The method of decommissioning needs to be applied to the designed decommissioning vessel which is only 32 meters wide (appendix A, 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 6).

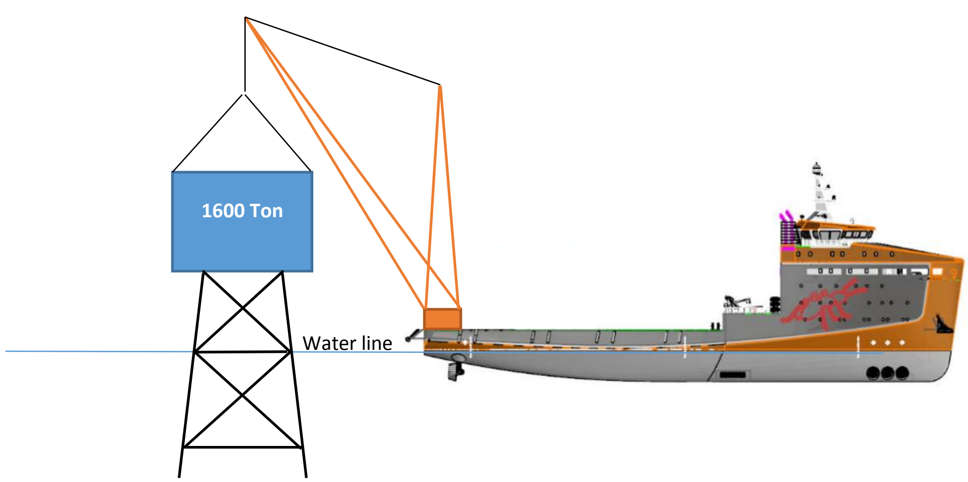

Figure 6 Lifting by heavy lifting crane

2.3. Decommissioning by lifting frame

The designed decommissioning vessel is now equipped with a lifting frame (figure 6,7). 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 7 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.

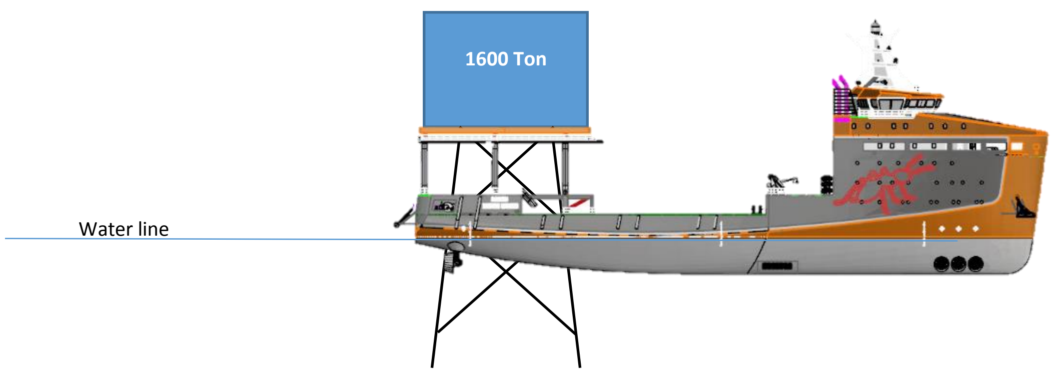

Figure 8 Lifting frame method

2.4. Chosen method

For the selection of a method, a selection matrix is used which rates the methods to the established variable requirements. For each requirement a weight factor is assigned, this factor determines the importance with respect to the other requirements.

By the selection matrix is 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 is be further developed.

3. Analysis lifting frame

Prior to the development of the heavy lifting frame, some analysis are carried out. All analysis are documented in appendix A and summarized in this chapter.

3.1. 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 itself is out of the scope, so this research only conducted the rules and standards the lifting frame has to meet. A standard for offshore heavy lifting constructions is not available. For this research the document '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 rules and standards, off appliance to the heavy lifting frame, are summarized in appendix I, chapter 4. These rules and standards are applied in the calculations of the forces (Appendix II).

3.2. Function analysis

The main function of the lifting frame 'decommissioning topside' is divided into sub-functions by a function analysis (figure 9). By the analysis a clear overview is generated of all the functions the lifting frame must comply to. Each sub-function is defined in this chapter.

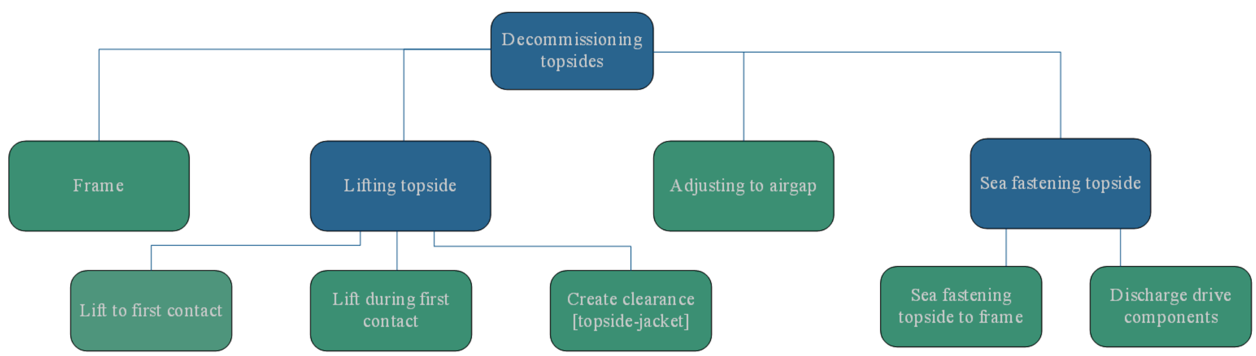

Figure 9 Function analysis 'decommissioning topsides'

3.2.1. Frame

The function of the frame is to transmit the forces, exerted by the drive components of the lifting frame and the force from the vessel to the topside. After the topside is lifted from the jacket, the frame transmits forces from the topside to the structure of the decommissioning vessel. The profile which makes contact with the topside is developed and assumed as upper-profile. The other dimensions and profiles of the frame entirely depends on the selected components for the other functions.

Figure 10 Upper-profile lifting frame

3.2.2. Lifting topside

Lifting the topside is the main function of the lifting frame. However, the force that is required in order to lift the topside is not generated by the lifting frame. The force is generated by the ballast system of the decommissioning vessel. The lifting frame only serves as construction to transmit the forces from the vessel to the topside and vice versa. Because of the importance of the ballast system a study is carried out in order to obtain knowledge of the ballast system and the functionality of the ballast system accordance to the decommissioning process is accessed. This study is described in the analysis report, appendix I, chapter 5.

Lifting the topside is sub-divided in three stages of lifting, as displayed in the function analysis. The first stage is the lift in order to generate contact with the topside. After contact is realized the load is gradually transmitted from the jacket to the lifting frame by the increasing load bearing capacity of the vessel due to de-ballasting. As soon as the load bearing capacity reaches the total load of the topside, clearance between the jacket and topside is realized at the final stage of lifting. The functions are described below.

Lift to first contact

Figure 11 First contact with topside

Once the vessel is positioned around the jacket, the vessel starts de-ballasting and therefore the lifting process can start. The first phase is to make contact with the topside. The first contact moment is crucial because it determines the position of the lifting frame with the topside, and therefore the weight distribution of the topside to the lifting frame. Despite the dynamic positioning, the vessel is constantly in motion by the waves, tide and wind. Therefore it may occur the lifting frame hits the topside several times. This is undesirable due to the constantly changing forces on the lifting frame and can cause damage. Besides the lifting frame, the topside can also be damaged, depending on the impact force and the physical condition of the topside. If this situation cannot be avoided, the contact surface of the lifting frame must be adjusted by adding rubbers which can absorb these force and avoid damage.

Lifting topside

After contact with the topside is established the load of the topside will be taken over from the fixed steel jacket by the decommissioning vessel. The load-bearing capacity of the vessel is determined by the ballast capacitance. Therefore the vessel will be, for lifting a topside with the maximum weight, fully ballasted at the beginning of the lifting phase. During the lift process the ballast water is discharged from the ballast tanks, which increases the buoyancy of the vessel and therefore the upward force. The de-ballasting is a slow process. Therefore the weight of the topside is gradually taken over. Due to the movements of the vessel, the load bearing capacity is constantly changing. If these movements cannot be eliminated the lifting frame must be constructed in order to absorb these changing loads.

Ensure clearance between jacket and topside

During the de-ballasting of the vessel it occurs that the load-bearing capacity in a wave is higher than the total load of the topside, resulting in the detachment of the topside and the jacket. Once the vessel, by the waves, is moving down the load-bearing capacity reduces and the topside will drop back on the jacket. This situation is undesirable because this causes high stresses on the lifting frame and jacket. Also it may occur, by the movements of the vessel, the topside does not totally drop back on the jacket what causes a high moment force to the lifting frame, jacket and topside which can result in losing control. It is necessary to prevent this situation. At the time the load-bearing capacity of the vessel exceeds the total load of the topside, sufficient space between the jacket and topside must be ensured. This phase of the lifting process is considered as 'the point of no return', once the topside is loosened from the jacket it cannot be replaced on the jacket.

Figure 12 Topside detaches from jacket

3.2.3. Adjust to airgap

The airgap prevents waves to hit the topside and therefore serves as protection. The previous study to the platform dimensions (appendix I, chapter 2) has revealed the airgap for platforms installed in the North Sea varies between 16 and 20 meters. However, this research only gathered information of platforms in the North Sea, for other regions to little information is available. In order to gain knowledge of the diversity in airgap, a study is carried out to determine the required height adjustment of the lifting frame (appendix I, chapter 6). The airgap is determined as the distance between the bottom of the topside with the lowest astronomical tide. A study is done over the tidal difference, appendix I, chapter 7.

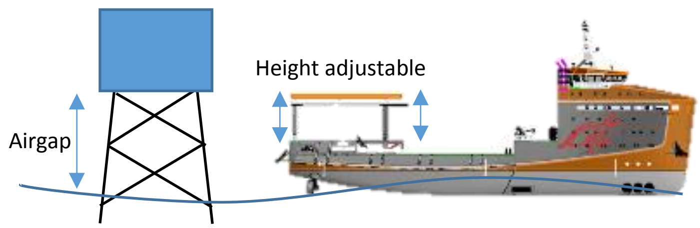

Figure 13 Adjust to airgap

3.2.4. Seafastening topside

The weather conditions during the lifting operation are restricted. The movements of the vessel are therefore kept low. After the topside is lifted, it is secured by its own weight by friction with the lifting beam. However, during transport to shore, the movements of the decommissioning vessel can be worse and are defined by the survival conditions according to the DNV-GL rules. In order to prevent the topside coming loose by these movements, it must be sea fastened. Also the drive components, used during the lift phase, have to be discharged. Not discharging these components increases probability of failure. Also if not discharged these components will be selected on the forces which can occur during transport which are much heavier than during the lift process.

3.3. Movements decommissioning vessel

As described, the main function of the lifting frame is to transmit the forces from the vessel to the topside and vice versa. This is a complex process due to the movements of the vessel. The topside is installed on the fixed steel jacket, while the lifting frame is mounted on a moving vessel. Therefore the movements of the vessel must be known in order to develop the lifting frame.

3.3.1. Movements

The movements of the vessel are categorized in translational and rational movements. The translational movements consist of heave, sway and surge. The rational movements consists of roll, pitch and yaw (figure 14), (The Calculate suite, n.d.). For the development of the lifting frame it is required the displacements, accelerations and rational movements are calculated. As defined in the scope, the movements are calculated by Damen Shipyards. However, some input is required in order to calculate the movements.

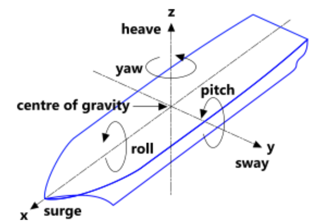

Figure 14 Movements ship

The generated acceleration and displacements by roll and pitch are different for every spot on the vessel. In appendix I, chapter 8.2 is determined for which spot the calculations must be carried out.

As the vessel is lifting the topside, the center or gravity (C.O.G.) changes, due to the increasing load at the aft of the vessel. As the C.O.G. changes by the increasing load, the movements of the decommissioning vessel will become less. The changed C.O.G. is calculated for a completely lifted topside (appendix I, chapter 8.2). The calculations must be carried out for the decommissioning vessel with and without topside.

3.3.2. Weather conditions

The movements of the vessel are, among others, calculated by the wave height and wave period, assumed as weather conditions. By higher waves the movements of the vessel increases and as the wave period is less, the accelerations of the vessel become higher because the vessel is moving up and down within less time. By defining the weather conditions, the operational window of the decommissioning vessel is determined and therefore the operational time of the vessel. The less the operational time of the vessel, the higher the dayrate (appendix I, chapter 3.2.1.). Scatter diagrams are used in order to obtain knowledge of wave data and define the weather conditions. Scatter diagrams are summarizing the wave climate and are representing the joint probability of wave height and period combinations during a period of time (Dubranna, n.d,). The calculation model, described in chapter 3.4 and appendix II, consists of a feature which calculates the operation time by a given wave height and period for the regions;

- North Sea;
- Gulf of Mexico;
- South Africa;
- Gulf of Oman;
- South Chinese Sea;
- Bay of Bengal;
- and Gulf of Thailand.

Which are established by Damen Shipyards.

3.3.3. Movement decommissioning vessel

For the movements, distinction is made for survival conditions and operational conditions. As mentioned, the operational conditions are determined by Damen Shipyards. However, during the project it turned out calculating the movements for operational conditions is complicated and was not completed in time to be used as input for the layout of the lifting frame. Besides the decommissioning vessel is still in development, determining the movements for a free sailing vessel, slowly taking over weight and at the same time de-ballasting is very complex. At least an indication of the movements is necessary for the process of this project and therefore the movements are calculated for the similar vessel the DOC8500. The movements are calculated for a wave height of 1.5 meter with period of 6 seconds. The survival conditions are calculated according the rules and standards by DNV-GL. The accelerations and roll and pitch are displayed in the table below for as well operational as survival conditions. As mentioned, the lifting frame transmits the forces in between topside and vessel. Therefore the maximum displacements must be known to determine the layout of the lifting frame. These displacements are added in the table. The displacements are not defined for survival conditions, because these conditions applies when the topside is lifted. Figure 15 is added for clarification of the movements.

Table 2 Movements decommissioning vessel operational and survival conditions

Movements decom. vessel	Operational conditions	Survival conditions
Vertical acceleration [m/s^2]	0.6	2.93
Lateral acceleration [m/s^2]	0.25	1.8
Longitudinal acceleration [m/s^2]	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	

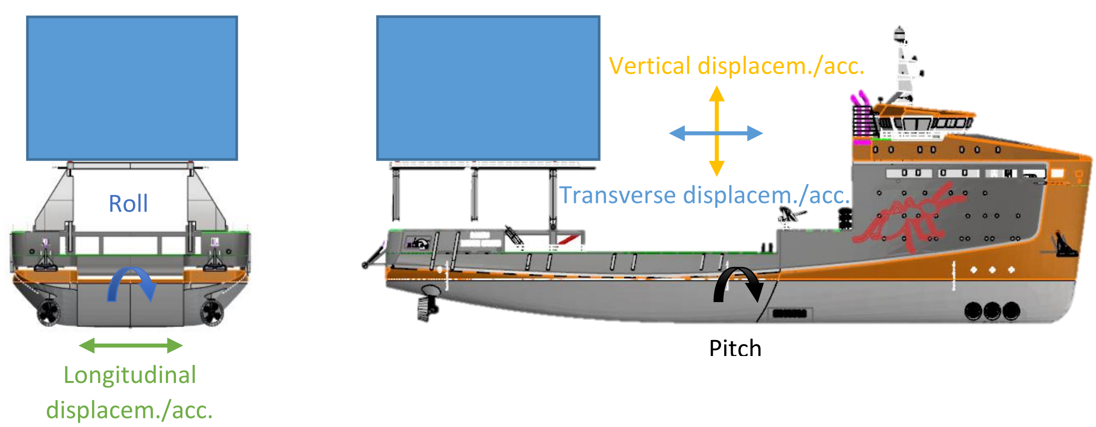

Figure 15 clarification movements vessel

3.4. Calculate occurring forces

Prior to the development 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 (chapter 3.2.4). These forces are calculated by a calculations model, made in Microsoft Excel. This model calculates the occurring forces from the topside to the lifting frame by the movements of the vessel and wind force and DNV-GL rules. In the model the dimensions of the vessel, dimensions of the topside, movements of the vessel and input by DNV-GL are variable. By these variable input Damen Shipyards is able to calculate the forces by changing input. The layout, functionality and calculations are described in appendix II. By the use of this appendix, Damen Shipyards should be able to use the model. As mentioned earlier this model is also equipped with scatter diagrams for several regions in order to calculate the operational window by the set wave height and period.

By the movements of the vessel, as described in the previous chapter, the greatest forces are calculated in the x, y and z direction of the vessel (figure 16). In order to calculate these greatest forces the worst conditions have to be selected in the calculation model for each force. This is described in appendix I, chapter 9. The resulting forces are displayed in the tables below for as well operational as survival conditions. By the rules of DNV-GL is determined, the used forces in order to calculate the buckling and excessive yielding of profiles must be by a factor. These forces are also displayed in tables.

Figure 16 X, Y and Z direction vessel

Table 3 Greatest forces operational conditions

Operational conditions			
	Force X direction	**Force Y direction**	**Force Z direction**
Without safety factor	1130.78 KN	1810.1 KN	16656 KN
With respect to buckling	1243.85 KN	1991.11 KN	18321.6 KN
With respect to excessive yielding	1560.47 KN	2497.94 KN	22985.3 KN

Table 4 Greatest forces survival conditions

Survival conditions			
	Force X direction	**Force Y direction**	**Force Z direction**
Without safety factor	5083.42 KN	7290.75 KN	20384 KN
With respect to buckling	5591.77 KN	8019.82 KN	22422.4 KN
With respect to excessive yielding	7015.13 KN	10061.2 KN	28129.9 KN

4. Development lifting frame

By the analysis to the lifting frame the lifting frame is developed. The development is carried out for each function.

4.1. Upper-profile

The profile which makes contact with the topside is considered as upper profile. The weight distribution from the topside has been accessed in appendix I, chapter 10. This assessment showed the amount of weight distribution points is equal to the amount of jacket piles, and are weight distribution places are in line with these jacket piles. This research also revealed, for a topside with the maximum weight of 1600 ton and a jacket consisting of 4 jacket piles, the minimum distance between the jacket piles is 12 meters.

4.1.1. Development upper-profile

By the difference in width of the jacket, and therefore the points where the forces can be transmitted to the lifting frame, it is desirable the lifting frame makes use of ‘stamps’. These stamps must be moveable in the lateral and longitudinal direction of the vessel, and therefore can be positioned at these particular points under the topside. However, due to the limited space next to the gap and the great height the lifting frame must cover due to the airgap, it is impossible to realize a movable structure to this decommissioning vessel.

Therefore, for the transmission of the forces is made use of a lifting beam which is placed below the topside. By figure xx the position of the lifting beams is indicated by the orange blocks and the red circles represents the contact surfaces. For the lifting beam a hollow rectangular profile is selected because this profile serves the best in absorbing forces in different directions. An additional advantage of a lifting beam is the forces are better distributed over a greater amount of supports.

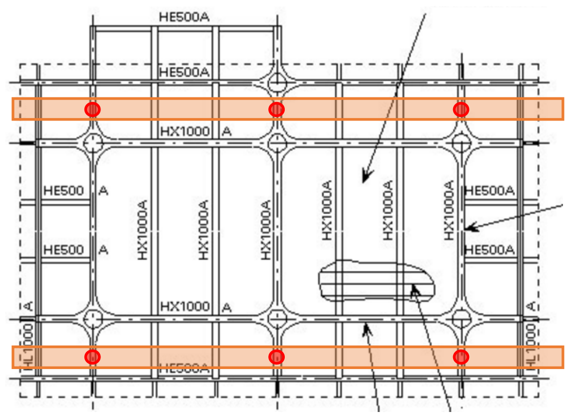

Figure 17 Weight distributional points topside

4.2. Lifting topside

As described in chapter XX the required force for lifting the topside is generated by the ballast system of the vessel. The transmission of these forces is complex due to the movements of the vessel.

4.2.1. Motion compensation

As dexribed, the decommissioning vessel is subjected to many movements. Before and during the lifting operation these movements must be absorbed or compensated by the lifting frame. This system is assumed as motion compensation system. During the study to these motion compensation systems it appeared these systems are very complicated. To gather information of what is already developed and acquire some knowledge of important things that needs to be taken into account during the development of the lifting frame, an external company is contacted. Two meetings took place which resulted in several options for motion compensating and knowledge of the difficulties with a motion compensation system.

Figure 18 Movements vessel

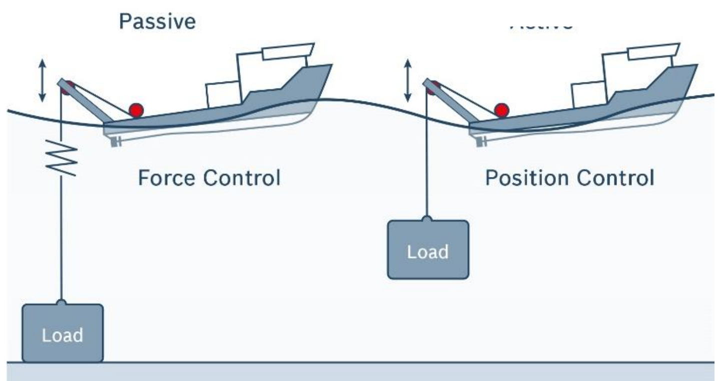

Figure 19 Passive/active heave compensation

The compensation of the movements can either be performed with a passive or active system. Passive compensators use a spring concept where active compensators use a motion reference unit. Figure 19 describes a passive and active heave compensator (Bosch Rexroth, n.d.).

Passive compensation can be performed with a fixed passive force (by means of springs) and variable passive force (by means of cylinders. Active motion compensation is performed by cylinders. The motions of the decommissioning vessel can be eliminated and held in place with reference to the topside.

The external company recommended to keep the motion compensation as close as possible to the load. The vessel exerts movements to the lifting frame, whereby forces are generated from the topside to the motion compensation system. As the distance between the motion compensation system increases, the forces are exerted over a larger length which generates a greater moment force to the motion compensation system. The company also recommended to perform the quick lift by another component than the motion compensation system. The motion compensation operates in different directions to the lifting beam in order to be able to eliminate all the movements in all directions. If the motion compensation is done by cylinders it can perform a quick lift. However, if the motion compensation fails in a specific direction during quick lift, the topside is exerted to a lateral acceleration instead of the desirable vertical acceleration. As mentioned, the quick lift is the point of no return. If this specific action fails, control of the lifting operation can be lost. By this knowledge is determined the motion compensation system must be placed right below the lifting beams and the quick lift is performed by another system.

4.2.2. General arrangement motion compensation

The motion compensation system eliminates the movements in all directions, so the passive or active compensation needs to be placed under the lifting beam in different directions (Figure 20). Lateral and longitudinal forces are compensated by just one or two compensators, the vertical force by all compensators.

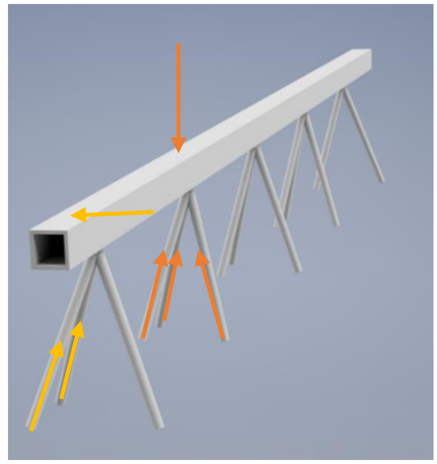

Figure 20 General arrangement motion compensation

As the lifting beam is attached to the topside, the lifting beam needs to be able to move with the topside in all directions. Therefore the compensation system is mounted to the lifting frame and lifting beam with a ball-bearing.

It must be determined weather passive or active compensation is added to the lifting frame

4.2.3. Passive compensation

In this chapter is examined whether passive compensation is applicable to the lifting frame for the different stages in the lifting process. In figure 21, the passive compensation by use of springs is pictured.

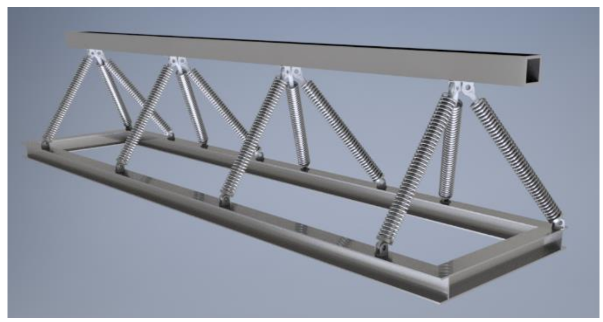

Figure 21 Passive compensation by springs

While positioning the decommissioning vessel around the jacket of the platform, the vessel has a vertical displacement of 2.4 meters. In order to avoid the lifting frame of making contact with the topside during positioning at least 2.5 meters clearance is required. Because of the passive compensation, the compensation system is fully extended. The required clearance therefore must be generated by the frame of the lifting frame by retraction and extension.

As soon as the decommissioning vessel is positioned, the lifting beam can make contact with the topside by extending the lifting frame. This phase is very important because it determines the position of the lifting beam with the topside and therefore the weight distribution. The vessel is, besides the vertical displacement, subjected to pitch roll and lateral and longitudinal displacement. Because of the passive compensation, the position of the lifting beam is determined by the timing of extending the lifting frame. In order to prevent the lifting beam dragging over the bottom of the topside, the first lift must generate enough friction so the lifting beam is fixed to the topside. The springs will move along with the movements.

The vessel is de-ballasting in order to generate load bearing capacity, but with the use of passive compensation, the vessel also needs to decrease its draft to compress the compensation whereby bigger force is exerted to the topside. By the movements of the vessel the passive compensation system is retracted and extended, resulting in constant changing loads to the topside and lifting frame. however, by these passive compensation, the movements of the vessel will decrease.

As soon as the compressed compensation system reaches the total load of the topside, the topside detaches from the jacket. As mentioned, once detached, enough clearance must be generated in order to ensure the topside does not drop back on the jacket. Because of the passive compensation, the vessel needs to increase its draft by the height of the movements of the vessel. If it is assumed, by the load of the topside, the vertical displacement is reduced to 1 meter, the vessel must decrease 1 meter draft. This is not possible because of the enormous amount of ballast the vessel needs to discharged in a single wave period. The clearance must be generated by extending the frame, what compresses the passive compensation system and generates clearance.

As the topside is detached from the jacket, the lifting beam must be fixed to the lifting frame, because of the uncontrollable passive compensation system. This is done by placing a fixed structure on top of the lifting frame, in between the passive compensation systems. As soon as the total load is distributed to the decommissioning vessel, the motion compensation system is compressed and therefore the lifting beam is lowered to the fixed structure and secured by its own weight figure 22. Thereby, the passive compensation system can only serve for topside within a limited range in weight.

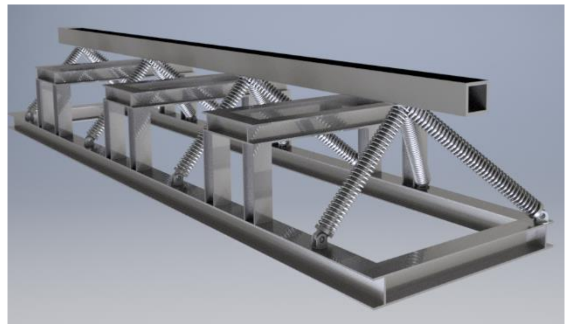

Figure 22 sea-fastening by use of passive compensation

4.2.4. Active compensation

The active compensation can be done by the use of cylinders. In basic, this system operates the same as with the use of passive compensation.

As the vessel is positioning around the jacket, the active cylinders are retracted whereby enough clearance is generated. As the vessel is positioned the lifting beams are fixed to the topside by the use of the active system. With motion reference to the topside, the lifting beams can be hold in place. By the use of this system the lifting beam can be placed at the desired place, in a controlled way.

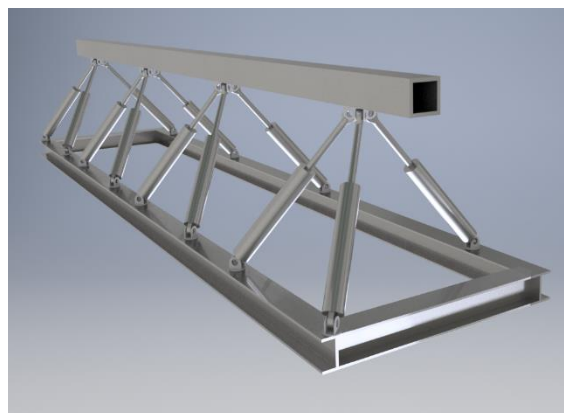

Figure 23 Active compensation by cylinders

As the vessel is de-ballasting, load bearing capacity increases and the passive force, exerted by the cylinders, is simultaneously increased. By this the use of this system the draft of the vessel remains the same and the de-ballast system only needs to generate force to lift the topside. By the passive force of the cylinders, the movements are compensated and the exerted force to the topside remains the same.

As soon as the load bearing capacity reach total load of the topside, the clearance must be generated. At this point the cylinders extend at their maximum, therefore the required clearance is only determined by the increasing draft of the decommissioning vessel due to the increased load.

4.2.5. Choice passive-active compensation

By the analysis to the function for as well passive and active compensation is determined only active compensation can be applied to the lifting frame, despite the more complicated system and required power unit for the active compensation cylinders. The great advantages of active compensation in comparison with the passive compensation is the controlled placement of the lifting beams under the topside and the less required clearance. Also, if the passive compensation is dimensioned for lifting a topside of 1600 ton, it cannot be used for lifting topsides of less weight. If the lifting frame is passive compensated, this system must be adapted to the weight of the topside.

4.3. Adjustment to airgap

One of the functions of the lifting frame is to adapt to the airgap. The study to the difference in airgap (appendix A, chapter 7) revealed the airgap worldwide varies from 8.7 meters to 20 meters. Since the airgap is defined as space between the bottom of the topside and lowest astronomical tide, also a study is done over the tidal range (appendix A, chapter 8). The tidal range differs for per region, the highest tide is 12 meters while some regions are relatively tideless. By timing the decommissioning operation, the tide can be used as extra generated load bearing capacity of the vessel. However, because some regions are tideless this is not taken into account for the development of the lifting frame.

4.3.1. Applications airgap adjustment

A height adjustment system for the airgap can be applied in different ways. These are addressed in this chapter.

Included in supporting frame

Depending on the design of the supporting frame, a height adjustment system can be incorporated in the design. This can be incorporated to the design by means of extendable profiles, in which a crane with extendable boom can be taken as example. These beams are capable in absorbing loads in different directions and can be powered by cylinders. Figure 24 (Grabcad, 2011)

Figure 24 Extendable beam

Advantages

- With the use of an extendable beam a great difference in height can be obtained.
- If the extendable beam is used in combination with a cylinder a great vertical force can be generated.

Disadvantages

- An extendable beam is, especially in sea state, susceptible to wear.
- An extendable beam, if it is completely retracted, remains a ‘dead-length’. This dead-length consists of the lower part and the length of other parts that cannot be retracted by the mounting of the cylinder.

Structure on lifting frame

In order to adapt to the airgap, the lifting frame can be adjusted. A construction can be placed on the lifting frame, adapted to the airgap. Figure 245 (Eriks metal work, n.d.)

Figure 25 Structure on lifting frame

Advantages

- Simple solution, no complicated system.
- Standard structures can be made in advance for different heights.

Disadvantage

- Because of the created distance between the topside and lifting frame, the forces which needs to be absorbed by the motion compensating system increases.
- By applying this, the preparation time will take longer.
- The external company recommended the motion compensation system needs to be kept as close as possible to the topside.

Integrated in the motion compensation system

The difference in airgap can be integrated in the motion compensation system. The motion compensation system is carried out by cylinders. As the stroke of the cylinders is increased, these can adapt to the airgap and compensate the motions of the vessel. Figure 26 (Mobile hydraulic tips, 2012)

Figure 26 Hydraulic cylinder

Advantages

- By integrating the height adjustment in the motion compensation cylinders, not an extra system needs to be integrated in the lifting frame.

Disadvantage

- The motion compensation cylinders must be carried out heavier since the stroke is increased.
- The forces, exerted to the cylinders is increased since the moment force increases by increasing height.

4.3.2. Choice height adjustable system

The applicability of the mentioned function fulfillers to the lifting frame is described. By these results and the research to the difference in airgap height a choice is made.

Applicability of structure on lifting beams

The external company recommended to keep the load as close as possible to the motion compensation system. The influence of the increasing distance between the topside and motion compensation system is analyzed.

Green block represents the topside, the black triangle represents motion compensation system and orange block is the structure in order to compensate the airgap. The black arrow is occurred lateral force due to the movements of the vessel and the red arrow is the reaction force to the created moment force (orange arrow).

The higher the structure, the greater the created moment force and therefore a greater reactional force by the motion compensation system. (see formulas)

In addition to the increasing forces to the motion compensation system, the structure, attached to the lifting frame, results in a more unstable situation.

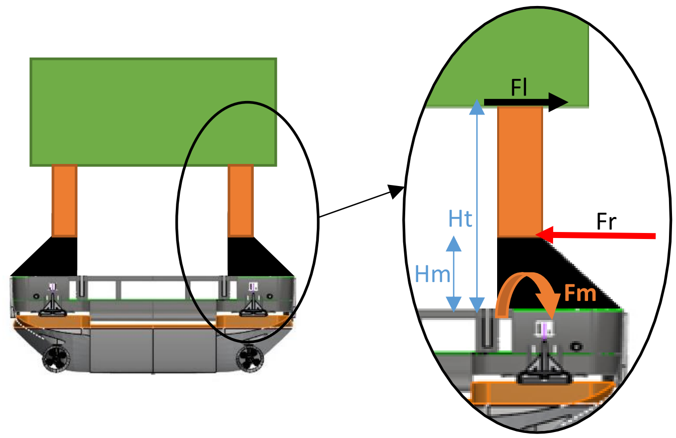

Figure 27 Structure on lifting beams

Formulas

Moment force (Fm) = Lateral force (Fl) * height topside (Ht)

Reactional force (Fr) = Fm / height motioncomp. (Hm)

Reactional force (Fr) = (Ft*Ht)/Hm

The greater Ht, the greater the reactional force (Fr)

Applicability including height adjustment in motion compensation system

As mentioned, the motion compensation system is exposed to both vertical as lateral forces. These forces are compensated by cylinders, mounted to the lifting beam in different directions.

In figure 28, the topside is represented with the green block, and the motion compensation cylinders with the orange lines.

As the vessel roll, a lateral force is generated to the motion compensation system. The higher the motion compensation system, the less the angle of the motion compensation cylinder, the higher the reactional force from the motion compensation cylinder.

$$Fmotioncomp. = F_{lateral} / \sin\theta$$

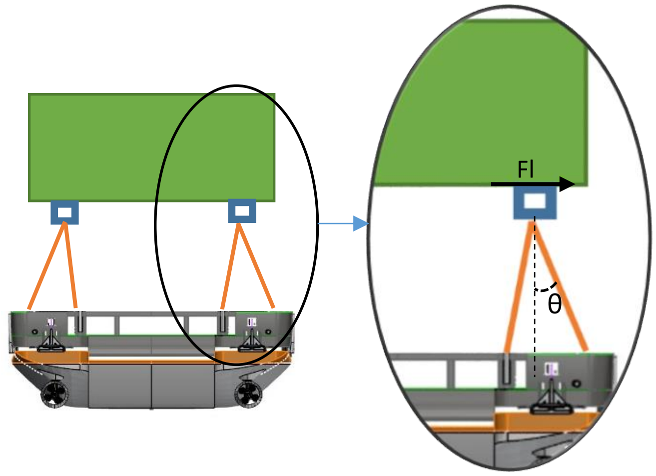

Figure 28 Cylinders for airgap adjustment

As the difference in airgap is compensated by the motion compensation cylinder, the reactional forces due to the lateral and longitudinal forces increases by the increasing height of the airgap and therefore the motion compensation system is dimensioned for greater forces.

The main disadvantage is the "dead length" consisting of the house length, mountings and piston (figure 29). As the stroke is increased, the housing length increases (SCS, 2012). The length of the cylinders is roughly calculated according to the following formula.

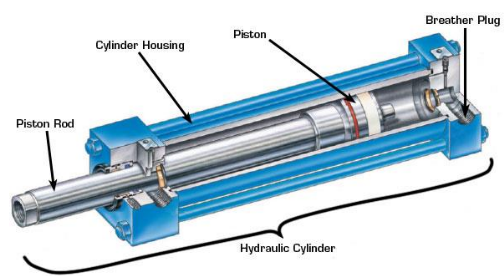

Figure 29 Cylinder layout

$$Lenght\ cylinders\ =\ Max.Airgap - height\ maindeck\ above\ sealevel + maximum\ vertical\ displacement$$

$$\text{Height maindeck above sealevel: } Depth\ mld. - \ draught\ summer\ = 8.5 - 5.83 = 2.67\ m$$

$$\text{Maximum vertical displacement} = \ vertical\ dicplacement/2 = 2.4/2 = 1.2\ m$$

$$Lenght\ cylinders\ =\ 20 - \ 2.76 + 1.2 = 18.44\ m$$

In addition to the fact cylinders of 18.4 meters are expensive, fully retracted cylinders still consists of a dead length of 9.44 meters.

Applicability of the extendable lifting frame

The lifting frame is placed at main-deck level. It is not preferred the frame is integrated in the vessel itself because, at the place the lifting frame is placed, the most important ballast tanks are located. These tanks generates the greatest part of the total load bearing capacity of the vessel, needed to lift topside (appendix A, chapter 6 "the ballast system"). The height of this frame is roughly calculated as (Figure 30):

$$Height\ frame\ =\ Airgap - \ height\ maindeck\ above\ sealevel - height\ motion\ compensation\ system$$

$$\text{Height maindeck above sealevel: } Depth\ mld. - \ draught\ summer\ = 8.5 - 5.83 = 2.67\ m$$

The height of the motion compensation system is twice the vertical displacement since the cylinders consists of a dead length, as long as the stroke of the cylinder, equal to the vertical displacement.

$$\text{Height motion compensation system: } 2x\ vertical\ dicplacement = 2.4 * 2 = 4.8\ m$$

$$Minimum\ height\ frame\ =\ 8.7 - 2.67 - 4.8 = 1.23\ m$$

$$Maximum\ height\ frame\ =\ 20 - 2.67 - 4.8 = 12.53\ m$$

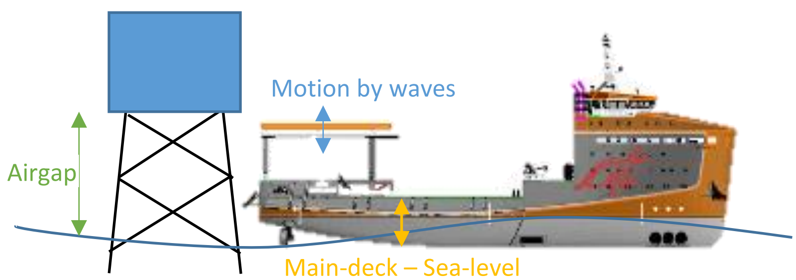

Figure 30 Extendable lifting frame for airgap adjustment

4.3.3. Conclusion

A lifting frame that must be applied to the decommissioning vessel cannot decommission platforms with an airgap of 8.7 meters and 20 meters. A height adjustable frame that consists of extendable beams cannot be constructed for 11.3 meter height adjustment because of the remaining dead length of the beams and the instable situation when fully extended. If the height adjustment is integrating in the motion compensation cylinders, these cylinders consists of a dead length of 9.44 meters, so these are not adjustable to the lowest airgap. Applying a fixed construction to the lifting beams, for the height adjustment results in a highly instable situation.

Therefore, in cooperation with Damen Shipyards, is defined the decommissioning vessel should be developed to be deployable in a defined region and not worldwide. Only data of the platform dimensions for the North Sea region is known, therefore the lifting frame must be four meters adjustable, more is desirable, not required.

By this knowledge the height adjustable frame is chosen for the adjustment to the airgap. By the height adjustable frame the stability of the lifting frame remains ensured and the motion compensation system is kept as close as possible to the topside, as recommended by the external company. The stroke of the cylinders is determined by the motions of the vessel and not by the airgap, so the length of the cylinders and power requirement is kept low.

4.4. Sea fastening topside

After the topside is lifted and before transport to shore the topside needs to be sea fastened. As mentioned for the transportation to shore, the movements of the vessel are determined by DNV-GL (assumed as survival conditions). In chapter 3.4, the greatest occurring forces are calculated in the x, y and z direction of the vessel. This forces shows the great difference in the forces for operational and survival conditions.

The main purpose of the seafastening of the topside is to assure the topside is fixed to the vessel what is done by welding the topside to the lifting frame. For welding and the stability of the vessel it is desirable the topside is lowered. Also the drive components used during the lift phase are discharged by seafastening. Therefore these drive components are selected on the forces which can occur during the lifting phase (operational conditions) instead of the forces during transport (survival conditions).

The seafastening must assure, the motion compensation cylinders and the cylinders used for the height adjustable frame are discharged. Also it is preferable if the topside is lowered in order to weld the topside to the lifting beam.

4.4.1. Discharge motion compensators

The motion compensation cylinders are discharged by lowering the lifting beam on to a fixed steel structure. The motion compensators are mounted in a way the cylinders can compensate the forces in each direction. In order to determine whether a fixed steel structure can be applied, the distribution and amount of the cylinders is determined.

Amount motion compensation cylinders

The lifting beam is supported by the motion compensation cylinders, which consists of three cylinders at each supporting point. The topside weight is exerted by two or three point loads to the lifting beam (represented by the orange arrows). As three motion compensation points are applied, the middle motion compensators compensates nearly all the topside weight (D-line, figure 32) and the lifting beam is subjected to an extreme bending moment (M-line, figure 32).

As four motion compensator points are applied, the forces are better distributed. The forces are at least distributed over two motion compensator points and the bending force of the lifting beam is less (figure 31).

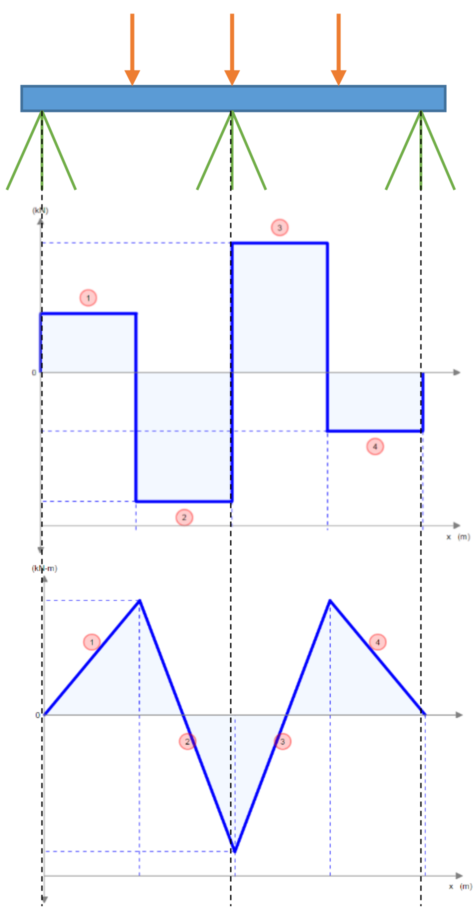

Figure 32 D-line and M-line three motion compensators

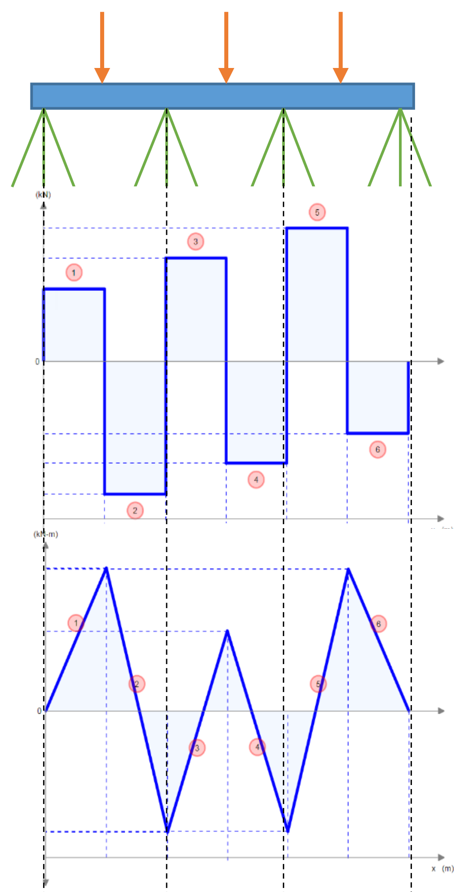

Figure 31 D-line and M-line four motion compensators

Dispersion motion compensators

The motion compensators transmits the forces to the lifting frame. The vertical forces are transmitted by all cylinders. The lateral and longitudinal forces are compensated by just one or two cylinders. The force of the cylinder is, in addition to the force from the topside, determined by the angle at which the cylinder is mounted.

The exerted force by the cylinder is exerted in the longitudinal direction of the cylinder. The vertical and lateral force can be calculated with the angle in which the cylinder is mounted according to sinus and cosines.

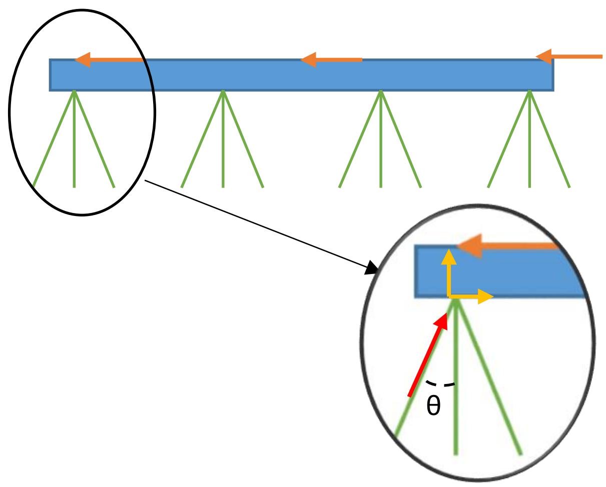

Figure 33 Dispersion motion compensators

The cylinders are dimensioned for operational conditions, the lifting beam for survival conditions. According to the calculation model the greatest vertical force is 16656 KN. If this is distributed over two lifting beams with each four motion compensation points, consisting of three cylinders the force for each cylinder is:

$$Vertical\ force\ per\ cylinder: \frac{16656}{24} = 964\ KN$$

The lateral force is 1130.8 KN, distributed over eight cylinders:

$$Lateral\ force\ per\ cylinder: \frac{1130.8}{8} = 141.34\ KN$$

The minimum angle at which the cylinder must be mounted in order to not exceed the vertical force is calculated according to the tangent.

$$\tan\ \frac{141.34}{964} = 8.5^{\circ}$$

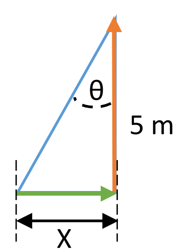

Figure 34 Angle motion compensators

The minimum angle in which the cylinder can act is 8.5 degrees. The maximum height of the cylinders is 5 meters, according to the vertical displacement of 2.4 meter and the dead length of the cylinder which is twice the length. The distance of the mounting of the cylinder with the mounting point at the lifting beam (black arrow, figure XX) is calculated according to:

$$Mounting\ cylinder\ (X) = \ \tan 8.5 * 5 = 0.8\ meter$$

With the longitudinal displacement of 1 meter, the distance of the mounting of the cylinder with the mounting to the lifting beam is 1.8 meter.

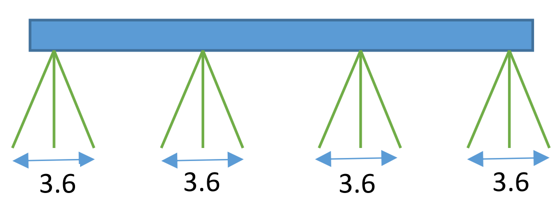

Figure 35 distance between motion compensators

Applying supporting structure

The calculations showed the motion compensation system uses 14.4 meters in length of the lifting frame. The supporting structure (yellow blocks in figure 36) can be placed at each side and in between the motion compensators.

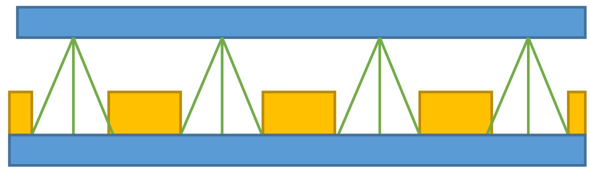

Figure 36 Supporting structure motion compensation system

In order to avoid collision between the fixed structure and the lifting beam during the lifting phase due to the motions of the vessel, the cylinders consists of an extra stroke of 0.2 meters. This 0.2 meters is not used during the motions compensation, so creates clearance between the lifting beam and fixed structure.

By the fixed structure, a wide support is created over which the occurring forces for survival conditions can be distributed. The lifting beam consists of a length next to the outer mounting points of the motion compensation systems which provides contact with the supporting structure once retracted.

4.4.2. Discharge drive components extendable frame

Since the adjustment to the airgap is done by the height adjustable frame, the cylinders, generating force for extending and retracting the frame, must be discharged. This system is based on the same principle as lowering the lifting beam. The height adjustable frame is constructed with extendable beams (figure 36). In between the supporting of the lifting frame, a fixed structure can be placed. After the topside is lifted, the extendable frame is lowered to its minimum height, so the forces are distributed to the fixed structure.

Figure 37 Lowering frame for seafastening

4.4.3. Conclusion

The forces from the topside are transmitted from the motion compensation cylinders to the fixed structure on the lifting frame. The drive components of the lifting frame itself are discharged by lowering the height adjustable frame on to a fixed steel structure. By retracting the motion compensation cylinders and the height adjustable frame the topside is lowered whereby welding the topside to the lifting beam is easier.

4.5. Quick lift

As soon as the load bearing capacity of the vessel reached the weight of the topside, quick lift is performed in order to avoid collision between the jacket and topside. First is determined what is the required clearance by the quick lift system

4.5.1. Required clearance

Due to the active motion compensation and by timing the operation, the required clearance is kept less. As the vessel is moving down due to the waves, the motion compensation system extends because the lifting beam is attached to the topside. When the vessel is at its lowest point, so the motion compensation system is fully extended. As the vessel is moving up, the cylinders are fixed, so the topside is lifted from its jacket. The last part of the weight of the topside is transported to the decommissioning vessel within seconds. This rapidly increasing load results in increasing draft, due to the ballast system, which cannot compensate the increased load as rapidly. As the vessel is moving down again, quick lift can compensate the increased draft with addition of 0.2 meters safety clearance.

The increasing draft is calculated according to Archimedes' principle. The principle indicates the upward force that is exerted to a body, immersed in fluid, is equal to the weight of the fluid the body displaces.

It is determined the quick lift is carried out after 80% of the topside is lifted. The system therefore generates an increasing load of:

$Weight\ topside[Ton] * 0.2$ -> $1600 * 0.2 = 320\ Ton$

In order to calculate the volume of the decommissioning vessel, the following formula is used.

$$Volume = Lv * Bv - lg * bg * F$$

$Lv = Length\ decommissioning\ vessel$

$Bv = Width\ decommissioning\ vessel$

$Lg = Lenght\ gap$

$Bv = Width\ gap$

$F = Form\ factor\ of\ decommissioning\ vessel$

The dimensions of the decommissioning vessel are listed in appendix B, chapter XX. The form factor is assumed 0.9, taken from the DOC 8500. This input results in the following calculation.

$$Volume\ [m^3/m_{draft}] = (84.15 * 32 - 24.6 * 14.4) * 0.9 = 2104.7$$

The average density of seawater at surface is 1.025 Kg/l = 1025 Kg/m^3 = 1.025 ton/m^3.

$$Load\ bearing\ \left[{}^{Ton}/_{m_{draft}}\right] = 2104.7 * 1.025 = 2157.31$$

The increasing draft by the increasing load due to the quick lift:

$$Increasing\ draft\ [m] = \frac{Increasing\ load\ [Ton]}{Load\ bearing\ \left[{}^{Ton}/_{m_{draft}}\right]}$$

$$Increasing\ draft\ [m] = \frac{320}{2157.31} = 0.148\ m$$

So, due to quick lift, the draft increases 0.148 meters, if the load is added to the center of the vessel. Now the load is added at the aft of the vessel, so the vessel will dive twice the increased draft, but as load is added to the aft, the fore ship is lifted out of the water with equal draft, still resulting in the average increasing draft of 0.148 m. With addition of the safety clearance of 0.2 meters, the required clearance is 0.348 meters.

4.5.2. Ballast tanks

Research to the ballast system (appendix A, chapter 6) revealed the de-ballasting can be performed by means of convenient use of the force of gravity. If ballast tanks are placed above the sea-level, these tanks can be unloaded by opening valves, de-ballasting rapidly.

Advantage

- In order to obtain clearance by using ballast tanks, no complex system is required.
- The gravity based ballast tanks can be used in addition to the quick lift system in order to prevent increasing draft.

Disadvantage

- If the existing ballast tanks above sea-level is not enough, additional ballast must be installed in order to generate the required clearance.

As calculated the load bearing of the decommissioning vessel is 2157.31 ton for each meter draft. The required clearance is 0.348 meters and therefore the draft must decrease with the same amount.

$$Ballast\ water\ [m^3] = Decreasing\ draft\ [m] * \frac{Load\ bearing\ [Ton]}{Density\ sea\ water\ [\frac{Ton}{m^3}]}$$

$$Ballast\ water\ [m^3] = 0.348 * \frac{2157.31}{1.025} = 732.43$$

The unloading capacity of the ballast tanks should be:

$$Ballast\ capacity\ [m^3/h] = {}^{ballast\ water[m^3]}\Big/_{\frac{wave\ period[s]}{2}} * 3600$$

$$Ballast\ capacity\ [m^3/h] = {}^{732.43}\Big/_{\frac{6}{2}} * 3600 = 878400$$

4.5.3. Integrate in height adjustable frame

With a quick-lift system integrated in the height adjustable frame, clearance can be created. A quick lift operation is a timed operation. As the load is almost taken over by the decommissioning vessel it can generate clearance by the elevation of the topside within a single wave period.

Advantage

- The quick lift system can be integrated in the height adjustable frame or as additional system.

Disadvantage

- By the quick lift system, the last part of the load of the topside is transferred to the vessel in just a few seconds, whereby the draft of the vessel will increase. The increased draft results in extra required clearance.

Since the height adjustable frame is using for lowering the topside after it is lifted, the drive components are selected for the total load of the topside. By timing the operation, so when the topside is moving down, the required power from the lifting frame for performing quick lift, is less than when the lifting frame is lowering to the fixed structure.

The maximum vertical force from the topside is determined by the vessel moving upward due to waves.

F vertical maximum = 16656 KN

As the vertical acceleration in the calculation model is changed from upwards to downwards the vertical force from the topside is:

F vertical minimum = 14736 KN

The calculations are done for a wave period of 6 seconds. The quick lift needs to be performed in half a wave period. The extra force due to quick lift is calculated as:

$$F_{quicklift} = topside\ weight[Ton] * \frac{required\ clearance[m]}{{Wave\ peroid}/{2}\ [sec]}$$

$$F_{quicklift} = 1600 * \frac{0.348}{3} = 185.6\ KN$$

4.5.4. Conclusion

Since the height adjustable frame is using for lowering the topside after it is lifted, the drive components are selected for the total load of the topside. By timing the operation, so when the topside is moving down, the required power from the lifting frame for performing quick lift, is less than when the lifting frame is lowering to the fixed structure. So because of the height adjustable frame, which can perform quick lift without adding a system, this is chosen to carry out quick lift.

5. Final design

By the analysis and development for the functions of the lifting frame, the final design is developed (figure 38). For every function is described how it is processed in the lifting frame.

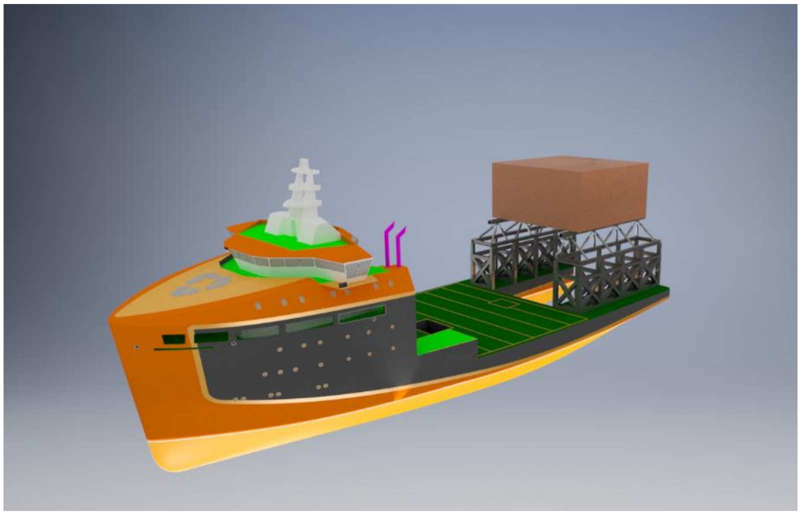

Figure 38 Decommissioning vessel with lifting frame

5.1. Lifting beam

The lifting generates contact with the lifting frame to the topside. This profile is calculated with respect to buckling, for operational conditions. The forces by survival conditions are greater, but since the profile is supported by a supporting structure, the beam is supported over an increased length instead of the mounting points of the cylinders. By strength calculations (appendix I, chapter X) is determined the upper profile is 700*700 mm, with a thickness of 50 mm.

5.2. Motion compensation system

By the previous chapter is determined the motions are compensated by the use of active compensation cylinders. By calculations it also revealed the cylinders must be positioned by at least 4 meters space. The cylinders needs to be able to move by al the movements of the vessel, so they are mounted by the use of hinges, and a ball bearing(figure 39), (Contarini, n.d.). This ball bearing allows to move with roll and pitch. Figure XX shows the side view of the cylinders. The length of the lifting beam is represented by the green arrow and consists of a length of 20 meters. The length of the lifting frame is as long as the gap so 24,6 meters. For seafastening is enough space in between the cylinders.

Figure 39 Ball-bearing cylinder

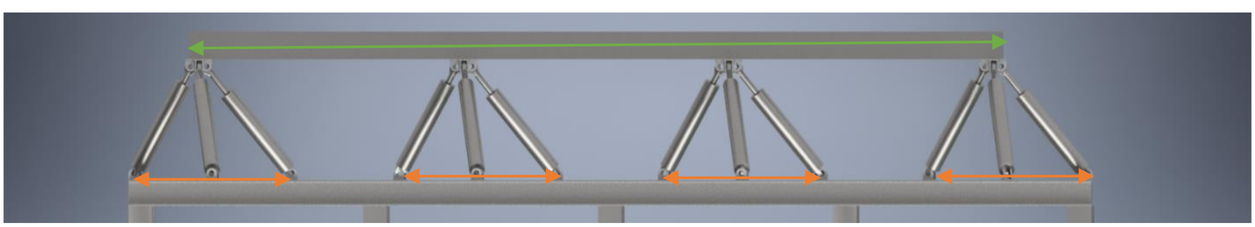

Figure 40 Motion compensation system applied to lifting frame

5.3. Adjustment to airgap

The height adjustment is done by the extendable beams of the lifting frame. Figure 41 displays the dimensions for a platform with an airgap of 20 meters and 16 meters. The left image for 16 meters, right image 20 meters.

The orange arrow represents the airgap, the green arrow the height of the main deck above sea level, the blue arrow the standard height of the frame and the red the adjustable length.

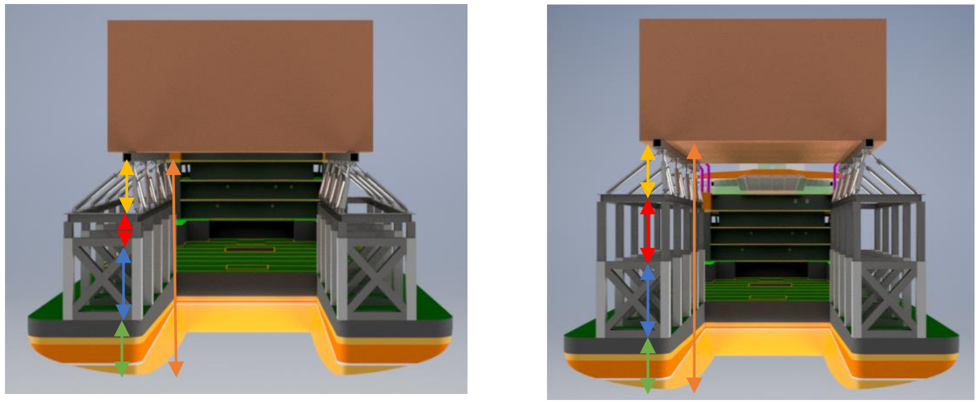

Figure 41 Airgap adjustment by lifting frame

The height of the main deck above sea level is 3.2 meters. And the average height of the cylinders is the 5 meters dead length with halve the stroke is 7.5 meters.

For an airgap of 20 meters the lifting frame have to compensate:

$$20 - 7.5 - 3.2 = 11{,}3 \; meter$$

For an airgap of 16 meters the lifting frame have to compensate 6.3 meter.

5.4. Sea fastening

The seafastening is done by retracting the cylinders, lowering the lifting beam to a fixed steel structure, placed on the lifting frame. The lifting frame itself is lowered by the use of the extendable beams of which the lifting frame consists. Also the lifting frame is placed on a fixed steel structure, within the extendable beams. The height adjustment therefore is not the required four meters in order to adapt to the airgap, but consists of another meter so it can sea fasten itself. Picture 42 shows the lifting frame, set for an airgap of 16 meters, still existing of space for seafastening.

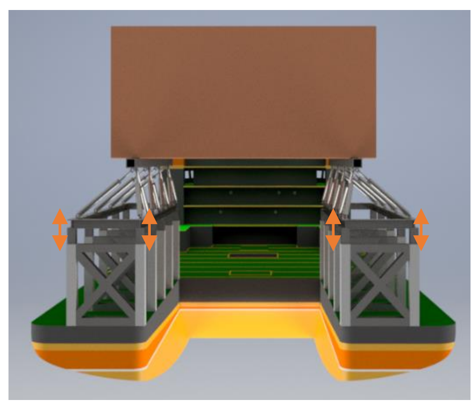

Figure 42 Reserve height adjustment for seafastening

5.5. Quick lift

The quick lift is carried out by the height adjustable frame. The drive components are still determined by the forces which occurring during the lifting place, by timing the quick lift, the drive components do not need to be carried out heavier.

6. Functionality final concept

For the final concept the functionality is proven for several stages in the decommissioning process.

As the vessel is near the platform, the dynamic positioning is activated. It takes several hours for the dynamic positioning system to learn what is the sea state and how to anticipate in order to keep the vessel in position. The vessel starts taking in ballast water whereby the draft increases. In advance, there should be knowledge of the dimensions of the platform and where the lifting frame must be attached to the topside. By this knowledge, the lifting frame can be set to the airgap of the platform by extending the height adjustable frame (figure 43). The height adjustment is done by the use of cylinders, which are placed at the sides of the extendable beams. These cylinders generate the force for height adjustment, and compensates the lateral and longitudinal forces. The height adjustable frame is consisting of hollow rectangular which are sensitive for these forces, especially when the frame is fully extended (figure 44).

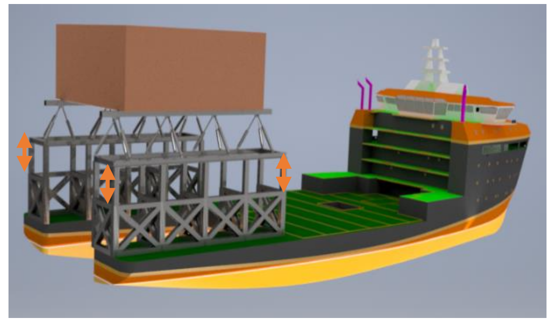

Figure 43 Height adjustable lifting frame

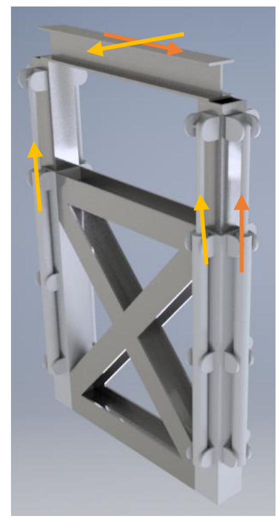

Figure 44 Extendable lifting frame

As the vessel is positioning around the jacket, the cylinders must be retracted in order to generate enough space between the topside and the lifting beams of the lifting frame. As the vessel is positioned, the lifting beam is lifted towards the topside by active motion compensation. With the topside as motion compensation reference, the lifting beam can, relatively to the topside, be held in position. By placing the lifting beam in active motion compensation mode, an ideal weight distribution from the topside to the lifting frame can be achieved. While positioned, the lifting beam is pressed against the topside by a passive force from the cylinders in order to keep the lifting beams in position.

While attached to the topside, the vessel starts de-ballasting and the load bearing capacity increases. The generated upward force from the vessel is simultaneously passed on to the topside by increasing the passive force in the cylinders. As the vessel moves, the cylinders are compensating these movements by extending and retracting. By the increasing passive force, the load of the topside is gradually from the jacket to the ship. By the added load from the topside, the movements of the vessel are becoming less. However, as mentioned earlier, Damen Shipyards cannot rule in what amount the motions are damped, so this is not included in this analysis. To prove the lifting frame is able to compensate all the movements roll, pitch, lateral motion, figure 45 and 46 are added.

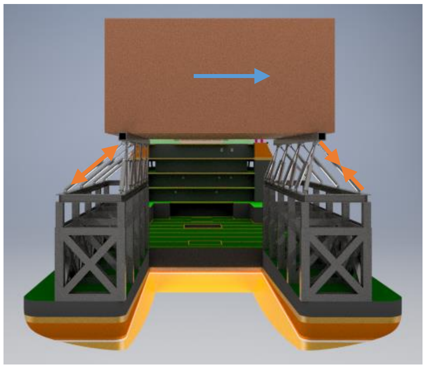

Figure 46 Lateral displacement

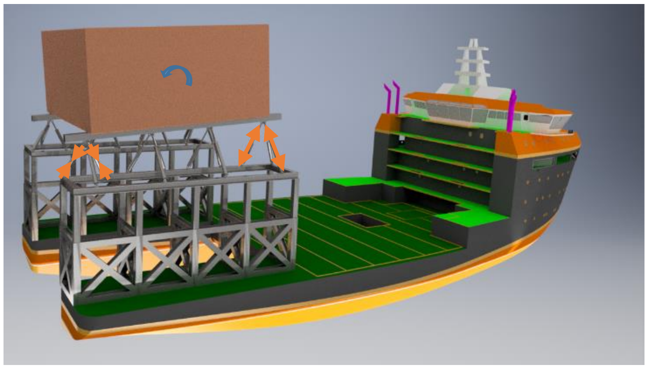

Figure 45 roll & pitch

As the load bearing capacity of the vessel reaches approximately 80 percent of the total weight of the topside, the lifting frame performs the quick lift by the use of the extendable lifting frame. The quick lift is separated in several stages.

1. As the vessel is moving down by the waves, the motion compensation cylinders are extending. At the lowest point of the vessel, the motion compensation cylinders are fixed, meaning the cylinders are not extending or retracting.
2. As the vessel is moving up, due to the fixed motion compensation cylinders, the topside is loosened from the jacket, and the draft of the vessel increases.
3. As the vessel is moving down again the quick lift is performed by the lifting frame, compensating the increased draft and safety clearance. Now, it is no longer possible for the topside to make contact with the jacket.

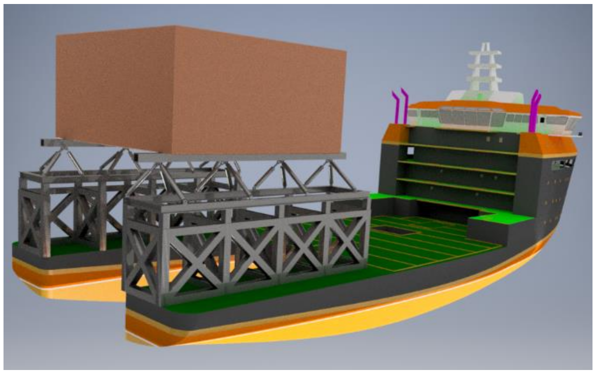

Figure 47 Sea-fastening

Before transport to shore. The topside can be sea fastened by retracting the motion compensation cylinders. The lifting beam is lowered to the fixed structure on the lifting frame. As the lifting beams are lowered, the extendable frame is lowered to its lowest position transferring the forces from the topside to the fixed steel structure. By this fixed steel structure the forces are distributed over the construction of the decommissioning vessel. The topside needs to be welded to the lifting beams where after the decommissioning vessel can sail back to shore. In figure 47, the extendable frame is lowered and the cylinders are retracted.

7. Prove to requirements

This analysis proves the designed lifting frame to the set of requirements.

- **The heavy lifting installation needs to be applicable to the designed decommissioning vessel.**
  As displayed by the figures in the previous chapter, the lifting frame can be added to the designed decommissioning vessel. The required ballast capacity, needed for lifting a topside of 1600 ton by the designed lifting frame, is sufficient. And the dimensions of the lifting frame are within the available deck space. The stability of the vessel remains secured, as well during the operation as for sailing to shore.

- **The heavy lifting installation needs to be able to decommission the topside of platforms with a fixed steel structure.**
  As described in the previous chapter, the lifting frame is able to lift topsides, standing on a fixed steel structure.

- **The heavy lifting installation must be able to operate with a wave height of 1.5 meters and a wave period of 6 seconds.**
  The lifting frame is designed to be able to compensate the motions of the vessel, which occur by 1.5 meter wave height and a wave period of 6 seconds.

- **The heavy lifting installation must ensure the topside can be sea fastened after lifting, before transport to shore.**
  The lifting beam of the topside is lowered on a fixed steel structure, discharging the motion compensation system and lowering the topside. The extendable lifting frame lowers to a fixed steel structure, discharging the drive components and lowering the topside. As the topside is lowered, it can be welded to the lifting beam.

- **The heavy lifting installation must not cause damage to the topside whereby the lifting operation is negative influenced.**
  By the active motion compensation, damage to the topside is prevented. By the topside as motion compensation reference, the lifting beam is placed with elimination of the movements of the vessel.

- **The heavy lifting installation must ensure the stability of the vessel during the lifting operation.**
  Calculations of Damen Shipyards showed the vessel remains stable for as well operational as survival conditions.

- **The heavy lifting installation needs to be adaptable to four meters height difference of the airgap.**
  By the height adjustable frame, the lifting frame can adapt to the difference in airgap by four meters, driven by cylinders.

- **The heavy lifting installation needs to be able to lift topsides with a maximum weight of 1600 ton**.
  To prove whether the lifting frame is able to lift topside by a maximum weight of 1600 ton, strength calculations must be carried out and the power requirements of the cylinders must be calculated, according to occurring forces of the calculation model. Due to the limited time for this project, strength calculations for the whole frame cannot be carried out. However, it is mentioned by the external company, the cylinders can easily compensate the occurring forces for a topside of 1600 ton. Also, for the stability calculations 200 ton was taken into account for the total weight of the lifting frame. The profiles of the lifting frame can be easy dimensioned within this 200 ton.

8. Recommendations

Concerning this project, there are several recommendations for Damen Shipyards with regard to the lifting frame for the decommissioning vessel.

8.1. Dimensions platforms

At the start of this project, information is gathered regarding the dimensions of offshore oil and gas platforms. However, during this research it turned out this information is not available on public sources on the internet. In order to gather information the operators/owners of the platforms, can be contacted. Or contact can be established with companies, currently developing or already developed decommissioning vessels or tools. By this study, the dimensions of the fixed steel jacket are of highest importance. These dimensions determines whether the decommissioning vessel with the developed lifting frame is able to decommission a sufficient amount of platforms.

8.2. Movement decommissioning vessel

The movements of the decommissioning vessel are calculated for the comparable DOC8500. To prove whether this final concept can function, the real movements of the decommissioning vessel must be calculated. At first a final weather window must be determined, in which the calculation model can be used. The calculation model calculates the operational window by wave height and period.

The movements must be calculated for a free-sailing condition and when the vessel is taking over the load from the topside. It is desirable the vertical movements of the decommissioning vessel are reduced, now the vertical displacement is 2.4 meters, which is very high. By reduced vertical displacement the less complex passive compensation can be used instead of active compensation.

8.3. Next design step

The final design of the lifting frame is developed at conceptual level, the functionality is proven in general. It is of importance a next design iteration is done for this concept to be able to prove whether this concept can work in combination with the designed decommissioning vessel. Strength calculations must be carried out and the power requirements must be calculated. These calculations can be done by the results from the calculation sheet. However, it is of importance the specific movements of the decommissioning vessel are calculated and the dimensions of the topside are determined.

8.4. Use of stamps in stead of lifting beam

Figure 48 Platform K13A, region North Sea

The lifting frame is now equipped with a lifting beam in order to generate contact with the topside. However, during this project, it turned out this is not the most ideal method. Figure 48 displays a platform, installed in the North Sea (De Manenschijn, n.d.). This particular platform requires a lot of preparations before decommissioning because of the dimensions of the jacket which are identical to the topside. Supports must be added to the topside where the lifting beam can make contact with the topside.

The gap of the decommissioning vessel is 14.2 meters wide. The lifting beam is positioned at the sides of the gap. As the topside is wider than the gap, it can be lifted with the lifting beam without major preparations to the topside. However, if the width of the topside is smaller than the width of the gap, a structure must be placed between the topside and lifting frame to transfer the forces.

To reduce the preparations to the topside, instead of a lifting beam, stamps can be used in order to generate contact with the topside. Beams are placed at the sides of the gap, able to move in longitudinal and lateral direction. As the decommissioning vessel is positioned, the stamps can be placed below the topside and generate contact. By this feature the stamps can be placed at the load transfer points with the topside, and less preparations are required to the topside.

9. Conclusion

By this project, the method for decommissioning had to be selected and developed at conceptual level in order to prove its functionality and compliance to the set of requirements.

By the set of requirements a method for decommissioning is chosen according to the established methods for decommissioning by the use of a selection matrix. This selection matrix revealed the lifting frame meets the requirements the best and is distinguished by the less sensitivity to weather conditions, the less negative impact on the stability and fastest operational speed.

In advance of the development of the lifting frame several studies are carried in order to obtain knowledge of the functions of the lifting frame. The main results from this analyses are:

- the compensation of motions of the vessel is the main function of the lifting frame in order to be able to transmit forces from the topside to the vessel and vice versa;
- the lifting frame needs to be adaptable to four meters height difference in airgap;
- and the motion compensation can only be done by active compensation.

By the results from the analysis and research to components to fulfill the functions of the lifting frame the final design consists of;

- a height adjustable frame;
- lifting beams to generate contact with topside;
- active motion compensation by cylinders;
- and a fixed structure, placed in between the cylinders and frame of the lifting frame in order to discharge the drive components and to be able to sea fasten the topside.

By the final design the functionality is proven for every phase of the decommissioning process, and the design is compliable to the set of requirements, which is proven by the functionality and several calculations.

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11. Appendixes

In addendum to this thesis three appendixes are added.

Appendix I

This appendix contains all the analysis in addition to the development of the heavy lifting construction

Appendix II

Appendix II describes the layout, functioning and calculations for the calculation model. This appendix can be used by the use of the calculation model.

Appendix III

This appendix contains information of the university as the competences for mechanical engineering and reflection to the graduation.