Preliminary design hold opening and load shifting system

Design for the Jumbo Maritime J1800-class vessels

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JUMBO

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by

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Preface

In front of you lies the report of the graduation assignment I conducted for nine months at Jumbo Maritime, located in Schiedam. This graduation assignment marks the completion of my master studies Offshore Engineering conducted at Delft University of Technology. With the report comes an end to my time at Jumbo Maritime, which I enjoyed throughout the whole process and for which I would like to thank my supervisor Kasper van der Heiden. Together with Kasper I would like to thank my fellow graduate students Joeri, Lex and Michel for the numerous laughters and coffee breaks we had through the time. In addition I would like to thank the colleagues at Jumbo Maritime for all their help and support, especially Ximena, who was a great help for all questions related to the structural analysis I conducted. Furthermore I would like to thank André van der Stap and Hayo Hendrikse for the support and tips and tricks to conclude my thesis in the set time frame. Also I would like to thank Federico Pisanò for completing my graduation committee

A special thanks to captain de Greef and the crew of the Jumbo Jubilee which gave me an unforgettable introduction into the life on board of one of Jumbo Maritime's vessels, together with incredible useful information for my thesis subject.

As this is the last part of my studying life, I would like to thank my family and friends for the support throughout the years, with a special thanks to my parents, since without their continuous support my studies would not have been possible.

Furthermore I would like to thank my girlfriend for the support during the times I struggled and for making the transition from my student life to the office life less hard.

Delft, May 2018
Sjoerd van der Meulen

Abstract

Part of the innovative character of Jumbo Maritime is a constant search into a more efficient operation of their heavy lift transport vessels. Areas of improvement involve optimizing port time. Currently Jumbo Maritime requires the onboard cranes to open the hold, decreasing effective use of the cranes. Furthermore an expensive load shifting system is needed when a piece of cargo heavier than 900 tonnes has to be loaded on front of aft of the ship, due to crane limitations.

In this report a study is done into an integrated solution for both issues experienced by Jumbo Maritime. A system that is able to open the hold and to shift a load to front and aft of the vessel. First, specifications of the new system are defined, after which a literature study is done exploring the options currently available in the industry.

After that, multiple concepts are generated, after which an integrated system is selected using a comparison method between concepts. The concept selected consists of a load shifting system using the hatches. Opening of the hold is accomplished by rolling the hatches to the aft where a stacking system is located. First the concept is dimensioned and further designed. The new design incorporates a new seafastening design of the hatches, one of the major challenges encountered in the assignment. The new design is evaluated in structural sense using the finite element analysis program ANSYS to prove its feasibility.

After structural feasibility is proven, the design is tested to its functional requirements and implications on operations for Jumbo Maritime are considered. The new system could reduce the minimum opening time of the hold by a factor two and could save around half a million euros on skidding rental costs yearly. As the system is autonomous, the risks involved for humans decrease significantly, beneficial for Jumbo Maritime's goal of zero Lost Time Injuries. Furthermore the impact on the stability of the vessel is minimal, so there is no impact on cargo loading operations.

An economic analysis is conducted to see if it is attractive for Jumbo Maritime to convert the current system onboard of the J1800-class vessels. Considering conversion rates of €4/kg for the structural conversion costs, a total conversion time of 33 days, it is proven that it is beneficial for Jumbo Maritime to convert the current vessels, with an overall value investment ratio of 1.04 and the payback time being 5.3 years.

Overall is concluded that a new integrated system for load shifting and hold opening is attractive to further investigate for Jumbo Maritime, both for their current vessels as well as new build vessels.

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Nomenclature

List of abbreviations

A.B.	Above Base
FEA	Finite Element Analysis
FEM	Finite Element Method
FID	Final Investment Decision
FPSO	Floating Production Storage and Offloading
HAZID	Hazard Identification
HPU	Hydraulic Power Unit
IT	Information Technology
JHA	Job Hazard Analysis
LTI	Lost Time Injury
LMRA	Last Minute Risk Assessment
MDHC	Main Deck Hatch Covers
MLC	Marine Labour Convention
NPV	Net Present Value
PLC	Programmable Logic Controller
PPU	Push/Pull Unit
RAV	Replacement Asset Value
RI&E	Risk Inventory and Evaluation
TEU	Twenty foot Equivalent Unit
VIR	Value Investment Ratio
WBS	Work Breakdown Structure
WSD	Working Stress Design

In loving memory of my father

1 Introduction and problem definition

1.1. General introduction

The graduation assignment is carried out at Jumbo Maritime. A study is conducted into a way to optimize port time and decrease rental costs. First a general introduction of the graduation company is given. After that the current method of operation of the shipping of cargo is introduced, necessary for understanding the problem that will be addressed in this thesis.

Jumbo Maritime

Jumbo Maritime is a heavy lift shipping and offshore installation contractor. It basically ships all the cargo that does not fit in a container and is of such a weight that it requires special attention. Currently Jumbo Maritime operates a fleet of ten vessels, all consisting of two starboard cranes, a large flush deck and a big cargo hold. Those ten vessels are from different types, developed through the years in-house by Jumbo Maritime, with a combined crane capacity ranging from 650 to 3000 tonnes. The focus of this report will be on the J1800-class vessels of Jumbo Maritime, which have two cranes of 900 tonnes capacity each. An example of such a vessel can be found in Figure 1.1. The cargo that Jumbo Maritime ships can vary from shiploaders, large reactors and turbines to pleasure craft and trains.

Figure 1.1: J1800-class vessel of Jumbo Maritime.

Furthermore Jumbo Maritime builds on a sound offshore installation track record since 2003, with two vessels capable working in dynamic positioning mode. Recent installation projects were focused on offshore wind and on mooring facilities for an FPSO unit (Floating Production Storage and Offloading).

Jumbo Maritime operates from its headquarters in Schiedam, where around 75 employees work. Besides the headquarters in Schiedam the company has regional offices all around the world, together with a big network of local agents.

Shipping of cargo

Shipping of cargo is one of the two main business units of Jumbo Maritime. The current method of operation of shipping of cargo is described for a complete understanding of the problem addressed. Cargo that is shipped by the vessels of Jumbo Maritime is either stored in the hold or put on deck, depending primarily on size and available space. If the hold has to be opened, the hold covers (hatches) have to be lifted off their place. The system Jumbo Maritime uses for opening and closing of the hold is fairly simple: the hold covers are lifted on and off the hold using the onboard cranes. There are eight hold covers to close off the hold during transit. The layout of the hatches on the main deck is depicted in Figure 1.2.

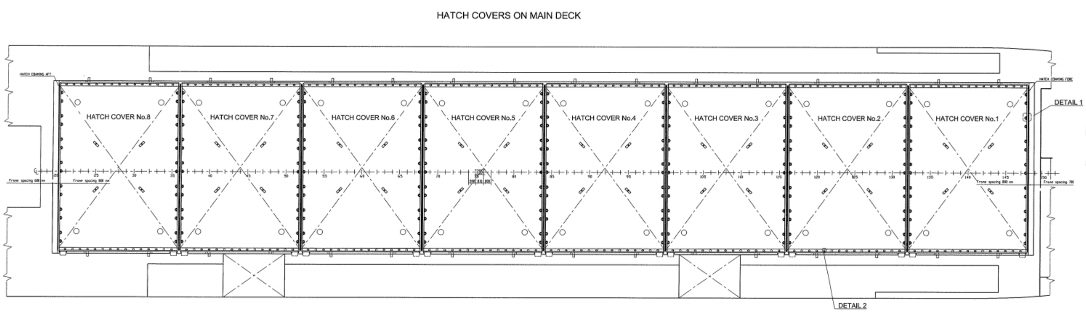


Figure 1.2: Hatch covers on main deck. Front of the ship is on the right.

As can be seen in Figure 1.2 the hatch covers are numbered, starting from the front of the ship towards the aft. These eight covers are divided into light and heavy types: numbers 4,5 and 6 are the heavy type and the rest the light type (1,2,3,7 &8). The light and heavy types differ in carrying capacity and therefore in mass. The mass of a heavy type is around 120 tonnes and of a light type the mass is around 100 tonnes. The dimensions of all the hatches is the same: 1600x12770x17060 mm (HxLxB). The details of the hatch covers can be found in Appendix A. A visual impression is given in Figure 1.3, where a hatch is visible. It has to be noted that this hatch is not in closed position, but simply stored on top of another hatch.

Figure 1.3: Side view of the hatches, humans for scale.

In Figure 1.4 the handling of a hatch can be seen. This is done using the onboard cranes, along with the help of two guides and a crane driver. In this figure also the flat top of the hatch is visible. This flush deck is important for storing the cargo on top of the hatch and foremost enables welders to sea fasten the cargo on deck, in order to prevent movement during transit at sea.

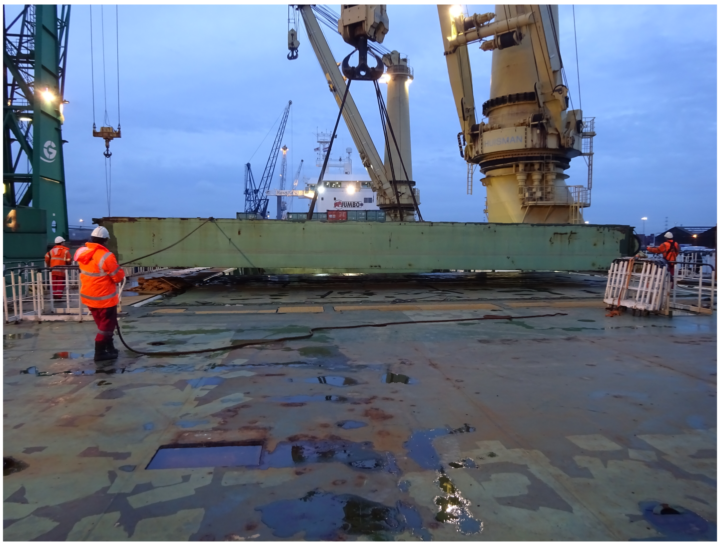


Figure 1.4: Hatch handling example.

The hatch covers are resting and secured on the coaming of the ship. The coaming is a raised section around the hold, both intended for a foundation of the hatch covers and as a mean to prevent water ingress. On the coaming several facilities are located to guide the hatches into place during lifting and to keep them in place during transit.

To keep the hatches on their place during transit at sea there are stoppers and cleats. The function of the stoppers is to prevent movement of the hatch in horizontal direction (longitudinal and lateral). The function of the cleat is to prevent movement in vertical direction, since the vertical acceleration can exceed the gravitational acceleration in transit. There is a difference between the starboard and port side stoppers. The starboard stoppers have a better fit with the hatch, to prevent movement in both lateral and longitudinal direction, whereas the port side stoppers only prevent movement in longitudinal direction. As can be seen in Figure 1.5, the fit is loose at port side to prevent the transfer of lateral forces through the hatches.

(a) Coaming with stopper and hatch on port side. (b) Coaming with stopper and hatch on starboard.

Figure 1.5: Stoppers located on the coaming (stoppers are red).

Currently, the hatches are lifted on and off in port, due to the fact that the onboard cranes can not be used during transit. Total opening of the hold takes around four hours, but depends heavily on the circumstances. To make the lifting easier and safer special guidance posts are located on the coaming to guide the hatch on the right position on the coaming. These guidance posts, together with the stoppers and cleats, are illustrated in Figure 1.6.

In order to prevent water from entering the hold, a rubber gasket is in place along the total length of the coaming. This rubber gasket is located between the coaming and the hatch cover and ensures a watertight seal. The location of this rubber gasket can be seen in Figure 1.6, exactly in the small space between hatch cover and coaming, and is indicated with an arrow. The cross seams of the hatches are covered with tarpaulins during transit.

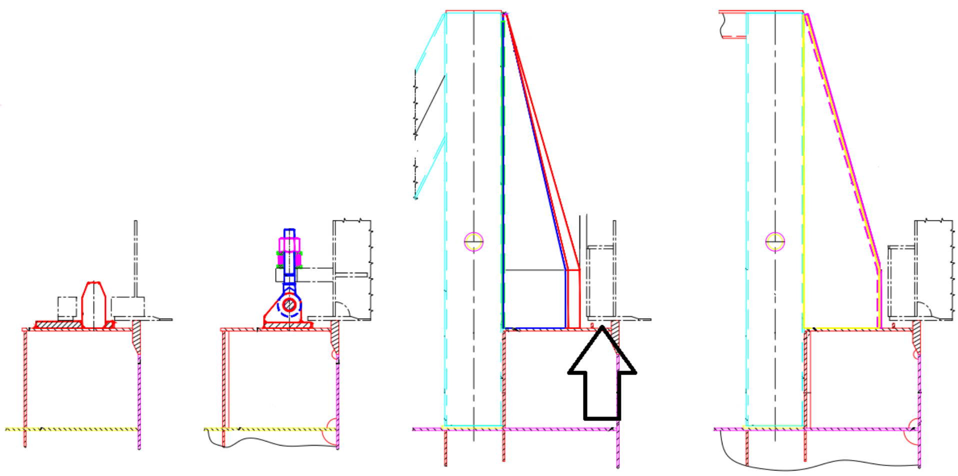


Figure 1.6: Stopper (1), cleat (2) and guidance posts on coaming. Arrow indicates rubber for weathertight closure.

A total layout of the port side and starboard coaming, with the locations of all different structures can be found in Appendix A.

Besides shipping cargo in the hold, the hatch covers can also carry cargo. This is done when there is no space in the hold or if the project cargo is too big, which happens often. An example of such cargo is depicted in 1.7. The procedure for loading cargo is much easier. Cargo is loaded using the cranes and is sea fastened on deck, either welding the cargo to the deck or using rigging/lashing.

Figure 1.7: Cargo loaded on hatch covers on a J1800-class vessel.

1.2. Problem statement

Current problems experienced by Jumbo Maritime on the J1800-class vessels during the shipping of cargo comprise basically of two parts. First, the hold is opened in port by using the cranes of the vessel. This is a time consuming and labour intensive process. Also, since it is done in port, time spent in port is longer than necessary, which increases costs. A system that replaces the current way of lifting on and off the hatches is desired.

Also the rated capacity of the onboard mast cranes can only be utilized close to the cranes, limiting the transporting capacity of the vessel, meaning that the 1800T can only be lifted in between the cranes, as is visible in Figure 1.7. To be able to load multiple heavy cargo loads on deck, a system that can shift cargo from mid-ship to front or aft (and back) of the ship is desired. Nowadays, if this is necessary, a system is rented from a third party. These systems are quite costly, reducing the profitability of projects.

With this information known, a **goal** for this thesis is defined:

"Develop and asses technical and economic feasibility of a system, or a combination of systems, for the Jumbo J1800-class vessels that enables them to shorten time spent in port, start handling cargo faster after mooring and enables the J1800-class vessels to load cargo of 1800 tons and shift it to front and aft of the ship".

1.3. Thesis approach

As this thesis comprises mostly of the development of a new design, a structured approach is required as designing itself can be a very chaotic process. This is done by using a so-called design methodology, which also stimulates the generation of out-of-the-box ideas. A design methodology is specially developed to give more structure to the process of designing: every design is different, but the process from idea to functioning prototype is largely the same. A fairly simple design methodology is the so called Engineering Design Process, an iterative process illustrated in Figure 1.8

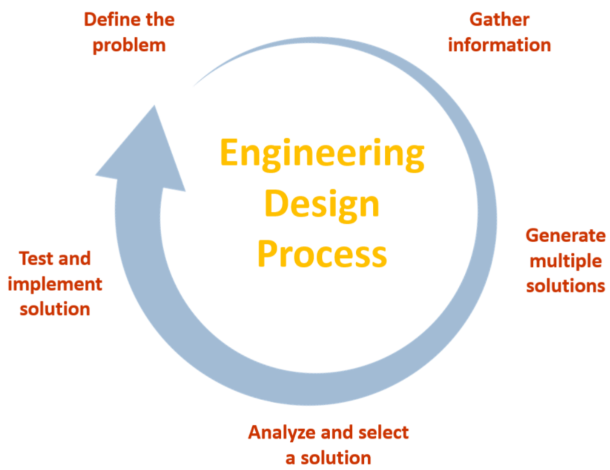


Figure 1.8: Engineering design methodology [30].

The loop depicted in Figure 1.8 will be iterated once this thesis, covering all the aspects. To further enhance the quality of the design and to elaborate more on the first two steps of the Engineering Design Process, an approach most used in the Information Technology (IT) sector is applied. This approach is depicted in Figure 1.9. The advantage of this method is that a very systematic path is taken to focus on the goal that should be achieved and the functions the user should be able to use, in order to keep the design options as broad as possible and encourage an creative solution.

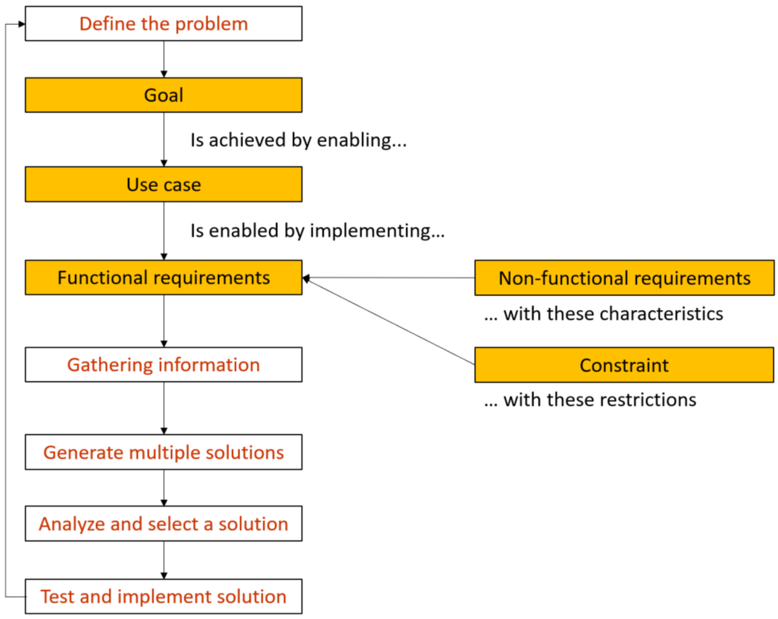


Figure 1.9: Design frame [6].

The goal defined in the problem definition fits in the design frame specified in Figure 1.9, where the deliverable is the functional requirements of the design, which are again the input for a more structured approach for the gathering of information. As said, this part is actually a sub-step of the problem definition, in order to fully understand the desires of the client and to be able to make a more successful design. Besides understanding the needs of the client, information is required about the technologies which will be used in the design. Note that the red titles in Figure 1.9 match the steps in the Engineering Design Process depicted in Figure 1.8.

The approach depicted in Figure 1.9 is explained in the following manner: The goal specified in the problem definition is achieved by enabling the following use cases of the design. These use cases are enabled by implementing functional requirements, which are characterized by non-functional requirements. The current situation will put some constraints on the new design.

Following from Figure 1.9, an important distinction between functional and non-functional requirements has to be made. A functional requirement describes what a system exactly should do, where non-functional requirements places constraints on how the system will do so. Non-functional requirements distinct themselves from constraints by the fact that non-functional requirements describe the constraints of the system itself, and constraints defined in Figure 1.9 describe constraints from the environment the system will work in. As this process is mostly used in the IT-sector, where often a specific software program is developed, there are some little adjustments. The use case of how the system is used is not literally enabling options, but by giving the options to the system and stakeholders. Important is to define the user of the system, which will not only be the crew of the Jumbo vessels, seen as the operators of the vessel, but also the customer and management of Jumbo Maritime.

1.4. Description of the design process

As is in the thesis approach explained, the structure of the report will follow the loop of the engineering design process, which is iterated once. The structure of the report is shortly listed here, with the use of the different steps in the Engineering Design Process.

Chapter 1. Introduction and problem definition
The problem and current situation of operation are described in this chapter. Together with the problem statement an introduction of Jumbo Maritime is given. The goal of the thesis is also defined here, together with the approach of the thesis and the structure of the design process.

Chapter 2. Definition of design requirements
In this chapter the use cases of the new system are defined, from which the design requirements are extracted. This is done using the path defined in Figure 1.9. The design requirements are used to test if the desires of Jumbo Maritime match the final design.

Chapter 3. Gathering information load shifting technology and hold opening systems
In this chapter an exploration is done into existing technology of the different techniques required for the design. This involves the load shifting and hold opening techniques currently used in the industry.

Chapter 4. Concept generation
With the problem defined, the needs of Jumbo Maritime clear and sufficient information gathered, solutions are generated. At the end of this chapter a design is selected with the use of multiple ranking analyses.

Chapter 5. Proof of concept
The design selected in Chapter 4 is dimensioned and quantified. After that the design is tested in structural sense using a Finite Element Analysis (FEA) program, ANSYS. The goal of this chapter is to proof that the concept is viable structural sense.

Chapter 6. Analysis of concept
The design is not a stand alone design, but will have to function in a bigger system, the operation of the vessel. In this chapter the effects of implementation on the operations of the vessel, together with the implications of the system on the current design of the vessel are examined.

Chapter 7. Economic analysis
An economic analysis of the new design is carried out to explore the benefits of the new system for current operations. The costs of the conversion of the J1800-class vessels are defined, like as the benefits. A conclusion is made regarding the question whether investing in a combined hold opening and load shifting system is beneficial for Jumbo Maritime.

Chapter 8. Conclusion and recommendations
After running through the whole design process once, multiple recommendations are given as input for a next iteration, in order to refine the design even more. Also a conclusion is given on the question if the preliminary design proofs its viability as a concept and has a chance to get incorporated in the current mode of operations of Jumbo Maritime.

2
Definition of design requirements

The first step of the Engineering Design Process is the problem definition. As said in Chapter 1, the design will be tested using functional requirements, defined by use cases which will enable user to use the system described by the goal. The purpose of this chapter is to define the use cases of the preferred system and extract from these use cases the functional requirements. These use cases are defined in order to fully fulfill the wishes of the user Jumbo Maritime and to design a system for the combined hold opening and load shifting system successfully. A focus lies on which different ways the ship now is used and how preferably the system will be used in the future, with the new system in place. After the use cases, the functional requirements will be described.Basically, these are the first two steps of the previously mentioned Figure 1.8.

2.1. Use case

A use case is defined by Cockburn, A. [8]:
"A use case captures a contract between the stakeholders of a system about its behaviour. The use case describes the systems behaviour under various conditions as it responds to a request from one of the stakeholders".

In other words it can be said that the use cases describe the different functions that a system has to be able to perform. With respect to the already defined goal the use cases describe on how the system is able to fulfill the goal set by the primary stakeholder, Jumbo Maritime. From all the use cases combined the functional requirements of the system are extracted. From these requirements the design will be tested to check if it fulfills the overall goal.

One use case will be completely written down in this chapter, with a reference to the other use cases, which are specified in Appendix B. The structure for the use cases is adopted from Cockburn, A. [8] and Bittner and Spence [5] and has the following items:

- Use case: the title of the use case.
- Scope: The intended scope of the use cases.
- Brief: A brief description of the intended behaviour of the use case.
- Precondition: The starting point of the actors and the system at the time the use case is to be started. This is because the main flow of events is of no use if the system is not in a specific starting condition [5].
- Minimal guarantee: The minimal performance of the use case.
- Success guarantee: If besides the minimal performance of the system in use extra functionalities or a better performance is guaranteed, it is deemed a success.
- Main success scenario: Also called the main flow of events. It is the section where the 'story' of the use case is told. It provides the description of how the system and actors collaborate to deliver the value promised by the use case, including all the things that can prevent the value from being achieved [5].

- Extensions: Also called the post-conditions. It is the state of the system when the use case ends [5].
- Performance criteria: To have more concrete design requirements, the performance criteria are here listed. Strength and deflection criteria are noted, with the accompanying code for the required safety. Also, more specific performance criteria can be noted.
- Operational constraints: There are always operational constraints that have to be regarded with the mentioned use case. For example the number of personnel that is available for the task or which of other operations restrict the operation described in the specific use case. The boundary conditions are mentioned here, together with the sea-states the use case is deemed to work in, which also are regarded as operational constraints.

All the use cases of the new system are listed here and can be found in Appendix B. For information purposes use case 1 is displayed in this chapter.

1. Shift cargo from midship to front or aft(and backwards) on the top deck (16255 mm A.B. or higher).
2. Open the hold.
3. Transport cargo in the hold without any water damage during transit.
4. Transport cargo on the top deck (16255 mm A.B. or higher).
5. Sea-fasten cargo on top deck (16255 mm A.B. or higher).

Use Case 1

Use case: Shift cargo from mid-ship to front or aft(and backwards) on the top deck (16255 mm A.B.(Above Base) or higher).
Scope: Combined load shift and hold opening system on the level of the top deck on board of a J1800-class vessel.
Brief: The system allows to be used in such a way that it is able to shift cargo located on the hatch cover from mid-ship (between the two cranes at hold cover positions 4,5 or 5,6 to front and aft of the ship: position 1,2,3 or 7,8).
Precondition: The hold does not have to be opened, the system is in such a way ready to receive a piece of cargo of maximum 1800 tonnes.
Minimal guarantee: The system is able to shift cargo from mid-ship to front or aft and back.
Success guarantee: Without major adjustments to current situation the system can be placed in working condition by the vessel crew and can be put into use and functions in such a time frame that is comparable with current skidding equipment, which is now hired.
Main success scenario:

1. Cargo heavier than 800-900 tonnes is loaded using both cranes, thus at mid-ship location.
2. Cargo is placed on top deck (16255 mm A.B.) at locations 4,5 or 5,6 of hold covers.
3. Vessel crew is able to shift load to positions 7,8 or 1,2,3.
4. Vessel crew is able to sea-fasten cargo (see use case 5).
5. Vessel sails to offloading location.
6. Vessel crew loosens cargo.
7. Vessel crew is able to shift cargo back at hatch cover location 4,5 or 5,6 to unload cargo using the on-board cranes.

Extensions: The system is able to open the hold after the cargo is unloaded.

Performance criteria:

- Stress: criteria according to DNV-GL regulations described in DNV-GL [14], together with the requirements of the load shifting equipment.
- Buckling checks according to Jumbo Maritime's best practice, in correspondence with DNV-GL [12].
- The system is able to open the hold after the cargo is unloaded.

Operational constraints:

- All deck hands are available for load shifting preparations.

- Sea states: no sea-state specified, as this use case is to be done in port.
- Boundary conditions:
  Vessel is moored in port.
  Vessel crew available to assist in completing use case.

2.2. Requirements of design

All the use cases combined represent all the functions the system has to fulfill. These functions result in requirements of the system: functional, non-functional. Also some constraints from the outside environment are placed on the system, which are also mentioned. The functional requirements defined in this chapter are used in Chapter 5 and 6 to see if the design fulfills the needs of Jumbo Maritime. As a summary, the design requirements for the use cases are summarized in Table 2.1, together with the non-functional requirements and constraints.

Table 2.1: Design requirements.

Use case	**Functional requirements**
1	Preparation time for load shifting: one working day in port (12 hours). Optimal maintenance scheme for Jumbo Maritime. System should be scalable, since the maximum required load is not always required. Maximum cargo load to shift on top of a hatch cover is 1800T. Strength should be examined using current regulations of DNV-GL.
2	System should be able to operate in a high level of autonomy. Flexibility should be guaranteed. Every hatch should be opened, although not all together at once. Less crane-driving hours involved than current system: 120-240 minutes requiring four workers (depending on conditions). Strength should be examined using current regulations of DNV-GL.
3	Rubber profile fitted on coaming in a gutter. Tarpaulins over cross seams of hatch covers. Securing of hatch cover on coaming in compliance with current regulations of DNV-GL.
4	Deck strength of 12 T/m^2 (hatch cover 4,5 and 6) or 8.7 T/m^2 (hatch cover 1,2,3 and 7&8). Maximum load on top deck lever for one hatch cover (12.68x17.00 m) is 1800T. To facilitate flexibility, hatch cover should be able to put overboard, so exposure to salt-water should not be a problem. Top deck level flush during transport. Strength examined according to current regulations of DNV-GL.
5	Top of hatch cover should be of a material that is easy weldable to, so S235 steel should be used. Top of hatch cover is equipped with double D-shaped recessed heavy load lashing eyes for seafastening. Seafasten hatch cover and cargo done using current regulations of DNV-GL.
	Non-Functional requirements Hatches should still be able to be lifted off. Positions of the hatches is interchangeable. System should have a service lifetime of 15 years.
	Constraints System should comply with the highest level of safety, corresponding with the company values of Jumbo Maritime. Adjustments to existing vessel structure is possible, but should be avoided where possible. System is not allowed to transfer transversal forces, no torsional stiffness available in the hatches. System has to operate without interfering with the onboard cranes structure.

2.3. Conclusion

With the use of the requirements listed in Table 2.1 the final design will be tested. As the scope of the assignment mainly focuses on opening the current hatches of the vessel, together with shifting a load using the hatches, the mode of operation of use cases 4 & 5 will not change significantly.

So, the design will not comprise of those two use cases, considering the fact that basically the same design of the hatch covers will be used. However, the functional requirements of these use cases will have to be regarded in the design, as it places constraints on the operation of the other use cases. For example the salt-water ingress requirement of use case 4.

Furthermore the constraints and non-functional requirements have to be considered, as for example safety is of high importance in the shipping and offshore industry Jumbo Maritime operates in. A newly developed system should be at least as safe as current operations, but it would be nice-to-have for Jumbo Maritime if the system is even safer, emphasizing the innovative and progressive character of the company.

3

Gathering information load shifting technology and hold opening systems

In this chapter the current technologies available for the fulfillment of use cases 1&2 are explored. A short summary of the applicable theory is given, together with available technologies and methods for shifting loads and opening holds. This is done to have sufficient information to explore the options available for the problem defined. For both technologies the current status of technology is described, together with the requirements and restrictions. Multiple examples will be given, all with their respective benefits and drawbacks.

3.1. Load shifting technology

As long as human kind has been involved in construction, shifting of loads is a major part of the process. The working principle has not changed a lot since the Egyptians used wooden rollers to transport the giant blocks of the pyramids. Basically the load shifting (skidding) technique consist of three main parts: A track over which the load is shifted (skidding track), a means to reduce the friction and a propulsion system.

Theory of load shifting

The theory of shifting a load comes down to the friction between two bodies, one being the load that is shifted, one being the body where the load is shifted over. Friction is the force resisting the relative motion of solid surfaces and material elements sliding against each other. For two solid surfaces in contact it is subdivided into two parts: static friction (non-moving surfaces) and kinetic friction (moving surfaces). This type of friction is also called Coulomb friction, as it was first described by Charles-Augustin de Coulomb, he described the frictional force between two surfaces by the following equation [46] :

$$F_f \leq \mu F_n \tag{3.1}$$

Where

- F_f is the friction force exerted by each surface on the other. Parallel to the surface, opposite to the direction of the net applied force.
- μ is the coefficient of friction, which is an empirical property of the contacting materials.
- F_n is the normal force exerted by each surface on the other, directed perpendicular (normal) to the surface.

The difference between static and kinematic friction is expressed in the coefficient of friction μ. The static friction coefficient is higher than the kinematic coefficient due to surface roughness. Two solid surfaces in contact are 'locked' into each other in a static situation. The difference between the static and kinematic friction is illustrated in Figure 3.1, where at point A the maximum static friction is reached, after which the object starts moving. The friction coefficient for sliding objects is lower than the static part, so the friction force decreases to point C.

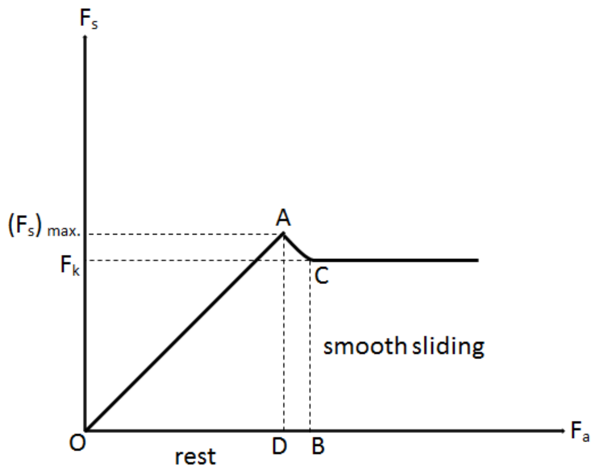


Figure 3.1: Standard friction model [9]. F_s is static friction force, F_a is the applied force on the body and F_k is the kinematic friction force.

So, in order to propel a body over a certain surface, the applied propulsion force has to exceed the maximum static frictional force $F_s max$. If the body starts moving, the frictional force will decrease to F_k, in this way the body will accelerate to a certain forward speed. If the movement is discontinuous, the static friction force has to be exceeded every moving step.

Propulsion force

The propulsion force for the load shifting mostly comes from either a hydraulic push/pull unit (PPU) or a strand jack. Both systems utilize the same principle, propulsion in the manner of a caterpillars walk: extending a hydraulic actuator by clamping onto the skidding track in case of the PPU or by clamping onto the strand in case of a strand jack. It has to be noted that the movement is not continuous since the hydraulic cylinders have a limited stroke and have to retract, i.e. a caterpillars walk.

(a) Push pull cylinder [26]. (b) Strand jack used for skidding [7]. (c) Winch [15].

Figure 3.2: Propulsion techniques for load shifting.

For extremely low frictional coefficients or small propulsion forces, also a winch connected to a cable could provide the propulsion force required for the motion. A major advantage of this system is the fact that the motion is continuous and thus much faster.

Skidding track and friction reduction

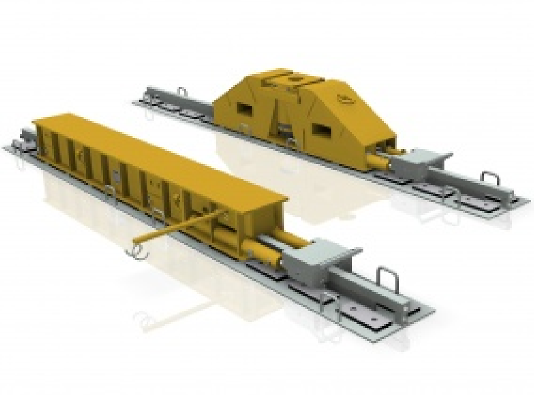
As said, a load shifting system consists of a propulsion force, together with a certain skidding track and some sort of friction reduction technology. Often the friction reduction technology and the skidding track are integrated and thus both parts are considered together. The friction reduction technology is focused on bringing down the required propulsion force by reducing the friction coefficient. It comes down to the fact that a low propulsion force enables the system to be as small and cheap as possible. Three widely used technologies to reduce friction are:

- Usage of Teflon pads

- Usage of rollers
- Usage of air cushions

Teflon pads

The most widely used method to reduce friction in a shifting operation is the use of Teflon pads between the two surfaces. The load shifting system usually consists of a load spreading device, a skidding track accommodated with Teflon pads and a pushing-pulling device, as illustrated in Figure 3.3b. The load spreading device can consist of a simple beam or a skid shoe. The propulsion force can also be supplied by a strand jack. A skidding shoe consists of a hydraulic jack which is able to lift the load from its supports. A skidding beam already has the load on located on the beam. Both load carrying devices are depicted in Figure 3.3



(a) Skidding beam (Left) and skidding shoe (Right) [17].

(b) Skidding track accommodated with Teflon pads and push/pull cylinders [41].

Figure 3.3: Teflon based skidding operation.

The DNV-GL code advises friction coefficients for Teflon against steel for static cases at 0.25 and for kinematic friction at 0.10 [61]. It has to be mentioned that the friction coefficient highly depends on temperature, the load and the surface quality and thus is highly case depending. Mammoet Europe B.V. considers values for Teflon friction as low as 0.1 for static friction. For all cases it is assumed that the surfaces are sufficiently greased , as this further reduces friction [31].

Rollers

Another way to reduce friction between two contact surfaces is to use small rollers. This either are static rollers, working like a conveyor belt, or rollers attached to the moving load, like wheels on a car. An advantage of the rollers over Teflon pads is the low friction coefficient: 0.02. Also both static and kinematic friction coefficients are equal, so no break out force is required to push the load. Furthermore, there is no grease required. A drawback however is that the rollers need to be installed with high precision to prevent the load running of the track and the chance of collisions is high even with the smallest deviation, as there is a low tolerance for deviations in the system. The most compact way to be able to shift the load over a track is to have the rollers attached to the cargo. A supplier who produces such a system is Hilman [25] and such a system is illustrated in Figure 3.4

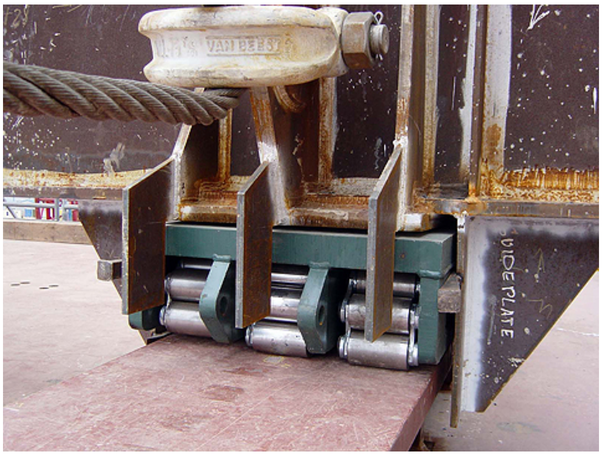


Figure 3.4: Hilman rollers propelled by a strand [57].

Air cushion

This heavy load shifting method utilizes an air cushion between the load and the sliding surface, reaching a very low friction coefficient, as low as 0.01. The air cushion is created by blowing high pressurized air in a sealed chamber between the skidding shoe and the surface below. The tolerance for straightness of the skidding track is higher than for the rollers, but there are some drawbacks to this system as well. First of all the system is prone to air leaks and does not provide a back up system. When the air pressure vanishes in case of an air leak the skidding operation has to be aborted. Furthermore the skidding means are square, which would be disadvantageous in space restricted cases. A supplier of the air cushion system is Hebetec, the system is illustrated in Figure 3.5 [24].

Figure 3.5: Hebetec system [2].

Summary of different load shifting systems

A short summary of the different load shifting systems is given in Table 3.1. The summary is made of systems that are already available from different suppliers. It is made in order to have a quantitative way of comparing the different systems with respect to carrying capacity and respective loads on the substructure. The overall dimensions of the load shifting methods are a good indication for suitability for Jumbo Maritime, as the overall available space in some areas is limited. From the overall dimensions the line loads and line pressures are given. Also it is indicated if a PPU is incorporated in the system. This is often the case and can save a separate propulsion system.

Table 3.1: Load shifting methods comparison [4] [39] [17] [25] [24].

Supplier	Load (tonnes)	Width track (mm)	Length system (mm)	Line load (kN/m)	Line pressure (kN/m^2)	With PPU? [Y/N]
ALE	300	560	7734	380	680	Y
ALE	500	800	9980	491	615	Y
ALE	650	700	9760	653	933	Y
Mammoet	200	420	6000	327	779	Y
Mammoet	600	680	9732	605	890	Y
Mammoet	700	840	5350	1234	1528	Y
Enerpac	125	400	2690	456	1140	Y
Enerpac	250	600	2784	881	1469	Y
Hilman	300	273	864	3406	12477	N
Hilman	500	508	864	5677	11175	N
Hilman	700	899	864	7948	8841	N
Hebetec	250	1147	7497	327	285	Y
Hebetec	385	1147	11605	325	284	Y

The rated loads and dimensions mentioned in Table 3.1 come from brochures of the respective suppliers. Clearly visible is that the Hilman rollers have a high carrying capacity with regards to the footprint, resulting in a high pressure distribution in the substructure. The Teflon skidding systems (ALE, Mammoet and Enerpac) all have comparable line loads, whereas the Hebetec system has a lower carrying capacity.

It has to be noted that the Hilman rollers are not standard supplied with a push-pull unit, resulting in a high line pressure. As all the other systems have an incorporated PPU, this results in an relatively lower line pressure, as the PPU takes up space. With selecting an skidding method, this has to be taken into account.

3.2. Hold opening systems

Holds are covered by hatch covers, which have one main function: weathertight closure of the hold. Besides this main function, other functions are possible, like a load carrying function. The hatch covers of Jumbo Maritime are also suited for that function, a lot of cargo is shipped on top of the hatches. There are many different kinds of hatch covers and many different ways of opening the hold. From Chapter 2 was concluded that the type of the hatch cover Jumbo Maritime uses will stay the same, so that the distinction is only made between the way of opening. The division is made into the following categories:

- Folding hatch covers
- Lift-away hatch covers
- Rolling hatch covers

Folding hatch covers

Folding hatch covers consist of two hatches which are connected by hinges and form a folding pair. This folding pair is folded by means of hydraulic power, which is exerted on the leading hatch of the pair. When the leading hatch is lifted by the hydraulic cylinder, the trailing hatch follows. This hatch is fitted with wheels and is able to roll over the coaming of the ship. Based on the vessel, multiple folding pairs of hatch covers are possible. Usually the folding starts at the front and aft of the vessel, after which the other pairs are rolled to that position and also are folded. In that way, multiple folding pairs are possible on board of a vessel. With hatch storage both on fore and aft position of the ship, the number of panels that can be folded can run up endless, but is usually limited to 12. There are multiple ways of operating the folding covers, often the end covers are connected to the ship with hinge arms rigidly connected to the covers, see Figure 3.6. The other pairs of hatch covers are normally lifted by means of a bell crank that is located outside of the coaming and grabs onto the hatch cover.

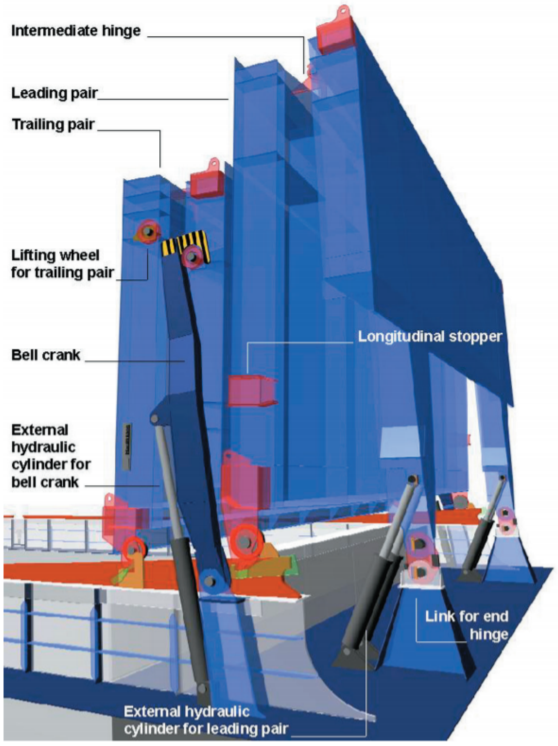


Figure 3.6: Folding hatch covers leading and trailing pair [33].

An advantage of this way of hold opening and closing is the small storage area required for the hatches. Also there is the possibility to already open the hatches when sailing, without the requirement to wait to open the hold after the vessel has been completely moored. A disadvantage is that the horizontal forces on the vessel during folding are of considerable size, especially with increasing hatch cover weight, which results in high capacity hydraulic cylinders and extensive steel construction work on board of the ship.

Lift-away covers

Lift-away covers are the most simple option for cargo vessels. The hatch covers seal the hold weathertight during transit, and when needed the hold is opened by lifting the covers away, usually using the onboard cranes of the vessel. This type of hatch covers is currently in use by Jumbo Maritime. The covers are usually stored on other hatches (space permitting), overboard in the water or on the quayside. This system offers a total opening of the hold, where other systems can't offer a total opening of 100 %. The big downside of this system is that the opening of the hold has to happen in port, since it is not possible to operate the cranes during transit. Also, the lifting and storing of the hatches is quite labour intensive. The lift-away covers enable huge flexibility in loading and discharging cargo and partial opening, the biggest advantage of this system. Lift-away covers are usually fitted with some sort of guiding device to ensure proper placement onto the coaming and to avoid unnecessary damage to the vessel and hatch.

Rolling hatch covers

Rolling hatch covers are hatch covers that are able to roll over the coaming, after releasing the necessary seafastening. This can be in longitudinal direction of the ship (front - aft), or in transverse direction of the ship (port side - starboard). Only rolling is not enough to open the hold, so the rolling hatch covers are divided into several subcategories based on the opening of the hold. These categories are:

- Piggy-back hatch covers
- Stacking hatch covers
- Side-rolling hatch covers

Piggy-back hatch covers

Like folding hatch covers, piggy-back hatch covers are stored in pairs. One hatch cover is lifted, usually by means of hydraulic power, after which the second cover is rolled under the first cover, as illustrated in Figure 3.7. The main advantage is that the system is quite simple as only one vertical movement is required. The biggest disadvantage is that the hold is only being opened for 50 %. When both covers are equipped with wheels or means to roll over the coaming, it is still possible to slide the covers back and forth and fill the hold beneath the covers. It is especially useful for vessels transporting standard sized cargo and do not need the full hold to be open at the same time.

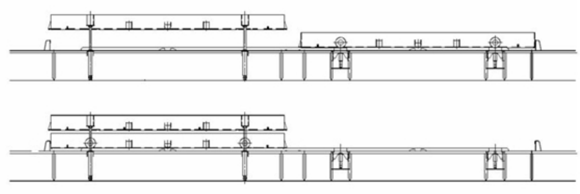


Figure 3.7: Piggy-back hatch cover pair [52].

Stacking hatch covers

A possible solution to increase the fraction of the hold that is open, is to stack more than two covers on top of each other, the so called stacking type. The working principle is basically the same as the piggy-back hatch cover. The stack is lifted to the required height and a cover is slid under the lifted stack. After this action, the hydraulic cylinders are retracted and the cover that had been slid under, is now the cover that is being lifted. Depending on the strength of the hatch covers and the capacity of the cylinder, multiple hatch covers can be stored in this way. The biggest advantage of this system is that the fraction of the opened hold can be increased until the point where only one hatch is still closed. Also, compared with folding hatch covers the system is more simple and the horizontal forces on the coaming are negligible. When there is a need for a total opening of the hold, this system can also be combined with the lift-away system so the total hold can be opened.

Side-rolling hatch covers

Side-rolling hatch covers are opened and stored in the transverse direction of the ship. Often this type of hatch cover consist of two panels, both sliding to one side of the ship. The system is mainly used on very large ore carriers, where total hold opening is not required and where is sufficiently free deck area is available. The system is displayed in Figure 3.8

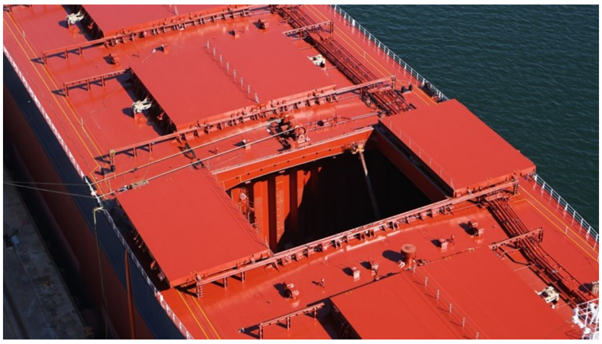


Figure 3.8: Side-rolling hatch cover [34].

As for Jumbo Maritime, there are two cranes located at starboard side of the ship, preventing the applicability of the side-rolling hatch covers to both sides. Rolling all the hatch covers to port side would theoretically be possible, but as this requires such a heavy modification to the ship design that it is not considered. Besides the heavy modifications this would also result in loss of lifting capacity, as the inside of the voids are filled with ballast tanks. Furthermore rolling to port side would result in the fact that loading from port side is impossible.

Summary of hold opening systems

In Table 3.2 a short summary of the different hold opening systems is given together with a verdict of applicability for Jumbo Maritime.

Table 3.2: Summary of applicability of different hold opening systems.

System	Applicable
Folding hatch covers	Yes
Lift away covers	No
Piggy back hatch covers	No
Stacking hatch covers	Yes
Side-rolling hatch covers	No

From Table 3.2 is concluded that there are two options to be considered for the hold opening system, being the stacking hatch covers and the folding hatch covers. The other three types have too many drawbacks to be considered a serious option. For the lift away hatch covers the cranes have to be used. As the goal of the new design is to minimize port time, using the cranes is not considered an option. Piggy back hatch covers allow only a 50% of the hold to be opened, which is not enough for big pieces of cargo. An extension of the piggy back covers, the stacking hatch covers are applicable, as the fraction of opened hold can increase significantly. At last the side rolling hatches will cause too many structural changes as well as these hatches will have to penetrate through the void, resulting in loss of loading capacity, loss of the possibility to load from port side.

4 Concept generation

Now that all technology available for designing a system that is able to fulfill the requirements is explored in Chapter 3, concepts are generated. Inherent to designing is the fact that there is not a single right answer. For all problems there are several options who might all be as good, as long as they fulfill the requirements specified in Chapter 2. In that chapter it has also been discussed that the design will be based on use cases 1 & 2. Use case 3 will be based on the design of the new system, as there are a lot of options available to close off the hold watertight.

The designs will only differ in the way of how use cases 1,2 and partly 3 are solved. The main difference is how the load shifting is done regarding the hold opening. Two options are available here, incorporate use case 1&2 in one complete system, or separate use cases 1 and 2 and develop a system for hold opening and have a modular system for skidding.

Within this distinction there are still a lot of different solutions available, which are discussed in the following sections. With the knowledge from Chapter 3, an already predefined selection of concepts is made. Within every decision that is made, two or three options are available. These options are ranked relative to each other, after which the best option is chosen. The ranking criteria are different from the design requirements stated in Chapter 2, as all solutions can achieve a certain base level, in which the design requirements are met. However, some solutions perform better, so in a ranking analysis this will be shown clearly. The comparison will be based on the Standard Competition ranking, in which concepts are ranked based on their fulfillment of the criteria, but it is possible to have an equal score. Standard competition is also called the '1224' ranking, in which equal concepts can receive the same score, after which a gap is left. In this ranking the lowest score is the better option, as score 1 is the best achievable score [22]. The criteria that will be used in the ranking comparison for the total system are:

- **Induced forces of both concepts**: Both concepts will have their own unique way of transferring the involved forces into the substructure, being the vessel. An estimation is made of the forces involved, the magnitude and the direction. The concept that has the lowest force, with the primary direction being vertical, is favourable, as relatively low forces imply an efficient design. The substructure transfers the forces in mostly vertical direction to the environment, being the water underneath the vessel.
- **Flexibility of the concept**: The grade of flexibility of the system to scale up or down or the ability of handling the two main functions of the new system in combination. A flexible system would give the user the ability to switch between two functions rather easily, with small adjustments. A so-called flexible system should be able to handle the multiple functions quite easily.
- **Capital costs**: A successful design is highly depending on the amount of resources spent. Costs can be divided into two parts, operational costs and capital costs. Operational costs focus on the costs involved in maintenance and operation, whereas the capital costs consider the expenditures upfront: engineering, acquisition of parts and installation. The capital expenditure will be estimated using the following criteria:
  - Engineering involved, for example the complexity of the system. A highly complex system, with a lot of new techniques, will require a high amount of engineering.

  - Number of parts involved, including standard parts. A high number of parts implies higher costs, although a low number of highly specialised parts can be regarded as expensive.
  - Amount of modifications required to the vessel.

  The operational costs comprise the cost of operations and the maintenance costs. These two parts will be regarded in the following criteria and will not be a part of this cost estimation, as it is per definition different.
- **Maintenance**: Maintenance requirements will have a large impact on the daily operations on board of the vessel, as well as the costs that are involved. The assumption is made that both concepts will be designed in such a way that the primary functions of the system will be fulfilled, but will be accompanied by a certain maintenance requirements, the preventive maintenance. Together with the preventive maintenance, irregular maintenance will have to be carried out, whenever a part breaks during operation. Regarding the fact that more moving parts involved in operation of the concept will mean more preventive maintenance, but also gives a higher change on irregular maintenance, the concept with the least moving parts involved will be preferred.
- **Impact on operations**: Impact on operations can either be positive, in a way that a lot of operational time is saved, or negative, when a lot of operational time is added. Addition of operational time is defined as the time added in the critical path of operation. If the system is able to operate in a high level of autonomy, personnel is able to perform other tasks, and thus no operational time is added. A high impact on operations could also be not being able to open all the hatch covers. Furthermore the impact on operations is estimated in the way of how the new system can be used in cooperation with other functions of the vessel.
- **Impact on ship design**. Although already mentioned in the capital costs, an extra note is made. A lot of modifications required to the current structure of the vessel does not only mean a high up-front expenditure, but also means that some other operations will have to change. For example, the hatches are sometimes used as a load spreader for a heavy project cargo load. If the impact on the ship design is such, that the hatches can not be used in that function, it is regarded as negative.
- **Mobilisation time**: As time spent in port is of high importance, the mobilisation time is regarded separately. Mobilisation time is defined as the amount of time required for the several systems to be ready for operations. Also the amount of time involved in switching between the two main functions will be covered.

It has to be noted that the ranking is based on the **lowest** score being the **better** option.

4.1. Hold opening system

The most used function of the new system will be the opening of the hold, as this is almost every port visit necessary. Also, since the hold opening system has influence on the second function of the system, the shifting of the load, this is the first thing that has to be decided. Analysis in Chapter 3 has pointed out that there are two options, folding or stacking. The first decision that will be made is between those two hold opening principles.

Description of both concepts

Folding

In the folding concept the hatches are paired, creating four pairs of two hatches. The hatches will be folded together, in a way that an initial deviation is imposed by some sort of lifting technique, which most probably is a hydraulic cylinder. The hatches will be rotated almost 90 degrees, storing them in a nearly vertical, rotated position.

Stacking

The hatches will be stacked vertically, by some sort of lifting technique, most probably hydraulic cylinders. The hatches will have to be able to travel over the coaming towards the stacking location and will be stored there in a near horizontal position.

Ranking analysis

Results of the comparison of the two hold opening principles can be found in Table 4.1.

Table 4.1: Ranking analysis stacking and folding technique.

	Stacking	**Folding**
Forces	1	2
Flexibility	1	2
Capital Costs	1	2
Maintenance	2	1
Impact on ship design	1	2
Impact on operations	1	2
Mobilisation time	1	2
Total	**8**	**13**

From Table 4.1 is concluded that a stacking technique for the hold opening is preferred. The explanation for the different scores depicted in Table 4.1 can be found in the following paragraphs.

Forces

Analysis of the opening sequence of a folding type hatch cover pair has pointed out that the horizontal forces play a significant role. In Appendix D the amplification factor for the horizontal forces is plotted. It can be seen that the horizontal forces are a very large amplification of the vertical gravity force. As the hatches weigh 120 tonnes each, these forces will be extremely high compared to the forces involved in stacking and thus are regarded very impractical, since a lot of steel would have to be added to cope with the involved forces. The working principle of folding hatches requires a certain deviation of the hatches before the horizontal motion can start, as it would be more of a buckling phenomenon than a controlled folding motion otherwise. To reduce the horizontal forces in this motion, the deviation should be as high as possible. So in order to reduce the horizontal forces, large cylinders are necessary to put the hatches in the desired position. To have an amplification factor of 5 for the horizontal force compared to the vertical force, an initial angle would have to be 10 degrees. This would mean an initial vertical displacement of 2.2 meters, which is quite impractical. On the other hand, stacking the hatches would only involve vertical forces, as the motion is only vertical, without a rotation.

Flexibility

The stacking motion is purely a linear motion of the hatches over the coaming, combined with a vertical motion at the stacking location. The folding motion is a rotational motion of the hatches around its endpoint, whether or not combined with a linear motion of the coaming towards the folding location. The motion involved in folding and skidding a load is fundamentally different, hampering the flexibility of the system to be used in a cooperative way. This in contrast to the motions involved in stacking, as both are linear over the coaming, creating an opportunity of cooperation.

Furthermore, once folded, the hatches are either stuck between, in front or behind the cranes. This is because the cranes are tilted inwards about 2.3 meters above the hatches. A pair of stacked hatches is able to travel along the whole length of the hold, but a pair of folded hatches will have to be put down first, before being able to travel over the whole length. This fact will be important in the case the hold beneath the hatches needs to be opened for cargo loading.

Furthermore, the fact that there are three heavy duty hatches and five normal hatches, the interchangeability in stacking is higher due to the fact that there are no folding pairs, but just single hatches.

Capital costs

Due to the high forces involved in folding, a high amount of modifications to the vessel will be required, as it is currently not designed for this purpose. Also, due to this fact, a large number of heavy, highly specialized parts have to be fabricated to make the folding possible. For example, big hydraulic cylinders for the initial deviation, bell cranks for the folding motion and large skid shoes that are able to lift the hatch of the coaming and can withstand the high horizontal forces.

The number of parts involved will be largely the same, as both techniques require the hatches to be raised of the coaming and onto a four points support. The folding hatches will all have their own dedicated device to be able to fold and secure the hatches, whereas the stacking technique requires one (or two) stacking locations, with a central system.

The engineering involved in the folding will most probably be higher, due to the higher forces, combined motions and individual systems.

Maintenance

The folding technique consists of a hinged connection between the two hatches and for the two hatches 4 supports, which are able to move. Together with these hatches, an initial lifting device is required, together with a device that provides the folding motion. The stacking technique consists of four supports for the hatches, which are able to move. At the stacking location a lifting device is present. The maintenance requirements for the stacking technique will probably be higher, due to the fact that double the moving supports are present, together with a heavy duty lifting device, which depends on the number of hatches to be stacked.

Impact on operations

Both systems can be designed in such a way that the operation is autonomous, so time spent in the critical path of being in port can be minimized. Opening the hold before entering the port has to be considered as an option, to have an high positive impact on operations. As stacking is very scalable, the sensitivity for bad weather is much lower, due to the fact that folding involves a high center of gravity of the hatches, together with a moving vessel could be unstable sooner. The positive impact of stacking could be higher. Also, partial opening could be significantly easier in stacking, due to the possibility of multiple stacking locations on the coaming, whereas folding is mostly done only at the front or aft of the vessel.

Impact on ship design

The hatches being paired together in folding means a lower flexibility in using the hatches as load spreaders, as the hatches first need to be disconnected. Also, due to the higher involved forces, the support structures on the vessel will probably be bigger. Considering this fact, the chance of interfering in other critical vessel infrastructure is higher with a bigger support structure.

Mobilisation time

Due to the fact that skidding and stacking could be complementary in mode of operation, mobilisation time of a load shifting system after using the stacking system is estimated lower than going from a folding system to a load shifting system. The difference between a folding system and a stacking system being ready for operation is regarded negligible.

4.2. Load shifting system

Having selected the technique of the hold opening system, a load shifting system has to be selected for the second function. Also, this technique has been studied in Chapter 3. A ranking analysis will be carried out between the different techniques. The forces, impact on ship design and impact on operations are left out of the analysis, as the forces are already accounted for in a more detailed way, as well as impact on ship design, with the dimensions and requirements of the skidding track. The impact on operations is for all different concepts the same, as the working principle is the same. Adding to the criteria mentioned at the start of Chapter 4, some other, important criteria for the skidding system are added. The added criteria are listed.

- **Carrying capacity**: The ability to carry high loads. All skidding systems can be designed in such a way that it is able to carry the load imposed, although an already designed skidding system is easier to use for the design. Furthermore the scalability of the carrying capacity is important, as the maximum load is not always required to be skidded.
- **Required width**: The required space for the skidding system is of importance when it is decided to incorporate the system in the structure of the vessel. The available width of the hold is often the condition which decides if a specific piece of cargo is able to be transported. If the skidding system requires a wide surface, the available width will be influenced.
- **Height**: Besides required width, the height of the system is also of importance. A higher skidding system means a higher centre of gravity of the project cargo with respect to the origin of the vessel. The higher center of gravity has its impact on the overall stability of the vessel and thus on the operability.
- **Tolerance to deformations of skidding track**: Deformations are expected on board of the vessel, as deformations provide strength required for carrying the load shifting technology. Tolerance to these

deformations can either be in vertical direction as in longitudinal direction. Load shifting technologies could have a low tolerance in vertical deformation of the skidding track, due to the loss of contact between skidding track and skidding technology. Also the skidding track could deform in longitudinal direction, resulting in relative displacements between consecutive parts of the skidding track. Both those deformations are accounted for in this criteria.

- **Friction coefficient**: A very important factor in the design of a skidding system as this determines the required propulsion force. A low friction coefficient means a low propulsion force, which is easier to supply. Also, a low propulsion force could mean a relatively high propulsion speed.
- **Requirements skidding track**: Besides the straightness of the skidding track another requirements can be set, for example hardness of the track or air tightness.
- **Redundancy requirements**: The amount of redundancy measures incorporated in the design. Hydraulic cylinders could require redundancy requirements due to the chance of pressure loss, more of those factors could be applicable.

Ranking Analysis

In Table 4.2 the results of the ranking analysis conducted for the selection of a skidding system can be found. Concluding from Table 4.2, the best option for the skidding operation are the rollers, having the highest score. Most important advantage of this system is the high concentration of forces, in other words, a small design with a high carrying capacity. The system of rollers selected will be the mobile type, less rollers are required this way and not the whole coaming will be covered in rollers, enabling more options for seafastening. The Hilman types will be used as they have the lowest relative score compared to the other options.

Table 4.2: Ranking analysis different skidding systems.

System	**Teflon**	**Rollers**	**Air cushions**
Carrying capacity	1	2	3
Flexibility	3	1	2
Costs	1	2	3
Maintenance	2	1	3
Mobilisation time	3	1	2
Width	2	1	3
Height	3	1	2
Tolerance to deformations of skidding track	1	3	2
Friction Coefficient	3	2	1
Requirements skidding track	1	1	3
Redundancy requirements	2	1	3
Total	**22**	**16**	**27**

Carrying capacity

Most important factor of the system is the carrying capacity, as the maximum load is 1800-1900 tonnes for skidding. Results in Table 3.1 show that a combination of all the systems should be able to carry the load, but the highest rating is with the Teflon based suppliers.

Flexibility

With a very high rated capacity, the Teflon based skidding systems are the least flexible in scaling up or down from the load, whereas the rollers and the air cushions can more easy scale from a small load to a high load by just adding carrying units. The rollers are easier to install than the air cushions, who require the air pads, so the rollers are a bit more flexible than the air cushions.

Capital costs

The air cushions are not a widely used skidding system, adding development costs. Also, being a relatively new and complicated technology, the engineering costs can be quite high. Together with that, the modifications to the vessel are extensive, with an air tight skidding track.
As the Teflon based skidding systems require less parts for a high carrying capacity, the capital costs will be lower in the number of parts involved. Also the engineering can be quite simple, as the working principle is quite simple. Being relatively large, the amount of modifications can be quite significant.

The rollers on the other hand involve a lot of moving parts for a high load, adding capital costs. Being a bit more complicated than Teflon skidding system, the engineering involved will be slightly higher. Being relatively small, the concentration of forces is higher, adding to the modifications of the vessel.

Maintenance
The Teflon based skidding systems require constant maintenance of the skidding track, since it requires lubrication in order to further reduce the friction between track and skidding shoe or beam.
The rollers on the other side consist of a high number of rollers, with a high chance of one of them failing. This being a high maintenance requirement, the system is also highly scalable, meaning that the number of hours an individual roller will be used is small, as the amount of hours ultra-heavy objects are shifted is small. The air cushions require an air-tight skidding track, which has to be maintained. Together with that the system is complicated and has a lot of parts that can fail, being the air supply or the cushions itself.

Mobilisation time
Being highly scalable, the mobilisation time of the rollers is high, when combined in two systems. With a big and heavy support, the Teflon based skidding system is harder to handle, adding installation time. With a higher weight of the air cushions compared to the rollers, the mobilisation time will be slightly higher for the air cushions.

Required width
The width of the rollers is the smallest, followed by a Teflon based skidding system, which again is followed by the air cushions.

Required height
The required height for the Teflon based skidding systems is relatively high, consisting either of a skidding shoe or a skidding beam with hydraulic cylinders. The rollers are very compact and thus also quite low. The air cushions are located in between the two.

Tolerance to deformations of skidding track
The rollers require full contact of all the rolls with the skidding track, meaning that a large deformation can cause one roller to lose contact and wearing or failing the other individual rolls. Loss of contact of one roll could happen quite soon as the individual rolls have a diameter of 14 mm and the roller itself is also 500 mm. The air cushions on the other hand have an air cushion which is able to cope with deformations in the order of several millimeters. The Teflon pads have the highest tolerance to as the Teflon pads can ensure full contact of the shoe with the pads, being a sort of deformation absorber.

Friction coefficient
The friction coefficient of the air cushions is the lowest, being 0.01. The rollers have a friction coefficient of about 0.05, whereas the friction coefficient of Teflon pads runs up to 0.2, depending on the conditions.

Requirements skidding track
The rollers require a hard steel subsurface, being steel grade S690. The air cushions require an air-tight subsurface and Teflon based skidding system requires the Teflon pads. Teflon pads are regarded more practical than an air-tight track. Also, a high tensile steel track is regarded more practical than an air-tight track.

Redundancy requirements
Being highly scalable, the rollers have the smallest redundancy requirement, as the rollers are load tested over their own capacity. Teflon based skidding systems have this as well, but being bigger, the required overcapacity if one fails is much larger, so more stringent redundancy requirements are applied. The air cushions have the largest redundancy requirements, as the sliding technology is not mechanically dependant, but also depends on air supply, meaning extra equipment necessary to ensure smooth operation.

4.3. Integrated system or two separate systems

The next decision that has to be made is if the system is made as a whole, integrated system or that the functions are dealt with separately. It is basically a choice of skidding with the hatches, or a skid-way integrated in the hatches, i.e. the hatches are only the foundation of the skid track.

Description of both concepts

Integrated hold opening and load shifting system

The integrated hold opening and load shifting system is a system that combines both functions and can be scaled up or down regarding the requirements of the project at hand. Load shifting and hold opening is done over the coaming of the vessel, over the whole length of the ship. The hatch is the foundation of the project cargo, as is normal during shipping and the skidding track is located beneath the hatch.

Separated skidding and hold opening system

In this concept both functions are separated. The hold opening is done using a separate shifting and stacking system. If the hold is fully closed, a skidding track is installed over the hatches, over which the load is shifted. The hatches are the foundation of the skidding track, as the load rests on the skidding track. Since the skidding system is not always necessary and can be containerized, it could be shipped to one of the four vessels, wherever it is needed.

Ranking Analysis

The results of the ranking analysis can be found in Table 4.4, covering the criteria listed at the start of this chapter. As is concluded from Table 4.4 the integrated system is favourable, as it has the lowest relative score, being the better option.

Table 4.3: Ranking analysis integrated and separate system.

	Integrated system	**Seperated system**
Forces	1	2
Flexibility	1	2
Costs	1	2
Maintenance	2	1
Impact on ship design	2	1
Impact on operations	1	2
Mobilisation time	1	2
Total	**9**	**12**

Forces

The forces involved in a separate system are regarded less positive, as the skid-track runs over the hatches, causing a large bending moment in the hatches. The hatches are not regarded a strong point of the vessel, with the big free span over the hold. A skid track incorporated in the coaming is regarded much more stable, with a more advantageous transfer of forces to the substructure, so this is regarded an advantage.

Flexibility

Having two systems hampers flexibility, since it is harder to switch between the two functions of the vessel, since the hold fully has to be closed before the skid track can be installed.

Capital costs

Two systems means two control systems and two times the costs of acquisition, although acquiring two systems for four vessels means less parts to be bought. On the other hand, there is not a single part that is reused, thus causing some parts to be doubled. The engineering costs will be slightly higher for the separate system, as the hatches require special attention. The modifications to the vessels structure will be basically the same, as either the hatches or the coaming requires attention.

Maintenance

Having a dedicated and small hold opening system decreases maintenance for the hold opening with respect to an integrated system. Another dedicated system for skidding could incorporate a containerized system that is separately shipped wherever it is necessary, decreasing maintenance requirements overall for all J1800-class vessels.

Impact on ship design

Having to adjust both the hatches and the coaming, for both opening the hold as skidding the project cargo is seen as a bigger disadvantage than only adjusting the coaming for the integrated system. Furthermore the impact on the hatches could have a bigger impact on the ship design, as it could interfere with the available area to seafasten the cargo.

Impact on operations

The integrated system can have a more positive impact on operations, as the skidding system can be build up before entering the port, whereas the separate system can only be prepared after the hold has been closed.

Mobilisation time

The mobilisation of an integrated system can be done during loading of the hold, or even before that, whereas the preparation of a skidding track over the hold can only be done when the hold is closed. The integrated system allows a big part of the mobilisation to be done outside of the critical path of operation of the vessel.

4.4. Propulsion of the hatch covers during hold opening and load shifting

With the decision of the rollers for the skidding of the load, together with the moving of the hatch covers, a propulsion system for these rollers has to be designed. With a selected integrated system the propulsion system should be able to both propel a maximum load of 1800T together with the hatches as a single hatch of 120T. With the propulsion systems analyzed in Chapter 3, there are basically three options for propelling the load: A strand jack, a push-pull unit and a winch. With the low friction coefficient of the rollers, being 0.05, the required propulsion loads are:

- Skidding: 96T.
- Hatch opening: 6T.

With such a high variety in the load that has to be propelled, together with the fact that the system is an integrated system with very specific use cases, two options can be defined.

Description of both concepts

Combined propulsion system for both functions

A combined system is designed for both skidding and hatch opening, with the capability of both propelling the 1920 tonnes at a maximum, as only the hatch of 120 tonnes. It will be permanently in place to perform both functions, whenever required.

Separated propulsion system for both functions

A separated system that has one component able to propel 120 tonnes of load, dedicated for hold opening and a component that is able to propel 1920 tonnes of load when in load shifting mode. As this system is not always permanently in place, the components necessary for load shifting has to be installed whenever required on either side of the hold.

Ranking analysis

In Table 4.4 the results of the ranking analysis can be found. With a small difference, the separate system is seen as a most favourable option, being more flexible and having a smaller impact on operations, as it is probably faster. The motivation for the scoring of the several criteria are listed below.

Table 4.4: Ranking analysis combined and separate system for load propulsion.

	Combined system	**Separate system**
Forces	2	1
Flexibility	1	2
Costs	1	2
Maintenance	2	1
Impact on ship design	2	1
Impact on operations	2	1
Mobilisation time	1	2
Total	**11**	**10**

Forces
The involved forces in a separated system are comparable with the involved forces in the integrated system, as they have to propel same loads. Together with the impact on the ship design, the way the forces are transferred into the substructure could be more favourable for the separated system, with the possibility of the propulsion system on the hatch instead of the coaming, as an integrated system would have. The separate system allows the heavy forces to be transferred more favourable into the substructure.

Flexibility
The flexibility of the integrated system is higher, as it is basically the same system that is responsible for both functions. It requires more effort for a separated system to switch between the two functions.

Capital costs
As the separate system consists of more components to be acquired, the capital costs will be higher. But, as the load propulsion system is only necessary every once in a while, there could be a sharing advantage as the design is for four vessels. For the integrated system the ultra-heavy load case is leading, increasing the capital costs of the hold opening system. It is estimated that four small hold opening systems, combined with two propulsion systems is relatively more cheap than four ultra-heavy duty hold opening and load shifting systems.
Furthermore the engineering costs and impact on the ship design will probably be lower for an integrated system, as it is just one component that is responsible for both motions. All in all, the combined system is regarded as a favourable option with respect to capital costs.

Maintenance
As the components in the separate system are smaller, it is expected maintenance requirements are less strict. Furthermore the heavy duty propulsion systems for load shifting are only half of the number compared to an integrated system, so the maintenance requirements for that are also less. The maintenance of those components could be done whenever not in use, so reducing the maintenance duties on board.

Impact on ship design
As the available space on board the vessel is limited, a small permanent design is favoured. Temporary components can be fitted in relatively easy during the execution of a project, but a permanent heavy duty system is harder to give space. It is for this reason that a separate small system is favoured.

Impact on operations
The impact on operations of a separate system is positive. A separate system allows the two components to be designed for their dedicated task, which enables them to be faster in that task. A fast and smooth hold opening system, combined with a relatively fast load shifting system has a greater positive influence on the operations as a system that has to combine both functions, decreasing the speed.

Mobilisation time
As the preparations for the integrated system are much smaller than for a separated system, that has to be prepared for load shifting, the mobilisation time for the integrated system is more favourable.

4.5. Total design
After deciding the major parts, the total basic design is made. The system will consist of an **integrated** system for both opening the hold and skidding the load. The hold will be opened by **stacking** multiple covers. When a skidding operation is required, some modifications are done for the propulsion system and the rollers. Skidding is done over the **coaming** by **using** the hatches.

5
Proof of concept

With the basic concept selected in Chapter 4, a next step is taken in order to see if the new concept would be a possible solution to the problem stated in Chapter 1. The next step in the Engineering Design Process is: Test and Implement solution. Implementation of the solution is discussed in Chapter 6, together with testing to the design requirements. The design is however first tested structurally in this Chapter. Before the design is tested, it is first is dimensioned and quantified. This includes the propulsion system, the stacking location and technology, the load shifting technology and new seafastening design. After that the total hydraulic system is dimensioned. After that ANSYS is used for the structural testing.

5.1. Dimensioning and quantification of the basic concept

As the design has been determined in the previous chapter, dimensioning is required before testing can take place. All the systems proposed in Chapter 4 are dimensioned and quantified in this section.

Propulsion system

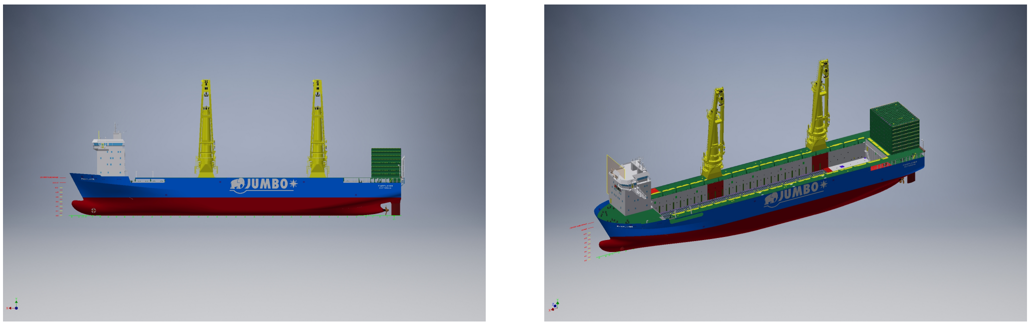
As is concluded in Chapter 4, the preferred propulsion for the hatches is a separated system, one for hatch opening and one for load shifting. As the primary goal for the hatch opening is speed as the new system has to reduce port time. With a low load (3T per side), the option selected is a winch. A winch is capable to deliver a force of 3T with a high speed, up to 23m/min [51], whereas a strand-jack or a PPU can not reach such speeds, but only up to 0.25 m/min for a strand jack or 2.5 m/min for a continuous push - pull unit [44] [19]. However, the winching speed should not exceed 10m/min as the rollers can not move faster than this without the need of cooling and lubrication. Furthermore, the length of the cable on the winch should be as long as the hold: 103 meter. As the vessel has a high generating capacity of electric power, most suitable power source for operation of the winches is electrical power, which will be considered.

For the load propulsion the propulsion force a winch can deliver is not enough, being 48T per side. The two options available are a strand jack or a PPU. As the space is very limited at the coaming, the PPU is not viable, as this needs to be positioned on the coaming. This leaves the strand jack as the only option, which can either be located on the hatch which has to be propelled, with a strong anchor block at the hold walls on front and aft, or the strand jack can be located at the hold walls, with the strands attached to the hatches. As the main advantage of the integrated system of load shifting and hold opening was speed, without a lot of adjustments to the hatch structure and without a high need of modifications when the project cargo needs to be shifted, it is preferred that the strand jacks are located at the hold walls, close to the winches. In this way only the strands for load shifting have to be attached to the hatches, without the need of placing and installing the strand-jack with accompanying HPU.

Stacking location

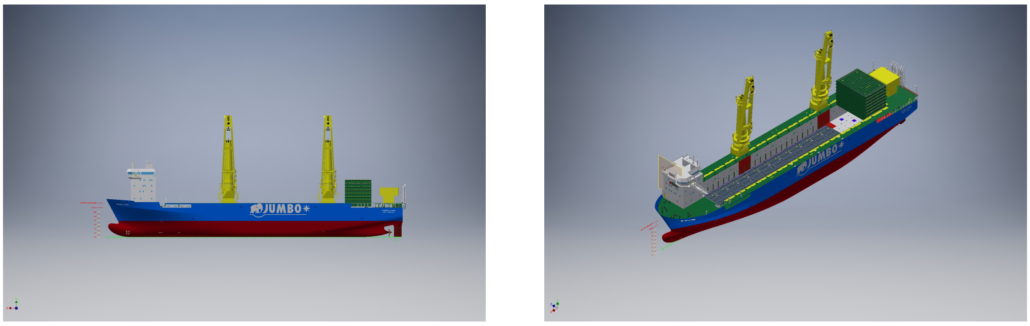
As Jumbo Maritime is a project cargo shipping company, it often requires vessels to sail empty to the loading location. It is thus assumed that the cargo deck is empty and the vessel is able to use the system when entering port. In this case the time constraint given in the functional requirements is less strict, since the time constraint is given for the situation when the vessel is already moored. With the assumption that the system is used before mooring and that the deck is empty, one stacking location is assumed to be sufficient. If further analysis shows that a second stacking location is required to enhance flexibility and to save time, it can be incorporated later.

With one stacking location deemed sufficient, the decision now at hand is where to put it. For this decision the cargo hold of the J1800-class vessel is important. At the location of hatch cover eight the garage deck is located. Underneath this deck the machine room is situated, meaning that the hold at location 8 is not as deep as the hold underneath the other seven hatches. Also, the garage deck is not as strong as the rest of the cargo hold, meaning that less heavy cargo can be stored there. Location eight would be the most suitable location for stacking. Another suitable location for stacking is the aft-deck. This can be considered when total opening of the hold is always required. A drawback of this solution is that the hatch first has to be lifted to the required height of the aft deck, and then skidded further to the aft of the vessel. Also, the stabilizer pontoons have to be relocated, but this is seen as a minor disadvantage. Both options can be seen in Figure 5.1 and 5.2.



(a) Side view vessel. (b) Birds eye view.

Figure 5.1: Stacking of hatches on aft deck.



(a) Side view vessel. (b) Birds eye view.

Figure 5.2: Stacking of hatches on location eight.

As a start the option depicted in Figures 5.2 will be chosen. If analysis of the final design shows that there are major setbacks to stacking at location 8, it can be reconsidered. This location is primarily chosen due to costs of the separate system lifting the hatches to main deck height.

Stacking technology

With a stacking location chosen, the stacking technology has to be selected. With the selected location at hatch 8 there is only one vertical motion required, together with the rolling of the hatches over the coaming. The rolling of the hatches will be discussed later. Since there is chosen for one stacking location, the following design parameters for the stacking technology are given.

Table 5.1: Design parameters stacking technology.

Number of hatches to lift	7
Total mass	760 tonnes
Required lifting height	1900 mm

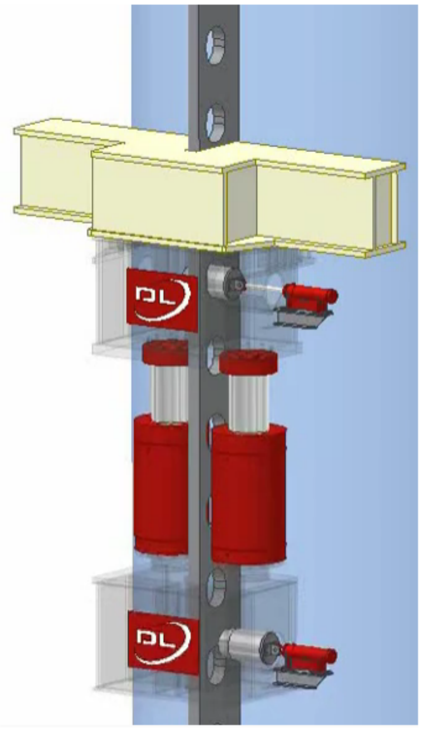
To ensure a stable lifting situation with built in redundancy, at least four lifting points are considered. The total stacking weight of the seven hatches equals 760 tonnes and the fact that the system needs to operate in a high level of autonomy, leaves few options remaining for the task. As is seen often, the required force will be generated by hydraulic actuators.

Starting at four lifting points, the total mass per point equals 190 tonnes. This mass has to be lifted 1900 mm, which can be done in one stroke (a single stroke option) or in multiple steps (a climbing tower). The big downside of a single stroke option is the very large stroke required, together with the high mass. This would result in a high hydraulic cylinder, altogether with a very big diameter cylinder to ensure the system stays stable at full stroke. The main advantage of a single stroke cylinder is the speed of the system, compared to a system that has to take multiple steps.

Considering that the system has to be implemented in an existing design, with a total available height at the stacking location of 2155mm, the option of the long stroke cylinder doesn't seem viable, as the total length of an hydraulic cylinder is almost 1.2 times the required stroke. Also the service life of a hydraulic cylinder decreases when it is often used at full stroke. In Enerpac [16] is stated that the 80% rule should be applied for both cylinder stroke as capacity as a rule of thumb for designing safe and stable hydraulic configurations. This will be done throughout the report. Applying the 80% rule to this lifting problem results in a required stroke for the single stroke option of 2375mm. Taking these facts into account, the **climbing** option will be chosen.

For the climbing option this means that the required lifting capacity for one point will be 237.5 tonnes.
Another important factor for the design of the stacking technology is that the mechanism that grabs onto the hatch should be retractable, in order to successfully lower the stacking device back into a position able to lift a consecutive hatch.

The proposed solution is a combination of two technologies. The required lifting motion is done in multiple steps in a way that would be comparable with the technology depicted in Figure 5.3a. To clamp the hatch that is lifted, a technology comparable with Figure 5.3b is used. In this figure the red blocks at the edges can be seen, these are hydraulically retractable and facilitate in this way the retraction of the hydraulic cylinders when the stack of hatches is put on the next hatch. It has to be noted that both technologies may be patented by the current manufacturer.



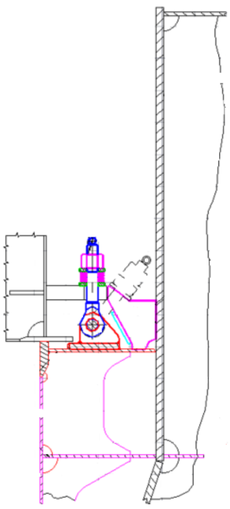
(a) Lifting motion [54].

(b) Clamping of hatch [43].

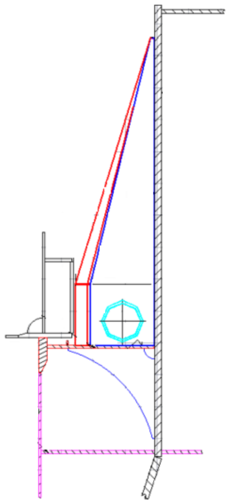
Figure 5.3: Stacking technology.

Load shifting technology

Decided is that the load shifting system will operate over the coaming of the vessel. Convenient, since the coaming runs over the total length of the vessel, but a disadvantage is that the current seafastening devices present on the coaming have to be redesigned and relocated. The redesigned seafastening will be discussed later on. The most critical location for the design of the skidding technology is near the starboard cranes, where the coaming is the smallest. Since the hatches have to be able to travel over the whole length of the ship, all hatches should be able to travel over the small part at the cranes. All can be seen in Figure 5.4



(a) Hatch cover sea securing.



(b) Hatch cover guide posts.

Figure 5.4: Coaming at starboard crane.

Considering that the guidance posts and the seafastening details will be removed from the coaming, the available space next to the hatch cover equals **405 mm**. As said, the skidding system is an integrated part of the hold opening system. In this perspective it should be scalable to the task at hand: skidding or hold opening. The system will be designed for one hatch cover length, being 12.8 meters.

Table 5.2: Design parameters load shifting system.

Task	**Load shifting**	**Hold opening**
Total mass to shift	1920 tonnes	120 tonnes
Available height	1600 mm	
Available width	405 mm	
Total length of hatch	12680 mm	

The system should comprise of the rollers and a device to lift the hatches from their seafastening position. Assumed is that the height of the stoppers will not change significantly. The current height is 200 mm. So, with a clearance of 100 mm and following the 80% rule of Enerpac [16], the required stroke of the hydraulic cylinders is 375 mm.

Table 5.3: Parameters Hilman rollers [48].

Required steel hardness skidding surface	S690
Maximum moving speed	10 meter/minute
Cycle life factor hold opening (10^5 cycles)	0.30
Cycle life factor skidding (10^4 cycles)	0.50
Required capacity for hold opening	118 T
Required capacity for skidding	188 T

The Hilman rollers have their own requirements, listed in Table 5.3. It can be seen here that the required surface hardness is quite high, but it has a high impact on the service life of the rollers. Also, the cycle life factor of the hold opening is much lower since the number of cycles required for those rollers is much higher, as this part of the system is used much more often. For the skidding part the cycle life factor is lower, but the required capacity is higher, assuming 12 rollers on each side of the hatch. For the hold opening only 2 rollers on each side is assumed. In Table 5.3 can be seen that the required steel for the skidding surface is steel S690, a very hard steel. This is incorporated by putting a steel S690 plate over the coaming, as an simple way of integrating the system in the old structure of the vessel. The dimensions of the selected roller can be found in Table 5.4. It is clear that the width of the roller does not exceed the available width at the starboard cranes. If the structural analysis shows that the impact on the coaming is high with the concentrated loads of the small version of the 200T roller, the selected roller for the port side can be selected bigger, since there is more space as the restriction of the cranes is not present.

Table 5.4: Parameters 200T Hilman roller.

Weight	174 kg
Width	200 mm
Height	171 mm
Length	914 mm
Capacity	200 tonnes
Number of Rolls	14
Roll Diameter	49mm
Roll Width	92 mm

On top of those rollers the cylinders will be located. Following the same 80% rule, the required capacities are summarized in Table 5.5. It can be seen that the required capacity for the skidding operation is much higher than for the hold opening. For the hold opening the system is overdesigned quite a lot. But, overdesigning means that the required pressure is low for lifting the hatches in hold opening mode, thus the operation time will be quite fast, so it is not deemed a disadvantage. So, the installed cylinders will have a capacity of 100T at full hydraulic pressure.

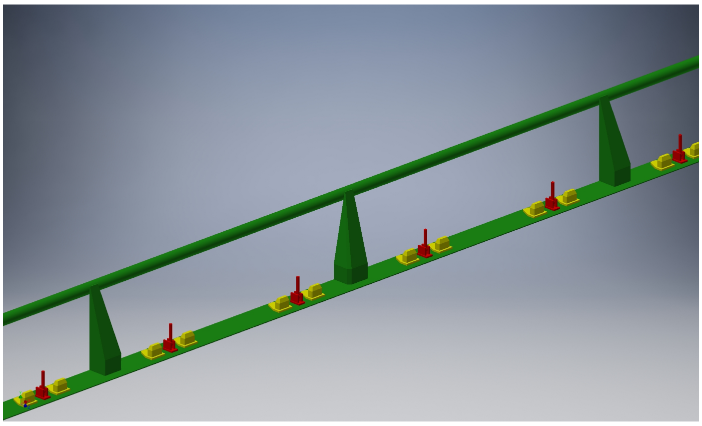
Table 5.5: Required capacity of hydraulic cylinders.

Capacity hold opening (4 cylinders)	37.5 tonnes
Capacity skidding (24 cylinders)	100 tonnes

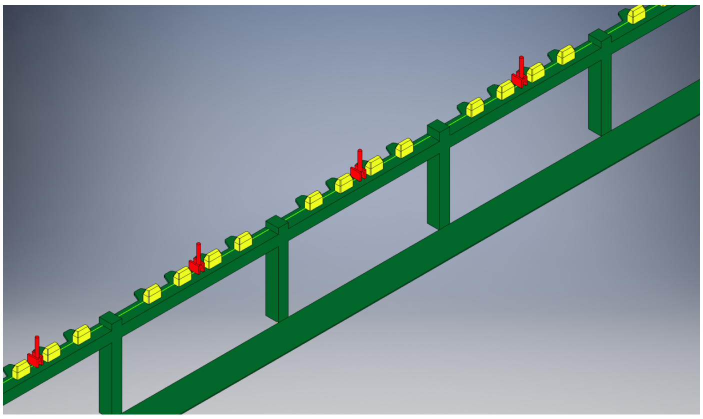
New seafastening design

With the coaming cleared and reserved as a load shifting track for the hatches, a new seafastening design has to be designed for the hatches. The design comprises of facilities to prevent motion in all three directions. To prevent torsional forces in the hatches, the movement in y-direction (transversal) is only restricted at one side of the hatches. Movement in x-direction is restricted on both sides to prevent rotation of the hatch. Currently, the movement in x and y direction is prevented by stoppers and the movement in z-direction is prevented by a bolted connection of the hatch using cleats. This is all done in accordance with the rules prescribed by DNV-GL [14].

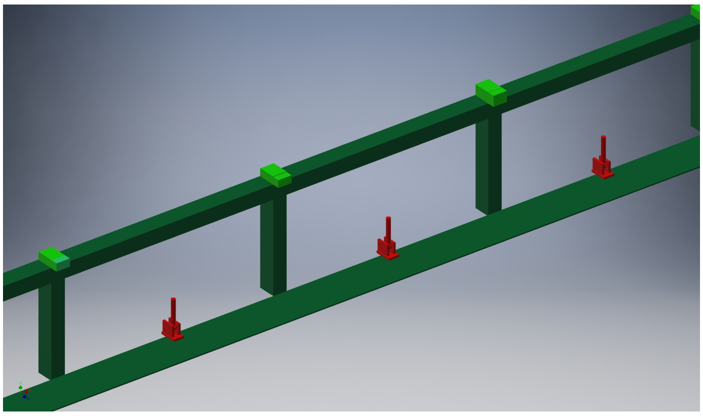
Since the loads will not change significantly, the first option explored is to relocate the current seafastening devices. As the starboard side is the most occupied side, it is chosen that the securing in two directions is done on the port side. The hatches are currently designed symmetrical to two sides, but in the new design this is not a necessary, as the need to rotate the hatches is less present. At starboard side the movement only has to be restricted in x-direction, which makes the design easier. On both sides the cleats will be present to prevent uplift.



(a) Current situation.



(b) New situation port side.



(c) New situation starboard.

Figure 5.5: Coaming detail.

In Figure 5.5 the seafastening details can be seen. In Figure 5.5a the current situation is visible. The new situation for port side is visible in Figure 5.5b. The stoppers(displayed in yellow) are located on a new beam between the pillars, which are doubled for structural strength, together with the seafastening cleats. The current stoppers are only located on port side, because on this side there is sufficient space. On starboard side there is a new stopper located on top of the pillars, solely for restriction of movement in x-direction. This is depicted in light green in Figure 5.5c. The cleats are shifted to the side here, to enable the rollers to pass by. The design of those cleats will not change much on port side, but due to the lack of space on starboard, another type of cleats will be used for seafastening the hatches in upward direction. These so called quick-acting cleats are fast applicable and allow the cleats to be located almost entirely next to the coaming. An example of a quick-acting cleat is depicted in Appendix F.20. A new beam is also located between the pillars on starboard side for reinforcement.

Hydraulic system

Besides the structural design of the system, also the hydraulic part of the system is dimensioned to be able to analyze the main functions. A lot of components use hydraulic fluid as a source of power to function. These components are:

- Hydraulic cylinders to lift the hatches of the coaming
- Hydraulic cylinders to stack hatches
- Strand jack for propulsion of the skidding load

A basic hydraulic system is depicted in Figure 5.6.

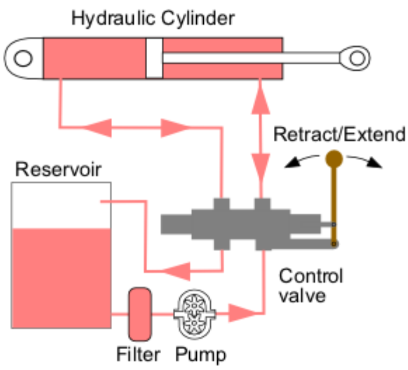


Figure 5.6: Basic hydraulic system [62].

Hydraulic power is provided by the pump and is in combination with the filter and reservoir called a Hydraulic Power Unit (HPU). This pump provides the required hydraulic pressure in the cylinder, which is then able to perform the task. HPUs are divided into two categories, which have both a distinct method of operation. The difference is in the operation of the pump, which can have a fixed flow or a variable flow. The fixed flow pump delivers a constant flow of hydraulic oil at the rated pressure, whereas the variable flow pump delivers a variable flow of hydraulic oil at a range of pressures. For applications where the load that has to be lifted is constant, a fixed flow pump is favourable, as this is more efficient. In applications where the loads vary greatly, the variable flow pump can have benefits, as the speed of operation is much higher. This because the flow is much greater at low pressures. To minimize pressure losses, it is common practice to have the HPU as close to the hydraulic cylinder as possible. Especially at large distances the pressure losses are significant.

Hydraulic cylinders to lift hatches of the coaming

The hydraulic cylinders that are meant to lift the hatch of the seafastening on the coaming operate in two distinct modes, one of hold opening and one of load shifting. It is therefore as that there are only four cylinders connected to the hatch when opening the hold, but 24 when skidding a load, a big difference in requirements for the hydraulic system. For this reason the hydraulic system is divided into two, one for load skidding and one for hatch opening. During hold opening, the hatch has to be able to travel over the whole length of the hold. To minimize pressure losses, the hydraulic power unit has to travel along with the hatch. Since the hatches have to be stacked, the HPU can not be located on top of the hatch, but has to be integrated somehow in the roller system. For skidding of the load it is not a problem that the HPU is located on the hatch cover.

Table 5.6: Requirements HPU hold opening and load shifting.

	Hold opening	**Load shifting**
Load per cylinder	30T	80T
Number of cylinders	4	24
Net area of cylinder	133.3 cm^2	133.3 cm^2
Required pressure	220 bar	590 bar
Required volume of hydraulic fluid per cylinder	5 liter	5 liter
Required total volume	20 liter	120 liter

For hold opening, there are four small HPUs located next to the cylinder to ensure fast operation, these relatively small HPUs have an output of 5.0 L/min from a fixed gear pump at the rated pressure of 250 bar. The HPUs will travel together with the hatch over the coaming. All HPUs need a reservoir of around 6 liters to account for losses in the hoses. To have a controlled lifting of the hatches, the hydraulic system needs to have a control system, which ensures that the lifting is synchronized and that the hatch is lifted evenly over all four lifting points. As it is difficult to place the whole system in hydraulic connection with each other, the cylinders will be equipped with pressure gauges and stroke sensors. Another advantage with the HPU travelling with the rollers is that there is only one cable running over the coaming towards the rolling hatch, the cable for the electronic power of the HPUs. These cables will be automatically spooled on a reel, to prevent collision of the roller with the cable. For load shifting, the load per cylinder is much higher, and thus the required pressure is much higher. The HPU for hold opening is not suitable for this function. Together with the fact that the required hydraulic fluid is much higher, a separate, big HPU is selected for the skidding. This HPU can stand on the hatch and can travel along with the load. As the HPU is located on the hatch, the hydraulic cylinders on either side of the hold all are connected to the same HPU, ensuring a safe and synchronous lifting operation. A visual representation of the different HPUs can be found in Figure 5.7.

(a) Small HPU for hold opening [27].

(b) Big HPU for a synchronous lifting system [18].

Figure 5.7: Stacking technology.

Hydraulic cylinders to stack the hatches

The details of the stacking technology can be found in Appendix E. The most important details are listed here, in Table 5.7.

Table 5.7: Details of stacking technology.

Cylinder rating	125 T
Stroke	550 mm
Operating pressure	271 bar
Net area of cylinder	453 cm^2
Required oil per cylinder	25 liter
Total oil requirement stack	50 liter
Total oil volume requirement during stacking	200 liter

As the load on the stack gradually increases with the number of hatches to be lifted, the required pressure increases from 32.5 bar to 228 bar, meaning a high variety in required pressure for the HPU. Considering this, a variable flow HPU would be the most suitable option. As the stacking position is stationary, the HPU can also be stationary and located beneath the deck. Below the deck the operating environment is less hostile, decreasing the requirements for the HPU. Flows up to 50-100 L/min are required to have a fast opening of the hold. From Technology [55], a HPU is selected with a variable flow, with a theoretical lifting speed of 12 meters for a climbing jack at full pressure. This requires a flow of 30 liters per minute for one climbing jack pair, so, the total flow needs to be 120L/min. This HPU is electronically driven and is built into the vessels structure.

Strand jack for skidding of the load

The strand jack required to pull the hatch towards front or aft has to be able to pull 48T. A strand jack with a minimal pulling force of 70T is depicted in Figure 5.8 and more detailed in Appendix E. A pulling force of 70T is a bit too much, but strand jacks with exactly 50T have to be custom made and would increase the costs. The characteristics of the strand jack can be found in Table 5.8.

Figure 5.8: Strand jack [24].

Rated capacity	70 T
Number of strands	7
Diameter of strands	15.7 mm
Stroke	280 mm
Operating pressure	400 bar
Effective area cylinder	203.6 cm^2
Required oil volume	5.7 liter

Table 5.8: Characteristics strand jack.

As can be seen, the operating pressure at maximum capacity is 400 bar, but also this can vary greatly, so also a variable flow HPU will be considered, to have an optimum speed for the skidding operation. As speed is not the driving factor, as skidding operations are generally done at very low speeds, not a high flow is required. Of more importance is the fact that the strand jacks on both port side as starboard move in a synchronous matter, otherwise there is a chance of derailing the rollers of the coaming.

5.2. Structural analysis

Testing of the design in structural sense is done using the static-structural analysis tool of ANSYS Workbench. First the applicable theory of the static structural FEM-solver (Finite Element Method) ANSYS Workbench is discussed, after which the choice for the static-structural analysis is justified. At last, the results of the analysis are shown.

ANSYS Workbench

ANSYS Workbench is a complete working environment using the total capabilities of the ANSYS software. ANSYS is a so called total Computer Aided Engineering program and it support engineers to use the full capabilities of numerical computing. ANSYS uses the theory of the Finite Element Method. The working principle of FEM models comprises of the division of complex geometry into small and simple elements, which is called meshing of the geometry. These small elements have a fairly simple formulation of the stresses. All these small elements coupled together represent the total behaviour of the total model.

For all those elements, the following equilibrium equation is solved:

$$-\sigma F = (\sigma + d\sigma)F + q dx = 0 \tag{5.1}$$

Which results in

$$\frac{d\sigma}{dx}F + q = 0 \tag{5.2}$$

With $\sigma = \epsilon E = \frac{du}{dx}E$:

$$\frac{d^2u}{dx^2}EF + q = 0 \tag{5.3}$$

These equations are solved for all elements in all degrees of freedom, translation in x-y-z and rotation around all the the axes. In this way the stress and the deformation are computed in the total geometry. It has to be noted that this method utilizes the fact that the material behaviour is linear and that the stress-strain relation is linear to the material properties. This is valid for the fact that the materials used in the simulation is steel and that the regulations prescribe that steel is not loaded until its yield strength, thus keeping the properties of the material linear.

It is of utmost importance that the boundary conditions of the geometry are well defined and that the subdivision of the total geometry into the small elements (meshing) is done in such a way that all special elements are described in more than one element, since the stress and displacement is taken as the mean in one element. For further information about the working principle of ANSYS, a reference is made to the theory manual of the program itself [29].

Analysis of ANSYS results

As ANSYS only computes the stress at a certain location, it does not analyze if the structure is safe and can handle the loads exerted on it. In the FEM-analysis the Working Stress Design (WSD) method is utilized, which compares the calculated stress with the permissible stress. This analysis is not done by ANSYS, but has to be done by hand, to check if the structure satisfies the boundaries given by this model.

First, the total structure considered can not be loaded higher than a certain basic usage factor of the structural steel. Besides the basic usage factor, the local peak stresses are also of special interest, as other rules apply to peak stresses.

The basic usage factor in the WSD method is defined as follows:

$$\eta_0 R \leq R_d \tag{5.4}$$

Table 5.9: Basic usage factor for WSD method.

		η_0
ULS	Max static loads	0.60
ULS	Maximum combined static and dynamic loads	0.80
ALS	Accidental loads and associated static loads	1.00

This is valid for the total structure, for points where there is a concentration of stress the mesh is refined. The rules for fine meshes are prescribed by DNV-GL and shown in Table 5.10.

Table 5.10: Multiplication factor yield stress for fine meshes.

			Mesh size		
Structural component	Design method	Load combination	50x50	100x100	200x200
Hull in general	DNV Rules for ships	Static + Dynamic.	1.53	1.33	1.13

In the analysis multiple types of steel are used: S235, S335 and S690. Lloyds gives the following properties for these types of steel (see Table 5.11). For steel S690 the properties are examined on a case-by-case basis, but first it is assumed that for peak stresses it can be loaded up unto the yield stress, as for the basic usage factor it is kept at 60%, as the fatigue life of steel S690 is comparable of that of S355 [10].

Table 5.11: Steel properties based on Lloyds guidelines.

Thickness Material	Tensile strength t<40 mm [MPa]	Tensile strength 40<t<100 mm [MPa]	Yield strength t<40 mm [MPa]	Yield strength 40<t<100 mm [MPa]
S235	360	324	235	212
S355	510	459	355	320

As no structure has a face thickness bigger than 40 mm, this results in the following admissible equivalent stresses.

Table 5.12: Limit stresses for steel in FEM-analysis.

[MPa]	σ_f	σ_e	$\sigma_{epeak50x50}$	$\sigma_{epeak100x100}$	$\sigma_{epeak200x200}$
S235	235	141	359	315	265
S355	355	201	543	472	401

Also a linear buckling analysis is carried out to ensure the structure is not loaded in such a way that there is a chance of buckling. A linear buckling analysis has some limitations, as it assumes an ideal elastic structure. It does not account for non-linearities in deformation and eccentricities of the loads. The results of ANSYS give a load multiplier. This load multiplier represents the factor the actual load has to be multiplied with to reach the linear buckling load. As this is a basic analysis, a best engineering practice is assumed, which means that the load multiplier has to be higher than 2. If the load multiplier is lower than 2, a detailed analysis is compulsory and is carried out using the DNV-GL code [12].

Applicable loads

In DNV-GL [14], applicable loads for the design of hatch covers and their respective substructure are specified. These five load cases will be shortly listed here.

Table 5.13: Load cases for hatch cover design.

Load case A	Vertical and horizontal weather design load
Load case B	Cargo loads
Load case C	Container loads
Load case D	Loads due to liquids in hold
Load case E	Loads due to elastic deformations of the ship's hull

These load cases represent the loads the hatch will endure in the total usage life of the hatch and also during all weather events. As stated, the system will only be in use during port visits or during very light weather. So, load case A is not applicable for the system that is designed. Since the system will be designed for heavy cargo and not for containers, load case C is also discarded first. Liquids are not present in the hold, so load case D is also not relevant. If elastic deformations of the hull seem to be a large problem, load case E will have to be checked later. The load case for the design will be primarily the cargo loads, load case B. In the guideline is stated DNV-GL [14]:

"The load on hatch covers due to distributed cargo loads, in kN/m^2, resulting from heave and pitch, i.e. ship in upright condition, shall be obtained from the following formula:"

$$P_L = P_c(1 + a_v) \tag{5.5}$$

where:

P_c = uniform cargo load in kN/m^2
a_v = vertical acceleration addition

To proof the working of the system in port, the acceleration addition is reduced to zero. So, only the static case will be examined. In this case, the design load is the static load of the cargo and a static structural approach in ANSYS is justified.

Coaming strength analysis

The coaming surface is designed for the loading of the rollers on the coaming. This loading is divided into two parts, with both their respective loading on the coaming. This can be seen in Table 5.14.

Table 5.14: Load cases coaming.

Load case	Load [tonnes]	Number of rollers units per side	Number of individual rolls	Load [N/mm]
Hold opening	120	2	28	228.5
Load shifting	1920	12	168	610

The loads of the rollers are given as input in ANSYS. Multiple options are available for load input, but given the fact that the load of one individual roll can be seen as a line pressure over the width of the roll, the most accurate results will be obtained when the loads per roller are put in as line pressures. Clearly, load shifting is the governing load case with the highest line pressure and the highest number of rollers. The total input for this load case can be seen in Figure 5.9.

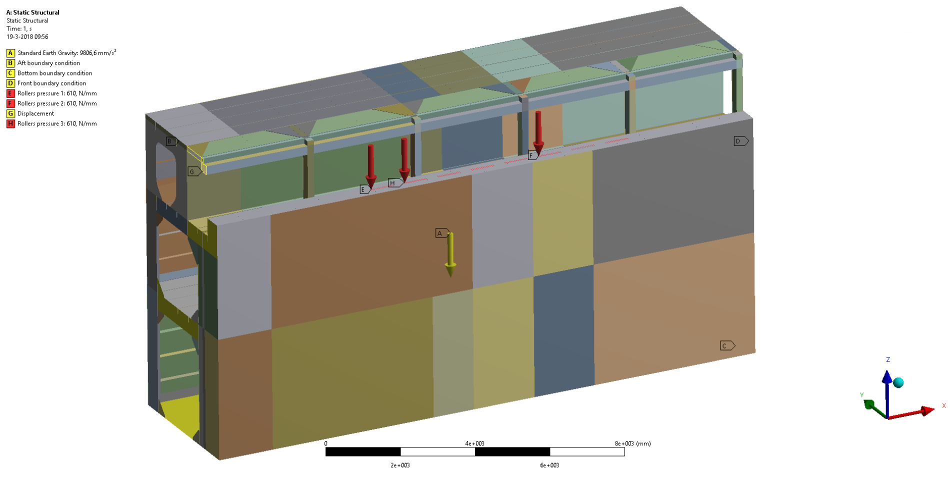


Figure 5.9: Loads on coaming during skidding on port side.

The total deformation and stress can be found in Appendix F for both starboard and port side. The results are summarized in Table 5.15. It is clear that for both sides the peak stresses are much lower than the allowable stresses. In fact, the unity check is quite low. But seen that the analysis is purely static, it might be beneficial to have a low unity check. An option that can be considered is a smaller skidding track plate, although the small deformations for the track are beneficial for the life-time of the rollers. Buckling also seems not a problem, as the load multiplier is much higher than the allowable multiplier.

Table 5.15: Results coaming stress and deformation port side and starboard.

	Port side	**Starboard**
Mesh size		100x100 mm
Thickness S690 reinforcement plate		75 mm
Maximum allowable peak stress coaming		315 MPa
Maximum allowable peak stress plate		690 MPa
Maximum allowable deformation rollers [49]		2 mm
Maximum stress coaming	150.0 MPa	169.0 MPa
Maximum stress skidding track	71.52 MPa	73.7 MPa
Unity check coaming	0.48	0.54
Unity check skidding plate	0.10	0.11
Maximum deformation	1.2 mm	1.49 mm
Load multiplier buckling analysis	3.35	3.08

Hatch cover strength analysis

As said, to the basic design of the hatch cover not a lot of adjustments are made. The structural adjustments are in the connection of the rollers to the hatch cover, which is done by simply attaching a beam to the hatch cover, which has to transfer the load from hatch cover to the rollers, both during load shifting as hold opening. The new geometry of the hatch cover can be found in Appendix F, with the loading details depicted in Figure 5.10.

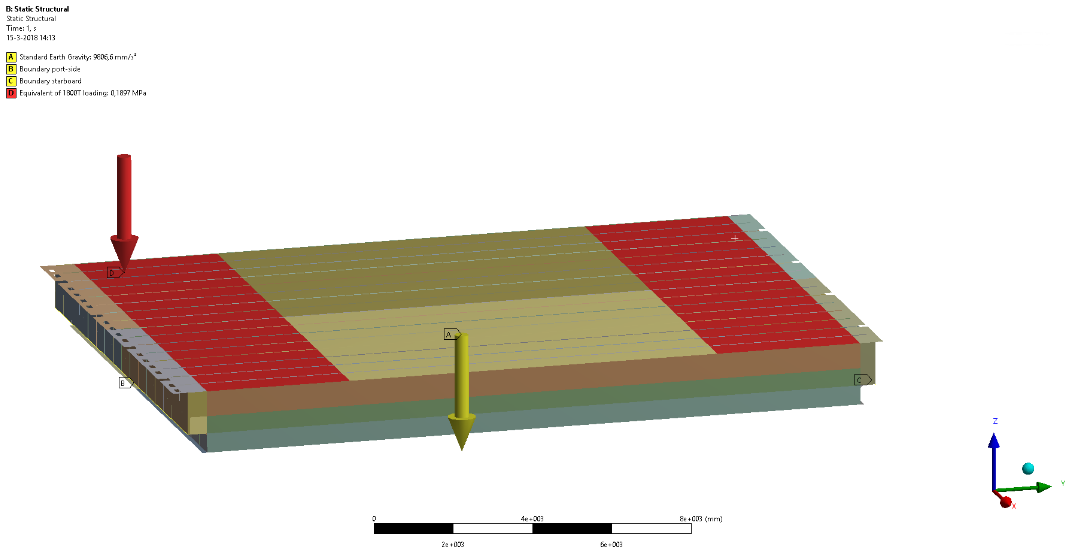


Figure 5.10: Hatch cover loading case.

The connection of the beam to the coaming is modelled as a connection which is restricted in all directions, except the rotation in x-direction (longitudinal). This represents the reality, where the connection is by the hydraulic cylinders equipped with a tilt saddle that are on top of the rollers. These allow rotation in x-direction. An example of a tilt saddle is shown in Appendix F Figure F.19. This rotation is necessary, since the beam deforms under the load of the hatch. If the rotation is not allowed, very high peak stresses will be present in the beam. The results of the analysis can be found in Appendix F and are summarized in Table 5.16. The unity check is quite high for the static case only, but is in the acceptable limit. Also, the high peak stress is due to the given boundary condition, with the other stress being well below the high peak stress, as is also visible in Figure F.19. As the location of the boundary condition is not in the field of interest of the analysis, this does not pose a problem. The connection between hatch cover and beam is more important and in this region the stresses stay well within the limit. The maximum deformation is in accordance with normal experienced deformations of Jumbo Maritime's hatches under high cargo loads.

Table 5.16: Results hatch cover stress and deformation.

Mesh size hatch	100x100 mm
Maximum stress	195 MPa
Maximum allowable peak stress	315 MPa
Unity check	0.62
Maximum deformation	15.6 mm

Stopper strength analysis

Since the design utilizes the part of the coaming where previously the stoppers of the hatch covers were located, a new location and working principle of the hatch cover stoppers has to be designed. The preliminary design can be found in Figure 5.5. The loads are determined using the guidelines of the DNV [14]:

$$F_h = m \cdot a_i \tag{5.6}$$

Where:

a_i = the acceleration, in m/s^2:

$a_i = 0.2g$ for acceleration in longitudinal direction

$a_i = 0.5g$ for acceleration in transverse direction

m = sum of mass of cargo lashed on the hatch cover and of the hatch cover itself.

This results in the following loads for port side stoppers and starboard stoppers:

Table 5.17: Design loads seafastening.

	$F_{transversal}$ [kN]	$F_{longitudinal}$ [kN]
Starboard	0.0	1883.5
Port side	9420	1883.5

Loading on port side and starboard differ significantly, as can be seen in Table 5.17. It is for this reason that the seafastening design for port side and starboard differ. At port side loading is quite high, so the current situation is reinforced with structural steel. The geometry is depicted in Figure 5.11

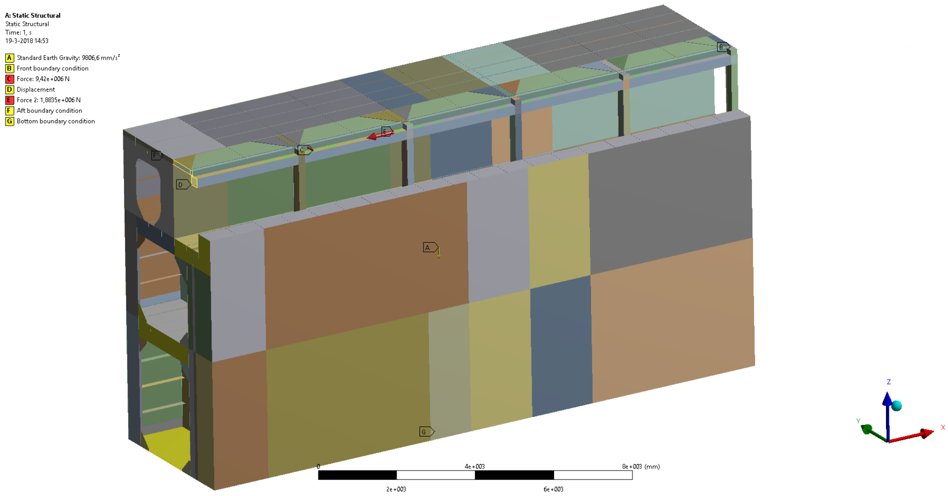


Figure 5.11: Geometry of port side seafastening structure.

The geometry of the starboard side does not have to be altered for the seafastening system. The spacing of the pillars will remain 3.2 meters, as is necessary for the skidding operations. The geometry is depicted in Figure 5.12.

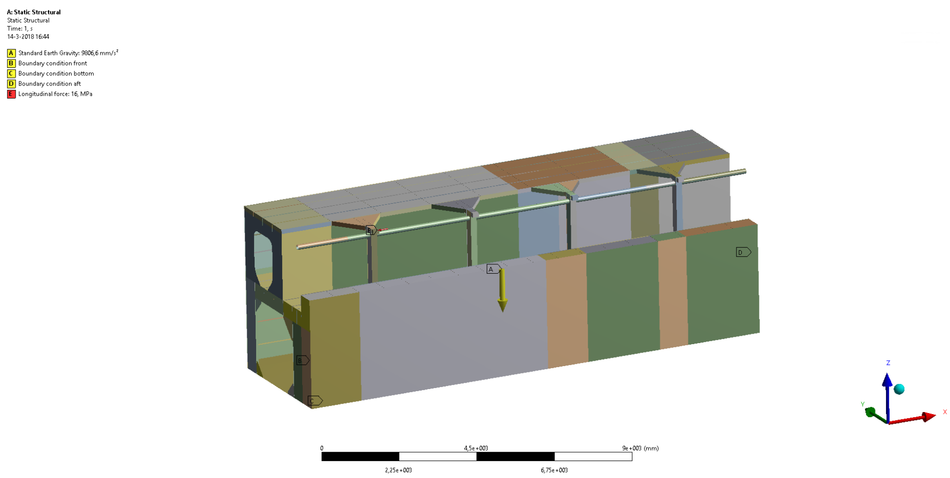


Figure 5.12: Geometry of starboard seafastening structure.

Since the design of the stopper comprises of a dynamic load, the basic usage factor is higher, as there are also dynamic loads considered. This is because the forces which the stoppers are designed for are by definition dynamic forces. The basic usage factor that is used from Table 5.9 is equal to 0.80. The results are summarized in Table 5.18 and are visually displayed in Appendix F. It is clearly visible that the criteria for both stresses and buckling checks are met.

Table 5.18: Results stopper stress and deformation port side & starboard.

	Port side	**Starboard**
Mesh size hatch	100x100 mm	
Maximum allowable peak stress	315 MPa	
Maximum stress	283 MPa	197 MPa
Unity check	0.90	0.63
Maximum deformation	5.09 mm	1.96 mm
Load multiplier buckling analysis	2.4	3.09

6
Analysis of concept

With the basic design finished, dimensioned and with proven feasibility in structural sense, the possible implications of the design are analyzed. First, the design is tested to the design requirements defined in Chapter 2. After proving that the design meets the needs of Jumbo Maritime, the implications of implementation of the new design on the vessel are evaluated. Implications considered entail operations, ship design and the applicability of the system to old projects. Furthermore, the safety of the new design is evaluated.

6.1. Testing of design to requirements

The design is extensively explained in Chapter 5 and the design requirements were established in Chapter 2 and are again stated in Table 6.1. The design is tested to these requirements to check if it fulfills the needs of Jumbo Maritime. The requirements following from use cases 4 &5 are left out of Table 6.1 as the execution of these use cases is not changed in the new design. A remark is made towards the strength requirements stated in Table 6.1, as these all have been handled in Section 5.2 and thus will not be considered in this analysis of the design requirements. Also the fulfillment of use case 3 has not changed, which leaves the evaluation of the design to testing to the functional requirements defined for use cases 1& 2, together with the constraints and non-functional requirements imposed on the design.

The constraints and non-functional requirements are regarded separate from the functional requirements, as the constraints and non-functional requirements put boundaries on the design, meaning the design would not have been complete without fulfilling these requirements and have been covered indirectly during the design process. It will be however covered in short.

Fulfillment of non-functional requirements

The non-functional requirements consist of three items, being:

- Hatches should still be able to be lifted off
- Positions of the hatches is interchangeable
- System should have a service lifetime of 15 years

The first two requirements are dealt with in the design, making it possible to lift the hatches of with the onboard cranes, as is nowadays common practice. As the hatches can still be lifted of, it makes them suitable to be interchanged. This allows the heavy hatches to be used for the cargo piece that requires it, on either location of the vessel. The total system is designed for 15 years, so this requirement is also dealt with, but not tested extensively.

Fulfillment of constraints

The constraints consist of four items, regarding:

- Safety
- Adjustment to vessel structure
- Transferring transversal forces in the hatches

- Interfering with crane structure

The safety aspect of the new design will be covered in a separate section, being Section 6.4. Adjustments to the vessel structure is covered in Section 6.3. Transferring transversal forces is not possible due to the fact that the seafastening design is designed with those specifications, discussed in Section 5.1. Where also is specified that the crane structure is left intact, as the design does not interfere with the onboard cranes.

Table 6.1: Design requirements.

Use Case	**Functional requirement**
1	Preparation time for load shifting: one working day in port (12 hours). Optimal maintenance scheme for Jumbo Maritime System should be scalable, since the maximum required load is not always required. Maximum skiddable load on top of a hatch cover is 1800T. Strength should be examined using current regulations of DNV-GL
2	System should be able to operate in a high level of autonomy Flexibility should be guaranteed. Every hatch should be opened, although not all together at once. Less crane-driving hours involved than current system: 120-240 minutes requiring four workers (depending on conditions) Strength should be examined using current regulations of DNV-GL
	Non-Functional requirement Hatches should still be able to be lifted off Positions of the hatches is interchangeable. System should have a service lifetime of 15 years
	Constraints System should comply with the highest level of safety, corresponding with the company values of Jumbo Maritime Adjustments to existing vessel structure is possible, but should be avoided where possible System is not allowed to transfer transversal forces, no torsional stiffness available in the hatches. System has to operate without interfering with the onboard cranes structure.

Fulfillment of functional requirements

The new design is evaluated with respect to the functional requirements, which are stated for use cases 1&2. These requirements will be evaluated in the same order as discussed in Table 6.1.

Preparation time load shifting system

First requirement mentioned in Table 6.1 is the preparation time of the load shifting system, which should occur in less than one day in port. In normal service, only the hold opening system is in function, meaning that there are four rollers on the coaming, two on each side. The rollers are all accompanied by a small HPU, which travels along with the rollers.

To be able to shift a load on top of the hatches, rollers have to be added. together with hydraulic cylinders. Depending on the size of the load to shift, the number of extra rollers to be placed on the coaming can run up to twenty, ten on each side. Since the rollers weigh up to 175 kilograms, an additional lifting tool is required to place them, adding installation time. Together with the rollers the cylinders have to be installed, which also weigh around 120 kilograms.

As the cargo load will be resting on top of the hatch and all hydraulic cylinders combined have to lift the hatch, a lot of hydraulic power is required. The power will be supplied by multiple HPUs located on top of the hatch cover. These HPUs are controlled by a control system which enables a synchronized lift. Furthermore, the rollers will be interconnected mechanically, to ensure the rollers can move with the help of the winches, as is required in between to consecutive skidding operations. Also the small HPUs will have to stay together with the four rollers dedicated to hold opening in order to be able to shift the hatches between two skidding operations. The basic flow for the skidding operations can be seen in Appendix B,Figure B.1.

Table 6.2: Basic work flow skidding operation.

Step	Activity	Duration [hr]
	Preparation	
1	Position hatches in between cranes at mid-ship in order to be able to lift cargo on	1
2	Retract rollers to opened hold, to add extra rollers and cylinders	2
3	Position all the rollers under hatch cover & prepare strand jack for operation	2
4	Disconnect four rollers from small HPU & connect all hydraulic cylinders to HPU	2
5	Prepare strands for strand jack & prepare HPU for strand jacks	2
6	Test HPU and hydraulic cylinders, as well as strand jack	1
	Execution	
7	Lift cargo on top of the hatch	6
8	Lift hatch and shift to front or aft	3
9	Disconnect rollers from big HPU, connect four rollers to small HPU	2
10	Prepare other hatches, either for extra cargo shifting or for closing the hold	2
	Total time	23

The strands of the strand jack weigh around 1.17 kg/m [16]. The total strand length required for skidding operations equals the total length of the hold, being 103 meters, as the strand jacks for shifting from front (or aft) to mid-ship are located on the opposite side of the hold. This results in a total weight of one strand being 121 kg. For both strand jacks a maximum of seven strands are required, bringing the total weight to 1690 kg.

Preparation of the strands on port side is relatively easy, as this is possible over the whole length of the vessel over the void. For all the strands some sort of reel cart could be prepared, so that multiple times a reel containing a strand can be loaded and rolled out. On starboard side the strands could probably be rolled out using the hold opening winches. This however requires some more work, as the winch wires first have to be detached from the rollers and then reattached to the strands. A note has to be made to the winch wires, as these will be attached to the rollers together with the strands during skidding.

A lot of preparations for the skidding can be done already outside the critical path of being moored in port, such as the preparation of the rollers next to the coaming, getting the strands ready on deck and preparing the HPUs, together with the necessary hoses. With the total preparation time being 10 hours and the possibility of doing a lot of tasks outside the critical path, the preparations of the load shifting system should be well possible within one working day in port.

To conclude, in comparison with conventional skidding methods, a lot of time is saved due to the fact that the skidding track is permanently installed. Time otherwise required for positioning the tracks, connecting the tracks to each other and aligning and securing the tracks on the hatches, which easily take up to a day of working time.

Scalability of the system and maintenance requirements

Use case 1 requires the system to be scalable and have an optimal maintenance scheme for Jumbo Maritime. An optimal maintenance scheme for Jumbo Maritime does not necessarily mean low maintenance, but primarily it means a maintenance and prevention scheme that is focused on a smooth operation during port time. Necessary maintenance could either be done during sailing for the bigger components, as the big HPUs or stacking technology, or a replacement strategy for small components that are relatively cheap. It is defined in such a way since replacing a component is much cheaper than losing a day in port for the complete vessel, regarding the day-rates of the vessels.

For this system scalability is not a problem, as the operation prescribes how much rollers have to be added to the string of rollers to be able to shift the project cargo. Maintenance is done in such a way that the chance of failing during operation is reduced significantly.

Opening time

With the hydraulic system designed in Section 5.1, the opening time of the system is estimated. Operation of the system is described in Table 6.1. The total sequence is more elaborately explained in Appendix H. The lifting speeds for the stacking of hatches are derived from the supplier, under the assumption that the HPU is a variable flow HPU [55].

Table 6.3: Time involved in hold opening sequence.

Time to lift hatch from seafastening	1 min
Time to position rollers beneath hatch	1 min
Time to position hatch above seafastening	1 min
Time to put hatch on seafastening	1 min
Time to position stacking technology in hatch	1 min
Time to lift hatch 7	2 min
Time to lift hatch 1	14 min
Time to roll hatch 7	2 min
Time to roll hatch 1	18 min

The total opening time is estimated at **97 minutes** in total. This time is a minimum opening time, under assumption that the system is fully autonomous and no problems arise during operation. In Appendix G,Figure G.1 the total sequence of the hold opening can be seen in a Gantt chart. The critical path is highlighted with a red colour and is basically the part of the hold opening consisting of the hatch cover rolling. This is due to the fact that the distances over which the hatches have to be transported are in the order of 100 meters in the end, with the limiting factor being the maximum transport speed of the rollers, being 10m/min.

In order to have a faster hold opening system, the rollers can be adjusted until they can reach a speed of 15 meters per minute, which would cut the transport time in half. The total effect on the total opening time would be a reduction of 17 minutes. Whenever required, special measures can be taken. First, this is disregarded, as the hold opening with a travelling speed of 10 meter/minute is already seen as a major time saver.

Load shifting time

An analysis is made in order to estimate the time required for load shifting operations. Several distinct phases in the load shifting operation are distinguished. The reason for this is that loading operations are substantially different every time a heavy load is loaded, but the phases in between the actual loading are considered the same, and will take almost the same amount of time every time it is used. The phases covered are:

- Preparations for load shifting to front
- Load shifting to front
- Preparations for load shifting to aft
- Load shifting to aft
- Closing the hold

As cargo for load shifting operations usually consist of pieces bigger than one hatch, shifting with two hatches is considered in the analysis of the load shifting time. Shifting with two hatches means that the total load will be a bit bigger due to the added mass of one hatch but it also means that the cargo load is divided over two hatches instead of one, resulting in a lower line load.

The results of the evaluation of preparation times can be found in Table 6.4, with operational times equal to the operation times involved in hold opening, which were stated in Table 6.3. An additional explanation of the hold opening sequence can be found in Appendix G.

Table 6.4: Time spent during load shifting.

Phase	Time [min]
Bringing hatch 1 & 2 in load shifting position	67
Load shifting to front	173
Bringing hatch 7 & 8 in load shifting position	59
Load shifting to aft	125
Close hold	30

A major advantage for a load shifting system on board of the vessel is the fact that the skid track is permanently installed. This saves precious time of installing the skid track, which has to be done with high precision. A recent project involved shifting two reactors of 900 tonnes each, during this project the skidding track was installed with an accuracy of 5 mm. The total time for the shifting operations in port were one week, where a significant part of the operations included installing the skid-track. The total project scope was shifting the two reactors to the front of the ship, over a total distance of about 36 meters.

Autonomy of the hold opening system

A major disadvantage of the old system is the number of working hours involved in port, reducing the effective working time loading cargo as both crew and cranes are occupied with hold opening. An advantage of the system is the high level of autonomy it can possibly operate. Some instruments possible to achieve this goal are discussed.

As the rollers are attached to the winch wire that propels the rollers, it is possible to accurately determine the position of the rollers using a cable counter device. These devices can guarantee a precision of 0.05 % [53], which means a precision of 6 cm over the total length of the hold, falling within acceptable limits regarding lifting of the hatch covers. Using the cable counter, connected to a Programmable Logic Controller (PLC), the rollers are automatically positioned underneath the hatches. The HPUs are also electronically activated, so the lifting of the hatches is incorporated in the operation of the PLC. The hydraulic cylinders are outfitted with a stroke counter, to ensure the stroke of the cylinder is enough to pass the seafastening structures and to control if all the cylinders have the same and required stroke. As pressures for the four cylinders can differ, also a control system of valves is connected to the HPUs, to ensure an evenly distributed and safe lifting process.

The lifting system for the hatches also operates in a highly autonomous way, requiring only one operator [56]. This could be further extended in total autonomous operation, but regarding the high loads involved, it is preferred that there is some human control. Control of the lifting operation is done from the bridge, where there is a clear view over the total hold. The only thing the officer involved would have to do is to press a button every time a hatch has to be lifted and when it is clear that the next hatch is located underneath, which should be clearly visible from the bridge. In addition to visual confirmation, cameras are also be installed at location 8, to have an even better overview. If however one of the systems does not seem to work in automatic mode, it should be possible to control the whole system manually to ensure operation, although this would involve more working hours. To ensure safe operation of the lifting system, consisting of four separate systems, multiple measures are built in the control system. First of all, the occurring hydraulic pressures inside the four points are measured, to check an evenly distributed lifting process. Furthermore the strokes are checked, to validate that the four points move at the same pace. Besides the checks inside the control mechanism, mechanical measures are in place to ensure all four points are in full contact with the hatches, using contact pads which are deformable. In the extreme event that one point fails completely there is sufficient back up capacity in the other three points, as the cylinders are load tested at 125 % of their rating, together with the fact that the system is designed on 80 % of the working load of a cylinder.

Flexibility

Currently, the system is designed in such a way that it is possible to open the total deep part of the hold, with the stacking above the garage-deck of the vessel. This particular stacking location is chosen as the carrying capacity of the garage-deck is quite low and no big project cargo parts are stored there. However, stacking at location 8 reduces the overall flexibility of the vessel operation. So in order to open location 8, two options are available. Hatch 8 can be lifted of using the onboard cranes, as nowadays is normal, or hatch 8 will be stacked on hatch 7 and will be rolled back to hatch 7. Only the pressure rating of the small HPU has to be adjusted for this purpose, as the rollers and cylinders itself are able to carry such a load. As it is expected that hatch 8 has to be opened during a port call, after the rest of the hold is filled with cargo, first is chosen for the lift-away system. If however this proves to be insufficient, the HPUs can be adjusted.

Crane driving hours hold opening

The new system completely reduces the crane driving hours to zero, as the system is designed in such a way that no crane is necessary during normal operation of hold opening. It means that loading preparations can start immediately after mooring, as the cranes are available immediately and thus reducing the involved port time.

Together with complete crane-less operation of hold opening, the working hours of the personnel involved are reduced as well, making them available for other tasks. If the system is as autonomous as stated in the previous section, the required personnel for opening the hold is reduced from 4 to 1. As the system is also faster, being 97 minutes for the total hold, instead of the current 120-240 minutes, the total reduction can be up to 6.5 - 14.5 working hours, a great reduction in the busy period of entering port and handling cargo.

6.2. Impact on operations

The new system is specially designed for the J1800-class vessels of Jumbo Maritime and has to function in the total operation of the vessel. First an analysis is made for the applicability of the new system on recent projects. After that the impact of the new system on the need of skidding projects is evaluated. Furthermore the new system has a distinct mode of operation of stacking the hatches at the aft position. The impact of this stack on the operations is defined, after which a conclusion is drawn on the question whether the new system is applicable to current operations.

Applicability in recent projects

As the system is designed for J1800-class vessels, the impact on operations in past projects of the J1800-class vessels is analyzed to see its applicability. All the shipping projects of the vessels of the years 2016 and 2017 are checked. Three options are possible: the system is direct applicable, the system is not required, or there would be no possibility to use the system. The percentage of usability is calculated using the number of port calls where hold opening would actually be required.

A note is made regarding the Jumbo Javelin, as this vessel made a series of port calls where the system would be partly useful, but would not give a direct advantage. This number is not displayed in Table 6.5, but equals 13 port calls, which have been left out of the evaluation.

The results of the analysis can be found in Table 6.5, where the estimated applicability is **65%**.

Table 6.5: Applicability of system to past projects.

Vessel	Total port calls	Not required	Direct applicable	Not possible	Percentage of usability [%]
Fairpartner	36	11	20	5	80
Fairplayer	25	10	13	2	87
Jumbo Javelin	50	12	17	8	45
Jumbo Jubilee	32	8	16	8	67
Total	**143**	**39**	**68**	**23**	**65**

Load shifting operation

Furthermore, to give an indication into the need for a load shifting system, in the analysis of the two years, the shifting system would have been applicable during **one** shipment, which was a voyage from from Brazil to China. A total of three FPSO Modules were shipped, from which two modules had to be shifted, one to the front of the vessel and one to the aft. The total planning of the load shifting contractor is depicted in Table 6.6.

Table 6.6: Load shifting project voyage Brazil - China.

Activity	**Days**
Sailing of vessel from mobilization port to loading port	4
Installation skidding equipment on vessel	2
Loading module 1	0.5
Skidding module 1	0.5
Repositioning skidding equipment	2
Loading module 2	0.5
Skidding module 2	0.5
Shipping from Brazil to China	39
Preparations in China (not in critical path)	2
Skidding module 1	0.5
Unloading module 1	0.5
Repositioning skidding equipment	2
Skidding module 2	0.5
Unloading module 2	0.5
Removal and packing skidding equipment	3
Demobilization equipment from China	40
Total rental time	**98**

The total rental price for the equipment, accompanied by the hire of four persons of the subcontractor was about €285.000. As can be seen in Table 6.6, the total rental time includes transit to China from Brazil and the demobilization of the equipment back to the subcontractors office. On top of that, the repositioning and installation of the equipment takes up to 9 days in the critical path of the vessel.

With the new system in place, with a mobilization time of one day, repositioning of 0.5 day and time spent on demobilization again one day, the total saved time in this project could run up to 7 days. Considering the day-rate of the vessel being around € 25.000, the additional savings could be € 175.000. This would bring the total saving for one skidding project up to **€ 460.000**.

Impact on stability

When the system will be used, all the hatches will be stacked at the aft of the vessel, at location eight of the main deck hatch covers. With a stack of 12.8 meters high, and the weight of an individual hatch cover being 100-120 tonnes, the stability of the vessel will be affected. The effect of the stack on the vessel stability in port will be evaluated, as the system will only be used in port. The results of the evaluation can be found in Table 6.7.

Table 6.7: Comparison stability closed hold and stacked hatches.

	Closed hold	Stacked hatches
Metacentric height [m]	3.83	3.77
Trim [m]	0.72	2
Maximum shear force [%]	51	56
Maximum bending moment [%]	38	44

As can be seen in Table 6.7 the metacentric height decreases 0.06 meters, almost a negligible difference. More important is the trim increasing 1.18 meters, so the vessel will tilt longitudinally. This has to be compensated, due to the fact that for loading the vessel has to be in horizontal position. This is achieved by ballasting the fore peak of the vessel, although this will increase the bending moment in the vessel. However, due to loading the hold, the bending moment will decrease due to the fact that there is cargo stored in the middle of the vessel. Also the allowable bending moment increases in port with 30 %, which ensures sufficient loading capabilites for the vessel. It can therefore be concluded that stacking the hatches on position 8 has a small effect on the total stability, although requiring the vessel to ballast the fore peak to achieve an even ship. This however does not have significant consequences for the loading capabilities of the vessel.

6.3. Impact on ship design

As the design has to be incorporated in the vessel, the impact on the ship design will be discussed. An estimation of the amount of steel that has to be added is given, as well as a summary of the major changes and possible effects.

First, several structures have to be removed from the vessels structure, being:

- Diagonal part of guide pillars on coaming
- Stoppers on coaming
- Cleats on coaming
- Fenders of the hatches

Furthermore, several structures have to be added to the vessel, being:

- Extra guide pillars (spacing 3.2 meter instead of 6.4)
- Coaming reinforcement
- Circular beam between pillars starboard
- Reinforcement between pillars port side
- Adjustments to hatch cover
- New stoppers port side
- New stoppers starboard
- New cleats starboard and port side

The new pillars on both port side and starboard will be spaced every 3.2 meters instead of the current 6.4 meters. As there are multiple facilities located in the void, together with some doors to access those facilities, it has to be assured that there will be no clashes of the pillars with the doors with respect to opening and closing. Considering the available height in the corridor and the height of the doors, it appears that there will be no significant problems, but it is a point of consideration.

Also, the total space between the void and pillars will be covered with structural steel on port side. A point of consideration is the fact that the green water will take longer to be removed from the top deck during heavy weather as currently the water flows away through the lattices between the pillars. Some modifications can be made to the structure, including some holes, but it will not equal the lattices currently installed on board of the vessel. A positive implication is the increased deck strength, as the lattices give problems due to a lack of strength. There is no possibility to store shackles on top of the lattices and they are not suitable to drive over with a fork lift.

Besides the structural steel that has to be added, equipment required for execution of both functions has to be incorporated in the vessel structure. A distinction is made between hold opening and load shifting equipment. Hold opening equipment will have to be permanently installed, whereas load shifting equipment is installed whenever a project requires it.

For hold opening the following equipment is installed:

- Winch (4x)
- Climbing jack facilities (4x) at location of hatch 8
- Hydraulic cylinders and HPUs for hatch lifting (4x)
- Rollers for both hold opening(4x)
- Hydraulic power system for hatch stacking
- Control system

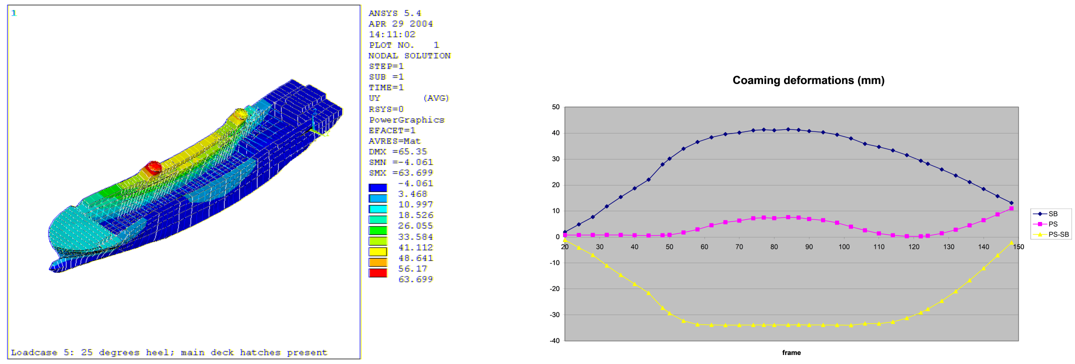
For load shifting preparations are made in order to easily install the following equipment:

- Strand jack and accompanying facilities (4x)
- Hydraulic cylinders for hatch lifting when in load shifting mode (20x)
- Rollers for load shifting (20x)
- HPU for strand jack system
- Synchronous lifting system for load shifting

All equipment has to be able to operate in a hostile marine environment.

Stopper design

The starboard stoppers change significantly, with only restrictions in longitudinal direction left, instead of both longitudinal and transverse direction. This implies that the starboard coaming can move without moving the hatch, as the hatch is only restricted in transverse direction on the port side coaming. The loads on the coaming can be such that the deformations are significant, as can be seen in Figure 6.1. This analysis is however done with the current main deck hatches present, without the new unconstrained starboard hatches.



(a) Load case: 25 degrees heel.

(b) Coaming deformations during load case.

Figure 6.1: Coaming deformations.

As can be seen in Figure 6.1b, the coaming deformations at starboard are significant, also is clearly visible that due to the fact that the hatch is restricted in transverse direction on both sides, as the maximum deformation is limited at 33 mm. In the new design it has to be assured that the hatch cover stays on the coaming regardless of the deformations.

Decrease in void strength

With the loss of the part of the guidance pillars on the coaming, it is well possible that the void strength decreases, furthermore the effect of the extra pillars is examined as well. The old situation, new situation port side and new situation starboard are compared with each other with respect to stress and deformation. Results are all summarized in Table 6.8. The total loading model can be found in Appendix C.

Table 6.8: Analysis void strength.

	Old situation	New situation port side	New situation starboard
Maximum stress [MPa]	225.93	110	261
Maximum deformation [mm]	4.97	3.07	3.85

The comparison points out that the starboard section decreases slightly in strength, whereas the port side section shows an increase. The decrease at starboard side is not seen as very problematic, as much more cargo is stored at port side, due to the fact that the starboard side is quite occupied with cranes and other equipment.

6.4. Safety assessment

Safety is of paramount importance to Jumbo Maritime and a specially in-house developed program is in place to focus on safety. At Jumbo Maritime zero Lost Time Injuries (LTI) is the goal and operation to the highest safety standards is a mean to achieve this goal. For this purpose Jumbo Maritime developed the Stay Well program.

Part of the Stay Well program is the risk management of operational, health, safety and environmental hazards. Jumbo Maritime uses a layered approach to safely and effectively manage all the risks involved. This approach has four levels:

- Risk Inventory and Evaluation (RI&E)

- Hazard Identification Study (HAZID)
- Job Hazard Analysis (JHA)
- Last Minute Risk Analysis (LMRA)

The first level, being the RI&E, is a mandatory assessment required by both the Dutch ARBO as the MLC (Maritime Labour Convention). It forms the complete assessment for the occupational safety, health and welfare risks. It is a document made for the whole vessel. This is followed by a HAZID, which is a method for early and systematic identification of potential hazards and threats for a complete new job, starting from arrival to departure of a vessel, comprising of all the potential risks involved and identified by several different departments. From the general hazards, a more detailed analysis is carried out for specific individual jobs and tasks within a scope of work: The Job Hazard Analysis. A JHA goes more into detail and describes hazards and risk reducing measures for each individual step during a job. At last, a Last Minute Risk Analysis is developed by Jumbo Maritime. This is a yellow plastic pocket size card as a tool for each crew member to determine whether he or she is prepared to do the job at hand or not.

One of the constraints placed on the new system is the level of safety during operation. As the new system describes a new job, being hold opening by using the new system, a new JHA is made to be able to compare both old and new situation. This document can be found in Appendix I, together with the risk matrix. Only the hold opening safety is compared, as the skidding is nowadays done by a third company, who makes its own safety analysis during a project.

The JHA is divided into the distinct tasks of the hold opening. In these tasks there is a distinction between mechanical failure of all the components and the human involvement in the operation. In comparison with the current system in place at the vessels, there is a serious decrease of people involved in the total operation and therefore the operation will logically be safer for people involved. However, there are some points that require attention during operation. As the system is highly autonomous, other processes will continue on board the vessel. It therefore has to be clear during total operation for all personnel on board of the vessel that the system is running, as hatches are moving and there are moving parts on the coaming. To notify crew, an alarm can go of every time a new task is initiated by the system. Furthermore the hold will be opened, so the fences around the hold have to be placed before opening, as there is a significant chance of people falling in otherwise. Also the operation of the hatches has to be safe, seeing the high loads that are involved. Monitoring of the operation using cameras is required. Furthermore the system is designed in such a way that pressure loss of one cylinder does not result in a total failure of the stacking mechanism, resulting in the loss of hatches into the cargo hold.

Comparison of safety aspects

Comparing both the current system and the new system it is concluded that this new system can contribute to the goal of Jumbo Maritime of zero Lost Time Injuries on board of the vessels. The risks involved in operation are transferred from the workers in the current situation to mechanical parts of the new system. Into those mechanical parts a high redundancy is built in, in order to have a safe operation. Engineering up front can ensure a smooth operation, with only risks remaining for assets, environment, schedule and reputation, as also can be seen in the risk matrix depicted in Appendix I. The highest risks are attributed to the damaging of assets in the hold in case of a hatch falling into the hold. It is however possible to reduce this risk in a high way by making it extremely unlikely that in case of a mechanical failure a hatch can fall into the hold, seen its increased width at port side and the fact that also the total starboard side coaming is covered by a hatch.

All in all it is safe to say that human risk decreases with the new system and with sufficient engineering and thoughts up front, the operation can be made safe by proper engineering and selection of proper equipment for execution of the tasks involved. However, until current date no incidents have been reported, so no figures can be given to estimate the increase in overall safety. Only a warning has been issued by the QHSE department after a worker rode along with the hatch when it was being lifted from the hold. A conclusion is drawn upon the fact that safe operation of the hold opening does not necessarily mean that there are no risks involved. Operation will include less human risks in the new system, thus decreasing the overall chance on an incident.

7
Economic analysis

After analyzing the design in Chapter 6, an economic analysis regarding profitability is done for the new design. The economic projections for Jumbo Maritime are analyzed and quantified. First, the costs of implementation are examined, after which the benefits are explored. A cost benefit analysis is then made, with an accompanying advice for Jumbo Maritime.

7.1. Theory of economics

The economic analysis is performed over multiple years, due to the expected life time of 15 years. Therefore some theory is described, necessary for understanding the underlying principles required to perform an accurate economic prediction. Use is made of the term: 'Time value of money', which is explained in the following manner. Investors, or a company, prefer to receive money today instead of receiving the exact same amount of money in a couple of years, since the potential of money can grow in a period of time. In other words, the value of money depreciates over time, normally with a yearly percentage of 5-10 %. In this report, a discount rate of 5% is assumed. The present value of the total lifetime is expressed in the Net Present Value (NPV). With the given discount rate, the formula for the total Net Present Value equals [59]:

$$NPV = \sum_{t=1}^{T} \frac{C(t)}{(1+i)^t}$$

With

- C(t) = Cash flow in corresponding year t
- i = Discount rate
- t = Cash flow period

All costs have to be expressed in the NPV values to give an accurate prediction of the profitability of the new system. As the capital costs are already in present values, due to the fact that they have to be paid upfront, they do not depreciate. Furthermore two other concepts are used to determine the added economical value of the new system, being: the estimated the payback year, in which the system starts earning money after the initial costs and the Value Investment Ratio (VIR), which equals:

$$VIR = \frac{NPV}{CAPEX}$$

With

- NPV = the NPV of the total future cash flow
- CAPEX = Capital expenditure (initial investment value)

7.2. Costs of system

In this section the total costs of the system will be examined. The total costs of the system consist of the following major items, which will be examined separately

- Equipment
- Conversion of J1800-class vessel
- Operational costs

Equipment

The equipment required for the new system is a big part of the total investment costs and is therefore analyzed. The equipment required for the conversion was previously listed in Section 6.3. The total costs of equipment for only the hold opening system is summarized in Table 7.1. As the equipment listed comprises only of the major components of the system, an additional surcharge of 10 % is added for small components, such as cables and small structural works.

Table 7.1: Price specifications of hold opening system.

Equipment	**Unit prize [€]**	**Source**	**Quantity**	**Total prize [€]**
Rollers Hilman 200T	2.100	[58]	4	8.400
Cylinders hold opening 100T	7.200	[21]	4	28.800
Saddles cylinders	210	[20]	4	840
Hydraulic power unit hold opening cylinders	900	[28]	4	3.600
Propulsion winch	18.000	[32]	4	72.000
Climbing system cylinders and HPU	536.000	[11]	1	536.000
Climbing bars	1.866	[11]	14	26.124
			Subtotal	675.764
			Additional parts (10 % of subtotal)	67.576
			Total prize	743.340

Table 7.2: Price specifications of load shifting system.

Equipment	**Unit prize [€]**	**Source**	**Quantity**	**Total prize [€]**
Rollers Hilman 200T	2.100	[58]	20	42.000
Cylinders hatch lifting 100T	7.200	[21]	20	144.000
Saddles cylinders	210	[20]	20	4.200
Strand jack system, including HPU and strands	72.5000	[3]	1	72.500
Synchronous lifting system	50.000	[60]	3	150.000
			Subtotal	412.700
			Additional parts (10 % of subtotal)	41.270
			Total prize	453.970

Conversion of J1800-class vessel

To accommodate the new system, the vessel has to be conversed quite significantly structurally to account for the increased forces on the coaming, altogether with creating the necessary infrastructure for the equipment. The conversion costs are divided into multiple parts. First the cost involved in the structural conversion of the vessel, secondly the costs involved in integrating the new equipment on board of the vessel and furthermore the costs of the lost time spent on the yard for the vessel, in other words, time that otherwise could be spent doing projects.

Conversion cost

From the structural analysis performed in Section Section 5.2, an estimation is made of the additional steel that has to be added to the existing vessel structure. All this is summarized in Table 7.3. As can be seen, a lot of steel is required for the conversion of the steel hatches. If new hatches will be acquired, this could be reduced, but first this amount of steel is considered. Furthermore an additional 25% of steel is added, due to the fact that there is still a high uncertainty in the necessary steel for implementation of the various new components.

In the surcharge also the adjustments to location eight of the hatches is included. With a structural analysis that is performed with a higher level of detail, this level of uncertainty could be reduced.

Table 7.3: Estimation of total additional steel.

Additional steel port side	101 tonnes
Additional steel starboard	75 tonnes
Additional steel hatch covers	203 tonnes
Contingency steel	25%
Total additional steel	473.75 tonnes

As is normally done in conversion projects, a unit price per kilogram of steel is used to estimate the total conversion costs. As this depends on the location of the conversion yard, three options are given in Table 7.4. The unit prices depicted are the total price for new build vessels in current market conditions. These prices compare well with respect to costs involved in conversion projects. For logistical matters, as well as a higher quality guaranteed in Western-Europe, these yards are first considered, bringing the conversion costs to **€ 1.895.000**.

Table 7.4: Conversion costs around the world.

Yard location	**Unit price per kilogram steel [€]**	**Total conversion cost [€]**
Turkey	3	1.421.250
Western Europe	4	1.895.000
China	1.5	710.625

Integration of new parts into vessel structure

Besides the acquisition of parts for execution of both load shifting and hold opening functions, the parts also need to be installed on the vessel. A division is made into parts that need to be permanently installed on the vessel and parts that are installed whenever a project requires them. As all parts of the hold opening system will be permanently in place on the vessel, these parts need to be integrated. The equipment required for the load shifting system is an extension of the hold opening system and is only be installed on board of the vessel when required. This results in the fact that only hold opening equipment is permanently installed. An additional surcharge of **75%** on top of the capital costs is accounted for installation on board of the vessel, resulting in addition of **€ 557.505**.

Lost time costs

Conversion costs are not the only costs related to the total costs of the system, lost time involved in conversion is also accounted for. Docking a vessel is very costly, given the current day rates of the vessel. Therefore it is of high importance that the total operation goes as smooth as possible, without any delays. For this purpose, the total conversion process is planned. A work-breakdown structure (WBS) is made, to get an overview of all the tasks at hand, together with the time involved in the process. A WBS is a project management tool oriented on a breakdown of deliverables into smaller components. This breakdown helps to organize the total work involved in the project into small, manageable sections that have a clear scope and time budget [1]. The WBS can be found in Appendix J, as well as the accompanying Gantt chart for a more detailed view of the planning of the conversion. The planning of the conversion is based on an actual planning of a docking of a J1800-class vessel.

The total time involved in the conversion is **32.5 days**. With the total time involved in the conversion, the lost time costs are defined. These costs equal the total time of the vessel in dock times the day-rate. This results in a total of **€ 812.500**.

As these costs are quite high, it might be favourable to combine the conversion together with a special survey. A special survey is required for a vessel every five years, due to classification society rules [13]. A special survey basically includes a thorough check of the complete vessel and hull, to guarantee its safe operation for the coming five years. For the J1800-class vessels, this special survey for all four vessels are scheduled in 2018 and 2019, which makes it beneficial to combine the conversion and the special survey. The last special survey conducted on a J1800-class vessel was scheduled for 28 days. Although some conversion projects might interfere with survey tasks, it is estimated that both projects are combined, resulting in a 20 days time saving. Due to the combination of a special survey together with the conversion, the lost time costs are estimated at **€ 312.500**.

Operational costs

Not only the costs upfront contribute to the total cost of the system, but also the cost during operation. Major parts of operational costs are the replacement costs and maintenance costs.

Replacement of rollers

A large part of operational costs can be accounted for the costs of replacements, and therefore it is analyzed if the rollers need to be replaced in the design lifetime of 15 years. The rollers are considered since it is expected that these experience the most wear and tear during their life time, as it is the part that moves the most. Rollers are designed for a certain number of rotations, which translates to a certain distance travelled. It is assumed that the wear only occurs when the rollers travel under a load, so only when carrying a hatch. As there are two modes the rollers are being used in, the analysis is done separately for hold opening and load shifting. For a total hold opening sequence, the rollers are carrying a load for half of the time, as they have to travel back an forth to location 8, where the hatches are stacked. The total distance travelled for hold opening (or closing) is 28 times a hatch length; 360 meters. So, for one port call where the system is utilized, the rollers travel 720 meters in loaded condition. From Section 6.2 the total use of the system is deducted. Around 18 port calls are done in a year for one vessel, with an applicability of 65 %, resulting in 12 port calls where the system is used. Assuming that the hold always has to be opened completely, the rollers travel 8640 meter in a year.

For load shifting operations, 24 rollers will be used, so the load on the roller is different. With the load on the roller being different, the life-time of a roller is also different. For a load shifting operation, including one shifting operation to front and one to aft, with loading and discharging, the distance travelled in one operation under full load is 200 meters.

Table 7.5: Lifetime analysis rollers [48].

	Hold opening	**Load shifting**
Total design rotations	$5 \cdot 10^5$	$1 \cdot 10^4$
Diameter individual roll	49 mm	49 mm
Total rotations in one year	28.000	650
Lifetime of roller	17 years	15 years

From Table 7.5 it is concluded that for both load shifting and hold opening operations, the lifetime of the rollers is sufficient. Problems might occur in the last year of operation, where the rollers almost have had their number of rotations. It has to be noted however, that for increasing number of port calls, or higher number of load shifting operations, the lifetime decreases, so it is recommended that this is kept track of. Also, for the load shifting life time estimation is assumed that a load of 1800T is shifted every time, which does not have to be the case, so 15 years lifetime is a conservative approach. Furthermore it might be the case that the hold is not opened completely every port call, further increasing the lifetime of the rollers. A first analysis points out the rollers are selected properly, if however the expected operation conditions will vary, the selected rollers have to be reconsidered.

Maintenance and replacement other components

As the day-rate of a J1800-class vessel is around €25.000, it is of the highest priority that a vessel does not waste unnecessary time and therefore functioning equipment is of high importance. With this fact known, a maintenance and replacement strategy is defined.

For small and relatively cheap equipment, being the rollers, the hydraulic cylinders attached to the rollers and the small HPUs, a sparing philosophy is adapted. In this way small components are kept spare, to easily replace those parts when they break during critical time spent in port. For bigger equipment, being the stacking technology, the winches and load shifting equipment, a preventive maintenance scheme is adopted.

Multiple reasons can be given for a preventive maintenance scheme. First of all, in between usage of the system a lot of time is available for maintenance during voyages. Secondly, the big equipment is too costly to have spare, a spare stacking cylinder costs around € 134.000, and a winch €18.000.

Regardless of which maintenance scheme is adopted, a global cost of maintenance is defined. Maintenance costs are related to the costs of replacing an entire asset. A so-called percentage of the Replacement Asset Value (RAV) is used for estimation of maintenance costs. The RAV again is related to the equipment costs. Optimal yearly maintenance costs related to this RAV lie between 1-3 % [50]. A conservative choice of maintenance costs will be estimated at 3 % of the replacement asset values. The yearly maintenance costs can be found in Table 7.6.

Table 7.6: Maintenance costs estimation.

Yearly maintenance costs hold opening system	€22.300
Yearly maintenance costs load shifting system	€13.619
NPV maintenance costs hold opening system [15 years]	€231.469
NPV maintenance costs load shifting system [15 years]	€141.362

7.3. Benefits of system

With the costs clearly analyzed, the benefits of the system are explored, to give a clear insight if it might be beneficial for Jumbo Maritime to install such a system on the J1800-class vessels. The benefits are divided in several parts, being:

- Reduced port costs
- Reduced rental prices skidding system
- Increased availability

Reduced port costs

A possible benefit of the new system could result in lower port costs, as time spent in port could decrease. Before an estimation is given of the possible port costs savings, the build up of port costs is explained.

Port costs

Port costs differ from port to port, but can globally be divided into three parts [42]:

- General tariffs
  - Port dues
  - Wharfage
- Facilities tariffs
  - Berth hire
  - Transit storage (short term)
- Service tariffs
  - Pilotage
  - Towage
  - Berthing/unberthing, mooring
  - Stevedoring, wharfhandling
  - Equipment hire
  - Cargo processing
  - Warehousing
  - Fuel, utilities

From these three port costs, only the facility tariffs are time dependant, with berth hire being the one where savings can be realized. Other costs will remain constant, as these are purely related to a port call, with or without the new system these costs will be have to accounted for. For the year 2016, the total time spent in port, combined with the total spent port costs, are summarized in Table 7.7. This information is retrieved from Jumbo Maritime's own internal system.

Table 7.7: Port costs summary of 2016.

Vessel	**Number of port calls**	**Time spent in port [days]**	**Mean port costs [€]**
Jumbo Jubilee	20	6.09	20.981
Fairpartner	23	5.4	19.745
Jumbo Javelin	39	2.14	19.575
Fairplayer	17	4.81	21.389
Mean	**24.75**	**4.15**	**20.210**

Assumed by Jumbo Maritime is that the facility tariffs equal about 30 % of the total port costs. With a mean time spent in port of 4.15 days, or 99.6 hours, the total reduced port costs are estimated. As explained, the time spent on handling hatches depends on the circumstances, resulting in a win of 3 to 12 hours per hold opening or closing operation. This results to a total time saved for one port call from roughly 6 to 24 hours. The estimation is made based upon the average port calls made in 2016 and 2017, depicted in Table 6.5.

Table 7.8: Estimation reduction port costs.

Total port costs	€ 20.210
Facility tariffs	€ 6.063
Reduction [low bound]	6 hours
Reduction [high bound]	24 hours
Reduction [low bound]	€ 365
Reduction [high bound]	€ 1.461
Applicability new system	65 %
Total reduction yearly [low bound]	€ 4.273
Total reduction yearly [high bound]	€ 17.093
Mean total reduction yearly	€ 10.683
NPV total reduction [15 years]	€ 110.889

From Table 7.8 is concluded that the total savings for one J1800-class vessel on yearly basis are not high, but can contribute to a total beneficial situation for Jumbo Maritime.

Reduced rental prices skidding system and possibility of cooperation

With the total cost of the rental system being € 288.970, the need for the skidding system is first considered, to explore the possibility of a shared skidding system for the four J1800-class vessels.

Trend for skidding system rental

As can be read in Section 6.2, only one rental of a skidding system was required in two years time for all four vessels. The years considered in Section 6.2 are 2016 and 2017. In Figure 7.1 can be seen that the oil price made a steep drop in 2014, followed by two years of decline. It is therefore logical that the need for skidding systems was low in the years considered, as historically Jumbo Maritime had a lot of projects related to oil and gas. For example, refinery reactors, FPSO modules or even parts for offshore jackets. So, low oil prices mean low investments and thus not a lot of projects.

Figure 7.1: Oil prices for the years 2013-2018 (checked 16-05-2018) [37].

In Figure 7.1 also can be seen that the oil price is recovering, with a significantly higher price for 2018 compared to the years 2015-2017 [38]. A higher oil price normally means a grow in field developments coming online, an indication for new projects for Jumbo Maritime. An important signal for upcoming shipping projects is the number of Final Investment Decisions (FID) for oil and gas projects. With a decline of 132 FIDs from 2014 to 2015 and a further decline in 2016 of 45 projects, it was not a surprise the need for skidding was low in 2016 and 2017, as the average project duration is 2-3 years. The number of FIDs is slowly growing, with an increase of 32 projects in 2017 [40] [36].

Therefore an estimate is made that the need for skidding equipment will grow after years of decline of FIDs. Where the need of skidding equipment was only one project in two years during the downturn, for a growing number of FIDs it is estimated that the number of projects grow from one in two years, to one per year. The estimation made is preliminary and has to be examined more thoroughly, as the oil prices are highly fluctuating and it is therefore hard to give a firm estimation.

Reduced rental costs

As can be seen in Table 7.9, the estimation that the number of projects will grow in the coming years leads to a NPV of the total reductions of rental prizes in 15 years of €4.7 Million. Savings for one year could run up to €460.000, making it already attractive to consider.

Table 7.9: Savings skidding system rental total lifetime for all J1800-class vessels.

Skidding projects per year	1
Savings for one skidding project	€ 460.000
Savings per year	€ 460.000
NPV Savings total lifetime	€ 4.774.643
NPV Savings one vessel total lifetime	€ 1.193.661

Shared load shifting system

With an estimation of one load shifting project per year, a potential new benefit arises. As the acquisition costs of a skidding system is around € 453.970 per vessel, it is investigated whether sharing one load shifting system is beneficial for Jumbo Maritime. Jumbo Maritime already has a system of shared lifting beams, which are being transferred from vessel to vessel. This is also possible for a load shifting system, which suits itself for containerization. As there are several so-called bunker ports in the world, being a central location on busy traffic lanes, these ports also suit itself for storing the skidding equipment container, where it can be picked up by the vessel. If the vessel does not pass the specific bunker port, it can also be shipped by a third company, which costs around €1.500 per container [47]. Storage of a container is estimated at € 12/week for a Twenty Foot Equivalent Unit (TEU) container. The results of the analysis for a shared load shifting system are depicted in Table 7.10. A project duration of a skidding operation is normally three months, including mobilisation, execution and demobilisation. With only one load shifting operation per year, the system will be in use for three months, resulting in nine months of idle time. So, the system will have to be stored on a quay side for 39 weeks. With this storage location, it is estimated that the system has to be shipped one time to the project. It could well be that the container can be picked up by the dedicated vessel, but a conservative approach is taken. In Table 7.10 can be seen that sharing one load shifting system for four vessels is beneficial. If there is a sudden increase in load shifting projects another system can be acquired. The total costs involved in renting justify the acquisition of another, self owned system, also as the infrastructure is readily available on the vessels.

Table 7.10: Sharing load shifting system benefits and costs for all J1800-class vessels.

Increased benefits load shifting system sharing	
Reduction maintenance costs [yearly]	€ 40.857
Reduction capital expenditure	€ 1.361.910
NPV total reduction 15 years	€ 1.785.995
Increased expenditure load shifting system sharing	
Storage costs containerized load shifting system (39 weeks)	€ 473
Shipping costs containerized load shifting system (1 time)	€ 1.500
NPV total costs 15 years	€ 20.474
NPV result 15 years	€ 1.765.521

Increased availability of J1800-class vessels

As can be read in Section 6.2, the estimated applicability of the system is 65 % and the average number of port calls equal 18 per year. As for the reduction of port costs, also the increased availability for the J1800-class vessels is estimated. Again, a total time saving for one port call is estimated at 6 to 24 hours. The utilization of the J1800-class vessels is estimated at 94%, after analysis of the voyages of 2016 [23].

Table 7.11: Increased availability one J1800-class vessel.

Average number of port calls per year	18
Time saving for 1 port call[low bound]	6 hours
Time saving for 1 port call[high bound]	24 hours
Total time saved in one year [low bound]	108 hours
Total time saved in one year [high bound]	432 hours
Day-rate J1800-class vessel	€25.000
Utilization rate	94%
Total yearly saving [mean]	€ 265.375
NPV total savings (15 years)	€ 2.744.122

7.4. Summary cost-benefit analysis

With the total costs and total benefits known for the lifetime period of 15 years, a conclusion is drawn on the question whether a combined hold opening and load shifting system is beneficial for Jumbo Maritime to implement. First, the total costs and total benefits are summarized in Table 7.12 and 7.13.

Table 7.12: Total costs of new system for one J1800-class vessel.

Capital expenditure	
Equipment hold opening	€ 743.340
Equipment load shifting	€ 453.970
Conversion	€ 1.895.000
Integration of equipment	€ 557.505
Lost time costs	€ 312.500
Total	**€ 3.962.316**
Maintenance costs	
Yearly maintenance hold opening	€ 22.300
Yearly maintenance load shifting	€ 13.619
NPV total costs maintenance hold opening 15 years	€ 231.469
NPV total costs maintenance load shifting 15 years	€ 141.362
NPV total costs [15 years]	**€ 4.335.146**

Table 7.13: Total benefits of the new system for one J1800-class vessel.

Savings related to hold opening	
Yearly savings port costs	€ 10.683
Yearly increased availability	€ 264.375
NPV total savings hold opening in 15 years	€ 2.855.011
Savings related to load shifting	
NPV total savings load shifting in 15 years	€ 1.193.661
NPV total savings in 15 years	€ 4.048.672

In Table 7.14 the summary of costs and benefits for the whole fleet of four J1800-class vessels is given, with a maximum net result of **€ 619.624** in 15 years.

Table 7.14: Summary costs and benefits all four J1800-class vessels.

NPV total costs all vessels 15 years	€ 17.340.584
NPV total benefits all vessels 15 years	€ 16.194.687
Net result 15 years	€ -1.145.897
NPV Additional benefits skidding sharing 15 years	€ 1.765.521
NPV result 15 years	€ 619.624

Even more interesting than the total benefits of the system in the design lifetime of 15 years is the payback period. The payback period is the time involved in earning back the upfront investment by yearly savings. In case of the acquisition of four load shifting systems, the payback period equals 5.9 years, whereas the payback period equals 4.7 years when only one load shifting system is bought, due to lower capital costs and lower maintenance costs.

Table 7.15: Payback period calculation.

Capital costs(4 shifting systems)	€ 3.962.316
Capital costs(1 shifting system)	€ 3.621.838
Yearly benefits	€ 706.308
Yearly costs (4 shifting systems)	€ 35.919
Yearly costs (1 shifting system)	€ 25.705
Net result yearly (4 shifting systems)	€ 670.389
Net result yearly (1 shifting system)	€ 680.603
Payback period (4 shifting systems)	5.9 years
Payback period (1 shifting system)	5.3 years

Besides the payback period, the VIR is estimated at **1.04**, in case of acquisition of one load shifting system. This means that in net present values, the benefits are 1.04 times higher than the capital costs. A VIR of 1.04 means that the investment will be beneficiary to the company, as the long term results are higher than the capital costs. However it might be beneficial to explore other investment options, as there might be higher Value Investment Ratios possible with the same capital investment.

7.5. Sensitivity analysis of economic predictions

The performed economic analysis is based on a number of assumptions. A sensitivity analysis of the economic predictions is performed to give more insight in the results. Goal of this analysis is to check what the most important drivers of the economic performance are and to identify areas that require additional research to further solidify the predicted profitability of the new system. The results are depicted in Table 7.16, where the assumption is made that one load shifting system will be acquired, which will be shared. The analysis is done for the total of four vessels, so the total investment is considered.

Table 7.16: Sensitivity analysis economic predictions regarding NPV total investment and payback period.

Varying factor	NPV [Million €]	Payback period [years]	VIR [-]
Increase of steel prize to €8/kg	- 6.96	8.1	0.70
Decrease of steel prize to €1.5/kg (yard in China)	5.36	3.6	1.49
Decrease of skidding projects to one per two years	- 1.77	7.8	0.89
Increase of skidding projects to two per year	5.39	3.3	1.35
Conversion time of vessel 32.5 days	- 1.38	6.1	0.92
Maintenance costs to 6 % of RAV	- 0.45	5.5	0.97
Day rate of vessel to €20.000/day	- 1.33	5.7	0.91
Decrease of port calls to 9/year	- 5.09	6.7	0.67
Savings of skidding rental system to € 300.000/project	- 1.04	6.8	0.93
New build vessel instead of current J1800-class	9.45	2.0	2.40

As can be seen in Table 7.16 the conversion costs regarding the steel prize is a very important factor for the economic profitability of the new system for the J1800-class vessels. It is beneficial for Jumbo Maritime to choose a yard in China instead of a yard in Western-Europe to have a higher profitability. Furthermore the need for skidding projects is of high importance and a more detailed analysis has to be performed into the expected occurrence of those projects, as it either could result in a positive or negative NPV. The profitability on the other hand does not depend greatly on the maintenance costs. If a new build vessel would be outfitted with a new system, this would result in a higher NPV and a lower payback period, due to the fact that the conversion and lost time costs would decrease to zero.

Overall is concluded that the profitability is depending on a number of factors, either one capable of diminishing the expected profit. Before an investment decision is made, it is therefore of importance that the factors that the expected profit is based on are validated. Otherwise cost savings should be realised.

7.6. Conclusion cost-benefit analysis

With all the costs and benefits of the system summarized the conclusion is made that investing in the newly designed system might be beneficial for Jumbo Maritime. However, investing in a load shifting system present on all J1800-class vessels results in a negative NPV of € -1.1 million. If only one load shifting system is acquired this results in a NPV of € 620.000. In this way it could be a cost saving project for Jumbo Maritime. Also, for a fleet that is already in service for 9 years, a payback period of 5.9 to 5.3 years is attractive, as the system is able to earn itself within remaining the economical life time of the vessels.

Another option would be to build the system in new vessels, which would drastically lower the capital costs, as the conversion cost and lost time costs would not be considered. Only in equipment costs would be considered, leading to a maximum NPV of **€9.4 Million** and a payback period of 2.0-2.6 years, due to the high positive net result of around **€ 680.000** yearly. This was however outside the scope of this assignment and is therefore not further investigated.

One of the most important factors that play a role in the profitability of the new system is the reduced rental costs of the load shifting system, as a third of the savings are accounted for in the comparison. A more detailed analysis of the expected need for skidding system can be carried out to get a more detailed insight in the possible savings of the system. Also the selection of a yard plays a significant role in the expected profitability.

8 Conclusion and recommendations

With the design process now completed a conclusion is made, accompanied by some recommendations. These recommendations entail suggestions for a possible next step in the Engineering Design Process, which was stated in Chapter 1. This process was iterated only once, so a next step can be done. Furthermore recommendations for Jumbo Maritime with respect to the design itself are given, in which points of improvement are given to further maximize the applicability of the new system.

8.1. Conclusion

With a proven technical feasibility of the design in Chapter 5, a proven operational feasibility in Chapter 6 and a proven economical feasibility in Chapter 7, it is concluded that overall the new design for a combined hold opening and load shifting system can be beneficial for Jumbo Maritime.

A reference is made to the goal stated in Chapter 1, which was:

"Develop and asses technical and economic feasibility of a system, or a combination of systems, for the Jumbo J1800-class vessels that enables them to shorten time spent in port, start handling cargo faster after mooring and enables the J1800-class vessels to load cargo of 1800 tons and shift it to front and aft of the ship".

The system that has been developed for the J1800-class vessels enables the vessel to open the hold in 97 minutes during mooring operations. In this way the time spent in port is shortened six to 24 hours and the crew is able to start loading cargo faster. This is even more the case since less workers are required for hold opening tasks, so preparation works can start sooner as well. Furthermore the system enables Jumbo Maritime to load multiple pieces of cargo of 1800T at mid-ship location and shift it to front and aft using the hatches. This system can be mobilized in a reasonable time frame, being one day. Total applicability of the system on the J1800-class vessels shipments is estimated at 65 %, based on previous projects conducted.

From a static structural analysis conducted is concluded that it is technically possible to convert an existing J1800-class vessel to integrate the newly developed system, with total conversion works taking up to 33 days, where a total of around 475 tonnes of steel would have to be integrated in the existing structure, for which a new seafastening design is developed.

Economically it would be beneficial for Jumbo Maritime as well. The Net Present Value of the total investment involved in converting a J1800-class vessel totals € 619.624 when one load shifting system is acquired for the total fleet of four vessels. The payback period of 5.3 years is also attractive for the company, as it allows a fast return on investment for Jumbo Maritime. The Value Investment Ratio equals 1.04, meaning the investment proves it feasibility in present day values.
Another benefit of the design for Jumbo Maritime is the improved safety of operations, with less workers involved and a highly automatized system, it emphasizes Jumbo Maritime's ambition to have zero Lost Time Injuries.

It therefore is concluded that overall the new system has several benefits which justify additional investigation by Jumbo Maritime to explore implementation.

8.2. Recommendations

As it is beneficial to explore the possible implementation of the new design into the vessels of Jumbo Maritime, some recommendations are given. The recommendations are split into two parts, one being the input for a next step in the Engineering Design Process, the central process in this assignment and some overall recommendations with respect to the design for the company Jumbo Maritime.

Input for next iteration Engineering Design Process

Several points of attention are given for a next iteration step, which is basically input for the new problem definition stated in Chapter 1. A first step would be a more detailed structural analysis for the design of details, like the part where the stacking technology grips onto the hatches, or the part where the cylinder lifts the hatches of the seafastening. Furthermore, the scope shifted from existing vessels to new build vessels. In this way, a next step could incorporate a total new design, which could enhance the integration of the system into a vessel structure, further reducing the need for additional steel works.

A second remark is made to the functional requirement of all the hatches being able to shift a load from mid-ship to front or aft. Due to changing wishes of Jumbo Maritime this can be reconsidered, which also makes the option of a combined folding and stacking system more viable.

Several recommendations are given to the structural analysis carried out. First, a combined analysis of both void loading and seafastening loads can be carried out, to give a more detailed insight in the combined stresses involved. Moreover, the overall analysis can be carried out in a higher level of detail, with special attention to the connection points.

Recommendations Jumbo Maritime

In order to further investigate the feasibility of a combined hold opening and load shifting system for the vessels of Jumbo Maritime, some recommendations are given. Most important for Jumbo Maritime will be the possible profit involved in implementation of the design, financially as well as overall benefits.

The financial benefits can be maximized if the design will be implemented in a new build vessel, instead of the conversion of existing vessels. Multiple reasons can be given for this, as the lost time costs are not incorporated in the total costs then, as well as the payback period is quite long for vessels that are already in service for more than 9 years. An additional recommendation on the subject of financial profit can be made with respect to the expected use of load shifting systems. The cost benefit analysis depends on these costs quite significantly, so a more thorough analysis can be done into the expected need of renting skidding equipment.

Besides the expected need for the load shifting system for the J1800-class it also can be considered to only adjust one or two vessels for a load shifting system and select those vessels for the projects that require the system. This could result in lower investment costs for conversion, as the imposed structural loads are much lower for only a hold opening system. This can be further investigated by Jumbo Maritime.

Overall benefits stretch further than only the financial aspect, being the safety of the operation. This can be increased considerably, but further effort has to be put into the redundancy requirements of the system, accompanied with a new guideline for autonomous systems in operation in Jumbo Maritime's vessels.

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A

Hatch cover dimensions and lay out of the vessel

The details of the Main Deck Hatch Covers(MDHC) are depicted in Table A.1, together with the conventions for the dimensions of the hatch cover in Figure A.1. As can be clearly seen, there is a distinction between hatch covers 4 to 6 and the rest. This distinction is made due to the fact that hatches 4 to 6 are of the heavy type, with a higher carrying capacity. The rest of the hatches is of the normal type. Also between hatches of the same type there is a spread of around one to two tonnes. As convention, in this report the weight of the heavy type is set at 120 tonnes and of the light type of 100 tonnes.

In Figure A.2, the total layout of the hold with the coaming is depicted, together with all the structures that are located on top of the coaming.

Table A.1: Details of hatch covers Jumbo Jubilee.

	Weight [tonnes]	Height [m]	Length [m]	Breadth [m]	Z [m]	X[m]	Y [m]
Hatch cover no 1	97.900	1.600	12.770	17.060	0.921	6.420	8.628
Hatch cover no 2	98.900	1.600	12.770	17.060	0.921	6.420	8.628
Hatch cover no 3	97.900	1.600	12.770	17.060	0.921	6.420	8.628
Hatch cover no 4	120.100	1.600	12.770	17.060	0.921	6.425	8.610
Hatch cover no 5	119.600	1.600	12.770	17.060	0.921	6.425	8.610
Hatch cover no 6	120.000	1.600	12.770	17.060	0.921	6.425	8.610
Hatch cover no 7	98.100	1.600	12.770	17.060	0.921	6.430	8.628
Hatch cover no 8	99.000	1.600	12.770	17.060	0.921	6.430	8.628

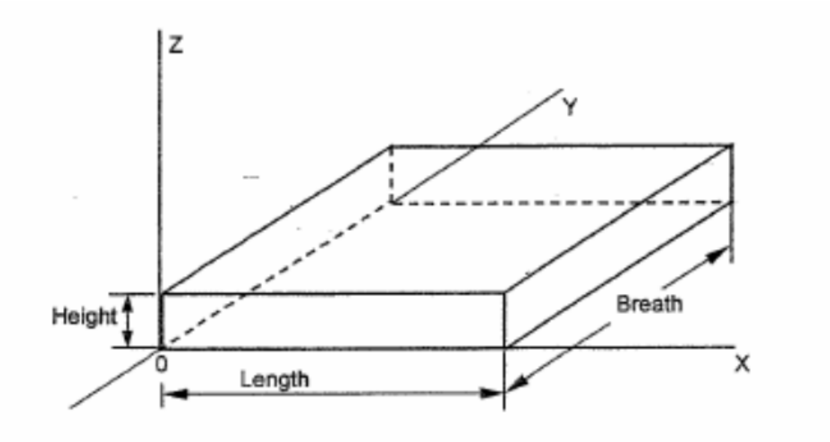


Figure A.1: Dimensions of hatch cover.

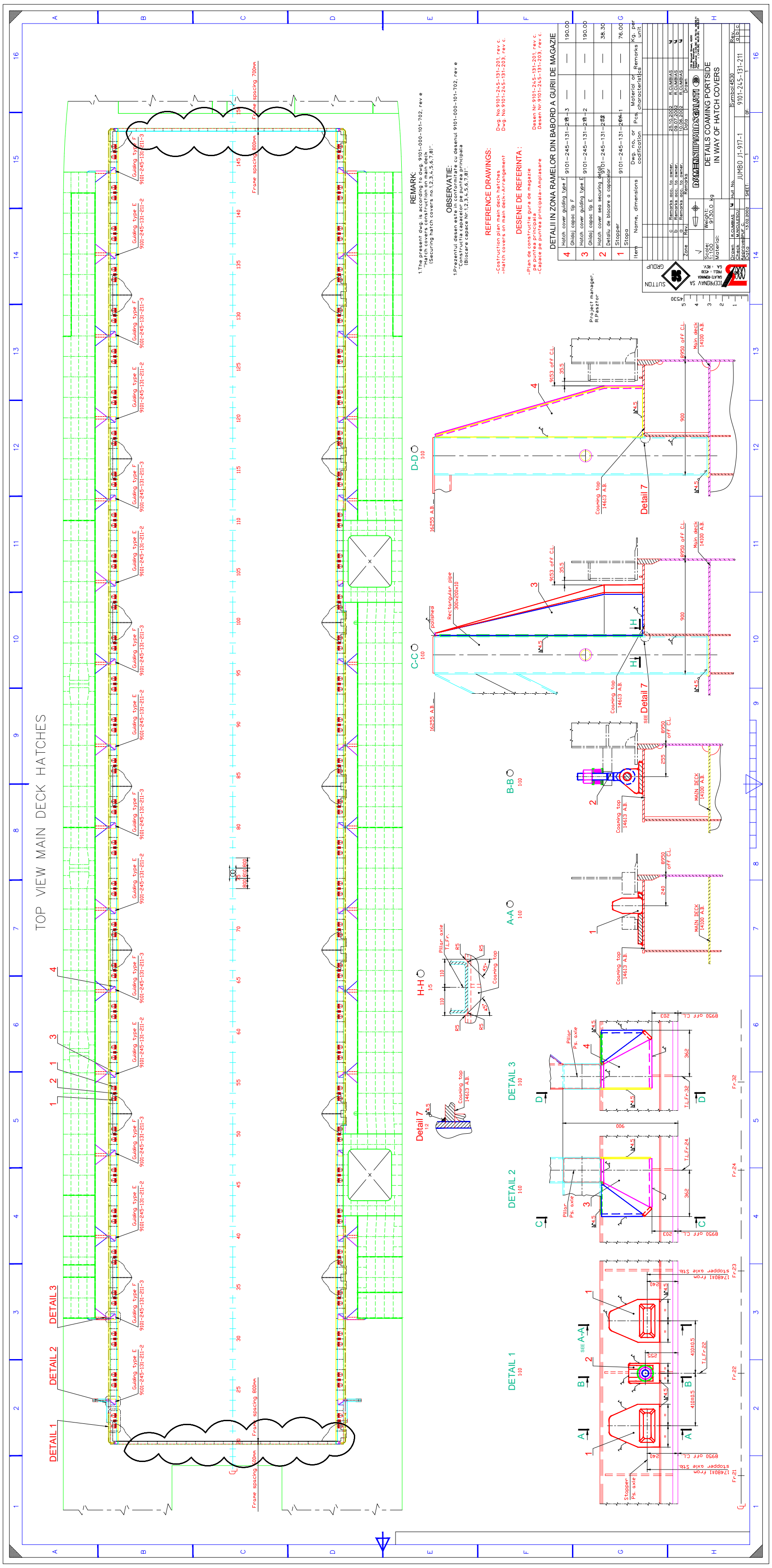


Figure A.2: Lay out of the hold.

B

Use cases

All the use cases are here written in the style adapted of Cockburn, A. [8] and Bittner and Spence [5].

Use case 1

Use case: Shift cargo from mid-ship to front or aft(and backwards) on the top deck (16255 mm A.B.(Above Base) or higher).
Scope: Combined load shift and hold opening system on the level of the top deck on board of a J1800-class vessel.
Brief: The system allows to be used in such a way that it is able to shift cargo located on the hatch cover from mid-ship (between the two cranes at hold cover positions 4,5 or 5,6 to front and aft of the ship: position 1,2,3 or 7,8).
Precondition: The hold does not have to be opened, the system is in such a way ready to receive a piece of cargo of maximum 1800 tonnes.
Minimal guarantee: The system is able to shift cargo from mid-ship to front or aft and back.
Success guarantee: Without major adjustments to current situation the system can be placed in working condition by the vessel crew and can be put into use and functions in such a time frame that is comparable with current skidding equipment, which is now hired.
Main success scenario:

1. Cargo heavier than 800-900 tonnes is loaded using both cranes, thus at mid-ship location.
2. Cargo is placed on top deck (16255 mm A.B.) at locations 4,5 or 5,6 of hold covers.
3. Vessel crew is able to shift load to positions 7,8 or 1,2,3.
4. Vessel crew is able to sea-fasten cargo (see use case 5).
5. Vessel sails to offloading location.
6. Vessel crew loosens cargo.
7. Vessel crew is able to shift cargo back at hatch cover location 4,5 or 5,6 to unload cargo using the on-board cranes.

Extensions: The system is able to open the hold after the cargo is unloaded.

Performance criteria:

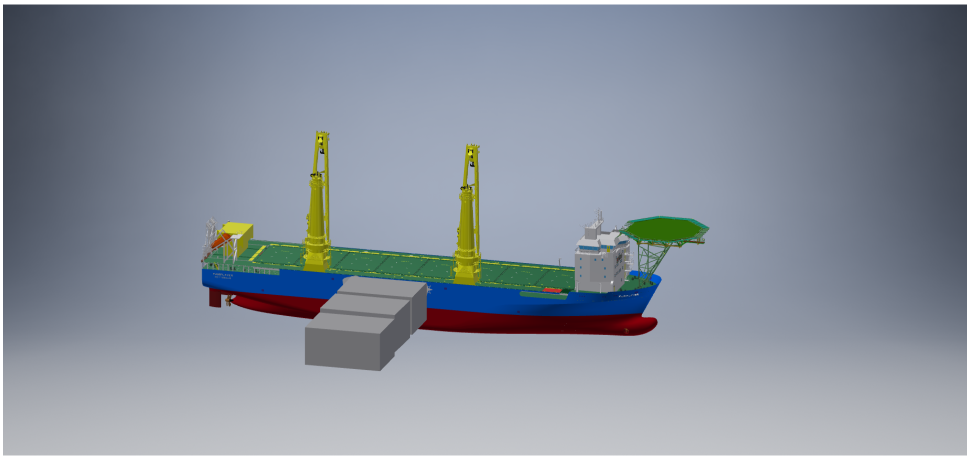
- Stress: criteria according to DNV-GL regulations described in DNV-GL [14], together with the requirements of the load shifting equipment.
- Buckling checks according to Jumbo Maritime's best practice, in correspondence with DNV-GL [12].

Operational constraints:

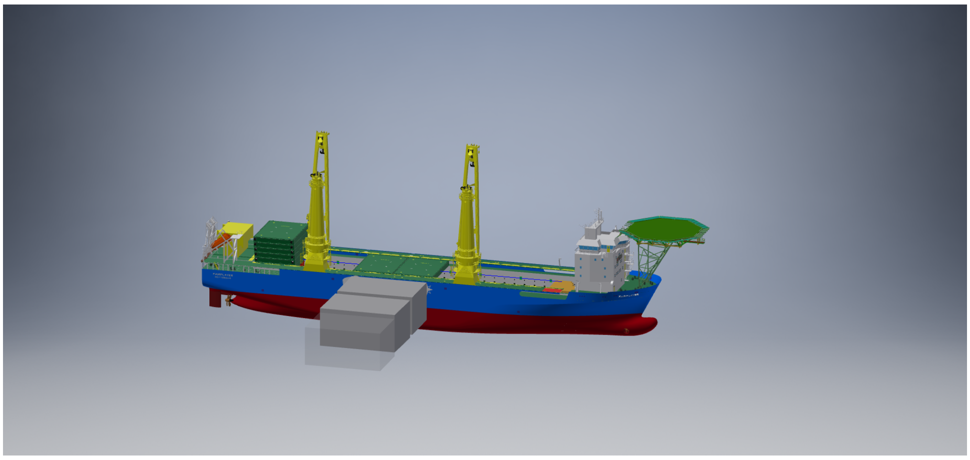
- All deck hands are available for load shifting preparations.

- Sea states: no sea-state specified, as this use case is to be done in port.
- Boundary conditions:
  Vessel is moored in port.
  Vessel crew available to assist in completing use case.

In Figure B.1 the basic flow of use case 1 is visualized. Unloading is the exact reverse of loading and is thus not displayed.



(a) Vessel receives cargo next to vessel.

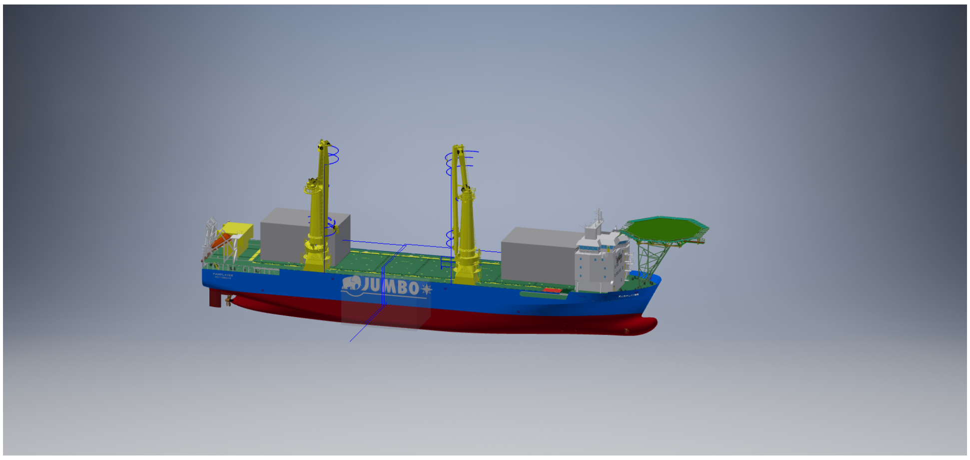


(b) Hatch 1 & 2 are brought in position mid-ship to receive cargo.

(c) Cargo is loaded on hatch 1&2 at position 4&5.

(d) Cargo shifted to position 1&2, hatch 7& 8 are brought to position 4&5. Hatches 3,4,5,6 are stored at location 3.

(e) Cargo is loaded on hatch 7&8.



(f) Cargo shifted to position 7&8 and hold is closed.

(g) Cargo is loaded on hatches 3,4,5 & 6.

Figure B.1: Basic flow of use case 1.

Use case 2

Use case: Open the hold.
Scope: Combined load shift and hold opening system on the level of the top deck on board of a J1800-class vessel.
Brief: The system allows to be used in such a way that it is able to open the hold without the use of onboard cranes.
Precondition: No cargo is on the hatch covers.
Minimal guarantee: Hold can be opened without the cranes.
Success guarantee: The system can be described as a success if either the time it takes to open the hold is shorter, or that the working hours involved in the opening and closing of the hold is less, regarding the resting time required in port for vessel crew.
Main success scenario:

1. Vessel enters port without cargo on top deck.
2. Vessel crew is able to start opening hold before being moored.
3. System operates with minimum help of vessel crew, start opening hold.
4. Vessel is moored to loading location.

5. Hold cargo is loaded.
6. Hold is closed using the same system in reverse.
7. Vessel crew is able to load cargo on top deck when hold is fully closed.

Extensions: After use case 2 is fully completed, the system is in neutral position.

Performance criteria:

- Stress: criteria according to DNV-GL regulations described in DNV-GL [14].
- Buckling checks according to Jumbo Maritime's best practice, in correspondence with DNV-GL [12].
- When use case 2 is fully completed, the system is in neutral position, meaning that either one of the use cases can be initiated.

Operational constraints:

- Available hands on deck is limited to four during sailing or when moored, if the system is to be operated during mooring, only one person is available.
- Sea states: current operation is planned for entering port, dynamic analysis has to point out what the limiting sea state is. Extensive modifications are unwanted and if no wave height is allowed, operation will be done in port.
- Boundary conditions: Vessel is either entering port or already moored.
- System has to be powered by the current power supply of the vessel.
- If there is cargo on deck, in conflict with point 1 of the basic flow of this use case, several options are available. Either cargo is offloaded in accordance with use case 4,5 and possibly 1, or cargo is not to be offloaded in that specific port. In that case, the system should be able to cope with it.

Use case 3

Use case: Transport cargo in the hold without any water damage during transit.
Scope: Combined load shift and hold opening system on the level of the top deck on board of a J1800-class vessel
Brief: The system allows to be used in such a way that it is able to transport cargo in the hold without ingress of water during transit.
Precondition: Hold is closed.
Minimal guarantee: Hold is closed off watertight during transit, using some sort of system.
Success guarantee: Hold is closed of watertight during transit, using some sort of system without extensive modifications or efforts required by crew every time it is used.
Main success scenario:

1. System is in place when hold is about to be closed.
2. When hatch cover is resting on its foundation, system in function.
3. System is secured for transit.
4. Vessel sails to offloading location.
5. System is retracted before hatch cover is lifted of its place.
6. System can stay in its place during loading/offloading.

Performance criteria:

- Stress: criteria according to DNV-GL regulations described in DNV-GL [14].

- Buckling checks according to Jumbo Maritime's best practice, in correspondence with DNV-GL [12].
- System is ought to be mechanical, as hydraulic or electrical seafastening requires a back-up.
- System requires none, to almost none, attention of crew during transit.

Operational constraints:

- Sea states: Governing sea-state is described by DNV-GL [14].
- Boundary conditions: Vessel is sailing.

Use case 4

Use case: Transport cargo on the top deck level.
Scope: Combined load shift and hold opening system on the level of the top deck on board of a J1800-class vessel
Brief: The system allows to be used in such a way that it is able to transport cargo on the top deck at a level of 16255 A.B., in such a way that structural integrity of the cargo is guaranteed after transport. It should be strong enough to transport 1800 tonnes on the top deck, accompanied by all the induced forces during transport. This use case is written for hatch covers 4,5 and 6. Deck load of 8.7 T/m^2 has to be considered for hatch covers 1,2,3 and 7 and 8.
Precondition:
Minimal guarantee: System is able to load cargo with an induced pressure of up to 12 T/m^2.
Success guarantee: If higher loads than 12T/m^2 are possible, it should be considered a success.
Main success scenario:

1. Vessel crew prepares deck for cargo, marks the location. Possible reinforcing and load spreading measures are taken if load is higher than 12T/m^2.
2. Vessel crew receives cargo close to vessel.
3. Vessel crew prepares cargo for loading. Also lifting blocks, ropes and shackles are prepared.
4. Vessel crew loads cargo using onboard mast-cranes.
5. Vessel crew is able to put cargo on top deck level, on the marked location.
6. Vessel crew loosens lifting equipment.
7. Vessel crew loads other pieces of cargo if necessary.

Performance criteria:

- Stress: criteria according to DNV-GL regulations described in DNV-GL [14].
- Buckling checks according to Jumbo Maritime's best practice, in correspondence with DNV-GL [12].
- After unloading cargo, the system is in neutral position, meaning that either one of the use cases can be initiated.

Operational constraints:

- Cargo accelerations during transit are given by DNV-GL [14].
- Current operations of J1800-class vessels only allow 3 of the 8 hatches to transport 12T/m^2, as only three hatches are of the heavy type. The other type is design for loads up to 8.7T/m^2.

Use case 5

Use case: Sea-fasten cargo on top deck level
Scope: Combined load shift and hold opening system on the level of the top deck on board of a J1800-class vessel
Brief: The system allows to be used in such a way that it is able to secure the cargo from moving during transit due to wave-wind induced loading during transport. This should be able by using the current sea-fastening means Jumbo currently uses, shackles and stoppers welded on top of the hatch covers. This should be done on the same level as the cargo is transported, see use case 4.
Precondition: Use case 5 starts when use case 4 is finished.
Minimal guarantee: Crew is able to sea-fasten cargo.
Success guarantee: Cargo is sea-fastened without extra requirements necessary, for example welding extra D-rings or first applying a weldable surface.
Main success scenario:

1. After loading cargo as described in use case 4, Vessel crew prepares cargo for sea-fastening.
2. Vessel crew sea-fastens cargo in shortest time frame possible with standard means of Jumbo Maritime.
3. Vessel sails to offloading location.
4. Vessel crew is able to loosen cargo in shortest time frame possible.

Performance criteria:

- Stress: criteria according to DNV-GL regulations described in DNV-GL [14].
- Buckling checks according to Jumbo Maritime's best practice, in correspondence with DNV-GL [12].
- After loosening and unloading the cargo, the system is in neutral position, meaning that either one of the use cases can be initiated.

Operational constraints:

- Sea-state: Cargo accelerations during transit are given by DNV-GL [14].
- Standard means of Jumbo Maritime are stoppers and lashings. Stoppers are basically strips of steel welded to the hatch cover, next to the cargo. Lashings consist of shackles, turnbuckles and chains. Both seafastening means are depicted in Figure B.2 & B.3.

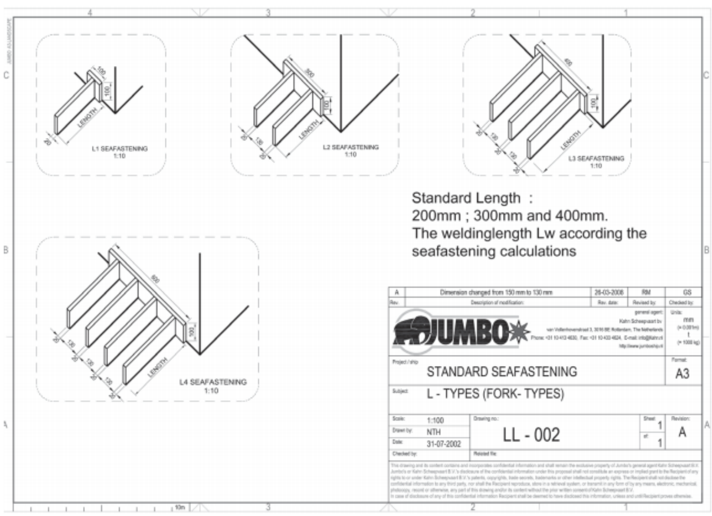


Figure B.2: Examples of seafastening stoppers.

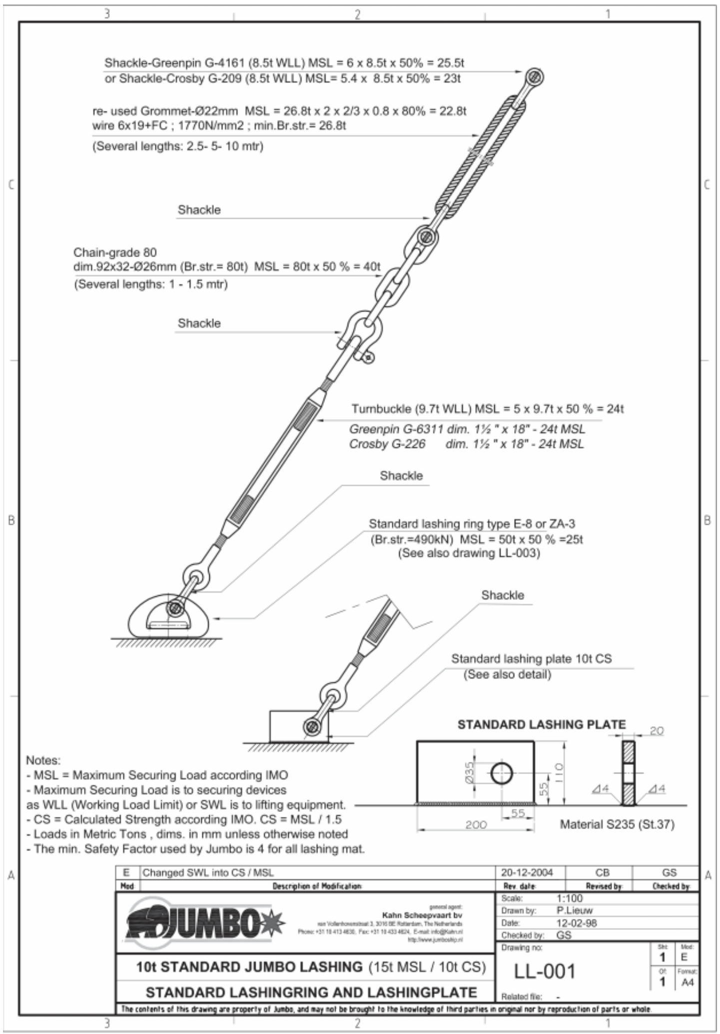


Figure B.3: Examples of lashings.

C

Design requirements

From the use cases specified in Appendix B, the design requirements are subtracted.

Functional requirements

The requirements are specified for the different use cases, so it is possible that for different use cases the same requirements are applicable. If this occurs they are mentioned multiple times.

Use case 1: Shift cargo from mid-ship to frond or aft (and backwards) op top deck level

- Preparation time for load shifting: one working day in port (12 hours).
- Optimal maintenance requirements for Jumbo Maritime.
- System should be scalable, since the maximum required load is not always required.
- Maximum cargo load to shift on top of a hatch cover is 1800T.
- Strength should be examined using current regulations of DNV-GL

Use case 2: Opening of the hold on top deck level (Main deck hatch covers)

- System should be able to operate in a high level of autonomy.
- Flexibility should be guaranteed. Every hatch should be opened, although not all together at once.
- Less crane driving hours involved than current system: 120-240 minutes requiring 4 workers (depending on conditions).
- Strength should be examined using current regulations of DNV-GL.

Use case 3: Transport cargo in the hold without any water damage during transit

- Rubber profile fitted on coaming in a gutter.
- Tarpaulins over cross seams of hatch covers.
- Securing of hatch cover on coaming in compliance with current regulations of DNV-GL.

Use case 4: Transport cargo on top deck level, on top of hatch cover

- Deck strength of 12 T/m^2 (hatch cover 4,5 and 6) or 8.7 T/m^2 (hatch cover 1,2,3 and 7&8).
- Maximum load on top deck level per hatch cover (12.68x17.00m): 1800 T.
- To facilitate flexibility, hatch cover should be able to put overboard, so exposure to salt-water should not be a problem.
- Top deck level flush during transport.
- Strength examined according to current regulations of DNV-GL.

Use case 5: Sea-fasten cargo on top deck level

- Top of hatch cover should be of a material that is easy weldable to, so S235 steel should be used.
- Top of hatch cover equipped with double D-shaped recessed heavy load lashing eyes for seafastening.
- Seafasten hatch cover and cargo done using current regulations of DNV-GL.

Non-functional requirement

- Hatches should still be able to be lifted off.
- Positions of the hatches is interchangeable.
- System should have a service lifetime of 15 years.

Constraints

- System should comply with the highest level of safety, corresponding with the company values of Jumbo Maritime.
- Adjustments to existing vessel structure is possible, but should be avoided where possible.
- System is not allowed to transfer transversal forces, no torsional stiffness required in the hatches.
- System has to operate without interfering with the onboard cranes structure.

D

Amplification factor horizontal forces during folding

Amplification factor horizontal forces compared to the vertical forces
The horizontal forces involved in the folding of the hatches can be computed as a multiplication of the gravity force. This so called amplification factor α is computed in Equation D.2. The variable θ is in degrees and is the angle between the hatch and the horizontal. Zero degrees means a horizontal hatch. In Figure D.1 only half of the problem is depicted, as two hatches will be folded against each other. Due to symmetry, A_y equals then mg

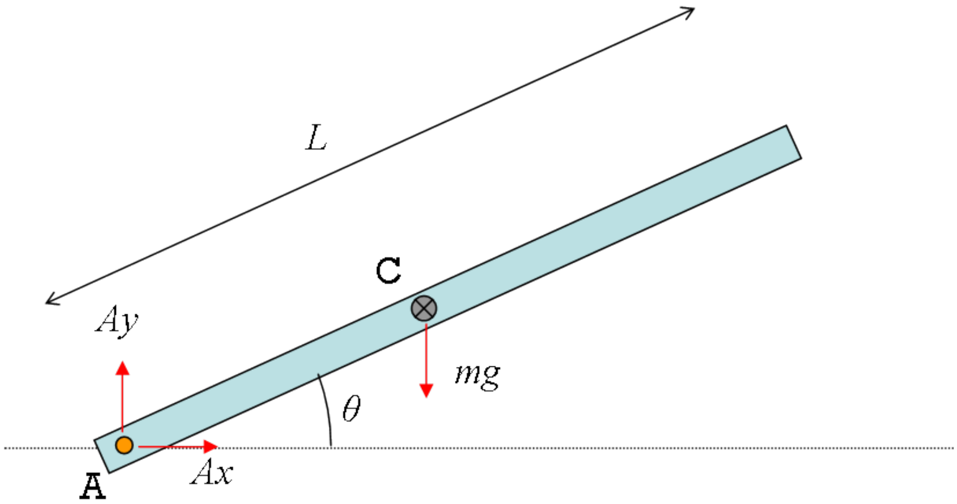


Figure D.1: Free body diagram of folding hatch cover [45].

$$Amplification \quad \alpha = \frac{cos(\theta)}{2 \cdot sin(\theta)} \tag{D.1}$$

$$A_x = mg \cdot \alpha \tag{D.2}$$

The amplification factor α is visually presented in Figure D.2. For reference, an initial angle θ of 10 degrees would mean an initial displacement of the hinge of 2.2 meters. So, even with an initial displacement of 2.2 meters, the amplification of the horizontal force with respect to the vertical force is still 2.8.

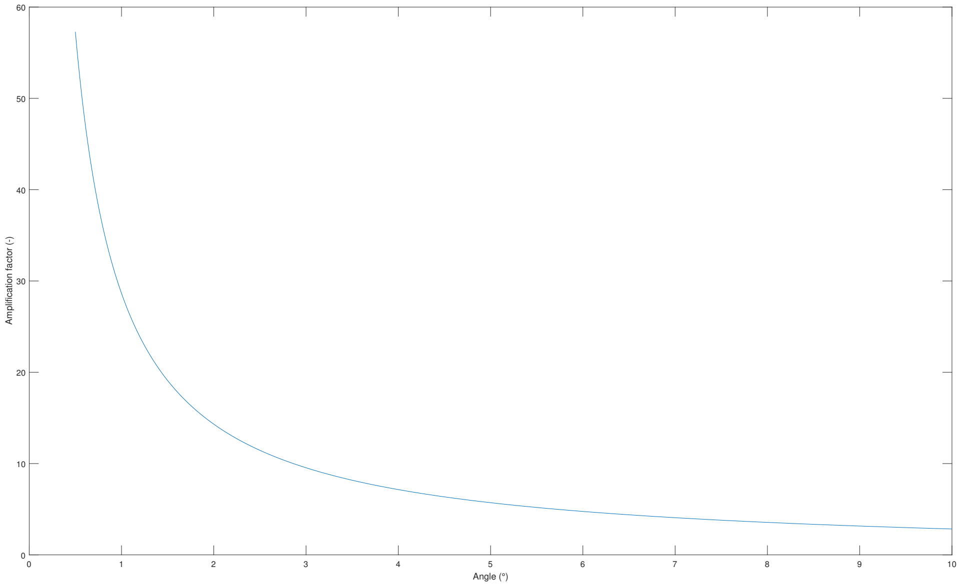


Figure D.2: Amplification factor α.

E

Details of stacking technology

In this appendix more in detail information of the used stacking technology and strand jack system can be found.

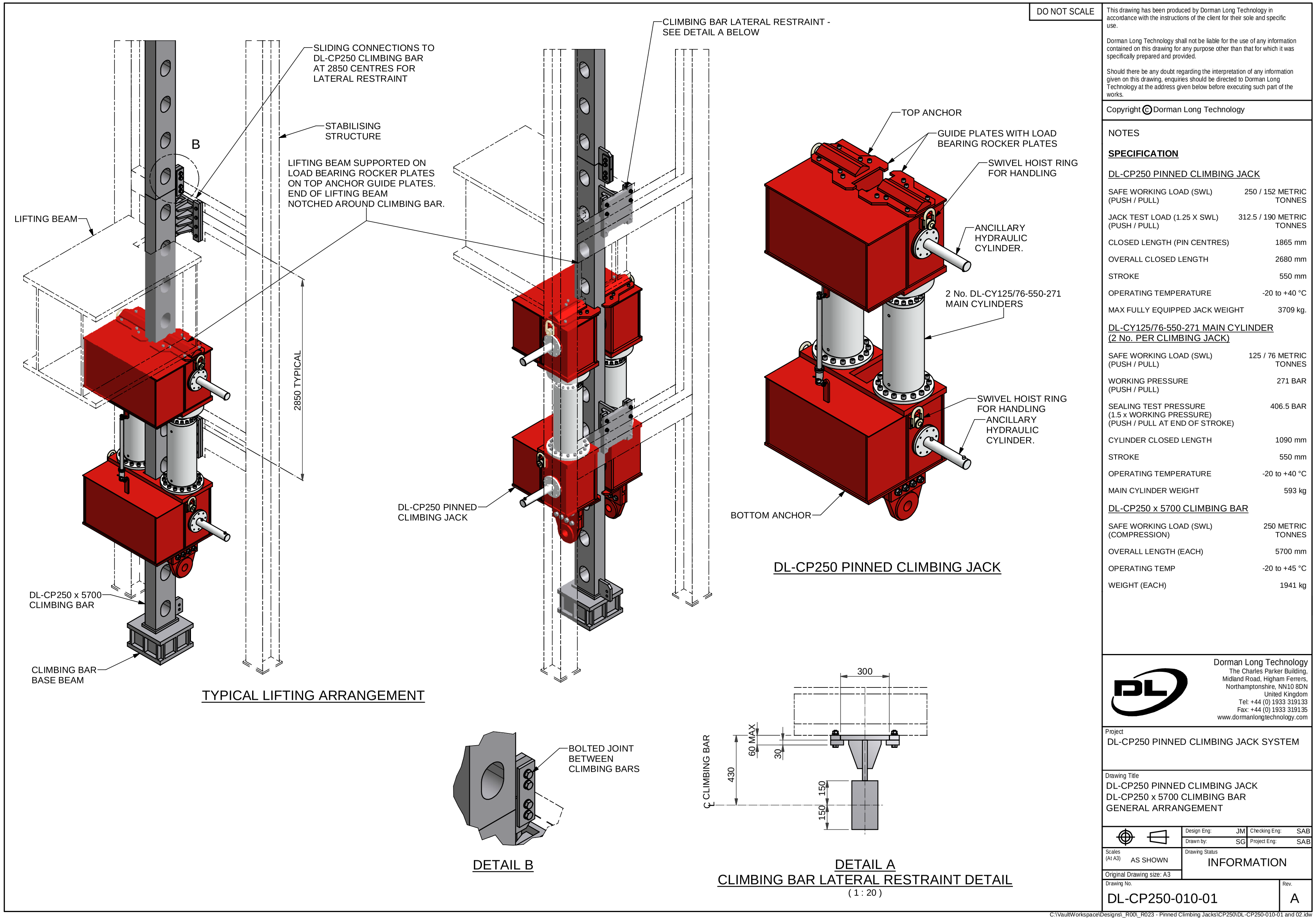


Figure E.1: Details of stacking technology, page 1 [54].

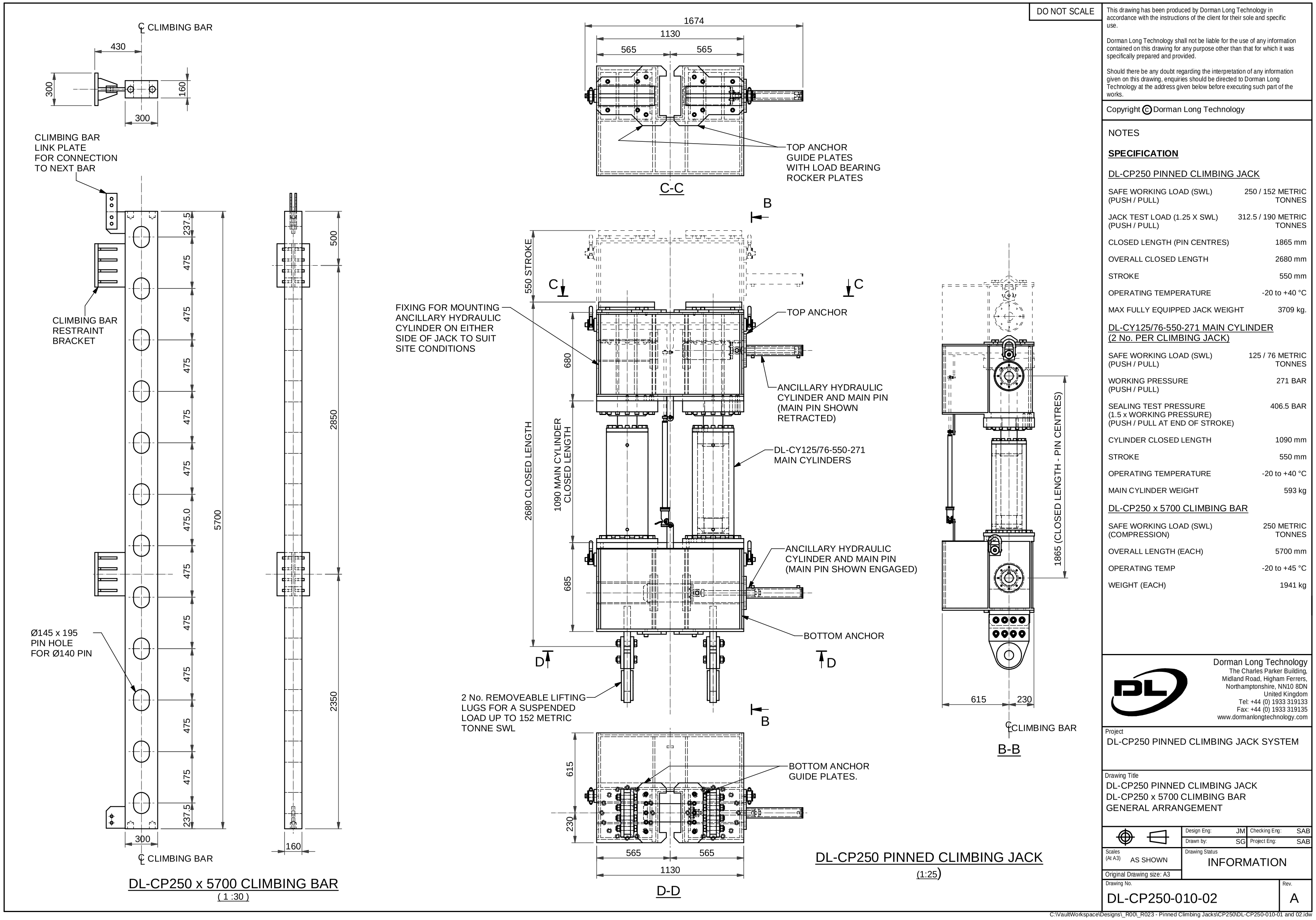
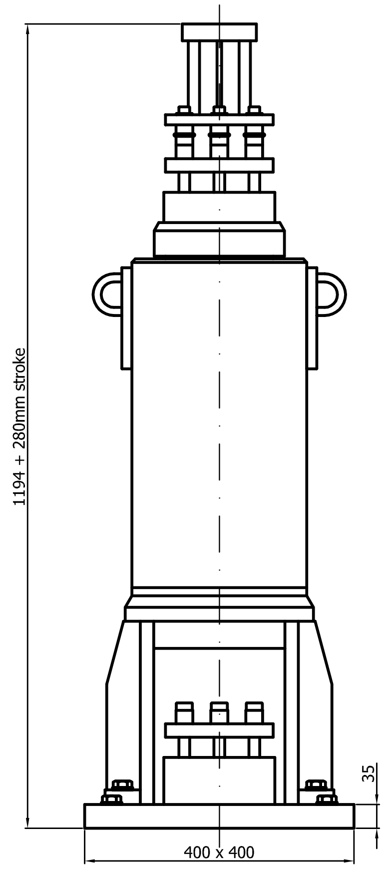


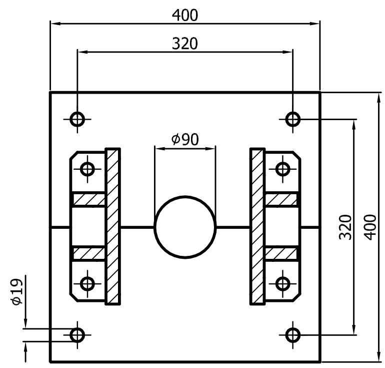
Figure E.2: Details of stacking technology, page 2 [54].

Strand jack **H-70**

Technical Data

Capacity:	700 kN
Piston stroke:	280 mm
Area "Pressureline":	203.6 cm²
Area "Returnline":	97.5 cm²
Qty of strands:	7 pieces
Height without Stroke:	1194 mm
Base plate:	400 x 400 mm
Attachement:	4 pieces M16
Weight:	290 kg





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Hebetec Documentation

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Figure E.3: Strand Jack [24] .

F

Results static structural analysis

In this chapter all the results of the different ANSYS calculations can be found. ANSYS calculations were limited to deformation, stress and buckling. The stress checks are divided into two sections, peak stress and basic stress. As explained in Section 5, the basic usage factor determines the amount of stress permitted in the global structure. To analyze if the occurring stress is higher than allowed basic stress, all occurring stress higher than the permissible stress is highlighted in one colour. It is in this way clear which region needs special attention, in order to determine if there is in fact peak stress, or if a relatively large region experiences high stress and adjustments need to be done.

Structural analysis load shifting operation

A structural analysis is carried out for the load case of a maximum load on a hatch cover, being 1800 tonnes, which is shifted over the coaming using the maximum number of Hilman rollers, being 12 on each side. Due to model limitations, eight rollers are modelled. This is not a problem as the maximum stress is expected in the centre, close to the rollers. The rollers to the side that are missing would not have influenced this. The load shifting load case is the governing load case for the coaming, as the induced loads during hold opening are much lower than during a maximum load shifting operation.

Port side section in cargo shifting loading condition

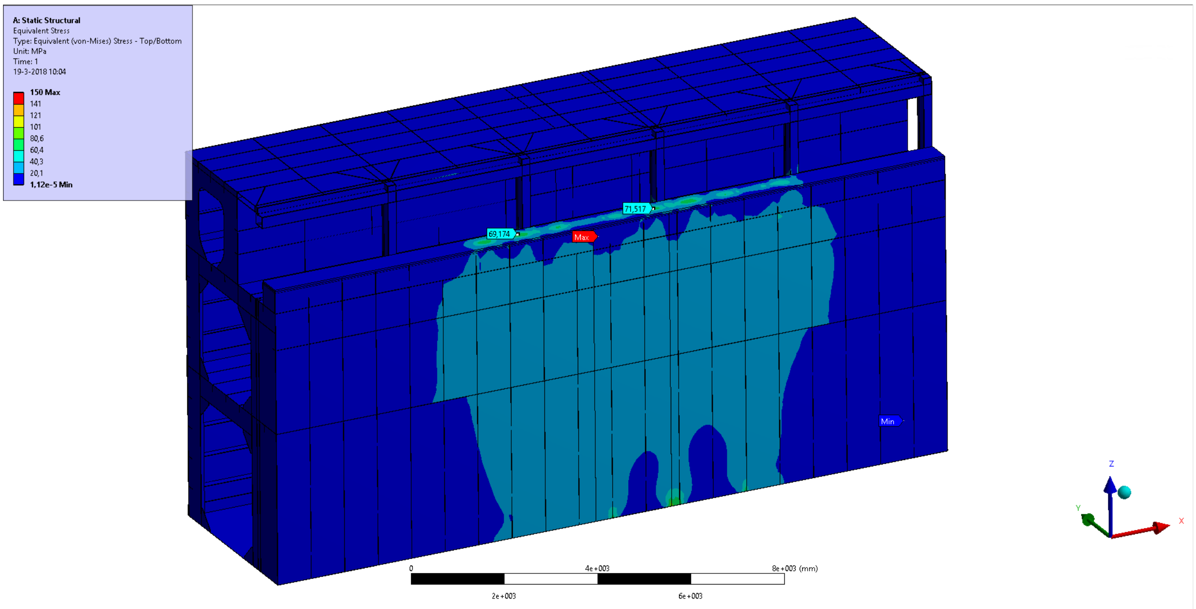

Figure F.1: Equivalent von-Mises stress coaming port side during skidding operation of 1800T.

In Figure F.1 it is clear that the stresses are generally low and within the basic usage factor. There are small regions with peak stresses, mostly at the connection of the coaming with the main deck, as can be seen in Figure F.2. Here it is clearly visible that the peak stress area only covers two or three elements. A possible explanation for this high peak stress are the sharp corners, but as it is such a small area it can be disregarded. The basic stress is well below the 141 MPa and this design is thus regarded as satisfactory.

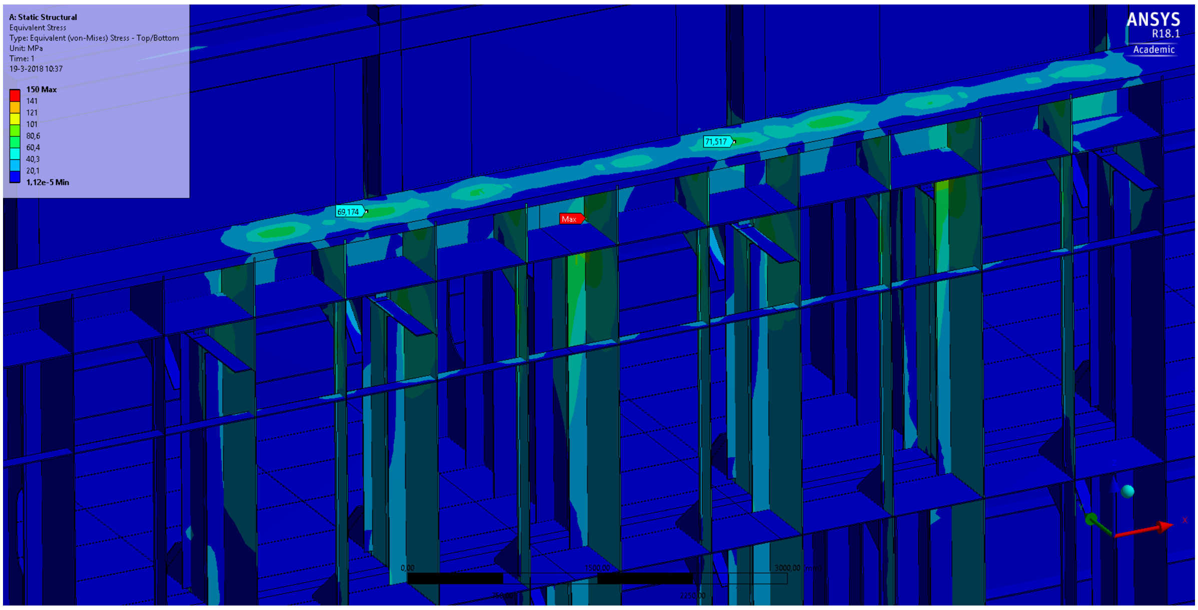

Figure F.2: Peak stress area coaming port side during skidding operation of 1800T.

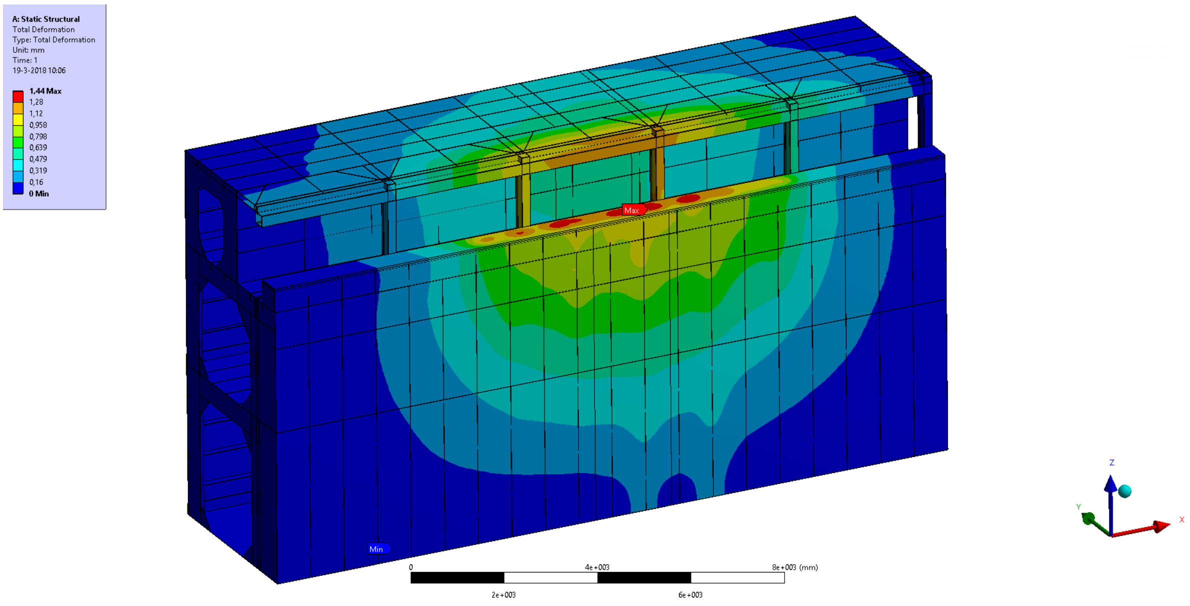

Figure F.3: Total deformation coaming port side during skidding operation of 1800T.

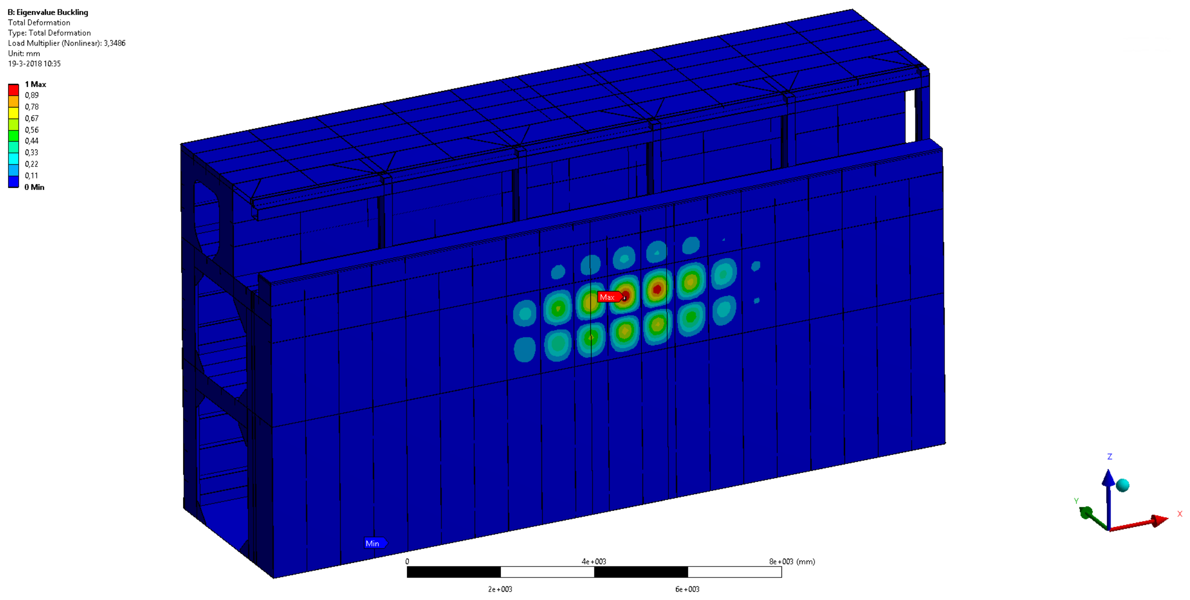

Figure F.4: Buckling analysis coaming port side during skidding operation of 1800T.

The area of highest probability of buckling is highlighted in Figure F.4. The load multiplier is given in the legend of the figure, being 2.53. This means that if the load is 2.53 times higher than the current load, linear buckling would occur. As can be seen, the hold wall is most susceptible to buckling, which is logic, as this is the largest unsupported span and the hold wall is heavily loaded during a skidding operation. Of course this is a rough estimate, as there are a lot of non-linearities involved, but the multiplier is higher than 2, which is regarded safe.

Starboard section in cargo shifting loading condition

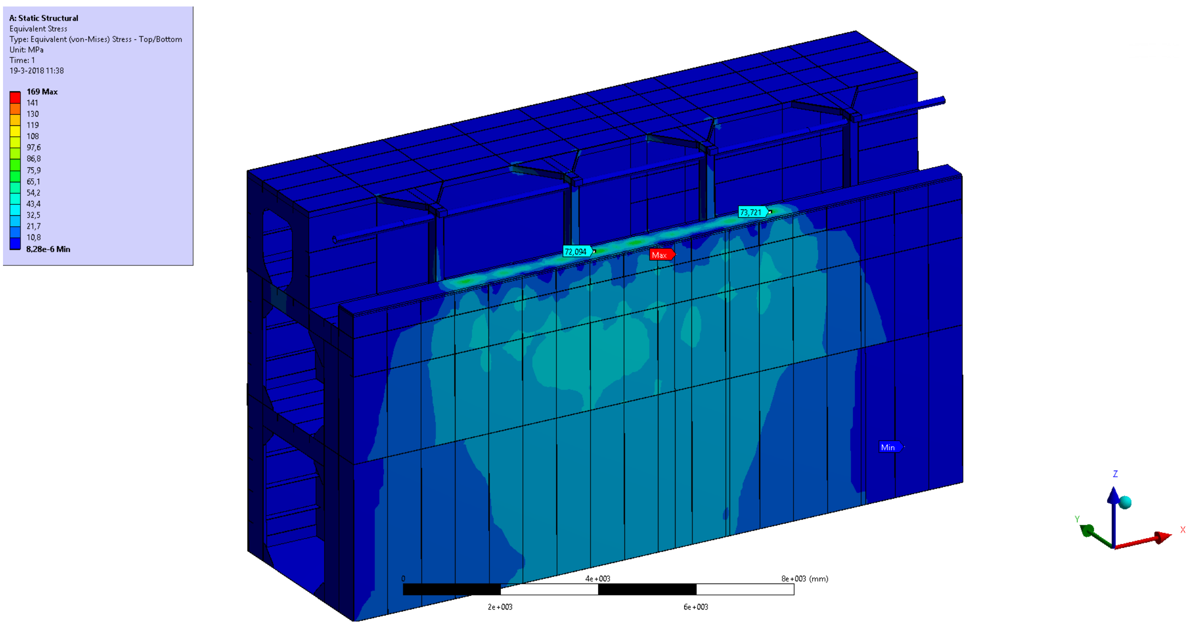

Figure F.5: Equivalent von-Mises stress coaming starboard during skidding operation of 1800T.

Again, it is clear in Figure F.5 that the stresses are generally well below the allowed stress of 141 MPa, with the peak stress of 169 MPa. Analysis of the peak stress in Figure F.6 points out that it is only a small area that experiences the peak stress and thus the design proves satisfactory.

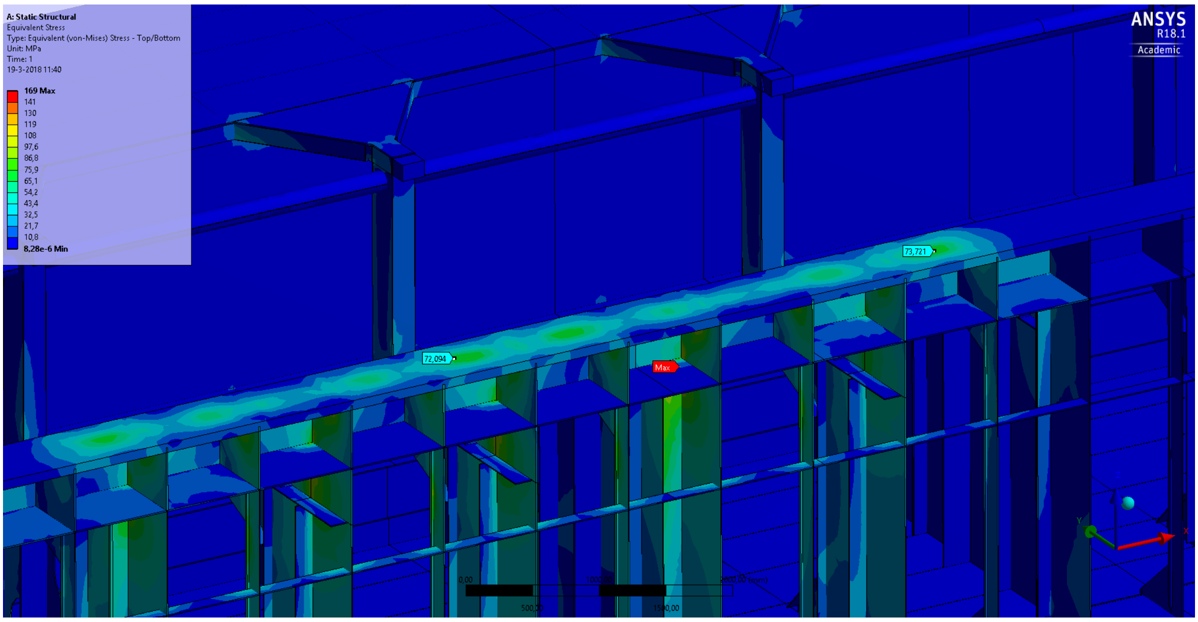

Figure F.6: Peak stress area coaming starboard during skidding operation of 1800T.

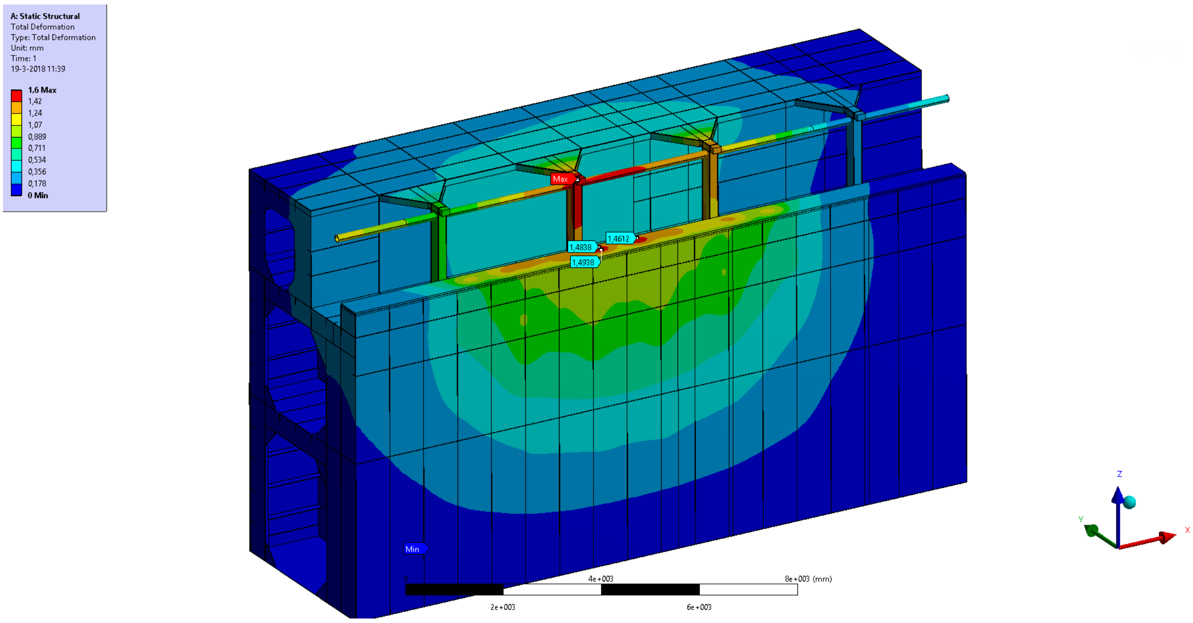

Figure F.7: Total deformation coaming starboard during skidding operation of 1800T.

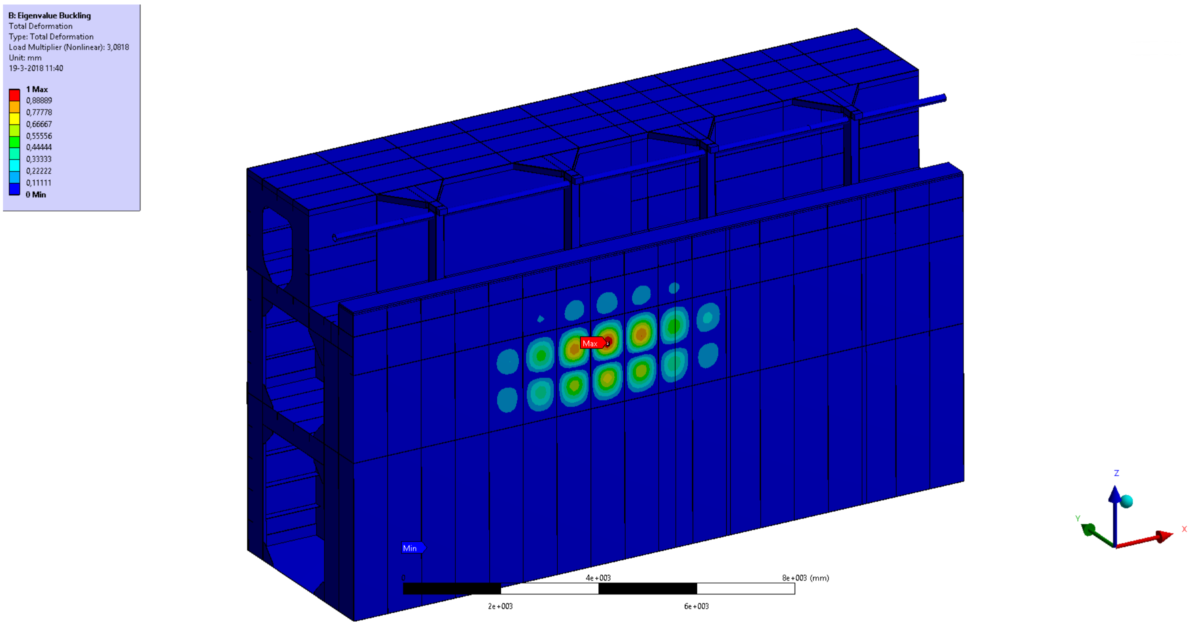

Figure F.8: Buckling analysis coaming starboard during skidding operation of 1800T.

In Figure F.8 the buckling analysis results can be found, for the starboard side during a skidding operation of 1800T, the design load. As can be seen, the hold wall is most susceptible to buckling, which is logic, as this is the largest unsupported span and the hold wall is heavily loaded during a skidding operation. The load multiplier is at 3.08 high, which is regarded safe.

Hatch cover in cargo shifting loading condition

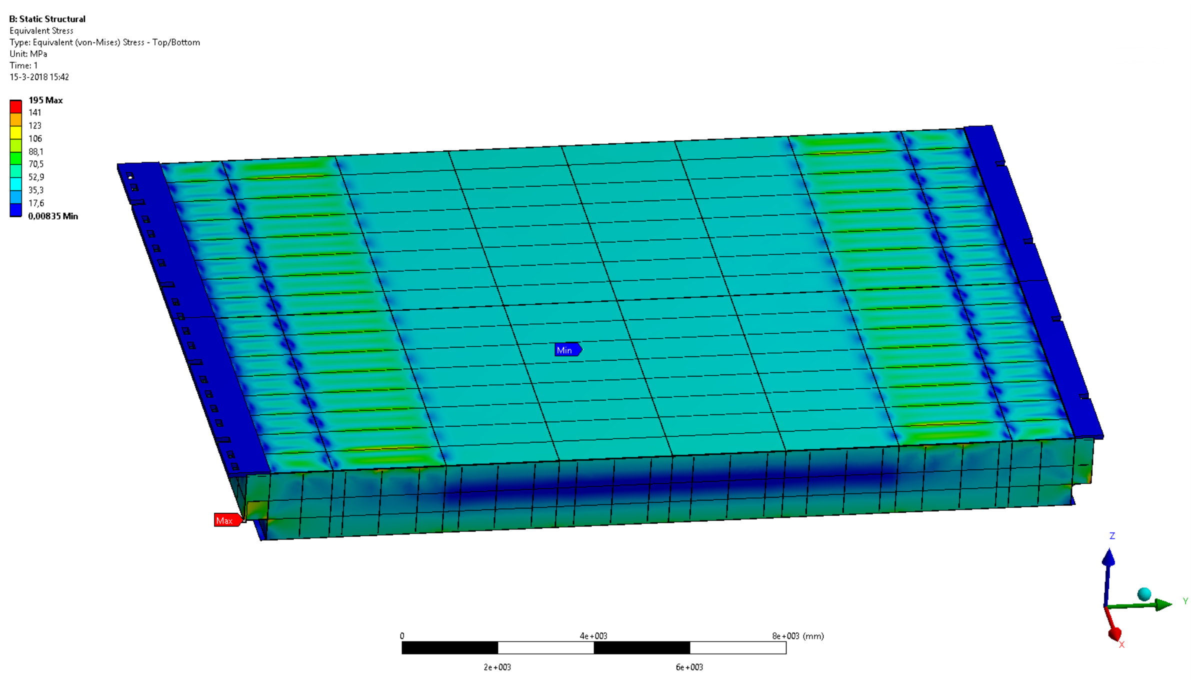

Figure F.9: Equivalent von-Mises stress Hatch during skidding operation of 1800T.

The equivalent stresses involved in lifting a hatch with an evenly distributed load of 1800T on top of it are depicted in Figure F.9. Here also the DNV code is applied. The basic stress is clearly lower than 141, with a high peak stress at the corner of the support, being a limitation of the boundary condition given. Disregarding these limitations the hatch stays well within the acceptable limits of allowable stress.

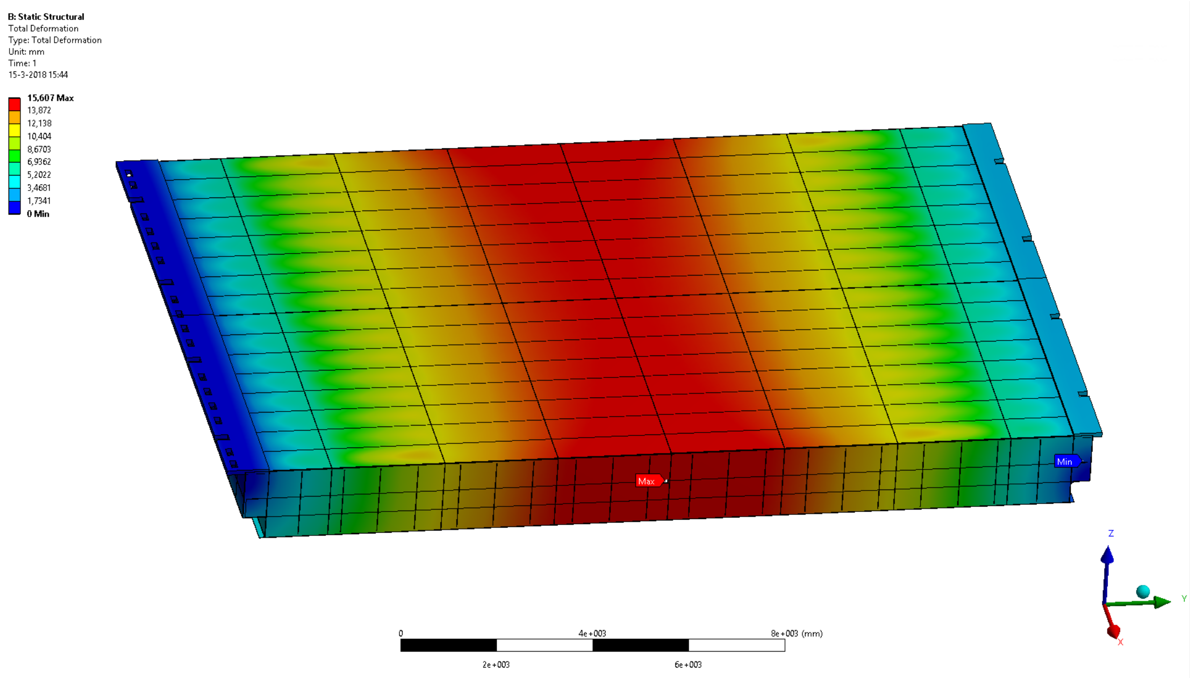

Figure F.10: Total deformation hatch during skidding operation of 1800T.

Structural analysis seafastening

Port side section in seafastening loading condition

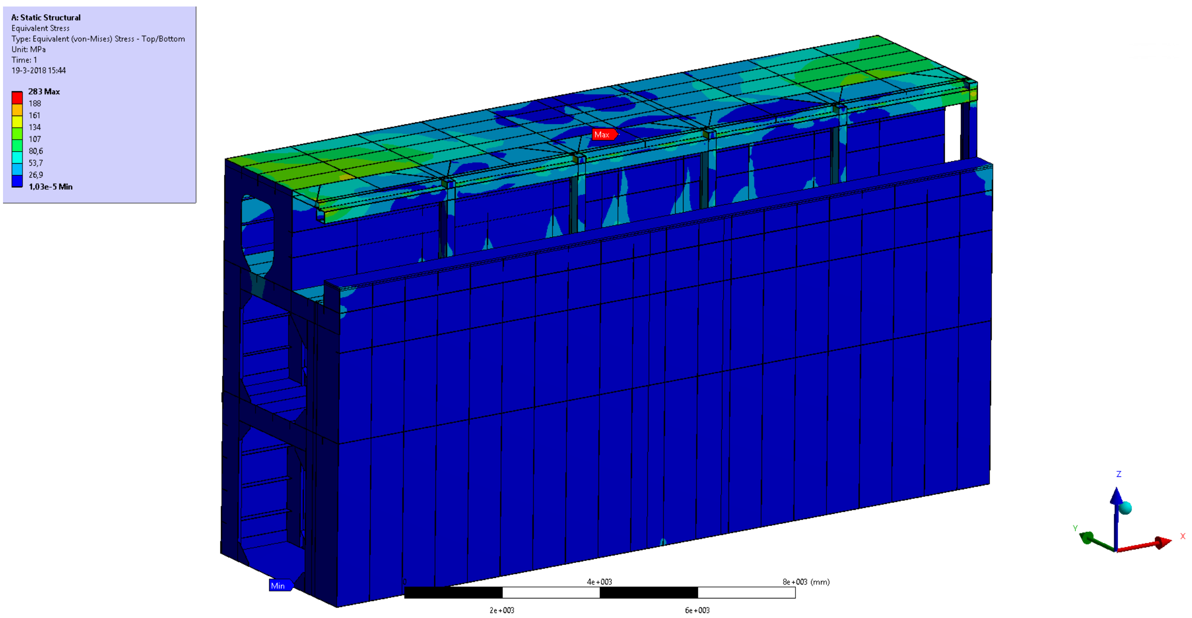

Figure F.11: Equivalent von-Mises stress seafastening system port side.

The equivalent stress involved in the extreme case for the seafastening of the hatches on port side can be found in Figure F.11. As seafastening regards a dynamic force, the basic usage factor for dynamic loads is applicable, resulting in an allowable basic stress of 188 MPa. As can be seen, almost the total structure experiences stresses lower than 188 MPa, with the highest stress being 283 MPa

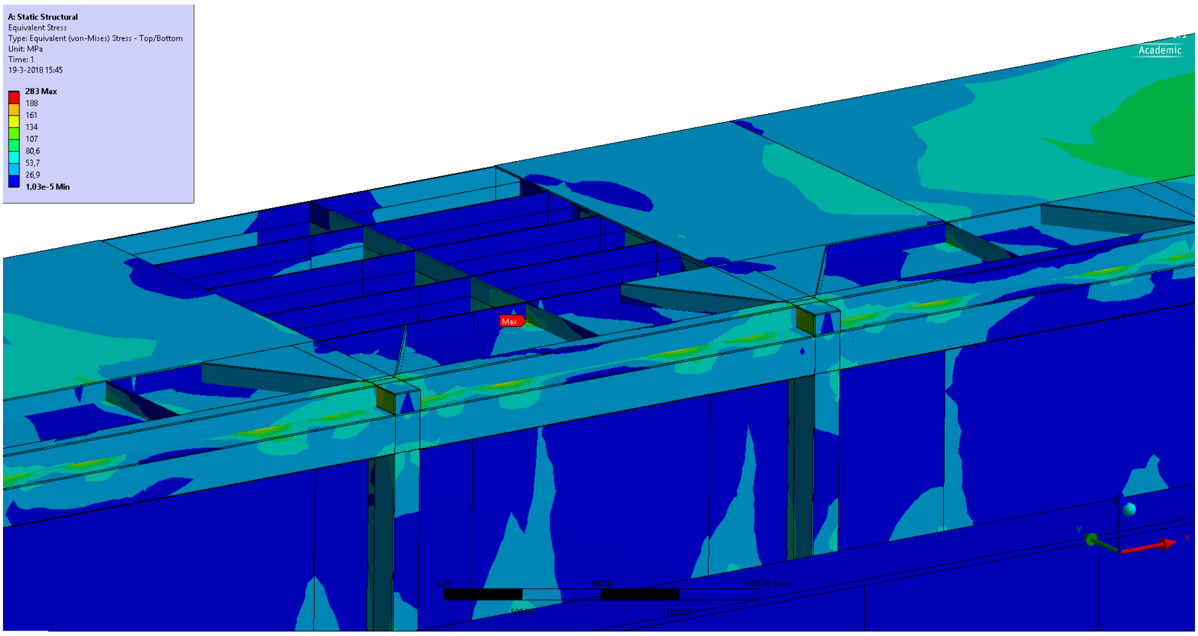

Figure F.12: Equivalent von-Mises peak stress seafastening system port side.

The peak stress regarding this load case is found in Figure F.12, where a tiny region experiences higher stresses. In this case it is regarded as a peak stress, with an allowable maximum stress of 313 MPa. The maximum stress is lower than 283, so it is regarded safe.

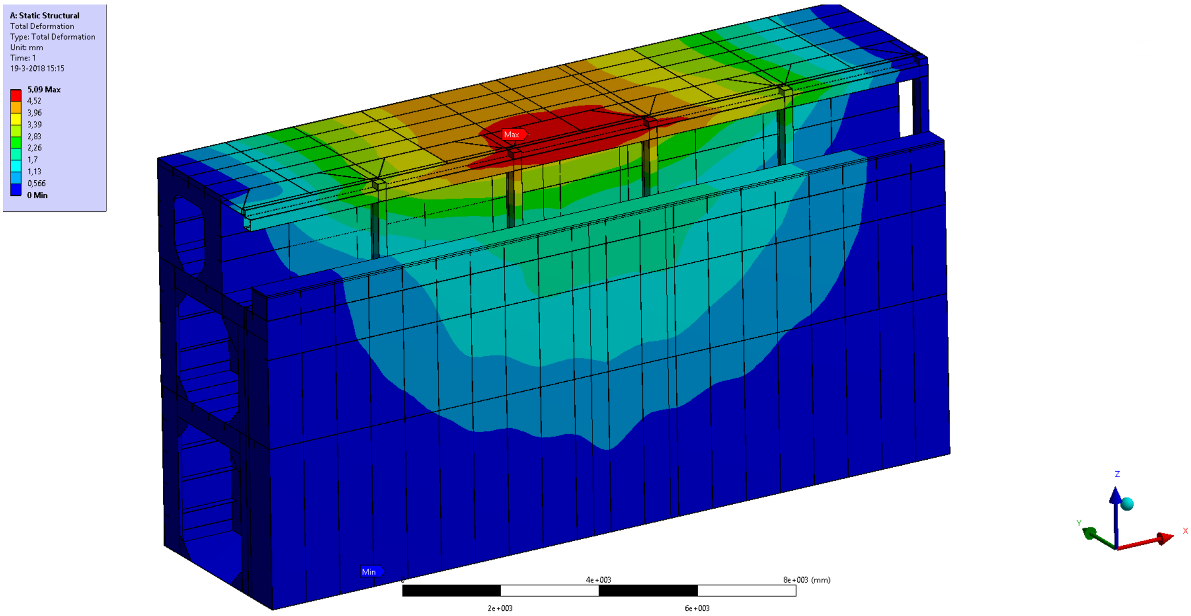

Figure F.13: Total deformation seafastening system port side.

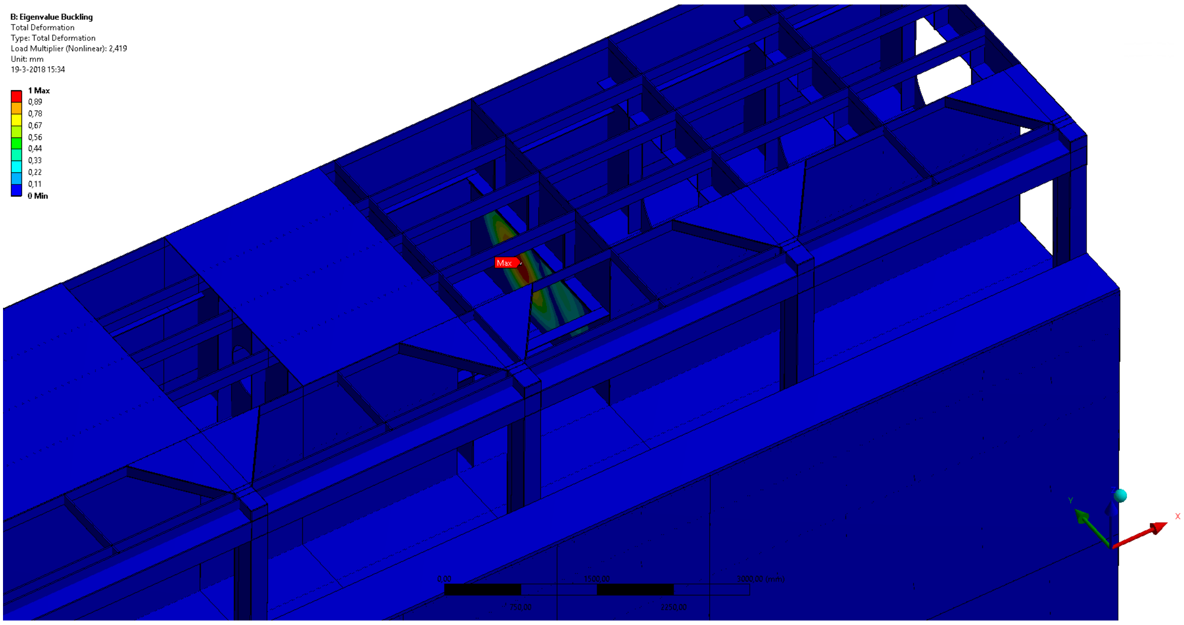

Figure F.14: Buckling analysis seafastening system port side.

The most likely face to buckle is depicted in Figure F.14. The load multiplier is higher than 2, so also this check is passed.

Starboard section in seafastening loading condition

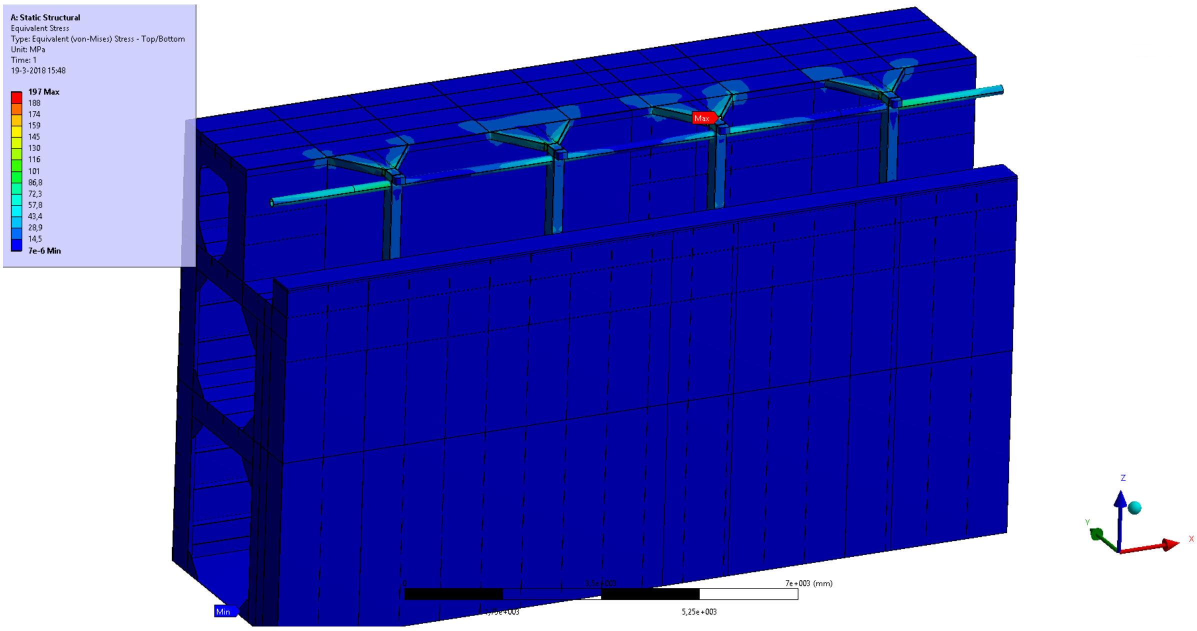

Figure F.15: Equivalent von-Mises stress seafastening system starboard.

The equivalent stress involved in the extreme case for the seafastening of the hatches on starboard can be found in Figure F.15. As seafastening regards a dynamic force, the basic usage factor for dynamic loads is applicable, resulting in an allowable basic stress of 188 MPa. As can be seen, almost the total structure experiences stresses lower than 188 MPa, with the highest stress being 197 MPa

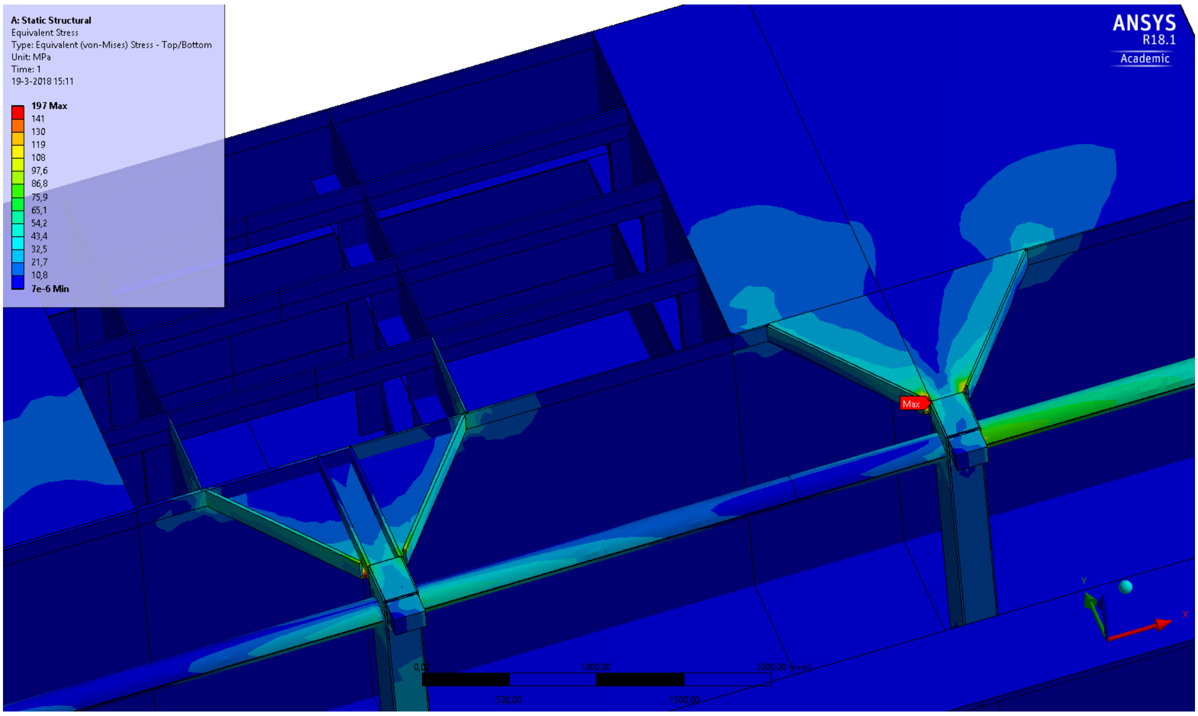

Figure F.16: Peak stress seafastening system starboard.

The peak stress is experienced in the pillars, where the connection of the vertical pillar to the void deck is causing high stresses. The maximum allowable stress is 313 MPa and the actual stress is 197 MPa, well below the limit.

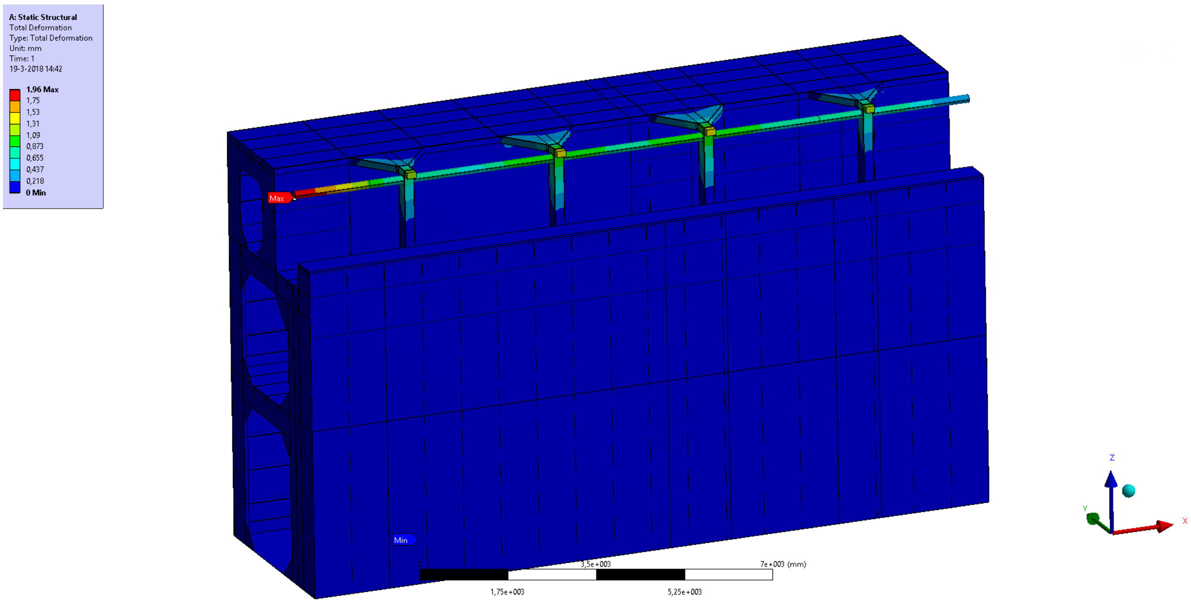

Figure F.17: Total deformation seafastening system starboard.

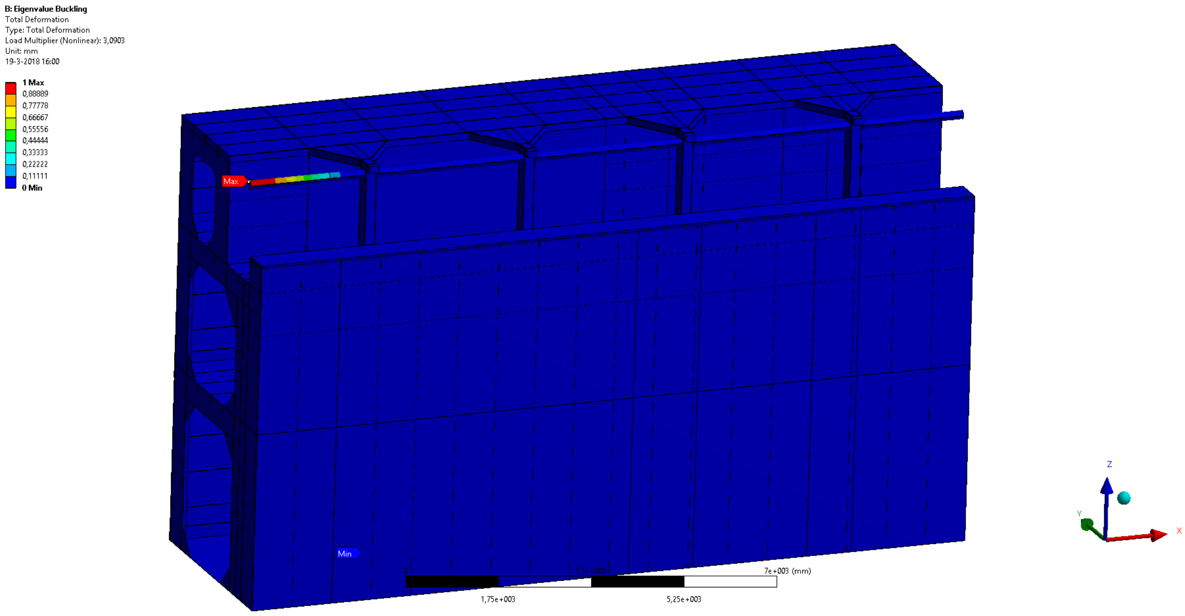

Figure F.18: Buckling analysis seafastening system starboard.

The most likely part to buckle is depicted in Figure F.18. The load multiplier is higher than 2, so also this check is passed.

Details of connection hatch cover-cylinder and starboard cleat

In Figure F.19 a so-called tilt saddle is depicted. This tilt saddle ensures that the hatch cover can deform, in order to reduce peak stresses at the connection points between cylinder and hatch cover. Analysis of the deformation of the hatch cover shows that this deformation is in order of 1 mm, as can be seen in Figure F.10.

Figure F.19: Tilt saddle on top of hydraulic cylinder [20].

In Figure F.20 an example of a starboard section cleat is depicted. The cleat is positioned in a diagonal manner, meaning that also horizontal forces could be transferred. In order to eliminate this option as much as possible, the angle of the cleat with the horizontal should be as high as possible.

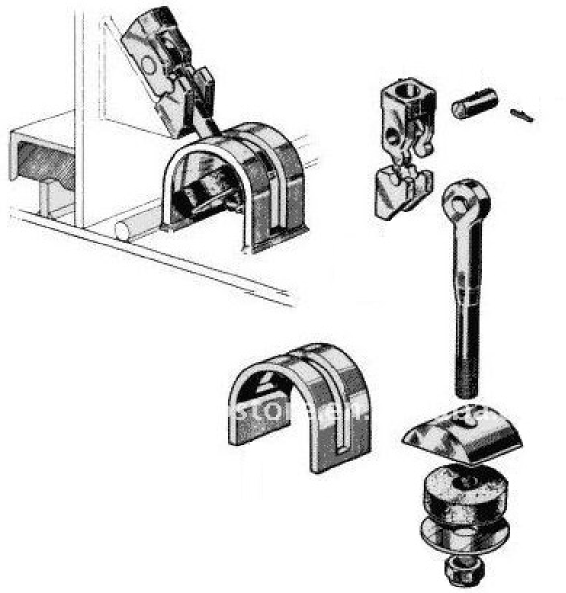

Figure F.20: Quick acting cleat example [35].

G
Analysis of hold opening and load shifting system

The opening of the hold consist of multiple parts working together. It consists of the stacking technology, the rollers lifting the hatch of the seafastening and the winch propelling the rollers. The steps required for opening the hold are depicted in Figure G.1. The major steps are described here, with the red bars as the critical path, which are the steps of the rolling hatches.

It is a continuous process of a single hatch that is being transported to the aft, where it is lifted. During the lifting of the hatches, another hatch will be transported to the aft until all hatches are stacked at the aft.

Besides the hold opening, a similar process is done for the load shifting operation. Preparation for a load shifting operation to the front of the vessel does not differ a lot from the hold opening sequence, apart from the fact that only positions 4&5 have to be cleared for hatches 1&2. Load shifting to front is the actual shifting of the load from position 4&5 to 1&2. This means that hatches 5-8 will be stacked at location 8, with hatches 3&4 resting at positions 6&7, reducing stacking time. Preparations to swap from hold opening to cargo shifting mode have to be done when the hatches are in position, in the same time as the loading of the cargo.

After load shifting to the front of the vessel, hatches 7&8 have to be brought in position to be able to shift cargo to aft of the vessel. Load shifting to aft is the actual shifting of the load from position 5&6 to 7&8. Preparing the hatches is done in reverse order of hold opening, with bringing hatch 3&4 to their final positions and stacking hatches 5&6 on top of hatch number 4. Stacking of those hatches has to be done using the onboard cranes, as there are no stacking cylinders at position 4. After that, hatches 7&8 are brought to position 5&6, where they will be loaded with the heavy cargo. After shifting the cargo to the aft, the hold can be closed. Closing the hold is again done using the onboard cranes.

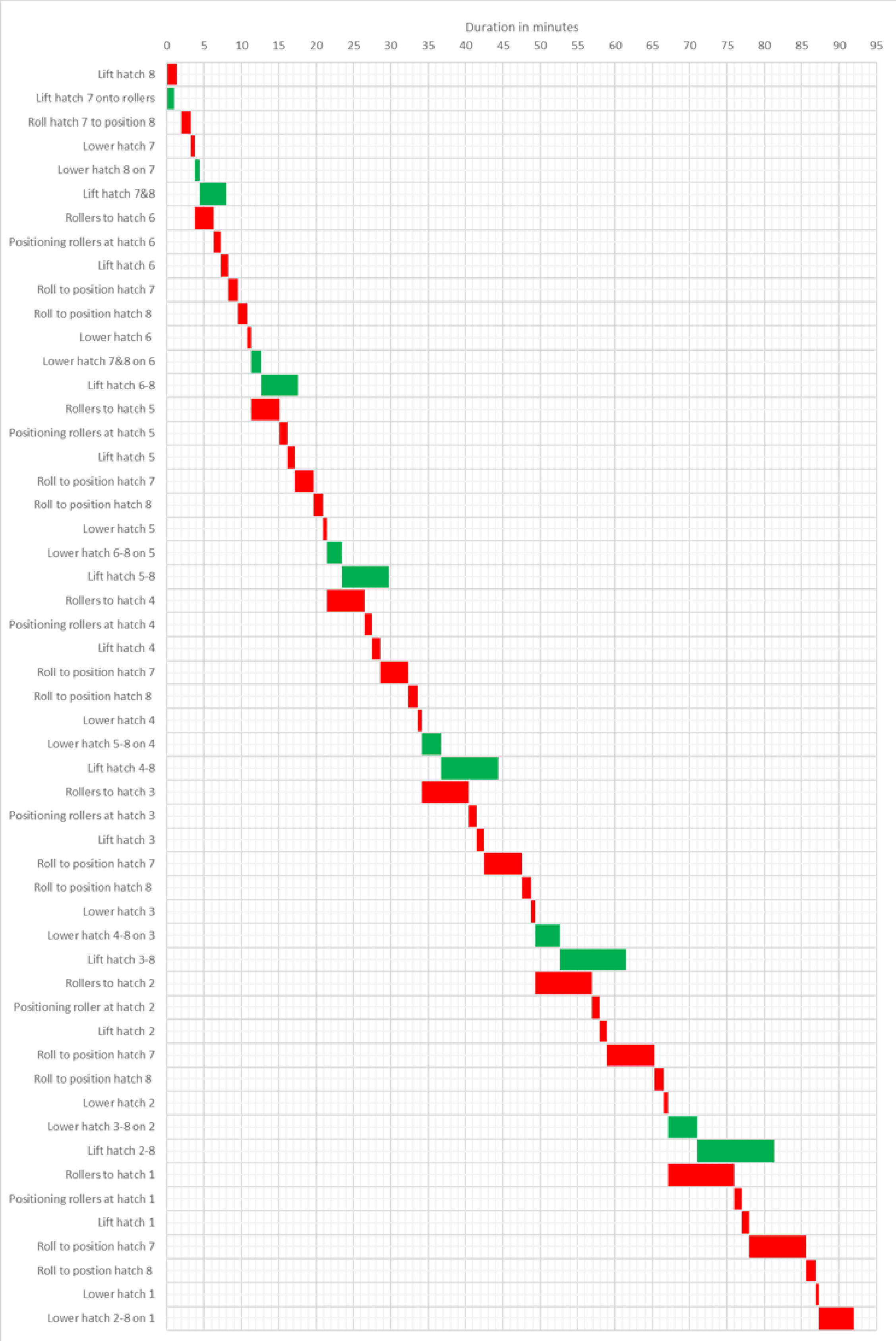

Figure G.1: Gantt chart of hold opening sequence.

H

Analysis of void strength in new ship design

An analysis is carried out into the void strength as the design changes significantly at that part of the vessel. For comparison, the void section is loaded by a horizontal force, equalling 4800 kN. Considering the rules of DNV-GL [14] it equals the transverse loading of 980 tonnes of cargo. To put this in perspective: the maximum loading on the void, without the use of load spreaders, is 10 T/m^2, which would result in a load of 160T at the marked location. The imposed load is exaggerated to clearly see the differences and identify the weak spots. An additional note has to be made for the comparison, as it is done without the loading of the seafastening of the hatches on the void, as this is present in the new situation and not present in the current situation. It is regarded as a reasonable assumption, since the chance of a high load on the void accompanied with a high load on the hatch is small.

Loading void in current situation

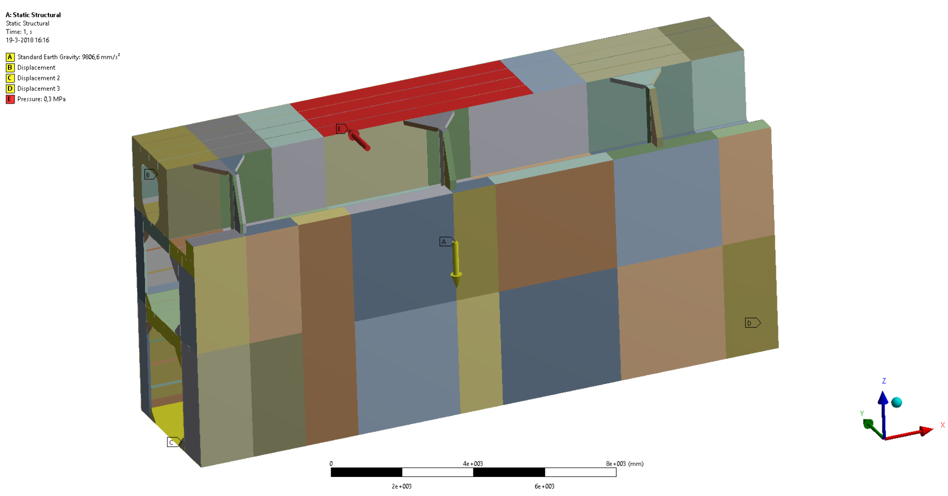

Figure H.1: Loading of void - Current situation.

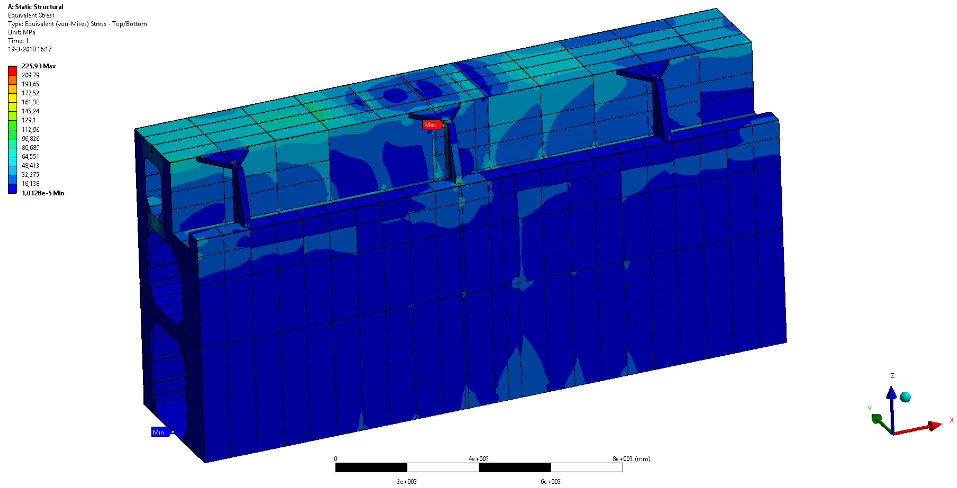

Figure H.2: Equivalent von-Mises stress void - Current situation.

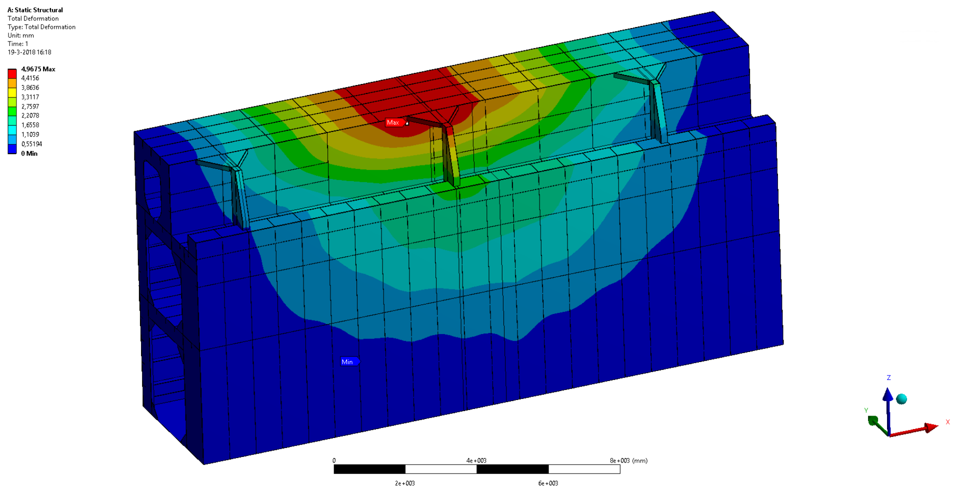

Figure H.3: Deformation of void - Current situation.

Loading void in new situation at port side

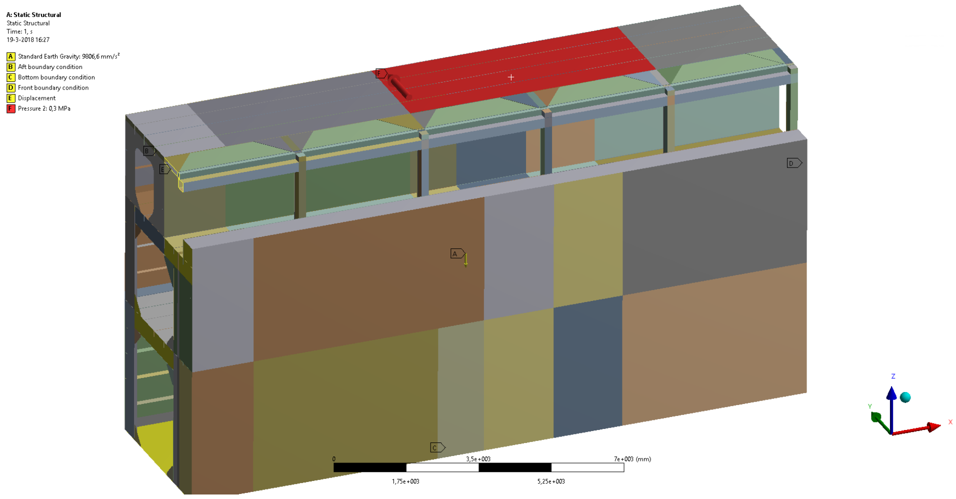

Figure H.4: Loading of void - Port side new situation.

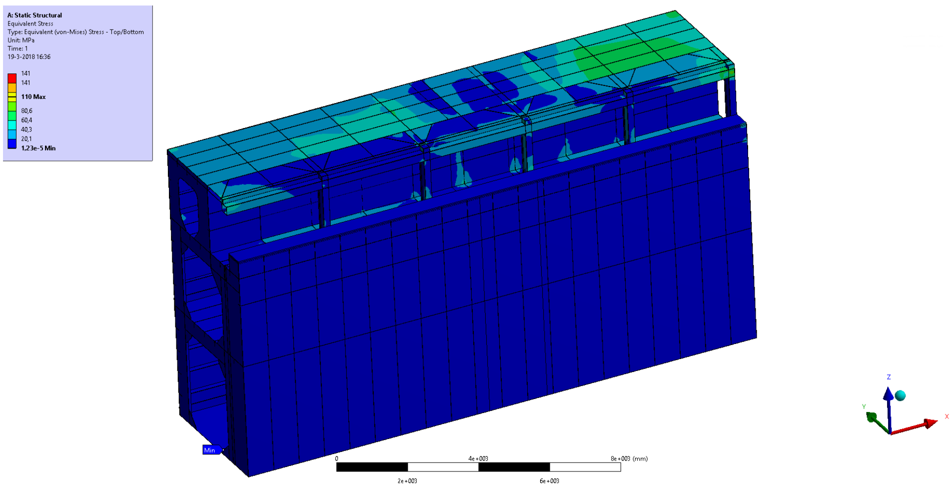

Figure H.5: Equivalent von-Mises stress void - Port side new situation.

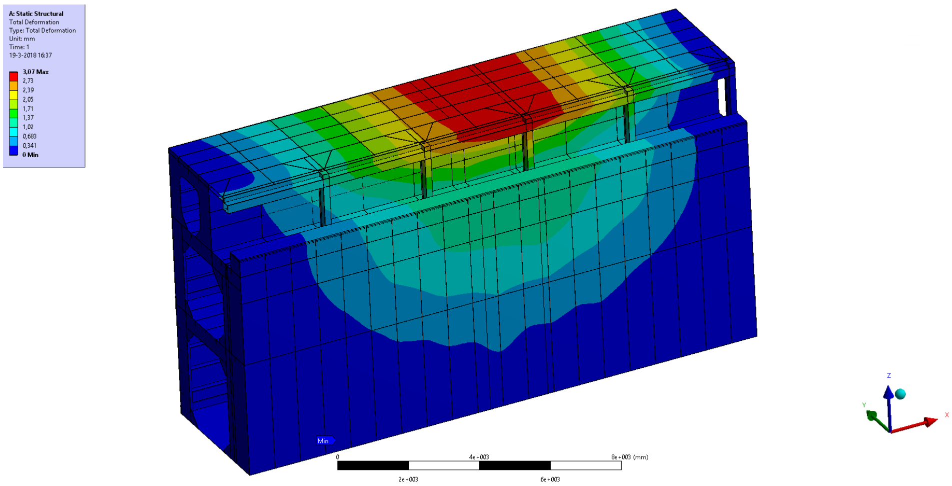

Figure H.6: Deformation of void - Port side new situation.

Loading void in new situation at starboard

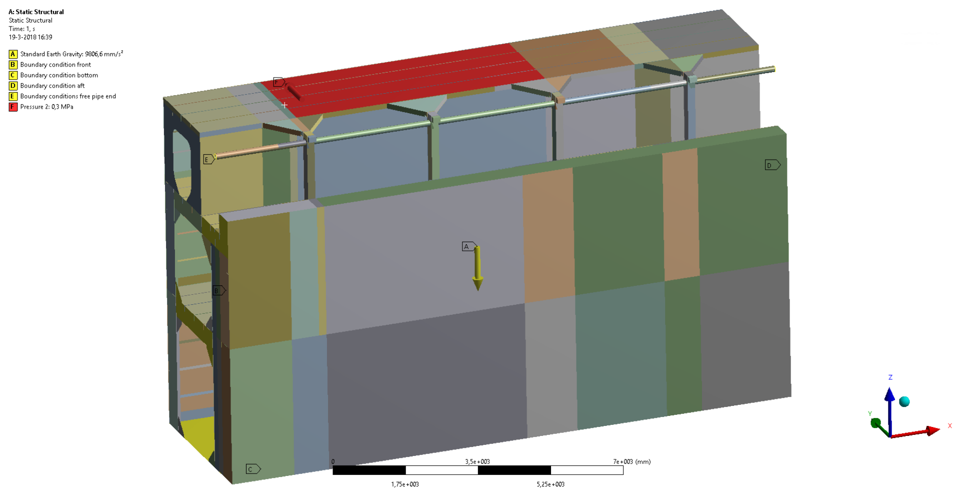

Figure H.7: Loading of void - Starboard new situation.

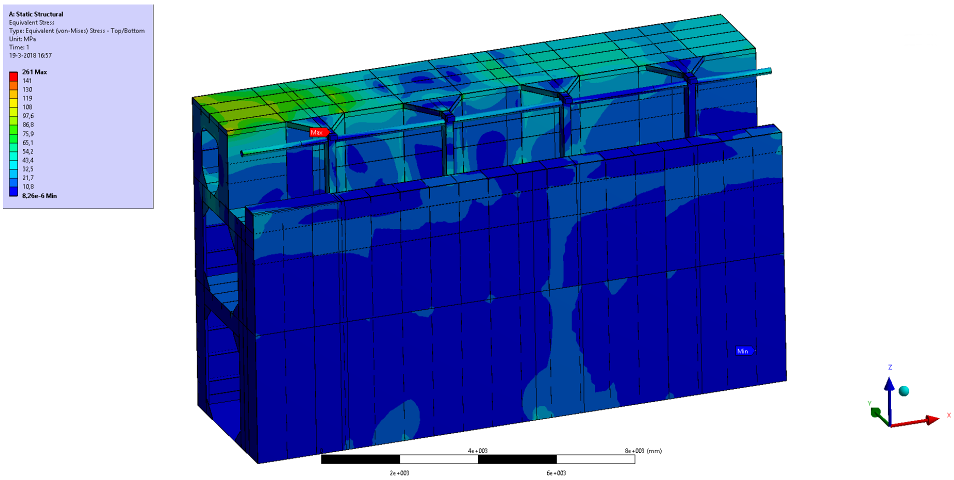

Figure H.8: Equivalent von-Mises stress void - Starboard new situation.

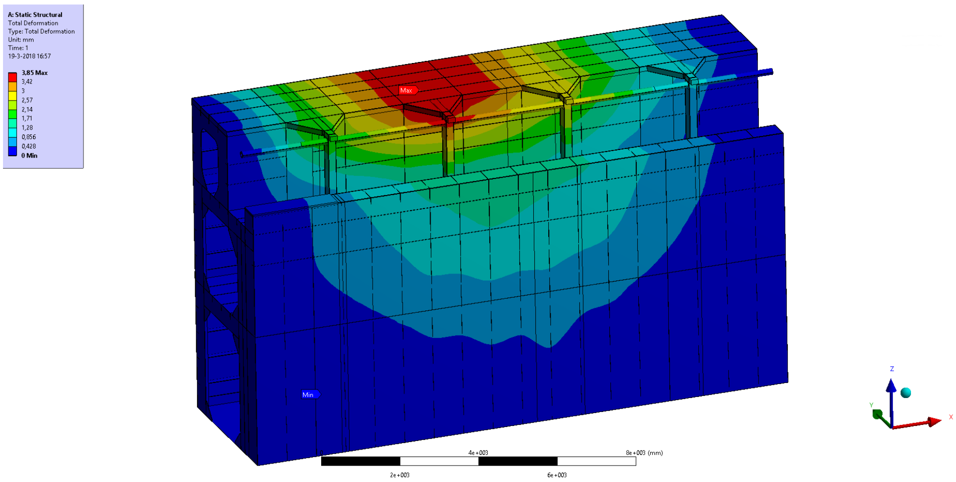

Figure H.9: Deformation of void - Starboard new situation.

The higher stresses in the new situation at starboard side are explained by the disappearance of the diagonal elements of the pillars, while it is assumed these took the most of the loading in horizontal direction. The deformation however is smaller, as the structure appears to be more rigid due to the increase of structural steel. On port side the deformation and the stresses are lower in the new situation, probably due to the fact that the increase of reinforcements for the vertical pillars. Summarizing, the new situation does not mean a high decrease in strength on starboard side, and even means a increase in strength on port side, having a positive effect on load carrying capacity of the void, with the exception that the seafastening loads of the hatch are not incorporated in this comparison. In a next iteration step a more detailed analysis of the combined effect of the seafastening loads on the pillars and the effect of the decrease of void strength can be done.

I

Safety assessment hold opening

In this Appendix the job hazard analysis for the new system is displayed, accompanied by the risk matrix of Jumbo Maritime. A low risk is regarded as safe by Jumbo Maritime, so whenever a risk is identified that is medium or high, control measures are taken to reduce the likelihood of occurring. Severity of a risk involved is often much harder to do, as this requires a total different approach to the task at hand. In Figure I.1 the risk matrix can be found. In this matrix blue is identified as a low risk, whereas yellow and red are medium and high risks, which are unacceptable for Jumbo Maritime. In Figure I.2 to I.3 the Job Hazard Analysis of the hold opening is depicted.

Risk Matrix

(03 Oct 2017, version 2)

SEVERITY	CONSEQUENCES					INCREASING LIKELIHOOD				
	People	**Assets**	**Environment**	**Schedule**	**Reputation**	**1** Very Unlikely Never heard of in the heavy lift/shipping/ Offshore Industry	**2** Unlikely Heard of in the heavy lift/ shipping/ Offshore Industry	**4** Possible Has happened at Jumbo in the past 5 years or more than once per year in the heavy lift/shipping/ Offshore Industry	**8** Likely Has happened on a vessel/yard or project location or more than once per year at Jumbo	**16** Very Likely Has happened more than once per year on a vessel or within a project.
0	No injury or health effect	No damage	No effect	No impact	No impact	0	0	0	0	0
1	First aid injury	Slight damage < 100K€	Slight effect	1 hour delay	Slight impact	1	2	4	8	16
3	Medical Treatment injury	Minor damage 100K€ - <1000K€	Minor effect	1-12 hours delay	Minor impact	3	6	12	24	48
6	Restricted, Lost work injury or partial disability	Moderate damage 1000K€ - 2000K€	Moderate effect	12-48 hours delay	Moderate impact	6	12	24	48	96
12	Permanent disability or 1 fatality	Major damage 2000K€-5000K€	Major effect	48 hours – 7 days delay	Major impact	12	24	48	96	192
24	Multiple fatalities	Massive >5000K€	Massive effect	More than 7 days delay	Massive impact	24	48	96	192	384

Template: Form – Standard Policy or Statement – JMS 03.600.01.01	Version: 0

Figure I.1: Risk matrix Jumbo Maritime.

Form - Job Hazard Analysis

03-100-05-01
Date: 25-01-2017
Version: 1

Project / (Project Number):	Graduation thesis Sjoerd van der Meulen	**Vessel:**	J1800-class
		Date:	
Job:	**Hold opening**	**JHA leader:**	
Person in charge of job:	**Officer in charge**	**JHA team:**	

All responsible persons listed below shall clearly report completion of their duties to the person in charge

No	Task	Risk (what can go wrong?)	Initial Risk Level (high/medium/low)	Control Measures	Residual Risk per measure (high/medium/low)	Follow up by (resp. person)
0	Before operation	Workers around without knowing the risks involved	Medium (48)	Name risks involved in compulsory safety induction. Sound alarm and light signals before operations start, check whether or not people are in corridor as rollers start moving.	Low	Officer in charge
1	Position rollers under hatch	Misalignment of rollers	Low			
		Jamming of winches	Low			
		Failure of rollers	Low			
		Trapping of person in wires of rollers	Medium (24)	Sound alarm and light signaling when positioning rollers to make people aware of danger.	Low	Officer in charge
2	Lift hatch onto rollers	Failure of hydraulic hoses, causing an oil spill	Low			
		Failure of HPU, causing hatch to be tilted	Low			
		Failure of one of four cylinders, causing hatch to be tilted	Low			

Figure I.2: Job Hazard Analysis, page 1.

		Loose material on hatch	Medium (24)	Before lifting checking if there is material on the hatches.	Low	Officer in charge
		Cleats still attached to hatches before lifting	Medium (24)	Check if al cleats are loosened before lifting.	Low	Officer in charge
		Person walking on top of hatch	Medium (48)	Sounding alarm and light signaling when lifting. Always make use of the safety fences.	Low	Officer in charge
3	Roll to position 8	Failure of rollers, causing hatch to fall down	Medium (24)	Always use properly maintained rollers, evaluate state every time it is used	Low	Master
		Failure of HPU, causing hatch to fall down	Medium (24)	Ensure HPU has safety measures to cope with pressure loss	Low	Master
		Failure of cylinder, causing hatch to fall down	Medium (24)	Ensure cylinder has safety measures to cope with pressure loss	Low	Master
		Open hold, people can fall in	High (96)	Always make use of the safety fences and optical and acoustic warning signals.	Low	Officer in charge
4	Lower hatch at position 8	Misalignment of the hatch, causing the hatch to be positioned wrong on top of seafastening	Low			
		Jamming of cylinder, not being able to lower hatch	Medium (24)	Carefully monitor operation, anomalies will be noticed by control system.	Low	Officer in charge
		Trapping between hatch and seafastening	Medium (24)	Sound alarms when lowering. No people interference allowed during operation.	Low	Officer in charge
5	Connect stacking technology to hatches	Misalignment, not being possible to lift hatches	Low			
		Attachment failure, not being possible to lift the hatches	Low			
		Trapping of person due to interfering with jammed equipment	Medium (48)	Never interfere with running equipment, only properly trained	Low	Officer in charge

Figure I.3: Job Hazard Analysis, page 2.

				personnel allowed to carry out corrective measures		
6	Lift hatches	Failure of stacking cylinders, not being able to lift hatches	Low			
		Failure of top anchor, risk of dropping hatches	Low			
		Failure of bottom anchor, risk of dropping hatches	Low			
		Failure of HPU, no movement	Low			
Insert more lines above if needed						

Figure I.4: Job Hazard Analysis, page 3.

J

Work breakdown structure and gantt chart of vessel conversion

To estimate the lost time costs of the vessel, a work breakdown structure is made, with an accompanying Gantt chart. The WBS can be found in Figure J.2 and the Gantt chart can be found in Figure J.3. The total work involved in the conversion of the J1800-class vessel is divided into clearly recognisable parts:

1. Preparation works prior to docking
2. Adjustments to coaming structure
3. Adjustment of location hatch eight
4. Propulsion system of the hatches
5. Adjustments to hatches
6. Total control system and electronics

As can be seen, the works are divided into preparations, work relating to the specific parts of the design and a global part regarding the control system. For all six parts, a more elaborate explanation is given.

Preparation works prior to docking

The preparation works comprise of the following actions:

1. Preparation coaming
2. Preparation of location hatch eight
3. Preparation hatches
4. Preparation control system
5. Preparations on board of vessel

To minimize time spent for the vessel during conversion, a lot of parts can be prepared for placement on the vessel. As the sole purpose of the WBS is to estimate the time the vessel spends in conversion, the preparation time is not considered. Before the vessel arrives at the yard, the steel sections for the coaming and hatches will be prepared, ensuring a smooth conversion of the vessel. Also, on board of the vessel some preparations can be taken, some cleaning works and demolition preparation. Assumed is that all preparations are done before the vessel arrives and the vessel is ready for the conversion works without any delays.

Adjustment of coaming

A major part of the conversion process is adjusting the coaming. The coaming has to be strengthened for the roller loads, together with the relocation of the seafastening structures. Location eight of the hatches is considered separate, because at this location also the stacking technology has to be located.
The works are divided into several parts:

1. Remove hatches onto quay side
2. Remove old structures

3. Rebuild port side
4. Rebuild starboard side

Construction works on starboard and port side differ significantly due to the different designs of the new structures added. As these works take place on the respective sides of the vessel, they take place at the same time.

Remove hatches onto quay side

After arriving at the yard, the first thing that has to be done is placing the hatches onto the quay side. The hatches will be adjusted on a separate location, whereas the demolition works can not start with the hatches still present.

Estimated time involved in placing the hatches onto the quay is **0.5 days**.

Removal of old structures

Before the already prepared new sections can be placed, the old structures have to be removed over the total hold length. The structures that have to be removed consist of the vertical pillars, the seafastening structures, the coaming plate, together with other small items. In contrast with the construction of the coaming, depicted in Figure J.1, the process is reversed. As can be seen, scaffolding has to be erected in the hold, to make the coaming more accessible.

Figure J.1: Construction of coaming.

At the end of this phase, the coaming will be cleared of the old structures, ready for the previously prepared sections on the yard. The estimated time of demolition of the coaming is **7 days**.

Rebuild port side

For rebuilding the port side of the vessel, the following consecutive works have to be carried out:

- Reinforcing void
- Preparation coaming substructure
- Outline and place steel S690 plate
- Place prefabricated steel sections

- Place stoppers and cleats

Reinforcing the void and preparation of the coaming substructure can be carried out at the same time, as several different locations have to be considered. Furthermore after a section of the steel S690 plate is placed, the prefabricated steel sections can follow, after which the placement of stoppers and cleats can start, working their way from front to aft.

Reinforcing void
At some locations the void has to be reinforced due to the increased loading of the seafastening of the hatches. This work is limited to increasing plate thickness at the location where the vertical pillars are attached to the void.

For the seven hatch locations, the estimated time spent is estimated at **7 days**.

Preparation coaming substructure
The coaming has to be prepared for the steel S690 plate that it has to carry. This preparation works have to be done for all seven locations. Time spent is estimated at **7 days**.

Outline and place steel S690 plate
Over the whole length of the coaming a thick steel S690 plate has to be placed, with a high precision, taking preparation time. The steel plate will consist of several parts, being placed in consecutive order. Estimated is that for seven locations the time spent is **7 days**.

Placement of prefabricated steel sections
After the first section of the steel S690 plate is placed, the placement of the prefabricated steel sections can commence. As a total section is completely prepared on the yard, the only thing that has to be done on board the vessel is outlining and welding to the substructure. For seven locations, the time spent is **7 days**.

Placing stoppers and cleats
After the total steel sections are placed, only the cleats and stoppers have to be welded to the structure. This is done after placement on board the vessel, as outlining the stoppers is very precise, as they have to fit perfectly. For one hatch, 16 stoppers have to be placed, together with 8 cleats. For seven locations, a total of **5 days** is reserved to complete the total placement.

Rebuild starboard side

Contrary to port side, no void reinforcement has to take place at starboard side. This results in the following works at starboard side:

- Preparation coaming substructure
- Outline and place steel S690 plate
- Place prefabricated steel pillars
- Place steel beam between pillars
- Place cleats

As for the port side structure, the works can be done in consecutive order, as the works have to be done for seven locations. First, the coaming substructure has to be prepared, after which the steel S690 plate can be placed. When this is placed, the prefabricated steel pillars can be placed next to the coaming. Between those pillars a circular steel beam is welded, after which the cleats can be placed.

Preparation coaming substructure
Comparable with the works on port side. Time spent is **7 days**.

Outline and place steel S690 plate
After the preparation works at location one are done, the steel S690 plate can be outlined and placed, taking one day for each location, in total **7 days**.

Placing prefabricated steel pillars
For every hatch location, four pillars are placed. These prefabricated pillars are fitted with the new starboard stoppers and have to be lined out carefully. For all seven locations, the time spent is **7 days**.

Placing steel beam between pillars
After the pillars are placed, they have to be interconnected with a circular steel beam. Sections of 3.2 meters each have to be placed between all pillars, four in total for all hatch locations. Time spent for seven locations is estimated at **7 days**.

Placing cleats
After all reinforcement works are done, the cleats have to be placed for seafastening the hatches. For one hatch location eight cleats have to be placed, resulting in 56 for all seven locations. A total of **4 days** is reserved for these works, which only can be finished after all other works are finished as well.

Adjustment location hatch eight

Besides the seven 'normal' hatch locations, hatch location eight also has to be adjusted. But as this location also comprises of the stacking technology, which complicated the conversion works, a special planning is made for this part of the conversion.

The works consist of:

1. Adjustment coaming and substructure
2. Placement of stacking technology
3. Placement of hydraulic system

Adjustment coaming and substructure

Like the other seven locations, location eight also has to be prepared and adjusted for the rolling hatches. These works consist of:

- Reinforce substructure at stacking location
- Prepare coaming substructure
- Outline and place steel S690 plate
- Place prefabricated steel sections starboard and port side
- Place stoppers and cleats

Reinforce substructure at stacking location
As the stacking technology climbs along specially constructed climbing bars, preparations have to be taken to transfer the forces of the stacking technology to the substructure, as the total loads can run up to 190 tonnes. So, in difficult to reach places at location eight reinforcements have to be added. This has to be done at four locations, two on each side of the vessel. With the locations being hard to reach and the reinforcement works extensive, the estimated time spent is **5 days**.

Prepare coaming substructure
After the reinforcement works, the coaming is prepared for the steel S690 plate, taking up approximately **1 day**.

Outline and place steel S690 plate
Following the preparation works, the steel S690 plate is placed, taking also approximately **1 day**.

Place prefabricated steel sections starboard and port side
After placement of the steel S690 plate, the prefabricated section on port side can be placed, together with the steel pillars on starboard. Together with the steel pillars, the circular beam is placed. Estimated time spent is **2 days**.

Place stoppers and cleats
At last, the stoppers and cleats can be placed on port side, along with the cleats on starboard. This takes approximately **1 day**.

Placement of stacking technology

As the stacking technology consist of several parts, these all have to be placed in consecutive order.

1. Installation of climbing bars
2. Installation of bottom anchor
3. Installation of hydraulic cylinders
4. Installation of top anchor and hatch grab system

Installation of climbing bars
On top of the reinforced substructure the climbing bars will be installed. The climbing bars can easily be connected and have to rise above main deck level, as the hatches have to rise above main deck level. Installation of climbing bars is estimated at **1 day**.

Installation bottom anchor
The bottom anchor is the first part of the moving parts of the stacking technology and has to be installed on the climbing bars. For all four locations, this is estimated at **1 day**.

Installation hydraulic cylinders
On top of the bottom anchor, two hydraulic cylinders are installed, each on a side of a climbing bar. This takes approximately **1 day**

Installation top anchor and hatch grab system
The top anchor is installed on top of the hydraulic cylinders and has a specially designed hatch grab system installed. Also installation of this part takes approximately **1 day**.

Placement of hydraulic system

For the stacking technology hydraulic power is required, supplied by a dedicated hydraulic system. This has to be installed below deck, protected from the environment and connected to the cylinders at the stacking location. Works consist of:

- Prepare HPU location below deck
- Place HPU at location
- Preparation hydraulic connections
- Connection and testing of hydraulic system

Preparation of the HPU and placement can already commence at the start of the conversion works, as it is at a complete other location than the majority of the work. The hydraulic connections can also be prepared in advance, for an easy placement of the actual hydraulic hoses. Connection can only be done after all the parts are in place.

Prepare HPU location below deck
To protect the HPU from the harsh marine environment, it is placed beneath deck, at a central location with respect to the four stacking points. Placement of the HPU has to be prepared, as much of the space below deck is already occupied. Preparation time can take up to **7 days**.

Placement HPU at location
As the HPU is placed below deck, which is hard to reach, installation of a big HPU for the stacking technology can be quite challenging, having to go through multiple small hatches before reaching the final location. Installation can therefore take up to **3 days**.

Preparation hydraulic connections
Preparation of the hydraulic connections can start as soon as the demolition works are completed and are necessary for pulling the hydraulic hoses from below deck to the respective stacking points. Preparation can take up to **4 days**.

Connection and testing of hydraulic system
After installation of the stacking technology, the hoses can be connected to the HPU and the system can manually be tested, taking up to **1 day**.

Propulsion system of hatches

Besides the vessel being structurally capable of carrying the hatches, the hatches also have to be propelled. Conversion work related to the propulsion system consist of:

- Front placement
- Aft placement
- Placement of rollers
- Installation and testing

Front placement

Winches and strand jacks will be placed on main deck level and since these works do not interfere with the coaming, it can start immediately at the beginning of the conversion. Conversion works will be conducted in consecutive order and consist of:

1. Allocation space front winches
2. Preparation winch location
3. Preparation and reinforcement strand jack location
4. Placement of winches

Allocation space front winches
Several structures are already present in front of location one at main deck level. To be able to place the winches and strand jacks, space has to be allocated. This means that structures will have to be replaced, which takes time. Time for allocation is therefore set at **6 days**.

Preparation winch location
With sufficient space available for placement of the winch, the winch location has to be reinforced, as the pulling force can equal five tonnes, preparation time is set at **2 days**.

Preparation and reinforcement strand jack location
Besides the winch for hold opening, also a strand jack has to be placed during load shifting. As load shifting is not often done, only the placement location will be reinforced, the strand jack will not be present throughout the lifetime, but only during project execution. This means that the location has to be reinforced to be able to transfer 48 tonnes of pulling force of the strand jack to the substructure. Available time for preparation and reinforcements is set at **3 days**.

Placement of winches
When the substructure is prepared and reinforced, the winches can be placed, which takes approximately **1 day**.

Aft placement

Like the front placement, aft placement conversion works can start as soon as conversion starts. Also here space has to be allocated, but in contrast to the front placement, at the aft there is more space available for the winches and strand jacks. Works consist also of:

1. Allocation space aft winches
2. Preparation winch location
3. Preparation and reinforcement strand jack location
4. Placement of winches

Allocation space aft winches
As there is more space available at the aft, allocation time for the winches is shorter and estimated at **3 days**

Preparation winch location
Winch location reinforcement will be the same as the front location and is set at **2 days**.

Preparation and reinforcement strand jack location
Strand jack location preparation and reinforcement is the same as on front placement and is set at **3 days**.

Placement of winches
Winches will also be placed in **1 day**.

Placement of rollers

After the works on the coaming are finished, the rollers for hold opening can be installed. Works for placing the hold opening rollers consist of:

1. Place rollers and hydraulic cylinders on coaming
2. Place HPU hold opening
3. Install wires and connect to rollers
4. Connect HPU and cylinders

Place rollers and hydraulic cylinders on coaming
On both sides of the vessel two rollers with accompanying cylinders will have to be placed. The two rollers on one side have to be connected in such a way that they can be propelled forwards and backwards. Rollers are already prepared for placement of the hydraulic cylinders, so placement will only take up **0.5 day**.

Place HPU hold opening
Together with the rollers the HPU for hold opening has to be placed on the coaming. The HPUs are located on a roller as well, to be able to travel along with the hydraulic cylinder. With the placement of the rollers, the placement of the HPU will also take up **0.5 day**.

Installation wires and connection to rollers
The rollers will be propelled by the winches in hold opening. The wires have to be installed on the winches, after which they can be connected to the rollers. It is assumed that the winches are installed with the wires already attached. This results in a total installation time of the rollers to the wires of **1 day**.

Connect HPU and cylinders
Together with the installation of the wires, the HPU can also be connected to the hydraulic cylinders. The installation of hydraulic hoses of the HPU and cylinders will take up **0.5 day**.

Installation and testing

With all the structures in place for the propulsion of the hatches, the electronics have to be installed, with testing of the propulsion system afterwards. The works consist of:

1. Prepare electronic connections winches and rollers
2. Connect winches and rollers
3. Test operation winches manually

Prepare electronic connections winches and rollers
After the structural adjustments to the coaming are finished, the electronic connections can be prepared for the winches and rollers. The HPUs attached to the rollers require electronic power for operation and will therefore be connected to the onboard electronic system by the use of an automatic reel for electronic wires. The winches are stationary and only require a socket. As electronic power is available at numerous locations at the vessel, preparation of electronic connections only takes **2 days**.

Connect winches and rollers
Connection of the winches and rollers to electronic power is set at **0.5 day**.

Testing operation of winches
With the winches connected to the rollers and connected to electronic power, as well as the HPUs connected to power, the operation can be tested manually. Manual testing is set at **1 day**.

Adjustment of hatches

Besides adjustments to the vessels structure, the hatches also have to be adjusted to be carried by the rollers. As these adjustment works can be carried out on a separate location, it can start immediately after the vessel placed the hatches on the quay side. Conversion works consist of:

- Removal current seafastening structure
- Placement port side section
- Placement starboard section

First, the current structures at the sides of the hatches have to be removed. After this is done for one hatch, the port side section can be attached, after which the starboard section is attached. The conversion works can follow each other from hatch to hatch, saving time.

Removal current seafastening structure

After moving the hatches to the removal location, which takes **0.5 day**, the current side structures can be removed. For one side of the hatch, it is estimated to take up to one day, which totals the total work to **16 days**.

Placement port side section

Placement of port side sections can start two days after starting the removal of seafastening structures. Placement of the port side sections consist of lining out the new section, together with welding it to the hatch. It is estimated that this takes two days for one hatch, equalling **16 days**.

Placement starboard section

Placement of starboard sections can start two days after starting the port side sections. Placement of the starboard sections consist of lining out the new section, together with welding it to the hatch. It is estimated that this takes two days for one hatch, equalling **16 days**.

Control system and electronics

The total control system for the new design will be located on the bridge, where preparations have to be taken. The several parts have their own control system, which will have to be integrated in the bridge, after which it has to be tested. Conversion works consist of:

- Preparation bridge connections
- Preparation control system rollers
- Preparation control system stacking technology
- Integration and testing complete system

Preparation bridge connections

Preparations for the bridge connections can start immediately after conversion works start. On the bridge a panel has to be located for total control, together with the required pulling of wires to the respective parts of the system. Preparation works and wire pulling takes up to **4 days**.

Preparation control system rollers
Preparation of the control system for the rollers consist of the following items:

- Pulling necessary wires
- Prepare and connect rollers control system
- Connection to final system

Pulling necessary wires
From the bridge connection wires have to be pulled to the winches and rollers on front and aft on main deck level. The rollers have to be connected to the system for operation of the HPUs. This will be done in the same way as the connection to the electronic power system, by an automatic reel connected to the front. Pulling of the wires can take place after the coaming is finished and takes up to **3 days**.

Prepare and connect rollers control system
After the rollers and HPUs are placed, together with the winches, it can be connected to the total control system. This takes **1 day**.

Preparation control system stacking technology
Preparation of the control system for the stacking technology consist of the following items:

- Pulling necessary wires
- Connection to final system

Pulling necessary wires
From the bridge connection wires have to be pulled to stacking location eight and the HPU, located beneath the deck. Pulling of the wires can take place after the coaming is finished and takes up to **3 days**.

Connection to final system
After the wires are pulled and the system is in place, it can be connected to the final system, which takes up to **1 day**.

Integration and testing complete system
The integration and testing of the complete system consist of the following items:

- Test functionality individual systems
- Test total system without hatches
- Test total system with hatches

Text functionality individual systems
Both the roller system as the stacking system has to be tested individually, before the total system can be tested. Testing of the individual systems takes up **1 day**.

Test total system without hatches
The total system has to be tested before the hatches are placed back. This also takes up to **1 day**.

Test total system
The hatches have to be placed back, after which the total system can be tested thoroughly. The total testing can take up to **2 days**.

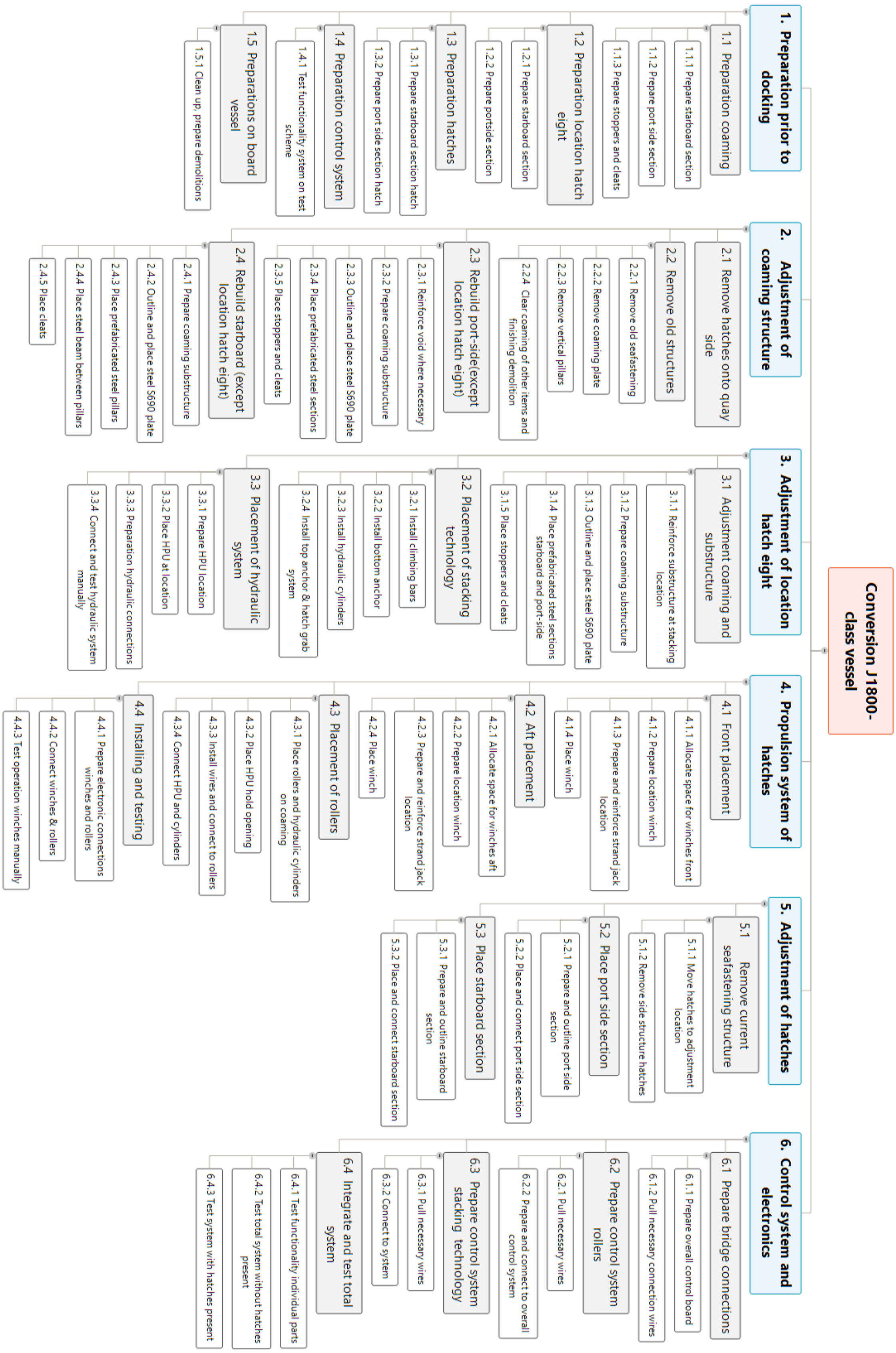

Figure J.2: Work breakdown structure vessel conversion, level 4.

	Tas...	Task Name	Duration
1		Conversion J1800-Class vessel	32,5 days
2		⊞ 1. Preparation prior to wharfage	0 days
17		⊟ 2. Adjustment of coaming	22 days
18		2.1 Remove hatches onto quay side	0,5 day
19		⊟ 2.2 Remove old structures	11 days
20		2.2.1 Remove old seafastening	3 days
21		2.2.2 Remove coaming plate	2 days
22		2.2.3 Remove vertical pillars	4 days
23		2.2.4 Clear coaming of other items a...	2 days
24		⊟ 2.3 Rebuild port-side(except locati...	10,5 days
25		2.3.1 Reinforce void where necessary	7 days
26		2.3.2 Prepare coaming substructure	7 days
27		2.3.3 Outline and place steel S690 pl...	7 days
28		2.3.4 Place prefabricated steel sectio...	7 days
29		2.3.5 Place stoppers and cleats	5 days
30		⊟ 2.4 Rebuild starboard (except locat...	10,5 days
31		2.4.1 Prepare coaming substructure	7 days
32		2.4.2 Outline and place steel S690 pl...	7 days
33		2.4.3 Place prefabricated steel pillars	7 days
34		2.4.4 Place steel beam between pillars	7 days
35		2.4.5 Place cleats	4 days
36		⊟ 3. Adjustment location 8	15 days
37		⊟ 3.1 Adjustment coaming and substr...	9 days
38		3.1.1 Reinforce substructure at stacki...	5 days
39		3.1.2 Prepare coaming substructure	1 day
40		3.1.3 Outline and place steel S690 pl...	1 day
41		3.1.4 Place prefabricated steel sectio...	1 day
42		3.1.5 Place stoppers and cleats	1 day
43		⊟ 3.2 Placement of stacking technology	4 days
44		3.2.1 Install climbing bars	1 day
45		3.2.2 Install bottom anchor	1 day
46		3.2.3 Install hydraulic cylinders	1 day
47		3.2.4 Install top anchor & hatch grab ...	1 day
48		⊟ 3.3 Placement of hydraulic system	15 days
49		3.3.1 Prepare HPU location	7 days
50		3.3.2 Place HPU at location	3 days
51		3.3.3 Preparation hydraulic connectio...	4 days
52		3.3.4 Connect and test hydraulic syst...	1 day
53		⊟ 4. Propulsion system of hatches	25 days
54		⊟ 4.1 Front placement	9 days
55		4.1.1 Allocate space for winches front	6 days
56		4.1.2 Prepare location winch	2 days
57		4.1.3 Prepare and reinforce strand ja...	3 days
58		4.1.4 Place winch	1 day
59		⊟ 4.2 Aft placement	6 days
60		4.2.1 Allocate space for winches aft	3 days
61		4.2.2 Prepare location winch	2 days
62		4.2.3 Prepare and reinforce strand ja...	3 days
63		4.2.4 Place winch	1 day
64		⊟ 4.3 Placement of rollers	2,5 days
65		4.3.1 Place rollers and hydraulic cylin...	0,5 day
66		4.3.2 Place HPU hold opening	0,5 day
67		4.3.3 Install wires and connect to roll...	1 day
68		4.3.4 Connect HPU and cylinders	0,5 day
69		⊟ 4.4 Installing and testing	3,5 days
70		4.4.1 Prepare electronic connections ...	2 days
71		4.4.2 Connect winches & rollers	0,5 day
72		4.4.3 Test operation winches manually	1 day
73		⊟ 5. Adjustment of hatches	19,5 days
74		⊟ 5.1 Remove current seafastening s...	16,5 days
75		5.1.1 Move hatches to adjustment loc...	0,5 day
76		5.1.2 Remove side structure hatches	16 days
77		⊟ 5.2 Place port side section	16 days
78		5.2.1 Prepare and outline port side s...	8 days
79		5.2.2 Place and connect port side se...	8 days
80		⊟ 5.3 Place starboard section	16 days
81		5.3.1 Prepare and outline starboard ...	8 days
82		5.3.2 Place and connect starboard s...	8 days
83		⊟ 6. Control system and electronics	32 days
84		⊟ 6.1 Prepare bridge connections	4 days
85		6.1.1 Prepare overall control board	2 days
86		6.1.2 Pull necessary connection wires	2 days
87		⊟ 6.2 Prepare control system rollers	4 days
88		6.2.1 Pull necessary wires	3 days
89		6.2.2 Prepare and connect to overall ...	1 day
90		⊟ 6.3 Prepare control system stackin...	4 days
91		6.3.1 Pull necessary wires	3 days
92		6.3.2 Connect to system	1 day
93		⊟ 6.4 Integrate and test total system	4 days
94		6.4.1 Test functionality individual parts	1 day
95		6.4.2 Test total system without hatche...	1 day
96		6.4.3 Test system with hatches present	2 days

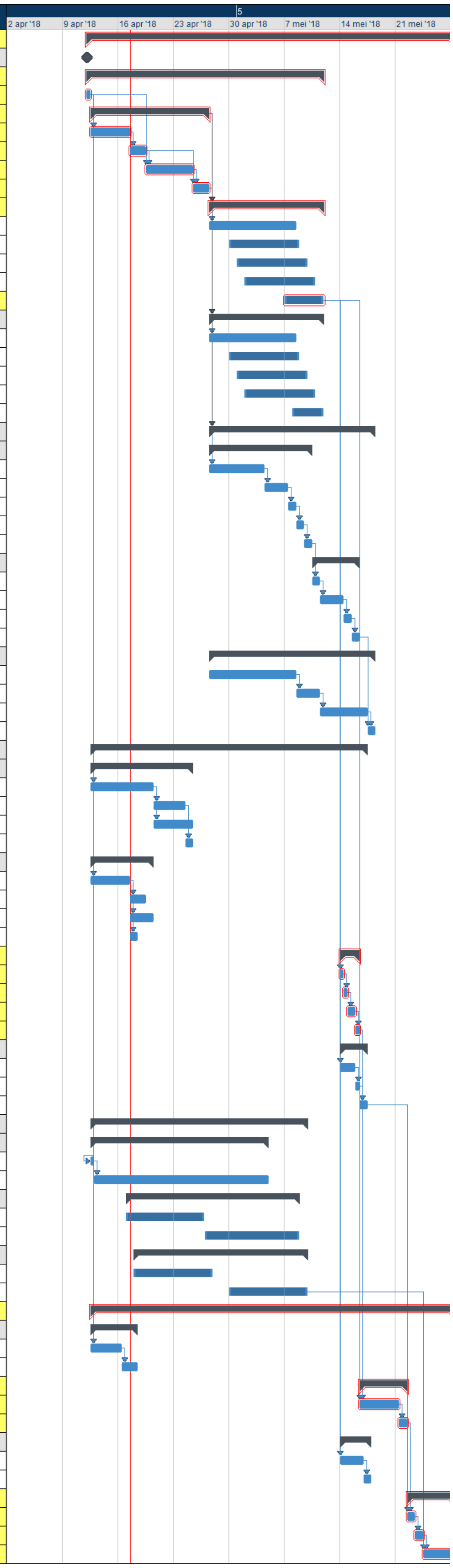

Figure J.3: Gantt chart of total conversion project, critical path marked in yellow.