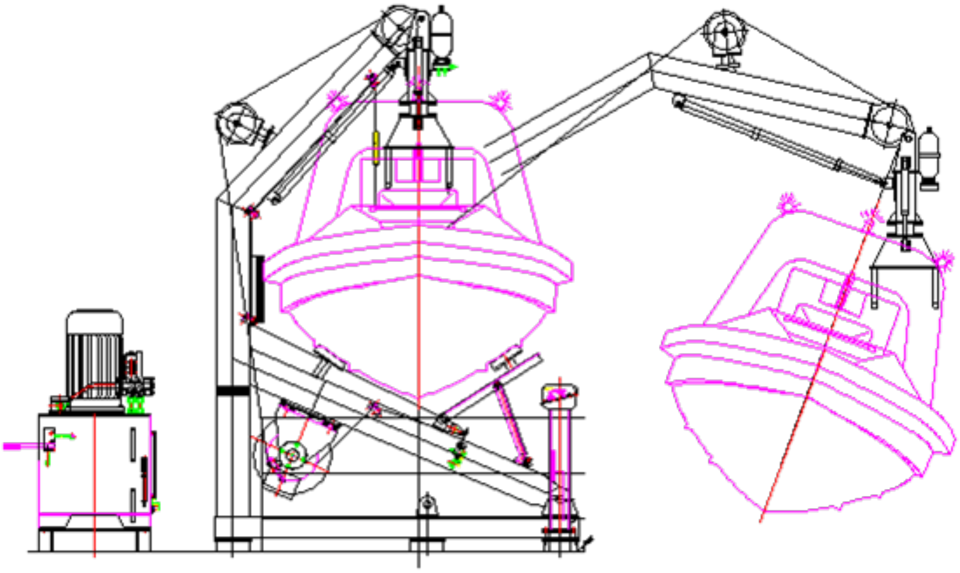
Rescue craft davit performance on an FPSO in heavy sea states & davit design proposal

Master Thesis

by

L.M. Klaver



Rescue craft davit performance on an FPSO in heavy sea states and davit design proposal

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L.M. Klaver

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This thesis is confidential and cannot be made public until March 17 2022.

Abstract

The aim of this research is to increase the workability of a rescue craft launch and retrieval system on FPSOs in heavy sea states. Although a rescue craft's purpose is to improve safety, multiple incidents recorded in the GISIS database have proven that the launch and recovery operation can be dangerous or even deadly. The problem research shows that the davit system is the main cause for incidents, which are related to design flaws, lack of maintenance and human errors, the three parameters for a successful launch. The opinion of the author is that a different type of launch and recovery system can lead to improvement of these three parameters and to an increased workability of the system. To compare a new design with the conventional design, a computational model of both designs is built in Matlab to simulate the launch of a rescue craft from an FPSO in various sea states. The conventional model shows dangerous accelerations in high sea states and the risk to collide with the hull of the FPSO. The concept design aims to reduce these motions and, in addition, provide a more redundant design with easy maintenance and focused on reducing human errors. After comparison, the concept design proves to reduce dangerous motions during launch and increase the workability in high sea states, while being very simplistic, robust and easy to operate. However, in the splash zone the concept model does not mitigate dangerous motions sufficiently. To further substantiate this conclusion, it is advised to further investigate the splash zone model and to develop a more detailed model of the concept design.

L.M. Klaver
Delft, March 17 2020

Contents

1

Introduction

This thesis focuses on the workability of a rescue craft launch and retrieval operation from an Floating Production Storage and Offloading unit (FPSO) in high seas. This introduction will give insight in which systems are currently used by the industry, the current operation practices and the problem research performed for this thesis.

1.1. Rescue craft

Rescue crafts are relatively small open crafts, either rigid, inflated or both. Rescue crafts carry up to 6 people and have a minimum cruising speed of 6 knots. A bigger type is the Fast Rescue Craft (FRC), which is designed for speeds of 20 knots or higher and can carry up to 15 people. Rescue crafts are mainly used in Man-Over-Board (MOB) operations but can also fulfill the function of towboat to tow life boats in case of an emergency evacuation. Rescue crafts should not be mistaken for lifeboats or life rafts, which main focus is the evacuation of people in case of an emergency and can therefore carry up to 80 persons. Just like lifeboats, rescue crafts are mandatory for every merchant vessel, including offshore platforms and FPSOs. All rescue crafts have to comply with a number of regulations. The International Convention for the Safety Of Life At Sea (SOLAS) is considered the most important international maritime treaty related to improving safety at sea and was drafted after the Titanic crash [10]. It is adopted by the International Maritime Organization (IMO) and sets standards in construction, equipment and operation for merchant vessels including FPSOs. This convention includes requirements for life-saving appliances (LSA) including life- and rescue boats. The technical standards for these LSAs are stated in the Life-Saving Appliance code.

1.2. Davit system

A davit is a crane-like system used to deploy and recover work boats, lifeboats, life rafts and rescue crafts alongside a ship's hull. The craft is attached to the fall which is connected to the arm of the davit. It is lowered and retrieved using winches. Various types of davit system exist, shown in Figure 1.1, which in this report are categorized in T-type, A-type and G-type davit systems. A T-type davit is a single arm, crane type davit with telescoping, slewing and luffing options. The A-type davit has an A-frame which works as a luffing arm. The G-type davit also has a luffing arm and is equipped with a cradle to support the vessel. This is especially suitable for handling heavier vessels such as FRCs and work boats.

The regulations for davit systems are also stated in the SOLAS treaty. The technical details related to rescue craft davit systems are stated in the LSA code [8] and comprise among others regulations with respect to minimum an maximum lowering and retrieval speeds, maximum loads it must be able to endure and required systems and redundant systems.

For FRC davit systems additional technical requirements are stated which comprise among others that the davit must be fitted with a device that dampens the forces due to interaction with waves when the FRC is launched or recovered. Also, an automatic high-speed tensioning device must be installed which prevents the wire fall from going slack in all sea state conditions in which the FRC must operate. Lastly, the lowering speed when fully loaded must not exceed 1 m/s. The minimal hoisting speed shall not be less than 0.8 m/s.

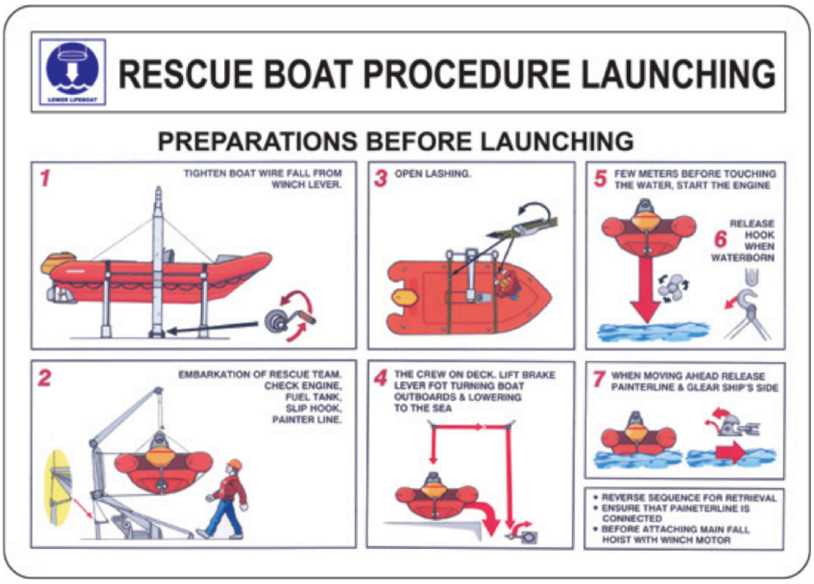
Devices such as a damping device and high-speed tensioning system can be added to the davit and improve the workability of the system. The damping device often is a hydraulic shock absorbing cylinder, which reduces the shock forces on the rescue craft and the crew. The high-speed tensioning system, also called constant tension

Figure 1.1: fltr: G-type, A-type, T-type davit system

system, wave riding recovery mode or wave compensation system is a device that is installed on the boom of the davit system and absorbs the wire rope slack caused by a swell when the rescue craft is lifted or lowered and relieves the impact. Another system is the heave motion compensation winch, which compensates the movements of the vessel the rescue craft is launched from. To compensate the movements of the vessel when the rescue craft is stowed, it is possible to add an anti-pendulum system, which controls the rescue craft's motions when docked and ensures safe boat handling when moved outside the docking station. More optional systems exists to improve workability. However, the downside of these systems is that a davit system can become very complex and expensive for maintenance and operation.

1.3. Launch and retrieval process

The launch and retrieval operation of a rescue craft must be executed with great care, as accidents happen easily when not done properly. In Figure 1.2 the launching procedure is described step by step. This procedure exists of five phases. First of all, the crew boards the craft. Then the rescue craft is lowered while keeping the rescue craft positioned parallel to the side of the vessel using the painter line, which is attached to the fore of the craft. When the rescue craft enters the splash zone, it is still connected to the davit and experiences the forces induced by the movement of the FPSO and the waves. Before sail away, the rescue craft must be disconnected from the davit hook and secondly the painter line must be disconnected. Then the rescue craft can sail away from the vessel. When retrieving the rescue craft this procedure is executed in reversed order.



RESCUE BOAT PROCEDURE LAUNCHING

PREPARATIONS BEFORE LAUNCHING

1 TIGHTEN BOAT WIRE FALL FROM WINCH LEVER.

2 EMBARKATION OF RESCUE TEAM. CHECK ENGINE, FUEL TANK, SLIP HOOK, PAINTER LINE.

3 OPEN LASHING.

4 THE CREW ON DECK, LIFT BRAKE LEVER FOT TURNING BOAT OUTBOARDS & LOWERING TO THE SEA

5 FEW METERS BEFORE TOUCHING THE WATER, START THE ENGINE

6 RELEASE HOOK WHEN WATERBORN

7 WHEN MOVING AHEAD RELEASE PAINTERLINE & GLEAR SHIP'S SIDE

- REVERSE SEQUENCE FOR RETRIEVAL
- ENSURE THAT PAINETERLINE IS CONNECTED
- BEFORE ATTACHING MAIN FALL HOIST WITH WINCH MOTOR

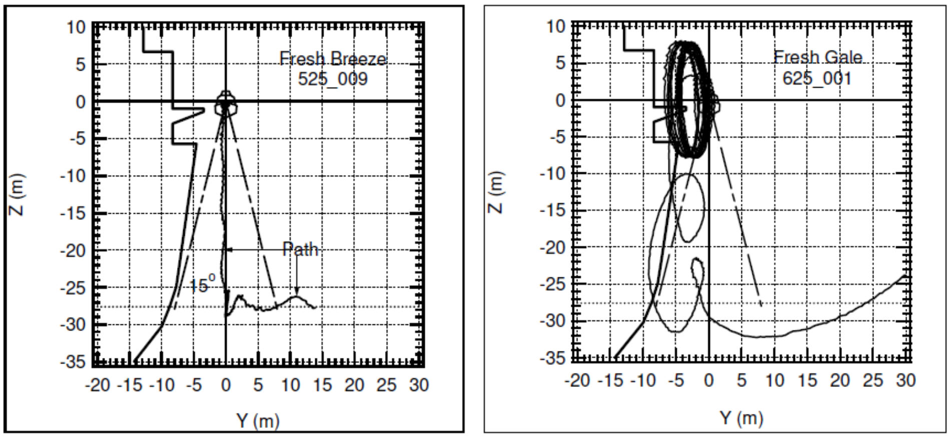
Figure 1.2: Rescue craft launch procedure instructions

1.4. Problem research

To define the problem this research will concentrate on, an extensive problem research has been conducted existing of a literature study, interviews with the industry, an incident analysis and a comparison of regulations for LSA equipment with offshore cranes.

1.4.1. Literature study

The majority of the research, conducted on the launch and recovery operation of rescue crafts is related to two projects. The National Research Council of Canada's institute for Marine Dynamics has executed a set of scale model experiments for lifeboat performance[16] and the SAFECRAFTS project has developed computational models to simulate a lifeboat launch [19]. The aim for the scale model experiments came forth from the lack of regulations regarding the capability of the evacuation system performance as a function of weather conditions. Three sets of experiments have been performed, where a conventional davit launched twin-fall lifeboat, called Totally Enclosed Motor Propelled Survival Craft (TEMPSC), is launched from an FPSO [16] or from a platform [17] [18]. In all experiments, the TEMPSC was deployed from the windward side in regular waves. The experiments focused on the performance of a lifeboat launch operation in various weather conditions, the development of performance parameters to analyse the success of the operation and to provide possible solutions to improve the performance in heavy sea states.



(a) Beaufort 5

(b) Beaufort 8

Figure 1.3: Results scale experiments with FPSO [16]

This research concludes that model tests are a reliable method to measure the performance of lifeboat launching and clearing. The experiments provided the following insights:

- High sea states lead to a reduction of the system's launch performance
- The distance the lifeboat is pushed away by the wave at the moment it reaches the splash zone is most influenced by severe weather and becomes larger for higher sea states
- Solutions provided by the experimental research to increase performance of an evacuation operation aim to reduce the motions of the lifeboat in splash zone only. None of the solutions provided influence the launch path of the life boat while the results show significant motions, especially for FPSO launched lifeboats (see Figure 1.3b).

In addition, no collisions occurred during the launch from both the FPSO and the platform. The researchers expected that such an event would occur and because of the absence of a collision it was advised to pursue this further in more realistic sea. However, this advice has not been followed up. Note that for all obtained results one must keep in mind that scale effects influence the results. These possible effects have not been further analysed in the experiments.

The second research discussed in this study is the SAFECRAFTS project, which objective is to develop an assessment method for evaluating the performance of life saving appliances. As a part of this project computational models have been developed to simulate motions from the start of the launch until splash-down and sail away. Both models are built in the time domain and apply a numerical method to predict the lifeboat's motions. First, a relatively simple 2 degrees of freedom (DoF) pendulum model [5] models the FPSO and lifeboat as rigid bodies, the lifeboat's fender as a spring-damper element and the wire as a single spring element. Also, the model includes the stiffness of the davit's arm and shock damper, which is only acting when a certain force in the wire is exceeded, and a possible collision with the hull of the FPSO. The main assumptions are:

- The FPSO and lifeboat motions are modeled in the 2 dimensional plane only
- FPSO rolling is harmonic
- the wire axis does not incline from the FPSO's plane of symmetry
- Aerodynamic, hydro-static and hydrodynamic reactions, non-linear FPSO motions, splash zone behaviour of the rescue craft and damping in the system are neglected

This model was further developed as a 6 DoF model that simulates the full operation, from launch to entering the splash zone, release of hooks and sail away [6]. The FPSO and lifeboat are modeled as rigid bodies, the wires, the davit arm and shock absorber as spring elements and it includes aerodynamic, hydro-static and hydro-dynamic loads, slamming and a potential collision with the hull. Additional systems are the brake, which controls the reeling out velocity, a "catch" to include elasticity and damping properties of the lifeboats hull and a locking device to disconnect the lifeboat at water level.

The two models have provided insight in a method to model elements, forces and motions of a rescue craft when launched alongside an FPSO. The added value of the 2 DoF model is that it is fast, gives insights in motions to help a designer in monitoring behaviour of the launched lifeboat and in investigating the influence of technical en environmental parameters. However, it cannot model the full operation and excludes environmental influences, irregular waves and damping. The second model accounts for 6 DoF, the full operation and includes water and wind loads. However, its computation time is long for designing purposes and little insight is given in how the model is built. Notable from the simulation tools is that the models do show collisions for certain wave heights. These collisions can lead to dangerously high accelerations equal to ten times the gravity [4].

To finalize, the SAFECRAFTS project concludes that a simulation tool is fit for designing purposes and that high sea states decrease the performance of the operation. Therefore, the advice is given to set operational limits for the launch of lifeboats with respect to sea states.

1.4.2. Interviews

According to the industry, the success of a rescue craft operation depends on three success parameters: A good and reliable design, a qualified and trained crew and proper execution of routine maintenance and testing. The following conclusions where defined after gaining insight in the operation of a rescue craft on-board an FPSO:

- The rescue craft and davit system are not custom-built for operation on board an FPSO. Both are not designed for the severe environmental conditions FPSOs can encounter
- The FPSO's large free board cause the rescue craft to be very exposed to weather conditions during launch and retrieval
- Success of the operation depends largely on the crew. Mistakes by the coxswain can lead to collisions with the hull of the FPSO or difficulties with positioning the rescue craft when dis- or re-connecting to the davit. Also, when the procedure for the launch and retrieval operation is executed incorrectly, or when miscommunication occurs between the davit crew and rescue craft crew, the operation can fail quickly
- Equipment failure of the davit and rescue craft occurs frequently. Possibly the vendor's maintenance instructions are not adequate, the design is not easy to maintain or fit to operate in an offshore environment or the maintenance is not executed properly

The second interview was conducted with one of the leading LSA vendors, Palfinger, who confirms that no regulation exists with respect to weather conditions. SOLAS states that the launch and retrieval of lifeboats and rescue crafts must be tested in calm conditions to which they refer to as a "flat sea". Palfinger's products are only tested and approved in accordance with this requirement. Their boats are tested up to sea state 3, and theoretically rescue crafts are designed for operation up to sea state 3 (Hs $\approx$ 1m) and fast rescue crafts up to sea state 5 (Hs $\approx$ 4m). For higher sea states they advise larger crafts with bigger engines and even use work boats instead of rescue crafts for MOB situations. Thus, the davit and rescue craft are not fit for the various environmental conditions it has to operate in and the regulations do not require them to adapt. Palfinger mentions there are additional systems to increase workability, such as a slewing or telescoping painter boom, constant tension devices or anti-pendulum devices, but this will also come at a higher price. They acknowledge that launching an retrieving of rescue crafts is still a dangerous situation, even with their systems. They confirm that a large part of the operation depends on the skills of the crew and the coxswain.

1.4.3. Incident analysis

After interviewing the FPSO industry and the vendor of LSA equipment, Palfinger, it was still difficult to decide where this research could contribute most to reduce the number of incidents. Therefore, an extensive incident analysis is performed over the GISIS database of 70 incidents related to LSA equipment [11]. The aim of this incident analysis was to investigate the following:

1. To which of the two systems, the davit or the boat, the incident was related
2. The severity of the incidents and thus the necessity for improvement
3. The moment that the incident occurred in the launch and retrieval operation
4. The influence of weather conditions on the operation
5. The most occurring failure in relation to the success parameters: Design, Crew and Maintenance

The following conclusions were found during this analysis:

1. The majority of the incidents is related to davit failure
2. Most incidents occur during mandatory monthly testing, which is often executed in calm weather conditions and not under pressure. As severe incidents already occur under these conditions, it is important to improve the current operation
3. Most incidents occur in stowed position during maintenance. However, notable is that the incidents that occur during the most dangerous part of the operation, namely luffing, lowering, lifting and splash zone are mainly related to failure of the davit
4. Not enough information on the weather conditions during the incidents is provided to draw a conclusion
5. All success parameters had an almost equal share in the incident analysis, concluding that the conventional davit and rescue craft operation falls short in its design, its maintenance procedures and in the crew's performance

1.4.4. Regulations

Following from the literature study, industry insights and incident analysis, regulations for LSA equipment appears to not cover all aspects necessary for a safe operation. Therefore, this section compares the regulations for davits to the regulations for man-riding cranes, because both systems serve the same purpose, namely transferring people. This provided insight in gaps in the regulations and thus were room for improvement is.

Various standards, such as DNV-GL, Lloyd's Register or the American Bureau of Shipping (ABS) define the regulations for the engineering, operation and maintenance of offshore cranes specifically. Next to these, most countries also developed national standards. In The Netherlands the NEN code applies and specifically for offshore cranes the NEN-EN 13852-1 regulations [13]. For davit systems on the other hand, the regulations are stated in the SOLAS treaty, as explained in the Introduction. The technical standard for LSA equipment is covered in Chapter 3 of the SOLAS regulations and is revered to as the LSA Code [8]. On a first basis, the gaps between crane operations and davit operations are:

- Davit cranes are especially designed for man-riding but use relatively low standards, while man-riding crane regulations are very stringent

- Cranes are operated by skilled crane-operators, while davit systems are operated by a crew that only needs a training to qualify

- For man-riding cranes the operational limits are clearly defined with respect to wave height and wind speeds, while the requirements for davits only state that launching operations must be possible in calm weather conditions without any requirement for it's maximum operational capacities

Resulting from the comparison of the NEN code and the SOLAS regulations, the following main differences were defined. The safety factor of the wire for man-riding cranes is equal to 10, where the davit's wire is equal to 6. In addition, a crane cannot exceed 50% of its Safe Working Load (SWL) when used for man-riding purposes, but no such limit exists for davit cranes. The operational limits for cranes and man-riding cranes are clearly defined by the hand of maximum wave height, velocity limits and visibility demands. For davits however, no operational limit is defined in SOLAS. Also, redundancy measures for man-riding cranes are more stringent. A number of limiters are applied to prevent among others, undesired slewing of the boom, slack in the wire and overload. Also, during an emergency recovery the rescue craft must be retrieved with a minimum of 10% of it's normal lifting velocities with a brake on a separate circuit. For davits however, slack and overload protection are not mandatory and an emergency hand gear is sufficient, which will not reach the required 10% of the velocity set for man-riding cranes. Also, these brakes are tested for 1.5 times the maximum working load where man-riding cranes and normal cranes test the brakes for 1.6 times the working load. Complying with the man-riding crane regulations could have reduced the number of incidents but such a design results in a very complex and expensive system.

Operational limits

Although SOLAS does not provide operational limits with respect to the weather conditions, other codes have given guidance for operational limits. For a rescue craft operation, two methods provide criteria given in Table 1.1. The sea keeping criteria defined by Nordforsk (1987) [14], provide a limit for the maximum vertical accelerations a fast small craft can endure. The second method is defined in the 2000 Code for small high speed crafts [9] and gives an indication of safety levels based on the maximum horizontal accelerations. These limits are useful to determine whether a rescue craft operation is considered safe while working outside its design scope.

<table>
<tr><th colspan="4">Maximum vertical accelerations [14]</th></tr>
<tr><td><i>Level 1</i>
<i>at bridge</i></td><td colspan="2"><i>Level 2</i>
<i>at Forward Perpendicular</i></td><td><i>Level 3</i>
<i>Maximum</i></td></tr>
<tr><td>0.275 g</td><td colspan="2">0.65 g</td><td>1.0 g</td></tr>
<tr><th colspan="4">Maximum horizontal accelerations [9]</th></tr>
<tr><td><i>Level 1</i>
<i>Minor effect</i></td><td><i>Level 2</i>
<i>Major effect</i></td><td><i>Level 3</i>
<i>Hazardous effect</i></td><td><i>Level 4</i>
<i>Catastrophic effect</i></td></tr>
<tr><td>0.20 g</td><td>0.35 g</td><td>2 g</td><td>> 2 g</td></tr>
</table>

Table 1.1: Operational limits small craft

1.4.5. Findings problem research

To summarize, in this section a literature study is performed to provide insight in the influence of weather on the launch operation. Understanding of LSA operations at FPSOs and the current practice of the LSA industry was gained in interviews. Next, an incident analysis gave insight in the nature of the incidents and which approach has the biggest impact to reduce incidents. Following from the incident analysis, a indication of possible improvements of the current davit system is given based on the regulations for man-riding cranes together with criteria for operational limits of a rescue craft operation in severe sea states. This resulted in the following conclusions:

- Most incidents are related to the davit system, which causes the majority of the incidents during the most dangerous phases of the operation, namely launch, lift and splash-down
- The success of the operation is significantly influenced by the environmental conditions. Severe sea sea states can lead to extreme motions and potential collisions against the FPSO’s hull
- SOLAS does not define maximum operational limits with respect to environmental conditions and the LSA equipment is only tested for low sea states. However, a set of operational limits is defined by Nordforsk [14] and the HSC 2000 code [9], which can be used to rate the safety of a rescue craft launch operation
- The conventional design is not custom-built to operate on FPSOs, where operations have a higher risk due to the severe weather conditions FPSOs operate in, their stationary position and high free board
- The conventional design can be improved by following the regulations of man-riding cranes, but the davit will become very complex and financially not attractive
- Human errors occur during maintenance and launch and lift operation and are either caused by the maintenance crew, coxswain and rescue craft crew or davit crew

All combined, the three success parameters, proper design, qualified and experienced crew and proper maintenance are not met. Based on these findings the following research question is defined:

> ”How can the workability of the launch and retrieval system of a rescue craft on FPSOs be increased in heavy sea states?”

1.5. Report set-up

This report is structured as follows. Chapter 2 presents the paper, which contains a concise explanation of this research. The conclusions and recommendations obtained from this research are discussed extensively in Chapter 3, followed by a word of thanks. In the appendix additional results from an investigation into existing motion compensating devices is included.

2
Paper

Rescue craft davit performance on an FPSO in heavy sea states and a davit design proposal

L.M. Klaver, A. Cabboi, A. Metrikine

Abstract - The aim of this research is to increase the workability of a rescue craft launch and retrieval system on FPSOs in heavy sea states. Although a rescue craft's purpose is to improve safety, multiple incidents recorded in the GISIS database have proven that the launch and recovery operation can be dangerous or even deadly. The problem research shows that the davit system is the main cause for incidents, which are related to design flaws, lack of maintenance and human errors, the three parameters for a successful launch. The opinion of the author is that a different type of launch and recovery system can lead to improvement of these three parameters and to an increased workability of the system. To compare a new design with the conventional design, a computational model of both designs is built in Matlab to simulate the launch of a rescue craft from an FPSO in various sea states. The conventional model shows dangerous accelerations in high sea states and the risk to collide with the hull of the FPSO. The concept design aims to reduce these motions and, in addition, provide a more redundant design with easy maintenance and focused on reducing human errors. After comparison, the concept design proves to reduce dangerous motions during launch and increase the workability in high sea states, while being very simplistic, robust and easy to operate. However, in the splash zone the concept model does not mitigate dangerous motions sufficiently. To further substantiate this conclusion, it is advised to further investigate the splash zone model and to develop a more detailed model of the concept design.

2.1. Introduction

This research investigates the launch of a rescue craft from a Floating Production and Offloading unit (FPSO). Rescue crafts are relatively small vessels which carry up to 15 people and are mainly used in Man-Over-Board (MOB) operations. These crafts should not be mistaken for lifeboats, which sole purpose is to evacuate large groups of people at once. A rescue craft is launched with a davit, which is a crane-like system used to deploy and recover work boats, lifeboats, life rafts and rescue crafts alongside a ship's hull. The vessel is attached to the wire fall, which is connected to the arm of the davit. It is lowered and retrieved using winches. Rescue crafts are mandatory on all merchant vessels, including offshore platforms and FPSOs.

Figure 2.1: Vestdavit davit system and rescue craft

Currently, this launch and retrieval operation is still considered a dangerous operation, which is acknowledged by the FPSO industry as well as one of the leading vendors in the LSA industry, Palfinger. According to the GISIS database [11], incidents occur frequently, of which some result in injuries or even death. Although this operation is known to be dangerous, the regulations for Life-Saving-Appliances (LSA) equipment called SOLAS are not sufficient. A comparison of the regulations for offshore man-riding cranes, which are also certified to lift rescue crafts, with SOLAS, concludes that, among others, no operational limits with respect to weather conditions are available for LSA, safety factors are lower, less redundancy measures are implemented and less limiting systems are required for davit systems.

The lack of regulations, especially regarding the operational performance related to weather conditions, initiated a set of model scale experiments for lifeboat performance, executed by the National Research Council of Canada's institute for Marine Dynamics [16]. The experiments focused on the performance of a lifeboat launch operation from both an FPSO and an offshore platform in various weather conditions, the development of performance parameters to analyse the success of the operation and possible solutions to improve the performance in heavy sea states. This research concludes that model scale experiments are a reliable method to measure the performance of lifeboat launching and clearing. The experiments provided the following insights:

- High sea states lead to a reduction of the system's launch performance
- The distance the lifeboat is pushed away by the wave at the moment it reaches the splash zone is most influenced by severe weather and becomes larger for higher sea states
- Solutions provided to increase the performance of an evacuation operation relate to the behaviour of the lifeboat in the splash zone only. None of these influence the launch path during launch.

Furthermore, it is important to note that the no collisions occurred with the hull of the FPSO nor with the platform during the launch operation. The advice, given in the research, to further pursue this unexpected result in more realistic sea states, has not been followed up. Lastly, for all obtained results one must keep in mind that scale effects influence the results. The possible effects have not been further analysed in the experiments.

A second large project, the SAFECRAFTS project, was a EU sponsored research and development project to evaluate the costs associated with ship evacuation systems and an evacuation system fit for the increasing size of cruiser passenger ships [19]. As part of this project two computational models were developed to simulate motions from the start of the launch until splash-down and sail away. Both models are built in the time domain and apply a numerical method to predict the lifeboat's motions. The first model uses a simple two degrees-of-freedom (DoF) model to simulate the lowering of a rescue craft from a ship [5]. This model has a short computation time, but cannot model the full launch and excludes environmental loads, irregular waves and damping. The second model is a 6 DoF representation of a lifeboat launch and simulates the start of the launch until entering the splash zone and disconnection of the lifeboat [6]. This model is a very advanced simulation tool, but little insight is given in how the model is built or which parameters are used and its computation time is long for designing purposes. All in all, a simulation tool proofs to be useful for designing purposes. In addition, the SAFECRAFTS project also states that high sea states decrease the performance of the operation and advises to set operational limits for the launch of lifeboats with respect to sea states.

Both researches conclude that weather has a significant influence on the performance of a launch operation, but this does not explain the many incidents with LSA equipment. To find the cause of the incidents interviews with the LSA industry were held and an incident analysis was performed. Concluded from this research is that incidents are caused by either design flaws, lack of maintenance or human errors. Most of these incidents are related to the davit system, which causes the majority of the incidents during the most dangerous phases of the operation, namely launch, lift and in the splash zone. The failures are often related to the winch, brake and wire, which are of key importance for a successful operation. The current design can be improved by following the regulations of man-riding cranes, but this is financially not attractive and will still not solve all design flaws, reduce maintenance and make it easier to operate. Therefore, it is the opinion of the author that only a new type of launch system can reduce the number of incidents in all three areas.

Based on these findings the following research question is defined:

> "How can the workability of the launch and retrieval system of a rescue craft on FPSOs be increased in heavy sea states?"

This research question is answered as follows. The motions of a rescue craft using a conventional davit system are analysed with a computational model, which is explained in Section 2.2. This model is validated in Section 2.3. In Section 2.4 a new concept is developed that is expected to increase the workability in high sea states. This concept is compared with the conventional davit system in Section 2.5. Finally, the discussion and the conclusions for this research are given in Section 2.6 and 2.7.

2.2. Model development

This section explains the development of a computational model in Matlab that simulates the launch operation of a rescue craft from an FPSO. This model provides understanding of the forces and elements contributing to the motions of a rescue craft during launch.

The basis for the model built in this research is the simplistic 2 DoF model developed for the SAFECRAFTS project [5], discussed in Subsection 1.4.1 and Figure 2.2. The rescue craft (RC) and FPSO are rigid bodies and the davit wire is a spring element with stiffness K. A collision event is modeled where the rescue craft's fender acts as a spring-damper system. The results for the 2 DoF, angle ϕ and displacement u, obtained with both basic models are comparable. Therefore, the Matlab model built for this research forms a good foundation for further development.

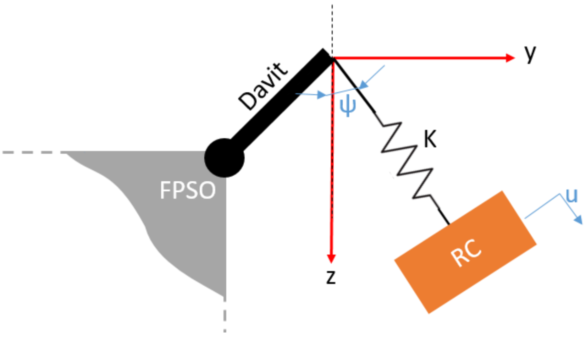


Figure 2.2: Schematics simplistic model [5]

The extended model has the aim to increase the appliance and reliability of the model. Therefore, the following modifications are introduced:

- Non-linear ship motions based on sea states in Figure 2.4
- Additional DoF to allow rotation of the rescue craft
- Additional point mass representing the wire locking device
- Damping of all DoF
- The collision is modeled as a force acting on the rescue craft instead of a separate mass-spring-damper system
- Wind loads based on values in Figure 2.4
- splash zone behaviour

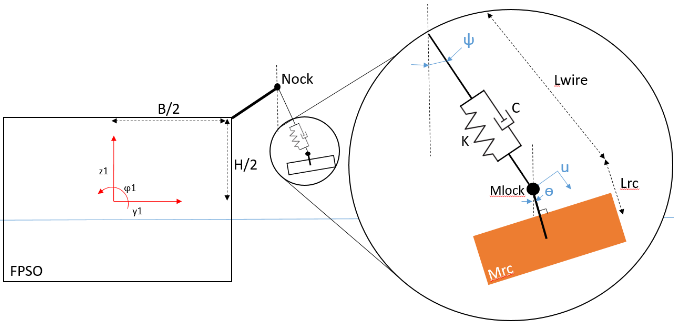
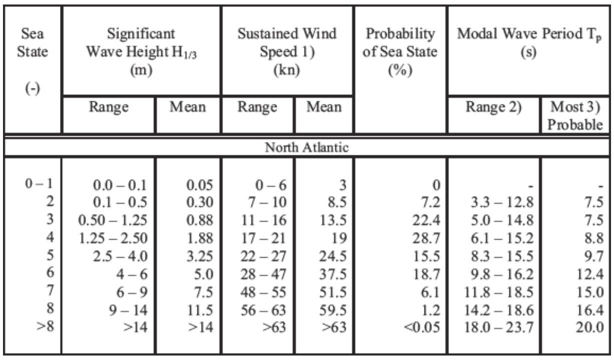


Figure 2.3: Schematics final model

As the purpose of this model is to serve as a quick analysis tool for the launch of a rescue craft and the design of a new launch device, it is important to built a relatively simple and quick model that captures the most important motions and forces. Therefore, the following assumptions are made:

- Only first-order waves are acting on the FPSO. Higher orders, environmental or mooring forces are neglected
- The worst-case scenario is simulated, assuming waves and wind coming from the beam direction
- The wire consists of a single, massless spring-damper element without any bending or torsion properties. It only moves in the 2D plane
- The wind force only acts in the horizontal direction on the rescue craft during launch
- The collision is modeled as a spring-damper force acting on the centre of gravity (CoG) of the rescue craft in the horizontal direction only
- The splash zone assumes regular waves and only models the motions of the rescue craft in the vertical direction. Horizontal forces exerted by the waves, wire or collision with the hull are neglected as well as other environmental forces such as current and wind



Sea State (-)	Significant Wave Height $H_{1/3}$ (m)		Sustained Wind Speed 1) (kn)		Probability of Sea State (%)	Modal Wave Period T_p (s)	
	Range	Mean	Range	Mean		Range 2)	Most 3) Probable
North Atlantic							
0 – 1	0.0 – 0.1	0.05	0 – 6	3	0	-	-
2	0.1 – 0.5	0.30	7 – 10	8.5	7.2	3.3 – 12.8	7.5
3	0.50 – 1.25	0.88	11 – 16	13.5	22.4	5.0 – 14.8	7.5
4	1.25 – 2.50	1.88	17 – 21	19	28.7	6.1 – 15.2	8.8
5	2.5 – 4.0	3.25	22 – 27	24.5	15.5	8.3 – 15.5	9.7
6	4 – 6	5.0	28 – 47	37.5	18.7	9.8 – 16.2	12.4
7	6 – 9	7.5	48 – 55	51.5	6.1	11.8 – 18.5	15.0
8	9 – 14	11.5	56 – 63	59.5	1.2	14.2 – 18.6	16.4
>8	>14	>14	>63	>63	<0.05	18.0 – 23.7	20.0

Figure 2.4: Sea states [1]

2.2.1. Equations of Motion: launch

The equations of motion to describe the launch are obtained with the Lagrangian approach. The position of the rescue craft with respect to the centre of gravity (CoG) of the FPSO are as follows:

$$\begin{aligned} y_{rc} &= y_{nock} + l_{wire}\sin(\phi) + l_{rc}\sin(\theta) \\ z_{rc} &= z_{nock} - l_{wire}\cos(\Phi) - l_{rc}\cos(\theta) \end{aligned} \tag{2.1}$$

3 DoFs describe the full motion of the rescue craft during launch, namely the extension of the wire u, the angle of the wire with the vertical ϕ and the angle of the rescue craft with the vertical θ. The motions of the nock of the davit, y_{nock} and z_{nock} depend on the motions of

the FPSO's CoG. Furthermore, the motions of the rescue craft in the horizontal and vertical direction depend the wire length ($l_{wire} = l_0 + v\mathrm{d}t + u$), composed of its initial length $l_0 [m]$, the running-out speed of the wire $v[m/s]$ and the extension of the wire $u[m]$. Lastly, the $l_{rc}[m]$ is the length of the connection to the CoG of the rescue craft.

The kinetic energy is defined as the superposition of transverse and rotational kinetic energy of the rescue craft. The potential energy is a superposition of its gravitational energy and spring energy. Damping for all three DoFs is included and the external forces acting in the horizontal direction are the wind force and the collision force.

After applying the Lagrange method, the following equations of motion describe the motions of the rescue craft during launch.

$$\boldsymbol{M\ddot{w}} + \boldsymbol{C\dot{w}} + \boldsymbol{Kw} = \boldsymbol{F_{external}} \tag{2.2}$$

Where:

$$\boldsymbol{w} = [u \ \phi \ \theta]$$

Here, $\boldsymbol{w}$ represents a vector containing the three DoF and $\boldsymbol{M}$ the corresponding mass matrix. $\boldsymbol{C}$ represents the damping of all DoFs and $\boldsymbol{K}$ represents the spring coefficients. Lastly, $\boldsymbol{F_{external}}$ is a summation of the wind and collision force acting on the rescue craft in horizontal direction.

Wire modeling

Both $\boldsymbol{C}$ and $\boldsymbol{K}$ include damping and stiffness coefficients of the wire, which is modeled as a single spring-damper element with spring coefficient $K[N/m]$ and damping coefficient $C[kg/s]$. The modeling approach is similar to the simplistic model [5]. Here, K is a superposition of three elastic components: the stiffness of the wire, which depends on its length, cross section area and steel Young's modulus, the stiffness of the davit arm, which is a constant value, and a shock absorber, which only acts in case the load on the wire reaches a force equal to $M_{rc}g$. The total spring coefficient is determined following Equation 2.3.

$$K = \frac{1}{\frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3}} \tag{2.3}$$

Here, $k1$ is the wire stiffness, $k2$ the davit stiffness and $k3$ the shock absorber's stiffness. The damping is a superposition of the wire damping and the davit arm's damping. The wire damping c_1 is a percentage of the critical damping, which depends on $k1$ and the rescue craft's mass M_{rc}. The davit arm damping c_2 is also a percentage of the critical damping, which depends on k_2 and M_{rc}. The total damping coefficient is as follows:

$$C = \frac{1}{\frac{1}{c_1} + \frac{1}{c_2}} \tag{2.4}$$

2.2.2. Equations of motion: Splash zone

For the rescue craft's behaviour in the splash zone a different model is used, given in Figure 2.5. This model considers only one DoF, Z, representing the vertical motion of the rescue craft's CoG. This motion is induced by both the wave forces and the pulling force of the wire. The wire is attached to the nock of the davit, which motions in the vertical direction are represented by Z_0. The main assumptions are:

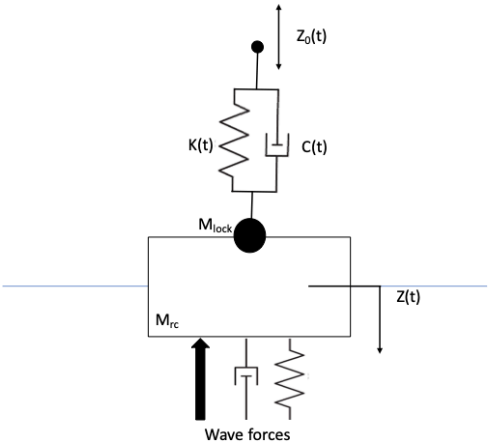


Figure 2.5: Schematic model of a rescue craft in the splash zone with explanatory coefficients

- The wave and wire forces only act in the vertical direction
- The rescue craft's motions do not influence the motions of the davit nock
- Regular waves are considered
- The rescue craft is modeled as a rigid point mass with a rectangular shape
- Slamming, wire slack, buoyancy and damping forces are included in the vertical direction
- Added mass, inertia and drag forces are neglected

The equation of motion for the vertical direction only is as follows:

$$M\ddot{z} + C(t)\dot{z} + K(t)z = C(t)\dot{z_0} + K(t)z_0 \tag{2.5}$$

The wire force, given in Equation 2.6, only acts when in tension and the wave forces, Equation 2.7, only act when the rescue craft is in contact with the water.

$$F_{wire} = C(t)(\dot{z} - \dot{z_0}) + K(t)(z - z_0) \quad \text{if } F_{wire} > 0 \tag{2.6}$$

$$F_{waves} = F_{slamming} + F_{buoyancy} + F_{damping} \quad \text{if } z < \zeta_a \tag{2.7}$$

The wave forces are divided in slam forces, buoyancy forces and damping forces. The slam force is defined according to the definition given in DNV-GL [3] with Equation 2.8:

$$F_{slam} = \frac{1}{2}\rho C_s A_w v_n^2 \quad [N] \tag{2.8}$$

Here, ρ is the water density, C_s a constant slamming coefficient, A_w the water contact area, and v_n the velocity of the rescue craft relative to the waves. The slam force only acts on the rescue craft at the moment it comes in contact with the water.

Next, the buoyancy force, given in Equation 2.9, is modeled as a spring element acting vertically on the CoG of the rescue craft.

$$F_{buoyancy} = K_{buoyancy} \cdot T_{rc}(t) \quad [N] \tag{2.9}$$

Here, $K_{buoyancy}$ represents the restoring coefficient which is multiplied with the changing draft of the rescue craft T_{rc}. The restoring coefficient is equal to the density of sea water times gravity and the area of the submerged part at the water plane.

The hydrodynamic damping of the motion of the rescue craft is also represented as a force in Equation 2.10 and is proportional to the velocity of the rescue craft relative to the vertical wave velocity v_n.

$$F_{damping} = C_{damping} \cdot v_n \quad [N] \tag{2.10}$$

$C_{damping}$ represents the damping coefficient and is defined as a percentage ξ of the critical damping in Equation 2.11.

$$C_{damping} = \xi \cdot 2\sqrt{K_{buoyancy} M_{rc}} \quad [kg/s] \tag{2.11}$$

2.2.3. Loads during launch

The loads acting in the model during launch are divided into environmental loads, which consider the motions of the FPSO due to hydrodynamic loading, wind loading acting on the rescue craft, and the collision load, which acts onto the rescue craft only when the craft is in contact with the hull of the FPSO.

Hydrodynamic loading

The motions of the FPSO can have a significant impact on the severity of the rescue craft's motions as was concluded from the literature study. The response of the FPSO depends on the waves it encounters. To represent random waves, various spectra have been developed such as the Jonswap and Bretschneider (ITTC) spectrum [12]. With the wave spectrum the random wave amplitudes are obtained as follows:

$$\zeta_a(\omega) = \sqrt{2 S_\zeta \Delta\omega} \tag{2.12}$$

Here, $S_\zeta(\omega)$ represents the selected wave spectrum, $\Delta\omega$ the change in frequency and $\zeta_a(\omega)$ the random wave amplitudes.

With the FPSO's Response Amplitude Operator (RAO), which is the ratio between the amplitude of a body in water relative to the wave amplitude, the response of the FPSO $Z_a(\omega)$ is calculated as follows:

$$Z_a(\omega) = RAO \cdot \zeta_a = \frac{Z_a}{\zeta_a} \cdot \zeta_a \tag{2.13}$$

Finally, the elevation of the FPSO as a response to the waves is calculated as follows:

$$z_r(t) = \sum_{i=1}^{N} Z_i = \sum_{i=1}^{N} \bar{Z}_{a_i} \cos(\omega_i t + \epsilon_{r_i}) \tag{2.14}$$

Here, the FPSO's response elevation $z_r(t)$ is a summation of the regular motions of the FPSO with response amplitudes Z_a and phases ϵ_r. The FPSO's motions for sway, heave and roll are acting at the coordinate centre, equal to the FPSO's CoG.

Wind loading

The wind force implemented in the model only affects the motions of the rescue craft and not the motions of the FPSO. The wind force per sea state is based on the range of wind velocities stated in Figure 2.4. It provides a range of velocities and the mean velocity for each sea state. Using a Normal Distribution a variable velocity vector for wind is computed and used in Equation 2.15 to determine the wind load.

$$F_{wind} = \frac{1}{2} \rho_{air} A C_d v_{rel} |v_{rel}| \tag{2.15}$$

Here, $\rho_{air}[kg/m^3]$ is the density of air, $A[m^2]$ the area of contact, $C_d[-]$ the wind coefficient and $v_{rel}[m/s^2]$ the rescue craft's velocity relative to the wind.

Collision load

The collision is modeled as a force which acts on the rescue craft's CoG, only when the rescue craft is in contact with the hull of the FPSO. The rescue craft and FPSO are modeled as rigid bodies, but the rescue craft's fender is modeled as a linear spring-damper element. To capture the collision event, the model switches to a smaller time step. The collision force is given in Equation 2.16:

$$F_{collision} = K_{fender} \cdot \delta(t) + C_{fender} \cdot v_{rel}(t) \tag{2.16}$$

Here, K_{fender} is the stiffness of the fender, proportional to the indentation of the fender $\delta[m]$, and C_{fender} its damping coefficient, proportional to the relative velocity of the rescue craft $v_{rel}[m/s]$. It is important to note that damping of the fender is only acting when the horizontal, relative velocity of the rescue craft is larger than zero. When the velocity is negative, the rescue craft loses contact with the hull of the FPSO and only the elastic property of the fender acts on the rescue craft.

2.2.4. Obtained insights

The final model is able to simulate the launch of a rescue craft from an FPSO in irregular sea states from start until reaching the splash zone. From the results of the launch simulation a clear increase of the rescue craft's horizontal motions is shown over time, as illustrated in Figure 2.6.

A possible explanation for this phenomena is that the system's natural frequency comes close to the resonance

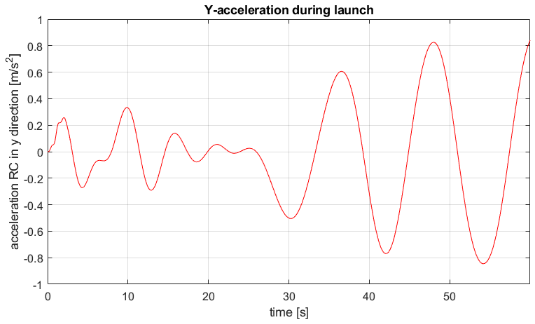


Figure 2.6: Horizontal acceleration CoG rescue craft during launch

frequency of the FPSO. This explanation is analysed for sea state 5 (Hs = 3.25m and Tp = 9.7s). The DoF mainly related to the swinging motion is the angle of the wire with the vertical ϕ, which is impacted mostly by the roll motion of the FPSO. Therefore, the roll response spectrum is used in this analysis. This response spectrum has a resonance frequency at $0.48 rad/s$ and a wave induced resonance frequency at $0.81 rad/s$. In Figure 2.7, both peak frequencies are compared to the natural frequency of angle ϕ, which changes over time as the length of the wire changes.

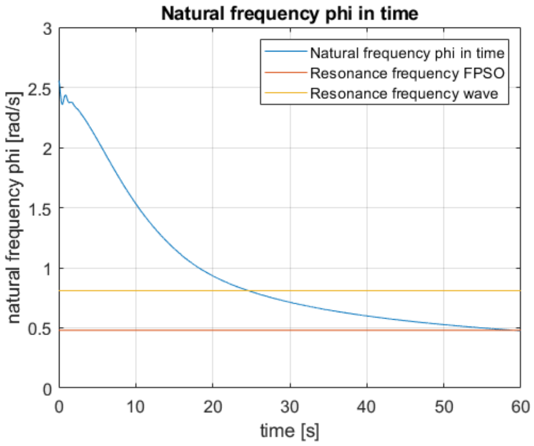


Figure 2.7: Natural frequency of angle ϕ in time

Between 25 and 60 seconds the system is within the resonance range of the roll motion of the FPSO. The resonance range explains the increase of horizontal acceleration of the rescue craft after 25 seconds in Figure 2.6.

This analysis shows that resonance could lead to increasing motions, which could potentially result in a collision. To determine whether resonance is increasing the risk of a collision, the resonance range for every sea state is investigated. It was found that for the lower sea states, 1 to 5, the resonance range of the FPSO influences the rescue craft's motions during launch. However, for higher sea states, the rescue craft reaches the water before it is close to the resonance of the FPSO. Therefore, resonance does not increase the risk of a collision.

2.3. Model validation

As no real time data was available to compare the results with, the Matlab model was verified with a model built in Orcaflex [15]. Orcaflex is a software capable of analysing dynamic systems in offshore marine environments. This validation is useful to understand the strengths and weaknesses of the Matlab model. For comparison of both models the following case study is used.

Rescue craft

This case study is based on the Magnum-750 MKII Fast Rescue Craft from Viking Norsafe [20] with parameters given in Table 2.1. This rescue craft is of average size and qualified for operation on an FPSO.

Parameters rescue craft	Symbol	Value	Unit
volume	V	5	m^3
length, width, height	l, b, h	7.7, 2.9, 2.09	m
damping x, y, z	C	4.2, 2, 5.3	$kN/(m/s)$
drag area x,y,z	-	6,7, 15.4	m^2
drag coefficient x,y,z [2]	Cd	0.89,0.89,1.75	-
mass	M_{rc}	3700	kg
moment of inertia	I_{xx}, I_{yy}, I_{zz}	3.9, 19.6, 20.9	$tonm^2$
centre of buoyancy x, y, z	CoB	0, 0, 0.23	m
centre of gravity x, y, z	CoG	0, 0, 0	m
slam area	A_p	15.4	m^2
slam coefficient[3]	Cs	0.02	-
added mass coefficient x,y,z [2]	Ca	1, 1, 1.36	-

Table 2.1: Rescue craft parameters

Davit

The Viking Norsafe Fast Rescue Craft Davit [21] is compatible with the Magnum-750 MKII Fast Rescue Craft and has the parameters stated in Table 2.2.

Parameters davit	Symbol	Value	Unit
mass	M	3600	kg
outreach, height	D_{out}, D_{height}	2, 3	m
safe working load	SWL	4077	kg
max lowering height	l_{max}	31	m
max hoisting speed	$v_{up_{max}}$	18	m/min
max lowering speed	$v_{down_{max}}$	48	m/min
wire rope diameter	d	18	mm
wire rope MBL	MBL	298	kN
wire rope stiffness	K	1960	N/mm^2

Table 2.2: Parameters davit

2.3.1. Motions FPSO

The motions of the FPSO have a significant influence on the motions of the rescue craft. The main assumptions are given in Table 2.3.

	Orcaflex	**Matlab**
1	First order wave loads	First order wave loads
2	ITTC spectrum	ITTC spectrum
3	6 DoF motions	3 DoF motions
5	Displacement RAOs	Displacement RAOs

Table 2.3: Assumptions FPSO motions

Both models use the approach explained in *Wire Modeling*, Subsection 2.2.1. For comparison the standard deviation of the vessel responses at the CoG for sway, heave and roll is calculated. For similar RAOs it is expected that the differences in standard deviation is within 1%. In Table 2.4 the differences for every sea state is given.

seastate	Sway	Heave	Roll
1	0%	0%	0%
2	0%	0%	0%
3	0%	1%	0%
4	0%	1%	0%
5	0%	0%	1%
6	0%	0%	**3%**
7	0%	0%	0%
8	0%	0%	**3%**
9	0%	0%	**4%**

Table 2.4: Standard deviation differences FPSO motions

Differences higher then 1% are found for roll in sea state 6, 8 and 9. For these sea states, the Matlab results are higher, meaning motions of the rescue craft will be exaggerated for these sea states.

2.3.2. Wire modeling

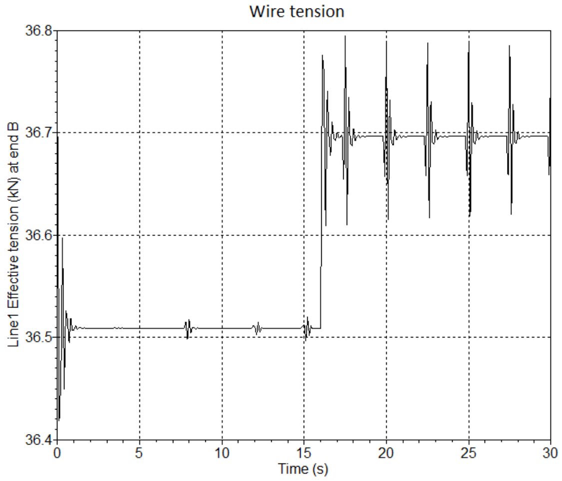
The wire influences the motion of the rescue craft as it's elongation is a DoF in the system. The assumptions used are given in Table 2.5.

	Orcaflex	Matlab
1	FEM model	1 element
2	mass segments	massless
3	3D plane	2D plane
4	Linear axial tension	Linear axial tension
5	Neglects torsion	Neglects bending and torsion
6	Rayleigh damping	Critical damping

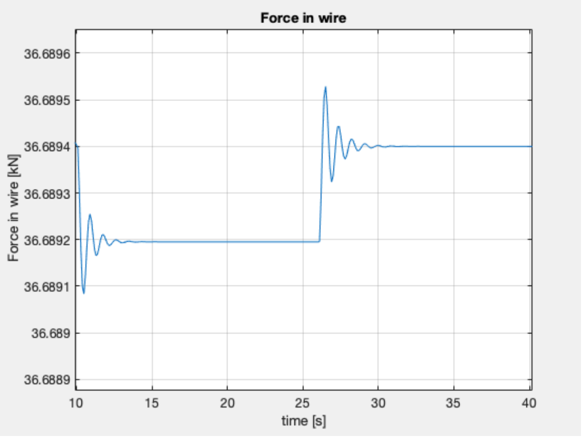
Table 2.5: Assumptions wire

The Finite-Element-Model (FEM) used in Orcaflex moves in the 3D plane and allows for axial tension and bending in the wire, while the Matlab model is limited to the 2D plane and uses only 1 massless segment which cannot bend. To analyse the influence of this simplification the wire's axial tension is compared for sea state 1 in Figure 2.8.

Both models show an acceleration period of 16 seconds during which the tension in the wire is lower, after which it is stable at a tension of approximately $36.7kN$. The main differences in results are the load in the wire during acceleration and the duration until the excitation is damped out. These differences are considered small enough to neglect. Therefore, the modeling of the wire is considered valid.



(a) Orcaflex



(b) Matlab

Figure 2.8: Wire tension force in sea state 1

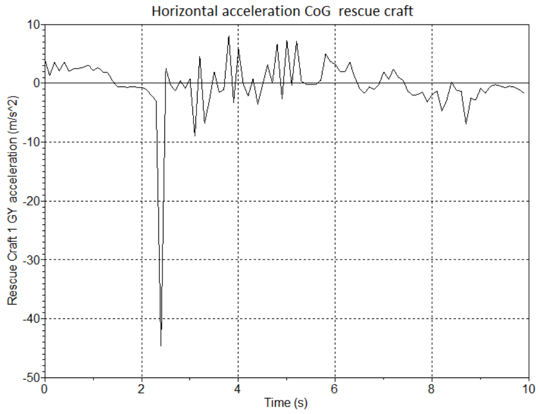
2.3.3. Collision

The collision has a large influence on the accelerations of the rescue craft and is therefore compared using the assumptions given in Table 2.6.

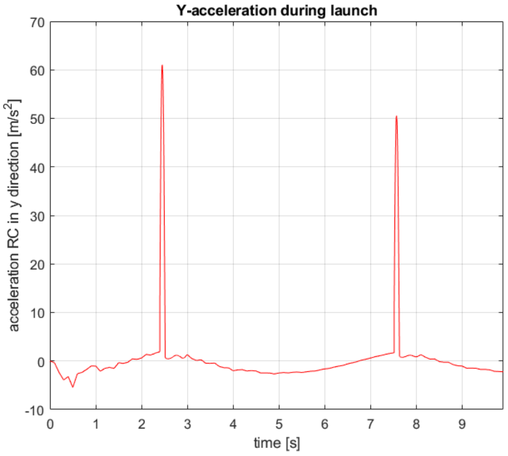
	Orcaflex	Matlab
1	Linear fender model	Linear fender model
2	Reaction force acts on variable contact area	Reaction force acts on constant contact area
3	Reaction force acts in all lateral directions	Reaction force acts only in horizontal direction
4	Reaction force acts on side RC, introducing moments	Reaction force acts on CoG RC, neglecting moments
5	6 DoF motions rescue craft	3 DoF rescue craft

Table 2.6: Assumptions collision

For comparison both models release the rescue craft under an angle of $20°$against the hull of the FPSO with a wire length of $10m$ with no reeling-out velocity. The wire in Orcaflex is modeled with segments of $1m$. The results are given in Figure 2.9 and the values in Table 2.7. The initial velocities and accelerations before the collision are similar in both Matlab and Orcaflex.



(a) Orcaflex



(b) Matlab

Figure 2.9: Horizontal collision acceleration rescue craft

Noticeable from these results is that the number of collisions in Matlab is lower, the accelerations are higher and the duration of the collision and penetration depth smaller compared to Orcaflex. This difference is influenced by the fact that Matlab only considers a horizontal reaction force, where Orcaflex directs it normal to the FPSO hull, resulting in a lower horizontal reaction force. Also, the force depends on the area in contact with the rescue craft, which is constant in Matlab but varies in Orcaflex and could lead to lower forces. In addition, the difference in penetration depth suggests that the fender in Matlab has a higher stiffness and damping force compared to Orcaflex, while using similar coefficients. Lastly, the slack forces in the wire in Orcaflex caused by the collision damp the motion of the rescue craft, which is not possible with the 1 element model in Matlab.

	Matlab		Orcaflex 20 elements		
Collision	1	2	1	2	3
Horizontal acceleration [m/s^2]	61.0	50.5	44.7	4.7	7.0
Horizontal collision force [kN]	221	182	176	16	6.0
Duration collision [s]	0.12	0.12	0.2	0.3	0.2
Horizontal penetration depth [cm]	8.7	7.2	22	8.7	1.9

Table 2.7: Collision comparison

Concluded from these results is that the area of contact and the fender stiffness is significant for the magnitude of the reaction force. In addition the slack forces in the wire in Orcaflex, that occur due to the collision, have a large influence on the path of the rescue craft after the collision. In addition, the 2D representation for a collision is not sufficient as collisions cause rotations which brings the rescue craft out of the 2D plane. Collisions are therefore expected to be exaggerated in acceleration magnitude in Matlab.

2.3.4. Splash zone

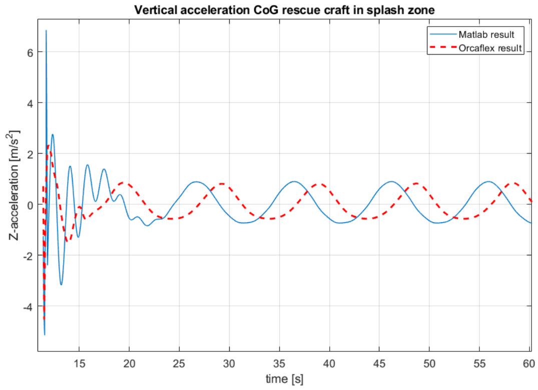
The splash zone is considered a high risk environment as the rescue craft is connected to the davit wire while being moved by the waves. The simplistic model used in Matlab, as described in Subsection 2.2.2, is compared to the model in Orcaflex, which uses the main assumptions stated in Table 2.8.

	Orcaflex	Matlab
1	Rescue craft modeled as 6 DoF object	Rescue craft modeled as rigid 1 DoF object
2	Regular waves	Regular waves
3	Forces applied: - Gravity at CoG - Buoyancy at CoB - Hydrodynamic loads at CoB - Slam load at CoB	Forces applied: - Gravity at CoG - Buoyancy at CoG - Damping at CoG - Slack forces wire at connection - Slam load at CoG
5	Buoyancy depends on submerged volume, water plane area and draft	Buoyancy depends on submerged volume, water plane area and draft
6	Hydrodynamic loads based on Morison equation and include added mass, drag and damping	Added mass and drag neglected, damping included as damper
7	Slam force is constant	Slam force is constant
8	Slack forces wire neglected	Slack forces wire included

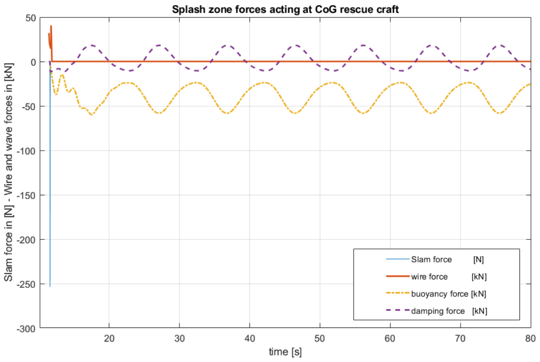
Table 2.8: Assumptions splash zone

Figure 2.10a shows the vertical acceleration of the rescue craft at the moment it reaches the water during the Orcaflex and Matlab simulation. Both results have a period of 9.7 seconds, equal to the wave period. Orcaflex shows a slightly smaller amplitude in motion compared to Matlab, but more noticeable are the differences in acceleration during the first 10 seconds. These accelerations are only present in the Matlab results and are caused by the wire slack force acting on the rescue craft. The slack force arises at the moment the rescue craft reaches the water and its velocity is slowed down by the slam force for a brief moment of time, as is illustrated in Figure 2.10b. Another reason for a slack force to occur is when the wire is not long enough to follow the rescue craft in the high waves.

Concluding from the results for the splash zone, the motions can be simulated for the vertical direction only using the simplified method in Matlab. In addition, the Matlab model captures slam forces when the rescue craft enters the water and slack forces when the wire is not long enough. The damping and the motion amplitudes are slightly higher in Matlab.



(a) Vertical motions rescue craft in splash zone



(b) Matlab splash zone forces

Figure 2.10: Motions and forces acting on rescue craft in splash zone

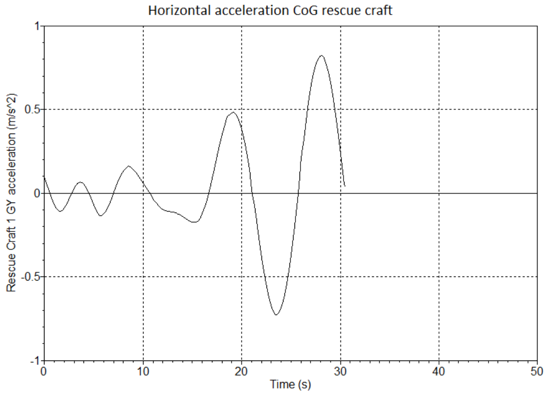
2.3.5. Launch

The launch simulation gives an indication whether the magnitudes of the accelerations in both models are similar for the same sea states. The main assumptions given in Table 2.9 are used, which are in line with assumptions made in the previous sections.

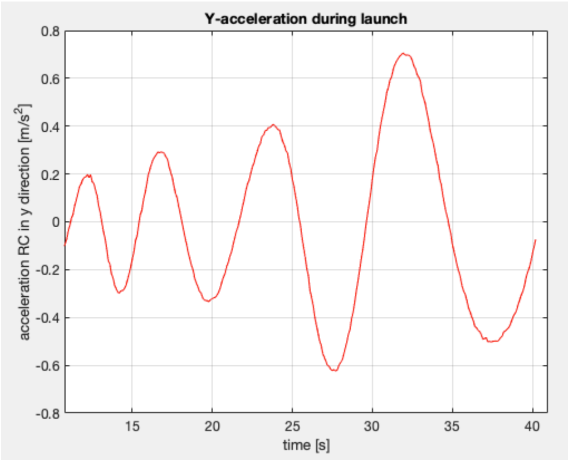
	Orcaflex	Matlab
1	Rescue craft modeled as a rigid 6 DoF object restricted to 2D plane only	Rescue craft modeled as rigid 3 DoF object
2	FPSO motions: - ITTC wave spectrum - 6 DoF FPSO motions - Only first order wave loads	FPSO motions: - ITTC wave spectrum - 3 DoF FPSO motions - Only first order wave loads
3	Wire: - FEM model with 2m segments - Rayleigh damping	Wire: - Single massless spring-damper element - Stiffness wire includes stiffness davit arm and shock absorber - Only acts in tension
5	Collision: - Reaction force neglects damping - Reaction force acts on varying contact area - Collision is linear	Collision: - Reaction force includes damping - Reaction force acts on constant contact area - Collision is linear
6	Wind: - API spectrum - Force acts only on rescue craft	Wind: - Normal distributed - Force acts only on rescue craft

Table 2.9: Assumptions launch

In Figure 2.11 the horizontal accelerations are compared for sea state 5, because these motions are the most influenced in beam waves.



(a) Orcaflex



(b) Matlab

Figure 2.11: Horizontal accelerations during launch in sea state 5

Overall, both models show similar magnitudes of the rescue crafts motions. In addition, both models have a launch period of approximately 30 seconds. Therefore, it is concluded that the rescue craft's motions during launch obtained with the Matlab model are reliable.

2.3.6. Findings

The strength of the Matlab model are:

- Sea state 1 to 5 and 7 are reliable in terms of FPSO motions
- Wire modeling is correct when no collision occurs
- splash zone is very simplistic but captures slam and slack forces and motions of a realistic magnitude
- The motions in full launch have reliable magnitudes
- Fast computation time

The weaknesses of the Matlab model are:

- The roll motion amplitudes are too high for sea state 6, 8 and 9
- The collision event assumes that the motions and accelerations due to collision are too high
- Damping of davit elements is neglected

2.4. Concept development

For the development of a new concept to launch and retrieve a rescue craft on an FPSO the Engineering Design Process is used [7]. This process exists of a set of steps that are useful for engineers to define requirements, organize ideas, consider all potential solutions and to finally develop the concept.

The first steps, *problem definition* and *background research*, are fulfilled in the Problem Research (Section 1.4) and were used to define the following assessment criteria:

- Larger distance between (re)connection location of the rescue craft and the hull of the vessel to reduce the risk of a collision with the hull and to have an easier escape route
- No human interaction involved in (re)connection of the rescue craft
- Always provide an escape route to prevent the crew from being stuck in the splash zone or half-way the launch or lift
- Reducing swinging motion and therefore risk of collision
- Make the system more redundant to prevent breakdown of major components to impact the operation
- Make the design less complex to make maintenance easier

Design targets

These assessment criteria have a large influence on the workability of the launch and lift operation of a rescue craft and are therefore important to meet. In the third step, *specify requirements*, these criteria are used to define four major needs the new design must meet, which are referred to as Design Targets:

- Redundant design
- Easy maintenance
- Human Factor Engineering
- Within Operational Limits (Table 2.10)

A redundant design is considered a design that has the ability to recover the rescue craft crew at any point of the operation unharmed. Easy maintenance considers the simplicity of the system and the accessability of the system's parts. Human Factor Engineering aims to lower the human influenced errors, thereby making the system easier to operate. Lastly, the new design must be safe to operate in all sea states. Therefore, operational limits must be defined to measure the safety of each launch. Although SOLAS does not provide operational limits with respect to the weather conditions, other codes have given guidance for operational limits. For a rescue craft operation, two methods provide criteria given in Table 2.10. The sea keeping criteria defined by Nordforsk (1987) [14], provide a limit for the maximum vertical accelerations a fast small craft can endure. The second method is defined in the 2000 Code for small high speed crafts [9] and gives an indication of safety levels based on the maximum horizontal accelerations. These limits are useful to determine whether a rescue craft operation is considered safe while working outside its design scope.

Maximum vertical accelerations [14]		
Level 1 at bridge	*Level 2 at Forward Perpendicular*	*Level 3 Maximum*
0.275 g	0.65 g	1.0 g

Maximum horizontal accelerations [9]			
Level 1 Minor effect	*Level 2 Major effect*	*Level 3 Hazardous effect*	*Level 4 Catastrophic effect*
0.20 g	0.35 g	2 g	> 2 g

Table 2.10: Operational limits small craft

Next to these four Design Targets, a number of minor needs was defined such as costs, ease of installation, resources needed and size as support in the brainstorm process, which is the fourth step. In *brainstorm, evaluate and choose solution*, four viable concepts were tested for the four major needs. In this paper, the solution from this brainstorm process is discussed.

Final concept

The final concept that is compared to the conventional design is given in Figure 2.12. This concept consists of a long boom which rotates around a hinge on the side of the FPSO. The rescue craft is attached to the end of the boom and is lowered far away form the hull when the rescue craft is close enough to the water. For recovery the rescue craft positions itself below the boom, reconnects and is fully reeled in, after which the boom is recovered.

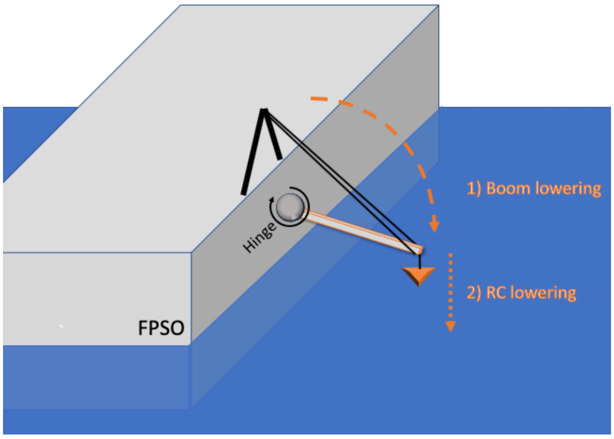


Figure 2.12: Final concept

Summarized, this concept has the following seven advantages:

- Controlled descent and ascent by boom
- Splash zone far away from hull FPSO

- Does not occupy much more space compared to conventional davit system
- Very simplistic and robust design
- Redundancy created via double wire security and only one rotating hinge
- Boom provides an escape route during launch and in splash zone
- No luffing, but entering rescue craft via platform

The disadvantages compared to the existing davit system are:

- The hinge halfway is exposed to sea water which means it needs extra maintenance
- The hinge's maintenance is on the side of the FPSO
- More material needed for this system
- Heavier system

To conclude, this concept design is able to meet almost all assessment criteria. The arm ensures a larger distance between the hull and the rescue craft in the splash zone. An escape route via the arm is provided during the full operation. The swinging motion is reduced by the arm as well as the risk of collision with the hull and the concept has a redundant and simple design. Lastly, the human influenced errors are decreased, but a skilled crew is still necessary for the operation of the system. Maneuvering the rescue craft for (dis)connection is easier compared to the existing system as it does not happen close to the hull, but human involvement is still necessary. This final concept is compared against the conventional davit system.

2.5. Concept comparison

To compare the workability of the concept with the conventional davit, the loads and accelerations of the davit are compared in various sea states using a Matlab model of the concept.

2.5.1. Concept Matlab model

The model for the design concept, hereafter referenced to as the Concept Model, is developed in a similar way as the model for the conventional davit. Figure 2.13 illustrates the schematics of this model.

The equations of motion are derived with the Lagrange method and are based on the positions of the rescue craft defined in Equation 2.17:

$$\begin{aligned} y_{rc} =& y_{hinge} + l_{boom}\sin(\beta) \\ & + l_{wire}\sin(\phi) + l_{rc}\sin(\theta) \\ z_{rc} =& z_{hinge} + l_{boom}\cos(\beta) \\ & - l_{wire}\cos(\Phi) - l_{rc}\cos(\theta) \end{aligned} \tag{2.17}$$

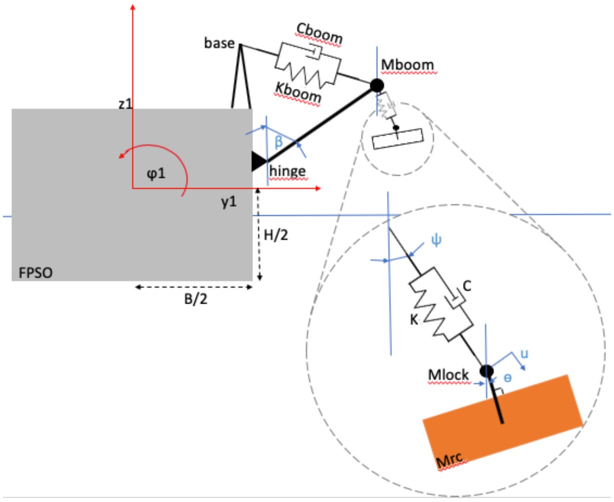


Figure 2.13: Schematics final design concept

Here, an additional DoF is included, namely the angle of the boom β, which influences the position of the boom and thus the length of the boom wire. The length of the rescue craft wire is equal to $l_{wire} = l_0 + v\mathrm{d}t + u$ with a velocity $v[m/s]$ equal to zero until the boom's angle β has reached its maximum.

The equations of motion for the 4 DoF, given in Equation 2.18, are derived with the Lagrange method:

$$\boldsymbol{M\ddot{w}} + \boldsymbol{C\dot{w}} + \boldsymbol{Kw} = \boldsymbol{F_{external}} \tag{2.18}$$

Where:

$$\boldsymbol{w} = [\beta\ u\ \phi\ \theta]$$

Here, $\boldsymbol{w}$ represents a vector containing the 4 DoF and $\boldsymbol{M}$ the corresponding mass matrix containing the three point masses, M_{boom}, M_{lock} and M_{rc}. $\boldsymbol{C}$ represents the damping of all DoF and damping of the boom wire C_{boom} and $\boldsymbol{K}$ represents the spring coefficients. Lastly, $\boldsymbol{F_{external}}$ represents the wind load acting on the rescue craft in horizontal direction.

Splash zone

A similar approach is used as for the Conventional Model, described in Subsection 2.2.2. It is assumed that the boom is not influenced by the motions of the rescue craft.

FPSO motions

The FPSO motions are based on a similar approach as used in the Conventional Model, explained in Subsection 2.2.3.

Wire motions

In this model both the wire connected to the boom and the wire connected to the rescue craft must be considered. The boom's wire is modeled as a spring-damper system with a stiffness coefficient K_{boom} and damping coefficient C_{boom} that both depend on the length of the boom's wire as given in Equation 2.19:

$$\begin{aligned} \text{Stiffness coefficient: } K_{boom} &= \frac{1}{\frac{1}{k_{base}} + \frac{1}{k_{wire_{boom}}}} \\ \text{Damping coefficient: } C_{boom} &= \frac{1}{\frac{1}{c_{base}} + \frac{1}{c_{wire_{boom}}}} \end{aligned} \tag{2.19}$$

Both K_{boom} and C_{boom} are a summation of the boom wire and the base properties, where k_{base} is a constant and $k_{wire_{boom}}$ depends on the wire's cross-section area, Young's modulus and length. The damping coefficients c_{base} and $c_{wire_{boom}}$ are percentages of the critical damping which depends on the stiffnesses and the boom's and rescue craft's mass. The rescue craft's wire is similar to the approach used in the Conventional Model in Subsection 2.2.3. The main difference is that the davit stiffness and damping $k1$ and $c1$ are equal to K_{boom} and C_{boom}.

Collision

Due to the length of the boom in the Concept Model, a collision is prevented and therefore not considered.

2.5.2. Design target performance

In Section 2.4, four design targets were defined, which are critical to increase the workability of a rescue craft launch system. The performance of the Concept design is compared to the Conventional design based on these targets.

Redundant design

The redundancy of the launch and lift operation is improved with the Concept design. This concept provides an escape route during launch and in the splash zone via the boom, a double wire security of the boom and a strong but simple design.

Easy maintenance

The simplicity of the Concept makes the design easier to maintain compared to the conventional system, which can reduce the number of maintenance-related incidents. A remark on the Concept is that the hinge of the boom is located on the side of the FPSO, which exposes the hinge to sea water and is more difficult to reach for maintenance.

Human Factor Engineering

The Concept design is operated from inside the rescue craft instead of from the FPSO. This provides the crew a better position to estimate the weather conditions and the moment of splash down. In addition, the location of splash down is far away from the FPSO's hull, which allows the rescue craft to be positioned against the waves for splash down and to approach the hook from every direction for retrieval. These factors make the design more fit for the crew to operate.

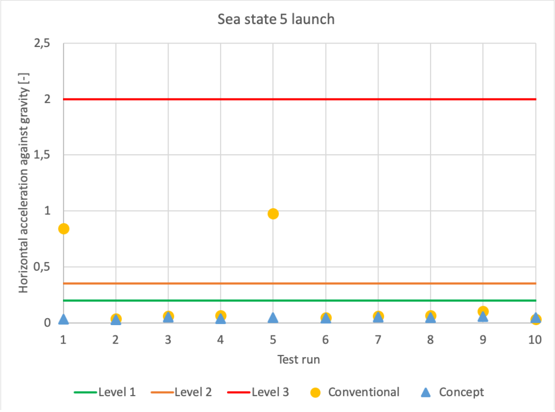
Within Operational Limits

This design target is measured using the Operational Limits defined in Table 2.10. For this comparison the parameters defined in Table 2.11 are used in combination with the rescue craft parameters from Table 2.1. The results of 10 test runs for sea state 5 and 7 are compared.

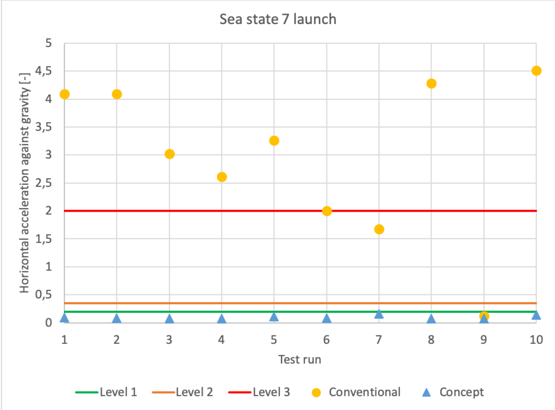
Parameters	Symbol	Value	Unit
Mass	M_{boom}	5000	kg
Length boom	l_{boom}	14.4	m
Lowering speed boom	v	0.8	m/s
Lowering acceleration boom	a	0.1	m/s^2
Lowering speed rescue craft	v_{rc}	0.8	m/s
Lowering acceleration craft	a_{rc}	0.1	m/s^2

Table 2.11: Parameters Concept Model

Figure 2.14 compares the horizontal accelerations during launch in sea state 5 and 7. Noticeable is the clear increase of horizontal accelerations with the Conventional Model, with results even higher then the level 3 limit, while the Concept Model's accelerations stay below the first level, even in high sea states. The vertical launch accelerations however, stay below the first level in both the Conventional as the Concept Model.



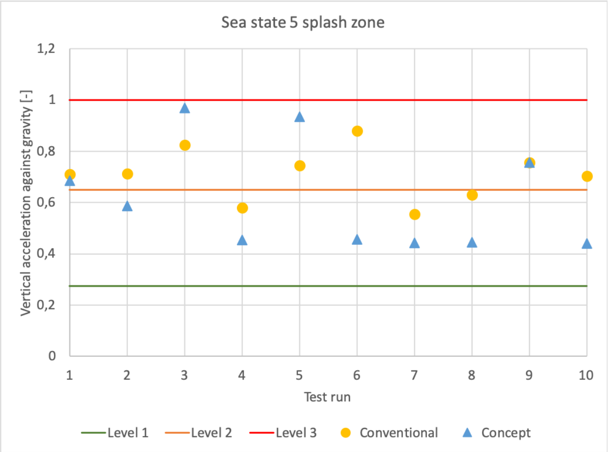
(a) Sea state 5



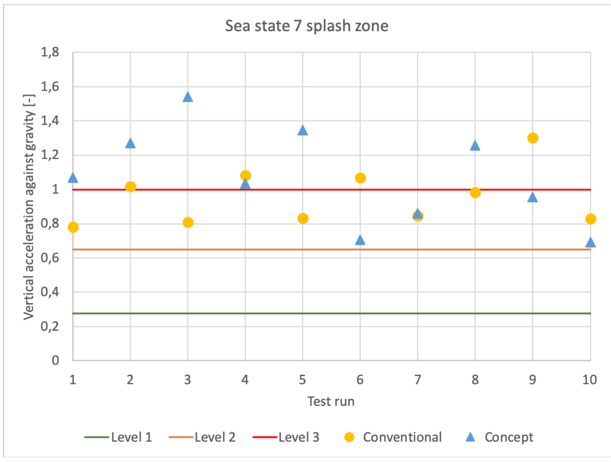
(b) Sea state 7

Figure 2.14: Horizontal acceleration launch w.r.t. safety levels

Figure 2.15 compares the vertical accelerations in the splash zone in sea state 5 and 7. These results show dangerously high accelerations of the rescue craft and are mainly caused by slack forces in the wire.



(a) Sea state 5

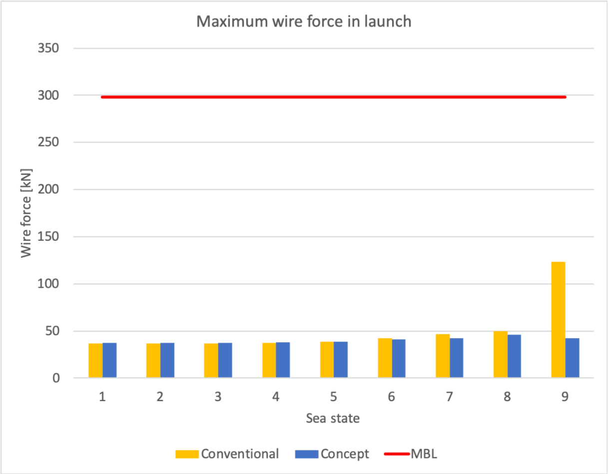


(b) Sea state 7

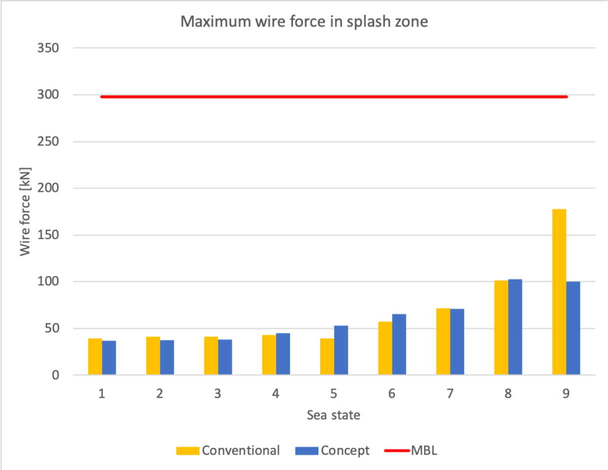
Figure 2.15: Vertical acceleration splash zone w.r.t. safety levels

Lastly, the wire force of the wire connected to the rescue craft of both models is compared in Figure 2.16, where the limit is equal to the Maximum Breaking Load (MBL) of the wire. Although the wire force in the Conventional Model clearly increases more in high sea states than the Concept Model, both models do not reach the MBL during launch or in the splash zone.

Based on the results, the Concept design improves the performance during launch significantly for high sea states. In the splash zone however, the vertical accelerations in both models are exceeding the safety levels for the crew, making a launch in high sea states still a dangerous operation. All in all, the Concept Design proves to perform better on all 4 Design targets making the launch operation safer, but one must not forget that a small vessel such as a rescue craft is vulnerable in heavy sea states, making the launch of a rescue craft still a risky operation.



(a) Sea state



(b) Sea state

Figure 2.16: Vertical acceleration splash zone

2.6. Discussion

The aim of this thesis is to increase the workability of a rescue craft launch operation in high sea states, for which two models in Matlab are built and validated. However, the simplifications made in the Matlab model are less reliable for such high sea states as the motions are highly non-linear. Orcaflex includes higher order wave loads, mooring loads, added mass and damping in the three dimensional plane, thereby making the FPSO's motions more reliable. It is possible to obtain the motions from Orcaflex at the davit's nock position and implement those into Matlab. This could make the model more realistic for high sea states.

Preventing a collision is very important for the safety level of the operation. When no collision occurs, as in Figure 2.14b test run 9, the Conventional system stays well below the safety levels for higher sea states. Notable is that the experiments conducted by the National Research Council did not result in a collision for conditions up to sea state 6/7, while the results from the computational models performed for the SAFECRAFTS project do show collisions. The simulations with the Matlab model built for this research also results in collisions for higher sea states. The swinging motions of a rescue craft can be influenced by among others the wind loading, the damping of elements in the system and the painter line. It is possible that the wind load acting on the rescue craft is too high, increasing the risk of collisions. Also, it is expected that the friction of components of the davit, such as the winch, will reduce the swinging motions of the rescue craft. Lastly, the model neglects the painter line, which is used to control the rescue craft's motion during launch and is attached to the fore of the rescue craft. It was assumed that this line will have neglectable effects on the horizontal swinging motions, but it is possible that the effect of this force on the motions is underestimated.

Lastly, the results in the splash zone for high sea states are exceeding the safety levels for the crew with both concepts. The high vertical accelerations are caused by the slack forces in the wire, which occur at the moment of impact with the water or when the wire's pay-out velocity is too low. The splash zone is modeled in a very simplistic manner and the slack forces in the wire have not been validated. However, from these results one can conclude that besides the launch system, the rescue craft must be designed to operate in high sea states. Accelerations can be reduced by for example timing the drop of the rescue craft on the wave's crest, constant tension in the wire and quick release hooks, but the splash zone remains a dangerous location. Although the Concept has improved the conditions with the drop further away from the hull, a controlled descent and control of the system by the rescue craft crew, slack forces and high accelerations remain a risk.

2.7. Conclusions

All in all, the rescue craft's davit performance in heavy sea states has been analysed with a model built in Matlab, which is validated using the simulation software Orcaflex. The performance of the davit is measured using the operational limits related to the horizontal and vertical accelerations of the rescue craft. Next, with the findings in the Problem Research, assessment criteria were defined which led to 4 design targets a new launch concept must fulfill. A final concept is selected and a Matlab model is developed, which is used to compare the performance with the conventional system. This concept proofs to increase the workability of a rescue craft launch operation in high sea states for the 4 design targets defined.

To conclude, this research delivers a model fit for design purposes with a quick simulation time and which is validated with Orcaflex. In addition, a new type of launch system is designed, which increases the workability and the safety of the crew in all weather conditions and on all 4 design targets, redundant design, easy maintenance, human factor engineering and within operational limits. The large boom offers an escape route during every phase of the launch operation. The system is very simplistic which makes maintenance less complex, thus reducing the risk of human errors in maintenance operations. In addition, the boom provides distance from the hull of the FPSO, making it easier to position the rescue craft for sail away or re-connection. Lastly, the results from the model comparison clearly show that the Design Concept is safe for launching a rescue craft in every weather condition as it limits the rescue craft's motions for the largest part of the launch.

It is recommended to further develop the Matlab model using the more realistic FPSO motions obtained by Orcaflex as input for the Matlab model, include the damping properties of davit elements, implement a painter line force acting on the rescue craft during launch and further develop the splash zone model using a computational fluid dynamics software. For further development of the Design Concept, it is advised to contact Kenz Figee as they have been working closely with this project to realise the final design.

3

Discussion and Conclusions

The motivation for this thesis is to reduce the number of incidents related to davit launched LSA equipment. These incidents relate to design failures, lack of proper maintenance or human errors and range from small incidents to incidents with injuries or even death. To investigate where this research could contribute most in reducing the number of incidents with rescue craft launch operations, an extensive problem research is performed, which consists of a literature study, interviews with the LSA industry, an incident analysis and a comparison of regulations for davit systems with man-riding cranes. This research proved that most incidents are related to davit failure, which mainly occur during the most dangerous part of the operation, the luffing, launch, splash zone and lift phase. Severe weather conditions make the operations even more risky as literature shows a clear correlation between higher sea states and deteriorating launch performances. Currently, no operational limits exist for the operation of LSA with respect to weather conditions and LSA is not designed to operate in such weather conditions as SOLAS states that it must only be tested for 'flat seas', resulting in rescue crafts and davit systems unfit to launch in severe offshore environments.

Therefore, this thesis aims to increase the workability of a davit launch operation from an FPSO in high sea states. This is possible by either upgrading the current design or developing a new design. The current design for davit systems could be improved by following the regulations for offshore man-riding cranes, which are much stricter. However, this will make the davit system financially very unattractive, increase the maintenance load and make the design very complex. All in all, it will not improve the current design, make maintenance easier nor reduce human errors. Therefore, this thesis has provided a new design for a rescue craft launch system from an FPSO which aims to increase the workability in high sea states, while being very simplistic, robust and easy to operate.

This thesis is divided into three phases. First a computational model is developed in Matlab, which simulates the launch of a rescue craft with the conventional davit system in the two dimensional plane. This model is validated using the simulation software Orcaflex to investigate the strengths and weaknesses of the model. The next phase is the development of a new concept using the Engineering Design Process. This resulted in four design targets the new design must meed and a final concept which is expected to increase the workability in all sea states. In the last phase of this thesis a computational model of the final design is built in Matlab, which is used to compare the performance of the conventional design with the performance of the concept design based on the four design targets.

3.1. Discussion

The aim of this thesis is to increase the workability of a rescue craft launch operation in high sea states, for which two models in Matlab are built and validated. However, the simplifications made in the Matlab model are less reliable for such high sea states as the motions are highly non-linear. Orcaflex includes higher order wave loads, mooring loads, added mass and damping in the three dimensional plane, thereby making the FPSO's motions more reliable. It is possible to obtain the motions from Orcaflex at the davit's nock position and implement those into Matlab. This could make the model more realistic for high sea states.

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2.14b test run 9, the Conventional system stays well below the safety levels for higher sea states. Notable is that the experiments conducted by the National Research Council did not result in a collision for conditions up to sea state 6/7, while the results from the computational models performed for the SAFECRAFTS project do show collisions. The simulations with the Matlab model built for this research also results in collisions for higher sea states. The swinging motions of a rescue craft can be influenced by among others the wind loading, the damping of elements in the system and the painter line. It is possible that the wind load acting on the rescue craft is too high, increasing the risk of collisions. Also, it is expected that the friction of components of the davit, such as the winch, will reduce the swinging motions of the rescue craft. Lastly, the model neglects the painter line, which is used to control the rescue craft's motion during launch and is attached to the fore of the rescue craft. It was assumed that this line will have neglectable effects on the horizontal swinging motions, but it is possible that the effect of this force on the motions is underestimated.

Lastly, the results in the splash zone for high sea states are exceeding the safety levels for the crew with both concepts. The high vertical accelerations are caused by the slack forces in the wire, which occur at the moment of impact with the water or when the wire's pay-out velocity is too low. The splash zone is modeled in a very simplistic manner and the slack forces in the wire have not been validated. However, from these results one can conclude that besides the launch system, the rescue craft must be designed to operate in high sea states. Accelerations can be reduced by for example timing the drop of the rescue craft on the wave's crest, constant tension in the wire and quick release hooks, but the splash zone remains a dangerous location. Although the Concept has improved the conditions with the drop further away from the hull, a controlled descent and control of the system by the rescue craft crew, slack forces and high accelerations remain a risk.

3.2. Conclusions

To conclude, this research delivers a model fit for design purposes with a quick simulation time and which is validated with Orcaflex. In addition, a new type of launch system is designed, which increases the workability and the safety of the crew in all weather conditions and on all four targets, redundant design, easy maintenance, human factor engineering and within operational limits. The large boom offers an escape route during every phase of the launch operation. The system is very simplistic which makes maintenance less complex, thus reducing the change for human errors in maintenance operations. In addition, the boom provides distance from the hull of the FPSO, making it easier to position the rescue craft for sail away or re-connection. Lastly, the results from the model comparison clearly show that the Design Concept is safe for launching a rescue craft in every weather condition as it limits the rescue craft's motions for the largest part of the launch.

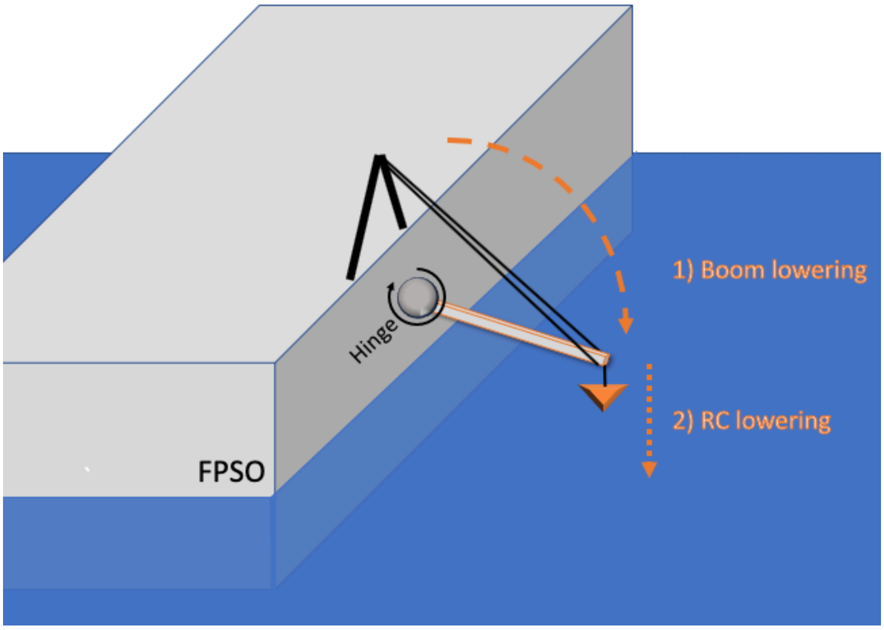


Figure 3.1: Concept Design

3.3. Recommendations

Improvements on the model will provide a more reliable tool for future projects. The following updates are advised:

- Obtain the FPSO's motions at the nock of the davit in Orcaflex and implement these into Matlab for more realistic motions
- Include friction of davit elements in the model
- Include the painter line force in the model
- Validate the splash zone behaviour of the rescue craft using a computational fluid dynamics software
- Include the re-connection and lift of the rescue craft in the model

To further investigate the Design Concept, it is advised to contact Kenz Figee as they have been working closely with this project to realise the final design.

4

Word of thanks

After a bit more then 9 months of working on this thesis I can say I am proud of the work I delivered. However, this could not have been made possible without the support of SBM, and specifically Alexei Bereznitski, who has taken the time to read through my work, provide feedback and help me whenever I hit a wall.

I would also like to thank my supervisor from the TU Delft, Alessandro Cabboi, whose door was always open. I have walked in numerous times with questions and he has always provided me with helpful answers. Also, my professor Andrei Metrikine found the time in his schedule to ask the critical questions that helped me improve my work.

Next, I would like to stress how important the crane-building company Kenz Figee has been for my work. They have been a tremendous support in gaining knowledge on offshore cranes and understanding the regulations for cranes and davits. They have made a lot of time available to help me with the concept development and to discuss all my, some times far-fetched, brainstorm ideas.

Lastly, my thanks goes to the wonderful people at SBM, who have made the past months a lot easier to get through.

A

Additional findings

In this appendix four compensation devices are considered. The use of such devices can increase the workability of the conventional davit system, according to LSA manufacturers. Both Vestdavit and Palfinger, two renown LSA manufactures, state that with these devices a davit launch operation can continue up to sea state 6. This research is based on the results from the Matlab model built for this thesis. For all conclusions given in this chapter, keep in mind the simplifications of the Matlab model.

A.1. Shock damper

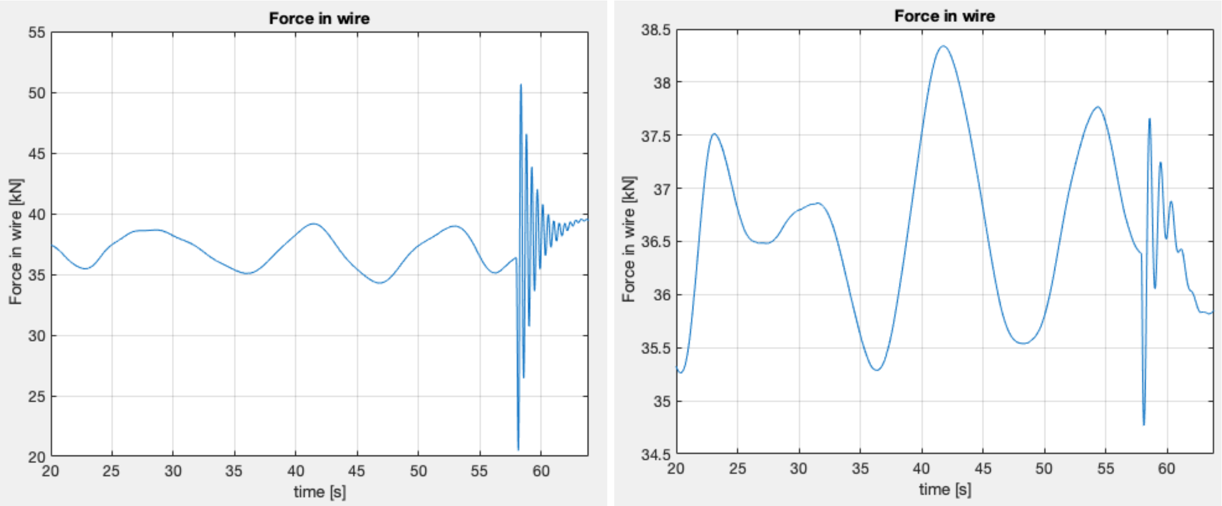
The shock damper is a device to lower shock forces in the wire fall. Such a device is required for Fast Rescue Crafts only, as stated in the LSA regulations:

> 6.1.7.2 The launching appliance shall be fitted with a device to dampen the forces due to interaction with the waves when the fast rescue boat is launched or recovered. The device shall include a flexible element to soften shock forces and a damping element to minimize oscillations. [8]

The shock damper is included in the Matlab model built for this thesis and is modeled as a spring element, which is activated only when a certain load in the line is exceeded. In the model this exceeding load is equal to the weight of a fully loaded rescue craft. The effect of the shock damper on the motions of the rescue craft is analysed for the conventional davit system.

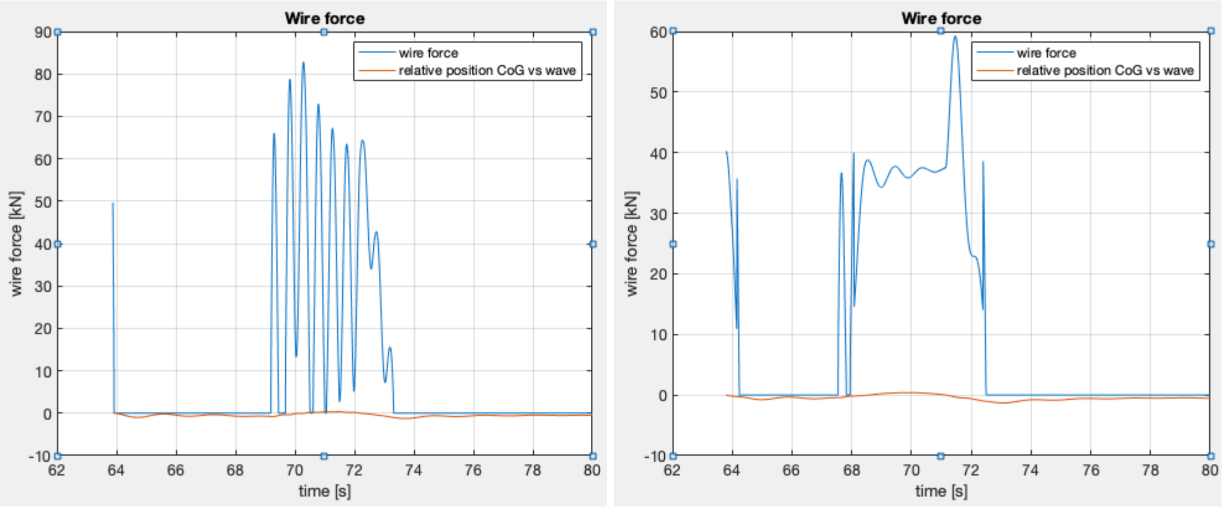
For this comparison a davit system without shock damper device is compared to a davit with such a device in sea state 6 (Hs = 3.5m and Tp = 12.4s) with a pay-out velocity of 0.5 m/s. With a low pay-out velocity, the risk is higher for slack forces to occur when in the splash zone. This is useful for analysing the effect of the shock damper in the splash zone as well. The force in the wire for both situations is given in Figure A.1.

Notable from the results is that the shock damper reduces the load in the wire significantly, both during launch as in the splash zone. The lower the change of forces in the wire, the lower the velocities of the rescue craft. Therefore, it is advised to include a shock damping device in the conventional davit system.



(a) No shock damper acting during launch

(b) Shock damper acting during launch



(c) No shock damper acting in splash zone

(d) Shock damper acting in splash zone

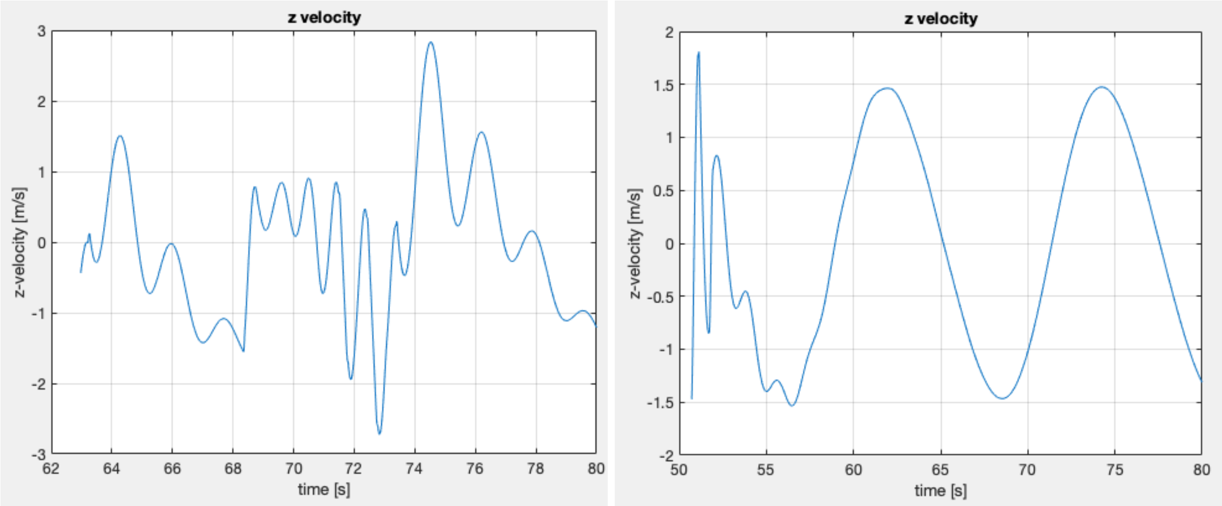
Figure A.1: Forces in wire with and without shock damper in sea state 6

A.2. High-speed winch

At the moment the rescue craft is lifted out of the water, the speed of lifting is important to reduce the risk of the next wave hitting the rescue craft. To ensure the winch can operate in higher sea states, a winch with high pay-out velocities is necessary with a maximum of 1m/s or 60 m/min, according to LSA regulations. According to the LSA manufacturer Vestdavit the minimum velocities for davit winches per sea state are:

- Sea state 1: 18m/min
- Sea state 2-3: 36m/min
- Sea state 4: 40m/min
- Sea state 5-6: 50m/min

The impact of the rescue craft lower and lift velocity is also clearly seen in the motions of the rescue craft during launch and in the splash zone. For higher velocities, the motions of the rescue craft during launch are less severe and the risk of slack forces in the wire in the splash zone is lower. To illustrate the impact of the pay-out velocity, the rescue craft's velocity in the splash zone is compared for a pay-out velocity of 0.5m/s and 0.8m/s in Figure A.2. For a pay-out velocity of 0.8m/s the rescue craft is less affected by slack forces. Therefore, a winch capable of lowering the rescue craft with at least 40 m/min is advised to increase the workability.



(a) Pay-out velocity of 0.5 m/s

(b) Pay-out velocity of 0.8 m/s

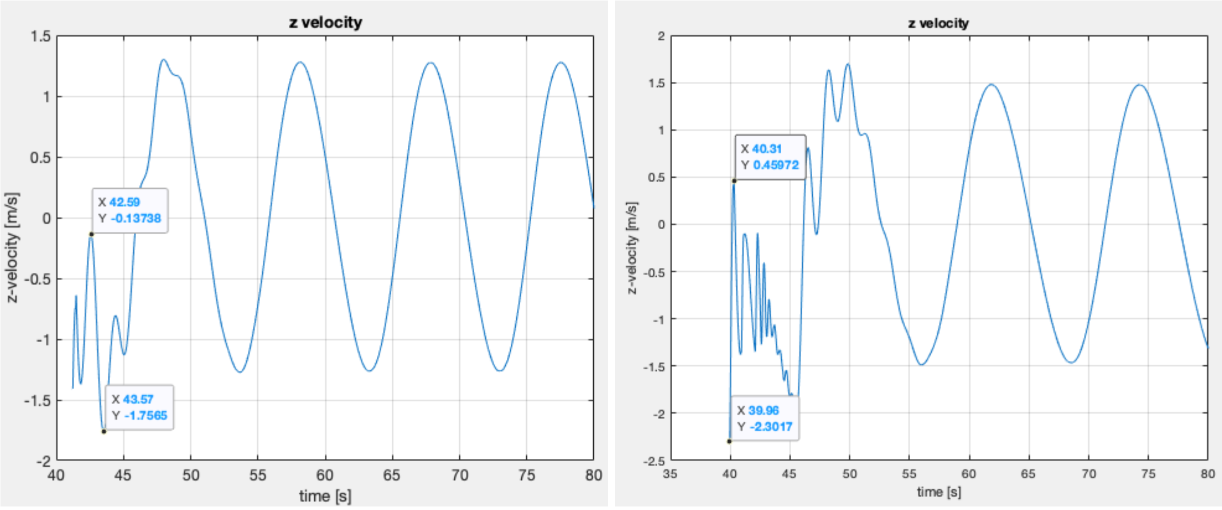
Figure A.2: Comparison of the rescue craft's vertical velocity in the splash zone for various wire pay-out velocities

A.3. Constant tension system

When the rescue craft is re-connected with the davit wire, the constant tension device keeps the wire under tension to prevent slack forces. Note, this system is only activated when the rescue craft is reconnecting, not when it is disconnecting. Such a device is required for Fast Rescue Crafts as stated by the LSA regulations:

> 6.1.7.3 The winch shall be fitted with an automatic high-speed tensioning device which prevents the wire from going slack in all sea state conditions in which the fast rescue boat is intended to operate.[8]

Such constant tension devices use a high-speed winch to compensate the up and down movement of the rescue craft in the waves. To analyse whether such a system could reduce the accelerations in the splash zone the application of a constant tension system with speeds up to 120 m/min is analysed. Included in Figure A.3 are the splash zone velocities of the rescue craft in sea state 5 and 6.



(a) Sea state 5

(b) Sea state 6

Figure A.3: Rescue craft motions with in splash zone

For sea state 5 the maximum change in velocity of the rescue craft is 1.6 m/s, equal to 97 m/min. Therefore, a winch with 120 m/min would be sufficient to cope with the quick changing motions in the splash zone and therefore reduce dangerous accelerations in the splash zone. However, for sea state 6 and up, the change in velocity is too high for the constant tension winch. The maximum change is equal to 2.8 m/s, or 166 m/min. In these sea states, slack forces will occur despite the constant tension device.

Concluding, such a constant tension device is promising for minimizing undesired slack forces when connected to the davit wire. Also, the best moment to lift can be timed at the moment when the dynamic forces and lift force are as low as possible, which is at the top of the wave. Therefore, it is recommended to add such a device to the davit for offshore operations. However, one must keep in mind that such a device is also limited to sea states. For sea state 6 and up, one must still expect slack forces in the splash zone. Note that this conclusion is solely based on the values obtained with the simple splash zone model built in Matlab. Motions of the rescue craft can be overestimated due to the simplifications of the model. Manufacturers of LSA equipment advise to use a davit system up to sea state 6.

A.4. Active heave compensation system

An active heave compensation (AHC) system is already used in many offshore cranes. However, for davit systems such a device is a fairly new appliance. Therefore, little information is provided on AHC devices for davit cranes. The question whether such a system is interesting for davit systems was asked to Kenz Figee. They were sceptical to the use of an AHC system for a rescue craft. Such a device is very complex and therefore difficult to maintain. Also, the need for heave motion compensation is also questionable as these vertical motions are not very significant during launch, as illustrated in Figure A.4.

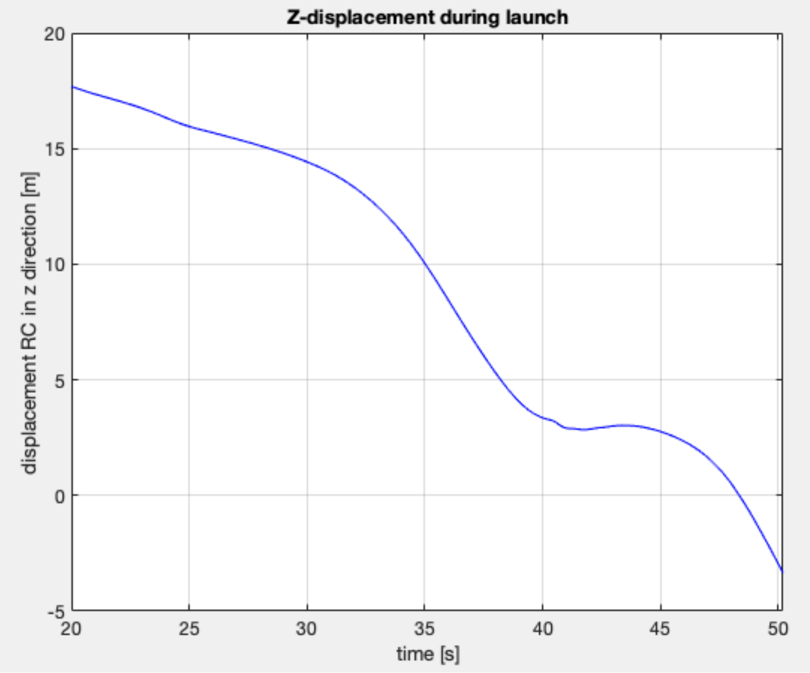


Figure A.4: Vertical motion during rescue craft launch in sea state 6 (Hs = 3.5m and Tp = 12.4m)

In addition, when the device is out of sync, the vertical motions will be enhanced instead of compensated, which will make the whole launch operation even more unsafe. For offshore man-riding cranes, it is therefore not allowed to activate the AHC system will hoising personnel. Therefore, it is not advised to use an AHC device on a davit system.

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