Limiting Operational Wave Criterion for Spool Installation Lift

With emphasis on analysis and wind-wave modeling

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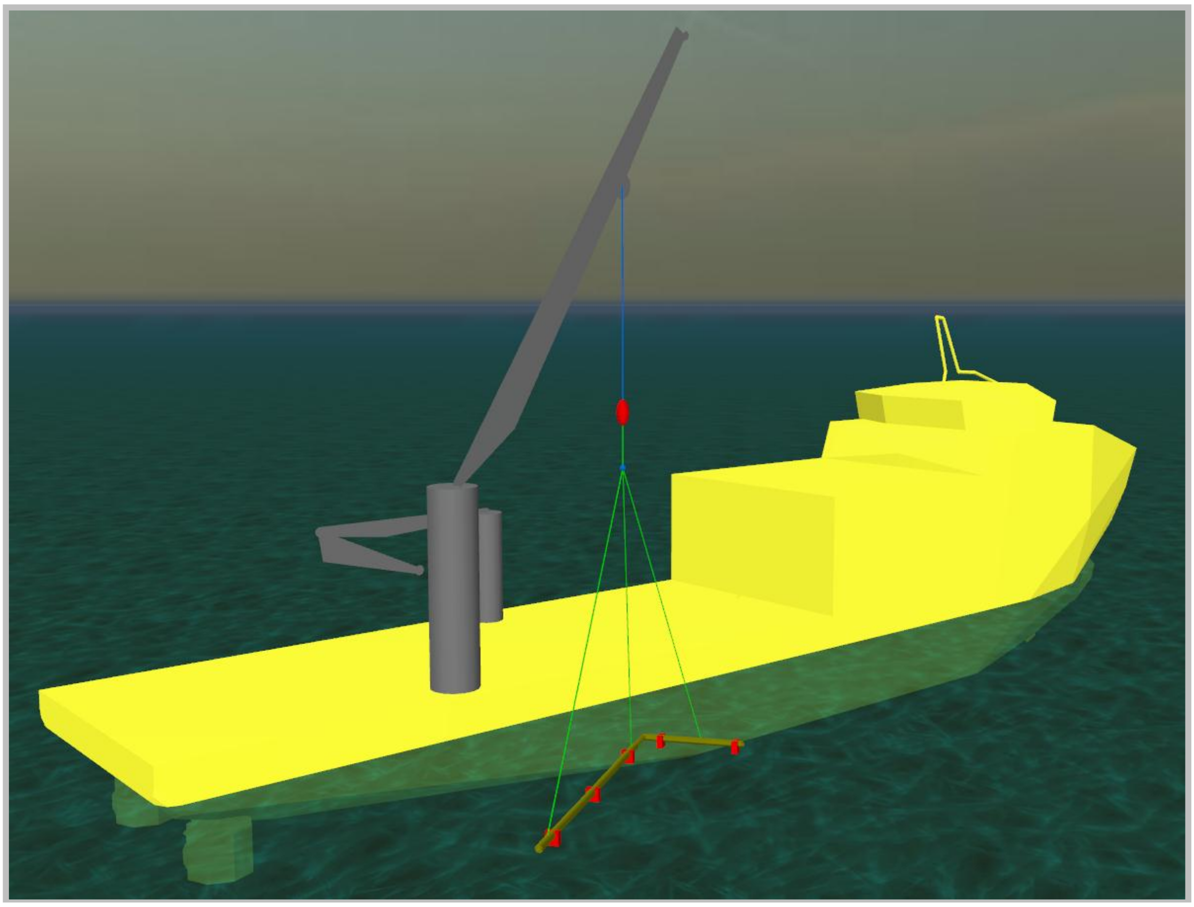

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MASTER'S THESIS

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Preface

This report is the Master's Thesis project of Dreng Å. Viki. It marks the end of my Offshore Technology, Marine and Subsea Technology study at the University of Stavanger. It is the conclusion of a four and a half month investigation of the limiting wave criterion and related analyses for a spool installation lift operation from offshore construction vessel.

This report has been written in collaboration with the offshore engineering and construction service company Technip. The report may well be of interest to anyone involved in the offshore industry, in particular those involved with marine lifting operations from construction vessels. The report puts focus to the DNV regulations dealing with the extent of the analysis of motion and load response for weather restricted marine operations and the resulting limiting wave criterion giving the sea states for which an operation can and cannot be carried out.

I would like to take this opportunity to thank my supervisor at Technip, Engineering Manager M. Dahle for his help with the thesis and also his initiative to provide me with a desk and computer at Technip's offices in Stavanger, for a large part of the time working with the thesis. At the office, I would especially like to thank Discipline Supervisor on Hydrodynamic Analysis, R. Rossi, for his valuable help and advice related to software modeling and analysis. The undersigned had no previous experience with the software used for dynamic analyses in this report. A great deal of the work has therefore been dedicated to learning the software. Being able to take it to a level of creating text script files to perform batch processing of analyses would most likely not have been possible without his help.

At the University my profound thanks goes to my faculty supervisor prof. O.T. Gudmestad. First of all for his inspiring lectures during my time at UiS, and now also for his time and effort related to my thesis. He has provided me with relevant reading and valuable feedback on my work. The opportunity to come by his office for advice and discussion has meant a great deal.

Stavanger, 15th June, 2015

Dreng Å. Viki

Abstract

Spools are rigid pipe sections which are parts of the infrastructure for transporting produced hydrocarbons and injection fluids subsea. Installing them includes a subsea lifting operation commonly carried out by use of the crane on an offshore construction vessel. Such operations are highly sensitive to waves, and usually limited by conditions such as excessive pendulum motions of the lifted structure and occurrence of slack lifting slings during transition through the wave zone. The industry practice is to perform software analyses of vessel motions and hydrodynamic loading acting on the spool(s) when deployed and lifted through the wave zone, in order to establish a limiting operational wave criterion. That is to determine acceptable sea states for such a lifting operation to be safely carried out.

A new Offshore Standard was recently issued, the **DNV-OS-H206** "**Loadout, transport and installation of subsea objects (VMO Standard – Part 2-6)"**. The new standard distinguishes between characteristic vessel motions generated by wind seas and the once generated by swell. A new requirement is introduced demanding that the wind sea is regarded as short crested when analyzing vessel response for operations that are independent of vessel heading. In addition, a minimum requirement to consider the situation where the wind sea and swell is acting with 90° degrees difference in propagation direction is introduced for subsea lifting operations.

This report addresses the problem of whether or not including spreading when describing the wind sea is more conservative for spool installation lifting as compared to earlier recommended practice where waves could be assumed being long crested. Furthermore, the question about potential benefits of doing more detailed assessments of the combination of the wind sea and swell than the minimum required by DNV-OS-H206 is raised. Both aspects are referring to the resulting limiting operational wave criterion, where conditions in the North Sea and Norwegian Sea are of interest.

A case study including a thorough process of establishing a model in the software package OrcaFlex, of a state of the art spool installation lift has been the basis for the investigations carried out. The model consists of an installation vessel, lifting arrangement and spools with properties modeled at a level of detail making it representative for the real world system. A range of dynamic time domain analyses have then been carried out where the system is subjected to sea states relevant for the problem defined. The methodology is, however, similar for all analyses carried out. Simulating the lowering from approximately 2 meters above deck level down to the sea surface identifies potential excessive pendulum motions, whereas as the wave zone crossing is assessed by running simulations for selected positions through the wave zone, ensuring that loads from the irregular sea is transferred to the system. Vessel motions are described by detailed RAO values and all relevant wave induced hydrodynamic loads experienced by the lifted spools are accounted for.

Analyses in a wind sea comparison study showed that modeling the wind sea as short crested waves described by the JONSWAP spectrum introduces significantly higher roll motions to the installation vessel. This subsequently leads to both excessive pendulum motions for a wide range of wave peak periods and large hydrodynamic loading on the spools because of increased crane tip motions, slamming loads in particular. The acceptable significant wave height for carrying out the lifting operation reduces. Considering this particular spool installation lift as representative also for other similar operations one can in general conclude that the limiting operational wave criterion for deployment and lifting through the wave zone for spool installations is more conservative as a result of these regulations being implemented.

A combined wind sea and swell study revealed that the situation where wind sea and swell is acting with 90° difference in propagation direction and where the swell approaches the vessel as beam sea with periods coinciding with the natural period of the vessel's roll motion and/or the horizontal motion of the lifted spools, as the most critical wave situation one can encounter. This study also showed that there are several benefits of doing analyses that are more refined where the wind sea and swell are modeled as separate wave trains. First, it allows one to identify a range of sea states characterized by other possible directions of the wind sea and swell than the worst case scenario, for which the operation is considered safe to carry out. Another profound merit is the opportunity to account for the vessel's heading relative to the wind sea and swell directions. This allows one to benefit from performing analyses based on conditions more similar to the actual offshore operation, where the vessel will be able to obtain an optimal heading relative to the wind sea and the swell. This advantage is particularly evident for situations of swell dominated sea states due to the essential assumption that it is reasonable to model wind sea and swell as separate wave trains, where the swell is assumed regular and not prone to the requirement of analyzing response for directions $\pm 15°$ of the assumed vessel heading, as is the requirement for wind sea.

The new standard's distinction between characteristic vessel motions generated by wind seas and the once generated by swell should be seen as an encouragement to establish a new practice where these consistently also are analyzed separately. This is further supported by the fact that weather forecasts providing information about wave conditions at an installation site, which the decision to initiate an operation is based upon, can now provide information on a level much more detailed than what is currently utilized for establishing the actual limiting operational wave criterion for an operation. That is, information about height, period and direction of wind sea and swell, separately. The draft of a possible future practice where such detailed analyses, performed during transit or waiting on weather is presented in this report.

An interesting continuation of the work in this report would be to investigate the new regulations' level of conservatism. This would require a comparison of analyses results and actual measured vessel motions. Also the issue of dynamic positioning accuracy and hence level of uncertainty related to the vessel's ability to maintain heading throughout an operation should be included in such a study. The usefulness of the presented possible future practice of establishing limiting operational criteria and initiating operations offshore should be further assessed by applying it in practice for an actual spool installation lift operation. This includes preparing a methodology where also uncertainty in forecasted wave period can be accounted for, as an extension of todays $\propto$-factor which accounts only for uncertainty in the forecasted significant wave height.

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Nomenclature

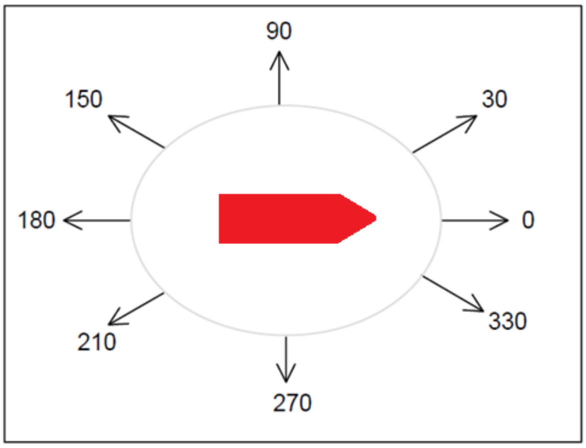
Nautical terms for vessel

Stern: The back or aft-most part of a vessel
Bow: Foremost part of a vessel

Starboard: Right side of vessel when facing the bow
Port: Left side of vessel when facing the bow

Direction conventions for waves

The direction from which waves are coming **relative to the vessel** is measured in degrees counter clockwise from the vessel stern. A relative direction of 180° means a wave coming from ahead, while a direction of 90° means a wave coming from starboard side. This is illustrated in the figure beneath.



Wave direction relative to vessel

The direction from which waves are coming **relative to the earth** is measured in degrees clockwise from north. Waves of direction 90° are hence coming from east.

Coordinate system

Vessel motions and wave properties are referred to in a three dimensional Cartesian coordinate system, where the xy-plane is horizontal and the z-axis is vertical.

Abbreviations

CFD	Computational Fluid Dynamics
CoG	Center of Gravity
DAF	Dynamic Amplification Factor
DNV	Det Norske Veritas
DP	Dynamic Positioning
DSV	Diving Support Vessel
ECMWF	European Centre of Medium Range Forecasting
FPSO	Floating Production Storage and Offloading unit
IOR	Increased Oil Recovery
JONSWAP	Joint North Sea Wave Project
MBL	Minimum Breaking Load
MEG	Monoethylen Glycol
MWL	Mean Water Level
NCS	Norwegian Continental Shelf
NMI	Norwegian Meteorological Institute
OCM	Offshore Construction Manager
PLET	Pipe Line End Termination
RAO	Response Amplitude Operator
ROV	Remotely Operated Vehicle
SHL	Static Hook Load
SWL	Safe Working Load

List of Symbols

a	Wave amplitude
A	Cross sectional area
A_p	Horizontal projected area of object
A_w	Effective cross sectional area
A_{33}^{0}	Low-frequency limit heave added mass
A_{33}^{∞}	High-frequency limit heave added mass
c	Wave speed of propagation
c_f	Fill-factor for wire
C_A	Added mass coefficient
C_D	Drag coefficient
C_E	Water exit coefficient
C_M	Inertia coefficient
C_E	Slamming coefficient
d	Water depth
D_o	Outer pipe diameter
D_i	Inner pipe diameter
D_w	Wire diameter
$D(\theta)$	Directional spreading function
E	Young's Modulus
E_w	Total wave energy per unit area
E_k	Fluid kinetic energy
f	Wave component frequency in hertz
f_D	Drag force per unit length

f_M	Inertia force per unit length
f_p	Spectral peak frequency in hertz
f_W	Fluid force per unit length
F_B	Buoyancy force
$F_{B,spool}$	Buoyancy force per unit length of fully submerged spool
F_D	Drag force
F_E	Water exit force
F_{hyd}	Hydrodynamic force
F_I	Inertia force
F_{max}	Maximum force
F_S	Slamming force
$F_{sling,max}$	Maximum dynamic sling load
$F_{static-min}$	Minimum static force
F_W	Total fluid force
F_{wd}	Wave damping force
F_{we}	Wave excitation force
g	Gravitational acceleration
G	Shear modulus (modulus of rigidity)
h	Submergence relative to surface elevation
H_{m0}	Significant wave height
H_s	Significant wave height
$H_{s,swell}$	Significant wave height swell contribution
$H_{s,total}$	Total significant wave height
$H_{s,wind\ sea}$	Significant wave height wind contribution
I	Second moment of area
J	Polar moment of inertia
k	Wave number
k_n	Wave number component
K_a	Axial stiffness
$K_{a,pipe}$	Axial stiffness of pipe
K_b	Bending stiffness
$K_{b,pipe}$	Bending stiffness for pipe
$K_{t,pipe}$	Torsional stiffness for pipe
l	Length of hoisting line
l_p	Pipe length
L	Wave length
m	Mass per unit length of hoisting line
M	Mass of lifted object
MBL_{sling}	Minimum breaking load for slings and grommets
n	Directional spreading constant
N	Number of samples in a wave record
OP_{LIM}	Limiting operational environmental criteria
OP_{WF}	Forecasted operational criteria
S_ζ	Wave spectrum
S_J	JONSWAP wave spectrum
$SWL_{Crane\ wire}$	Safe working load for crane wire
SWL_{Crane}	Safe working load for crane
t	Time

T	Period of regular wave
T_{0h}	Natural period for horizontal motion of a lifted object
T_C	Estimated maximum contingency time
T_p	Spectral peak period
T_{POP}	Planned operation period
T_R	Operation reference period
T_z	Mean zero up-crossing period
u	Water particle velocity
$\dot{u}$	Water particle acceleration
u_h	Horizontal water particle velocity
$\dot{u}_h$	Horizontal water particle acceleration
u_v	Vertical water particle velocity
$\dot{u}_v$	Vertical water particle acceleration
u_r	Water particle velocity relative to cylinder
$\dot{u}_r$	Water particle acceleration relative to cylinder
$\dot{u}_w$	Water particle acceleration relative to earth
v_e	Water exit velocity
v_s	Slamming velocity
V	Displaced volume of water
V_R	Reference volume for added mass
W	Submerged weight of object
W_0	Weight of object in air
x	Distance x-direction
x_a	Surge motion amplitude
y	Distance y-direction
y_a	Sway motion amplitude
z	Distance z-direction
z_a	Heave motion amplitude

α	Alpha factor
β	Constant related to the equilibrium range
γ	Peak enhancement factor
γ_c	Consequence factor
γ_f	Load factor
γ_m	Material factor
γ_r	Reduction factor due to end termination or bending
γ_{sf}	Nominal safety factor for slings and grommets
γ_{tw}	Twist reduction factor
γ_w	Wear and application factor
Γ	Gamma function
δ	Angle of twist for pipe
Δ	Mass of water displaced by body
$\Delta\omega$	Circular frequency interval
Δt	Time interval in wave record
ε_n	Random phase angle component
ζ	Free surface wave profile
ζ_{a_n}	Wave amplitude component
$\overline{\zeta_{a_n}{}^2}$	Mean square value of wave amplitude component
ζ_n	Vertical displacement component in a wave record
θ	Angle between elementary wave trains and main wave direction
θ_a	Pitch motion amplitude
θ_p	Main wave direction
ν	Poisson ratio
ρ	Mass density of water
σ	Spectral width parameter
σ_a	Spectral width parameter from JONSWAP experimental data
σ_b	Spectral width parameter from JONSWAP experimental data
σ_ζ	Standard deviation of water level
σ_ζ^2	Variance of water level
τ	Time history of wave elevation
T	Torque
ϕ_a	Roll motion amplitude
ψ_a	Yaw motion amplitude
ω	Circular wave frequency
ω_n	Circular wave frequency component

1 Introduction

1.1 Background and Motivation

The term spool or spool piece, frequently used in the oil and gas industry, refers to a short segment of rigid pipe with a connector at either end. They come in a variety of configurations and are vital components in the subsea infrastructure for transporting produced hydrocarbons and injection fluids subsea. The need to handle considerable elongations and contractions of steel pipelines due to temperature changes during production startup and shut down, has established the use of spools as a common method for tie-in of pipelines to production platforms. Figure 1-1 illustrates an example where spools are used in the transition between a pipeline and a jacket structure platform. A configuration consisting of several bends enables the spools to deflect and effectively recover longitudinal strains in the pipeline and hence it reduces the possibility for material yielding and failure modes such as local pipeline buckling.

Around the early 80s the oil and gas industry entered what many refers to as the subsea boom period. Satellite developments of subsea wells were tied back to fixed platforms. This technology made smaller discoveries located outside the effective drilling reach of existing platforms economically feasible to produce. As field discoveries exceeded the water depth manageable for fixed platforms, new configurations consisting of having all wells placed subsea and producing back to Floating Production Storage and Offloading units (FPSO) evolved.

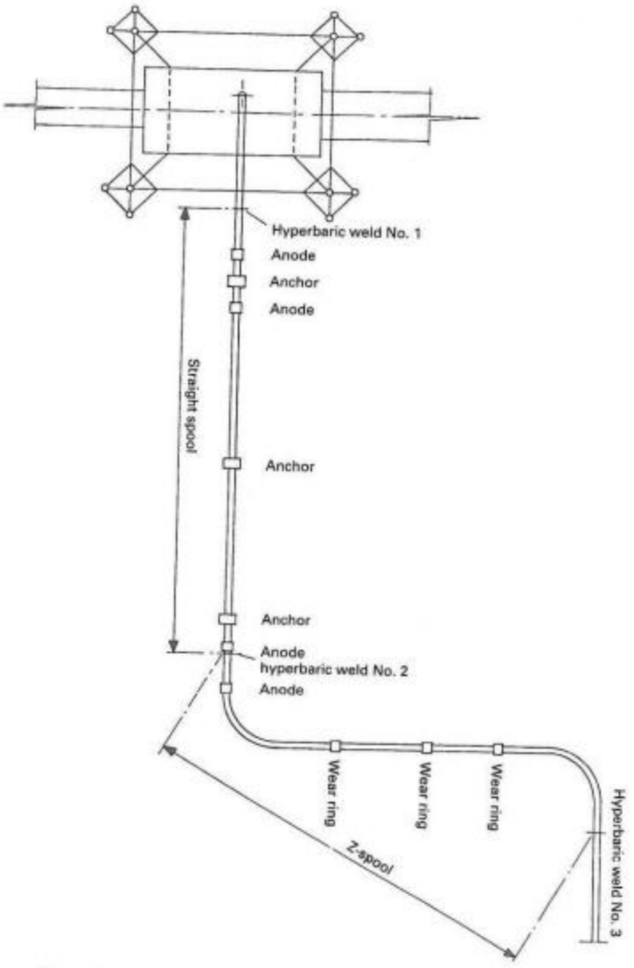


Figure 1-1 Tie-in spools (Braestrup, et al., 2005)

Along with this development followed an extensive infrastructure of subsea production equipment and in-field flowlines. The use of rigid spools has over the years been heavily adopted for making up the connections in these networks. An example where rigid spools are used for connecting facilities such as pipeline end terminations (PLET), x-mas trees and manifolds in a cluster solution is presented in figure 1-2. Spools are fabricated from accurate measures obtained after the facilities are installed, which enables some degree of flexibility when drilling the wells and installing the subsea facilities. New oil and gas field discoveries and their subsequent production developments are constantly reaching new areas. At the same time the industry faces an increased demand for enhanced oil recovery and many of the older fields are upgraded for the purpose of extended production life. This results in new wells tied-back to existing production facilities and hook up of new platforms to the production lines in mature fields.

Due to their extensive areas of application, installation of spools has become a marine operation frequently encountered by the offshore contractor companies. The means for transporting and installing spools offshore is heavily dependent on the size and configuration of the spool. Spools are generally long and slender structures, resulting in the footprint area often being a much larger challenge than the weight. Essentially, it breaks down to the question about finding the most cost effective solution for transport and installation. In cases where spools can be transported on the deck of an installation vessel, this will most likely be the preferred option. The same vessel is then used for transport and the actual installation lift, eliminating the need for support from other vessels, which is associated with high cost. To enable use of this method, spools are in some cases also fabricated in sections to be connected subsea, in order to meet the limitations on the deck area of the installation vessel.

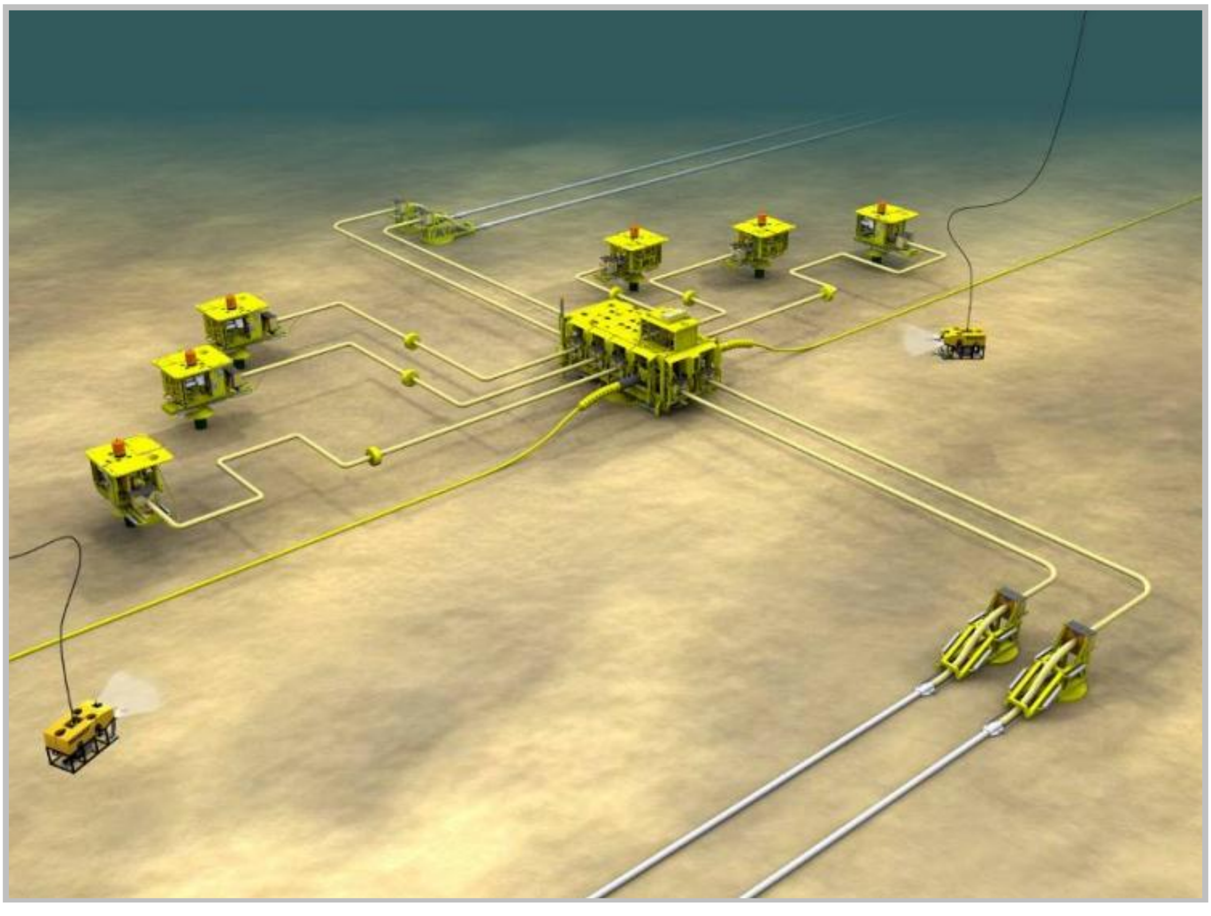


Figure 1-2 Spools in cluster solution (Aker Solutions, 2015)

The installation vessels are typically construction vessels, facilitating a transport deck and large installation cranes, as the one seen in figure 1-3. The installation lift comprises bringing the spool from the vessel deck to its designated tie-in point on the sea bed, a so called subsea lifting operation. The slenderness of spools normally dictates the need for an extensive lifting arrangement in order to avoid overstressing the section when lifting it. An example of this can be seen in figure 1-4, where a spool is lifted by an arrangement of various spreader bars and slings. Such installation lifts requires detailed planning and analysis to ensure a safe execution. The term “weather criteria” is frequently used for referring to an acceptable upper limit of environmental loading for marine operation. For spool installation lifts from a construction vessel, we are in particular concerned with the criterion related to waves. Waves result in vessel motions that can limit the operation. Transition through the wave zone is regarded as a critical phase. The hydrodynamic wave forces are largest at the surface, as this is where the water particles have their maximum velocity. Furthermore, the buoyancy force acts on the spool when submerged in water. Hydrodynamic forces exceeding the static weight of spool and lifting arrangement has the potential to make lifting wire and slings go slack, resulting in dangerous snap loads. Such situations have to be avoided in order to ensure a safe operation.

Installation lifts for spools are in general, independent of vessel heading, meaning that vessel heading can be adjusted to reduce the vessel motions to a minimum. Often this will be achieved by orienting the vessel bow towards the apparent wave direction. The nature of waves is however much more complicated. In general we can split wind generated waves into two distinct categories. A **wind sea** consists of waves generated by the local wind field and is characterized by individual wave crests propagating in various directions, deviating from the mean direction. **Swell waves** are waves that have propagated out of the area where they were generated and can travel long distances in open sea. Wind sea and swell can for this reason approach a vessel from widely different directions. Swell approaching a vessel from the side is known to have caused not only situations where operations have had to be aborted, but also resulted in incidents related to excessive pendulum motions of the lifted structure. “Beam sea” is a term frequently used for referring to this situation, where waves come at an angle approximately perpendicular to the vessels heading.

Figure 1-3 Construction vessel

Spool installation lift operations require relatively calm sea states to be performed. Ideally, one would seek to perform such operations during seasons with statistically calmer sea states. However, as spools make up vital connections in flow paths, the increase in earnings of getting production started as soon as possible will in many cases justify the cost of extensive waiting on weather when carrying out the installations during seasons of more challenging wave conditions. In an industry based on tendering, such operations are subjected to a high level of competition between the contracting companies. An increase in the limiting wave criterion for carrying out spool installation operations can have large commercial advantages. Stricter criterion can correspondingly be a large disadvantage.

Determining the limiting wave criterion for a certain spool installation lift is based on performing analyses of the dynamics of motion and load response for the considered operation. This includes analyzing vessel motions and hydrodynamic effects acting on the spool as it is lowered through the wave zone. The industry relies on technical requirements and guidance from DET NORSKE VERITAS (DNV) in order to ensure a sufficient level of safety. Description of the sea states to consider, requirements to the extent of analysis and their related acceptance criteria are important aspects. Regulations directly related to the problem definition in this report are presented in the following subchapter.

Figure 1-4 Spool lifting arrangement (Gloaguen, et al., 2007, p. 8)

1.2 Regulations

As an overall requirement the document **DNV-OS-H101 "Marine Operations, General"** states that "*All possible combinations of wind sea and swell should be considered*" when planning for marine operations (DNV, 2011 a, p. 21)

Furthermore, **DNV-RP-H103 "Modelling and analysis of marine operations"** gives guidance for modeling and analysis of marine operations, in particular for lifting operations including lifting through the wave zone. It is in this document stated that:

"*For subsea lift operations that may be performed independent of vessel headings, vessel response should be analyzed for wave directions at least* $\pm 15°$ *off the vessel heading stated in the procedure*" (DNV, 2011 b, p. 61)

The intention of this practice is to account for the fact that even though orienting the vessel directly towards the waves, realistic wind sea consists of waves propagating in directions deviating from the main direction. Furthermore, the vessel will not be able to keep the exact same heading throughout an operation. The same document defines a criterion to ensure that snap loads are avoided in crane wire and individual lifting slings, as the object lifted is exposed to hydrodynamic loading:

$$F_{hyd} \leq 0.9 \cdot F_{static-min} \qquad [N] \tag{1.2-1}$$

A margin of 10 % to the start of slack slings is required. In other words, the tension in crane wire and individual slings must at all times be larger than or equal to 10 % of the minimum static tension.

September last year (2014) a new Offshore Standard was released, the **DNV-OS-H206** "**Loadout, transport and installation of subsea objects (VMO Standard – Part 2-6)"**. This is a new document in a series of documents replacing the DNV "Rules for planning an Execution of Marine Operations". This document distinguishes between characteristic vessel motions generated by wind seas and the once generated by swell. Regarding wind sea, this document clearly states that in addition to analyzing vessel response for wave directions at least $\pm 15°$ off the vessel heading, also:

"*Short crested sea with spreading n=2 used in the directional function, ref. DNV-OS-H101 Sec. 3 C902, should be applied for operations that are independent of vessel heading*" (DNV, 2014, p. 27).

A new requirement is hence set to take account for the directionality in a realistic wind sea and the uncertainty related to the vessel's ability to maintain heading throughout the operation, when analyzing vessel response. In this new standard, more focus is also put on the effects of swell and it is stated that:

"Critical swell periods should be identified and considered in the design verification" (DNV, 2014, p. 27).

As for the issue of directionality between the wind sea and swell, this is addresses under the section for vessel motions and accelerations:

"For subsea lifting operations it is normally sufficient to consider the most unfavorable relevant combination(s) of simultaneous wind seas and swell. As a minimum the combination of wind sea and swell acting with $90°$ $(or\ 270°)$ *difference in propagation direction should be considered"* (DNV, 2014, p. 26)

The new standard is less conservative on the acceptance criterion for avoidance of snap loads, by only demanding that the sling tension must be greater than zero (DNV, 2014, p. 38):

$$F_{hyd} \leq 1.0 \cdot F_{static-min} \qquad [N] \tag{1.2-2}$$

The 10 % margin still applies to the tension in crane wire.

1.3 Problem Definition and Scope of Work

This report will first of all investigate the effects the new requirements for analysis of characteristic vessel motions generated by wind sea will have on the limiting wave criterion for spool installations, as compared to earlier recommended practice. In other words, to determine whether or not including spreading when describing wind sea is more conservative than earlier recommended practice. This will also include accounting for the new acceptance criterion for avoidance of slack slings.

In the new standard, more focus is clearly put on also considering the effects of swell, and to reveal critical periods for installation lifts. Nevertheless, only considering the most critical periods for critical directions seem very simplistic, as the real situation often is more complex. An investigation of the effects of wind sea and swell acting with various degrees of directionality will be conducted, to determine the effects on the limiting wave criterion for carrying out a spool installation lift operation. The goal is to identify potential benefits of doing more detailed assessments of the combination of wind sea and swell than the minimum required by DNV and hopefully be able to extend the limiting criterion for waves. This includes looking into the practice of how analysis results relate to the practice of initiating and carrying out the operation offshore. New regulations often entails the need for a change of current practice. Potential opportunities and benefits of changing current practice in how limiting wave criteria are established shall therefore also evaluated. The North Sea and Norwegian Sea, with their related wave conditions will be the areas of interest.

Answering this problem will first of all require a state of the art review of how these installation lifts are performed and how limiting wave criteria are established. Furthermore, a detailed study of the theory of waves and how wave theory relates to the conditions in the areas of interest will be conducted. The effect of these waves on vessel motions and objects lowered through the wave zone will be thoroughly assessed.

An industry example case study for a specific spool installation and vessel will be the basis for the investigations carried out. The intention is to create a software model for this particular installation lift, detailed enough to represent a realistic basis for comparison of this lifting operation in different sea states. Modeling and dynamic analyses will be performed using the OrcaFlex software package.

1.4 Limitations

A typical subsea lift is split into the following main phases (DNV, 2011 b):

- Lift of from deck and maneuvering object clear of vessel
- Lowering through the wave zone
- Further lowering down to sea bed
- Positioning and landing

In a complete design verification all of these phases have to be thoroughly evaluated, as they all have particular challenges and risks related to them. This report will however concentrate the focus around the phase of **lowering through wave zone**. This includes the situation where a spool is suspended from the installation crane and lowered towards the sea surface, as well as the situation where the spool crosses the wave zone. The reasoning behind this limitation is that for a spool installation lift in the considered area, this will usually be the most critical part with respect to waves, covering the potential limitations due to excessive pendulum motions and the challenges of maintaining sling tension when crossing the wave zone. As a comparison, the phase of lowering down to the seabed is often regarded as the most critical in areas of much deeper water, say in the range 1000-2000 m.

A range of analyses will be performed related to the industry example case study. The acceptance criterion related to tension in individual slings and crane wire in order to avoid snap loads has already been emphasized. An operation can obviously also be limited by the maximum loads in components that are part of the installation lift. For the sake of completeness, also maximum capacities of lift rigging/slings, crane wire and vessel crane will be addressed and accounted for. The structural integrity of spools however, is outside the scope of what this report intends to cover. The case study is based on an already engineering approved design of spools and related lift rigging. Spools are hence assumed sufficiently dimensioned and the rigging designed not to impose any limitations for installation in sea states considered in this report.

It should be mentioned that when planning for marine operations there are in general several environmental phenomena that have to be considered, where wind, waves and current are the most important. As indicated, this report will limit itself to concern the effects of waves only. Furthermore, only waves generated by the interaction between wind and the sea surface will be addressed. In other words, waves generated by earthquakes, submarine landslides (tsunamis) and such are outside the scope of this report.

1.5 Structure of the Report

This report is divided into chapters structured in the following manner. First, in chapter 2, a state of the art review is presented on the industry practice related to performing subsea lifting of spools, determining limiting weather criteria and how these relates to weather forecasts. Chapter 3 gives an introduction to the case study designated for the work in this report, including the technical solution selected. Chapter 4 presents a summary of theory relevant for conducting calculations and analyses related to the case study in line with the problem definition. The software is described in chapter 5, along with a detailed description of modeling of the installation lift and waves related to the case study. Analysis methodology and preparatory work such as sensitivity studies of analysis parameters are addressed in chapter 6. Chapter 7 is an actual comparison study of the regulations for analysis of vessel response to wind sea. It is hence an investigation of the effects on the limiting wave criterion for the considered spool installation lift with respect to earlier DNV recommended practice and new DNV regulations. The results from chapter 7 is the starting point for the investigations carried out in chapter 8, where also the effects of swell is taken into account. The chapter presents analysis results for sea states in line with the minimum requirements from DNV, as well as a range of extended cases. Chapter 9 is designated to a discussion on potential opportunities based on the findings in chapter 7 and 8. Chapter 10 concludes the report, and finally, recommendations of further work are given in chapter 11.

A great deal of the work with this report has been the actual preparations leading up to the analysis results presented in chapters 7 and 8. The foundation for the analyses is a thorough theoretical study as well as extensive work dedicated to establishing an OrcaFlex model representative for the considered case study.

2 State of the Art

2.1 Rigid Spools and Installation Lifting from Construction Vessel

The installation lift for a spool from a construction vessel can in all simplicity typically be divided into three distinct systems:

- The installation vessel with its crane
- The spool(s) being lifted
- Lifting arrangement and slings

The installation vessels come in different varieties, but are in general vessels that are purpose built for transport and installation of subsea facilities. Diving Support Vessels (DSV) are frequently used for installation lifts, as the assistance of divers or Remotely Operated Vehicles (ROV) in many cases is required at some stage of an installation. The actual tie-in is the stage performed after the spool is landed subsea. Over the years the industry has been heavily dependent on divers to make up spool connections. The progress into constantly deeper water, by far exceeding the working depth of divers, has also brought remotely operated systems into the market.

Similar to flowlines, spools are normally steel pipes, often coated for the purpose of protection and/or thermal insulation. A spool will generally be a light structure to lift as compared to much of the other subsea production equipment installed from construction vessels. Such a hollow pipe with limited wall thickness will also in many cases have a large degree of buoyancy. During transport, a spool will be securely fastened to the vessel deck. The installation lift starts when this sea fastening is released and the spool is hooked up to the crane. In most cases the same lifting arrangement will be used for lifting the spool onto the vessel at the harbor and is hence already in place when going offshore. The long and slender appearance of spools is what makes them fairly complicated to lift. The fact that spools have no standard dimensions result in lifting arrangements also being customized to a particular spool installation lift.

During the installation operation the vessel will rely on a computer controlled Dynamic Positioning (DP) system for maintaining vessel heading and geographical position at the installation site. Such a system uses sensors and satellite communication wherefrom information obtained automatically engages the thrusters to overcome any changes in the location of the vessel (Rigzone.com, 2015). These are highly redundant systems, providing very accurate stationing-keeping abilities. Even so, an installation vessel is subjected to motions as a result of the sea state it is operating in. As the lifting arrangement and spool is lifted off the deck the system becomes highly sensitive to these motions. Excessive pendulum motions of the lifted spool can create dangerous situations for personnel and also result in damage to the spool or vessel facilities should the lift come out of control. Both the operation of maneuvering the spool clear of the vessel and lowering it through the wave zone can be aided by attaching wires from deck mounted winches to the lifting arrangement, so called “tugger wires”. Correct use of such wires can limit pendulum motions and rotation. This will, however, add more complexity to the operation with respect to synchronizing e.g. wire pay out and assuring that they do not snag onto other objects on deck. These wires are normally disconnected by use of ROV after the spool has been lowered through the wave zone.

2.2 Weather Criteria, Analysis and Forecasts

DNV classifies marine operations based on their planned duration and with respect to how accurately one can predict the environmental loads for the time of execution.

- **Unrestricted operations** are operations having a duration exceeding the time with reliable weather forecasts. The characteristic environmental conditions are estimated according to long term statistics for the designated site and season of operation.

- **Weather restricted operations**, on the other hand, are operations of duration short enough for the environmental loads to be forecasted with a reasonable confidence. Weather restricted operations has the advantage of being planned with environmental conditions selected independent of statistical data, but hence also operations having defined restrictions to the characteristic environmental conditions.

The differences of these categories of marine operations are perhaps best observed when it comes to the limitations for initiating the actual operation. An unrestricted operation will typically be designed for higher environmental loading, as one must plan for a situation where it is possible to encounter the seasonal maximum loading, at some stage during the execution. For weather restricted operations execution is based on waiting for a suitable weather window, i.e. forecasted period of sufficient length having acceptable weather. The duration of a marine operation shall according to (DNV, 2011 a, p. 28) be defined by an operation reference period, T_R:

$$T_R = T_{POP} + T_C \tag{2.2-1}$$

In which:

T_{POP} = planned operation period
T_C = estimated maximum contingency time

The planned operation period is the time it takes to perform the operation. The estimated maximum contingency time is added to account for uncertainties related to the planned operation time and intends to allow for additional time to complete the operation, should a situation occur where changing the initial schedule becomes necessary. Marine operations with a reference period less than 96 hours and a planned operation time less than 72 hours may normally be defined as **weather restricted**. In other words, it can in general be assumed that weather forecasts provide information about the environmental conditions at a site up to 4 days into the future with reasonable accuracy. It should, however, be emphasized that in situations where a corresponding reliable weather forecast is not considered realistic (e.g. areas or seasons), a shorter limiting reference period must be applied. Nevertheless, spool installation operations will almost without exception fall into the category of weather restricted operations, as they are usually not very time consuming operations. This is the case that will be considered throughout this report.

The flowchart in figure 2-1 outlines the procedure in determining whether or not an operation can be regarded as weather restricted. Assuming an operation is classified as weather restricted, the next step is to consider all aspects and establish limiting operational environmental criteria (OP_{LIM}), i.e. defining the limit for when the operation can be carried out. In general, limiting operational criteria for waves can, for example, be related to safe working on the vessel deck. It can, alternatively, be the limit for use of equipment such as ROV or crane, while for some marine operations it may be a limiting condition for use of diving systems or the vessel's DP system. As described in the introduction chapter, the limiting operational criterion that will be addressed throughout this report is the design criterion related to the actual lifting and deployment through the wave zone, established from analyzing the operation.

A simplified method for analyzing the hydrodynamic forces on objects lowered through the wave zone is presented in (DNV, 2011 b, p. 58). This method is based on the main assumption that the horizontal extent of the lifted object is relatively small compared to the wave length. In cases involving long slender structures like spools, more refined analyses are needed in order to establish loads in individual slings. Time domain analyses are therefore recommended for this purpose. Creating a software model of the installation vessel, lifting arrangement and spool and perform dynamic time domain analyses where the system is subjected to waves, is standard industry practice today. This allows one to consider the coupled system dynamics of motion and account for vessel response to waves and hydrodynamic loading on the spool in the same analysis. The intention of time domain analyses are hence to reveal sea states in which the considered operation can and cannot be carried out, by comparing analysis results to acceptance criterion for sling tension and lifted structure motions.

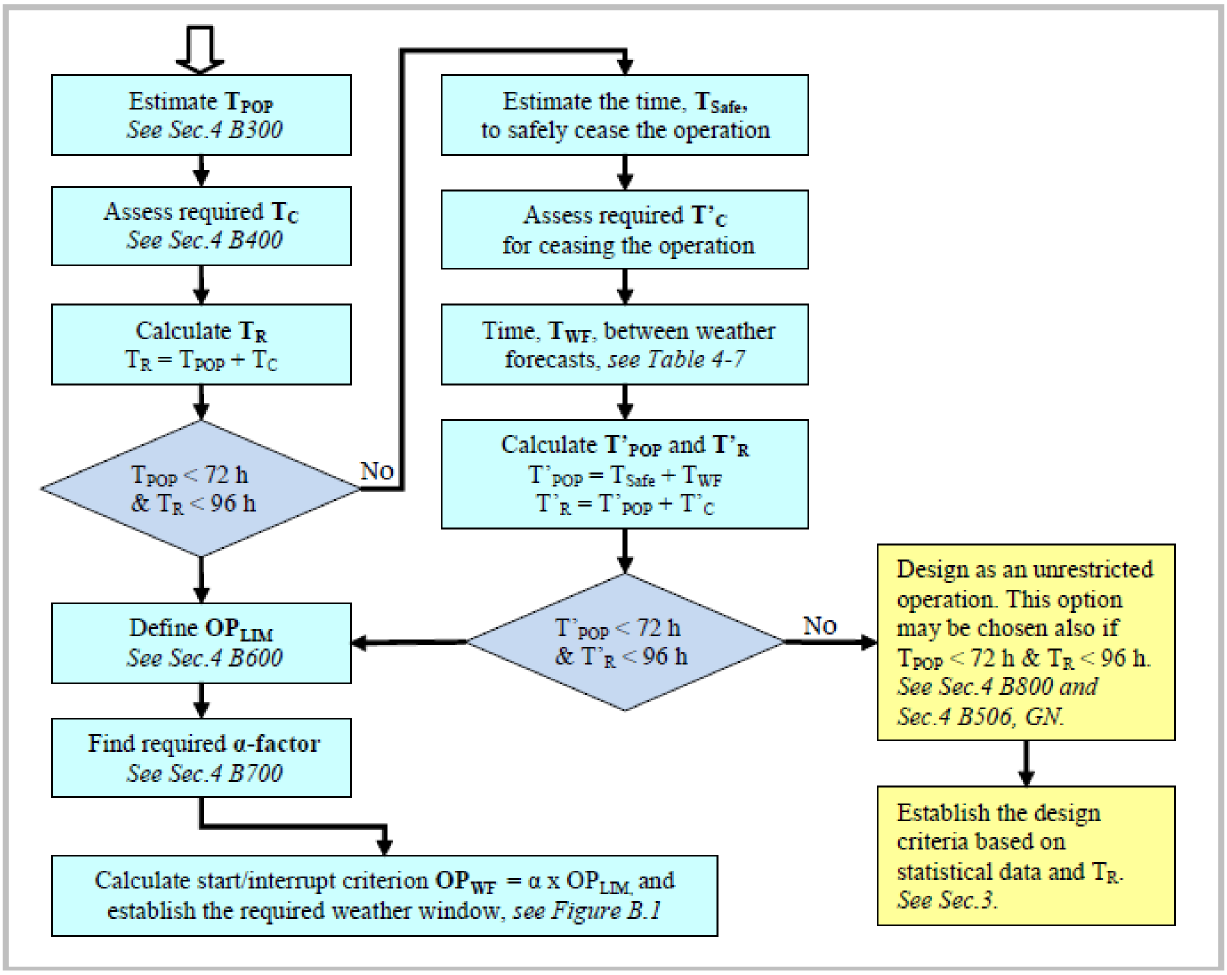


Figure 2-1 Restricted or Unrestricted Operation (DNV, 2011 a, p. 30)

The design method for motion and load response designated weather restricted marine operations is referred to as **Design spectra (stochastic) method** (DNV, 2011 a, p. 24). Random ocean waves are then described by wave energy spectra giving the energy content of an ocean wave situation and its distribution over a frequency range of the random wave. The most common way to address limiting waves for weather restricted marine operations is in terms of a maximum allowable significant wave height, H_s. Significant wave height is defined traditionally as the mean wave height (trough to crest) of the highest third of the waves in a sea state, intended to correspond well with the approximate wave heights visually estimated by experienced mariners. A more recent statistical description of the significant wave height along with a detailed explanation of wave spectra will be presented in chapter 4. A particular operation will in many cases also be limited by certain maximum wave height in combination with specific wave periods. Wave periods are commonly given as spectral peak period, T_p, which corresponds to the wave component with highest energy in a sea state. Sometimes also the mean period for zero up-crossing waves in a sea state, T_z, will be used.

Current practice of establishing limiting operational wave criteria is based on determining a maximum significant wave height and corresponding acceptable wave periods for an operation, assuming the vessel will be oriented directly towards the main wave direction during execution. Vessel response is in accordance with the earlier recommended practice presented in chapter 1.2, analyzed for wave directions $\pm 15°$ of this direction. Analyses are performed well ahead of the offshore execution. At the offshore installation site, project engineers onboard the installation vessel will rely on weather forecasts to determine when there is a suitable weather window to go ahead with the operation. As a minimum these forecasts will provide information about the significant wave height and corresponding period at the site. They normally also provide information about wave directions. As the atmospheric environment in general is chaotic and unpredictable, weather forecasts are less reliable the further into the future we look. This uncertainty in forecasting must according to (DNV, 2011 a, p. 31) be taken into consideration when planning for weather restricted marine operations. The recommended practice is to establish **forecasted operational criteria** - OP_{WF}, defined as:

$$OP_{WF} = \alpha \cdot OP_{LIM} \tag{2.2-2}$$

The α-factor will reduce a limiting operational wave criterion, by taking a value less than 1.0. Planning for a spool installation lift, we are in general not looking at very high values of significant wave height. Consider a situation where the criterion established is a H_s= 2.0 m. Combined with an α-factor of 0.8 this means that one needs a forecasted H_s not exceeding 1.6 m for the whole operation reference period, before one can initiate the operation. It is recommended that the α-factor for the North Sea and the Norwegian Sea should be selected by considering the planed operation time (T_{POP}) and a categorization of the level of weather forecast. This level relates to the effort made in obtaining reliable weather forecasts and the means of verifying them. The α-factors will in practice vary from 0,55 to 1,0, and logically approach 1 as the planned operation period reduces and weather forecast reliability increases. The α-factor can be increased by taking measures such as obtaining forecasts from two independent sources, which today is common industry practice. As seen in figure 2-2, the planned operation periods starting point is defined at the issuance of the last weather forecast. Standard industry practice is to have these updated at least every 6 hours. Having a dedicated meteorologist at site and also performing monitoring of design parameters such as wave height, and using this information to calibrate the forecasts will increase the α-factor. These are measures often practiced in the industry today. As spool installation lifts have rather short operational time, this also contribute to bringing the α-factor fairly close to 1.0 for such operations. For this reason, the initial limiting operational criterion established from analyses, will be decisive for the sea states one can expect to perform an operation in.

Deployment activities are only allowed to be started in decreasing or steady wave conditions. The final decision to start an operation is taken by the Offshore Construction Manager (OCM) and the vessel Master (Captain) onboard the installation vessel. Together they have the overall responsibility for safe execution of vessel operations. They will consider the actual wave situation and relate it to the response of the vessel. This can be regarded as an extra safety barrier, but also a practice to simplify the work of analyzing and establishing the limiting operational wave criterion for an operation. The OCM and vessel Master has the necessary experience to evaluate wave directionality and understand phenomena such as swell. For this reason, an operation may be called off based on the OCM and vessel Master's discretion.

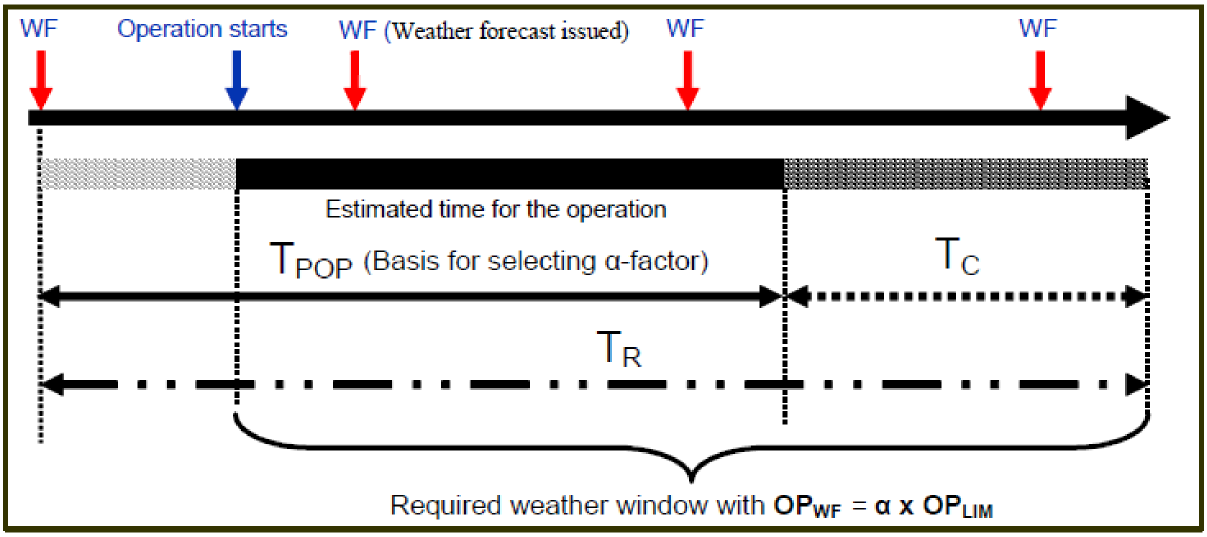


Figure 2-2 Operation periods (DNV, 2011 a, p. 29)

3 Industry Example Case Study

The case study designated this report is the deployment of spools for tie-in of a x-mas tree to a manifold at the East Kameleon reservoir at the Alvheim oil and gas field. The Alvheim area is located approximately 225 km west of Stavanger, in the North Sea in approximately 120-130 m water depth. The field location is indicated in figure 3-1. The Alvheim development comprises several reservoirs, which are all developed via subsea wells tied back to a FPSO unit. An Increased Oil Recovery (IOR) project intends to improve current production rates via development of new subsea well step-outs at several of these reservoirs. Technip Norge AS was awarded a work order which includes connecting the mentioned x-mas tree and manifold via a production spool and a gas lift spool, with diameters of 6''and 2'' respectively. Figure 3-2 indicates the route of the spools between the two facilities. The 2'' and 6'' spools are similar in configuration and each of them are fabricated in two sections with a bolted connection, located approximately where marked in red on the figure.

Figure 3-1 Alvheim field location (Statoil, 2015 a)

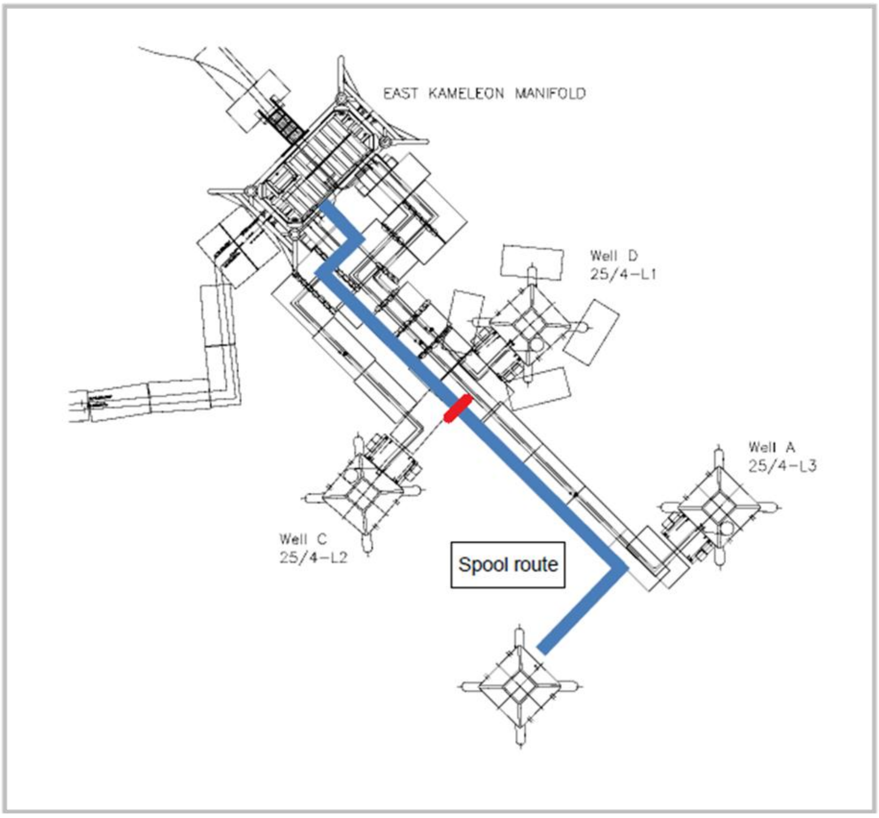


Figure 3-2 Spool route

The spools are designed to be connected by divers. This report will use the deployment of the L-shaped section of the 6’’ and 2’’ spool as case study. The actual installation was carried out during the time this report was written. For this reason it should make a good “up to date” example of an installation lift for spools, primarily with respect to the lifting arrangement and vessel used. Even though this particular case is a installation of spools at the Alvheim field in the North Sea, the installation lift should make a good example of a typicall installation lift for spools also in other regions of the Norwegian Continental Shelfe (NCS), such as the Norwegian Sea.

3.1 Spools and Lifting Arrangement

The deployment of the spools is performed by attaching them to a waterfilled strongback, as seen in figure 3-3. The strongback is a 20’’ L-shaped steel pipe with dimensions of 25x8.3 m, similar to the spools length dimensions. The strongback pipe provides the sufficient amount of stiffness in order to avoid overstressing the spools when lifted. The wall thickness of the strongback is 1’’. Waterfilling the strongback is a technique used to lower its buoyancy, and hence increase its weight in water, which is beneficieal when lifting through the wave zone. The spools are filled with Monoethylen Glycol (MEG), for the purpose of corrosin protection. The 6’’ spool is connected to the strongback using piggyback spacers and carbon steel band, as seen details of in figure 3-4. The 2’’ spool is attached to the 6’’ spool using piggyback blocks and carbon steel band, as seen details of in figure 3-5. This arrangement is mounted on 5 support frames, designed to support the assembly when landed in the target area on the seabed. This design enables divers to release the spools from the strongback before the strongback is recovered to deck. A drawing of the cross section of the arrangement at a support frame is presented in figure 3-6. The bundle of strongback and the two spools is deployed using a 3 leg bridle wire sling, as seen in figure 3-7. A single wire pennant connects the wire slings to the vessel’s crane block. The total weight in air of the lifting arrangement and spools is in the order of 20 Te.

Figure 3-3 Strongback and spools

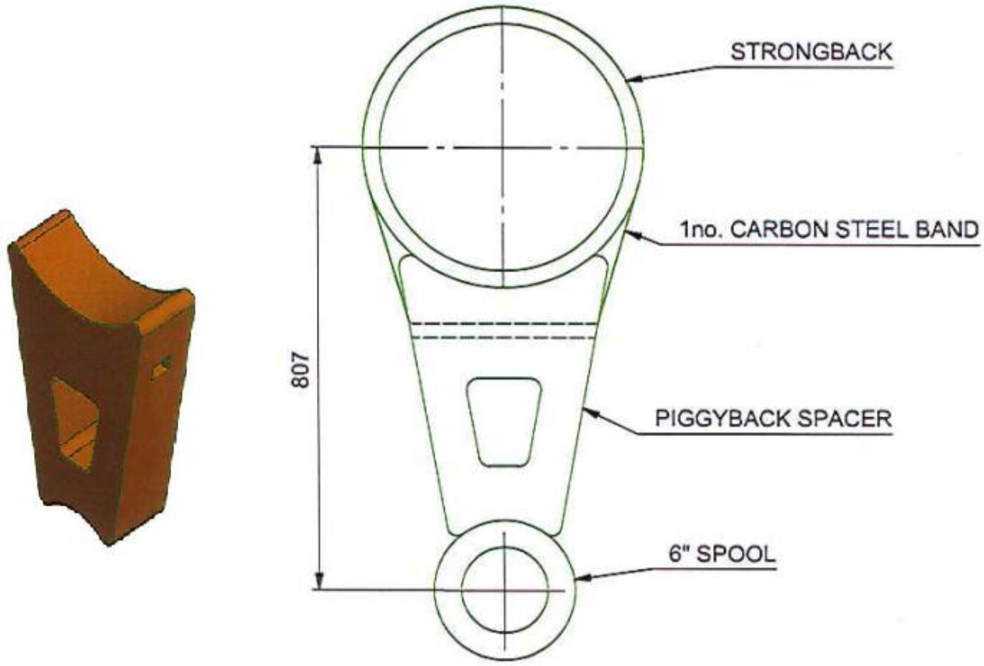


Figure 3-4 Strongback to 6'' spool connection

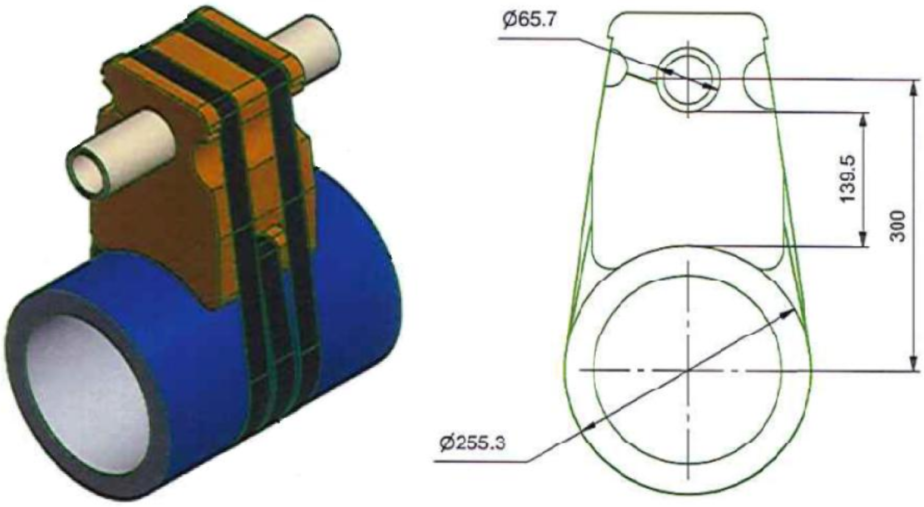


Figure 3-5 6'' spool to 2'' spool connection

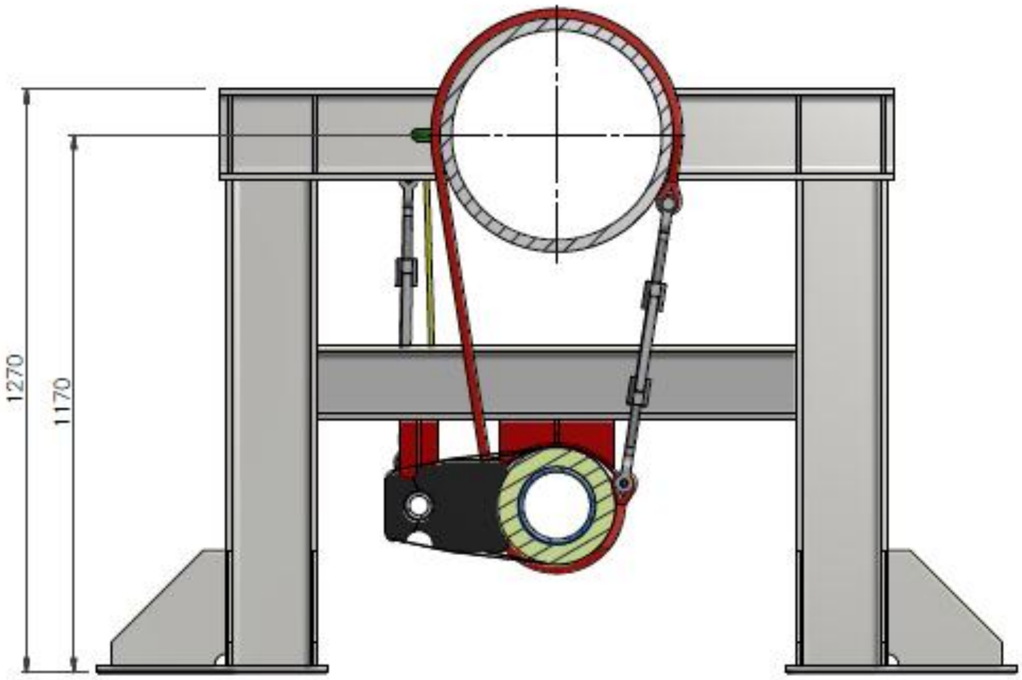


Figure 3-6 Cross section at support frame

Figure 3-7 Lifting arrangement

3.2 Vessel

The vessel nominated for the installation is the diving support and heavy construction vessel Skandi Arctic, as seen a picture of in figure 3-8. This vessel features a 24-man diving chamber complex and is highly used for installation of subsea facilities where the aid of divers is required. It is a state of the art vessel, designed with emphasis on good sea-keeping abilities and station-keeping performance. The vessel facilitates a large open deck of 1700 m^2 and a heavy construction crane. In other words, it customized for installation of subsea facilities. The principle dimensions of the vessel are listed in table 3-1. For more details around the vessel's specifications and capabilities the reader is referred to the vessel brochure in Appendix A.

The installation crane is a 400 Te box boom crane located on starboard side. 400 Te refers to the lifting capacity at a radius of 11m, (harbor lifts) in double fall. The weight in air of the lifting arrangement and spools can hence be regarded as low for such a crane. The design of the lift rigging does however require a crane with fairly large lifting height. The installation lift will be performed with a single fall crane wire and standard crane block which has a mass of 4.5 Te. The prepared OrcaFlex model of the system of vessel, lifting arrangement and spools is presented in figure 3-9. Much effort has been spent on obtaining a realistic model. At the same time, necessary simplifications has been made in order to make the model computationally efficient, to reduce simulation running time. One of these simplifications is the merging of strongback and the two spools into one equivalent spool. The process of modelling and important properties will be thoroughly described in chapter 5.

Figure 3-8 Skandi Arctic

Table 3-1 Skandi Arctic principle dimensions

Length overall	156,9 m
Breath	27 m
Draft (max.)	8,5 m
Deadweight	11.500 Te

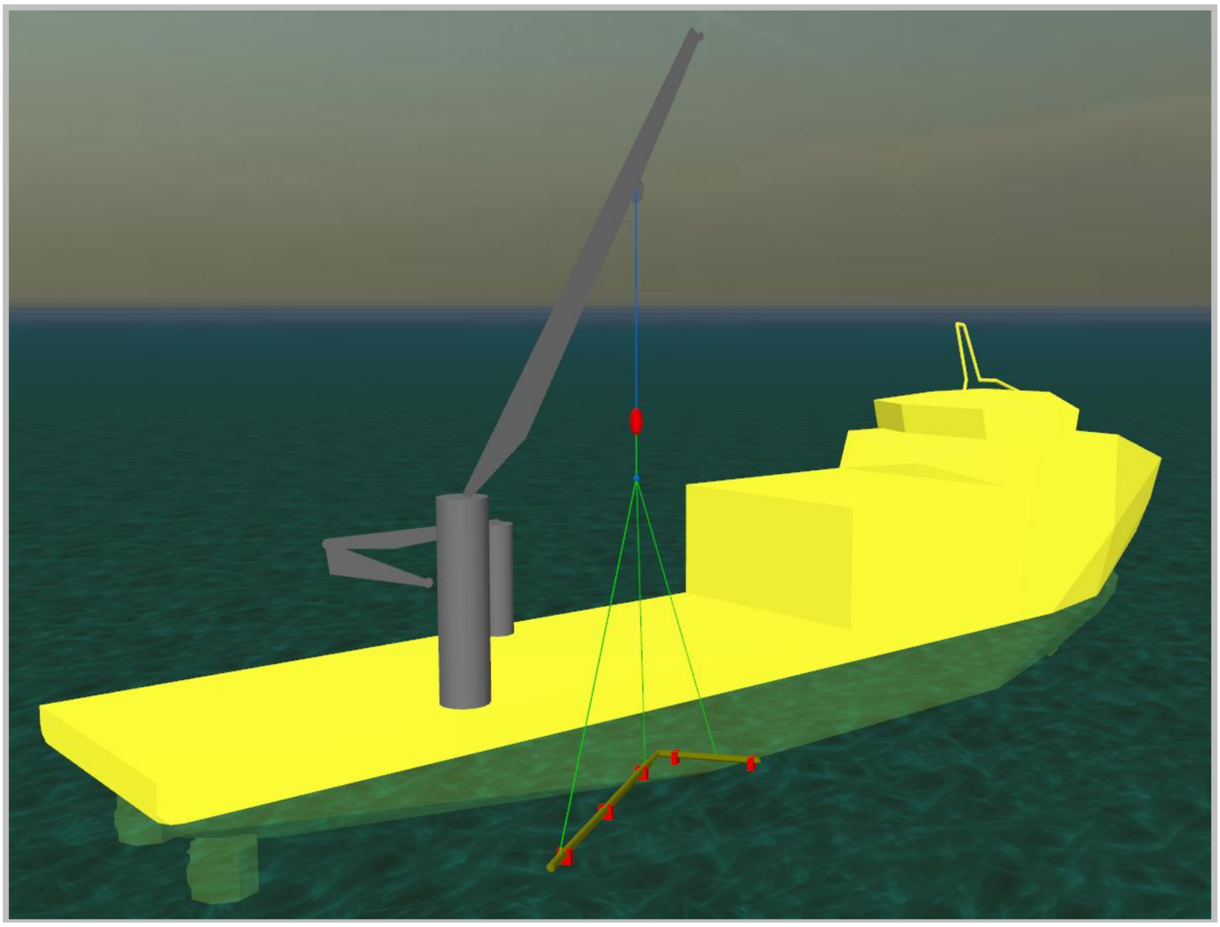


Figure 3-9 OrcaFlex model of complete system

4 Theoretical Subjects

This chapter intends to summarize the core of relevant theory investigated for the purpose of writing this report and present theory relevant for conducting calculations and analyses related to the case study.

A dynamic lift analysis includes describing the motion characteristics of the installation vessel and hydrodynamic loads acting on the lifted structure as a result of the installation sea state. These are topics addressed in this chapter. Furthermore, mechanics related to pipe sections and wires necessary for modeling are presented. For the sake of a clear presentation this chapter is divided into the following subchapters:

- Wind generated waves
- Vessel motions
- Loads and loads effect
- Horizontal pendulum motion
- Structural properties of pipes and wires

4.1 Wind-Generated Waves

When the wind starts to blow over smooth water there are small frictional effects. These create ripples on the water surface. As the wind increases, the ripples get larger until they soon become large enough to be pushed along by the wind as waves. The movement of these waves is slower than the wind and the pushing of the wind causes them to increase in size (Singleton, 2015). Waves are hence generated by winds blowing over a distance for a duration of time. This distance is referred to as fetch. Wind generated waves can be classified into two distinct categories (Journée & Massie, 2001, p. 5.2):

- **A wind sea** is a train of waves driven by the prevailing local wind field. These waves appear very irregular, as high waves are followed unpredictably by low waves and vice versa. Furthermore, individual wave crests propagate in various directions, deviating from the mean direction. The wave period and length is continuously varying and it is also common that smaller waves appear on top of larger crests.

- **Swell waves** are waves that have propagated out of the area where they were generated. As these waves move away from the source area, energy is transferred from short wavelength, high frequency waves to longer and longer, low frequency waves. Low frequency swell waves have the ability to propagate faster than the generating wind field and reach areas not yet influenced by this wind. Such waves can propagate for hundreds of kilometers in open sea through areas of calm winds. These waves are more regular and closer to sinusoidal in shape than those of a wind sea. They are longer and also their height is much more predictable.

The stronger the winds blow in an area, the larger will the swell be and the further will it travel. Storms in the North Atlantic Ocean create swell waves reaching the coast of Norway. Figure 4-1 presents an image of a dimensionless regional distribution of swell prevalence around Norway during winter. The figure is taken from the article “The wind sea and swell waves climate in the Nordic seas”, which presents a detailed study of wind sea and swell waves in the North Sea, Norwegian Sea and Barents Sea based on an analysis model developed by the

Norwegian Meteorological Institute (NMI) (Semedo, et al., 2014). Swell waves coming from west are known to be very dominating in the Norwegian Sea. The prevalence further south, in the North Sea is considerably lower due to the sheltering effect of Great Britain, which is clearly visualized in the figure. As a reference, an ocean map is presented in figure 4.2. Also swell waves coming from the North, generated in the Arctic Ocean reaches the coast of Norway. This is primarily observed in the summer, as the ice during winter significantly reduces the fetch in Arctic areas.

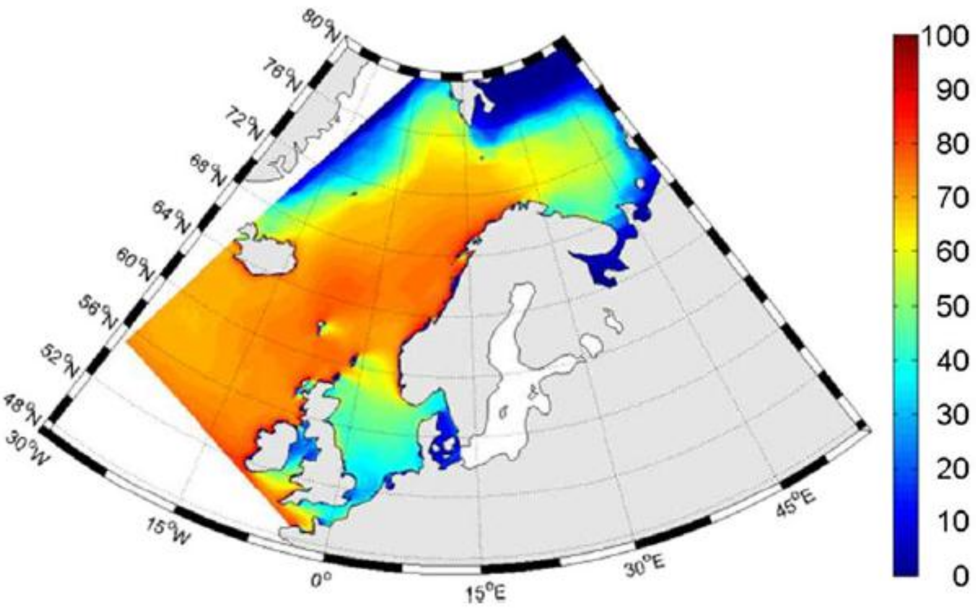


Figure 4-1 Regional distribution of swell prevalence (dimensionless) (Semedo, et al., 2014)

Figure 4-2 Ocean Map (Offshore Technology.com, 2015)

Wind seas are, generally, random in nature. In areas exposed to swell, these waves will add to the local wind sea and further complicate the irregularity. For planning and design purposes of marine operations, we must however rely on well proven theory for describing waves in order to analyze their effects on the considered system.

4.1.1 Regular Wave Theory

Regular waves have the characteristics of having a period such that each cycle has exactly the same form. The theory describes the properties of one cycle of the regular waves and these properties are invariant from cycle to cycle (Chakrabarti, 2005, p. 80). Even though there are no sea states that in reality appear this way, waves described by idealistic regular theory have proven very useful for many purposes. As mentioned, swell waves can appear with rather regular shape and for this reason in some situations be reasonably well described by regular wave theory. Regular waves are also the foundation for describing irregular sea states, which will be addressed in the next subchapter.

Linear wave theory is the simplest of the regular wave theories, also called small amplitude wave theory or Airy theory. The elevation of the free surface varies with space x and time t. The waves have the form of a sine curve and the free surface profile can be expressed in the simple form:

$$\zeta(x,t) = \mathrm{a}\sin(kx - \omega t) \tag{4.1-1}$$

In which the constants:

$a =$ wave amplitude
$\omega =$ frequency of oscillation of the wave
$k =$ The wave number

As illustrated in figure 4-3, the shape of the wave is the same for different times. Equation (4.1-1) can be rewritten as:

$$\zeta(x,t) = \mathrm{a}\sin \mathrm{k}(x - \frac{\omega}{k}t) \tag{4.1-2}$$

This form suggests that the wave profile moves in the horizontal direction with a speed of propagation:

$$c = \frac{\omega}{k} \tag{4.1-3}$$

The frequency of oscillation is the reciprocal of the wave period T and can be expressed as:

$$\omega = \frac{2\pi}{T} \tag{4.1-4}$$

The wave form repeats itself at each cycle and the wave number k can similarly be expressed in terms of the wave length L as:

$$k = \frac{2\pi}{L} \tag{4.1-5}$$

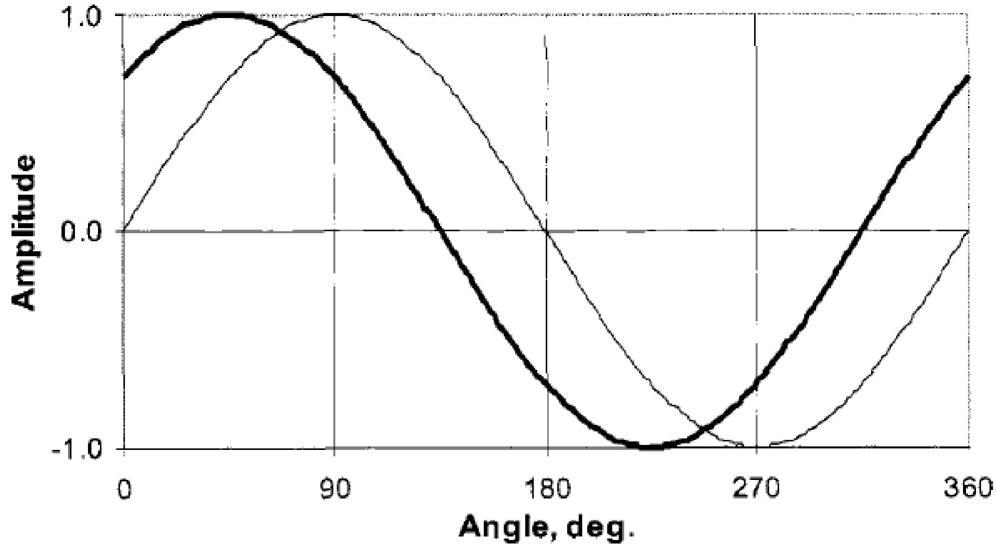


Figure 4-3 Free surface profile in linear wave (Chakrabarti, 2005, p. 84)

The kinematic properties of a wave are the water particle velocities and accelerations. The expressions for these properties based on linear wave theory are given in table 4-1. The equations expresses kinematic properties in two dimensions, horizontal (x) and vertical (z), where z has its origin at the Mean Water Level (MWL). The property g is the gravitational acceleration. These are relations derived from potential theory, and are based on a number of simplifying assumptions. The relations in the table are furthermore the version valid in deep water, defined by a depth to wave length ratio $\geq 1/2$. Water particles in a wave moves in an ellipsoid shape, which is described by the formulas given in the table. What should be noticed from the relations is that the kinematic properties in a linear wave decays exponentially and have their maximum when $e^{kz} = 1$. This is the case for $z = 0$, hence at the surface.

Table 4-1 Formulas for kinetic properties in linear wave theory (Gudmestad, 2014, p. 76)

Quantity	Deep water $d/L \geq 1/2$
Horizontal water particle velocity	$u_h = \frac{agk}{\omega} e^{kz} \cdot \sin[\omega t - kx]$
Vertical water particle velocity	$u_v = \frac{agk}{\omega} e^{kz} \cdot \cos[\omega t - kx]$
Horizontal water particle acceleration	$\dot{u}_h = agk \cdot e^{kz} \cdot \cos[\omega t - kx]$
Vertical water particle acceleration	$\dot{u}_v = -agk \cdot e^{kz} \cdot \sin[\omega t - kx]$

It is important to clarify the applicability of wave theories and their area of use. As mentioned, regular wave theories have proven very useful for many purposes and also higher order theories for describing wave forms that are closer to realistic waves have evolved. They are highly applicable for design of permanent offshore structures. A design wave of appropriate height and period, corresponding to desired return period is then selected. On the other hand, when designing for weather restricted marine operations, such as a spool installation lift, the approach is different. As we then are dealing with wave conditions selected independent of statistical data, the randomness of ocean waves becomes highly important. This requires a stochastic modeling of the sea surface.

4.1.2 Irregular Waves

Despite their complexity, wind waves can be seen as a superposition of many regular harmonic wave components. This theory was first introduced in hydrodynamics by (St. Denis & Pierson, 1953), and allows one to predict very complex irregular behavior in terms of much simpler theory of regular waves. In figure 4-4 one can see the result of adding together several sinusoidal waves, each with its own wave length, amplitude and frequency. The result is a more realistic image of what the cross section of waves at the sea surface could look like. It should be noted that in practice we are talking about a superposition of a large number of components in order to make a detailed and realistic description of irregular ocean waves. It is common to assume that the sea surface is stationary for durations of 20 minutes to 3-6 hours. In order to study the characteristics of an irregular sea state, one can make use of instruments to make a record of the water surface elevation as a function of time at a fixed location. The record will be sampled at a large number, N, equal intervals, Δt, as illustrated in figure 4-5. In practice one might make a record of about 15 to 20 min, spaced every half second. Unless there is a very long swell in the record, this is according to (Journée & Massie, 2001, p. 5;34) just long enough to capture enough waves, but still short enough to avoid influences such as results from tidal level change. The duration of the wave record divided by the number of times the record trace crosses the MWL in an upward direction is the mentioned mean zero up-crossing period, T_z.

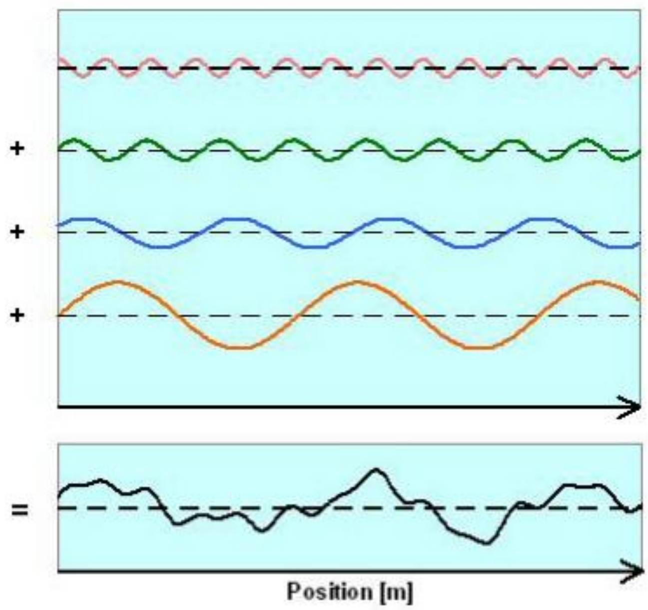


Figure 4-4 Irregular wave as a superposition of several regular waves

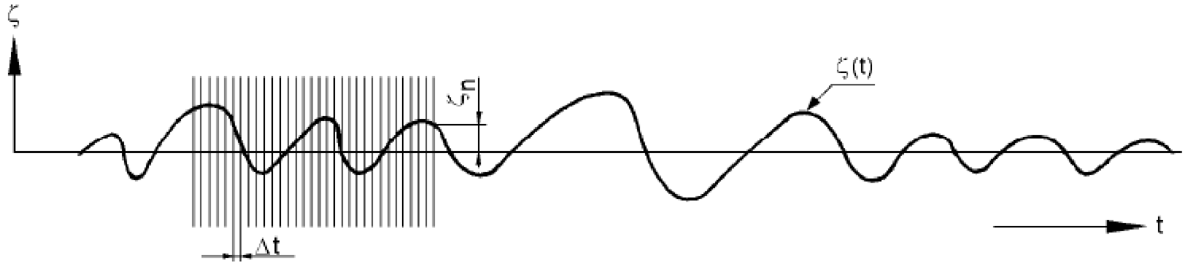


Figure 4-5 Water surface elevation time record (Journée & Massie, 2001, p. 5;34)

With N vertical displacements, ζ_n, relative to a defined MWL, the standard deviation σ_ζ of the water level $\zeta(t)$ can be defined as:

$$\sigma_\zeta = \sqrt{\frac{1}{N-1}\sum_{n=1}^{N} \zeta_n^2} \tag{4.1-6}$$

This standard deviation is related to the significant wave height by the relation:

$$H_s = 4 \cdot \sigma_\zeta \tag{4.1-7}$$

Since an irregular wave can be seen as the superposition of a series of sinusoidal waves, we can study the frequency characteristics of such an irregular signal using Fourier series analysis. To do this one selects a time record segment containing many waves, as the one in figure 4-5. One assumption in this analysis is that the wave record studied repeats itself. This is not exactly the case in reality, but regarded as negligible. Furthermore one assumes that the record of surface elevation is a result of waves traveling in the same direction, where the wave crests are parallel. These are referred to as **long crested** waves. In other words we discard energy transfer from one wave component to another. The wave elevation (in the time domain) of a long-crested irregular sea can be written as the sum of a large number of regular wave components (in the frequency domain):

$$\zeta(t) = \sum_{n=1}^{N} \zeta_{a_n} \cos(k_n x - \omega_n t + \varepsilon_n) \tag{4.1-8}$$

In which, for each component n:

ζ_{a_n}	= wave amplitude component	[m]
ω_n	= circular frequency component	[rad/s]
k_n	= wave number component	[rad/m]
ε_n	= random phase angle component	[rad]

A Fourier series analysis carried out for a time record at one location would not indicate anything about k, as this is location dependent. The Fourier series will hence yield a set of values for ζ_{a_n} and ε_n, each associated with its own ω_n. If enough Fourier series terms are included, the entire time record at that point can be reproduced using this set of values.

4.1.3 Energy Density Spectrum

If we again suppose a time history, as the one illustrated in figure 4-5, of the wave elevation during a sufficient long but arbitrary period:

$$\tau = N \cdot \Delta t \tag{4.1-9}$$

Further assuming that the instantaneous wave elevation has a Gaussian distribution (normally distributed) with a mean value of zero, which according to (Journée & Massie, 2001, p. 5;36) is a reasonable statistical distribution for waves if the range of frequencies in a wave field is not too large. As explained, the amplitudes ζ_{a_n} can be obtained by a Fourier analysis of the signal. However, for each little time shift of the history one will find a new series of amplitudes ζ_{a_n}. Therefore a mean square value of ζ_{a_n} is found: $\overline{\zeta_{a_n}{}^2}$. When $\zeta(t)$ is an irregular signal without prevailing frequencies, the average values $\overline{\zeta_{a_n}{}^2}$ close to ω_n will not change much as a function of the frequency, hence: $\overline{\zeta_a{}^2}$ is a continuous function (Journée & Massie, 2001, p. 5;38). The variance σ_ζ^2 of this signal equals:

$$\begin{aligned}
\sigma_\zeta^2 &= \overline{\zeta^2} \\
&= \frac{1}{N}\sum_{n=1}^{N} \zeta_n^2 = \frac{1}{N \cdot \Delta t}\sum_{n=1}^{N} \zeta_n^2 \cdot \Delta t \\
&= \frac{1}{\tau}\int_0^\tau \zeta^2(t) \cdot dt \\
&= \frac{1}{\tau}\int_0^\tau \left\{\sum_{n=1}^{N} \zeta_{a_n} \cos(\omega_n t - k_n x + \varepsilon_n)\right\}^2 \cdot dt \\
&= \sum_{n=1}^{N} \frac{1}{2}\zeta_{a_n}{}^2
\end{aligned} \tag{4.1-10}$$

In order to investigate how the energy in the sea is distributed on the different frequencies we express the wave amplitude ζ_{a_n} in a wave spectrum, $S_\zeta(\omega_n)$, which expression is defined by:

$$S_\zeta(\omega_n) \cdot \Delta\omega = \sum_{\omega_n}^{\omega_n+\Delta\omega} \frac{1}{2}\zeta_{a_n}{}^2(\omega) \tag{4.1-11}$$

Here, $\Delta\omega$ is a constant difference between two successive frequencies, as illustrated in figure 4-6. Multiplied with ρg, in which ρ is the mass density of water, this expression equals the energy per unit area of the waves in the frequency interval $\Delta\omega$. This is because the total energy in a wave per unit area is given by:

$$E_w = \frac{1}{2}\rho g \zeta_a{}^2 \tag{4.1-12}$$

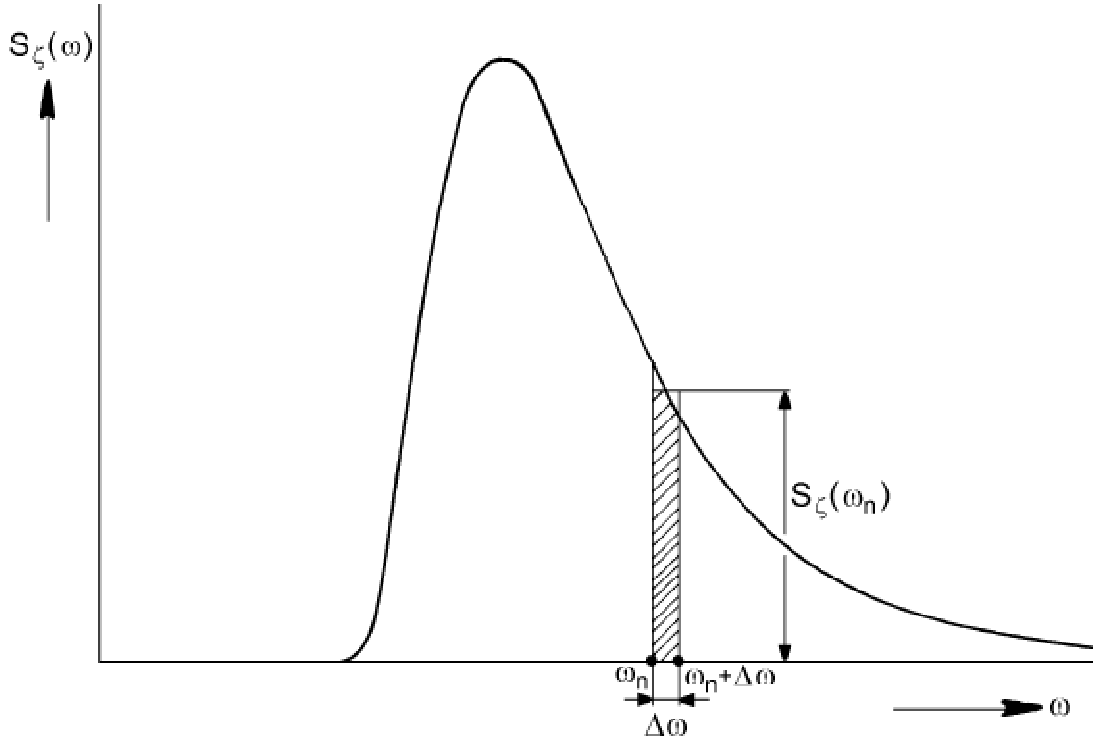


Figure 4-6 Definition of Spectral Density (Journée & Massie, 2001, p. 5;39)

The relation for the total wave energy is derived from potential theory. The reader is referred to (Journée & Massie, 2001, p. 5;17) for the details around this derivation. What should be noticed is that the energy in a harmonic wave is proportional to the wave amplitude squared which also means that spectral values are proportional to the wave amplitude squared.

By letting $\Delta\omega \rightarrow 0$, the definition of the wave energy spectrum $S_\zeta(\omega)$ becomes:

$$S_\zeta(\omega_n) \cdot d\omega = \frac{1}{2}{\zeta_{a_n}}^2 \quad (4.1\text{-}13)$$

Figure 4-7 gives a graphical interpretation of the wave spectrum and how it relates to the waves. To summarize what has been reviewed, the irregular wave history, $\zeta(t)$ in the time domain at the lower left hand part of the figure can be expressed via Fourier series analysis as the sum of a number of regular wave components, each with its own frequency, amplitude and phase in the frequency domain. The value $\frac{1}{2}{\zeta_{a_n}}^2(\omega)/\Delta\omega$ – associated with each wave component on the ω-axis is plotted vertically, which gives the wave energy spectrum, $S_\zeta(\omega)$. This spectrum can be described nicely in a formula. The phases cannot and are therefore usually discarded. What we are left with is the power spectral density function of the vertical sea surface displacement for a short term stationary irregular sea state. The frequency of the wave component associated with the peak of this density function is known as the angular spectral peak frequency. The corresponding period is the spectral peak period, T_p.

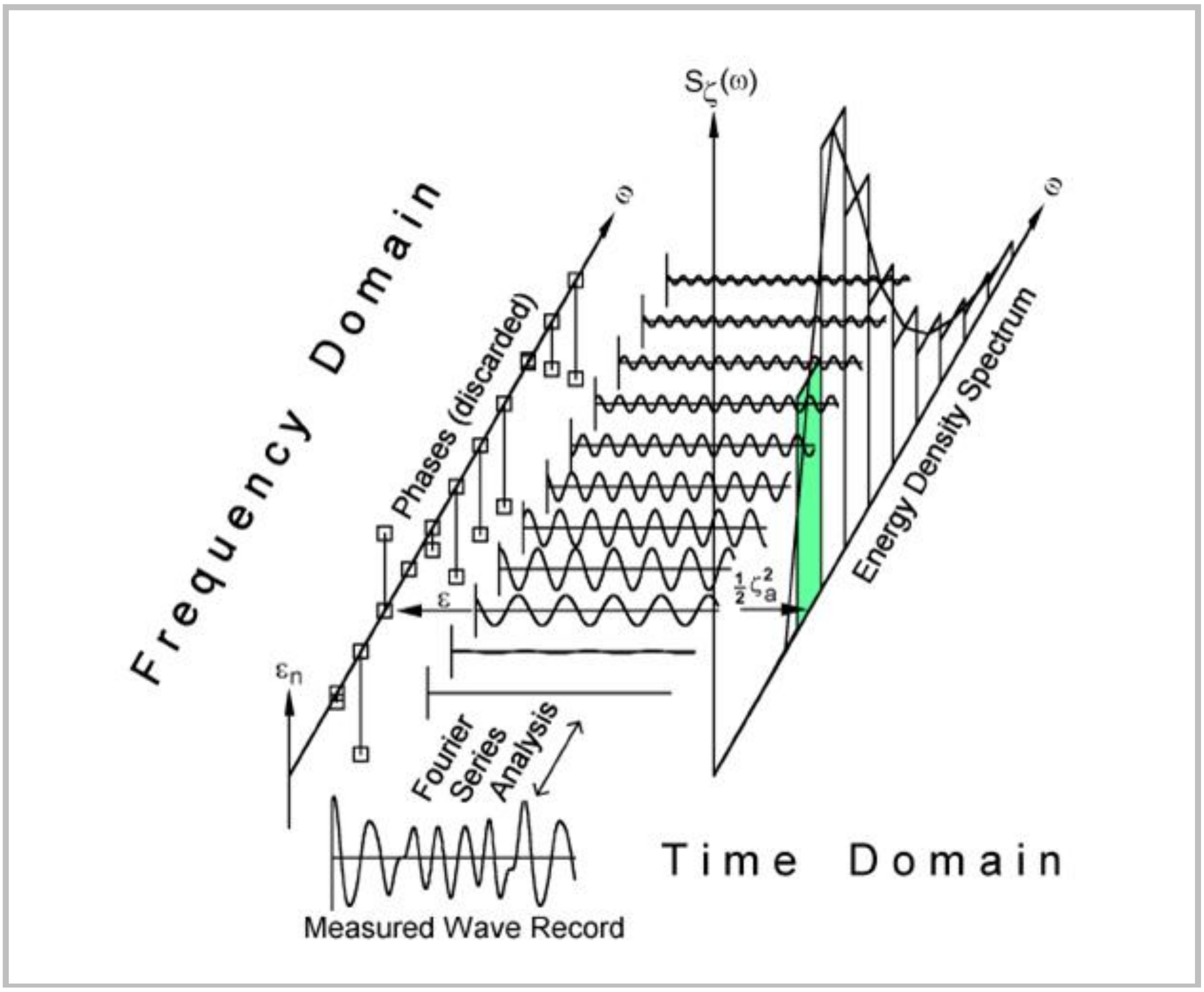


Figure 4-7 Energy Density Spectrum (Journée & Massie, 2001, p. 5;40)

4.1.4 Wave Spectrum Models

Over the years, several spectra have been developed in order to describe characteristics of irregular sea states in various areas. One of the basic elements in derivation of spectral models is describing the high frequency tail. The behavior of the high frequency part of the spectrum is given by the energy balance for waves generated by the local wind fields. The so called equilibrium range is an important concept in describing wind wave generation. It is based on assuming that if the wind blows steadily for a long time over a long fetch the waves will eventually come into equilibrium with the wind. The wave energy for a given frequency reaches an upper limit, where energy input from the wind is balanced by energy loss to other frequencies or by waves breaking. This concept was first introduced by (Phillips, 1958). The first and simplest attempts of establishing wave spectra were based on this concept of fully developed sea. The spectrum developed by (Pierson & Moskowitz, 1964) is an example of this. They used measurements of waves made by accelerometers on British weather ships in the North Atlantic to develop their spectra (Stewart, 2008, p. 285). An extensive wave spectra measurement project in the North Sea, known as the Joint North Sea Wave Project (JONSWAP) was carried out during a period of ten weeks in 1968 and 1969 (Hasselmann, et al., 1973, p. 7). From analyzing the data collected it was found that the wave spectrum is never fully developed, as assumed by Pierson and Moskowitz, but will continue to develop through non-linear interactions between waves for very long distances and time. The Pierson-Moskowitz spectrum is based on theoretical infinite fetch. As an extension to the Pierson-Moskowitz model, the

JONSWAP spectrum introduced a peak enhancement factor γ to represent a fetch limited condition. The JONSWAP spectrum is similar to the Pierson-Moskowitz spectrum, but has a more pronounced peak representing the fact that waves continue to grow with distance/time (Stewart, 2008, p. 288). The JONSWAP spectrum has become one of the most used wave spectrum for describing wave conditions in the North Sea. Even though the derivation of the energy density spectrum has been given in terms of angular frequencies, the spectrum function for the JONSWAP spectrum will here be presented in in terms of frequencies in hertz, as this is the formulation OrcaFlex uses:

$$S_J(f) = \beta(2\pi)^{-4} g^2 f^{-5} \cdot e^{\left(-1.25\left(\frac{f}{f_p}\right)^{-4}\right)} \cdot \gamma^{exp\left(-0,5\left(\frac{f-f_p}{\sigma \cdot f_p}\right)^2\right)} \tag{4.1-14}$$

In which:

β = constant related to the equilibrium range
f = wave component frequency
f_p = spectral peak frequency
γ = peak enhancement factor

σ is the so-called spectral width parameter, and is taken as:

$\sigma = \sigma_a \, for \, f \leq f_p$
$\sigma = \sigma_b \, for \, f > f_p$

Where the average values for the JONSWAP experiment data are as follows:

$\sigma_a = 0,07$
$\sigma_b = 0,09$

The first term in the function describes the high frequency tail, whereas the exponential term describes the peakedness of the spectrum. This JONSWAP spectrum formulation was derived by (Hasselmann, et al., 1973), whereas the governing parameters were subsequently defined by (Houmb & Overvik, 1976). They were presented in tabular form in terms of significant wave height and average period. As described in the previous section, spectral values are proportional to the wave amplitude squared, which in other words means that $S_\zeta(\omega)/{H_s}^2$ is a function of frequency and an average period only. A stationary sea state can hence be characterized by the significant wave height H_s and an average wave period such as spectral peak period or mean zero up-crossing period. A revised parameterization of the JONSWAP spectrum was presented by (Isherwood, 1987), based on the work of Houmb and Overvik. The parameters were described in the form of algebraic expressions, eliminating the need for interpolation between tabulated values, which has great practical convenience. This is also the parameter formulation obtained by OrcaFlex and will hence therefore be addressed here.

Of the total five parameters in the spectral function, the spectral width parameters are usually taken as constants, leaving α, f_p and γ to be determined in such a way as to give a spectrum with the required significant wave height, H_s and average period. Isherwood showed that α and f_p, non-dimensionalised with respect to H_s and T_z, can be expressed as a function of γ only, and that γ is a unique function of a single dimensionless parameter combining H_s and T_z, known as equivalent wave steepness. For the detailed derivation, the reader is referred to the technical note presented by (Isherwood, 1987). The results are presented in the following.

Equivalent wave steepness:

$$s = \frac{2\pi H_s}{g T_z^2} \tag{4.1-15}$$

Non-dimensionalised f_p and β:

$$f_p \cdot T_z = 0.6063 + 0.1164\gamma^{1/2} - 0.01224\gamma \tag{4.1-16}$$

$$\frac{\beta}{s^2} = 2.964 + 0.4788\gamma^{1/2} - 0.3430\gamma + 0.04225\gamma^{3/2} \tag{4.1-17}$$

It should be emphasized that these relations are valid for $\sigma_a = 0{,}07$, $\sigma_b = 0{,}09$ only.

Relationship between γ and s:

$$\gamma = 10.54 - 1.34 s^{-\frac{1}{2}} - \exp\left(-19 + 3.775 s^{-\frac{1}{2}}\right) \qquad for\ s \geq 0.037 \tag{4.1-18}$$

$$\gamma = 0.9 + \exp\left(18.86 - 3.67 s^{-\frac{1}{2}}\right) \qquad for\ s < 0.037 \tag{4.1-19}$$

The design spectra method is based on analyzing motion and load responses in a sea state characterized by a wave spectrum. To cover potential sea states one can face during the offshore execution, this requires investigating a range of significant wave heights and mean wave periods. For spool installation lifts we are in general considering fairly low significant wave heights, and (DNV, 2011 a, p. 24) states that the following period range should be considered:

$$8.9\sqrt{\frac{H_s}{g}} \leq T_z \leq 13 \qquad H_s \leq 5.7\ m \tag{4.1-20}$$

Calculation of this period range and conversion into peak period T_p for selected values of H_s, for the JONSWAP spectrum as defined by Isherwood is presented in table 4-2. Only significant wave height ≤ 3 m has here been considered. The lowest value for the period range increases as the significant wave height increases. This is based on the combinations of wave heights and periods that are likely to occur. For example a combination of H_s= 2 m and T_p=3 s is out of the picture, as waves break long before reaching such a steepness. Corresponding values for γ-factor are presented in table 4-3. The γ-factors take values from 0.9 increasing with wave steepness to values around 5.

Table 4-2 Frequency range for JONSWAP spectrum according to eq. 4.1-20

H_s [m]	T_z range [s]	T_p range [s]
0,5	2,0 – 13	2,8 – 18,4
1	2,8 – 13	4,0 - 18,4
1,5	3,5 - 13	4,9 - 18,4
2	4,0 - 13	5,7 - 18,4
2,5	4,5 - 13	6,4 -18,4
3	4,9 - 13	7,0 - 18,4

Table 4-3 JONSWAP γ-factor according to Isherwood

T_p [s]	H_s = 0.5 m	H_s = 1.0 m	H_s = 1.5 m	H_s = 2.0 m	H_s = 2.5 m	H_s = 3.0 m
3	4,79	-	-	-	-	-
4	1,67	5,11	-	-	-	-
5	0,92	3,46	5	-	-	-
6	0,9	1,27	3,69	4,79	5,38	-
7	0,9	0,92	1,59	3,57	4,52	5,06
8	0,9	0,9	0,99	1,67	3,31	4,22
9	0,9	0,9	0,91	1,05	1,63	2,96
10	0,9	0,9	0,9	0,92	1,06	1,51
11	0,9	0,9	0,9	0,9	0,93	1,05
12	0,9	0,9	0,9	0,9	0,9	0,93
13	0,9	0,9	0,9	0,9	0,9	0,9
14	0,9	0,9	0,9	0,9	0,9	0,9
15	0,9	0,9	0,9	0,9	0,9	0,9
16	0,9	0,9	0,9	0,9	0,9	0,9
17	0,9	0,9	0,9	0,9	0,9	0,9
18	0,9	0,9	0,9	0,9	0,9	0,9

The JONSWAP spectrum is plotted for a range of peak periods and significant wave height of 1.0 m and 2.0 m in figure 4-8 and 4-9. One should notice how the shortest peak periods with high γ-factors have more pronounced peaks. For the higher peak periods with γ-factors of 0.9 the spectrum is similar to the mentioned Pierson-Moskowitz spectrum. One can take notice how the spectral values increases 4 times from significant wave height of 1.0 m to 2.0 m, for these plots with γ-factors of 0.9. This because the spectral values are equal to the significant wave height squared.

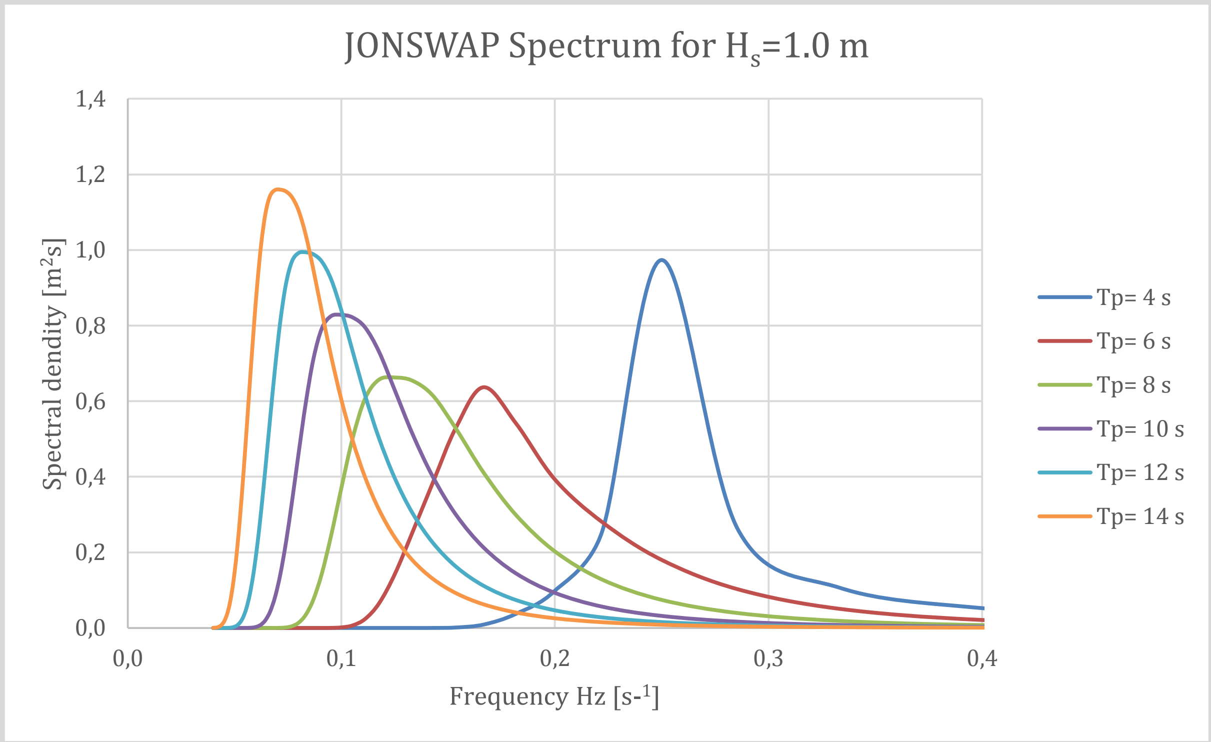


Figure 4-8 JONSWAP Spectrum for H_s= 1.0 m

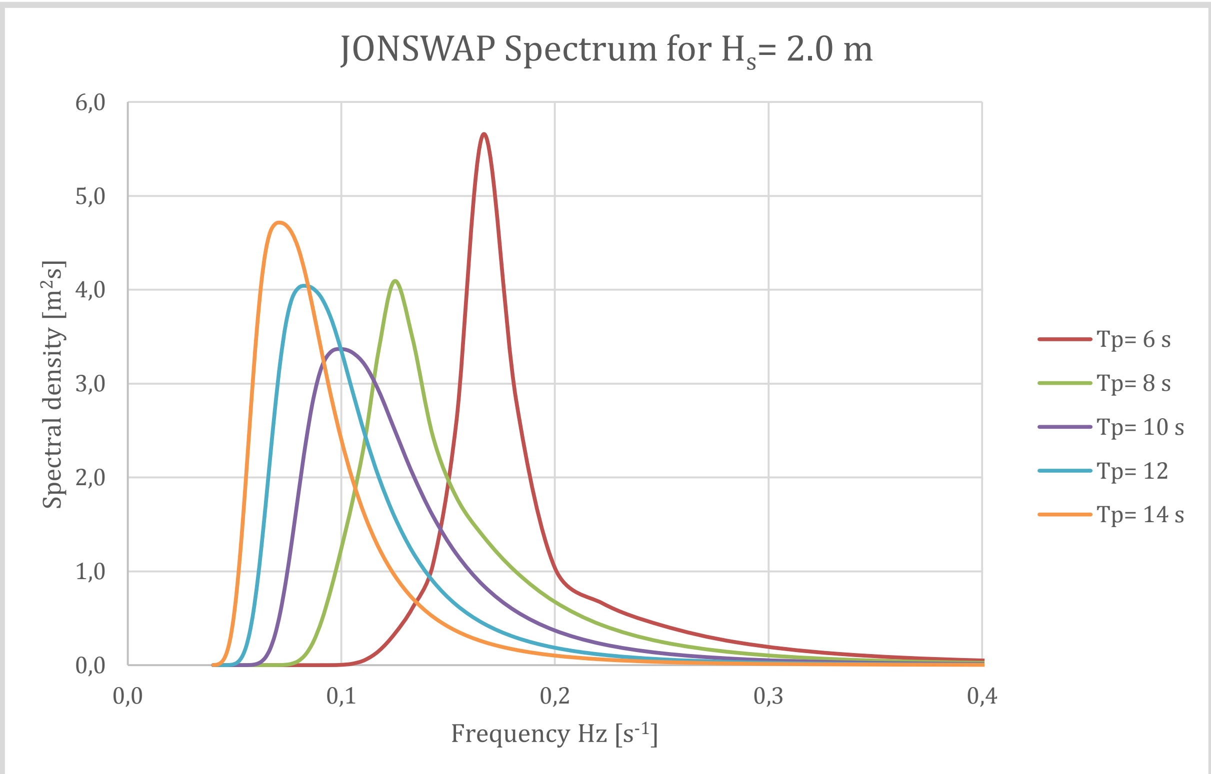


Figure 4-9 JONSWAP Spectrum for H_s= 2.0 m

4.1.5 Directional Spreading

So far, uni-directional wave energy spectra have been considered. These spectra describe an ideal condition where one assumes waves to travel in the same direction, where the wave crests are parallel. As previously mentioned, these are referred to as **long crested** waves. In reality, the wave energy spectrum derived from a record of surface elevations obtained at a particular point will invariably consist of contributions from several different wave directions. Phenomena as change in wind direction, influence of coastlines and bottom topography are some of the main contributors. This is illustrated in Figure 4-10, where summation of wave components coming from different directions results in an image that looks quite similar to the real sea surface.

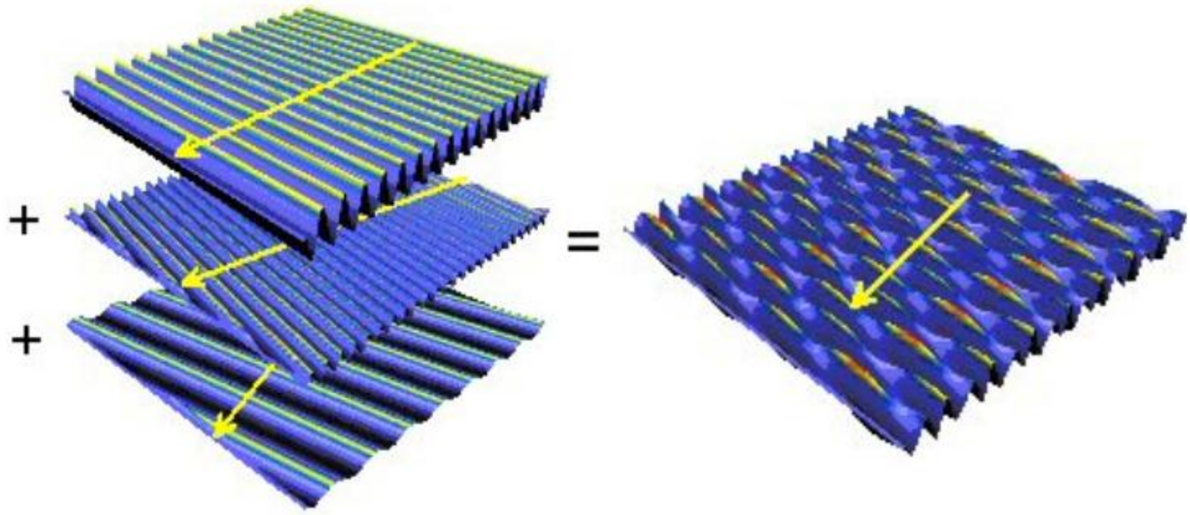


Figure 4-10 Superposition of regular waves from several directions

The presence of more than one long crested wave system results in alternate enhancement and cancellation of wave crests and troughs, and this phenomenon gives rise to the term **short crested** to describe the appearance of a wave system with a spread of wave directions (Lloyd, 1998, p. 55). The expression for a long-crested wave spectrum was in chapter 4.1.3 showed to be governed by the relation:

$$S_\zeta(\omega) = \frac{1}{2}{\zeta_a}^2(\omega)/d\omega \tag{4.1-21}$$

In the case of describing directional distribution of waves, there is a need for obtaining two dimensional directional short-crested wave spectra. According to (DNV, 2007, p. 35), directional short-crested wave spectra $S_\zeta(\omega,\theta)$ may be expressed in terms of the uni-directional wave spectra:

$$S_\zeta(\omega,\theta) = S_\zeta(\omega) \cdot D(\theta) \tag{4.1-22}$$

In which $D(\theta)$ is a directional spreading function, with θ as the angle between the direction of elementary wave trains and the main wave direction of the short crested wave system. The main direction of a sea state is often easily recognized and typically more or less aligned with the local wind (Lloyd, 1998, p. 56). The total energy in the spectrum will however remain unchanged, and the directional spreading function must fulfill the requirement:

$$\int_{0}^{2\pi} D(\theta)d\theta = 1 \tag{4.1-23}$$

Various directional spreading functions exist. A common directional function often used for wind sea, which also is the function referred to in the introduction chapter is:

$$D(\theta) = \frac{\Gamma\left(1+\frac{n}{2}\right)}{\sqrt{\pi}\,\Gamma\left(\frac{1}{2}+\frac{n}{2}\right)} cos^n(\theta - \theta_p) \tag{4.1-24}$$

In which:

Γ is the Gamma function and $|\theta - \theta_p| \leq \pi/2$
θ_p is the main wave direction

The spreading function distributes the wave energy in the range $\pi/2$ to each side of the main wave direction. This is illustrated in figure 4-11, where the wave energy is split into several elementary wave trains. The constant n, affects the degree of energy concentration. In general, the lower the value of n, the higher degree of short crested-ness it describes. A comparison of the spreading function for n=2 and n =4 is shown in figure 4-12. For n = 2, a higher degree of energy is distributed to the elementary wave trains with large angle to the main wave direction. As also stated in the introduction, DNV requires that a value of n= 2 is used when analyzing characteristic vessel motions generated by wind sea for operations that are independent of vessel heading.

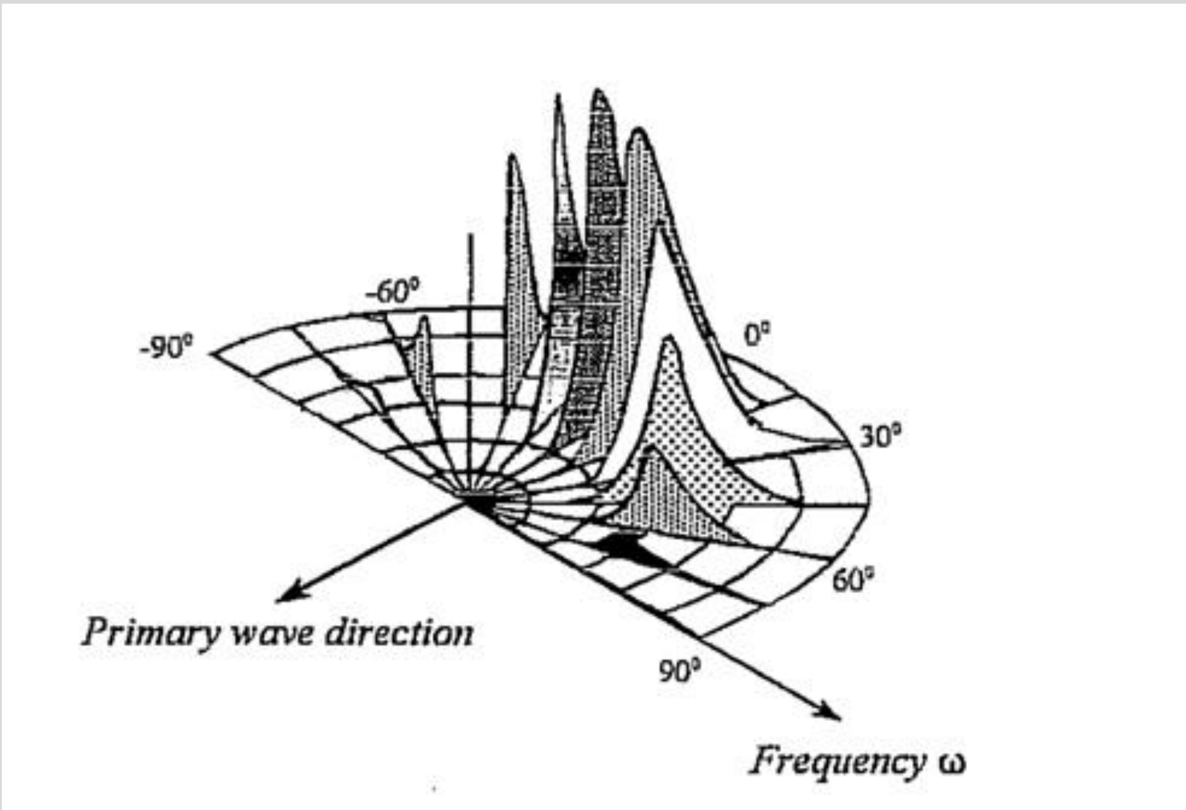


Figure 4-11 Directional wave spectrum (Lloyd, 1998, p. 56)

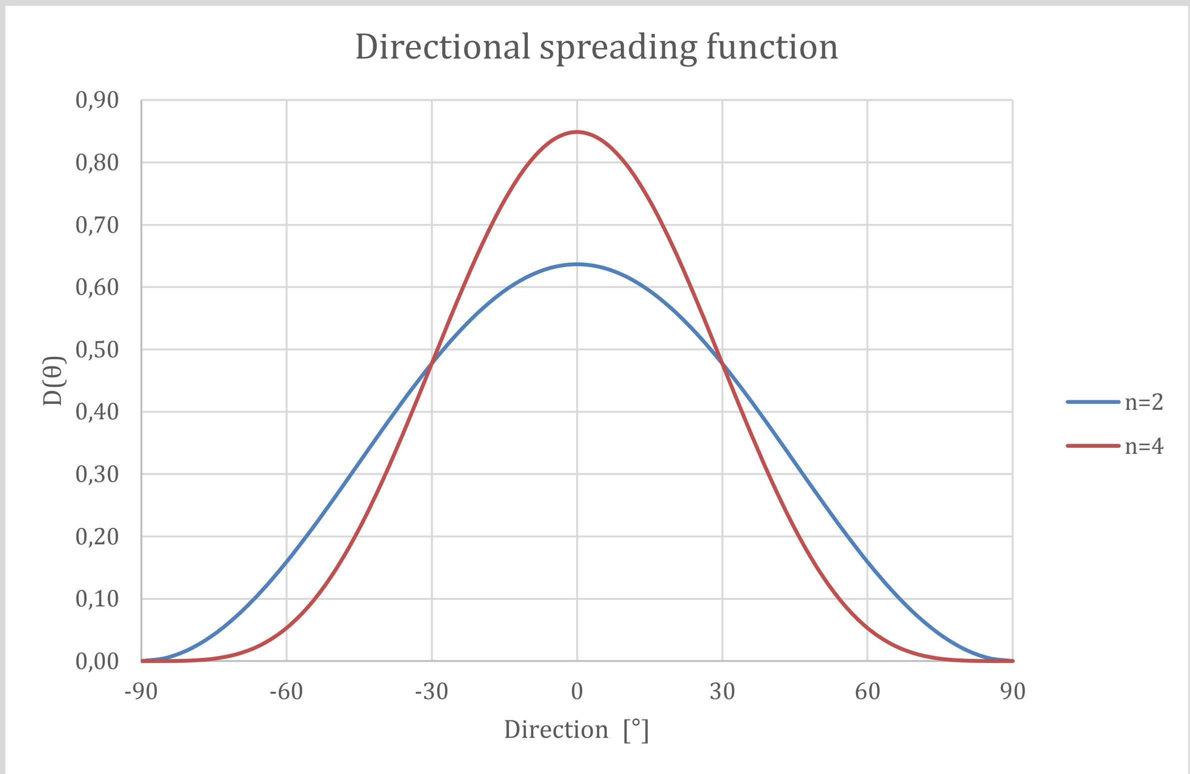


Figure 4-12 Directional spreading function

4.1.6 Combined Wind Sea and Swell

In situations of combined wind sea and swell, the swell waves will add to the locally generated wind sea and create a more complex sea state than what can be described by single peaked wave spectra such as JONSWAP. This is because the various sea systems (wind sea and swell) will usually have different peak frequencies. Double peaked spectra models have therefore been developed in order to give a more realistic description of such conditions. The Torsethaugen spectrum is an example of a double peaked spectrum. A plot of the spectral function for the Torsethaugen spectrum, retrieved from OrcaFlex is presented in figure 4-13. The spectrum has one peak corresponding to the local wind sea and one is governed by the swell component and is based on a simplified version presented by (Torsethuaugen & Haver, 2004). The original Torsethaugen model was established by fitting two JONSWAP shaped models to average measured spectra from the Norwegian Continental Shelf. These were data registered in the Northern North Sea and at the Haltenbanken area in the Norwegian Sea. As we can recall from the start of this chapter, swell is known to be more prevalent in the Norwegian Sea. As an example to illustrate the location, the Åsgard field as seen in figure 4-14 is located at the Haltenbanken area approximately 200 km of the coast of Trøndelag.

The total significant wave height for a sea state of combined wind sea and swell can be described by the relation (DNV, 2007, p. 34):

$$H_{s,total} = \sqrt{H_{s,wind\ sea}^2 + H_{s,swell}^2} \tag{4.1-25}$$

Obtaining a spectrum such as Torsethaugen when describing combined wind sea and swell does however include a clear limitation. The spectrum makes no allowance for directionality of the wind sea and swell component. In other words the spectrum describes a situation where wind sea and swell is assumed to travel in the same direction. As part of this report has the intention of investigating effects from considering directionality between wind sea and swell, this must be taken further. According to (DNV, 2011 a, p. 25), swell waves may be assumed regular in period and height, and may normally also be assumed independent of wind sea. The approach obtained for modeling combined wind sea and swell is described in chapter 5.1.4.

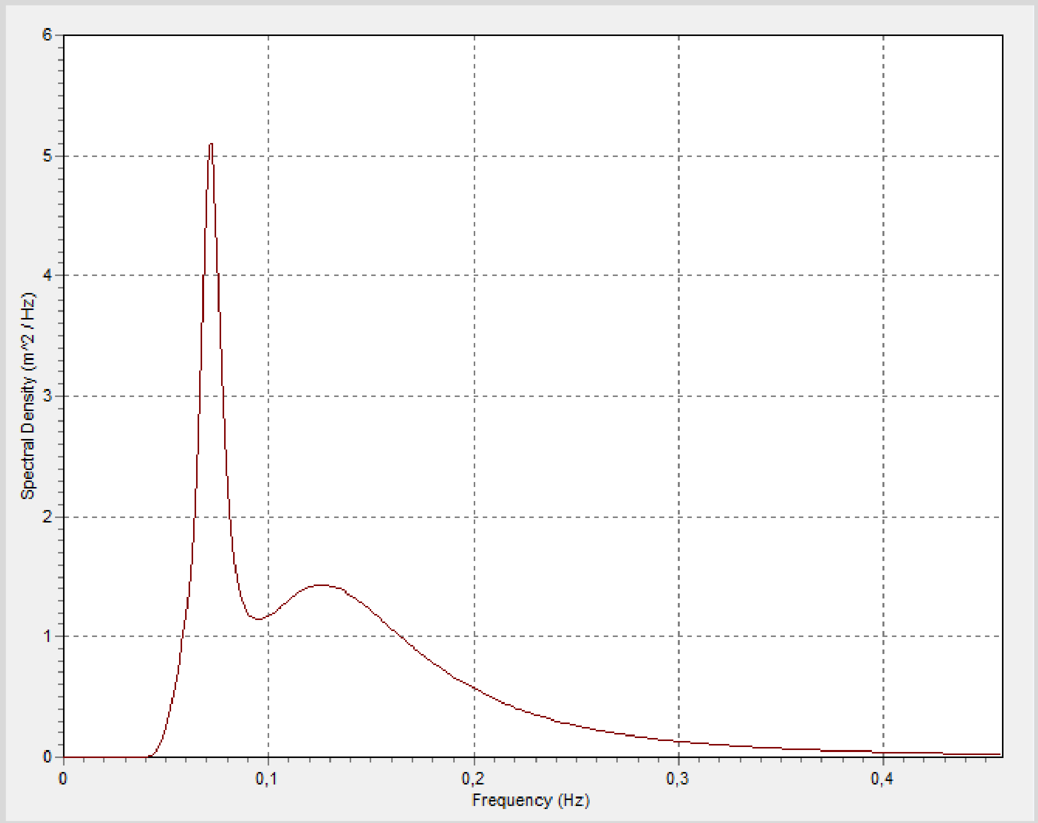


Figure 4-13 Torsethaugen spectrum for Hs = 2.0 m and Tp = 14 s

Figure 4-14 Åsgard Field location (Statoil, 2015 b)

4.2 Vessel Motions

A floating vessel without constraints is free to move in all six degrees of freedom. We distinguish between translational and rotational motions, and relate it to a fixed point on the vessel. With reference to figure 4-15, the three translations of the ships Center of Gravity (CoG) along the principal axes are defined as:

- Surge in the longitudinal x-direction
- Sway in the lateral y-direction
- Heave in the vertical z-direction

The rotation about these axes are defined as:

- Roll about the x-axis
- Pitch about the y-axis
- Yaw about the z-axis

The translational motions are coupled and hence depending on the rotational motions. An example of this can be how the total heave at the bow or stern of a ship will be the sum of the heave at CoG and also the pitch-induced heave (Gudmestad, 2014).

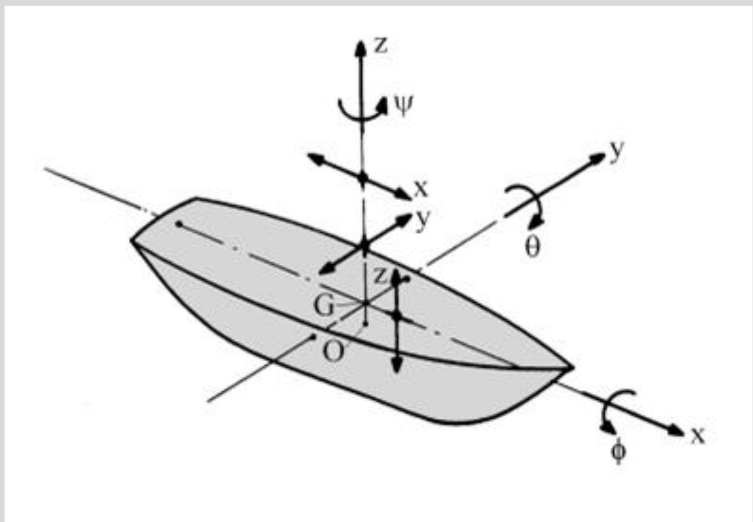


Figure 4-15 Vessel motions

A particular vessel's motion characteristics in waves, is commonly defined by transfer functions, also referred to as Response Amplitude Operators (RAOs). Displacement RAOs define the 1st order motion of the vessel in response to waves. These are hence values giving the ratio of vessel motion amplitude to wave amplitude. A single RAO value will express this ratio for a particular degree of freedom and waves of a particular period coming from a defined direction. Each of the RAO values will have a corresponding phase shift, which defines the timing of the vessel response relative to the wave. The RAOs for the translational motions are non-dimensional, as the amplitude of motion and wave amplitude both are given in meters. To give an example, a surge RAO of 0.5 in a wave of amplitude 2 m means that the vessel surges between -1 m and +1 m from its static position. The RAOs for the rotational motions are given as degrees per meter. For example a pitch RAO of 0.5^0/m in a wave of amplitude 2 m, means that the vessel pitches from -1° to +1°. The definition of displacement RAOs are given in table 4-4.

Table 4-4 Displacement RAO definition for all 6 degrees of freedom

Motion	Surge	Sway	Heave	Pitch	Roll	Yaw
RAO definition	$\frac{x_a}{\zeta_a}$	$\frac{y_a}{\zeta_a}$	$\frac{z_a}{\zeta_a}$	$\frac{\theta_a}{\zeta_a}$	$\frac{\phi_a}{\zeta_a}$	$\frac{\psi_a}{\zeta_a}$

As motion characteristics are dependent on vessel design, all type of vessels will have their unique RAO values. Furthermore, a particular vessel will typically have RAO values defined for different drafts as this influences the motion characteristics. RAO values can be represented in different ways, but with values defined for a sufficient number of wave periods one can make a graphical representation as the one in figure 4-16. The figure presents a plot of RAO values for a default vessel in OrcaFlex, a 103 m long tanker. Such a graphical representation makes it easier to get a feeling about the motion characteristics of the vessel. If we consider the situation of waves coming from a direction of 180^0, hence directly towards the vessel bow, we can see that sway, roll and yaw motions are all zero. We can from the figure easily spot that this tanker has a natural period in heave somewhere between 6 and 7 sec. This is hence the wave period which corresponds to resonant motions in heave. When the wave period gets very long both surge and heave RAO goes towards a value of one, as the vessel will move as a raft on the wave surface. Pitch motions on the other hand, goes towards a value of zero.

For wave direction of 90^0 the situation is completely different. In beam sea the surge is practically zero, while the sway RAO approaches a value of one as the period increases. The natural period of roll motion is around 9 seconds, clearly visualized by the peak of RAO value in the figure.

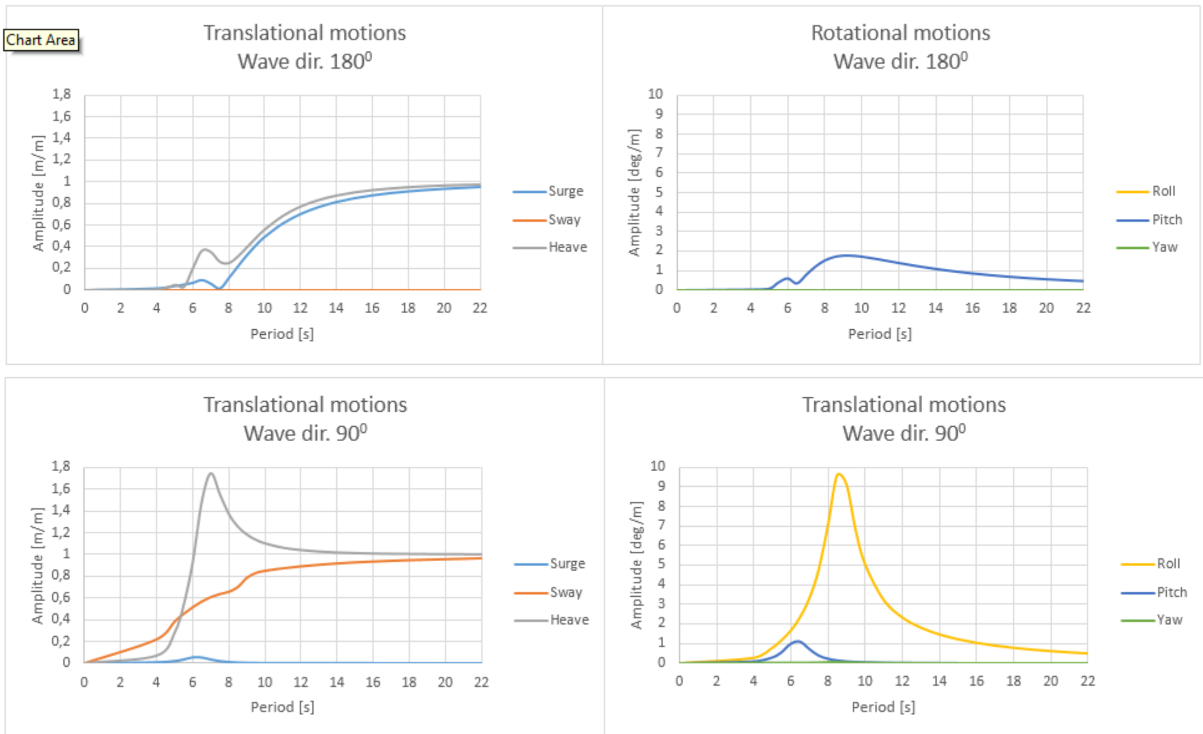


Figure 4-16 Plot of displacement RAOs for OrcaFlex default vessel

4.2.1 Response in Irregular Waves

Irregular waves acting on a vessel will result in irregular vessel response. Similar to how irregular waves can be described as a superposition of many regular harmonic wave components, the total vessel response in irregular waves will be the superposition of the response to all the components the sea state is composed of. The principle is shown in figure 4-17, for the heave motion being considered here. The left side of the figure represents the irregular wave history, as the sum of a large number of regular wave components. Each regular wave component can be transferred to a regular heave component by a multiplication with the RAO value $z_a/\zeta_a(\omega)$. The irregular heave history, $z(t)$ is obtained by adding up the regular heave components.

In the same manner as irregular waves are described by a wave energy spectrum one can also define the energy spectrum for the vessel response. Plotting of the value $\frac{1}{2}{z_a}^2(\omega)/\Delta\omega$ of each heave component on the ω –axis on the right side, results in the heave response spectrum, $S_z(\omega)$ (Journée & Massie, 2001, pp. 6-24). The same principle applies to motion in degrees of freedom.

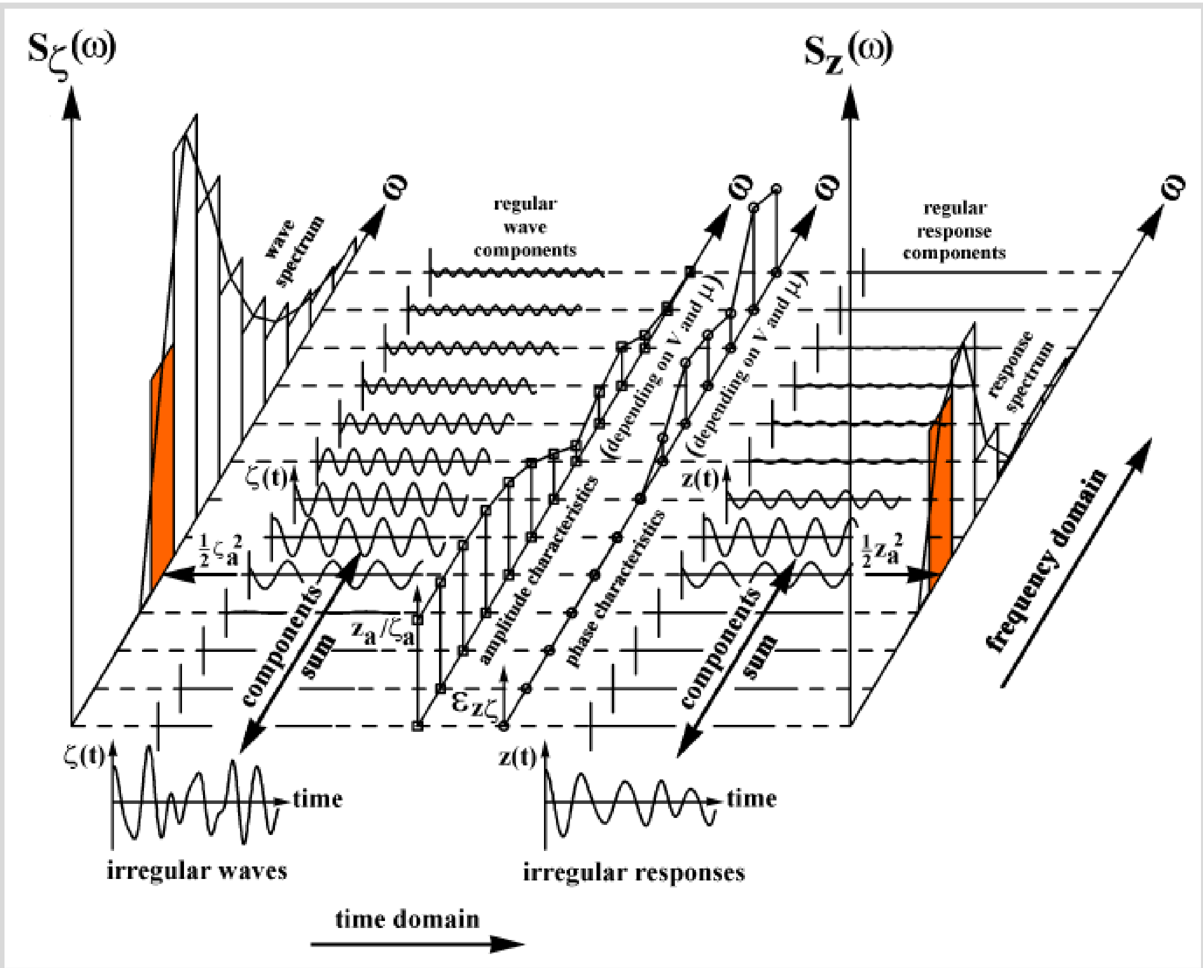


Figure 4-17 Transfer of Waves into Responses (Journée & Massie, 2001, p. 6;26)

4.3 Loads and Load Effects

The force experienced by the lifting wire and vessel crane tip while the lifted object is still in the air is the sum of a mean force and a time varying dynamic force. The mean force can vary due to effects such as lowering velocity, but essentially governed by the weight of the lifted object and lifting arrangement, i.e. the static force exerted by gravity.

The weight of the object in air is given as:

$$W_0 = Mg \quad [N] \tag{4.3-1}$$

In which M is the mass of object including pre-filled fluid within object. The total weight of lifted object and lifting arrangement/ rigging in air is often referred to as the Static Hook Load (SHL). The time varying dynamic force is the result of cane tip motion excitation on the lifted object. The maximum magnitude of this dynamic effect and hence the maximum force in the lift wire can be expressed in terms of a Dynamic Amplification Factor (DAF), by the relation:

$$F_{max} = SHL \cdot DAF \quad [N] \tag{4.3-2}$$

4.3.1 Hydrodynamic Loading

The interaction between water and an object lowered through the wave-zone results in forces due to several hydrodynamic effects. In general, the hydrodynamic forces generated by waves to be accounted for when assessing the response of the object are by (DNV, 2011 b, p. 27) given as:

F_B = buoyancy force
F_I = inertia force
F_D = drag force
F_{wd} = wave damping force
F_{we} = wave excitation force
F_S = slamming force
F_E = water exit force

What DNV refers to as wave excitation forces are the loads on a structure when it is restrained from any motion response when exposed to incoming waves. This is not the case when considering lift through the wave zone by use of slings. In general when an object moves in vicinity of a free surface, outgoing surface waves will be created. The energy of these waves comes from the work done to dampen the motion of the object. The resulting force on the object is the wave damping force. For slender elements like spools, it is common practice to regard the wave damping force as negligible when analyzing the lift through the wave zone. The remaining wave induced forces listed are highly relevant for spool installation lifts and will be described in the following sub-sections.

4.3.1.1 Buoyancy force

The buoyancy force for a submerged object is as given by Archimedes' principle equal to the weight of the displaced water:

$$F_B(t) = \rho g V(t) \quad [N] \tag{4.3-3}$$

In which $V(t)$ is the instantaneous displaced volume of water. If the center of buoyancy is not vertically above the center of gravity, the buoyancy force will exert a rotational moment on the lifted object, when lowered through the wave zone. The submerged weight of the object is defined as:

$$W(t) = W_0 - F_B(t) = [M - \rho V(t)] \cdot g \quad [N] \tag{4.3-4}$$

Considering circular objects such as spools, the buoyancy force per unit length, when fully submerged will be:

$$F_{B,spool} = \rho g \cdot \frac{\pi}{4} D_o^2 \quad [N/m] \tag{4.3-5}$$

In which D_o is the outer spool diameter.

4.3.1.2 Inertia and drag force

Inertia and drag are the force components related to water particle acceleration and water particle velocity, respectively, acting on an object. Forces exerted by waves on cylindrical slender objects is commonly described by the so called “Morison’s equation”, as introduced by (Morison, O'Brien, Johnson, & Schaaf, 1950). Morison’s equation was originally formulated for calculation of the wave loads on vertical piles extending from the bottom upwards above the wave crest. Throughout the years the theory has proven useful for many types of slender elements, and is applicable for members having cross sectional dimension considerably smaller than the wave length. The equation gives the sum of the inertia force and drag force per unit length on a cylinder, by the following relation:

$$f_W = f_M + f_D = \frac{\pi D_o^2}{4} \cdot \rho \cdot \dot{u} \cdot C_M + \frac{1}{2} \cdot \rho \cdot C_D \cdot D_0 \cdot u \cdot |u| \tag{4.3-6}$$

In which:

f_W = fluid force per unit length
f_M = inertia force per unit length
f_D = drag force per unit length
u = water particle velocity
$\dot{u}$ = water particle acceleration
C_M = inertia coefficient
C_D = drag coefficient

Inertia force component

The inertia force (or mass force) is proportional to the fluid acceleration, where the $(\pi D_o^2/4) \cdot \rho \cdot \dot{u}$ part is known as the Froude-Krylov component. This force is perhaps best understood by imagining the considered cylinder replaced by an equivalent volume of water. The mass of a unit length of the “water-cylinder”, $(\pi D_o^2/4) \cdot \rho$ must be undergoing an acceleration $\dot{u}$, i.e experiencing a force equal to $(\pi D_o^2/4) \cdot \rho \cdot \dot{u}$. If the physical cylinder is put back, the same force must act on it. The inertia coefficient C_M, is a dimensionless coefficient taking account of the effect off added mass on the cylinder. Added mass is the additional force due to distortion of the fluid flow by the presence of the body. This is a constant related to the shape of the body and its displacement. DNV gives recommendations on what coefficients to obtain, which is further discussed in section 4.3.1.3.

Drag force component

The drag force component of the Morrison's equation is caused by vortices generated in the flow as it passes the object (Barltrop & Adams, 1991, p. 307). Figure 4-18 illustrates how alternating vortices are shed from a cylinder. Eddy currents are very difficult to describe analytically and the relation giving the drag force is hence an empirical relation. Extensive testing has shown that the drag force is well described by a relation proportional to the square of the fluid velocity. This term includes a dimensionless drag coefficient, C_D. The selection of this coefficient is also discussed in section 4.3.1.3.

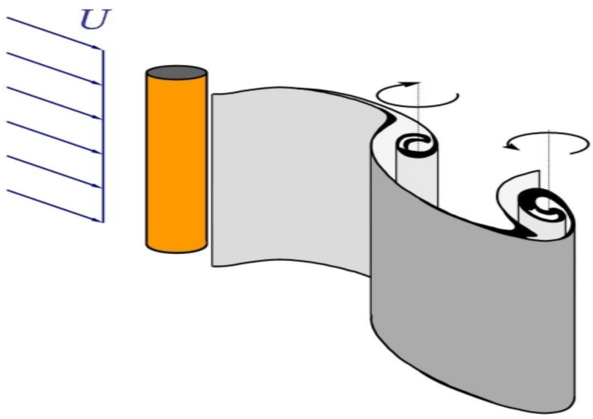


Figure 4-18 Vortices generated by fluid flow passed a cylinder (Violette, 2015)

4.3.1.3 Extended form of Morrison's equation and selection of coefficients

Even though Morrison's equation expresses inertia and drag forces on a static body, the same principles applies for moving objects. This is hence useful in a situation of lowering a spool through the wave zone. OrcaFlex calculates hydrodynamic loads using an extended form of Morison's equation which accounts for movement of the body, by separating the Froude-Krylov component from the added mass component. The extended form of Morison's equation used in OrcaFlex is given as (Orcina Ltd, 2015, p. 143):

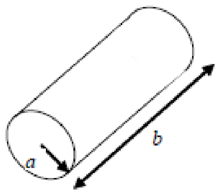
$$F_W = (\Delta \cdot \dot{u}_w + C_A \cdot \Delta \cdot \dot{u}_r) + \frac{1}{2} \cdot \rho \cdot C_D \cdot D_0 \cdot u_r \cdot |u_r| \quad (4.3\text{-}7)$$

In which:

F_W = total fluid force
Δ = mass of water displaced by body
$\dot{u}_w$ = water particle acceleration relative to earth
C_A = added mass coefficient
$\dot{u}_r$ = water particle acceleration relative to cylinder
u_r = water particle velocity relative to cylinder
C_D = drag coefficient

It should be noticed that the force is here given as a total body force, rather than per unit length. The term in parentheses is the inertia force. One part is proportional to fluid acceleration relative to earth (the Froude-Krylov component), and one proportional to fluid acceleration relative to the body (the added mass component). This modification allows for taking account of a body with a relative movement to the seabed. The term $C_a \cdot \Delta$ has the dimensions of mass and is what has become known as the added mass. It should again be emphasized that this is a constant related to the shape of the body and its displacement. It should not be viewed as a body of fluid trapped by and moving with the body, which is the case for some shapes. We are then talking about a phenomena called “trapped water”, which is different and should be treated as part of the body mass. An analytical added mass coefficient for cylinder, as recommended by DNV, is presented in table 4-5. We can see that for a given cylinder radius, the added mass coefficient goes towards a value of 1.0 as the cylinder length increases. V_R is a reference volume for the added mass.

Table 4-5 Analytical added mass coefficient for cylinder (DNV, 2011 b, p. 142)

Body shape		*Direction of motion*	C_A		V_R
			$b/2a$	C_A	
Right circular cylinder		Vertical	1.2 2.5 5.0 9.0 ∞	0.62 0.78 0.90 0.96 1.00	$\pi a^2 b$

The extended Morrison equation calculates the drag force term considering the fluid velocity relative to the body. When lowering a body through the wave zone, we are not considering a steady flow, but an oscillating flow. Unless Computational Fluid Dynamics (CFD) studies or model tests have been performed, the following guideline for drag coefficient on typical subsea structures in oscillatory flow is given (DNV, 2011 b, p. 70):

$$C_D \geq 2.5 \quad [-] \tag{4.3-8}$$

4.3.1.4 Slamming force and water exit force

Slamming forces are impulse loads with high pressure peaks occurring during impact between a body and water, for example when lowered through the wave zone. (Faltinsen, 1990, p. 282). At the time of contact between the body and the free surface, the fluid will be given a disturbance resulting in a mass of fluid accelerated and propagating away from the body. This means that there has to be force acting back on the body equal to the product of the mass of the fluid and its acceleration. According to (DNV, 2011 b, p. 33), the slamming force on an object lowered with a constant slamming velocity v_s (assumed positive) in still water can be expressed as the rate of change of fluid momentum:

$$F_S(t) = v_s \frac{dA_{33}^{\infty}(t)}{dt} \quad [N] \tag{4.3-9}$$

In which $A_{33}^{\infty}(t)$ is the instantaneous high-frequency limit heave added mass. Using this is based on the assumption that the local fluid accelerations due to water entry of the object are much larger than the acceleration of gravity. This corresponds to the high frequency limit for a body oscillating with a free surface.

The slamming force is commonly expressed in terms of a slamming coefficient C_S as:

$$F_s(t) = \frac{1}{2}\rho C_s A_p {v_s}^2 \quad [N] \tag{4.3-10}$$

Where C_S is defined by:

$$C_S = \frac{2}{\rho A_p v_s}\frac{dA_{33}^{\infty}}{dt} = \frac{2}{\rho A_p}\frac{dA_{33}^{\infty}}{dh} \tag{4.3-11}$$

In which:

dA_{33}^{∞}/dh	= the rate of change of added mass with submergence	[kg/m]
A_p	= horizontal projected area of object	[m^2]
h	= submergence relative to surface elevation	[m]

Considering water entry in waves, the relative velocity between lowered object and sea surface must be applied as the slamming velocity. This also includes accounting for the velocity due to crane tip motions. To simplify analysis the slamming coefficient is often taken as a constant. According to (DNV, 2007, p. 81) the slamming coefficient can be taken as $C_S = 5{,}15$ for a smooth circular cylinder. For flat bottom slamming, the coefficient should not be taken less than $C_S = 2\pi$ (DNV, 2007, p. 83).

The **water exit force** is a force also related to added mass, in general defined for objects lifted out of the water. The heave added mass increases as the object approaches the surface. Hence, the water exit force acts downwards, in the opposite direction to the exit velocity. According to (DNV, 2011 b, p. 35), the water exit force $F_E(t)$ on an object lifted up beneath the free surface with constant lifting velocity v_e (positive upwards) in still water can be expressed by the rate of change of fluid kinetic energy by the relation:

$$v_e\, F_E(t) = -\frac{dE_k}{dt} \quad \left[\frac{Nm}{s}\right] \tag{4.3-12}$$

$$E_k = \frac{1}{2}A_{33}^{0}{v_e}^2 \quad [Nm]$$

In which $A_{33}^{0}(t)$ is the instantaneous low-frequency limit heave added mass. Using the low-frequency added mass is based on the assumption that the local fluid accelerations during water exit is much smaller than the acceleration of gravity. This corresponds to the low frequency limit for a body oscillating beneath a free surface. Similar to the slamming force, the water exit force can be expressed in terms of a water exit coefficient C_e as:

$$F_E(t) = -\frac{1}{2}\rho C_E A_p {v_e}^2 \quad [N] \tag{4.3-13}$$

Where C_E is defined by:

$$C_E = \frac{1}{\rho A_p v_e}\frac{dA_{33}^{0}}{dt} = -\frac{1}{\rho A_p}\frac{dA_{33}^{0}}{dh} \tag{4.3-14}$$

Note that the rate of change of added mass is negative. For water exit in waves the relative velocity between the lifted object and sea surface must be applied as the velocity. From this we can reason that there will be a water exit force acting on an object being lowered, if the lowering velocity is smaller than the vertical downwards velocity of the sea surface. Water exit force is hence relevant when looking at an object being lowered through the wave zone. Furthermore, vessel motions introduces crane tip upwards movement even though lowering an object. Also for water exit force the coefficient may be taken as a constant to simplify analysis. Combining equation 4.3-11 and 4.3-14 we can reason that the coefficient can be taken as:

$$C_E = \frac{C_E}{2} \tag{4.3-15}$$

4.4 Horizontal Pendulum Motion

Crane tip motion will have the potential to cause excessive pendulum motions to the lifting arrangement and spools while suspended from the crane. The natural period of the system of lifting arrangement and spool is hence an important parameter. According to (DNV, 2011 b, p. 131), the natural period for horizontal motion of a lifted object in air is given by:

$$T_{0h} = 2\pi\sqrt{\left(\frac{l}{g}\right)\left(\frac{M+0.33ml}{M+0.45ml}\right)} \tag{4.4-1}$$

In which:

m = mass per unit length of hoisting line [kg/m]
l = length of hoisting line [m]

When neglecting the mass of hoisting line the relation reduces to the simple expression:

$$T_{0h} = 2\pi\sqrt{\frac{l}{g}} \tag{4.4-2}$$

4.5 Structural Properties of Pipes and Wires

Creating a realistic OrcaFlex model of the considered spool installation lift requires assigning structural properties of pipes and wires, stiffness properties in particular. The following formulas are based on the software user manual (Orcina Ltd, 2015, p. 393).

Axial stiffness

Axial stiffness of pipes and wires are given by:

$$K_a = E \cdot A \quad [N] \tag{4.5-1}$$

In which:

E = young's Modulus
A = cross sectional area
Axial stiffness for a pipe is hence governed by the relation:

$$K_{a,pipe} = E\frac{\pi}{4}(D_o^2 - D_i^2) \quad [N] \tag{4.5-2}$$

In which D_o and D_i are outer and inner diameter of the pipe, respectively. For wires, the effective cross sectional area is given as:

$$A_w = \frac{\pi \cdot D^2}{4} \cdot c_f \quad [N] \tag{4.5-3}$$

In which:

c_f = fill-factor for wire [-]
D_w = Wire diameter [m]

Bending stiffness

Bending stiffness is given by:

$$K_b = E \cdot I \quad [Nm^2] \tag{4.5-4}$$

In which I is the second moment of area, about an axis in the plane of the cross section through the centroid. For a pipe this is illustrated by NN' in figure 4-19, and the bending stiffness is governed by the relation:

$$K_{b,pipe} = E \cdot \frac{\pi}{64}(D_o^4 - D_i^4) \quad [Nm^2] \tag{4.5-5}$$

Torsional stiffness

The torque experienced by a pipe of length l_p when twisted through an angle δ is given by:

$$T = \frac{G \cdot \delta}{l_p} J \quad [Nm^2] \tag{4.5-6}$$

In which:

J = Polar moment of inertia $[m^4]$
G = Shear modulus (modulus of rigidity) $[N/m^2]$

The polar moment of inertia is the second moment of area about the axial axis, illustrated by OO' in figure 4-19. For homogeneous pipes $J = 2I$.The quantity G is related to the Young's Modulus and Poisson Ratio (v) of the material, through the following relation:

$$G = \frac{E}{2(1+v)} \quad [N/m^2] \tag{4.5-7}$$

The torsional stiffness, representing the torque resisting a twist of 1 radian per unit length of a pipe is therefore given by:

$$K_{t,pipe} = GJ = \frac{E}{2(1+v)} \cdot \frac{\pi}{34} (D_o^4 - D_i^4) \quad [Nm^2] \tag{4.5-8}$$

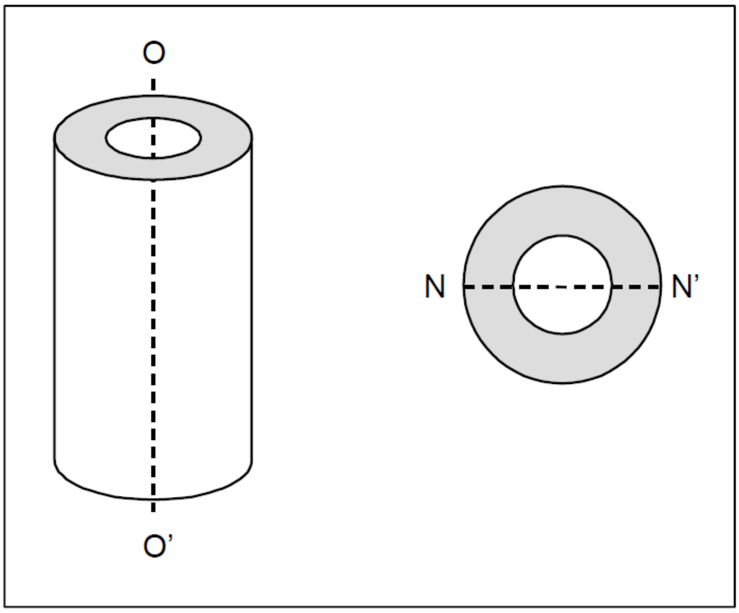


Figure 4-19 Homogeneous pipe (Orcina Ltd, 2015, p. 393)

5 Software and Modeling

OrcaFlex is a fully 3D non-linear time domain finite element software package developed by the company Orcina, intended for use in design and analysis of offshore marine systems. The software features a variety of possibilities for static and dynamic analysis and has been used for all the analyses carried out related to this report. In order to analyze a system in OrcaFlex, one must first build a mathematical model of the real-world system. This is achieved by using the various modeling facilities provided by the program. A model consists of the marine environment to which the system is subjected, plus a variable number of objects, placed in the environment and connected together as required. The level of detail in modeling is decisive for the accuracy in prediction of the real-world system behavior. As this often will be at the cost of increased analysis time, necessary simplifications must be made.

The intention of this chapter is to provide the reader with an understanding of what the analyses related to the spool installation cases study are based on. Focus is therefore put on the essence of modelling performed to obtain a realistic model for the case study and also to shed light on the limitations and simplifications of the software and model.

5.1 Vessel

OrcaFlex has a function for modeling vessels. These are rigid bodies described by a number of properties that can represent floating platforms, barges, ships etc. For the work in this report, an OrcaFlex model of the Skandi Arctic was provided by Technip. A picture of that model is seen in figure 5-1. For the Skandi Arctic model, motion characteristics are specified by displacement RAOs. RAO amplitudes and phases are specified for all six degrees of freedom for 48 different wave periods and wave heading direction for each 15^0. These characteristics have their origin from analyzing the vessel in the software ANSYS, and have been validated by model tests carried out at the facilities of Vienna Model Basin Ltd. in 2013. A plot of the displacement RAO amplitude values as a function of period for wave directions from 180^0 to 90^0, with 15^0 increment is shown in figure 5-2. These are the characteristics of the vessel at a draft of 8.5 m which is the case used throughout the analyses. OrcaFlex allows for modeling 2^{nd} order effects as well. An example is specifying transfer functions for wave drift loads, used for modeling vessel slow drift. As the vessel is kept stationary on DP during subsea lifting, it is assumed sufficient to analyses the lift considering the motions from displacement RAOs solely. From looking at the plots in figure 5-2, we can easily spot that the Skandi Arctic has a natural period in roll close to 11 s. One should in particular take notice of how the amplitude of motion in roll increases as the wave direction goes towards 90^0.

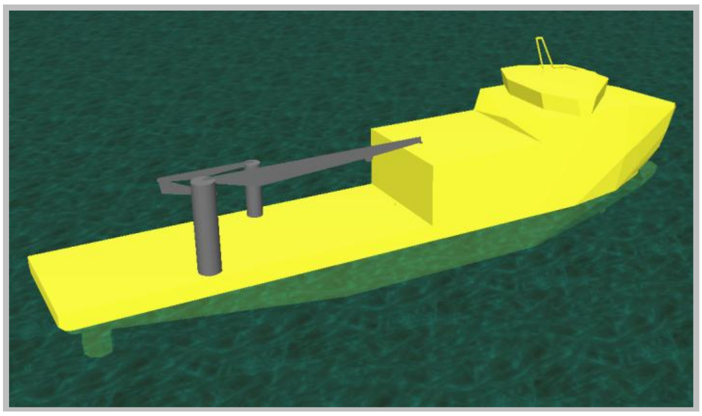
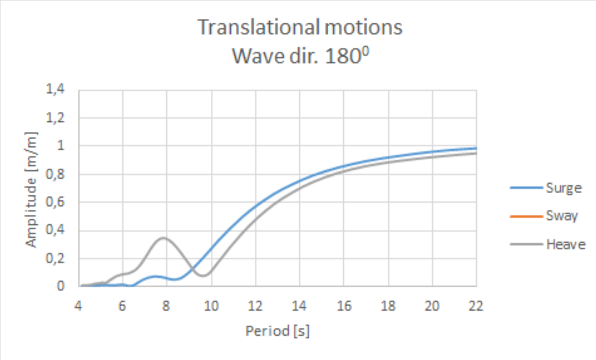
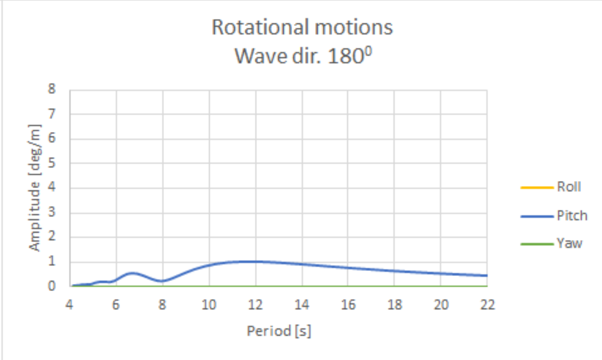
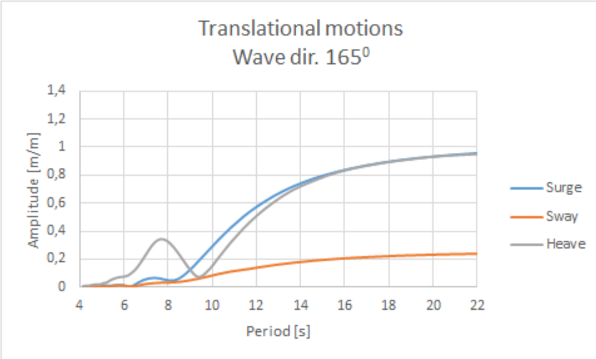
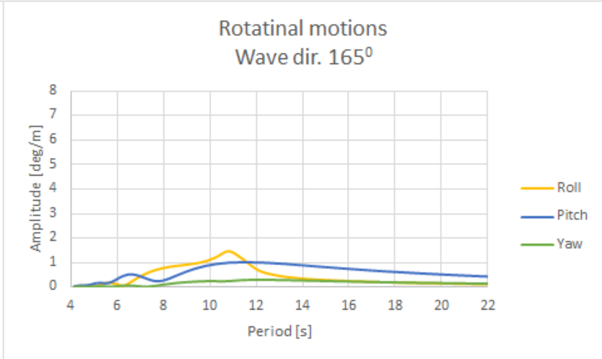


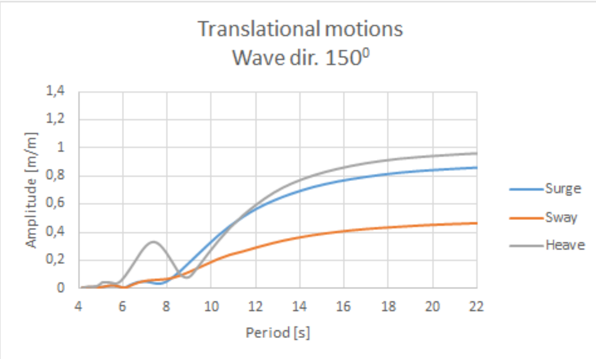
Figure 5-1 OrcaFlex model of Skandi Arctic

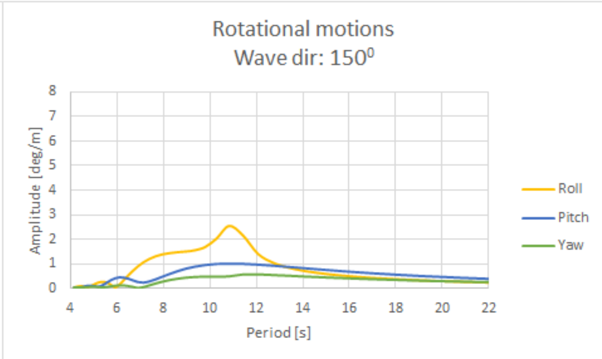

Translational motions
Wave dir. 180⁰
Amplitude [m/m]
Period [s]
Surge
Sway
Heave

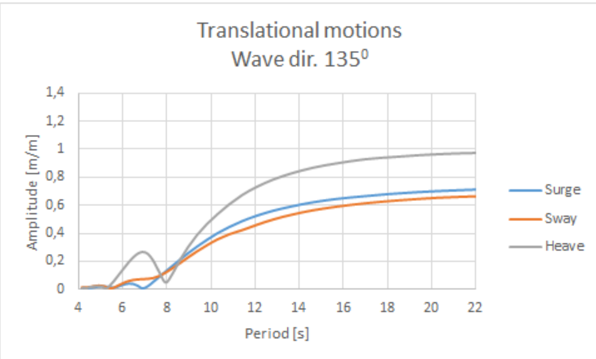

Rotational motions
Wave dir. 180⁰
Amplitude [deg/m]
Period [s]
Roll
Pitch
Yaw

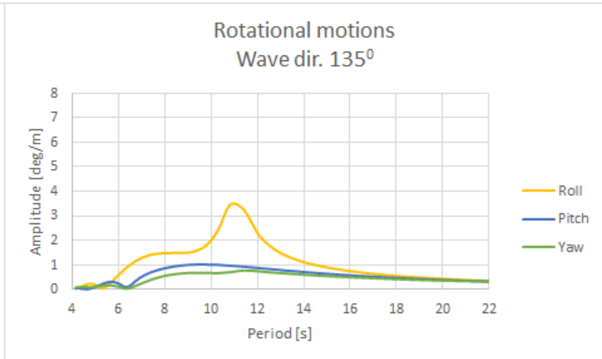

Translational motions
Wave dir. 165⁰
Amplitude [m/m]
Period [s]
Surge
Sway
Heave

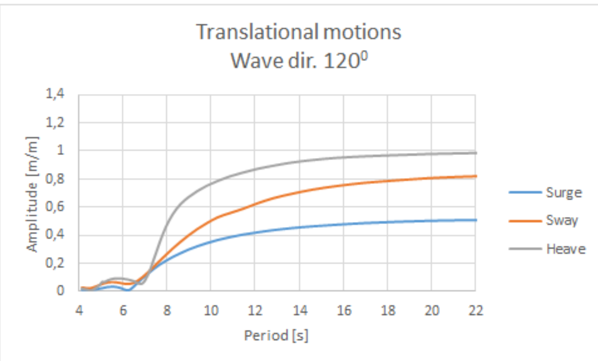

Rotatinal motions
Wave dir. 165⁰
Amplitude [deg/m]
Period [s]
Roll
Pitch
Yaw

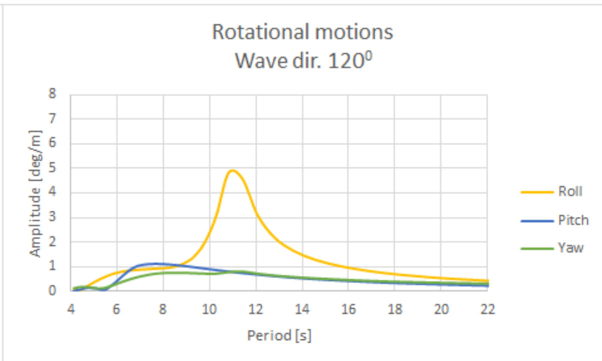

Translational motions
Wave dir. 150⁰
Amplitude [m/m]
Period [s]
Surge
Sway
Heave


Rotational motions
Wave dir: 150⁰
Amplitude [deg/m]
Period [s]
Roll
Pitch
Yaw


Translational motions
Wave dir. 135⁰
Amplitude [m/m]
Period [s]
Surge
Sway
Heave


Rotational motions
Wave dir. 135⁰
Amplitude [deg/m]
Period [s]
Roll
Pitch
Yaw


Translational motions
Wave dir. 120⁰
Amplitude [m/m]
Period [s]
Surge
Sway
Heave


Rotational motions
Wave dir. 120⁰
Amplitude [deg/m]
Period [s]
Roll
Pitch
Yaw

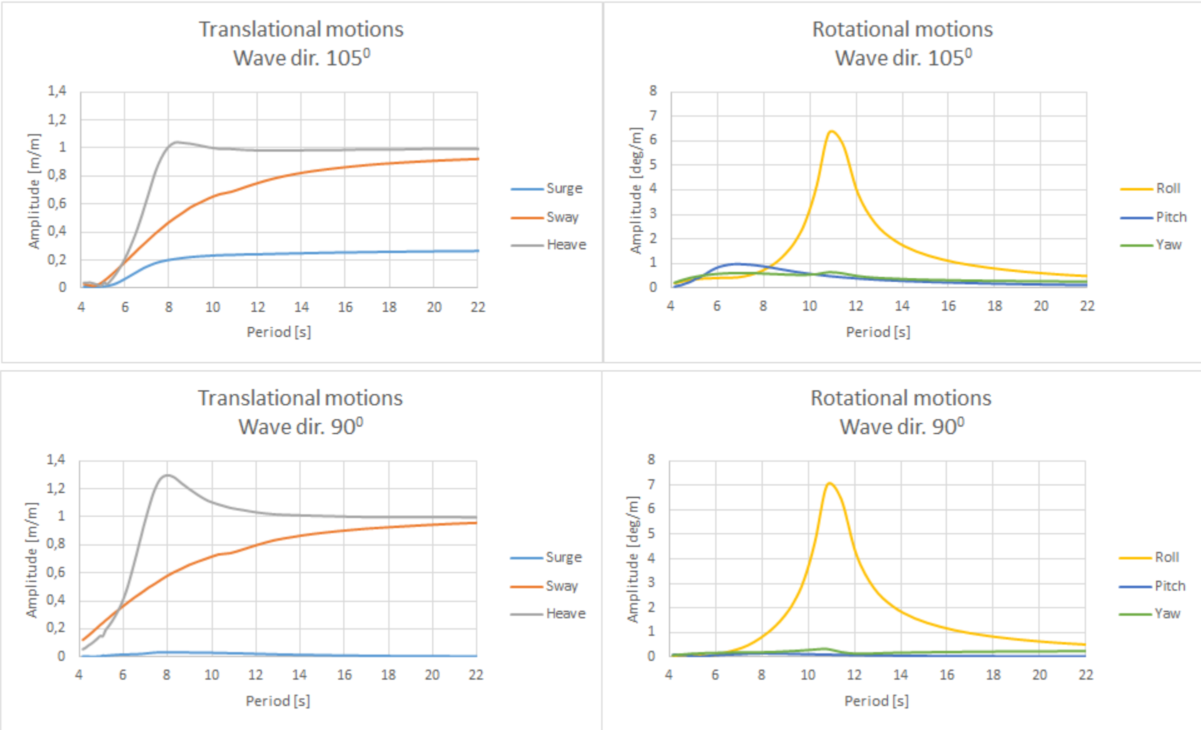


Figure 5-2 Displacement RAO amplitudes for Skandi Arctic

5.2 Lifting Arrangement and Spools

The lifting arrangement and spools have been modeled numerically in OrcaFlex after drawings of the actual spools and rigging chosen for the Alvheim subsea well tie in project. Figure 5-3 shows the side view of the 3 leg bridle wire sling arrangement. With a 3 m wire pennant connecting the wire slings to the crane hook the total height of the rigging is close to 30 m. The individual wires are attached to selected points on the strong back. Such a rigging is normally designed with wire sling lengths assuring the crane block is located directly above the CoG of the lifted structure. This is perhaps better illustrated when looking at a plane view drawing as the one in figure 5-4. Detailed rigging drawings are attached in Appendix B.

Links are simple spring or spring/damper connections linking two objects in the model together. They have no mass or hydrodynamic loading and are useful for modeling items such as wires/slings where these effects are small enough to be neglected. The simple spring (tether) type of links has been used for modeling the individual wire slings and pennant in the lifting arrangement. These are simple linear elastic ties that can take tension but not compression and are specified by un-stretched length and stiffness. The tether remains slack and does not apply a force if the distance between the ends is less than the un-stretched length. Winches are also mass-less connections linking two or more objects in the model, by a winch wire, which is fed from and controlled by a winch drive mounted on the first object. The winch drive can be operated at different modes. It can for example pay out or haul in the wire at a user- specified rate or rate of change. The winch function has been used for modeling the connection between the crane tip and crane block. The winch wire is not allowed to go into compression, so if the tension in the wire becomes negative in a dynamic analysis then the winch wire is considered to have gone slack.

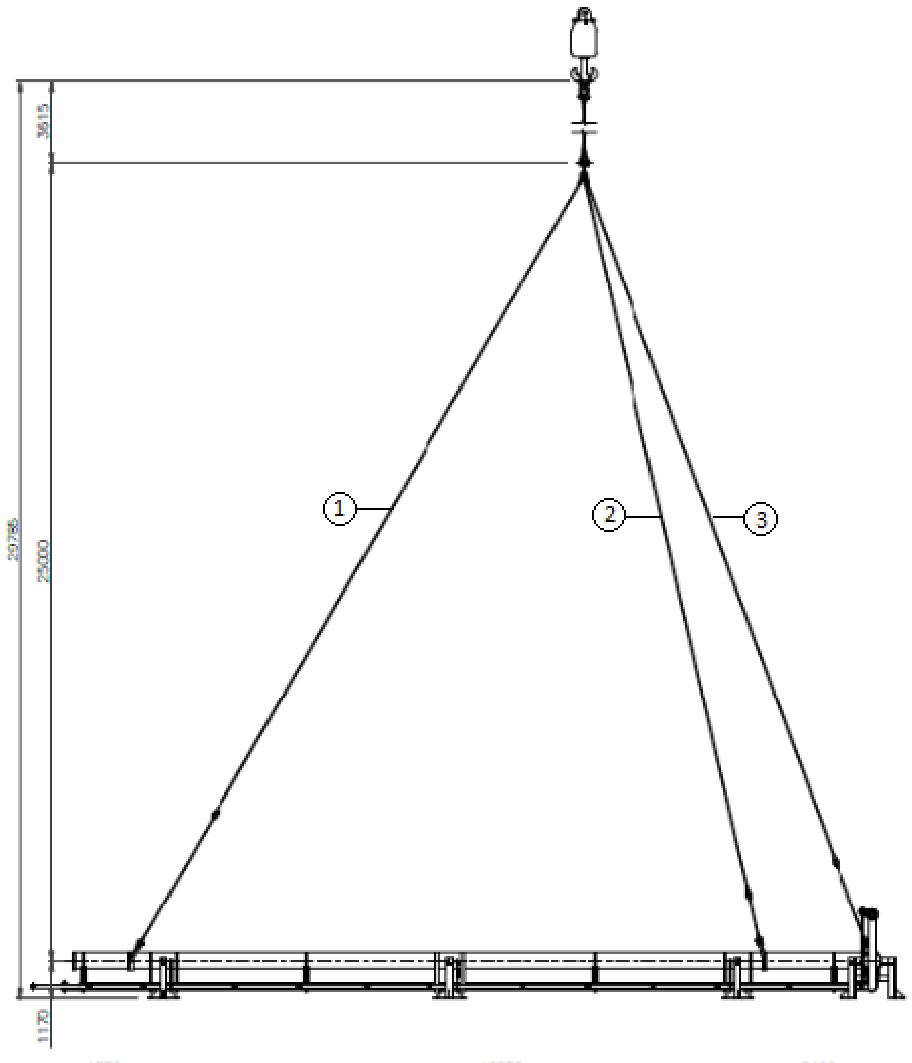


Figure 5-3 Lifting arrangement side view

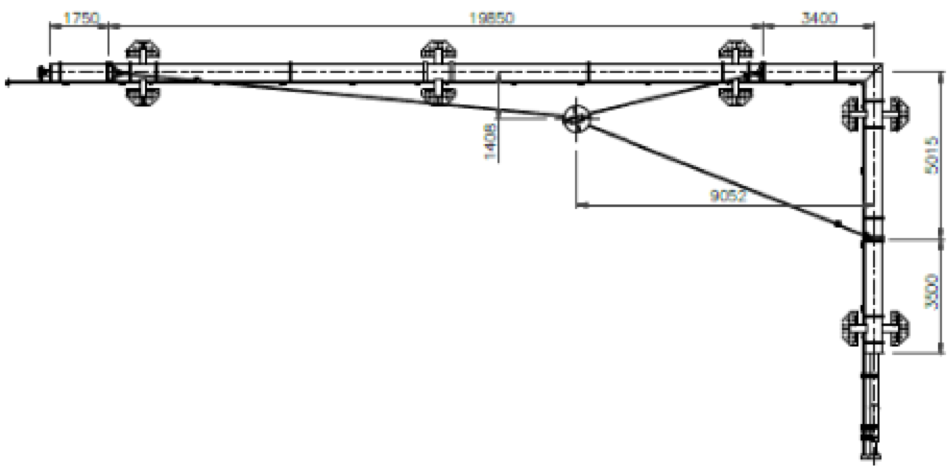


Figure 5-4 Lifting arrangement plane view

Wire lengths and stiffness's, as presented in table 5-1 has been implemented in the model. The length and diameters of wire slings and pennant are taken according to the rigging drawing in appendix B. The numbering of the three wire slings in table 5-1 refers to their location as according to figure 5-3. Fill factors and Young's modulus are retrieved from an internal Technip rigging catalogue and stiffness has been calculated according to the theory presented in chapter 4.5. The crane wire has been modeled with the properties of the actual main crane wire on Skandi Arctic which has a diameter of 90 mm.

The crane block has been modeled as a buoy with its real mass of 4.5 Te. Much effort was spent on an attempt of detailed modeling of the spools from isometric drawings, as seen an uncompleted example of in figure 5-5. After discussions with experienced engineers in Technip, it was decided to go for a more computationally efficient model, by merging the strongback, 2'' and 6'' spool to one equivalent L-shaped spool. Such simplifications are common practice as this will reduce analysis running time. The merging of the three pipes into one equivalent spool must however be done in a way that the model still is representative for the properties of the real system. Spool drawings are attached in appendix B.

Table 5-1 Wire properties

	Length [m]	Diameter [mm]	Fill factor [-]	Steel Area [mm^2]	Young`s modulus [MPa]	Stiffness [kN]
Crane wire	-	90	0,74	4708	130000	611998
Pennant	3,0	48	0,59	1068	103000	109967
Wire sling 1	27,7	32	0,59	475	103000	48874
Wire sling 2	24,5	32	0,59	475	103000	48874
Wire sling 3	25,7	32	0,59	475	103000	48874

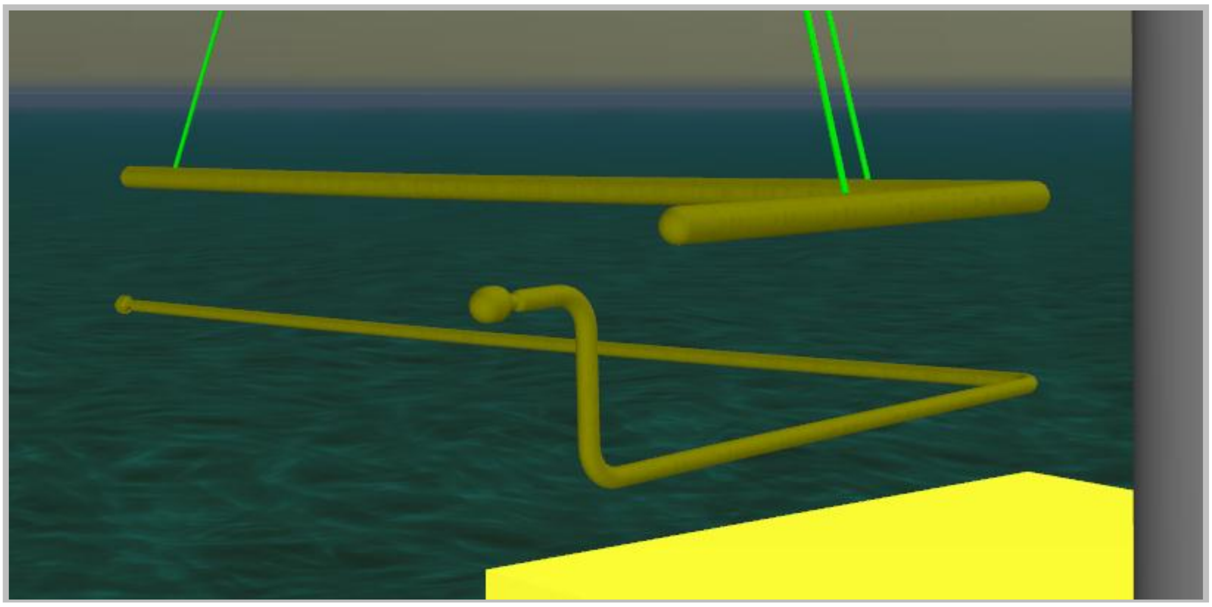


Figure 5-5 Detailed modeling of spools

A model of an equivalent spool with the length dimensions of the strongback has been used as the starting point. The first step in making an equivalent spool is to ensure a mass in air and mass in water equal to the bundle of strongback and the two spools. This is achieved by finding the right combination of diameter and wall thickness for the equivalent spool. Spool pipe lengths dimensions and thickness was accounted for in the calculations performed. Also coating thickness and density has been included. As the strongback is water filled and the spools are filled with MEG, the equivalent spool has been modeled with a content given a density specified by a weighted average between the two. The resulting weight in air and submerged state is presented in table 5-2. Weight is here presented as values converted into tonnes, which should be easier to relate to. One should take particular notice that this is a structure with rater large buoyancy. The total weight in air is around 19 Te while submerged the total weight is reduced to around 10 Te. The model weights has been verified by comparing the calculated results to the SHL in the crane wire from a static analysis in OrcaFlex, for both in air and submerged state.

The resulting equivalent spool is a steel pipe with outer diameter of 582 mm and a wall thickness of 25,6 mm. This pipe will have structural properties deviating largely from the real system. Bending stiffness and axial stiffness are proportional to D^4, and will hence be unrealistically high. Stiffness of the lifted structure must be regarded as an important parameter when lifting through the wave zone and can potentially have large impact on the results of tension in the individual lifting slings. To make the properties of the equivalent spool more realistic, it has been assigned values for axial, bending and torsional stiffness equal to the sum of the values for the three individual pipes. Calculations are based on the theory presented in chapter 4.5 and the results are presented in table 5-3. For the details around pipe dimensions and material properties, the reader is referred to information in Appendix C.

Table 5-2 Strongback and spool weight properties

	Total weight in air [Te]	Total submerged weight [Te]
Strongback	15,566	8,666
2'' Spool	0,525	0,388
6'' Spool	3,269	1,238
Equivalent Spool	19,361	10,292

Table 5-3 Strongback and spool stiffness properties

	Axial stiffness [kN]	Bending stiffness [kNm^2]	Torsional stiffness [kNm^2]
Strongback	8164071	238338	176628
2'' Spool	298989	102	76
6'' Spool	1147537	3569	2645
Equivalent Spool	9610596	242009	179349

5.2.1 Hydrodynamic Loading

The line element representing the equivalent spool has been modeled by a number of shorter segments in the order of 0.5 m. OrcaFlex calculates and applies buoyancy force and the drag and inertia force to each of these segments. Coefficients for added mass and drag force acting on the bundle are based on the dimensions of the equivalent spool modeled. In reality the arrangement of strongback and spools positioned close to each other will result in interference in the flow around them due to presence of the others, yielding an impact on the drag force and added mass. The simplification is made as the main objective of the analyses performed is to compare the lift with respect to different sea states, not assessing the hydrodynamic effects of the system in detail. This would potentially require very detailed modeling or CFD studies of the system.

In order to include slamming and water exit forces, buoys with the slamming and water exit properties of the structure are included in the model. The horizontal projected area of the strongback has been applied as the slamming area, evenly distributed on buoys placed with a spacing of 1 m along the equivalent spool, as seen in figure 5-6. The result is an area subdivided into 33 smaller areas. Due to the spools extent in the horizontal direction, a large number of buoys are required in order to realistically capture the loads from wave components of high frequencies. The buoys seen in the figure are only illustrations and do not represent the actual slamming area. In the same manner, buoys representing the slamming area of the support legs are connected to the equivalent spool. The program calculates slamming and water exit force according to the formulas given in chapter 4.3.1. Hydrodynamic loading will be calculated in terms of constant coefficients. The coefficient values assigned are selected in accordance with the theory in the same chapter and are summarized in table 5-4.

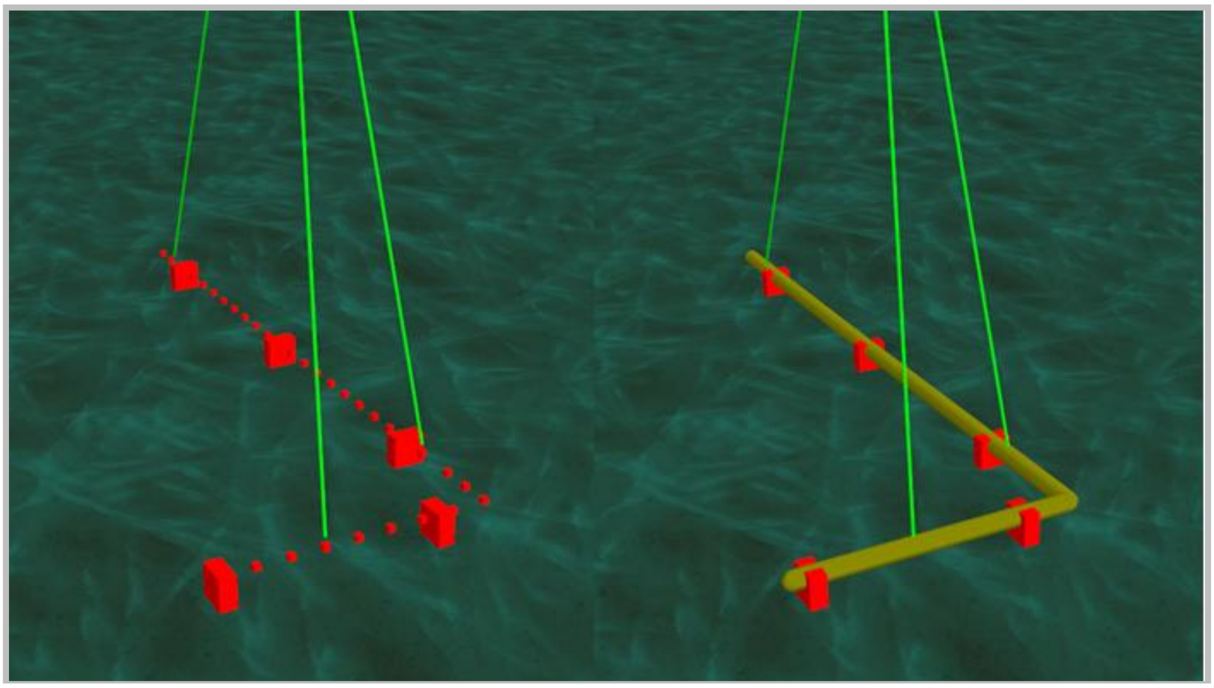


Figure 5-6 Slamming buoys and equivalent spool model

When a constant slam or water exit coefficient is used, the slam or water exit force is only applied while the buoy or cylinder is surface-piercing, no force is applied when the buoy or cylinder is fully-submerged. This is however regarded reasonable as the critical part of lifting through the wave zone is assumed to be the spools transition from air to fully submerged. The complete model of crane block, lifting arrangement and equivalent spool is presented in figure 5-7.

Table 5-4 Hydrodynamic coefficients and model dimensions

		Equivalent spool	Support legs
Added mass coefficient	C_A	1	
Inertia coefficient	C_M	2	
Drag coefficient	C_D	2,5	
Slamming coefficient	C_S	5,15	6,28
Water exit coefficient	C_E	2,58	3,14
Height [m]		0,508	1,27
Projected Area [m^2]	A_p	16,76	0,82 * 5

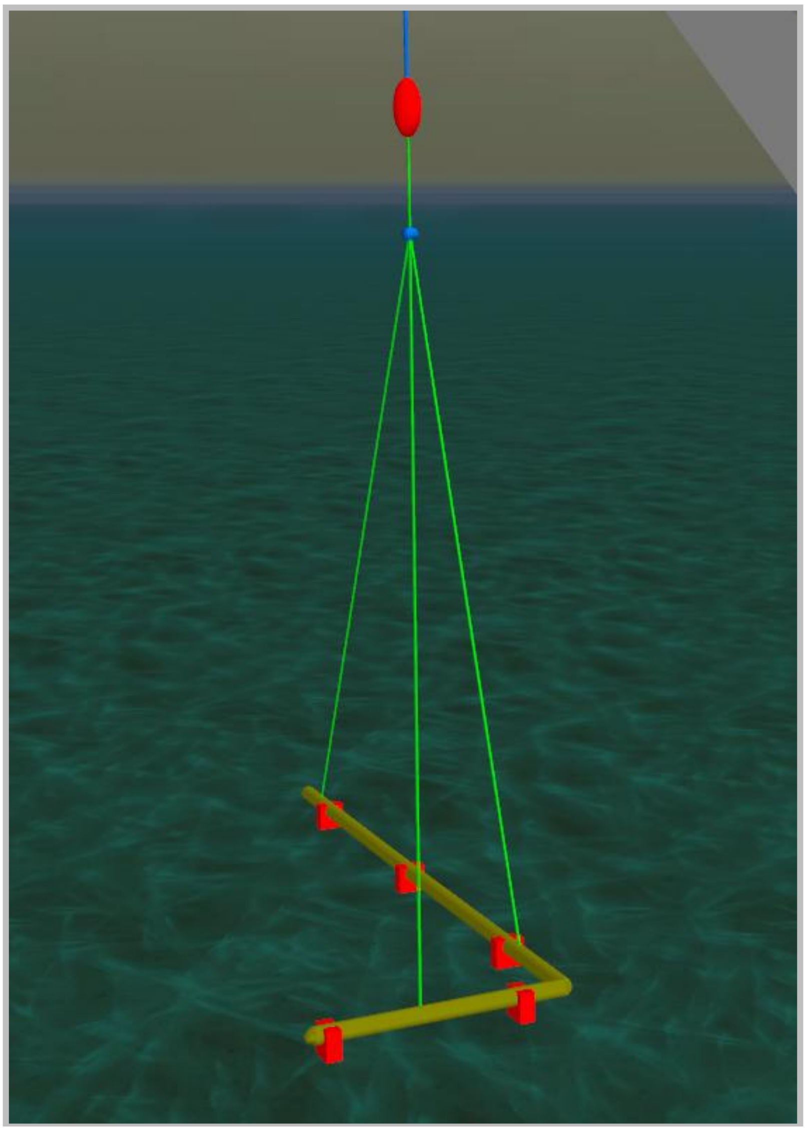


Figure 5-7 Complete lifting arrangement and equivalent spool

5.3 System

The spool is assumed deployed with the crane boom perpendicular to the vessel side at a radius of 23.5 m, as highlighted in red in figure 5-8. At this radius there is a relative distance from the crane block to the starboard side of the vessel (highlighted in green) of 20 m, which corresponds to a minimum clearance between the spool and vessel side of approximately 4 m at the most unfavorable position of rotation of the rigging. The spool and lifting arrangement is only suspended from the crane wire, hence assumed deployed without any wires attached for load control. This way there will be no horizontal forces interfering with the motions in horizontal direction, which should make it easier to interpret results with respect to pendulum motions. At the given radius the crane block has a maximum height from deck level of 39.5 m which is sufficient for the total rigging height with some additional clearance. This crane position will be used for all the analyses carried out. The complete model of vessel, crane, lifting arrangement and spool is presented in figure 5-9.

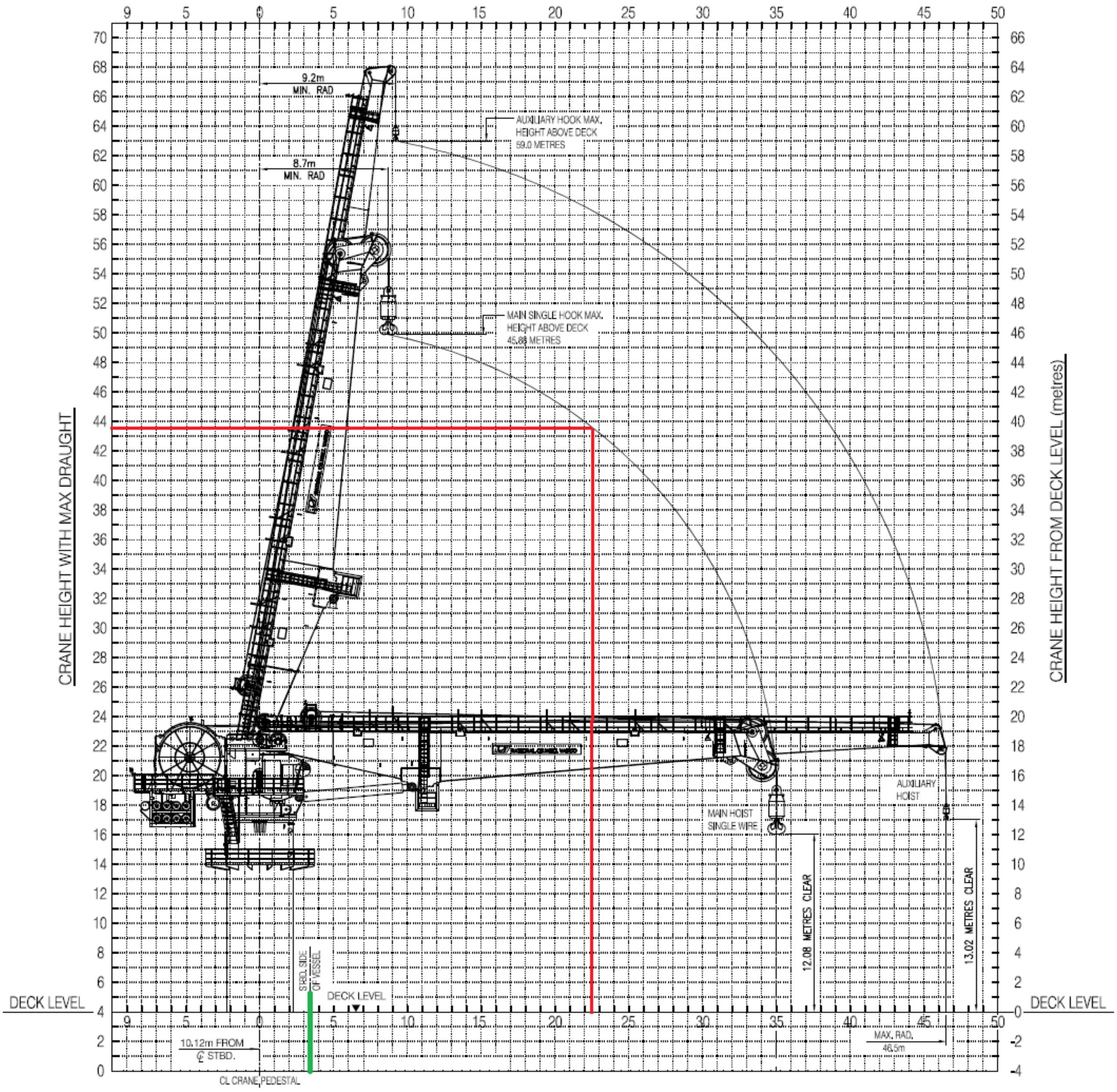


Figure 5-8 Details 400 Te crane with single wire

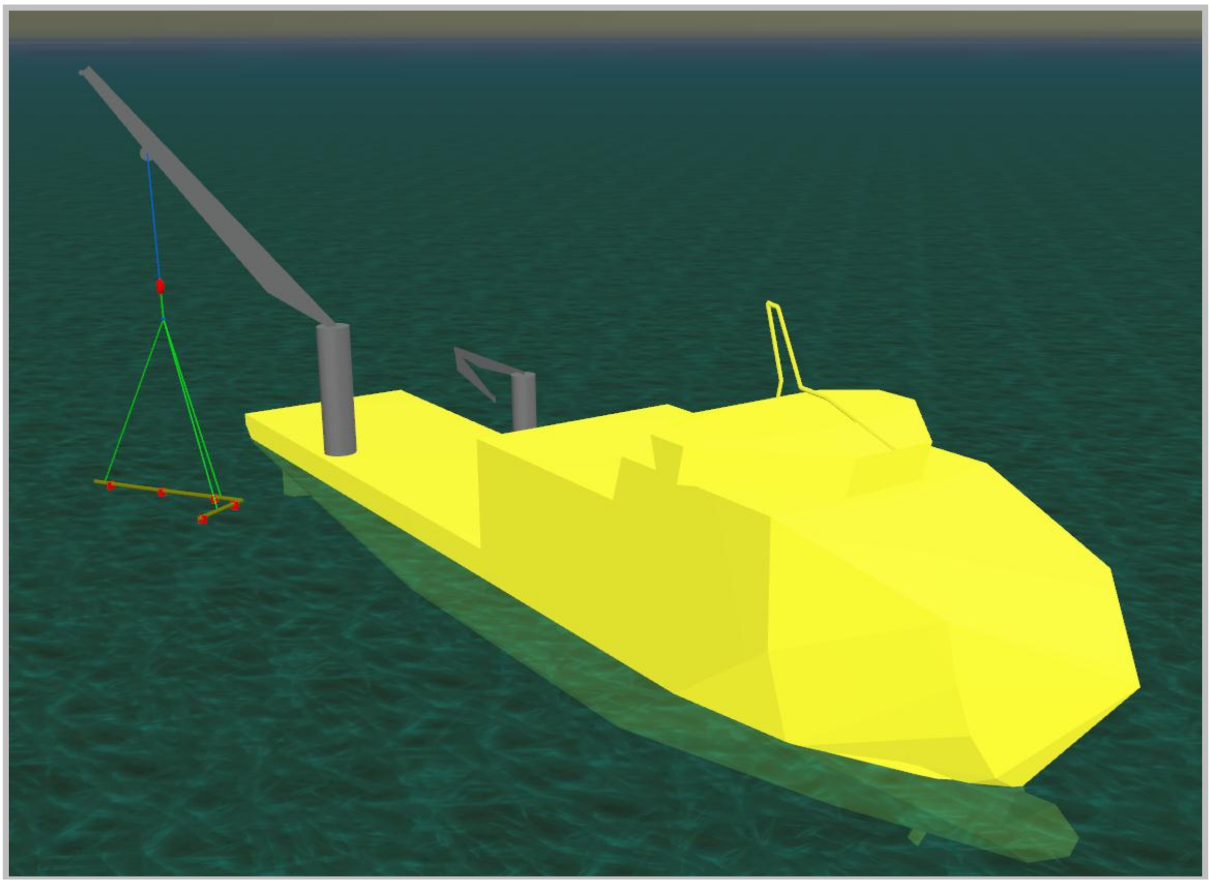


Figure 5-9 System of vessel, crane, lifting arrangement and spool

5.4 Waves

One can define a single wave train or number of different wave trains where the overall sea conditions are the superposition of the wave trains. Each wave train can be given a specified direction and described by a regular wave theory or as a random wave by choice of a spectrum.

When specifying a wave spectrum in OrcaFlex, the program creates a wave time history from a specified number of linear wave components. Wave component frequencies and associated phases are then automatically chosen to generate the spectra. A random number generator is used to assign phases, but the sequence is repeatable, so the same user data will always give the same train of waves. The wave components are added assuming linear superposition to create the wave train. Vessel responses and wave kinematics are also generated for each wave component and added assuming linear superposition.

The spectrum designated the analyses in the wind sea comparison study in chapter 7 is the JONSWAP spectrum, made up by 100 linear wave components. This should be sufficient to create a realistic irregular sea. Short crested sea is modelled by dividing the wave energy in 9 directions, which each are composed of 100 linear wave components. The higher the number of wave directions in the short crested sea, the more realistic it will appear. The choice of in total 900 linear wave components was established as an upper limit with respect to analysis running time. OrcaFlex automatically distributes the directions of elementary wave trains around the main direction as seen in figure 5-10. The figure is retrieved from OrcaFlex and shows a plot of the spreading function for n=2. The plot is identical to the one in chapter 4.1.5, but is here shown with 180^0 as the main wave direction. The dots indicate the elementary wave trains.

A generated irregular sea state will include wave components with periods shorter than the shortest period specified in displacement RAOs for the Skandi Arctic. As seen from the RAO plots in chapter 5.1.1, displacement RAOs are only given for periods larger than 4 sec. These values will hence be extrapolated when calculating the vessel response for shorter periods. As the displacement RAO amplitudes are very small for low periods and goes towards zero for the shortest periods the effects of this simplification is regarded negligible.

As mentioned, Torsethuagen spectrum makes no allowance for the directionality of wind sea and swell. OrcaFlex does however facilitate modeling of wave trains with different principal directions. As presented in chapter 4.1.6, DNV suggest that swell waves may be assumed regular in period and height, and may normally also be assumed independent of the wind sea. For the analyses in chapter 8, combined wind sea and swell has therefore been modeled using two separate wave trains, one for the local wind generated sea and one for swell. The wind sea is specified by the JONSWAP spectrum, while swell is modeled by adding a regular Airy wave specified by height and period, where height is measured from trough to crest.

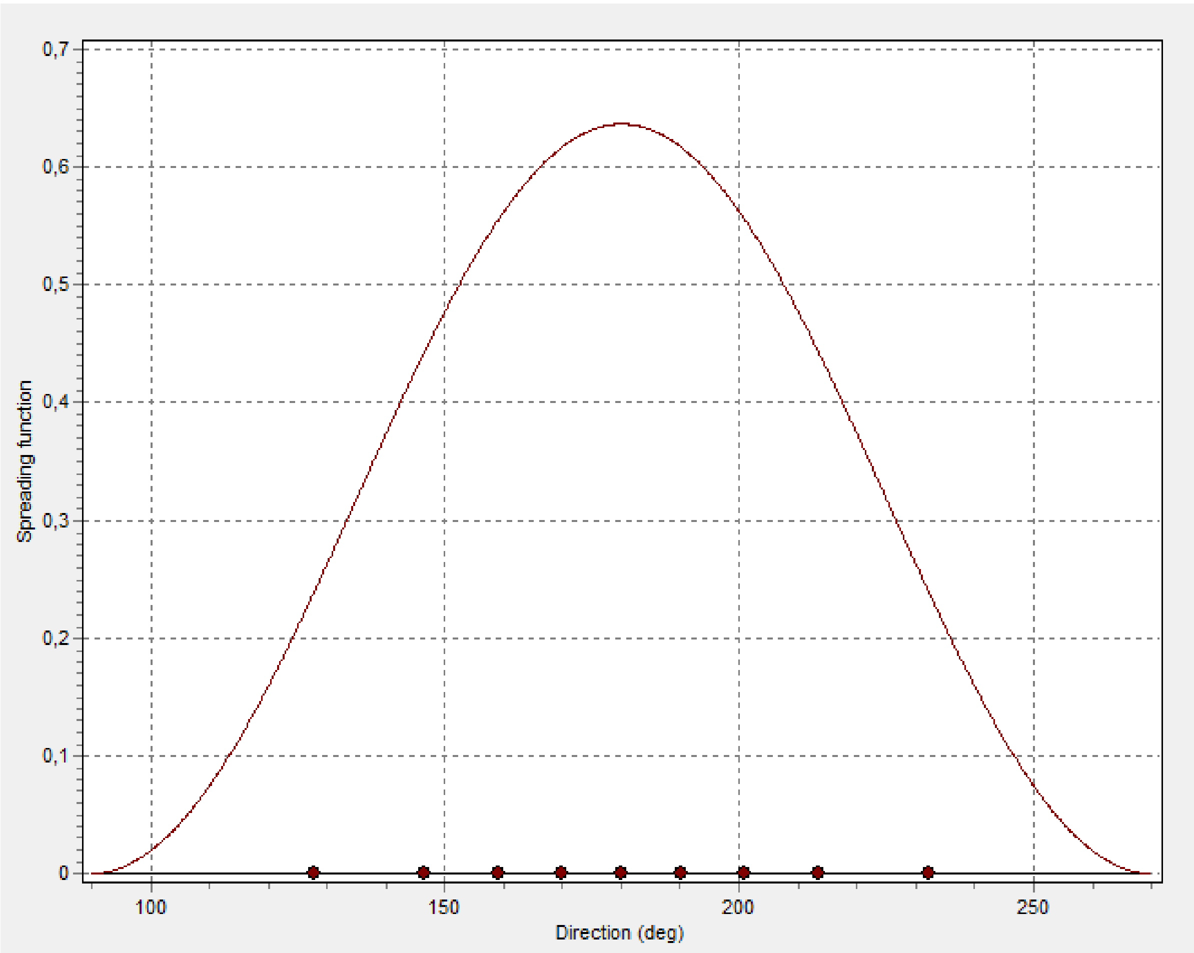


Figure 5-10 Directional Spreading function

6 Analysis Methodology and Preparations

The approach to the analyses carried out in the next two chapters is the same. Time domain analyses are carried out in order to investigate the tension in crane wire and slings when lowering the modeled spool through the wave zone. Separate time domain analyses of the lowering from approximately 2 meters above deck level down to the sea surface is conducted to identify sea states that can lead to excessive pendulum motions. These are dynamic time simulation of the model created, starting from the position derived by the static analysis. Before the main simulation there is a build-up stage, during which the wave and vessel motions are smoothly ramped up from zero to their full size. This gives a gentle start to the simulation and helps reduce the transients that are generated by the change from the static position to fully dynamic motion. This chapter will present the methodology for the analyses and the core of the related preparations made.

6.1 Lift trough Wave Zone Analysis

6.1.1 Methodology

In general, there are two methods for performing time domain analyses of a lift through the wave zone, ensuring the conditions of the irregular sea is transferred to the system of lifted object:

- A time simulation where the object is fixed in selected positions relative to the MWL. Each simulation must be sufficiently long enough to ensure the object is exposed to a range of waves in the irregular sea state. DNV recommends that the object is kept in selected positions for at least 30 min (DNV, 2011 b, p. 48). Several levels through the wave zone must be analyzed for each sea state to determine the maximum and minimum tensions.

- The alternative is to perform a series of repeated lowering. This method is based on continuous lowering of the object through the wave zone at a speed similar to the actual lift, e.g. 0.1 m/s. The same lowering is simulated a number of times, but the simulation time origin relative to the wave time origin is arbitrary every time. A large number of realizations are needed (in the range 50-100) in order to get a proper statistical fit. The maximum and minimum tension in crane wire and slings are extracted from each simulation and fitted to a probability distribution. From this distribution the maximum and minimum tension corresponding to the appropriate probability level can be calculated.

As the work in this report requires comparing a large number of sea states, simulation time and post processing time becomes a considerable issue. Each irregular sea state described by a spectrum will be a combination of H_s, T_p and wave direction. Considering the simple situation of running analyses for 0.5 m increments of H_s from 0.5 m to 3.0 m, combined with 10 values of T_p for 3 wave directions. This results in $6 \cdot 10 \cdot 3 = 180$ sea states. For the repeated lowering method it is reasonable to assume that for each of these 180 sea states one must possibly have 100 runs with duration of 3 min, i.e. 5 hours of simulation for each sea state. This is time consuming, as is the post-processing of the results in OrcaFlex.

An attempt was made to establish a simpler method with respect to performing the analyses, which still gave reasonable results for comparison of sea states. Continuous lowering through the wave zone at a very slow speed (long simulation) was investigated. An extensive comparison of the maximum and minimum crane wire tension for several wave heights and peak periods analyzed with respect to the sensitivity of the simulation time (lowering time) was carried out. After comparing lowering durations up to 60 min it was concluded that there is no consistency in maximum and minimum tensions converging towards a specific value as the simulation time increases. In other words, this is very dependent on the level the spool is located at when a particular wave comes. It is therefore reasoned that for this method to even be considered, one must probably perform the lowering over a period of several hours. Based on these findings it was decided to adopt the method of running analyses for selected positions through the wave zone. In order to avoid confusion it should be emphasized that for this method the spool will still experience vertical movement due to crane tip motions during the simulation, but the crane wire length is fixed.

The positions analyzed are a relative distance between center of spool and MWL of 1.5 m, 0 m and -1.5 m for the vessel’s equilibrium position in still water, as shown in figure 6-1. In the first position the spool and support legs are above water. Position 2 and 3 corresponds to partly submerged and fully submerged. Initially a larger number of positions, both higher and lower were considered, wherefrom these positions were found to give highest and lowest wire tensions. In addition to these three positions, analyses are carried out at a crane wire length where the spool does not interact with the water. One limitation of this method is that the lowering velocity is not taken into account in the relative velocity between sea surface and spool. The lowering velocity is however regarded small compared to the contribution from waves vertical movement and the spools vertical velocity due to crane tip motions. The lowering velocity is hence neglected.

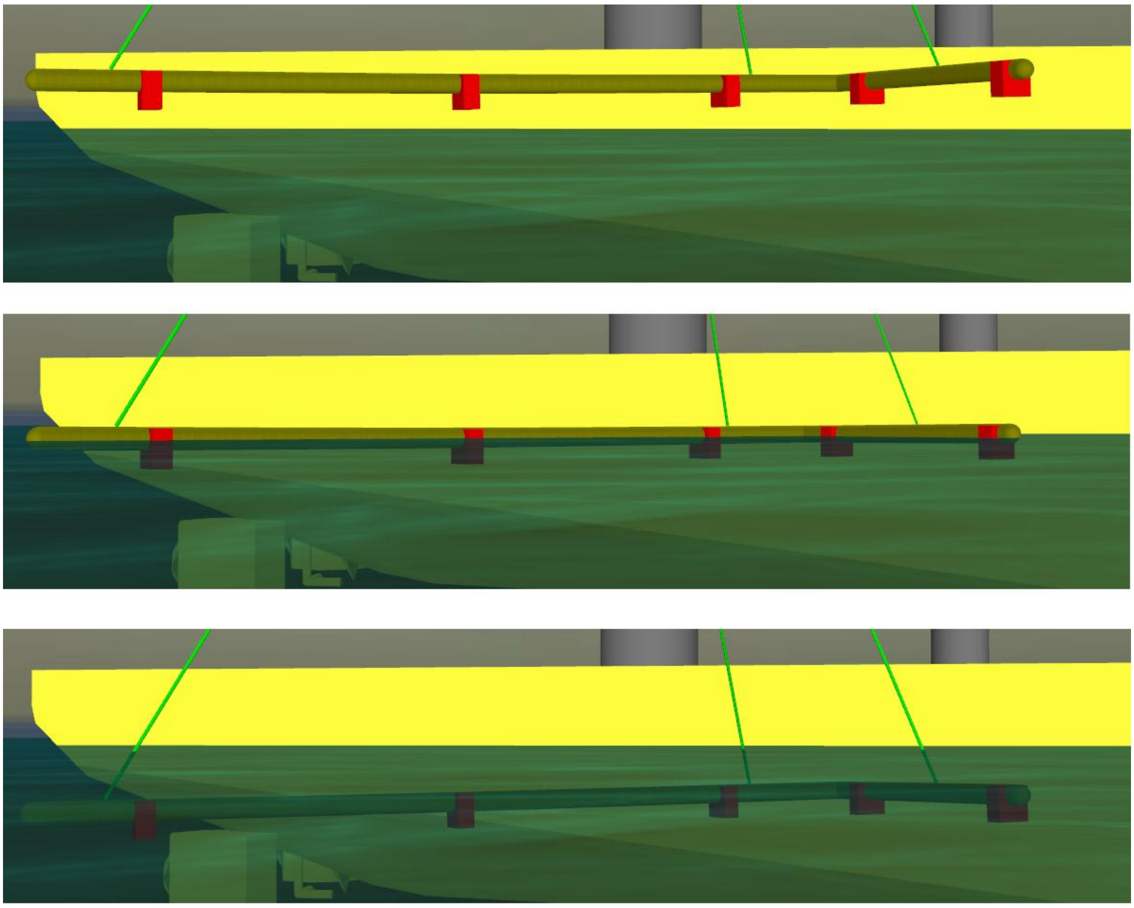


Figure 6-1 Levels of analysis through wave zone

6.1.2 Simulation Time Sensitivity Study

In order to optimize the simulation running time for dynamic analyses, a sensitivity study of the duration was carried out instead of adopting the 30 min recommended by DNV. The study was based on assessing the impact running time has on the crane wire minimum and maximum tension. Analyses were run with the spool partly submerged, exposed to long crested waves for selected wave heights and periods of the JONSWAP spectrum, with a direction of 180°. Simulations were run for 1, 2, 5, 10, 20, 30 and 40 min.

From the results of the analyses it could be observed that after a simulation time of 10 min, the maximum and minimum tension registered in the crane wire more or less levels out. This is seen from the plots in figure 6-2 to 6-5, which gives the results for significant wave heights of 1.0 and 2.0 m, in combination with peak period of 8 and 12 seconds. One should take notice that the column height in the diagrams does not have 0 as reference on the y-axis, but starts at 100 kN. Change (in percent) of maximum and minimum tension in the crane wire from 10 min to 40 min simulation time is presented in table 6-1. A change of 5.4 % is regarded reasonably small to conclude that for the analyses in this report, 10 minute simulations at selected positions through the wave zone is a sufficient duration to establish maximum and minimum tensions this system will experience when lifting through the wave zone in irregular sea states. This is assumed representative for all analyses carried out in chapter 7 and 8.

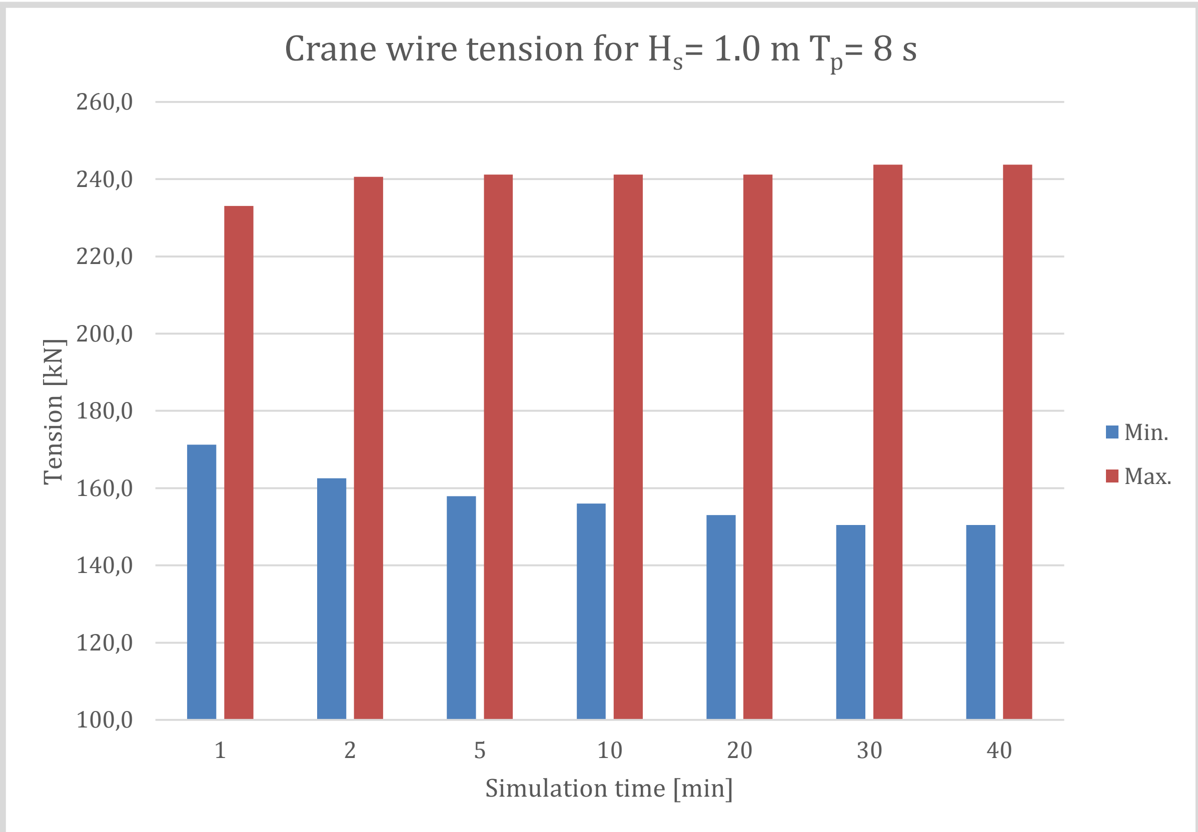


Figure 6-2 Crane wire tension

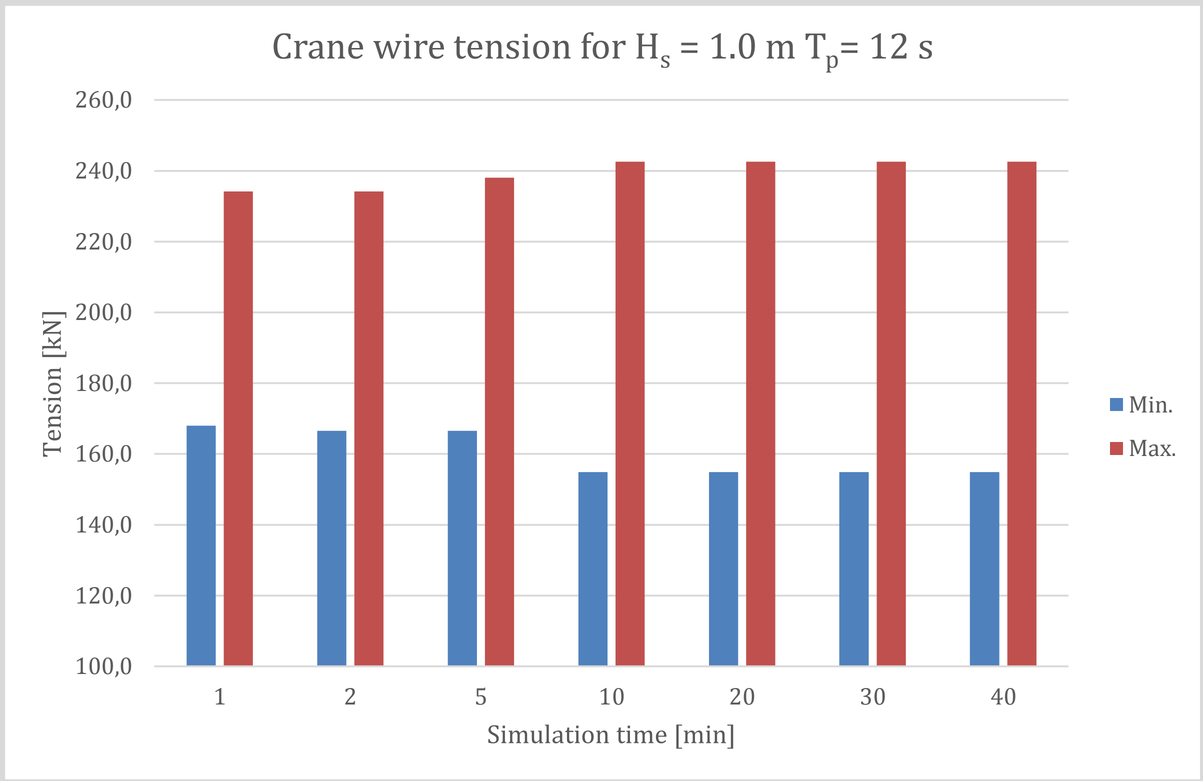


Figure 6-3 Crane wire tension

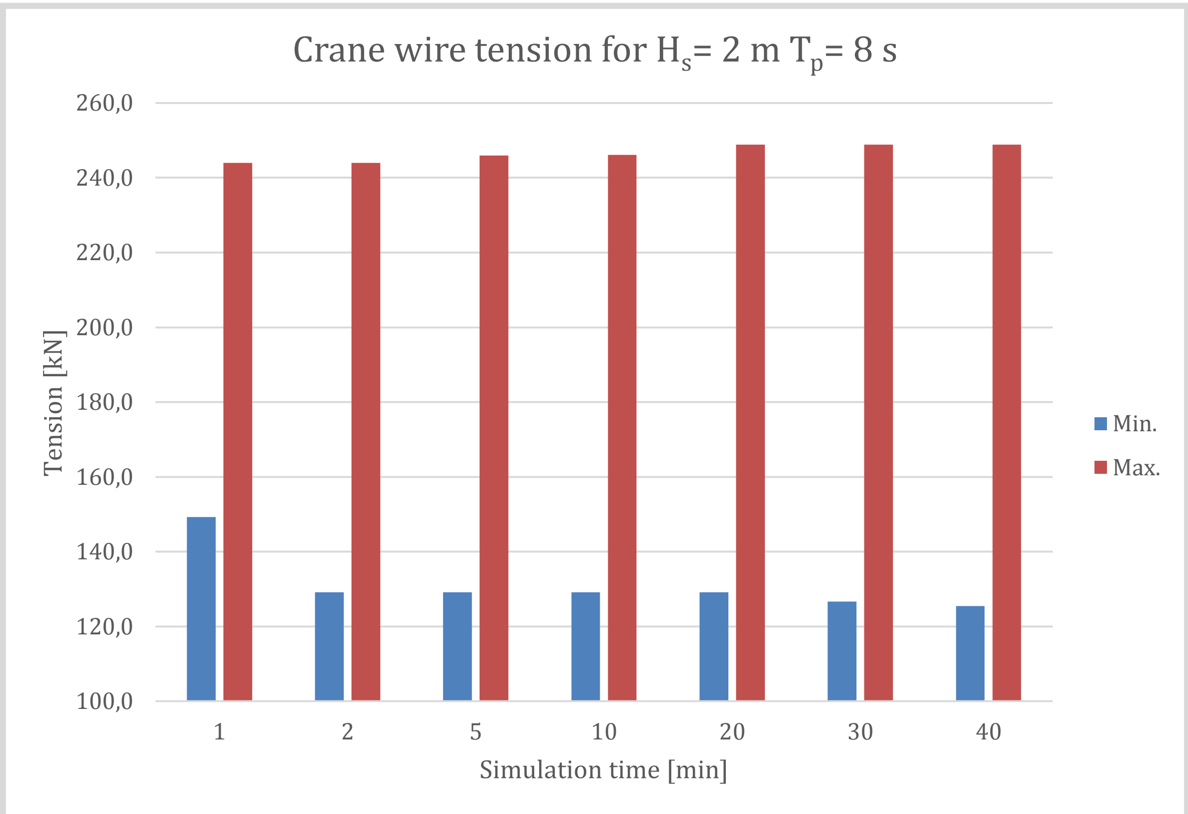


Figure 6-4 Crane wire tension

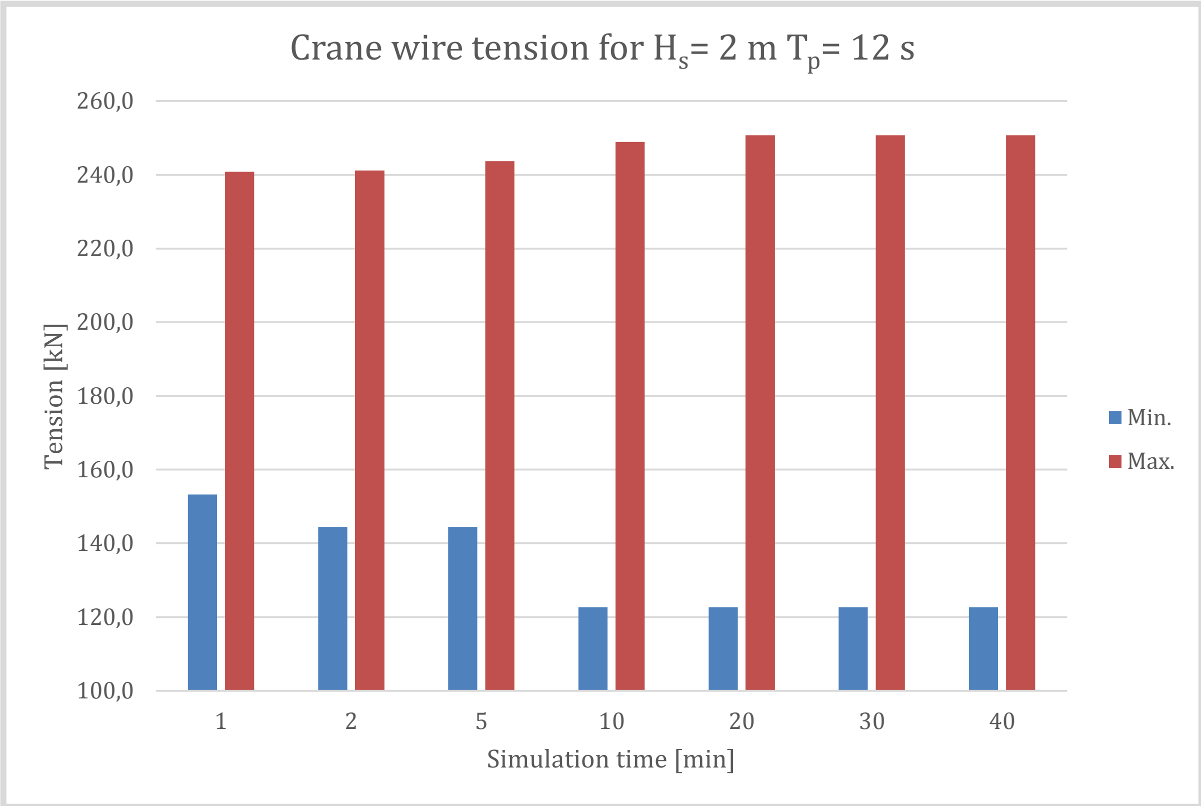


Figure 6-5 Crane wire tension

Table 6-1 Crane wire tension values and rate of change

Sea state		**10 min**		**40 min**		**Change in %**	
H_s [m]	**T_p [s]**	Min [kN]	Max [kN]	Min [kN]	Max [kN]	Min [kN]	Max [kN]
1	**8**	156,0	241,2	147,6	243,7	5,4	1,1
1	**12**	154,9	242,6	154,9	242,6	0,0	0,0
2	**8**	129,1	246,1	125,5	248,9	2,8	1,1
2	**12**	122,7	248,9	122,7	250,7	0,0	0,7

A plot of the crane wire tension time history for a 10 min simulation with H_s = 2.0 m and T_p = 12 s, at each of the three levels of submergence is presented in Figure 6-6. For the first position one can see that the dynamic force in the crane wire is distributed around a mean tension of around 240 kN, which corresponds to the weight in air of the spool and crane block. For the partly submerged level the plot shows a much higher level of tension variation, due to the variation in hydrodynamic forces. When the spool is fully submerged the tension is distributed around a mean force of around 150 kN, corresponding to weight of crane block and submerged spool.

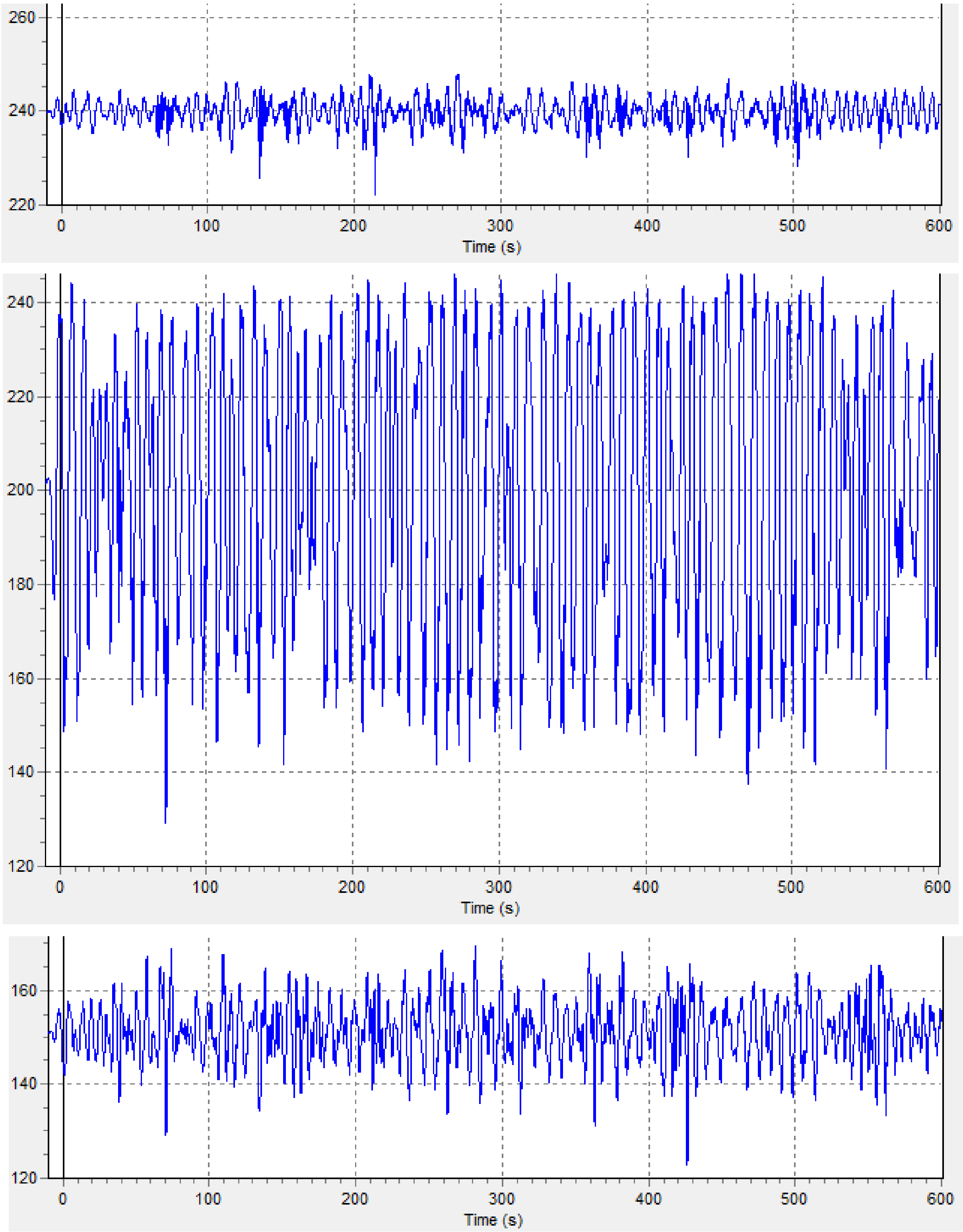


Figure 6-6 Crane wire tension time history for the levels through wave zone

6.1.3 Simulation Time Step Sensitivity Study

The time step in the dynamic analysis gives the interval for updating position, velocity and acceleration vectors of each body and line node in the model and hence also the interval for computation of the system equation of motion. A time step of 0,1 seconds means that this is updated 10 times per second. If the time step is too large one will not be able to capture all loads and motions, whereas a small time step results in very time consuming computations and slower simulations. It is for this reason important to optimize the simulation time step. In the same manner as for the simulation time a sensitivity study was carried out also for the time step. The diagrams in figure 6-7 and 6-8 shows how the maximum and minimum crane wire tension is affected by the change of time step, here presented for a significant wave height of 2.0 m and corresponding peak periods of 8 and 12 s. The tension values clearly levels out for a time step of 0.1 seconds. The tension values change (in percent) as result of reducing the time step from 0.1 s to 0.01 s is presented in table 6-2. A change in the order of 1 % by reducing the time step with a factor 10 is regarded reasonably small to conclude that for the analyses in this report a time step of 0.1 s provides a sufficient level of accuracy in establishing maximum and minimum tensions this system will experience when lifting through the wave zone in irregular sea states.

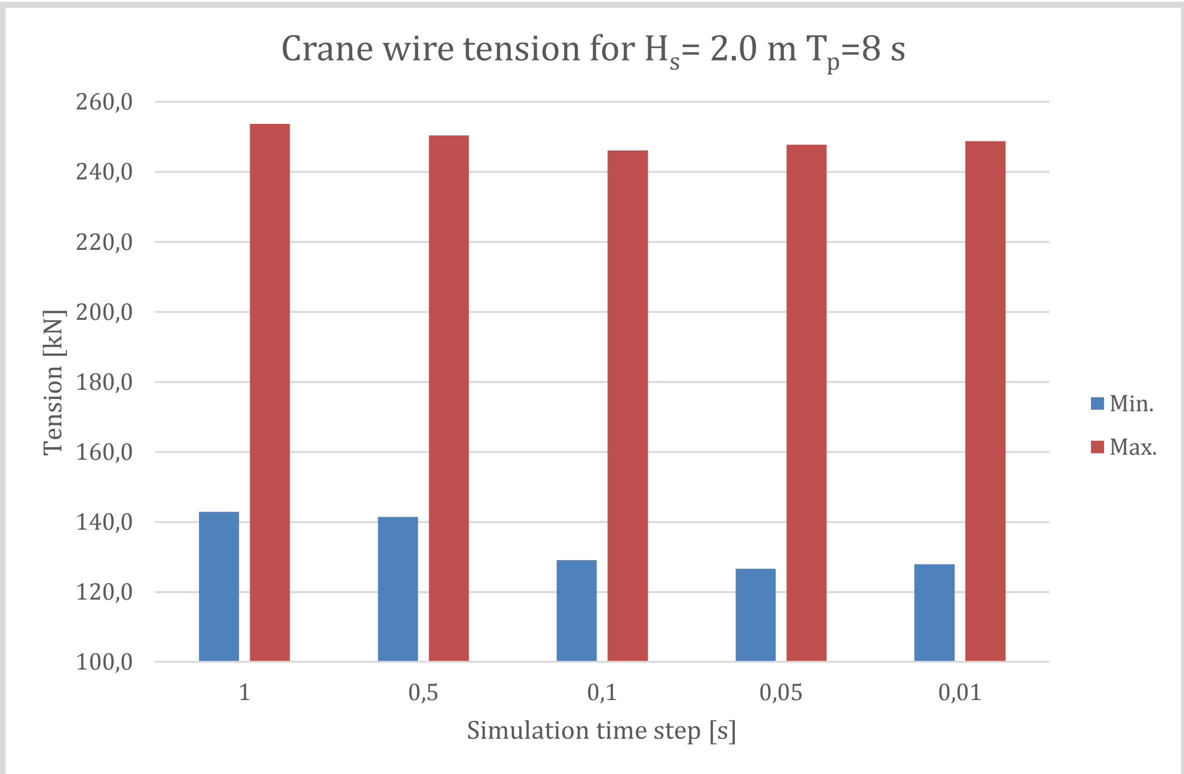


Figure 6-7 Crane wire tension

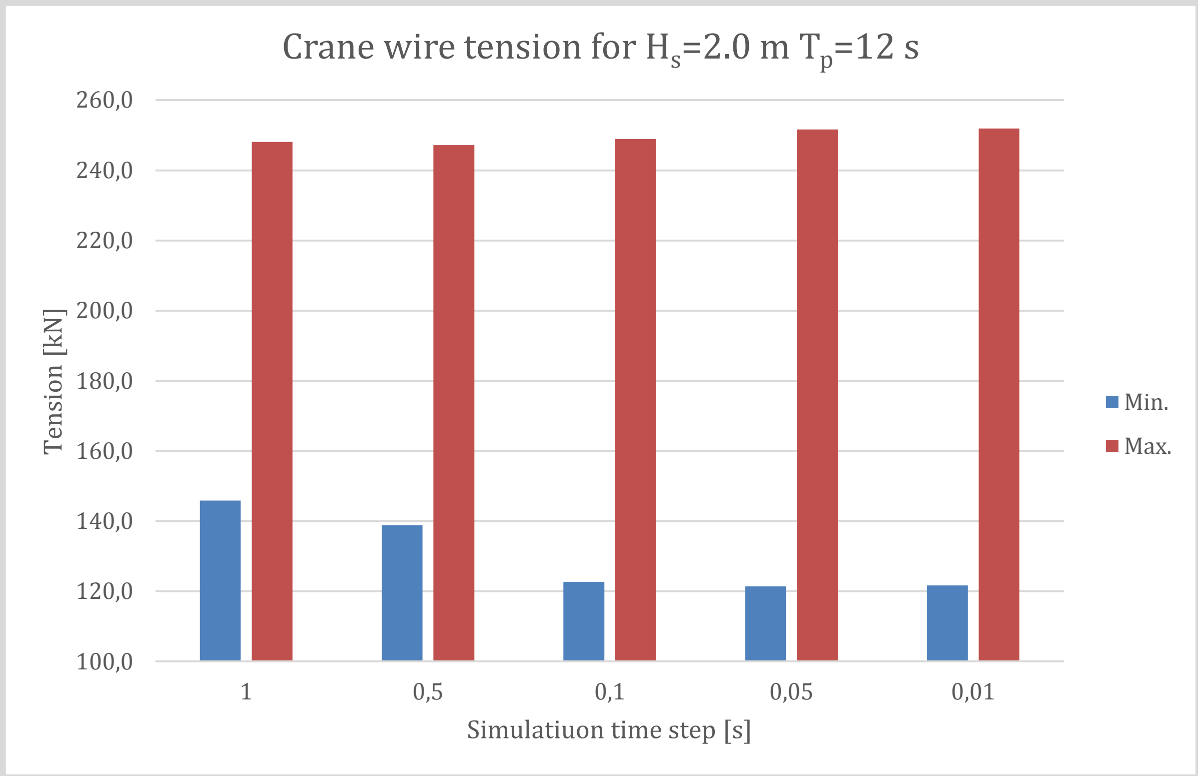


Figure 6-8 Crane wire tension

Table 6-2 Crane wire tension values and rate of change

Sea state		**Time step 0,1 s**		**Time step 0,01 s**		**Change in %**	
H_s [m]	**T_p [s]**	Min	Max	Min	Max	Min	Max
2	**8**	129,1	246,1	127,9	248,7	0,9	1,1
2	**12**	122,7	248,9	121,7	251,9	0,8	1,2

6.1.4 Safe Working Load and Safety Factors

According to (DNV, 2011 a, p. 6): "The intention of the load – safety and material factors in the VMO Standard is to ensure a probability for structural failure less than 1/10000 per operation (10^{-4} probability). In other words, for a given operation, e.g installation lift for spool, all the components of the system should fulfill this criterion. The elements of the system to be considered are the lifted structure, the lift rigging, the lift wire and the vessel crane. In order to ensure the integrity of the system with regards to failure it is mandatory to follow this principle. Each component of the system is designed for a Safe Working Load (SWL), directly related to an ultimate capacity (failure mode) by safety factors. As a reminder, this report does not consider the structural integrity of the spools installed.

The capacity of the main crane on Skandi Arctic for a lifting operation in single fall at a radius up to 25 m is limited to 200 Te. This capacity includes a DAF of 1.3 in the capacity limit, and is indicated in the load chart in figure 6-9 as Max. SWL. As the DAF is accounted for in the analysis, the maximum allowable tension in the crane wire is $200\,Te \cdot 1.3 = 260\,Te$. This is equivalent of a crane wire tension of 2550 kN. The SWL for the crane wire will always be superior to the one of the crane since the wire is designed for a load which corresponds to the maximum dynamic crane capacity with higher load factors:

$$SWL_{Crane\ wire} > SWL_{Crane} \tag{6.1-1}$$

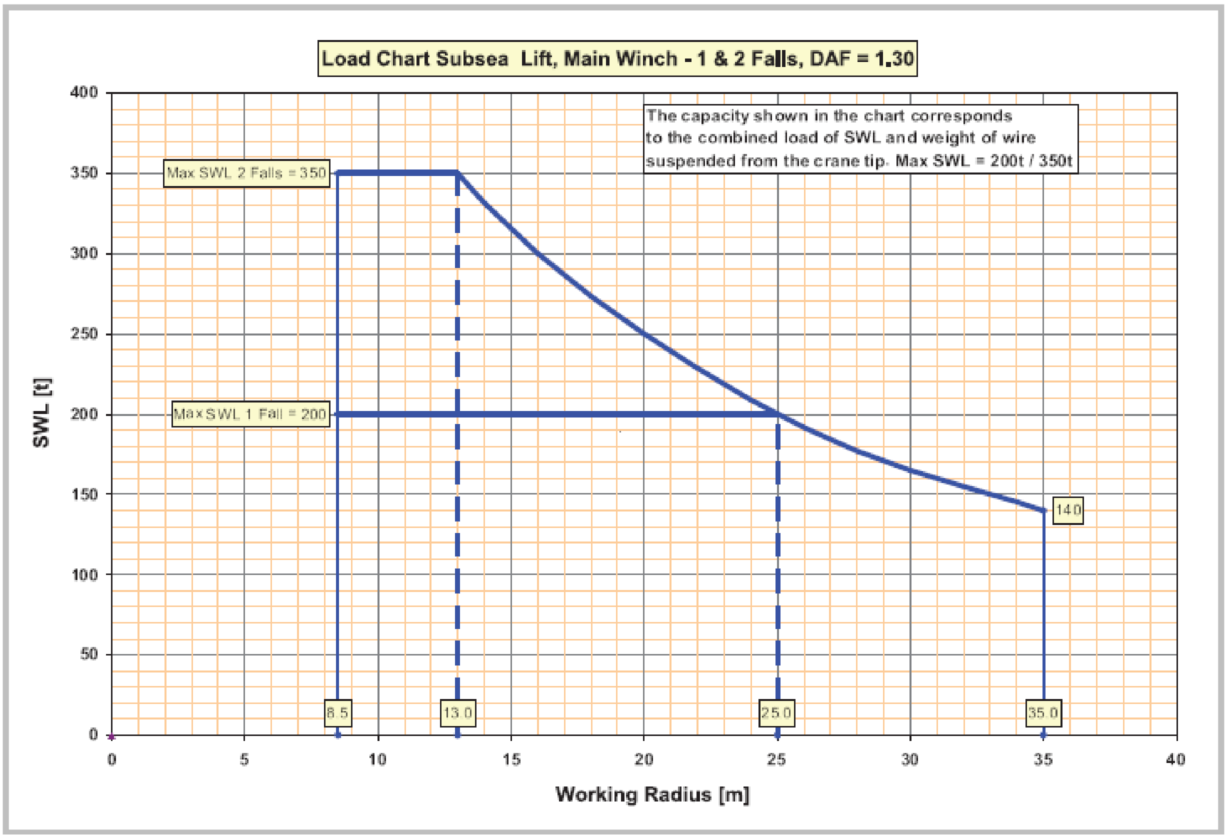


Figure 6-9 Load Chart for subsea lifts – Main Crane

According to (DNV, 2007, p. 25) the calculated maximum dynamic sling load $F_{sling,max}$ should fulfil the equation:

$$F_{sling,max} < \frac{MBL_{sling}}{\gamma_{sf}} \tag{6.1-2}$$

In which MBL_{sling} is the minimum breaking load and γ_{sf} is the nominal safety factor for slings and grommets. The safety factor should be taken as the greatest of the following products of partial factors:

$$\gamma_{sf} = \gamma_f \, \gamma_c \, \gamma_r \, \gamma_w \, \gamma_m \, \gamma_{tw}$$
$$\gamma_{sf} = 2.3 \, \gamma_r \, \gamma_w \, \gamma_{tw} \tag{6.1-3}$$

In which the partial factors are accounting for:

γ_f = load factor
γ_c = consequence factor
γ_r = reduction factor due to end termination or bending
γ_w = wear and application factor
γ_m = material factor
γ_{tw} = twist reduction factor

Safety factors are hence applied to account for uncertainty in material, load, lifting configuration etc. However, when performing refined software lifting analyses, the knowledge of the load is well controlled. Uneven distribution of load in the individual slings is accounted for. It is therefore possible to reduce the required safety factor. According to (DNV, 2007, p. 25), the safety factors related to the load (γ_f and γ_c) can be taken equal to $1.3 \cdot 1.3 = 1.69$. The SWL of the lifting slings can hence be expressed as:

$$SWL_{sling} = \frac{1.69 \cdot MBL_{sling}}{\gamma_{sf}} \tag{6.1-4}$$

The other partial factors for slings and grommet are in accordance with (DNV, 2007, p. 25) and the design of lifting rigging taken as:

γ_r = 1.12
γ_w = 1
γ_m = 1.5
γ_{tw} = 1

Resulting in a nominal safety factor $\gamma_{sf} = 2{,}84$. The SWL for individual slings and pennant in the lifting arrangement is governed by the relation:

$$SWL_{sling} = \frac{1.69 \cdot MBL_{sling}}{2.84} = \mathbf{0.6 \cdot MBL_{sling}} \tag{6.1-5}$$

MBLs obtained from the internal Technip rigging catalogue and calculated SWL for the various wires of the designated lift rigging is presented in table 6-3. The static tension in each wire retrieved from the static analysis in OrcaFlex is also included in the table, along with the 10 % level of static tension.

Table 6-3 Wire tension levels

	MBL [kN]	SWL [kN]	Static tension [kN]	10 % level of static [kN]
Crane wire		2550	239,8	23,98
Pennant	1929,2	1157	195,7	19,57
Wire sling 1	715	429	75,4	7,54
Wire sling 2	715	429	89,3	8,93
Wire sling 3	715	429	46,8	4,68

6.1.5 Acceptance Criteria for Lift through Wave Zone

The limiting sea states are determined on the basis of the following acceptance criteria:

Maximum loads
The maximum acceptable tension in crane wire, slings and pennant is governed by the SWL.

Slack sling avoidance
The crane wire and the slings used in the lifting arrangement shall not become slack. To fulfill this criterion in accordance with the DNV regulations presented in the introduction chapter:

- Dynamic load in the crane wire shall not be less than 10% of the static tension for any cases analyzed.

- Dynamic load in individual slings and pennant shall not be less than 10% of the static tension according to **Earlier recommended practice.**

- Individual slings and pennant must at all times have tension in them according to **New regulations.**

6.2 Excessive Pendulum Motion Analysis

6.2.1 Methodology

Acceptable maximum and minimum tension in crane wire or slings is of lesser importance if a particular sea state results in motions where the lifted spool is in danger of being damaged, or in other way jeopardizes safety due to excessive pendulum motions. For this reason, separate time domain analyses of the lowering are carried out in order to identify such situations. These analyses consists of lowering the spool from approximately 2 m above deck level, down to the sea surface. The speed of lowering must be low enough for potential excessive motions to develop and cover a sufficient length of the time series of an irregular sea state. The crane wire payout rate is for this reason set as low as 0,03 m/s for these analyses.

6.2.2 Acceptance Criteria for Excessive Pendulum Motions

All situations where the spool is registered to come closer than 0,5 m to the side of the vessel in the lowering analyses is registered as excessive pendulum motions. This is not a specific acceptance criteria in the DNV regulations, but established as a limit for this particular operation to be regarded safe.

6.3 Modal Analysis

The modal analysis feature in OrcaFlex has been used for analyzing natural modes of the modeled spool and its lifting arrangement. This is an analysis based on the static position of the modeled system which reports modes of oscillation about that static mean position. The interesting modes for this case are the natural periods of the pendulum motion. The mode shapes of pendulum motions are shown in figure 6-12. As the shape of the spool is unsymmetrical the analysis reports two mode shapes for the pendulum motion with corresponding natural periods.

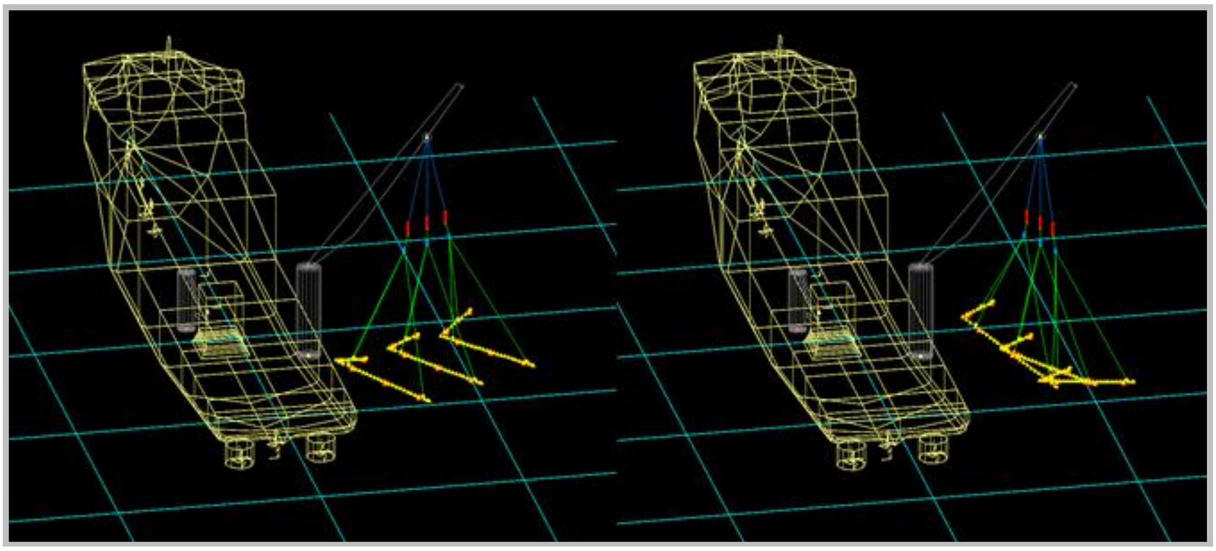


Figure 6-10 Mode shapes for pendulum motion, Left: Mode 1 Right: Mode 2

The spool is free to rotate during the lift and both of these periods are hence equally relevant with respect to risk of clashing with the ship. The analysis has been performed for crane wire lengths from 11 m to 20 m with 1 m increment. At 11 m wire length the spool is approximately 2 m above deck level while it is fully submerged at 20 m wire length. The results from the modal analysis are presented in table 6-4, along with results obtained from calculating the natural period for pendulum motion according to the theory in chapter 4.4. The calculated periods are based on the assumption that the length of hoisting line is the crane wire length plus the height of rigging. As seen from the results, the calculated values compare reasonably well with the once obtained from the modal analysis. Some deviations are to be expected, as the effect of crane block mass is included in the modal analysis, while neglected for simple calculations. The calculations do however provide a reasonable verification of the software modal analysis. The difference in natural period for mode 1 and mode 2 is minor. The period is in the range of 12-13 seconds for both modes while the spool is in the air. The natural period is increasing slightly as the wire length increase, which is in accordance with the theory and calculated periods. At 18 m wire length there is a sudden increase in natural period. This is due to the interaction with water, imposing considerable damping to the pendulum motion. Fully submerged the natural period is around 20 s.

Table 6-4 Natural period of pendulum motion

Crane wire length[m]	Calculated period [s]	Mode 1 period [s]	Mode 2 period [s]
11	12,85	12,17	12,47
12	13,00	12,32	12,61
13	13,15	12,47	12,74
14	13,31	12,61	12,88
15	13,46	12,76	13,01
16	13,46	12,9	13,18
17	13,61	13,04	13,28
18	-	19,62	16,56
19	-	20,16	18,97
20	-	20,35	19,13

7 Wind Sea Comparison Study

This chapter deals with the investigation of the effects on the limiting operational wave criterion for the spool installation lift when including directional spreading to the wave spectrum describing wind sea, as compared to earlier recommended practice where waves could be assumed being long crested. Also the new acceptance criterion for minimum sling tension is taken into account.

7.1 Analysis Methodology

In this comparison study, and hence for all the analyses carried out, the vessel is assumed headed directly towards the main direction of the wind sea. This result in comparing the lift carried out for the following two cases of wave directions relative to vessel:

Case 1: Long crested waves with direction 180 ± 15° **(Earlier recommended practice).**

Case 2: Short crested waves with direction 180 ± 15° **(New regulations).**

Performing dynamic analyses where the system of vessel, lifting arrangement and spool is exposed to waves with directions of 180 ± 15°, means that the directions 165°, 180° and 195° are analyzed separately and also checked against the acceptance criteria separately. These wave directions are illustrated in figure 7-1. For short crested waves these directions give the main direction from which elementary wave trains are distributed around. As explained in the previous chapter, the acceptance criteria for the two cases are the same, except the criterion for minimum sling tension. For case 1, a margin of 10 % to the start of slack slings is required. For case 2, it is sufficient to only have tension in the slings. In order to investigate the impact of the new criterion for minimum sling tension, the results from the analyses with short crested waves has also been checked against the earlier recommended acceptance criteria for minimum sling tension.

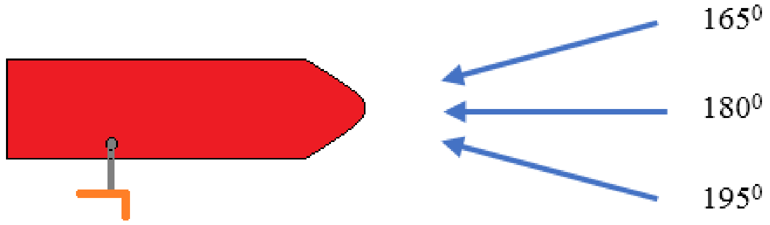


Figure 7-1 Wave directions

The fact that the comparison study is based on the JONSWAP spectrum makes it representative for an operation carried out at the Alvheim field in the North Sea. This is also the basis for selecting the range of wave peak periods to include in the analyses. Even though weather restricted operations are planned with environmental conditions selected independent of statistical data, one can narrow down the sea states necessary to consider by looking into wave statistics. The relation presented in equation 4.1-20, giving the period range to be considered for the design spectra method could be regarded to give extreme limits. A reduced range can therefore be considered based on joint probability of period and wave height applying scatter diagrams for the actual area (DNV, 2011 a, p. 24). A joint frequency distribution of significant wave height and peak period in the Alvheim area is presented in table 7-1. The table is retrieved from a design report for environmental conditions at the Alvheim field, provided by Technip. The wave statistics are based on actual measured data combined with model data from the European Centre of Medium Range Forecasting (ECMWF). Based on this table the upper range of peak period included in the comparison study is set to 13 seconds. This covers the majority of sea states in that area. The lower frequency range is taken according to the relation in eq. 4.1-20. One can see that the combination of H_s and T_p for which waves break is clearly visualized in a joint frequency table. H_{m0} is simply another symbol for significant wave height, where the subscript refers to the fact that it can be defined as four times the square root of the zeroth-moment of area under the spectral curve.

Time domain analyses have been carried out in accordance with the methodology presented in chapter 6. Sea states with significant wave heights of 0.5 m increment up to 3.0 m have been analyzed.

Table 7-1 Joint frequency distribution of H_s and T_p at Alvheim field

Joint frequency distribution of Hm0 vs. Tp for 100 years (3 hourly observations)																
Tp		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Sum
Hm0		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
0.5	1.0	6	661	4555	7901	6388	3279	1268	409	117	31	8	2	0	0	0	24624
1.0	1.5	0	242	4390	13626	15710	9952	4310	1454	415	106	25	6	1	0	0	50237
1.5	2.0	0	22	1379	9029	16277	13329	6568	2307	643	153	33	6	1	0	0	49746
2.0	2.5	0	1	221	3842	12437	14271	8343	3095	838	182	34	6	1	0	0	43270
2.5	3.0	0	0	16	1001	7008	12650	9394	3811	1013	199	32	4	1	0	0	35129
3.0	3.5	0	0	0	144	2745	9065	9409	4419	1187	213	29	3	0	0	0	27214
3.5	4.0	0	0	0	10	691	4998	8188	4821	1373	231	26	2	0	0	0	20341
4.0	4.5	0	0	0	0	104	2002	5950	4851	1572	260	26	2	0	0	0	14767
4.5	5.0	0	0	0	0	9	556	3455	4354	1750	305	28	2	0	0	0	10458
5.0	5.5	0	0	0	0	0	105	1547	3356	1838	366	34	2	0	0	0	7247
5.5	6.0	0	0	0	0	0	14	527	2151	1753	435	44	2	0	0	0	4926
6.0	6.5	0	0	0	0	0	1	138	1127	1469	492	59	3	0	0	0	3290
6.5	7.0	0	0	0	0	0	0	29	483	1057	510	78	5	0	0	0	2162
7.0	7.5	0	0	0	0	0	0	5	173	648	469	97	8	0	0	0	1400
7.5	8.0	0	0	0	0	0	0	1	53	340	378	110	11	1	0	0	894
8.0	8.5	0	0	0	0	0	0	0	14	155	266	111	16	1	0	0	563
8.5	9.0	0	0	0	0	0	0	0	3	63	165	99	19	1	0	0	351
9.0	9.5	0	0	0	0	0	0	0	1	23	91	78	21	2	0	0	216
9.5	10.0	0	0	0	0	0	0	0	0	8	45	56	20	3	0	0	131
10.0	10.5	0	0	0	0	0	0	0	0	2	20	35	17	3	0	0	79
10.5	11.0	0	0	0	0	0	0	0	0	1	8	21	14	3	0	0	47
11.0	11.5	0	0	0	0	0	0	0	0	0	3	11	10	3	0	0	28
11.5	12.0	0	0	0	0	0	0	0	0	0	1	5	6	3	0	0	16
12.0	12.5	0	0	0	0	0	0	0	0	0	0	3	4	2	0	0	9
12.5	13.0	0	0	0	0	0	0	0	0	0	0	1	2	1	0	0	5
13.0	13.5	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	3
13.5	14.0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2
14.0	14.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
14.5	15.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sum		6	925	10561	35552	61368	70222	59131	36881	16265	4931	1085	195	31	4	1	297157

7.2 Results

The results for the time domain analyses are presented in terms of tables displaying whether or not the acceptance criteria established in chapter 6 are fulfilled. The tables are presented with respect to combination of H_s and T_p, for each of the cases investigated. Separate tables are presented for the acceptance criteria related to sling tension and the one related to excessive pendulum motions. The table giving "Limiting operational criterion" is simply the combination of limiting sea states for sling tension and the limiting sea states for excessive pendulum motion. Hence, this table gives the sea states in which the operation can be regarded acceptable and unacceptable to carry out. It should be emphasized that the α-factor used for establishing forecasted operational criteria is not considered here.

The tables presented gives the combined results for the three wave directions analyzed. The tables for sling tension criteria are based on detailed results of minimum and maximum tension in crane wire, pennant and individual slings for each of the sea states and directions analyzed. These results are presented in appendix D.

The following color code is used in the tables:

Grey	Sea states outside the analyzed region
Green	Sea states fulfilling acceptance criteria
Red	Sea states not fulfilling acceptance criteria for sling tension
Yellow	Sea states not fulfilling acceptance criterion for excessive pendulum motions
Dark red	Combined acceptance criteria not fulfilled

7.2.1 Case 1: Long Crested Waves

Table 7-2 Limiting sea states for case 1

Limiting sea states sling tension												
H_s [m]	Wind sea direction [°]	T_p [s]										
		3	4	5	6	7	8	9	10	11	12	13
0,5	180 ± 15 Long crested											
1												
1,5												
2												
2,5												
3												

Limiting sea states excessive pendulum motions												
H_s [m]	Wind sea direction [°]	T_p [s]										
		3	4	5	6	7	8	9	10	11	12	13
0,5	180 ± 15 Long crested											
1												
1,5												
2												
2,5												
3												

Limiting operational criterion												
H_s [m]	Wind sea direction [°]	T_p [s]										
		3	4	5	6	7	8	9	10	11	12	13
0,5	180 ± 15 Long crested											
1												
1,5												
2												
2,5												
3												

The limiting sea states for sling tension are governed by the slack sling criterion. This mainly concerns the individual slings, but also pennant for some of the higher waves. In other words, maximum tensions are never exceeding the SWL.

From the table we can see that a range of H_s and T_p combinations result in slack slings. The general trend is that the higher the waves get, the more wave periods are restricted. An interesting observations should however be elaborated. The limiting significant wave height is stricter for the lower peak periods, in the range 5-6 s. As we can recall from chapter 4.1.4, these are sea states defined by wave spectra with more pronounced peaks (large γ-factors), where the wave energy is closer distributed around the peak period. For a particular significant wave height, lower peak period should correspond to higher vertical water particle velocity and acceleration. These are the parameters decisive for the hydrodynamic loading on the spool. Inertia force is proportional to the water particle acceleration, while drag force and slamming force are proportional to the velocity squared. Plots of maximum vertical water particle velocity and acceleration acting on the spools midpoint, taken from the analyses for wave direction 180^0 are presented in figure 7-2 and 7-3. Quite clearly, the velocity and acceleration reaches high values for the shortest periods.

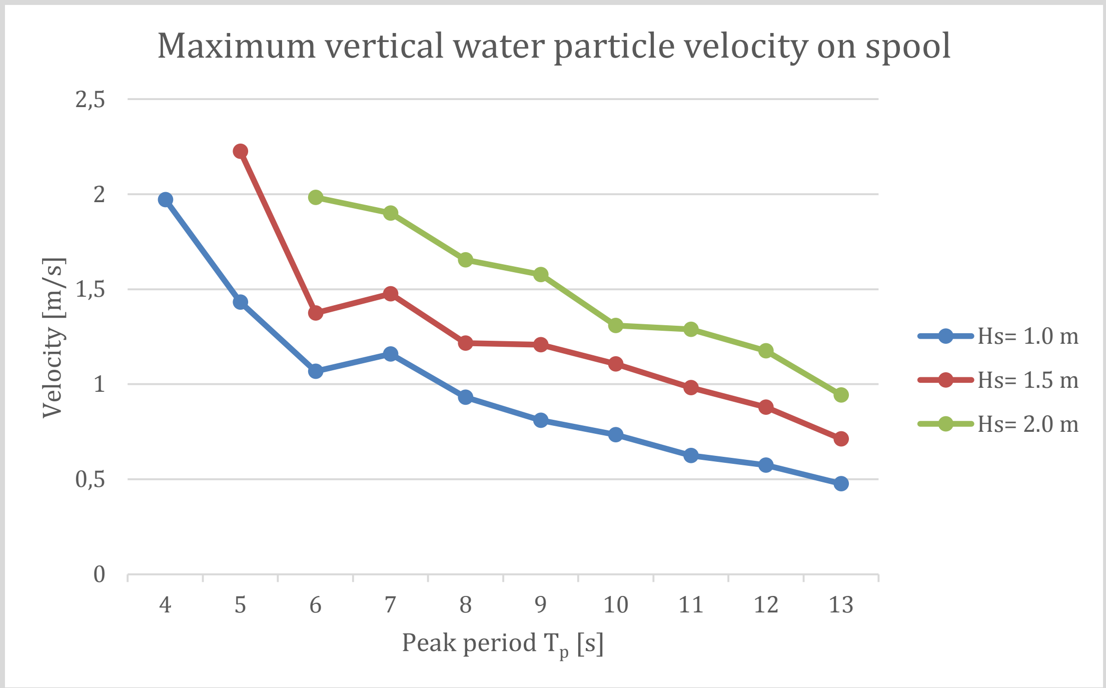


Figure 7-2 Maximum vertical water particle velocity on spool

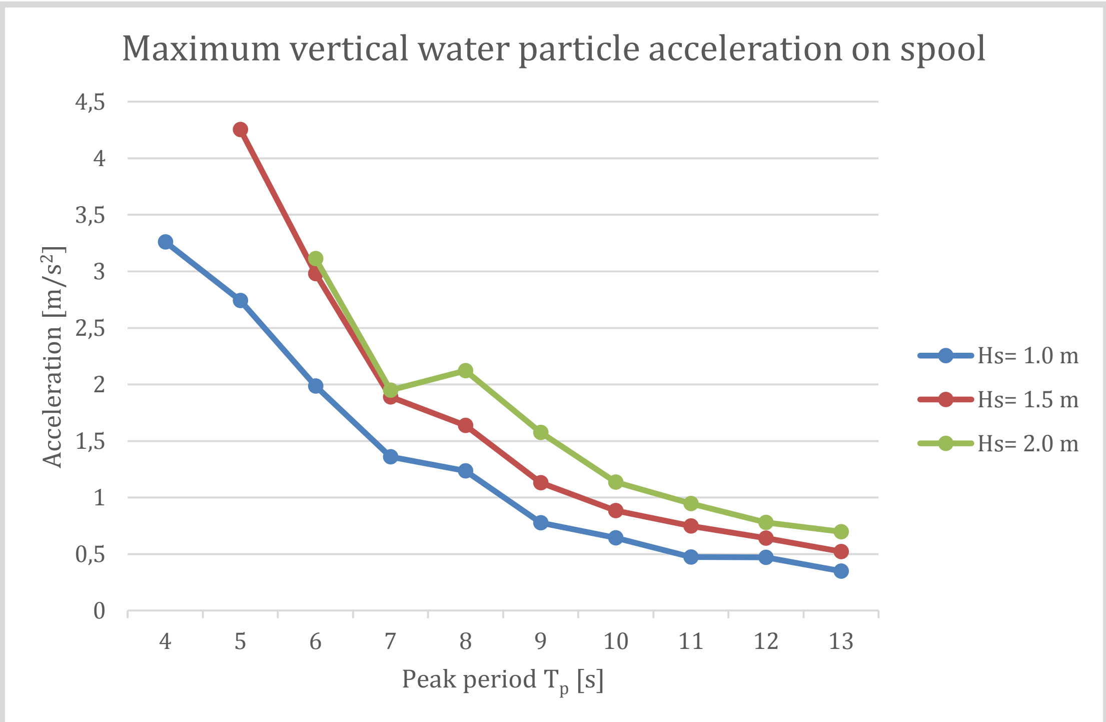


Figure 7-3 Maximum vertical water particle acceleration on spool

As expected the results also shows higher hydrodynamic loading for the analyses with shorter peak periods. There are in particular significant slamming forces acting on the spool when lifting through the wave zone. Figure 7-4 shows how the slamming force on one of the slamming buoys representing the spool varies with peak period and significant wave height. These results are also from the analyses with wave direction 180^0. Slamming forces increases as peak period reduced, and reaches rather high values for the sea states of shortest peak period. The spools slamming area consists of 33 of these buoys. As a reference, slamming force of 3 kN acting on each of these buoys is close to 100 kN, which equals the submerged weight of the spool. Obviously, maximum slamming will not occur along the whole spool at the same time, which also is the reason for dividing the slamming area into small segments. However, we realize that slamming has the potential to reduce the slings tension to go slack, particularly for sea states of short peak period.

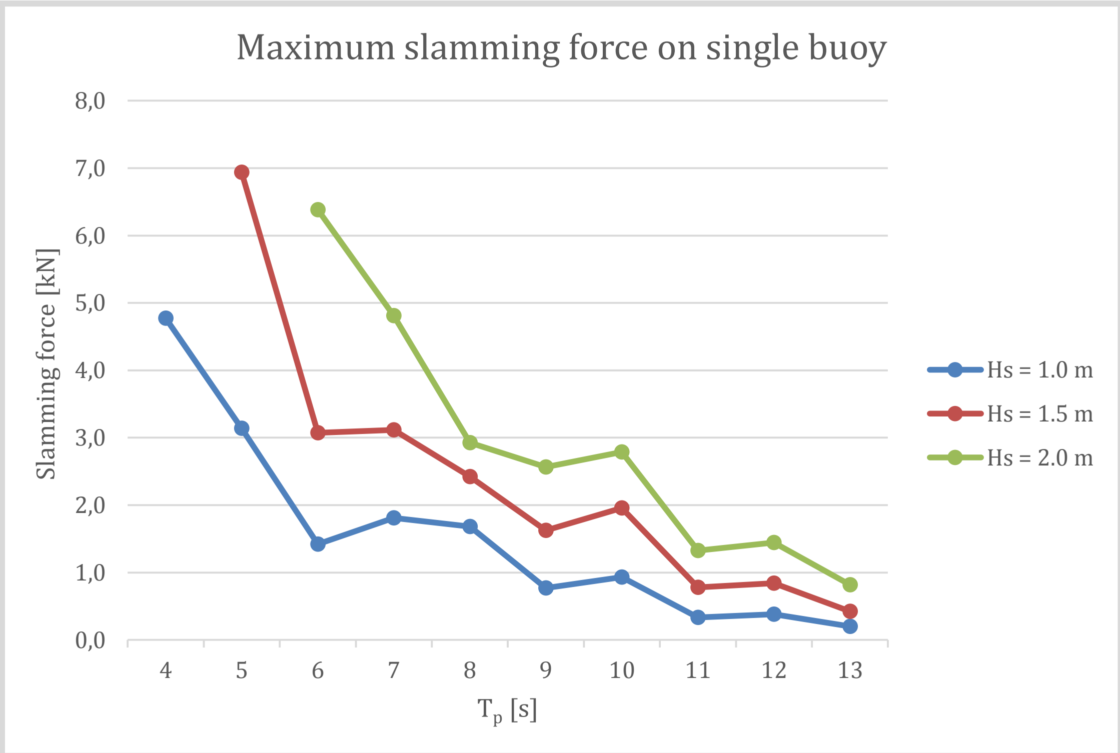


Figure 7-4 Maximum slamming force on single buoy

From table 7-2, one can see that excessive pendulum motions are registered for peak period of 10 sec for significant wave height 2 m and higher. Results shows that excessive pendulum motions towards the vessel side are closely correlated to the roll motion. For long crested waves the roll amplitude is zero for waves of direction 180^0. The excessive pendulum motions are caused by the waves with an angle to the vessel bow. A plot of the maximum roll amplitude for wave direction 195^0 is presented in figure 7-5. The roll amplitude is largest for a peak period of 10 seconds. As we can recall from chapter 5.1.1, 10 seconds is close to the vessel's natural period of roll motion and hence waves of this period result in large amplitudes of roll motion.

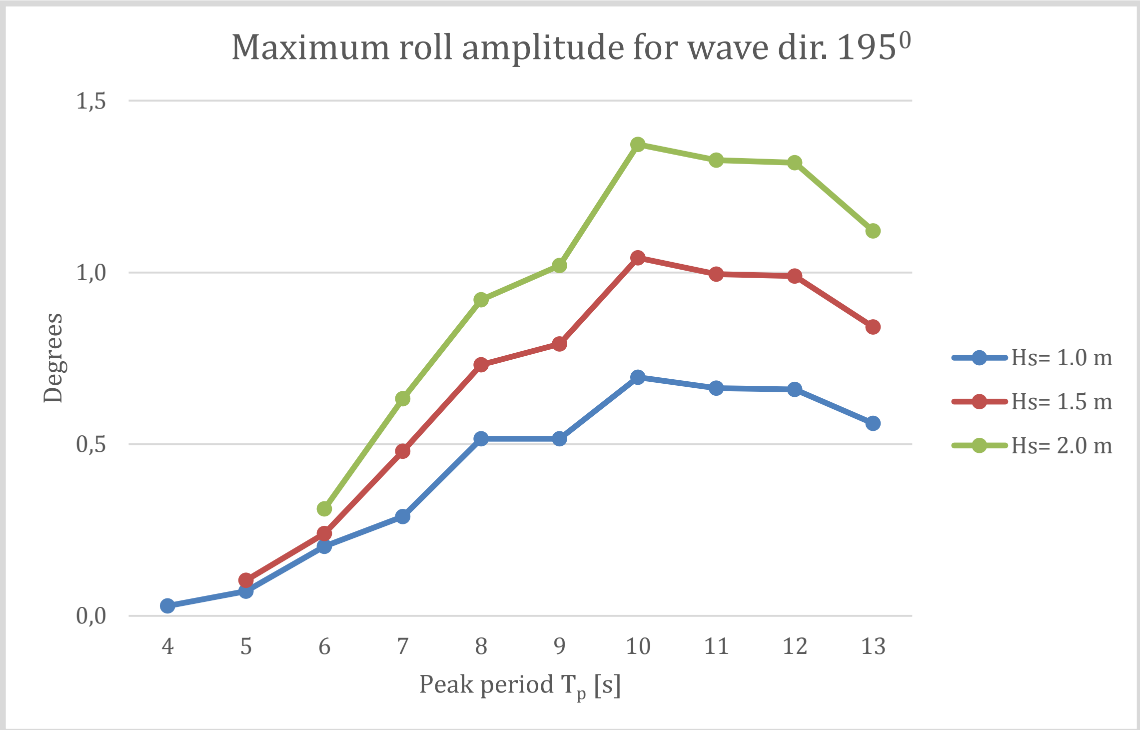


Figure 7-5 Maximum roll amplitude for wave direction 195^0

Limiting operational criterion
The limiting operational criterion for deploying the spool, given in table 7-2, is a sea states of significant wave height 1.0 m without any restrictions in the wave peak period. For sea states of significant wave height 1.5 m, the peak period is limited to the range 8-13 s. Furthermore, the for significant wave height 2.0 m is limited to peak periods in the range 12-13 s.

According to earlier recommended DNV practice, these are the limitations for carrying out the considered spool installation lift in sea states characterized by the JONSWAP spectrum.

7.2.2 Case 2: Short Crested Waves

Table 7-3 Limiting sea states for case 2

Limiting sea states sling tension												
H_s [m]	Wind sea direction [°]	T_p [s]										
		3	4	5	6	7	8	9	10	11	12	13
0,5	180 ± 15 Short crested											
1												
1,5												
2												
2,5												
3												

Limiting sea states excessive pendulum motions												
H_s [m]	Wind sea direction [°]	T_p [s]										
		3	4	5	6	7	8	9	10	11	12	13
0,5	180 ± 15 Short crested											
1												
1,5												
2												
2,5												
3												

Limiting operational criterion												
H_s [m]	Wind sea direction [°]	T_p [s]										
		3	4	5	6	7	8	9	10	11	12	13
0,5	180 ± 15 Short crested											
1												
1,5												
2												
2,5												
3												

Also in this case, the limiting sea states for sling tension are governed by the slack sling criterion.

Comparing the results in table 7-3 to table 7-2, it can be seen that the new regulations results in more sea states that are restricted with respect to sling tension. Excessive pendulum motions also restrict the operation for a wider range of wave peak periods and somewhat lower significant wave height. Waves with peak periods in the range 10-13 seconds in particular. One of the most distinct effects observed when applying short crested waves in the analyses is the effect it has on the vessel's roll motion. A comparison of the maximum roll amplitude in long crested and short crested waves of significant wave height 1.5 m is presented in figure 7-6 and 7-7. For a wave direction of 180^0 the vessel does not have any roll motion for long crested waves, as all the wave energy is applied in one direction. Short crested waves does however introduce roll amplitudes close to 2 degrees. The effect is also evident for waves with direction 195^0, where short crested waves induces roll motions with amplitude up to twice the amplitude for long crested waves.

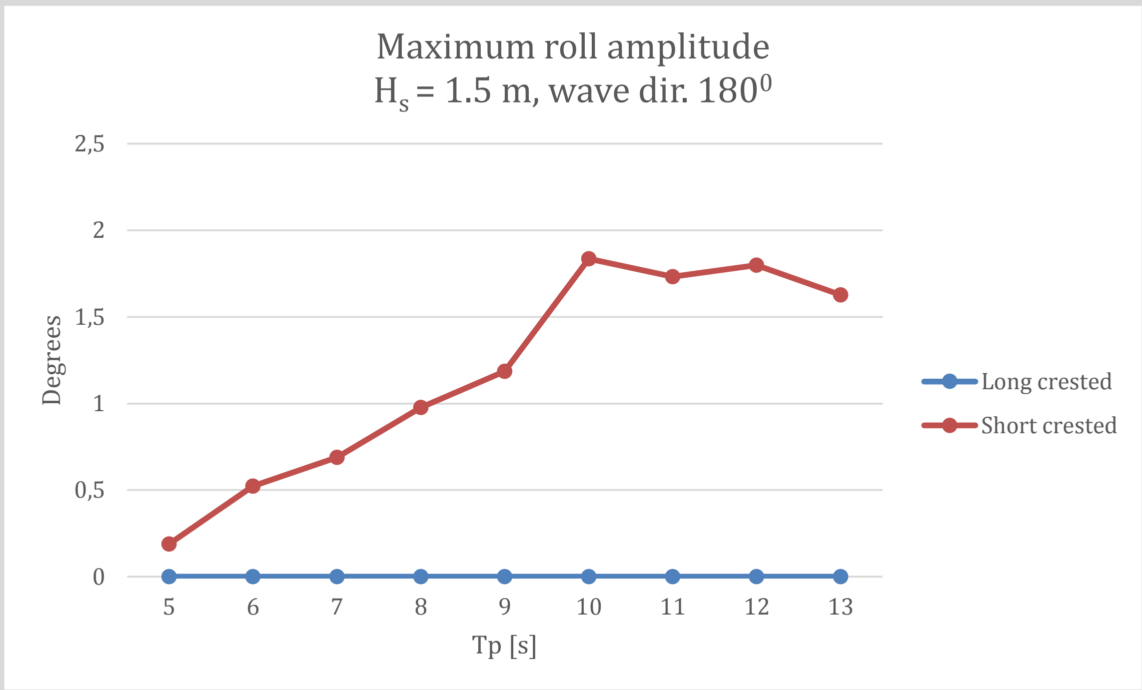


Figure 7-6 Maximum roll amplitude comparison for wave direction 180^0

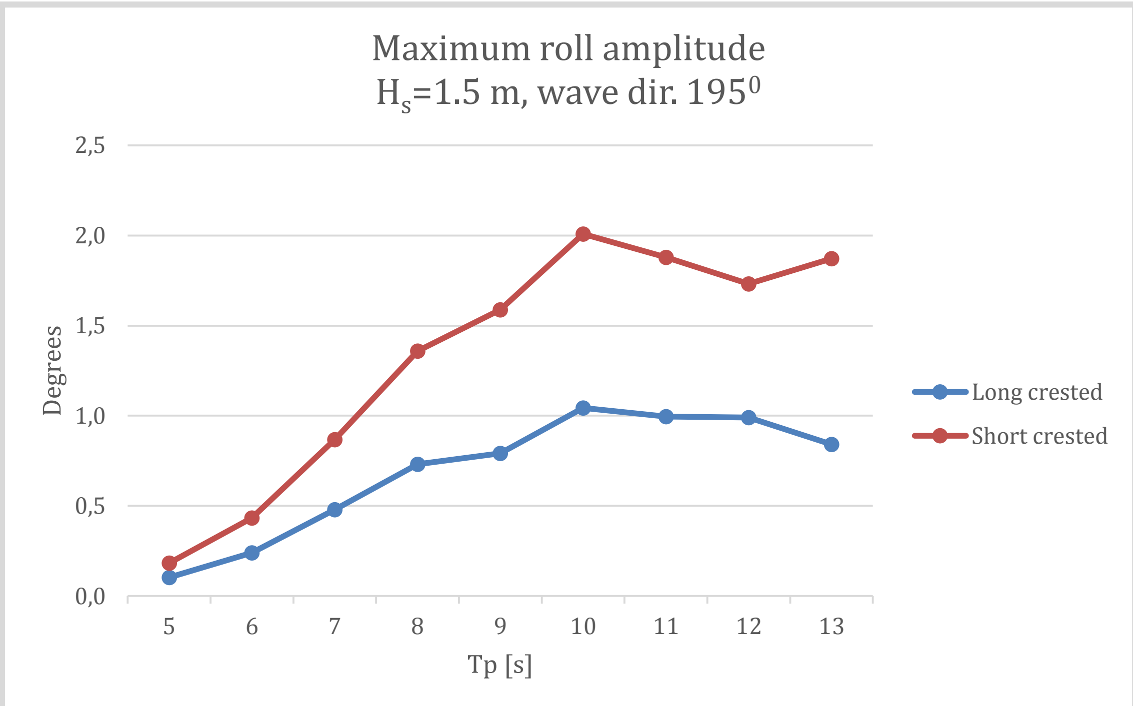


Figure 7-7 Maximum roll amplitude comparison for wave direction 195^0

The increased roll motion explains the limiting sea states for excessive pendulum motion. The periods of high roll amplitudes corresponds to the periods that are restricted in table 7-3. From the modal analysis in chapter 6.3 we can recall that the lifting arrangement and spool has a natural period of horizontal motion around 12-13 seconds. For short crested waves, these are periods resulting in excessive pendulum motions, together with periods close to the vessel's natural period in roll.

Larger roll motion subsequently leads to higher hydrodynamic loading by introducing vertical motion to the lifted spool. The plot in figure 7-8 presents a comparison of the maximum slamming force on single buoy for short crested and long crested waves of significant wave height 1.5 m and wave direction 180^0. Short crested waves result in larger slamming forces on the spool. This corresponds well with the sea states restricted due to occurrence of slack slings.

Figure 7-8 Maximum slamming force comparison

Limiting operational criterion

The limiting operational criterion for deploying the spool, given in table 7-3 is a sea states of significant wave height 1.0 m without any restrictions in the wave peak period. For sea states of significant wave height 1.5 m, the peak period is limited to 13 s alone.

According to the new DNV regulations these are the limitations for the considered spool installation lift in sea states characterized by the JONSWAP spectrum.

Accept criterion for minimum sling tension

In order to investigate the impact of the new accept criterion for minimum sling tension, the analyses with short crested waves has also been checked against the earlier recommended acceptance criterion for sling tension. The results are given in table 7-4. By comparing with the results in table 7-3, we can see that the sea states for which the operation is limited with respect to sling tension are identical. The new acceptance criterion for minimum sling tension does hence not yield an impact on the limiting operational criterion for this spool installation lift. That is, at least for the level of detail the analyses are carried out with here.

Table 7-4 Limiting sea states 10 % tension margin

Limiting sea state sling tension												
H_s [m]	Wind sea direction [°]	T_p [s]										
		3	4	5	6	7	8	9	10	11	12	13
0,5	180 ± 15 Short crested											
1												
1,5												
2												
2,5												
3												

7.3 Chapter Summary and Discussion

For all practical purposes the limiting operational criterion for the spool installation lift is reduced from a significant wave height of 1.5 m to a significant wave height of 1.0 m by performing analyses according to the new regulations. More detailed study of the analysis results showed that modeling the wind sea as short crested waves introduces significantly higher roll motions to the vessel which subsequently leads to both excessive pendulum motions for a wider range of wave periods and higher hydrodynamic loading on the spool, slamming loads in particular. Slamming loads are largest for the sea states of short peak period. For the JONSWAP spectrum these are sea states characterized by more concentrated wave energy close to the peak period, due to the peak enhancement factor. Excessive pendulum motions occur for wave peak periods around the natural period of the vessel's roll motion and periods coinciding with the natural period of horizontal motion of the lifting arrangement and spool. The accept criterion for minimum tension in individual slings has lesser impact. In fact, analyses for short crested waves gives the same limiting operational criterion when checked against the two different acceptance criteria for minimum sling tension. It should, however, be emphasized that the analysis are here carried out with an increment of significant wave height of 0.5 m and the results at a more detailed level could potentially reveal effects that are not captured here.

Limiting operational wave criterion in the range of a significant wave height of 1.0 m is fairly low, even for these type of installation lifts. The most interesting result here is however that the new regulations are more conservative than the earlier recommended practice. In a design situation, one would for example consider technical solutions as use of tugger wires for load control, as explained in chapter 2.1 in order to potentially extend the criterion. Such technical solutions has deliberately been left out of the consideration here as the objective was to compare the regulations. Making a very complicated model by incorporating such technical solutions has therefore been avoided.

8 Combined Wind Sea and Swell Study

This chapter and corresponding analyses deals with the limiting wave criterion for the spool installation lift in sea states characterized by combined wind sea and swell. As explained in chapter 2.2, current practice of establishing limiting operational wave criteria for operations that are independent of vessel heading, consists of analyzing the response of vessel, lifting arrangement and spool to waves with direction $180 \pm 15°$ relative to the vessel. One then assumes that the vessel's heading will be directly towards the main wave direction during the operation, and based on this obtains allowable significant wave heights and corresponding peak periods. This is similar to the practice carried out for the comparison study in chapter 7. For operations in areas characterized by high swell prevalence one would then normally perform analysis where the wave conditions are described by a two peaked spectrum such as Torsethaugen. The evaluation of directionality between wind sea and swell is usually left for the OCM and Vessel master and will be considered at the time of carrying out the actual operation. Based on experience and the observed vessel response to a sea state, they will make the final call regarding the feasibility of an operation, provided that weather forecasts gives acceptable significant wave heights and corresponding periods (with the α –factor included). An experienced vessel Master will also be able to ensure that the vessel obtains an optimal heading relative to the wind sea and swell present. In other words orient the vessel bow relative to the wind sea and swell direction to reduce vessel response. As presented in the introduction chapter, new regulations now gives more emphasis to separately consider characteristic vessel motions due to swell.

As discussed in chapter 4.1, the Åsgard field in the Norwegian Sea is an area of rather high swell prevalence. Conducting the considered spool installation lift in that area will certainly introduce the need to evaluate the effects of swell. An example of a forecast from the Åsgard field, as given by the weather service company StormGeo is presented in Figure 8-1. Information about waves is contained in the red box. This is a rather detailed forecast, and we can see that information is updated every 3 hours. The forecast gives information about the height, period and direction of wind sea and swell separately. It also gives a combined wave height and period in the columns under "total sea".

	Conf	Winds					Total sea				Wind wave			Swell			Weather	
Thursday	conf	Dir [°]	ws10 [m/s]	wg10 [m/s]	ws50 [m/s]	wg50 [m/s]	Hs [m]	Hmax [m]	Tp [s]	Tz [s]	Tz [s]	Dir [°]	Hs [m]	Hs [m]	Dir [°]	Tz [s]	AT [°C]	Vis [m]
30.10 00 UTC	High	276	14	18	17	22	4.3	7.5	9.2	6.2	7.2	282	3.6	2.4	330	10.1	7.3	10000
30.10 03 UTC	High	280	14	18	18	22	4.5	7.9	9.7	6.5	7.5	286	3.8	2.5	326	10.4	7.2	10000
30.10 06 UTC	High	283	14	17	17	21	4.5	7.9	10.0	6.6	7.5	288	3.5	2.7	322	10.4	7.2	10000
30.10 09 UTC	High	283	13	16	16	20	4.3	7.5	10.0	6.6	7.2	285	3.2	3.0	318	10.2	7.4	10000
30.10 12 UTC	Med.	285	11	14	14	17	4	7	9.9	6.4	6.2	285	2.5	3.1	312	9.8	7.4	10000
30.10 15 UTC	Med.	283	10	13	13	16	3.4	6	9.8	6.2	5.4	284	1.8	2.9	313	9.5	7.4	10000
30.10 18 UTC	Med.	289	8	10	10	12	3.2	5.5	9.7	6.3	4.3	287	1.0	2.9	317	9.1	7.2	10000
30.10 21 UTC	Med.	294	6	8	8	10	2.9	5.1	9.7	6.5	3.5	291	0.6	2.9	322	9.0	7.0	10000
	Conf	Winds					Total sea				Wind wave			Swell			Weather	
Friday	conf	Dir [°]	ws10 [m/s]	wg10 [m/s]	ws50 [m/s]	wg50 [m/s]	Hs [m]	Hmax [m]	Tp [s]	Tz [s]	Tz [s]	Dir [°]	Hs [m]	Hs [m]	Dir [°]	Tz [s]	AT [°C]	Vis [m]
31.10 00 UTC	Low	302	5	6	6	7	2.5	4.4	9.7	6.7	2.8	301	0.4	2.3	328	8.9	7.0	10000
31.10 03 UTC	Med.	317	4	5	5	6	2.3	4	9.5	6.9	2.1	318	0.2	2.2	333	8.8	6.9	10000
31.10 06 UTC	Med.	341	2	3	3	4	2.2	3.8	9.3	7.2	1.5	338	0.1	2.1	339	8.8	7.0	10000
31.10 09 UTC	Med.	21	1	2	2	2	2	3.5	9.1	7	1.4	22	0.1	1.9	345	8.9	7.0	10000
31.10 12 UTC	Low	77	3	4	4	5	1.9	3.4	9.0	6.8	1.9	75	0.1	1.8	351	9.0	7.2	10000
31.10 15 UTC	Med.	86	6	8	8	10	2	3.4	9.0	6.3	2.6	87	0.1	1.8	357	9.1	7.3	10000
31.10 18 UTC	Med.	94	9	12	12	14	2.1	3.7	10.4	4.7	3.8	96	1.0	2.0	29	8.9	7.4	10000
31.10 21 UTC	Med.	94	10	13	13	16	2.3	4	9.0	4.8	4.6	94	1.4	1.8	11	9.0	7.4	10000

Figure 8-1 Forecast for Åsgard field

Several interesting observations can be made from the forecast presented. First of all we can notice that the direction from which the swell is coming from is mainly in the range West to North, in accordance with the theory presented in chapter 4.1. Directions in the forecast are given relative to earth, according to the convention presented in the nomenclature. Swell is also characterized by somewhat longer periods than the wind sea for comparable wave height. All forecasted sea states are here consisting of both wind sea and swell. Individual wind sea and swell periods are given as mean zero up-crossing periods, while the total sea is additionally presented in terms of peak period. In chapter 4.1.6 a relation giving the total significant wave height for a sea state of combined wind sea and swell was given in eq. 4.1-25. The significant wave heights in the given forecast follows this relation well. The "Friday" forecast presents a sea state where significant wave height of the wind wave is as low as 0.1 m for a rather long duration. The low wind wave tells us that the local wind conditions are calm, something that also is reflected in the forecasted wind speeds of the area. A considerable swell is however still present.

The accuracy of wave forecasts has increased over the last years along with the development in computer technology and the models used for weather prediction. The short extract of a forecast presented shows how complex the situation of wind waves might be, with respect to heights, periods and directions. It also shows the level of detail of forecasts available for wave conditions.

8.1 Analysis Methodology

The starting point for the analyses in this chapter is the results from the comparison study in the previous chapter. Analysis showed that the for all practical purposes the new regulations for modeling of wind sea limits the considered spool installation lift to a wave height of H_S= 1.0 m. All analyses performed in this chapter are in accordance with the new regulations. Wind sea has hence been modeled as short crested waves and response to wind sea has been analyzed for wave directions $\pm 15°$ off the vessel heading. New regulations for sling tension acceptance criterion is also applied.

The emphasis in this chapter is put on the effect of adding a swell component to the wind sea, when analyzing the systems response to waves. The methodology here is to combine a wind sea characterized by a certain significant wave height and peak period described by the JONSWAP spectrum, with a swell component, modeled as described in chapter 5.4. As explained in the introduction chapter, new DNV regulations now demands that as a minimum the combination of wind sea and swell acting with 90° difference in propagation direction is considered for subsea lifting operations. Analyses are performed by varying the swell components angle to the main direction of the wind sea, as well as analyzing a range of swell periods, where 8-14 second has been selected. These are periods within a range assumed to potentially be limiting for the operation and at the same time likely to occur in combination with the considered wave heights. A range of cases have been analyzed, where also examples of adjusting the vessel's heading to the main wind sea direction has been investigated. The cases with the most important findings are presented in the following subchapter.

In case 1 the installation lift is exposed to a wind sea of significant wave height 1.0 m with peak period of 6 seconds, combined with a swell of 0.5 m height. The vessel heading is assumed directly towards the wind sea. The peak period of 6 seconds is selected as a best approximation to what peak period that is likely to encounter in combination with a significant wave height of 1.0 m. This is based on information in the scatter diagram presented in table 8-1. The diagram is retrieved from a metocean design report provided by Technip, where information is based on hindcast data from the NMI. For the other cases, peak periods for wind sea has been adjusted according to the significant wave height. For example, in a wind sea of significant wave height of 0.5 m the peak period is downgraded to 4 seconds. The selection of sea states for the rest of the cases will be commented along with the results. A listing of the cases is however given:

Case 1 **Wind sea JONSWAP (short crested): H_s = 1.0 m T_p = 6 s Dir. = 180 $\pm$ 15^0**
Swell H = 0.5 m

Case 2 **Wind sea JONSWAP (short crested): H_s = 1.0 m T_p = 6 s Dir. = 180 $\pm$ 15^0**
Swell H = 1.0 m

Case 3 **Wind sea JONSWAP (short crested): H_s = 0.5 m T_p = 4 s Dir. = 180 $\pm$ 15^0**
Swell H = 1.0 m

Case 4 **Wind sea JONSWAP (short crested): H_s = 0.5 m T_p = 4 s Dir. = 210 $\pm$ 15^0**
Swell H = 1.0 m

Case 5 **Wind sea JONSWAP (short crested): H_s = 0.5 m T_p = 4 s Dir. = 240 $\pm$ 15^0**
Swell H = 1.0 m

Case 6 **Wind sea JONSWAP (short crested): H_s = 0.1 m T_p = 2 s Dir. = 240 $\pm$ 15^0**
Swell H = 4.0 m

Table 8-1 Scatter diagram Åsgard field

Scatter diagram of significant wave height (H_S) and spectral peak period (T_p) at the Åsgard Field for a period of 100 years.
Duration of sea state is 3 hours.

H_S (m)	Spectral peak period (T_p) - (s)																					
	2-3	**3-4**	**4-5**	**5-6**	**6-7**	**7-8**	**8-9**	**9-10**	**10-11**	**11-12**	**12-13**	**13-14**	**14-15**	**15-16**	**16-17**	**17-18**	**18-19**	**19-20**	**20-21**	**21-22**	**22-23**	**Sum**
0-1	2	163	1158	2510	3606	3288	2652	1829	923	412	254	83	52	40	17	6	8		4			**17006**
1-2		73	2400	8419	13208	17271	19379	14983	10077	6446	3710	1819	852	544	319	140	110	46	31	15	12	**99854**
2-3			38	1171	6054	9975	11479	12656	11402	8860	5838	3808	1740	1006	569	213	200	63	38	15	8	**75135**
3-4				13	565	3148	6821	7850	7910	6800	5348	3412	2133	1290	642	254	212	48	25	10	8	**46488**
4-5					13	238	1904	4273	5331	4494	3650	2392	1604	946	519	244	173	35	15	2		**25835**
5-6						4	258	1121	2729	3208	2583	1488	862	635	327	123	133	13	6		4	**13492**
6-7							12	127	815	1827	1931	1096	600	413	238	135	52	4	4	2		**7256**
7-8								6	100	529	1150	1058	437	213	127	92	73				2	**3787**
8-9									8	106	352	771	321	194	46	56	37					**1890**
9-10										13	77	296	252	138	54	33	25	2				**890**
10-11											13	52	142	88	40	25	13					**375**
11-12												12	42	27	17	12	6					**115**
12-13													13	17	12	8						**50**
13-14														6	6	10						**21**
14-15														2								**2**
15-16															2							**2**
16-17																2						**2**
Sum	**2**	**237**	**3596**	**12113**	**23446**	**33925**	**42504**	**42844**	**39294**	**32694**	**24906**	**16287**	**9050**	**5562**	**2937**	**1352**	**1040**	**212**	**123**	**44**	**33**	**292200**

8.2 Results

The results of the time domain analyses are also here presented in terms of tables displaying whether or not the acceptance criteria given in chapter 6 are fulfilled. The tables present the results for a specific wind sea state in combination with the considered swell height applied with directions from 180° to 90° with an increment of 15°.

Separate results are presented for the criteria related to sling tension and the one related to excessive pendulum motion and finally a combination gives the limiting operational criterion.

The tables for sling tension are based on detailed results of minimum and maximum tension in crane wire, pennant and individual slings for each of the sea states and directions analyzed. These results are presented in appendix D.

The table color codes are similar to the results in the previous chapter:

Sea states outside the analyzed region

Sea states fulfilling acceptance criteria

Sea states not fulfilling acceptance criteria for sling tension

Sea states not fulfilling acceptance criterion for excessive pendulum motions

Combined acceptance criteria not fulfilled

8.2.1 Case 1

Table 8-2 Limiting sea states for case 1

Limiting sea states sling tension								
Wind sea direction [°]	Swell direction [°]	Swell T [s]						
		8	9	10	11	12	13	14
180 ± 15 Short crested	180							
	165							
	150							
	135							
	120							
	105							
	90							

Limiting sea states excessive pendulum motions								
Wind sea direction [°]	Swell direction [°]	Swell T [s]						
		8	9	10	11	12	13	14
180 ± 15 Short crested	180							
	165							
	150							
	135							
	120							
	105							
	90							

Limiting operational criterion								
Wind sea direction [°]	Swell direction [°]	Swell T [s]						
		8	9	10	11	12	13	14
180 ± 15 Short crested	180							
	165							
	150							
	135							
	120							
	105							
	90							

From the results in table 8-2, we can see that the acceptance criteria for sling tension are fulfilled for all sea states analyzed. A swell of 0.5 m in addition to the 1.0 m wind sea of peak period 6 seconds will not result in slack slings during lift through the wave zone. The same cannot be said about the acceptance criterion for excessive pendulum motions. Certain periods of swell for directions 90° and 105° result in unacceptable pendulum motions of the lifted spool. These are periods corresponding to the vessel's natural period of roll motion (11 s) and the natural period of the lifting arrangement and spools horizontal motion (12-13 s). This spool installation lift could hence not have been carried out in a head sea of significant wave height of 1.0 m and a modest swell of 0.5 m coming as beam seas with periods in the range 11-13 s. This is obviously an example of what DNV refers to as a "most unfavorable combination of simultaneous wind seas and swell".

The results in the table does however not only reveal the sea states that restricts the operation, but does also show that for a range of swell directions and periods, the acceptance criteria for the operation are fulfilled. The situation illustrated in figure 8-2, where the blue arrow represents the main direction of wind sea and the red represents swell is according to the analyses acceptable for all swell periods considered.

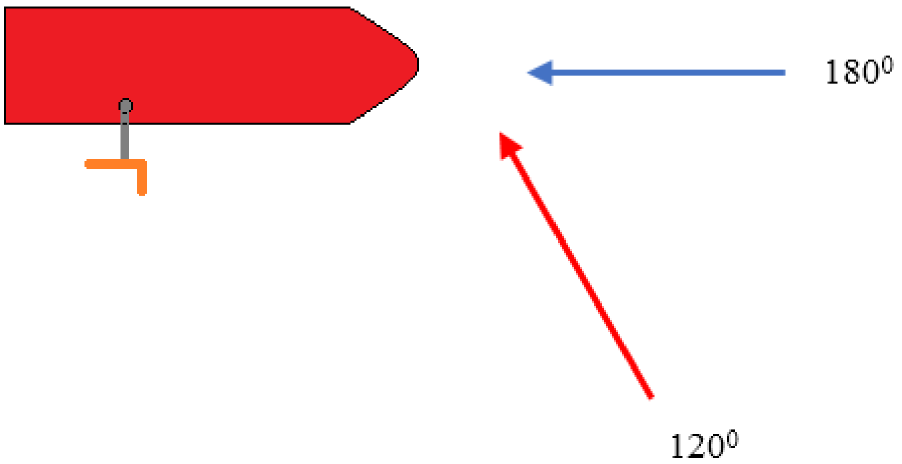


Figure 8-2 Acceptable wave directions case 1

Case 2 is similar to case 1, except that the swell height is increased from 0.5 m to 1.0 m.

8.2.2 Case 2

Table 8-3 Limiting sea states for case 2

Limiting sea states sling tension								
Wind sea direction [°]	Swell direction [°]	Swell T [s]						
		8	9	10	11	12	13	14
180 ± 15 Short crested	180							
	165							
	150							
	135							
	120							
	105							
	90							

Limiting sea states excessive pendulum motions								
Wind sea direction [°]	Swell direction [°]	Swell T [s]						
		8	9	10	11	12	13	14
180 ± 15 Short crested	180							
	165							
	150							
	135							
	120							
	105							
	90							

Limiting operational criterion								
Wind sea direction [°]	Swell direction [°]	Swell T [s]						
		8	9	10	11	12	13	14
180 ± 15 Short crested	180							
	165							
	150							
	135							
	120							
	105							
	90							

Increasing the swell height to 1.0 m, yields a situation where the operation also is limited by the criterion for minimum sling tension for a range of swell periods. The results clearly shows how the operation is limited by the somewhat lower swell periods with respect to sling tension, while the longer swell periods limits the operation in terms of excessive pendulum motions. The operation is now restricted for beam sea swell of periods 8-13 seconds. Swell with period 11 seconds impose the larges restrictions in terms of giving the lowest allowable angle of directionality between the wind sea and swell. This is not surprising, as it corresponds to the vessel's natural period of roll motion. Another interesting observation is that swell with period 14 seconds does not impose any limitations to the operation, regardless of direction. Still, there are directional combinations of the 1 m swell and head wind seas of significant wave height 1 m where the acceptance criteria are fulfilled. The situation illustrated in figure 8-3, is according to the analyses acceptable.

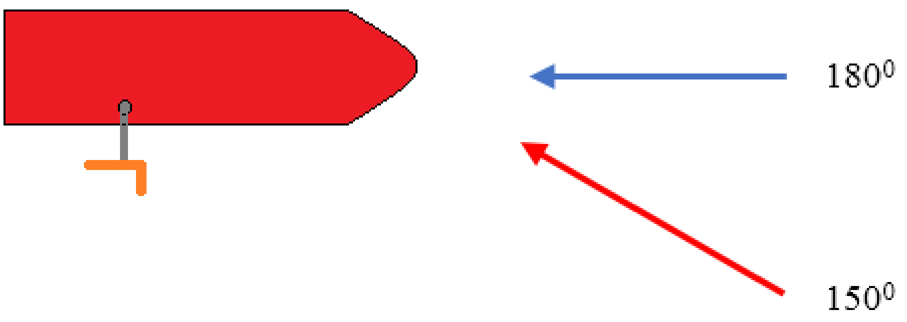


Figure 8-3 Acceptable wave directions case 2

In case 3 the significant wave height for wind sea is reduced to 0.5 m and the peak period correspondingly reduced to 4 seconds. The swell remains 1.0 m.

8.2.3 Case 3

Table 8-4 Limiting sea states for case 3

Limiting sea states sling tension								
Wind sea direction [°]	Swell direction [°]	Swell T [s]						
		8	9	10	11	12	13	14
180 ± 15 Short crested	180							
	165							
	150							
	135							
	120							
	105							
	90							

Limiting sea states excessive pendulum motions								
Wind sea direction [°]	Swell direction [°]	Swell T [s]						
		8	9	10	11	12	13	14
180 ± 15 Short crested	180							
	165							
	150							
	135							
	120							
	105							
	90							

Limiting operational criterion								
Wind sea direction [°]	Swell direction [°]	Swell T [s]						
		8	9	10	11	12	13	14
180 ± 15 Short crested	180							
	165							
	150							
	135							
	120							
	105							
	90							

Reducing the significant wave height for wind sea from 1.0 m to 0.5 m does only have impact on the limiting sea states related to sling tension. The results related to excessive pendulum motion are identical to the once in case 2. This is reasonable as the results in chapter 7.2 revealed no excessive pendulum motions for wind sea of peak period 4-6 seconds which confirms that the pendulum motion is here a result of adding the swell component. The maximum acceptable angle between wind sea and swell, when the vessel heading is straight towards the wind sea is 30^0, as illustrated in figure 8-4. This is similar to case 2.

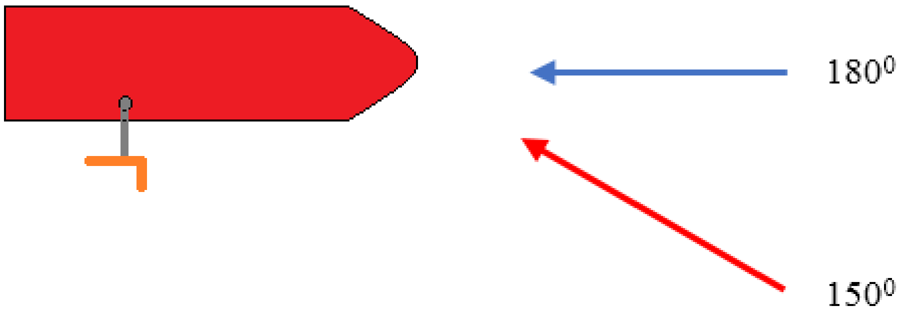


Figure 8-4 Acceptable wave directions case 3

The results indicate that there must be a potential to increase the maximum angle between the wind sea and swell by adjusting the vessel's heading to be somewhere between the two. The following cases 4 and 5 gives the results of analyses where the main wind sea direction is 210° and 240° relative to the vessel. The vessel's heading is hence assumed to be adjusted 30° and 60° relative to the main wind sea. Swell is still 1.0 m and directions of 180° to 90° are analyzed.

8.2.4 Case 4

Table 8-5 Limiting sea states for case 4

Limiting sea states sling tension								
Wind sea direction [°]	Swell direction [°]	Swell T [s]						
		8	9	10	11	12	13	14
210 ± 15 Short crested	180							
	165							
	150							
	135							
	120							
	105							
	90							

Limiting sea states excessive pendulum motions								
Wind sea direction [°]	Swell direction [°]	Swell T [s]						
		8	9	10	11	12	13	14
210 ± 15 Short crested	180							
	165							
	150							
	135							
	120							
	105							
	90							

Limiting operational criterion								
Wind sea direction [°]	Swell direction [°]	Swell T [s]						
		8	9	10	11	12	13	14
210 ± 15 Short crested	180							
	165							
	150							
	135							
	120							
	105							
	90							

8.2.5 Case 5

Table 8-6 Limiting sea states for case 5

Limiting sea states sling tension								
Wind sea direction [°]	Swell direction [°]	Swell T [s]						
		8	9	10	11	12	13	14
240 ± 15 Short crested	180							
	165							
	150							
	135							
	120							
	105							
	90							

Limiting sea states excessive pendulum motions								
Wind sea direction [°]	Swell direction [°]	Swell T [s]						
		8	9	10	11	12	13	14
240 ± 15 Short crested	180							
	165							
	150							
	135							
	120							
	105							
	90							

Limiting operational criterion								
Wind sea direction [°]	Swell direction [°]	Swell T [s]						
		8	9	10	11	12	13	14
240 ± 15 Short crested	180							
	165							
	150							
	135							
	120							
	105							
	90							

Results from case 4 and 5 shows that by adjusting the vessel's heading relative to the main wind sea, one can extend the acceptable angel of direction between the wind sea and swell for the operation. In other words, combinations of wind sea and swell directions restricting the installation lift when assuming the vessel is headed directly towards the wind sea are found acceptable by assuming the vessel's heading during installation is adjusted more towards the direction from where the swell is coming. In fact, the situation where the wind sea and swell is acting with 90° difference in propagation direction is found acceptable for the considered waves by assuming the vessel optimizes the heading to the situation illustrated in figure 8-5.

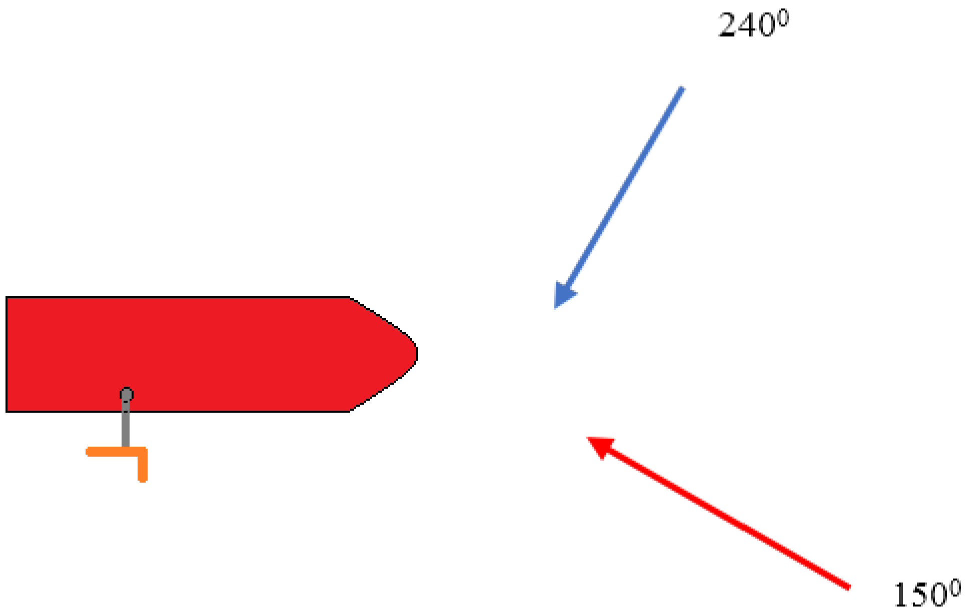


Figure 8-5 Acceptable wave directions case 5

Quite clearly, it is beneficial to adjust the vessel's heading relative to the main wind sea direction, when swell is present and coming from other directions. Obviously this potential will be amplified in sea states where the wind sea is low, but still has a considerable swell present. An example of such a sea state was seen in the forecast presented in figure 8-1. The following case 6 represent such a situation of highly swell dominated sea. The wind sea is further downgraded to a significant wave height of 0.1 m and a corresponding peak period of 2 seconds, assumed having a direction of 240° relative to the vessel. The swell component has a height of 4 m.

8.2.6 Case 6

Table 8-7 Limiting sea states for case 6

Limiting sea states sling tension								
Wind sea direction [°]	Swell direction [°]	Swell T [s]						
		8	9	10	11	12	13	14
240 ± 15 Short crested	180							
	165							
	150							
	135							
	120							
	105							
	90							

Limiting sea states excessive pendulum motions								
Wind sea direction [°]	Swell direction [°]	Swell T [s]						
		8	9	10	11	12	13	14
240 ± 15 Short crested	180							
	165							
	150							
	135							
	120							
	105							
	90							

Limiting operational criteria								
Wind sea direction [°]	Swell direction [°]	Swell T [s]						
		8	9	10	11	12	13	14
240 ± 15 Short crested	180							
	165							
	150							
	135							
	120							
	105							
	90							

From the results in table 8-7 it is obvious that a sea state with a swell of 4 m will be highly limiting for this operation, both due to criterion for sling tension and excessive pendulum motions. One interesting observation from the detailed tension results is that the operation will now also be limited due to maximum tension. In other words, the limitations due to sling tension are for some of the cases a result of exceedance of the SWL in slings. Large motions in swell of 4 m result in a significant dynamic contribution to the tension in lifting slings. It should be mentioned that the same sea states will also limit the operation due to occurrence of slack slings. The reader is again referred to appendix D for these detailed results.

The most interesting observation from the analyses for this case is, however, that the operation is still feasible in a situation where the swell is coming directly towards the bow of the vessel. This particular operation, which is limited to a wind sea of significant wave height 1 m, is based on the results from these analyses still regarded safe in a swell of up to 4 m with the right vessel heading.

8.3 Chapter Summary and Discussion

Results from analyzing the considered spool installation lift to a range of combined wind sea and swell sea states has been presented in this chapter. The analyses does not cover all possible combinations of wind sea and swell, but relevant selected cases revealing certain trends for the behavior of this spool installation lift has been investigated. Analyses showed that beam sea swell with periods coinciding with the vessel's natural period of roll motion and natural period of lifting arrangements horizontal motion is critical for this operation. The operation cannot be carried out under such conditions, even with swell heights as low as 0.5 m. These are, however, the most critical combinations of swell periods and directions and must be regarded as only a limited range of what combinations of combined wind sea and swell one can expect to encounter. Analyses also showed that combined wind sea and swell is acceptable for a range of sea states where the swell not approaches the vessel directly as beam seas.

Further analyses revealed that initial unacceptable conditions are manageable if one adjusts the vessel's heading to avoid beam sea swell. As earlier mentioned, this is in many cases what will be practiced offshore, during the actual operation. An experienced vessel Master will orient the vessel's heading to optimize vessel response. A good example will be to avoid beam sea swell to reduce vessel roll motion which is critical for the correlated crane tip motion when performing lifting operations over the side of a vessel. Current practice of analysis for establishing a limiting operational wave criterion does however not account for this operational practice of optimizing vessel heading.

In areas of high swell prevalence, one might encounter situations where wind seas gives a minor contribution to the total wave picture, while significant swell can still be present. Analyses in this chapter showed that the considered spool installation lift, initially limited to a significant wave height of 1.0 m wind sea, still can be safely executed in up to 4 m of swell if the vessel's heading is directly towards the swell. This is a result of assuming swell as independent of wind sea, and also avoiding the requirement to analyze response for directions $\pm 15°$ outside the assumed vessel heading, as is the requirement for wind sea. It should be emphasized that the swell is assumed regular and has a fixed wave height, whereas the maximum wave in an irregular sea state will be close to twice its significant wave height.

9 Discussion on Opportunities

9.1 Current Practice and Effect of New Regulations

Establishing the limiting operational wave criterion for an operation based on earlier recommended practice, consists of analyzing the response of vessel, lifting arrangement and spool to a wave spectrum of long crested waves with direction $\pm 15°$ of the vessel heading. The vessel is assumed headed directly towards the main wave direction for operations independent of vessel heading. The wind sea comparison study in chapter 7 showed that the new regulations demanding that wind seas are modeled as short crested waves result in a more conservative limiting operational wave criterion for the considered spool installation lift. Considering this particular spool installation lift as representative also for other similar operations one can assume that in general, limiting operational wave criteria for deployment and lifting through the wave zone for spool installations is now more conservative as a result of these regulations being implemented.

Wind waves are, in general, consisting of both wind seas and swell. That is, to a varying degree, dependent on the geographical area. New DNV regulations also requires that as a minimum, the combination of wind sea and swell acting with 90° difference in propagation direction should be considered for subsea lifting operations. Analyses in chapter 8 verified this as the most critical combination of wind sea and swell. In beam sea swell of certain critical periods the considered operation will become virtually impossible to carry out. Even though critical wave periods for an operation often will be established from analyses, the assessment of combined wind sea and swell and also final decision to initiate an operation is left for the OCM and Vessel master at the offshore site. The most important consideration of an operation is to ensure it is carried out with a sufficient level of safety. If new regulations prove more conservative, this only amplifies the need to look for ways to extend the limiting operational wave criterion, and still ensure that safety is maintained. There are some opportunities that deserves attention.

9.2 Opportunities and Related Challenges

The fact that the new standard distinguishes between characteristic vessel motions generated by wind seas and the once generated by swell is interesting. This indicates that a practice where these consistently also are analyzed separately may be the way to go. Even though the situation of wind sea and swell acting with 90° difference in propagation direction requires consideration and thus also analysis, it is **not reasonable** to base the limiting operational wave criterion for an operation that is independent of vessel heading, on this “worst case scenario”. At the time of carrying out the operation one might obviously be facing a less critical sea states, and for this reason it is hence more reasonable to base the criterion on analyses where this is accounted for. Performing analyses that are more refined, where angle of directionality between wind sea and swell, and also the practice of orienting the vessel to obtain an optimized heading is taken into accounted was in chapter 8 shown to have profound advantages. One can then identify situations where an operation is feasible, that would not have been revealed with the current practice of establishing the limiting operational wave criterion. The essential assumption here is that it is reasonable to model wind sea and swell as separate wave trains in the analyses, where the swell is assumed regular and not prone to the requirement of analyzing response for directions $\pm 15°$ of the vessel’s assumed heading. Analyses in chapter 8 showed that this can in particular be an advantage when facing sea states of significant swell and rather modest wind sea. In order for a practice like this to even be considered possible, one must be able to use these more detailed analysis results, compare them to weather forecasts and determine if the conditions are acceptable to go ahead with an operation. This is where it starts to get challenging. We have seen that it is possible to obtain weather forecasts with detailed information about wind sea and swell separately. First of all, the number of analyses one has to perform in order to cover all possible combinations of wind sea and swell with individual variations of heights, periods and directions are numerous. The corresponding analysis running time is enormous. Obviously, one can limit the number of analyses by eliminating unlikely sea states by considering wave statistics, and also concentrate the focus around swell periods that are critical. The extent of the analyses that has to be performed in order to accurately cover all potential forecasted sea states is still very laborious. In fact, looking at it this way, instead of checking an already established wave criterion against the weather forecasts to confirm acceptable, one could imagine a situation where the **weather forecast is the basis for the analyses**.

From forecasted wave heights, periods and directions one could perform analyses to check if the operation could be initiated. This would allow one to base the analyses on the actual conditions at the time of the operation, down to a level of separate wind sea and swell, while at the same time avoid having to perform this detailed assessment of sea states not relevant for the operation at the time of execution. Obviously, this also has its challenges. The limiting operational wave criterion is an important parameter in the planning and decision of mobilizing a vessel to go offshore in the first place. There is no reason to go offshore with expected sea states of wave height 3.0 m only to discover that the operation cannot be carried out before the waves reduces to 2.0 m. There must clearly be a certain understanding about the sea states one can expect to manage before going offshore. Furthermore, limiting operational wave criteria constitutes the basis for establishing characteristic loads for design of for example lift rigging. Usually, this will be an iterative process. Initial design of lift rigging is improved to extend the limiting operational wave criterion which again leads to increasing e.g. wire dimensions to handle the increased dynamic loads by operating in higher waves. Also sessions of risk assessment, often carried out weeks before the actual operation will address hazards closely correlated to the sea state one intends to perform the operation in. As briefly discussed in chapter 2.2, there are usually aspects to consider that may constitute limiting operational wave criteria for an operation, besides the one established from analyzing the dynamics of the lift. These may be hazards related to working on the vessel deck or using certain equipment, where an increase in wave height corresponds to increased risk.

Performing analyses based on weather forecasts furthermore introduces the challenge of having limited time between established analyses results and the initiation of an operation. Normally, independent engineering checks will be carried out to ensure safety of an operation. With limited time to complete analyses the chances of not detecting potential mistakes increases. The competence of personnel to perform and verify the analyses will be essential. There is also the issue of uncertainty in the weather forecasts. The use of $\propto$-factors only concerns the uncertainty in weather forecasting for the wave parameter significant wave height. Performing analyses based on weather forecasts and also distinguishing between wind sea and swell will potentially require a reevaluation of the practice in accounting for uncertainty in weather forecasts. Uncertainty in forecasted wave periods may be more decisive and have potentially larger effects for a particular operation.

9.3 Possible Future Practice

It is reasonable to assume that the new regulations from DNV entails the need to update the practice on how limiting operational wave criteria are established and how related analyses are performed. It may be relevant to consider a practice where the initial limiting operational wave criterion is established prior to the operation, whereas more detailed analyses based on forecasted wave conditions are used to support the decision of initiating the operation. Similar to current practice one would have to perform analyses to verify the integrity of all components in the system prior to the operation and at the same time establish maximum significant wave heights and corresponding peak periods for the operation. This gives a reasonable basis for planning, risk assessment and other related activities. During transit to the installation site or as close as possible up to the time of the actual lifting operation, analysis engineers onboard the vessel could analyze the lift at a level similar to what was presented in chapter 8. The complete software model of the system will already be established. As the basis for the analyses will be sea states predicted in weather forecasts this will significantly narrow down the amount of sea states requiring consideration. The vessel's heading relative to wind sea and swell direction should however be considered. Such a detailed assessment will in many cases enable characterizing sea states as acceptable, where current practice will be too conservative. This has the potential to significantly reduce time waiting on weather. Constant detailed assessment and analysis of up to date forecasted wave situation can then support the decision of initiating the operation.

The ability to identify and verify sea states in which the operation absolutely not should be initiated should also be regarded as a merit of this practice which is perhaps even more important.

10 Conclusions

10.1 Wind Sea Comparison Study

From the wind sea comparison study conducted it can be concluded that the new requirements in **DNV-OS-H206 (VMO Standard – Part 2-6),** demanding that wind sea is considered short crested for the purpose of establishing characteristic vessel motions when analyzing load response for operations that are independent of vessel heading, results in a more conservative limiting operational wave criterion for the considered Alvheim spool installation lift. This as compared to earlier recommended practice where assuming waves to be long crested was regarded adequate. Only waves represented by the JONSWAP spectrum has been considered in the comparison study, and accordingly, this conclusion only applies to the situation where short term sea states are described by this wave spectrum.

Applying short crested waves in the analyses resulted in stricter limitations in both allowable significant wave height and corresponding peak periods for the considered spool installation lift. For all practical purposes, the limiting operational criterion is reduced from a significant wave height of 1.5 m to 1.0 m. Assessing analyses results more in detail shows that modeling the wind sea as short crested waves introduces significantly higher roll motions to the vessel which subsequently leads to both excessive pendulum motions for a wider range of wave periods and higher hydrodynamic loading on the spool, slamming loads in particular. Excessive pendulum motions occur for wave peak periods coinciding with the vessel's natural period of roll motion and natural period of horizontal motion of the lifting arrangement and spool. The new acceptance criterion for minimum tension in individual slings, only requiring tension in slings and not setting a margin of minimum 10 % of the static tension yields lesser impact. In fact, the analyses for short crested waves gives the same limiting operational criterion when checked against the two different acceptance criteria for minimum sling tension. It should, however, be emphasized that the analyses are here carried out with an increment of significant wave height of 0.5 m. Analyses at an even more detailed level could potentially reveal effects that are not captured here.

The industry example case study considered throughout this report, with its designated vessel and lifting arrangement can be regarded as similar and comparable to a range of other spool installation lifts from construction vessels carried out in the industry today. That is, especially in terms of wave conditions restricting such operations, where vessel motions and hydrodynamic loads acting on the spool lifted through the wave zone lead to limiting conditions such as excessive pendulum motions and slack lifting slings. Considering this particular spool installation lift as representative also for other similar operations one can in general conclude that limiting operational wave criteria for deployment and lifting through the wave zone for spool installations is more conservative as a result of these regulations being implemented.

10.2 Combined Wind Sea and Swell Study

Analyses verified that the situation where the wind sea and swell is acting with 90° difference in propagation direction and where the swell approaches the vessel as beam sea with periods coinciding with the natural period of the vessel's roll motion and/or the horizontal motion of the lifted spool as a most critical wave situation one can encounter. This is clearly what DNV refers to as a most unfavorable relevant combination of simultaneous wind seas and swell. Even though this is a minimum consideration requirement for subsea lifting operations in the new **DNV-OS-H206** standard, this does however not make it a reasonable basis for establishing limiting operational wave criteria, certainly not for operations that are independent of vessel heading. Performing analyses that are more refined, where wind sea and swell waves are modeled as separate wave trains allows one to assess also the feasibility of carrying out the operation in sea states characterized by other possible directions of wind sea and swell. One of the profound benefits is the opportunity to analyze a situation where the vessel obtains an optimal heading relative to the wind sea and swell directions. This is actually what will be practiced offshore. The vessel Master will orient the vessel bow to ensure an optimal heading in terms of minimum vessel response to the sea state encountered. For lifting operations over the side of the vessel a good example will be to avoid beam sea swell due to its effect on the vessel's roll motion and hence also crane tip motions.

Wind waves are, in general, consisting of both wind seas and swell. That is, to a varying degree, dependent on the geographical area. This is however not covered by current analysis practice where the installation vessel is assumed headed directly towards a main wave direction specified by a wave spectrum. The essential assumption in the more refined analyses performed is that it is reasonable to model wind sea and swell as separate wave trains, where the swell is assumed regular and not prone to the requirement of analyzing response for directions $\pm 15°$ of the assumed vessel heading, as is the requirement for wind sea. The advantage is particularly evident for situations of swell dominated sea states. Analyses showed that the spool installation lift considered, initially limited to be carried out in a significant wave height of 1.0 m, could however be carried out in swell of up to 4 m with a vessel heading directly towards the waves.

A change of practice in establishing the limiting operational wave criterion for operations such as spool installation lifts will likely be necessary now, in conjunction with the new regulations introduced. Especially due to the increased focus on distinguishing between characteristic vessel motions generated by wind seas and the once generated by swell. The weather forecasts providing information about wave conditions at an installation site, which the decision to initiate an operation is based upon can now provide information on a level much more detailed than what is currently utilized for establishing the actual limiting operational wave criterion for an operation. That is, information about height, period and direction of wind sea and swell, separately. Analyzing load response for an operation where sea states are modeled at a similar level of detail enables one to identify sea states as acceptable which described only in terms of significant wave height and peak period would have been regarded unacceptable.

10.3 Possible Future Practice

The overall consideration when performing an operations is to ensure that a sufficient level of safety is maintained at all times. If new regulations are more conservative it should be seen as a motivation to make improvements of current practice, for example in how analyses are performed and how the limiting operational wave criterion for an operation is established. Ideally, one could benefit from a complete survey of an operations feasibility at a level of detail comparable to wave conditions in a detailed forecast. One of the main challenges, however, is the extensive workload related to analyses and post processing of analyses result. For this reason, a better approach would be to adopt a practice where only the actual decision of initiating an operation is supported by detailed analyses based on the actual wave situation forecasted at the time of execution. Analyses can be performed while the vessel is in transit or during waiting on weather. This has the potential to reduce time waiting on weather. Perhaps even more important is also the ability to identify sea states in which the operation absolutely not should be carried out.

11 Recommendations of Further Work

Analyses for smaller increments of significant wave heights should be carried out for the wind sea comparison study to reveal potential effects of the new acceptance criterion for minimum sling tension. Also performing analyses for the lift through wave zone where the repeated lowering method, described in chapter 6.1.1 is applied, instead of the method of analyzing several positions relative to the MSL should be carried out to, to complement the comparison study.

Whether or not the new regulations for analysis of vessel response to wind sea result in a more realistic prediction of what can be expected in a real situation, is another question. The requirement to assume wind sea as short crested and also to analyze the response where the main wave direction is $\pm 15°$ outside the assumed vessel heading can seem like an exaggeration of the spreading one realistically can expect to find in a wind sea. Unrealistically conservative regulations can counteract a positive development in the industry by resulting in operations becoming unnecessarily expensive. An attempt was made to establish contact with DNV employees responsible for the work of the new offshore standard DNV-OS-H206 (VMO Standard – Part 2-6), in order to understand what the regulations are based on and to obtain the reasoning behind introducing them. This proved difficult and was therefore not taken any further. An interesting continuation of the work in this report would be to investigate the new regulations' level of conservatism. This would require a comparison of analyses results and actual measured vessel motions. Also the issue of DP accuracy and hence the level of uncertainty related to the vessel's ability to maintain heading throughout an operation should be included in such a study.

Even though the vessel considered throughout this report can be regarded state of the art when it comes to motion characteristics for subsea lifting operations, both the study for wind sea and combined wind sea and swell should be carried out for other similar construction vessels used in the industry today. This can furthermore also be extended to include effect of technical solutions such as tugger wires for load control.

The usefulness of the discussed possible future practice of establishing limiting operational criteria and initiating operations offshore should be further assessed by applying it for an actual spool installation lift operation. This includes preparing a methodology where also uncertainty in forecasted wave period can be accounted for, as an extension of today's $\propto$-factor, only accounting for the uncertainty in forecasted significant wave height. Then there is obviously also the potential to consider adopting such a practice also for other weather restricted marine operations.

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Appendix A

Skandi Arctic Vessel Brochure

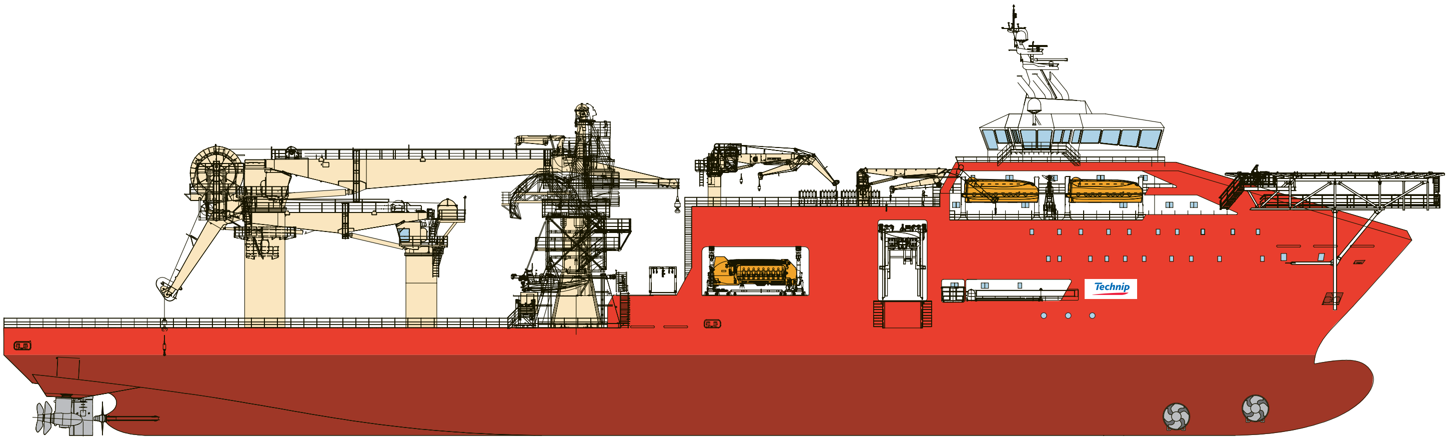
Technip

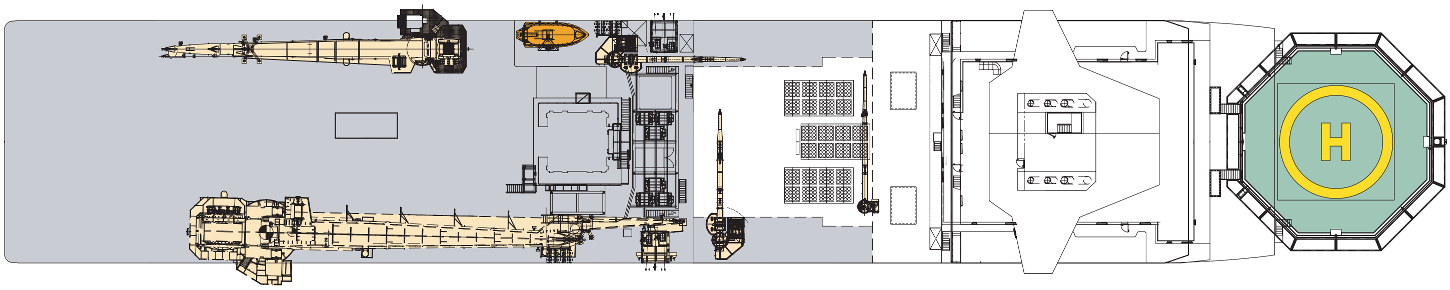
The Fleet

Skandi Arctic

Operational in 2009

Skandi Arctic





The Skandi Arctic is a purpose designed and built diving support vessel suitable for the demanding North Sea market and capable of working throughout the year in virtually all sea and weather conditions.

CAPABILITIES

Built in 2008 the vessel is designed, constructed and certified for worldwide trading. The Skandi Arctic provides services, which include saturation dive support for offshore construction and Inspection, Repair and Maintenance (IRM) operations. The vessel is one of the most modern diving support vessels in the world thanks to its Hyperbaric Monitoring and Control System (HMCS), which is used to support the 24-man diving chamber complex.
The vessel is designed with special emphasis on good sea-keeping abilities and excellent station-keeping performance.
The Skandi Arctic is environmentally friendly with low fuel consumption and features which comply with DNV CLEAN DESIGN requirements.

Cranage

The main lifting facility is a heave compensated box boom crane, with a lifting capacity of 400 Te at a radius of 11 m (harbour lifts). The vessel also has a knuckle boom crane with a lifting capacity of 58 Te at 11 m radius. Located at the dive workstation are two knuckle boom cranes with a lifting capacity of 5 Te at 14 m radius, which are suitable for offshore and subsea use.

Remotely Operated Vehicles (ROVs)

The vessel is fitted with two Workclass ROV Systems each equipped with heave compensated gantry and located in a dedicated hangar. These vehicles are rated to 3,000 m and capable of supporting a payload of 3 Te using various work packages.
An observation class ROV is installed on deck. The ROV systems are capable of carrying out intensive simultaneous Diving and ROV operations.

Diving Systems

The saturation diving complex, which is rated to 350 msw, consists of two 6-man and four 3-man living chambers and two 3-man diving bells (7 m^3 each). The system is supported by two 18-man hyperbaric lifeboats and is fully compliant with Norwegian 'Norsok' standards.

Pipe Laying Facilities

The vessel can be equipped with VLS (Vertical Lay System), and carousel/reels to lay flexible pipes through the working moonpool.

Specifications

Principal dimensions

Length overall	156.9 m
Length BP	137.7 m
Breadth	27 m
Depth to 1st Deck	12 m

Draft (design) 6.5 m
Draft (scantling) 8.5 m

Deadweight 11,500 Te at 8.5 m

Cranage

Main lifting facilities

- Type box boom crane
- Main hoist 400 Te at 11 m (harbour lift)
- Auxiliary hoist 30 Te at 46 m
- Active heave compensation

Additional lifting facilities

- 58 Te at 11 m (harbour lift) - Knuckleboom crane
- 5 Te at 15 m - Provision Crane
- 2 x 5 Te - Offshore cranes

Deck space

- 1,700 m^2 at 10 Te/m^2
- Deckload 5,500 Te at 1 m above the deck

Capacities

- Fuel oil 3,500 m^3
- Fresh water 1,800 m^3
- Ballast water 8,700 m^3

Working moon pool

7.2 m x 7.0 m

Dive moon Pool

2 off 4.2 m x 3.6 m

DP system

Kongsberg K-Pos dual redundant main system with single K-Pos back up system

Reference systems

- 4 x MRU
- 4 x Gyros
- 4 x Wind Sensors
- 1 x Fanbeam
- 3 x DGPS
- 1 x Seapath
- 1 x Radius
- 2 x HPR
- 2 x Tautwires

ERN

99.99.99

Power plant

- 6 x Wartsila 7L32
- Total generated power 19.2 MW

Propulsion

Forward

- 2 x 1.9 MW tunnel thrusters
- 2 x 1.5 MW retractable azimuth thrusters

Aft

- 2 x 3 MW Contra rotating azimuth thrusters
- 1 x center propeller 4 MW
- 1 x flap rudder

Endurance

Fuel consumption (typical)

- In port 5 m^3/day
- On DP 30 m^3/day
- Transit 60 m^3/day

FW making capacity 1 x 25 Te/day
2 x 35 Te/day

Maximum speed

16.5 knots at 5.8 m draught

Helideck

Sikorsky S-92

Accommodation

140 persons in 99 cabins

Lifesaving appliances

- Lifeboats 4 x 70 persons
- MOB 1
- SPHL 2 x 18 divers + 2 x 6 crews

Diving system

- Depth rating 350 msw
- No. in saturation 24
- No. of bells 2
- Bell volume 7 m^3
- System volume 347 m^3
- Gas storage at 200 bar 36,500 m^3
- Reclaim system fitted to bell
- Gas recovery for chambers
- Moonpool aeration system

ROV

1 x 1500m Observation Class ROV
2 x 3000m Work Class ROVs

Flag

Norwegian (NIS) for build

Classification

DNV 1A1, EO, DYNPOS-AUTRO(IMO III), SF, Dk(+), HELIDK-SH, ICE-C, CLEAN DESIGN, NAUT-AW, Comf V(3)C(3), DSV-SAT

Year built / Builder

2008 / Aker Yards

Dynamic Positioning System

The vessel (DP Class 3) is fitted with a dual Kongsberg K-Pos Dynamic Positioning System. DP computer positioning is aided by multiple position reference systems including a fanbeam, radius, taut wires, HIPAP and DGPS solutions.

Machinery / Propulsion

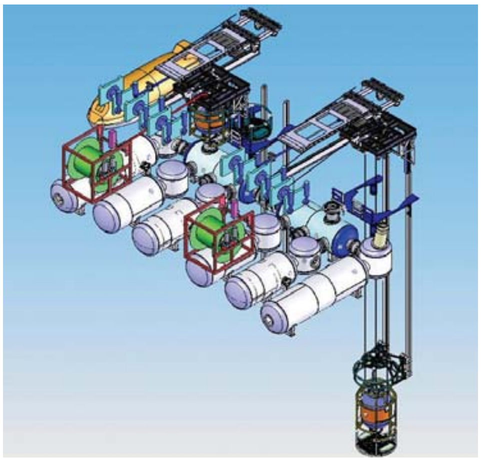
The vessel is powered by 6 Wartsila 7L32 diesel engines, each driving a generator, which provide a total output of 19.2 MW.

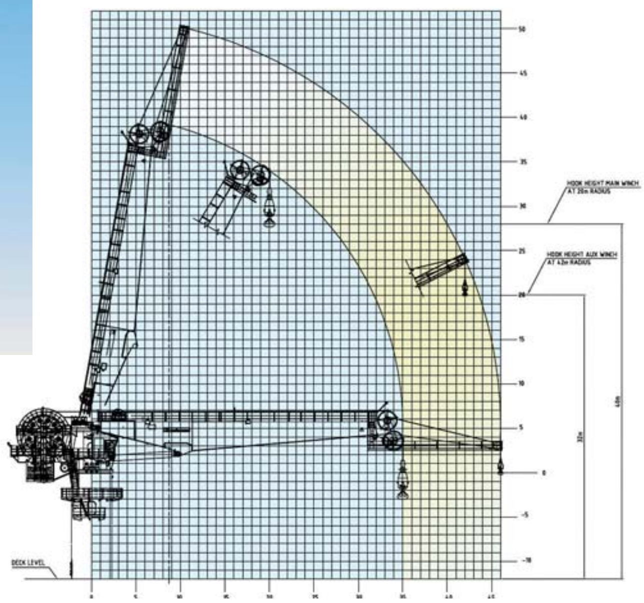
Working Deck

The open deck is 1,700m^2 with a uniform loading capacity of 10 Te/m^2. Additional under-deck storage and a lay-down area are also available.

Accommodation

The Skandi Arctic is fitted with 58 single cabins and 41 double cabins, each arranged with separate toilet and shower. Recreational facilities include mess-room, dayrooms, library, cinema and gymnasium. Accommodation is available for 140 people.





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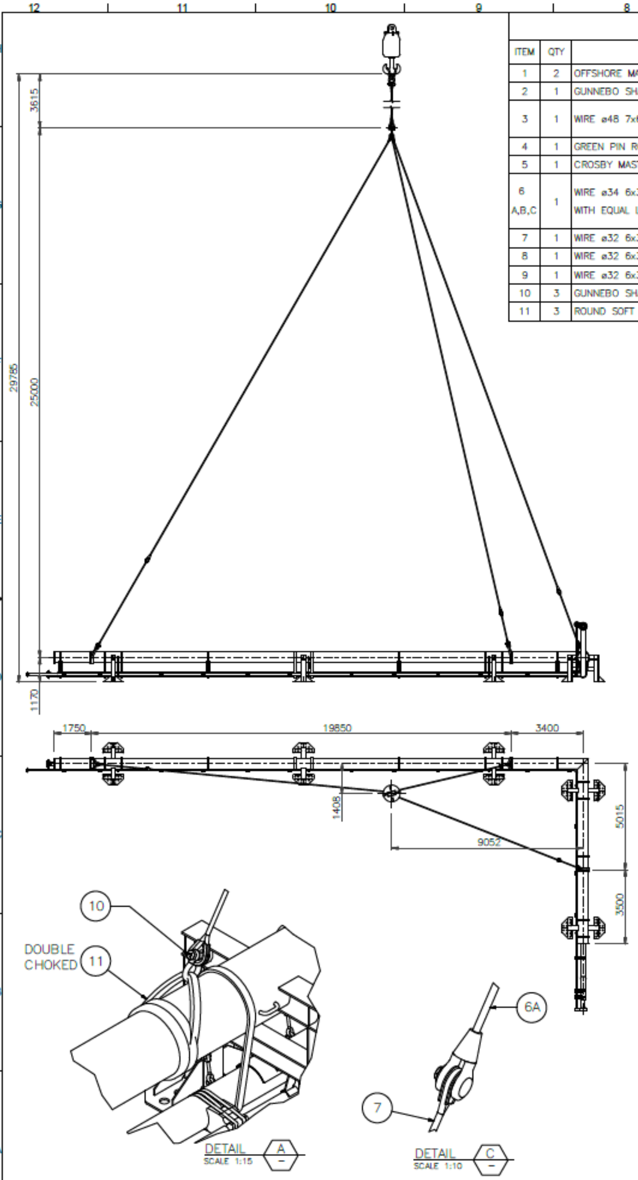
Appendix B

Rigging Drawings and Spool Isometric Drawings



RIGGING DETAILS – MATERIAL TAKE OFF TABLE

ITEM	QTY	DESCRIPTION	LENGTH (m)	MBL (Te)	WLL (Te)	COMMENT	UNIT MASS (kg)	EYE DETAILS TOP EYE	EYE DETAILS BTM EYE
1	2	OFFSHORE MASTERLINK			65,3	TYPE 60.6 OF	30		
2	1	GUNNEBO SHACKLE H855	0.255		55		40		
3	1	WIRE ø48 7x6x36 WS-CW	3.0	196.7		CABLE LAYED GROMMET WITH LASHING	30	HARD	HARD
4	1	GREEN PIN ROV RELEASE POLAR SHACKLE	0.197		35	P-5365 TYPE	20		
5	1	CROSBY MASTERLINK ASSEMBLY	–		38.5	A-345 (SF 5:1)	21		
6 A,B,C	1	WIRE ø34 6x36 IWRC 3-LEG BRIDLE SLING WITH EQUAL LENGTH	23.00	84.0		WITH STEEL FERRULES	405	HARD	OPEN SPELTER SOCKET S02 – MBL 125 Te
7	1	WIRE ø32 6x36 IWRC	4.70	72.9		ALLUMINIUM FERRULES	20.0	HARD	HARD
8	1	WIRE ø32 6x36 IWRC	1.54	72.9		ALLUMINIUM FERRULES	7.0	HARD	HARD
9	1	WIRE ø32 6x36 IWRC	2.70	72.9		ALLUMINIUM FERRULES	13.0	HARD	HARD
10	3	GUNNEBO SHACKLE H855	0.146		17		8.0		
11	3	ROUND SOFT SLING	4.0 E.L.		15				

NOTES:

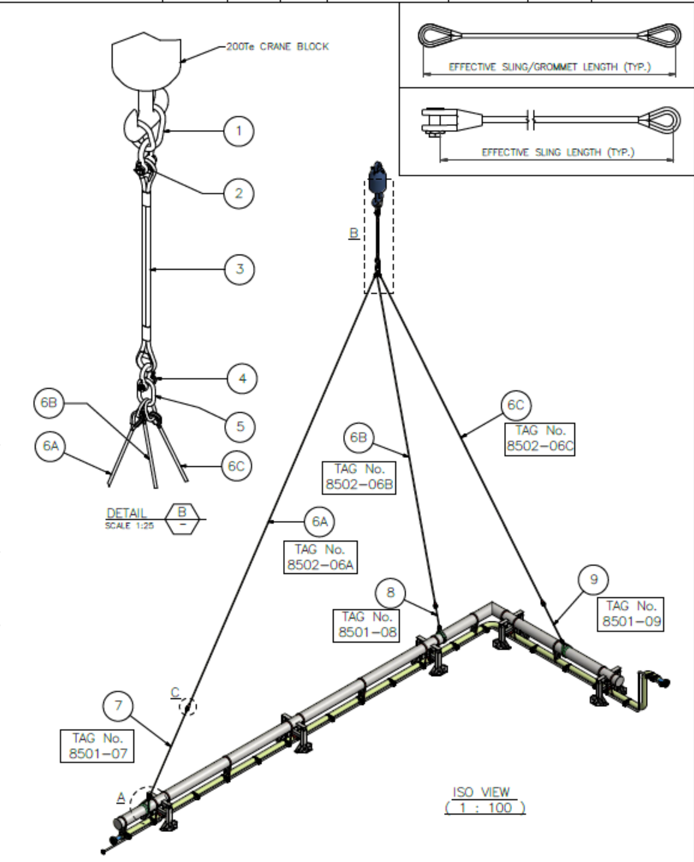
1. ALL DIMENSIONS AND ELEVATIONS IN mm U.N.O.
2. ALL WIRES TO HAVE ID TAGS FOR EASY IDENTIFICATION TO AVOID INSTALLATION ERRORS.
3. COG IS CALCULATED BASED ON WATER-FILLED STRONGBACK & MEG FILLED SPOOLS IN-AIR.
4. DOUBLE CHOKE ALL SOFT SLINGS.
5. RIGGING ATTACHMENT POINT ON STRONGBACK SHOULD NOT BE ON A CONNECTION WELD.
6. FOR DETAILS OF WEBSLING & PIGGYBACKS, SE REFERENCE DRAWING TABLE.
7. WIRES 6A & 6B TO BE PRE-SPLICED INTO ONE MASTERLINK EYE – SEE DETAIL B FOR INFO.
8. 3.1 CERTIFICATE FOR ALL RIGGING

TOTAL WEIGHT IN AIR – 22336 kg

TOTAL SUBMERGED WEIGHT – 11933 kg

EFFECTIVE SLING/GROMMET LENGTH (TYP.)

EFFECTIVE SLING LENGTH (TYP.)



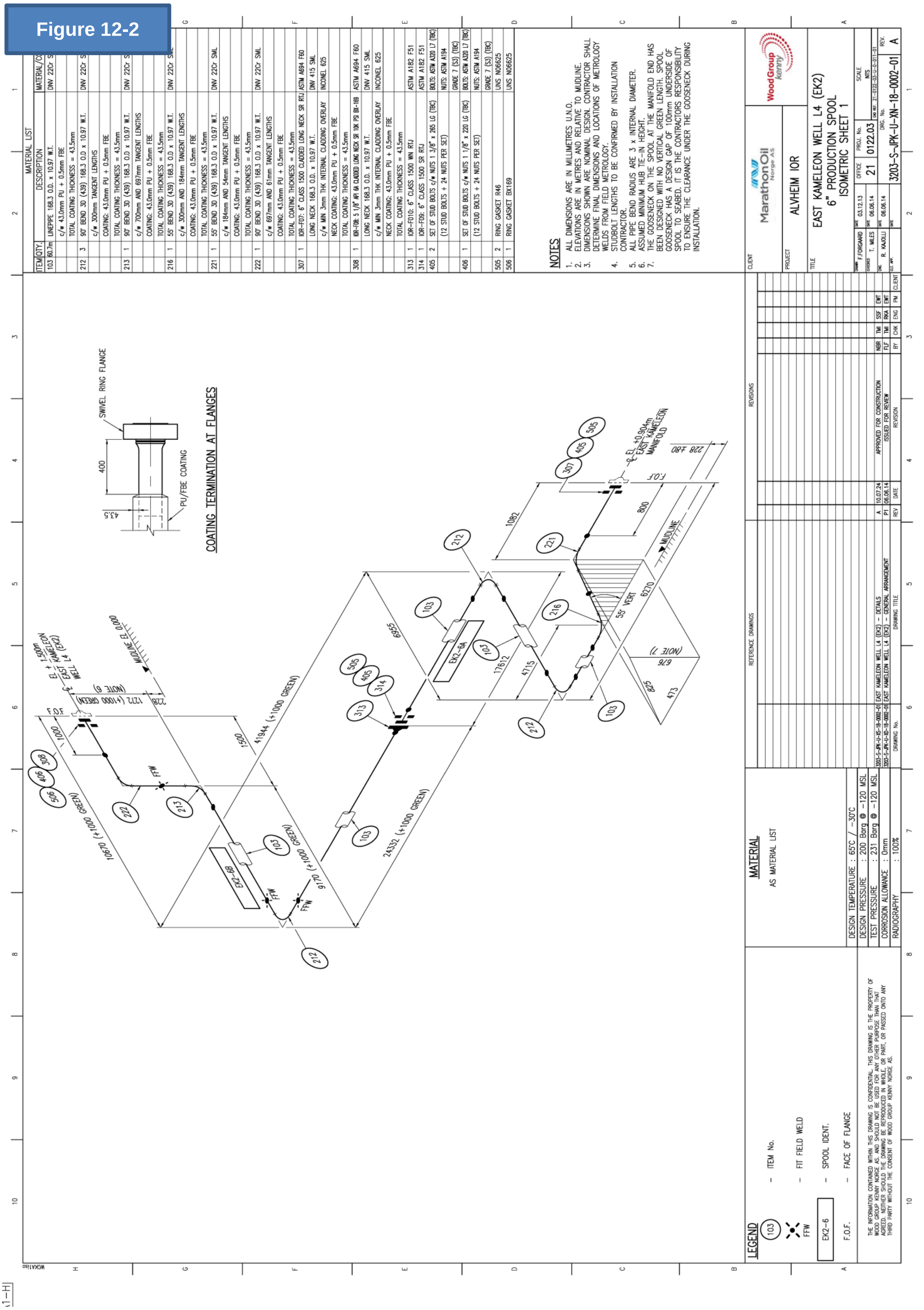
REFERENCE DRAWINGS

DRAWING NUMBER	TITLE
NK-NR035341-7101	STRONGBACK L-SPOOLS – GA DRAWINGS (EK2)
NK-NR035341-7102	STRONGBACK L-SPOOLS – SECTION & DETAILS SHT. 1 OF 2 (EK2)
NK-NR035341-7103	STRONGBACK L-SPOOLS – SECTION & DETAILS SHT. 2 OF 2 (EK2)

REV.	DATE	REASON FOR ISSUE	PREPARED	CHECKED	APPROVED
A	12.11.14	ISSUED FOR INFORMATION	PKO	BFL	MUN
–	07.11.14	ISSUED FOR IDC	PKO	BFL	
–	06.11.14	ISSUED FOR DIC	PKO	BFL	

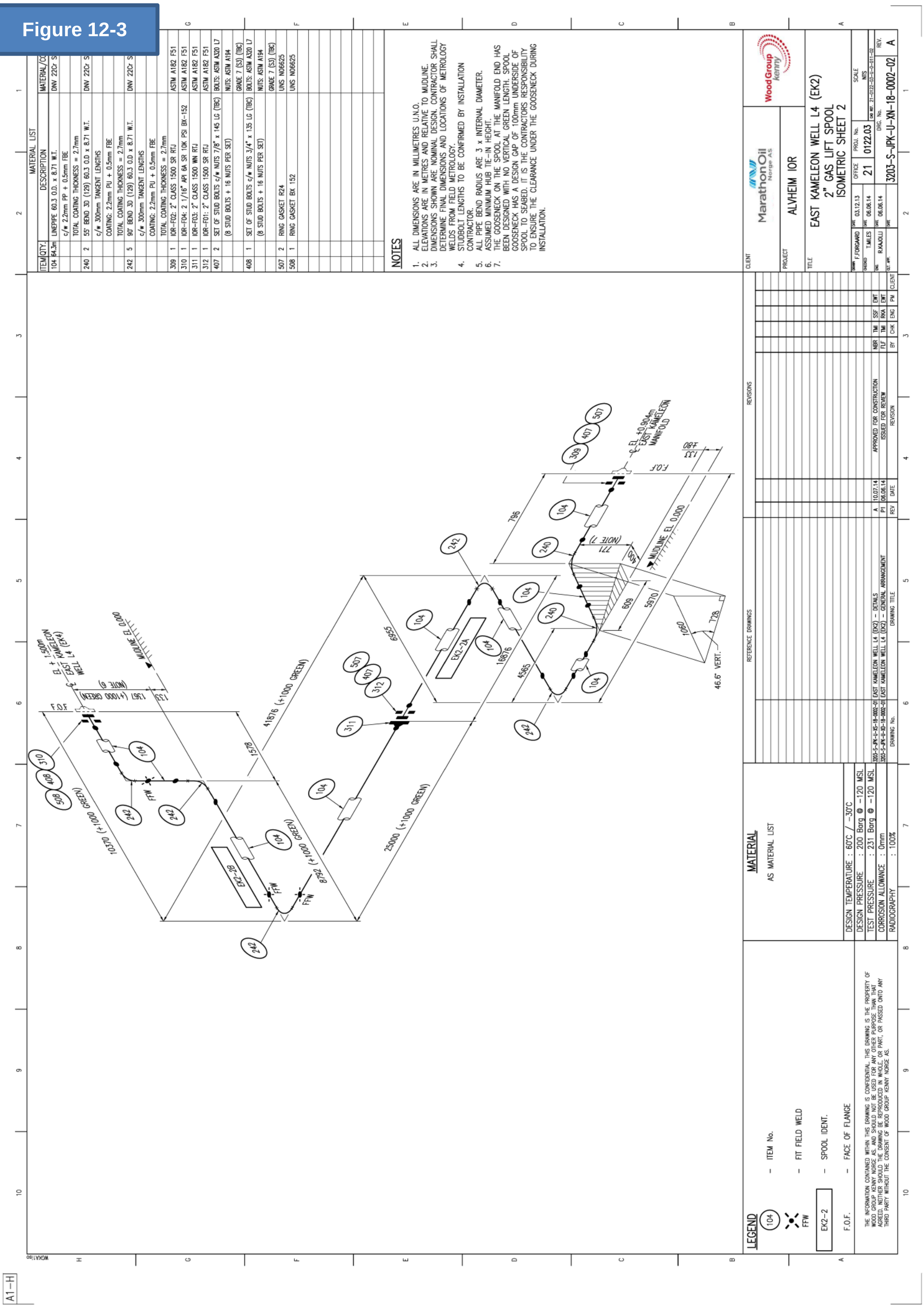
PACKAGE TITLE:
PO NO.:
DOC TYPE CODE(S):
TECHNIP NO DRAWING NO: NK-NR035341-8501 TECHNIP REV. 0
TAG NOS. / MANUFACTURER AND MODEL / TYPE
ACCEPTANCE CODES: 1 2A 2 3 4
DATE: PRINT NAME: SIGNATURE:
PROJECT NAME: ALVHEIM IOR SUBSEA WELL TIE IN PROJECT
DRAWING TITLE: SPOOL DEPLOYMENT LIFT RIGGING L-SPOOLS – EK2
DET NORSKE
SCALE 1:100 SIZE A1 CONTR. NO. 70398/A3913 AREA – SYSTEM 18 DRAWING NO. 3203-S-TKP-U-XD-18-9000-01 REV. A STATUS –

Figure 12-2



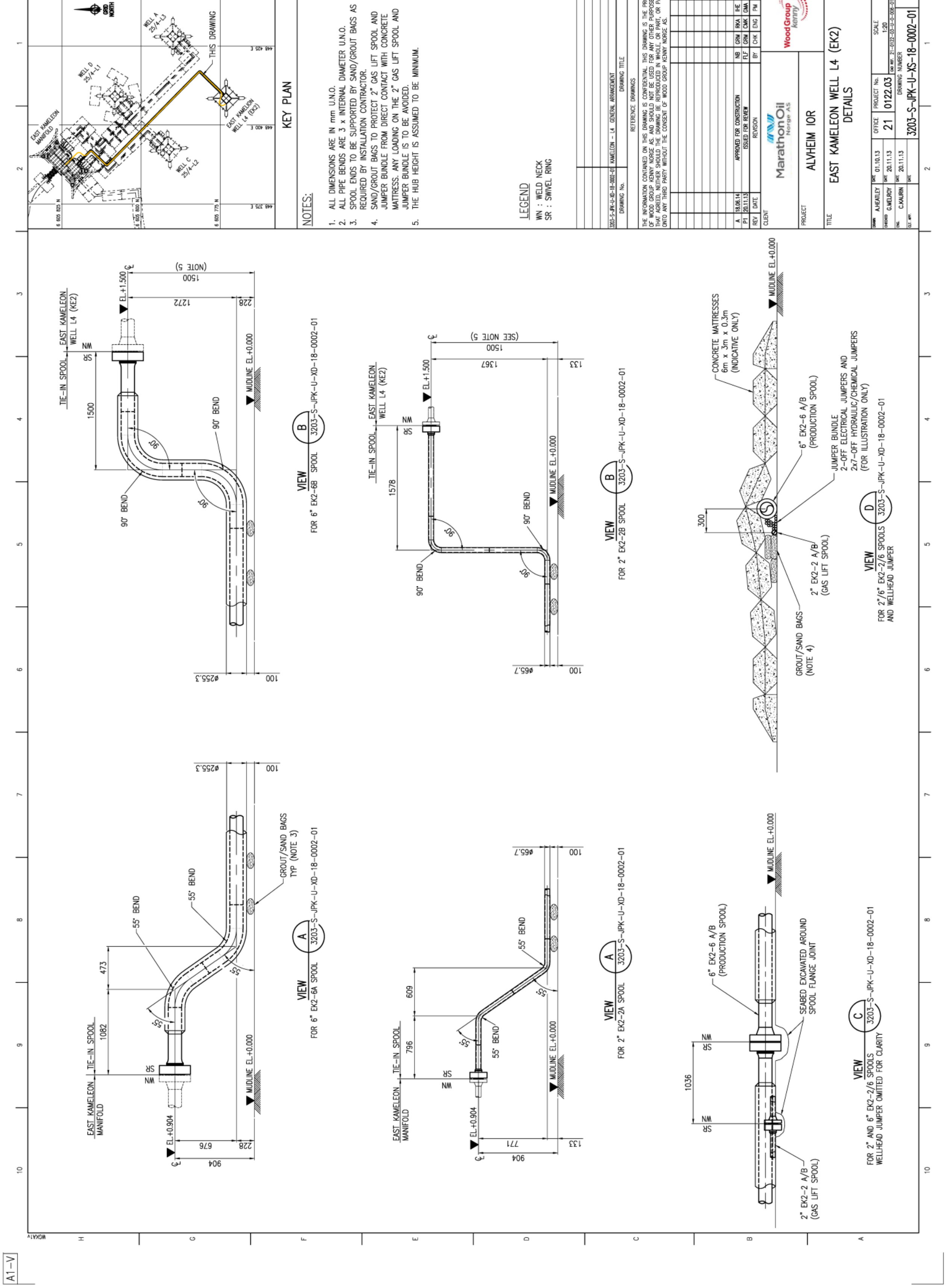
NOTES
1. ALL DIMENSIONS ARE IN MILLIMETRES U.N.O.
2. ELEVATIONS ARE IN METRES AND RELATIVE TO MUDLINE.
3. DIMENSIONS SHOWN ARE NOMINAL DESIGN. CONTRACTOR SHALL DETERMINE FINAL DIMENSIONS AND LOCATIONS OF METROLOGY WELDS FROM FIELD METROLOGY.
4. STUDBOLT LENGTHS TO BE CONFIRMED BY INSTALLATION CONTRACTOR.
5. ALL PIPE BEND RADIUS ARE 3 x INTERNAL DIAMETER.
6. ASSUMED MINIMUM HUB TIE-IN HEIGHT.
7. THE GOOSENECK ON THE SPOOL AT THE MANIFOLD END HAS BEEN DESIGNED WITH NO VERTICAL GREEN LENGTH. SPOOL GOOSENECK HAS A DESIGN GAP OF 100mm UNDERSIDE OF SPOOL TO SEABED. IT IS THE CONTRACTORS RESPONSIBILITY TO ENSURE THE CLEARANCE UNDER THE GOOSENECK DURING INSTALLATION.
MATERIAL LIST
COATING TERMINATION AT FLANGES
SWIVEL RING FLANGE
PU/FBE COATING
ALVHEIM IOR
EAST KAMELEON WELL L4 (EK2)
6" PRODUCTION SPOOL
ISOMETRIC SHEET 1
3203-S-JPK-U-XN-18-0002-01
MATERIAL
AS MATERIAL LIST
LEGEND
ITEM No.
FIT FIELD WELD
SPOOL IDENT.
FACE OF FLANGE

Figure 12-3



ALVHEIM IOR
EAST KAMELEON WELL L4 (EK2)
2" GAS LIFT SPOOL
ISOMETRIC SHEET 2
3203-S-JPK-U-XN-18-0002-02

Figure 12-4



KEY PLAN
NOTES:
LEGEND
WN : WELD NECK
SR : SWIVEL RING
VIEW B
VIEW A
VIEW C
VIEW D
EAST KAMELEON WELL L4 (EK2) DETAILS
ALVHEIM IOR
3203-S-JPK-U-XS-18-0002-01

Appendix C

Spool and Strongback Dimensions and Material Properties

	Unit	Strongback	2'' Spool	6'' Spool	Equivalent Spool
Steel properties					
Steel density	kg/m^3	7800			
Youngs modulus	Mpa	212000			
Poisson ratio	-	0,27			
Steel pipe dimensions					
Length	m	33,2	39,6	38,7	33,2
Outer diameter	mm	508	60,3	168,3	582,4
Inner Diameter	mm	457,2	42,9	146,4	531,13
Wall thickness	mm	25,4	8,71	10,97	25,6
Steel pipe structural properties					
Axial stiffness	kN	8164071	298989	1147537	9502356
	kN	9610596			
Bending stiffness	kNm^2	238338	102	3569	368965
	kNm^2	242009			
Torsional stiffness	kNm^2	176628	76	2645	273434
	kNm^2	179349			
Coating					
Coated length	m	-	39,6	37,8	
Coating thickness	mm	-	2,7	43,5	
Coating density	kg/m^3	-	1248	830	
Outer diameter with coating	mm	508	65,7	255,3	582,4
Content		Water	MEG	MEG	
Density	kg/m^3	1025	1115	1115	1052,9
Weight in air					
Pipe	Te	9,977	0,435	1,634	11,612
Coating	Te		0,026	0,908	0,000
Content	Te	5,589	0,064	0,727	7,749
Total weight in air	Te	15,566	0,525	3,269	19,361
	Te	19,361			
Buoyancy	Te	6,900	0,138	2,031	9,069
	Te	9,069			
Total submerged weight	Te	8,666	0,388	1,238	10,292
	Te	10,292			

Appendix D

Detailed Analyses Results

Safe working load and static tensions

	SWL [kN]	Static tension [kN]	10 % level [kN]
Crane wire	2550	239,8	23,98
Pennant	1157	195,7	19,57
Wire sling 1	429	75,4	7,54
Wire sling 2	429	89,3	8,93
Wire sling 3	429	46,8	4,68

Table colour code

Acceptable tension level

Unacceptable tension level

Wind Sea Comparison Study

Lift in Air - Long Crested Waves

H_s = 0.5 m   Wave direction 165^0

Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
0,5	3	239,1	240,5	195,0	196,3	73,5	77,1	88,2	90,0	45,4	48,2	1,00
	4	238,7	240,9	194,6	196,6	72,9	77,5	87,7	90,2	44,7	48,5	1,00
	5	238,5	241,1	194,6	196,8	74,0	76,6	88,6	89,8	46,1	47,6	1,01
	6	237,5	242,2	193,8	197,6	74,2	76,8	88,3	90,1	46,2	47,5	1,01
	7	236,7	243,0	193,2	198,3	72,8	77,8	88,1	90,5	45,4	48,3	1,01
	8	236,9	242,5	193,3	197,9	74,2	76,7	87,9	90,4	45,9	47,6	1,01
	9	237,2	242,6	193,5	197,9	74,0	76,7	88,4	90,1	46,3	47,3	1,01
	10	236,7	242,8	193,2	198,2	73,3	77,1	88,3	90,3	46,0	47,7	1,01
	11	236,7	243,2	193,2	198,5	73,2	77,3	88,0	90,4	45,9	47,6	1,01
	12	236,3	242,8	192,8	198,3	72,9	77,5	87,9	90,6	45,8	47,7	1,01
	13	236,8	243,8	193,3	199,0	73,5	77,3	88,0	90,8	45,9	47,7	1,02

H_s = 1.0 m   Wave direction 165^0

Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
1	4	237,3	242,4	193,4	197,9	71,8	78,6	86,7	90,7	43,6	49,3	1,01
	5	237,2	242,5	193,5	197,9	73,0	77,7	88,0	90,4	45,6	47,9	1,01
	6	235,0	244,9	191,7	199,9	69,9	79,7	86,8	91,3	43,3	49,6	1,02
	7	233,2	246,3	190,3	201,0	70,5	79,9	86,8	91,7	43,9	49,5	1,03
	8	233,6	245,4	190,6	200,3	72,3	78,1	86,2	91,5	44,9	48,3	1,02
	9	233,7	245,4	190,7	200,3	73,0	78,1	86,6	91,2	45,8	48,0	1,02
	10	232,4	247,2	189,6	202,1	70,3	79,2	87,0	91,8	44,9	48,6	1,03
	11	233,2	247,1	190,3	202,1	70,6	79,5	86,5	92,0	44,7	48,7	1,03
	12	231,8	248,0	189,1	203,0	70,2	79,2	85,4	92,5	44,5	48,9	1,03
	13	235,1	248,2	191,9	202,6	72,6	78,3	87,1	92,4	44,9	48,9	1,03

H_s = 1.5 m   Wave direction 165^0

Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
1,5	5	234,3	245,5	190,9	200,5	67,7	80,9	85,8	91,4	42,2	50,1	1,02
	6	232,5	247,4	189,7	201,9	72,4	79,1	86,7	91,5	45,3	48,6	1,03
	7	229,3	250,1	187,1	204,1	70,8	79,4	85,7	92,9	45,0	48,8	1,04
	8	231,0	248,4	188,5	202,7	71,0	80,4	85,7	92,7	44,9	49,0	1,04
	9	231,3	248,4	188,7	202,8	71,1	79,4	85,4	92,5	44,1	49,3	1,04
	10	226,1	254,8	184,3	209,1	69,7	80,3	83,2	95,8	40,9	50,9	1,06
	11	227,8	252,9	185,7	207,3	67,5	81,4	85,0	94,7	43,3	49,7	1,05
	12	227,2	253,5	185,3	208,1	68,9	80,4	82,9	95,1	43,3	49,8	1,06
	13	231,8	252,6	189,1	206,3	69,9	80,8	85,2	94,3	43,1	50,0	1,05

H_s = 2.0 m Wave direction 165^0												
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
2	6	230,4	249,3	187,9	203,5	69,3	80,4	86,1	92,9	44,1	49,3	1,04
	7	227,1	253,2	185,3	206,7	70,2	80,5	84,5	94,3	44,8	48,9	1,06
	8	226,9	251,7	185,1	205,4	69,6	80,4	84,7	93,7	45,1	48,9	1,05
	9	227,0	251,2	185,2	205,0	70,7	80,5	83,8	93,7	43,1	50,1	1,05
	10	222,7	259,9	181,5	214,0	67,6	83,4	80,5	98,2	40,6	51,9	1,08
	11	220,3	262,8	179,4	216,6	63,4	84,5	80,8	99,3	40,0	53,2	1,10
	12	220,0	263,3	179,1	217,0	63,8	83,9	82,1	99,4	42,1	52,5	1,10
	13	226,2	257,3	184,4	211,9	66,7	83,1	84,3	96,7	41,2	50,9	1,07

H_s = 2.5 m Wave direction 165^0												
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
2,5	6	228,7	250,8	186,6	204,7	70,5	81,1	85,4	92,9	44,4	49,1	1,05
	7	221,8	257,4	181,0	210,1	66,0	83,3	81,7	96,2	42,7	51,0	1,07
	8	225,5	253,0	183,9	206,5	66,9	83,4	83,6	95,1	42,8	50,8	1,05
	9	224,6	253,9	183,1	207,9	67,8	81,9	83,0	95,3	42,3	50,9	1,06
	10	212,6	269,8	173,2	222,8	63,8	85,3	76,5	101,7	38,7	53,9	1,12
	11	219,9	263,8	179,1	217,2	67,7	84,6	79,5	98,8	39,8	53,9	1,10
	12	211,5	276,4	171,9	229,0	58,9	87,8	79,4	104,7	38,2	55,3	1,15
	13	225,3	265,1	183,7	217,3	67,1	85,5	81,9	98,4	40,8	53,7	1,11

H_s = 3.0 m Wave direction 165^0												
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
3	7	221,3	258,8	180,6	211,2	67,8	82,9	82,2	96,5	43,2	50,2	1,08
	8	223,5	254,7	182,3	207,9	70,0	81,2	82,2	95,0	43,2	50,5	1,06
	9	224,2	257,6	182,8	210,5	65,3	82,9	82,7	95,5	42,1	51,7	1,07
	10	210,8	272,9	171,5	225,7	65,0	86,7	76,6	103,4	36,4	55,0	1,14
	11	207,4	281,1	168,5	233,4	61,0	88,9	73,6	106,7	35,4	57,0	1,17
	12	207,9	278,8	169,2	231,7	57,2	90,3	78,3	106,0	39,6	56,1	1,16
	13	215,9	272,2	175,5	225,9	64,1	87,4	78,6	103,4	36,5	55,1	1,14

H_s = 0.5 m Wave direction 180^0													
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
0,5	3	237,8	242,0	193,9	197,6	73,1	77,5	87,9	90,3	45,2	48,2	1,01
	4	238,3	241,5	194,3	197,2	72,4	78,0	87,9	90,2	44,9	48,6	1,01
	5	238,1	241,7	194,2	197,3	73,7	76,8	88,5	90,0	46,0	47,6	1,01
	6	237,5	241,7	193,7	197,3	74,1	76,6	88,5	90,0	46,2	47,4	1,01
	7	237,7	241,9	194,0	197,4	72,6	78,1	88,0	90,1	45,1	48,3	1,01
	8	237,8	241,8	194,1	197,3	74,5	76,5	88,5	90,0	46,4	47,3	1,01
	9	237,7	242,0	194,0	197,4	74,3	76,4	88,5	90,1	46,5	47,2	1,01
	10	237,7	241,8	193,9	197,3	74,2	76,3	88,4	90,0	46,4	47,2	1,01
	11	237,3	242,4	193,7	197,8	74,0	76,9	88,5	90,1	46,3	47,4	1,01
	12	237,6	241,7	193,9	197,2	74,4	76,5	88,5	89,9	46,4	47,4	1,01
	13	237,5	242,9	193,8	198,3	74,2	76,9	88,4	90,3	46,3	47,3	1,01

H_s = 1.0 m Wave direction 180^0													
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
1	4	236,6	243,1	192,9	198,6	71,4	78,8	87,4	90,9	44,1	49,1	1,01
	5	236,5	243,2	192,8	198,6	72,8	77,8	87,8	90,7	45,5	48,1	1,01
	6	235,6	244,7	192,1	199,8	69,7	80,3	86,7	91,2	43,3	49,5	1,02
	7	235,4	244,4	192,1	199,5	69,5	80,7	86,6	91,0	43,3	49,5	1,02
	8	235,9	243,9	192,5	199,0	73,5	77,6	87,7	90,7	46,0	47,8	1,02
	9	235,6	244,2	192,2	199,3	73,0	77,4	87,8	90,9	46,1	47,7	1,02
	10	235,4	243,7	192,0	198,9	72,9	77,3	87,7	90,7	46,0	47,6	1,02
	11	234,6	245,0	191,5	200,0	72,4	78,4	87,7	90,9	45,8	47,9	1,02
	12	235,5	243,5	192,1	198,7	73,4	77,5	87,8	90,6	45,9	47,9	1,02
	13	235,4	246,2	192,2	200,9	73,0	78,4	87,7	91,4	45,7	47,9	1,03

H_s = 1.5 m Wave direction 180^0													
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
1,5	5	234,1	245,6	190,6	200,6	67,6	81,1	86,0	91,8	42,3	50,3	1,02
	6	233,4	246,1	190,4	200,8	72,2	78,6	86,9	91,3	45,7	47,9	1,03
	7	232,9	246,6	190,0	201,2	72,1	78,4	86,8	91,7	45,7	48,2	1,03
	8	233,8	245,7	190,8	200,5	72,1	78,5	86,9	91,5	45,3	48,5	1,02
	9	233,6	246,7	190,6	201,4	72,0	78,4	87,2	91,8	45,7	48,2	1,03
	10	232,9	245,8	190,1	200,6	71,6	78,2	86,9	91,4	45,5	48,0	1,02
	11	231,8	247,7	189,1	202,3	70,7	79,9	86,8	91,9	45,2	48,5	1,03
	12	233,4	245,3	190,4	200,1	72,3	78,5	87,1	91,4	45,5	48,5	1,02
	13	233,5	249,5	190,6	203,7	71,6	80,0	87,0	92,5	45,0	48,3	1,04

H_s = 2.0 m Wave direction 180^0													
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
2	6	231,5	247,7	188,8	202,2	69,8	80,6	86,7	92,5	44,6	49,3	1,03
	7	230,3	249,4	187,9	203,5	70,8	79,7	85,8	92,4	45,2	48,3	1,04
	8	231,2	247,6	188,7	202,1	71,8	78,7	86,1	92,3	45,2	48,6	1,03
	9	231,5	248,5	188,9	202,8	71,5	78,9	86,4	92,3	45,4	48,2	1,04
	10	230,1	248,5	187,7	202,9	69,9	79,3	86,1	92,4	45,2	48,5	1,04
	11	228,7	250,6	186,6	204,8	69,0	81,3	85,8	92,9	44,6	49,0	1,04
	12	231,3	247,1	188,7	201,7	71,4	79,1	86,3	92,4	45,4	48,8	1,03
	13	231,6	253,0	189,1	206,7	70,2	81,6	86,5	93,7	44,3	48,9	1,05

H_s = 2.5 m Wave direction 180^0												
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
2,5	6	228,8	252,4	186,5	206,1	70,0	80,8	85,6	93,6	45,1	48,5	1,05
	7	223,9	257,1	181,6	210,4	60,5	86,0	81,4	96,0	38,7	52,9	1,07
	8	230,7	249,0	188,2	203,2	69,6	81,2	85,6	92,7	44,2	49,2	1,04
	9	228,9	250,0	186,8	204,0	70,6	79,9	85,6	92,8	45,1	48,7	1,04
	10	228,4	250,7	186,4	204,6	69,6	80,3	85,2	93,4	45,1	48,9	1,05
	11	227,7	252,3	185,7	206,2	68,6	82,6	85,4	93,5	43,8	49,5	1,05
	12	229,0	249,0	186,9	203,3	70,5	80,1	85,3	93,0	44,9	49,1	1,04
	13	229,6	256,8	187,4	210,0	68,9	83,2	85,9	95,1	43,5	49,7	1,07

H_s = 3.0 m Wave direction 180^0												
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
3	7	227,5	253,1	185,7	206,5	69,0	82,2	84,7	94,1	44,1	49,8	1,06
	8	229,8	250,4	187,4	204,4	70,5	80,2	85,8	92,8	45,3	48,4	1,04
	9	226,9	250,8	185,1	204,7	69,3	81,2	84,9	92,7	44,6	48,9	1,05
	10	225,4	252,7	183,8	206,9	67,7	82,1	84,5	94,1	44,2	49,7	1,05
	11	221,1	257,9	180,2	211,7	64,6	83,9	83,4	96,3	42,7	50,2	1,08
	12	226,6	254,1	184,9	207,9	68,9	80,8	84,7	94,8	43,9	50,1	1,06
	13	226,7	260,7	184,8	213,5	67,0	85,1	84,9	96,6	42,8	50,5	1,09

H_s = 0.5 m Wave direction 195^0												
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
0,5	3	236,9	242,4	193,1	198,1	73,0	77,9	87,7	90,6	45,0	48,5	1,01
	4	237,7	242,1	193,8	197,7	72,3	78,1	87,6	90,5	44,6	48,8	1,01
	5	237,3	242,3	193,5	197,8	73,5	77,0	88,1	90,4	46,0	47,7	1,01
	6	237,7	242,0	193,9	197,5	74,1	76,7	88,5	90,0	46,3	47,4	1,01
	7	237,2	242,5	193,5	197,9	72,2	78,2	88,1	90,5	45,1	48,6	1,01
	8	236,5	242,4	193,0	197,8	74,2	76,7	88,0	90,2	46,2	47,5	1,01
	9	237,2	242,8	193,6	198,2	74,0	76,7	88,3	90,4	46,3	47,4	1,01
	10	236,9	242,9	193,3	198,2	73,7	77,2	88,1	90,5	45,9	47,9	1,01
	11	236,7	242,9	193,1	198,2	73,1	77,4	87,8	90,5	45,5	47,9	1,01
	12	237,2	242,6	193,6	198,0	74,0	77,0	88,0	90,3	46,1	47,6	1,01
	13	236,2	242,8	192,8	198,2	72,9	77,6	88,0	90,5	45,9	47,9	1,01

H_s = 1.0 m Wave direction 195^0												
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
1	4	235,2	244,5	191,6	199,8	70,9	79,2	86,9	91,7	43,9	49,6	1,02
	5	235,2	244,0	191,7	199,3	72,2	78,2	87,2	91,0	45,5	48,2	1,02
	6	234,8	245,3	191,4	200,4	70,2	80,1	86,5	91,6	43,5	49,5	1,02
	7	233,8	245,9	190,6	200,7	68,6	81,1	86,3	91,6	43,1	50,0	1,03
	8	233,2	244,9	190,3	199,8	73,0	78,2	86,7	91,3	45,6	48,0	1,02
	9	234,6	246,0	191,4	200,7	72,2	78,2	87,4	91,8	45,4	48,4	1,03
	10	233,3	247,6	190,4	202,5	71,9	78,4	86,0	92,5	44,5	49,1	1,03
	11	232,7	246,9	189,9	201,8	71,9	78,7	86,4	92,3	43,9	49,5	1,03
	12	234,1	249,6	191,0	204,7	70,1	79,8	86,2	93,4	44,3	49,2	1,04
	13	232,5	246,7	189,7	201,6	71,5	78,6	85,8	92,4	44,0	49,0	1,03

H_s = 1.5 m Wave direction 195^0												
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
1,5	5	233,4	247,0	190,2	201,9	68,0	81,6	85,8	92,6	42,5	50,3	1,03
	6	231,4	247,6	188,6	202,1	72,2	80,0	85,8	91,8	44,8	48,3	1,03
	7	232,3	246,8	189,5	201,4	71,6	78,6	86,6	91,8	45,6	48,1	1,03
	8	231,5	248,3	188,9	202,7	70,6	79,6	86,0	92,4	45,0	48,7	1,04
	9	231,0	249,4	188,4	203,8	71,2	79,4	86,2	92,7	44,5	49,2	1,04
	10	229,7	253,1	187,4	208,0	70,6	80,5	84,0	95,1	43,6	50,6	1,06
	11	228,5	252,4	186,5	207,2	70,0	80,5	85,0	94,9	42,5	50,7	1,05
	12	230,5	255,0	188,0	209,7	69,5	82,2	84,4	95,6	42,0	50,7	1,06
	13	230,3	251,6	188,0	205,8	71,2	80,3	85,0	94,3	43,2	49,8	1,05

H_s = 2.0 m Wave direction 195^0													
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
2	6	230,6	249,8	188,1	204,0	69,8	81,1	85,7	92,6	44,2	49,3	1,04
	7	231,1	249,7	188,5	203,8	71,2	79,1	85,9	93,5	45,0	48,8	1,04
	8	229,2	249,4	187,0	203,6	70,6	79,6	85,0	92,9	45,1	48,6	1,04
	9	227,8	255,7	185,8	209,3	69,4	81,3	84,4	95,2	41,9	50,8	1,07
	10	225,7	262,2	184,0	216,5	67,6	84,7	81,7	99,5	41,0	53,6	1,09
	11	223,2	258,0	181,9	212,5	66,9	82,9	82,1	97,7	40,0	52,4	1,08
	12	226,4	267,6	184,5	221,8	65,2	86,9	83,8	101,6	40,0	54,0	1,12
	13	225,7	258,2	184,2	211,7	68,6	82,3	83,0	96,5	42,0	51,2	1,08

H_s = 2.5 m Wave direction 195^0													
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
2,5	6	227,1	253,9	185,2	207,4	69,3	81,9	84,7	94,0	44,3	49,0	1,06
	7	224,9	257,0	182,9	210,2	62,0	85,3	80,8	96,6	37,6	53,6	1,07
	8	226,7	252,2	184,9	205,8	67,8	82,2	83,4	94,9	42,8	50,5	1,05
	9	225,3	256,0	183,9	209,7	68,7	81,9	82,8	95,8	42,5	51,4	1,07
	10	216,2	273,8	175,9	226,7	65,5	87,8	78,8	103,3	37,4	54,1	1,14
	11	218,2	264,9	178,1	219,3	64,6	87,4	81,1	100,6	38,9	54,9	1,10
	12	222,2	276,8	181,0	230,5	64,7	89,5	82,0	105,9	38,5	56,2	1,15
	13	225,2	264,9	183,8	218,0	68,2	83,5	82,4	100,0	40,4	52,9	1,10

H_s = 3.0 m Wave direction 195^0													
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
3	7	228,0	251,1	186,0	204,9	70,1	80,8	84,6	93,6	43,3	49,6	1,05
	8	224,8	257,8	183,6	210,5	68,4	83,4	83,0	95,6	43,4	50,4	1,07
	9	219,3	262,4	178,9	215,1	67,8	83,4	81,7	97,7	41,0	52,0	1,09
	10	211,8	277,7	172,2	229,7	58,7	89,1	77,2	105,3	36,9	55,0	1,16
	11	212,5	280,7	173,3	233,8	59,3	91,3	79,6	107,2	38,8	57,4	1,17
	12	220,2	285,2	180,4	238,6	62,5	91,6	81,4	110,1	37,7	59,0	1,19
	13	217,3	265,2	177,3	218,4	62,5	85,0	80,6	100,1	39,5	53,5	1,11

Lift in Air - Short Crested Waves

H_s = 0.5 m Wave direction 165^0												
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
0,5	3	238,1	241,5	194,2	197,2	73,5	77,1	88,1	90,2	45,5	48,2	1,01
	4	238,2	241,4	194,2	197,0	73,5	77,1	88,3	90,1	45,6	48,0	1,01
	5	237,8	241,5	194,1	197,1	74,2	76,6	88,3	90,0	45,9	47,6	1,01
	6	237,1	242,6	193,5	198,0	73,8	76,6	88,2	90,3	46,1	47,5	1,01
	7	236,9	243,1	193,3	198,4	74,2	76,6	88,2	90,4	46,1	47,6	1,01
	8	236,2	243,4	192,7	198,6	73,7	77,2	88,0	90,5	46,1	47,4	1,01
	9	236,0	244,2	192,5	199,3	73,0	77,5	88,0	90,7	46,0	47,7	1,02
	10	235,5	244,0	192,2	199,1	73,0	78,2	87,5	91,2	45,4	48,2	1,02
	11	234,1	246,2	191,0	201,3	70,8	78,7	87,6	91,8	44,9	48,5	1,03
	12	232,4	248,5	189,6	203,6	70,8	79,7	87,2	92,5	44,7	49,1	1,04
	13	235,6	246,6	192,2	202,0	72,7	78,0	87,1	92,4	44,9	48,8	1,03

H_s = 1.0 m Wave direction 165^0												
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
1	4	237,1	242,6	193,3	198,0	73,6	77,2	87,6	90,6	45,3	48,1	1,01
	5	236,7	243,2	193,1	198,4	72,6	78,0	87,5	90,7	45,2	48,5	1,01
	6	234,2	246,3	191,1	201,0	71,7	78,6	87,3	91,5	45,2	48,7	1,03
	7	233,3	246,6	190,4	201,3	72,4	78,1	87,0	91,7	45,4	48,2	1,03
	8	232,4	247,0	189,6	201,5	71,7	79,3	86,7	91,8	45,1	48,6	1,03
	9	232,0	248,5	189,3	202,8	70,6	79,4	86,1	92,5	43,5	50,1	1,04
	10	230,8	248,4	188,3	202,8	70,1	79,6	85,5	93,2	44,2	49,8	1,04
	11	225,8	255,4	184,0	209,5	66,0	81,7	85,0	95,7	43,1	50,5	1,06
	12	228,4	254,7	186,3	209,4	66,6	82,6	85,7	95,4	42,9	50,5	1,06
	13	221,6	265,6	180,4	219,9	64,3	84,6	80,6	100,7	39,1	53,2	1,11

H_s = 1.5 m Wave direction 165^0												
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
1,5	5	234,0	245,3	190,8	200,2	70,8	79,4	86,5	91,9	44,4	49,6	1,02
	6	230,0	248,8	187,6	203,0	71,3	79,3	85,9	92,4	44,8	48,7	1,04
	7	230,0	249,6	187,7	203,7	70,0	80,2	85,8	92,6	43,6	49,7	1,04
	8	227,9	252,0	185,9	205,6	69,9	80,6	83,9	94,0	42,5	49,9	1,05
	9	227,5	252,5	185,6	206,1	67,0	82,6	84,2	93,8	42,0	51,7	1,05
	10	224,9	253,5	183,4	207,6	68,5	82,1	82,4	95,3	42,5	50,3	1,06
	11	216,3	268,4	176,0	222,5	64,3	87,3	78,0	101,9	37,3	54,3	1,12
	12	214,7	268,9	174,5	223,0	64,3	85,4	77,6	102,1	36,7	54,1	1,12
	13	208,7	286,2	169,5	239,0	58,7	91,7	74,2	109,2	36,1	57,5	1,19

H_s = 2.0 m Wave direction 165^0												
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
2	6	227,5	252,9	185,6	206,3	68,9	82,9	84,1	93,9	43,2	49,7	1,05
	7	223,2	255,6	182,1	208,6	68,5	81,4	83,6	95,0	43,6	50,3	1,07
	8	225,5	255,5	183,9	208,8	66,9	81,6	83,0	94,7	41,3	51,0	1,07
	9	221,6	256,4	180,0	209,2	60,8	85,1	83,9	95,6	41,3	52,0	1,07
	10	217,3	260,8	177,0	214,8	65,0	82,6	80,6	98,3	38,7	52,9	1,09
	11	204,4	278,6	166,0	231,5	55,6	90,1	77,1	106,3	38,0	55,5	1,16
	12	202,2	285,9	164,0	239,3	59,8	92,7	72,1	109,7	33,0	57,7	1,19
	13	183,8	327,8	148,5	277,6	51,9	105,9	63,9	127,1	29,8	67,0	1,37

H_s = 2.5 m Wave direction 165^0												
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
2,5	6	224,9	255,3	183,4	208,4	67,2	82,2	83,9	95,4	43,6	50,7	1,06
	7	221,6	256,8	180,7	209,6	66,7	82,7	82,6	95,7	43,7	50,1	1,07
	8	218,0	262,1	177,5	215,2	62,2	85,8	82,2	98,2	41,2	52,0	1,09
	9	212,9	261,1	173,5	213,4	61,8	86,8	80,5	96,8	43,2	51,2	1,09
	10	189,6	281,9	153,0	235,0	60,1	94,4	65,3	106,4	31,4	56,5	1,18
	11	193,9	292,4	156,7	244,6	49,0	95,1	74,9	112,4	36,1	59,5	1,22
	12	198,3	296,3	161,4	248,8	54,2	102,5	70,0	112,8	35,5	64,5	1,24
	13	168,4	346,1	133,8	293,2	34,7	113,0	64,9	135,5	29,0	71,3	1,44

H_s = 3.0 m Wave direction 165^0												
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
3	7	217,2	261,9	177,2	213,7	67,2	83,3	79,6	97,6	40,8	53,0	1,09
	8	213,3	264,5	173,6	217,1	60,3	87,1	79,6	99,2	38,5	53,8	1,10
	9	212,2	270,9	172,7	224,0	60,1	86,8	76,3	102,4	38,3	55,1	1,13
	10	196,6	279,6	159,9	233,4	53,8	91,1	71,5	108,5	30,7	57,7	1,17
	11	168,7	330,7	135,1	279,8	39,6	104,0	63,3	130,1	30,8	68,6	1,38
	12	172,7	321,4	138,1	271,4	39,2	110,7	66,4	124,9	31,1	66,6	1,34
	13	169,3	374,1	135,4	319,6	44,6	129,5	56,4	144,0	20,3	78,4	1,56

H_s = 0.5 m Wave direction 180^0													
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
0,5	3	237,8	242,0	193,8	197,6	71,0	78,9	87,2	90,7	43,8	49,3	1,01
	4	238,2	241,3	194,3	196,9	74,2	76,6	88,1	90,1	45,9	47,7	1,01
	5	237,8	241,7	194,1	197,2	73,8	76,9	88,3	90,1	45,7	47,9	1,01
	6	237,4	242,3	193,7	197,7	74,1	76,8	88,3	90,1	46,2	47,5	1,01
	7	237,3	242,8	193,7	198,1	74,1	76,9	88,3	90,2	46,1	47,6	1,01
	8	236,2	243,2	192,8	198,4	73,8	77,0	88,1	90,4	46,2	47,5	1,01
	9	235,3	243,6	192,0	198,8	73,3	77,4	87,9	90,5	46,0	47,5	1,02
	10	235,0	244,2	191,7	199,4	72,8	77,6	87,7	90,9	45,6	47,9	1,02
	11	235,6	245,2	192,2	200,3	72,4	78,0	87,6	91,0	45,3	48,4	1,02
	12	234,8	245,1	191,5	200,5	72,3	77,7	86,7	91,8	43,8	49,1	1,02
	13	233,4	247,7	190,4	203,0	69,9	79,3	86,6	92,6	43,8	49,2	1,03

H_s = 1.0 m Wave direction 180^0													
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
1	4	237,7	242,4	193,9	197,8	72,6	78,0	87,7	90,4	44,8	48,6	1,01
	5	236,2	243,7	192,7	198,8	73,1	77,8	87,9	90,8	45,5	48,0	1,02
	6	234,6	245,3	191,5	200,2	71,7	78,1	87,3	91,1	45,2	48,5	1,02
	7	234,5	245,8	191,3	200,5	72,3	78,6	87,5	91,3	45,4	48,1	1,02
	8	232,5	246,7	189,7	201,3	71,9	78,4	86,7	91,7	45,3	48,5	1,03
	9	230,4	248,2	188,0	202,7	70,7	79,1	85,4	92,8	42,8	49,8	1,03
	10	229,3	248,8	187,0	203,3	69,4	79,9	85,8	92,7	45,1	48,4	1,04
	11	229,6	250,6	187,3	205,3	69,0	80,2	84,8	94,0	44,2	49,3	1,04
	12	224,8	257,8	183,1	212,5	68,2	82,1	81,4	97,2	40,9	51,6	1,07
	13	225,0	262,6	183,2	216,9	65,6	83,9	83,2	98,9	40,7	52,2	1,09

H_s = 1.5 m Wave direction 180^0													
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
1,5	5	233,9	245,1	190,9	200,0	72,0	78,6	87,0	91,3	44,5	48,6	1,02
	6	231,1	249,4	188,6	203,5	71,4	80,6	85,9	92,3	44,2	48,8	1,04
	7	231,8	247,7	189,1	202,1	71,4	79,8	86,3	92,2	44,9	48,9	1,03
	8	229,4	249,7	187,2	203,7	70,3	80,3	85,1	93,0	42,9	50,7	1,04
	9	225,2	252,2	183,6	206,2	67,4	81,3	83,1	94,6	41,0	51,4	1,05
	10	221,3	257,9	180,6	211,5	70,7	80,3	81,1	97,0	43,5	51,2	1,08
	11	221,2	262,2	180,3	216,6	64,8	84,1	80,9	98,9	39,5	52,3	1,09
	12	219,3	266,2	178,7	220,3	62,4	85,7	82,0	100,4	40,2	53,5	1,11
	13	208,3	289,3	169,3	242,1	58,6	93,5	77,3	110,5	35,3	59,2	1,21

H_s = 2.0 m Wave direction 180^0												
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
2	6	226,2	252,3	184,6	205,9	69,2	81,3	84,5	93,3	43,8	49,9	1,05
	7	225,5	253,8	184,0	207,1	68,6	82,1	84,4	94,2	44,5	49,1	1,06
	8	224,5	254,6	183,1	207,8	68,8	82,3	83,1	95,1	42,5	51,5	1,06
	9	222,6	255,3	181,4	208,3	64,7	83,1	82,5	95,0	44,3	49,9	1,06
	10	215,2	261,3	175,4	214,6	64,1	84,5	80,3	96,9	38,9	52,3	1,09
	11	214,4	270,9	174,6	223,9	62,6	86,9	77,1	103,0	37,5	55,4	1,13
	12	215,4	276,3	176,0	229,8	58,3	91,5	81,3	104,1	38,6	54,4	1,15
	13	185,2	321,0	149,2	272,3	50,9	105,9	64,1	126,2	26,9	67,3	1,34

H_s = 2.5 m Wave direction 180^0												
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
2,5	6	222,1	256,7	181,1	209,5	67,2	82,2	83,7	95,1	43,5	50,8	1,07
	7	223,1	255,6	181,9	208,6	67,1	82,5	83,5	95,4	43,0	50,6	1,07
	8	217,5	259,6	177,5	212,0	65,0	83,2	80,1	97,3	39,9	52,5	1,08
	9	213,4	259,8	173,9	212,5	63,5	83,9	80,0	98,1	40,3	53,2	1,08
	10	207,6	272,5	168,9	225,1	63,1	87,3	75,1	103,4	35,6	54,9	1,14
	11	204,6	283,4	165,8	235,6	60,6	92,8	71,5	108,1	33,7	57,2	1,18
	12	190,4	311,7	154,7	263,2	52,8	103,7	66,6	120,7	28,7	64,6	1,30
	13	175,2	330,8	140,2	280,1	50,4	112,7	60,9	126,3	23,3	65,7	1,38

H_s = 3.0 m Wave direction 180^0												
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
3	7	217,7	262,4	177,5	214,2	65,2	85,6	80,6	97,9	41,1	51,8	1,09
	8	212,8	264,7	173,3	216,1	65,3	85,0	78,9	98,9	37,4	54,1	1,10
	9	201,8	272,6	164,2	223,7	55,5	89,7	77,0	101,9	39,1	54,0	1,14
	10	198,1	275,6	160,5	229,1	52,2	90,5	74,8	104,7	34,5	57,8	1,15
	11	170,9	324,4	137,2	273,9	38,3	106,3	61,0	125,0	24,0	68,4	1,35
	12	187,5	329,5	151,3	280,1	45,6	107,4	70,0	129,4	29,7	70,1	1,37
	13	171,9	382,4	138,3	327,3	37,5	125,8	65,6	152,0	27,6	78,0	1,59

H_s = 0.5 m Wave direction 195^0												
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
0,5	3	237,7	242,5	193,7	198,0	72,3	78,2	87,4	90,5	44,6	48,9	1,01
	4	238,0	241,7	194,1	197,4	74,3	76,5	88,1	90,2	45,9	47,7	1,01
	5	237,8	242,0	194,0	197,5	74,4	76,4	88,4	90,1	46,2	47,5	1,01
	6	236,7	242,4	193,1	197,8	73,7	77,0	88,1	90,3	45,7	47,8	1,01
	7	236,2	243,7	192,7	198,9	73,5	77,4	88,0	90,6	46,0	47,7	1,02
	8	233,9	246,1	190,9	200,8	72,9	77,9	87,1	91,4	45,9	47,8	1,03
	9	234,0	245,9	190,9	200,7	73,0	77,8	87,4	91,3	45,8	47,9	1,03
	10	234,4	245,5	191,2	200,5	72,7	78,1	87,6	91,1	45,3	48,1	1,02
	11	235,8	244,2	192,4	199,4	72,3	77,9	87,6	90,9	44,8	48,6	1,02
	12	234,9	245,0	191,6	200,5	72,3	77,7	86,4	91,7	44,5	48,8	1,02
	13	233,5	247,2	190,4	202,6	71,1	78,5	86,0	92,7	43,1	49,4	1,03

H_s = 1.0 m Wave direction 195^0												
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
1	4	237,0	242,7	193,2	198,0	71,7	78,8	87,3	90,8	44,2	49,0	1,01
	5	235,6	244,5	192,1	199,6	71,7	79,0	86,4	91,2	43,9	49,1	1,02
	6	234,2	245,9	191,0	200,7	72,2	78,6	86,3	91,7	44,8	48,5	1,03
	7	232,5	247,5	189,7	202,0	71,5	79,5	86,5	91,9	45,2	48,5	1,03
	8	228,1	252,4	186,2	206,0	70,0	80,6	85,1	93,7	44,3	49,1	1,05
	9	227,8	252,4	185,9	206,1	70,2	80,3	85,2	93,6	42,8	50,5	1,05
	10	227,7	251,5	185,7	205,7	68,2	81,5	85,5	93,6	43,8	49,4	1,05
	11	227,7	250,7	185,7	205,4	70,1	79,9	83,6	94,0	44,4	48,9	1,05
	12	229,2	250,8	186,9	205,7	67,6	81,0	85,5	94,0	43,1	49,5	1,05
	13	223,4	259,9	181,9	214,5	66,8	83,0	80,9	98,2	39,5	52,4	1,08

H_s = 1.5 m Wave direction 195^0												
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
1,5	5	232,9	246,2	189,9	201,0	70,0	81,0	86,0	91,8	43,4	49,6	1,03
	6	227,5	252,1	185,5	205,8	69,5	80,9	84,4	93,8	43,6	49,5	1,05
	7	227,6	250,7	185,7	204,6	68,8	81,1	84,7	93,7	43,8	50,1	1,05
	8	219,6	258,5	179,1	211,2	64,8	83,6	82,8	96,3	42,8	50,5	1,08
	9	221,0	259,4	180,3	212,0	66,4	83,4	82,0	96,5	40,3	52,3	1,08
	10	218,7	260,2	178,1	213,8	63,9	84,2	81,7	97,5	41,1	51,8	1,09
	11	223,1	260,0	181,9	213,5	67,6	83,8	81,3	97,3	39,9	52,2	1,08
	12	211,4	278,0	171,7	231,4	58,3	91,7	77,5	104,6	37,2	55,6	1,16
	13	203,0	289,2	164,6	242,1	54,0	94,4	77,2	110,2	35,4	57,9	1,21

H_s = 2.0 m Wave direction 195^0													
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
2	6	227,5	252,7	185,3	206,3	66,1	83,1	83,1	94,1	41,9	50,6	1,05
	7	221,6	258,1	180,8	210,6	67,0	83,4	82,7	96,0	43,6	50,1	1,08
	8	220,3	263,8	179,7	216,7	66,7	84,1	81,1	99,1	41,9	52,6	1,10
	9	212,2	264,9	172,9	216,8	61,1	87,5	80,2	98,5	43,0	51,3	1,10
	10	207,1	273,7	168,3	226,0	66,1	85,0	74,4	103,2	35,3	56,1	1,14
	11	205,3	274,8	167,0	228,0	58,8	89,5	77,8	103,5	37,2	55,6	1,15
	12	200,0	294,3	162,1	246,6	54,4	96,2	75,6	112,2	35,1	59,7	1,23
	13	183,5	316,0	147,8	267,3	51,4	104,0	63,3	121,9	27,8	63,3	1,32

H_s = 2.5 m Wave direction 195^0													
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
2,5	6	224,8	256,6	183,4	209,6	66,2	84,8	81,9	95,2	41,1	51,2	1,07
	7	215,8	263,6	176,0	215,2	63,4	86,2	81,0	98,6	40,8	52,6	1,10
	8	208,8	270,8	170,3	221,4	65,0	85,3	77,4	100,6	38,4	54,3	1,13
	9	204,6	274,6	166,7	225,7	64,2	89,4	76,1	103,5	37,5	54,2	1,14
	10	201,5	284,1	164,1	235,5	60,1	92,6	75,6	108,1	36,2	58,7	1,18
	11	191,4	294,6	154,9	246,5	52,1	101,3	66,3	113,3	31,3	59,9	1,23
	12	183,2	323,6	147,9	273,5	47,5	104,7	68,2	126,3	28,4	66,0	1,35
	13	173,3	335,8	139,4	284,5	41,2	110,2	65,4	130,1	27,7	69,7	1,40

H_s = 3.0 m Wave direction 195^0													
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]		DAF
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
3	7	206,3	270,3	167,8	220,8	59,1	89,1	74,4	101,4	35,1	55,4	1,13
	8	207,2	275,4	168,9	225,7	63,7	87,6	75,8	104,5	37,3	57,5	1,15
	9	185,6	296,8	150,5	245,6	57,5	95,0	66,1	112,9	29,8	60,2	1,24
	10	200,0	279,6	162,3	231,9	53,8	93,5	74,5	106,4	36,3	56,8	1,17
	11	167,0	318,3	132,7	268,7	33,6	107,0	64,8	122,4	25,6	69,7	1,33
	12	176,2	329,2	141,9	278,8	45,5	106,1	62,9	126,6	25,9	69,1	1,37
	13	174,8	336,5	140,5	285,2	40,4	110,9	67,2	131,3	29,6	67,6	1,40

Lift through Wave Zone - Long Crested Waves

H_s = 0.5 m Wave direction 165^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
0,5	3	148,3	242,0	104,2	197,6	39,6	77,3	45,9	90,5	23,4	51,1
	4	145,7	240,5	101,8	196,3	37,2	77,0	43,1	89,8	21,7	49,3
	5	144,5	241,2	100,6	196,8	35,9	77,0	43,2	90,1	21,6	49,4
	6	143,4	242,2	99,5	197,7	36,4	76,9	43,4	90,5	21,2	49,3
	7	143,2	243,1	99,1	198,3	36,0	77,0	43,7	90,4	20,9	49,1
	8	145,0	242,6	101,0	198,0	36,2	76,8	44,4	90,2	22,7	48,1
	9	145,8	242,6	101,9	198,0	37,3	76,6	45,1	90,2	22,3	47,5
	10	146,0	242,6	102,2	198,0	37,5	76,7	45,4	90,3	23,3	47,9
	11	146,5	243,4	102,6	198,7	38,1	76,7	45,7	90,5	23,2	47,7
	12	146,5	242,6	102,9	197,9	38,5	76,9	45,9	90,2	23,5	47,5
	13	147,3	243,6	103,6	198,8	39,1	77,3	46,4	90,5	24,3	48,0

H_s = 1.0 m Wave direction 165^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1	4	135,7	243,3	92,2	198,9	34,9	82,0	39,1	93,0	16,3	55,3
	5	134,1	246,5	90,4	202,1	29,2	78,5	34,4	94,6	15,8	52,0
	6	134,4	244,4	90,6	199,6	31,1	79,8	36,2	91,5	17,0	52,6
	7	134,3	246,3	89,9	200,9	33,1	79,7	38,2	91,9	16,9	51,5
	8	137,3	245,3	93,4	200,2	33,4	78,9	39,8	91,1	20,2	52,5
	9	139,5	245,3	95,6	200,2	35,6	78,7	41,4	91,3	19,1	50,9
	10	141,2	245,4	97,4	200,3	35,0	80,3	42,3	91,6	21,4	50,6
	11	141,2	247,0	97,5	201,6	35,6	78,4	43,0	92,0	20,9	49,4
	12	142,1	245,5	98,7	200,6	36,2	80,1	43,4	91,6	21,5	49,9
	13	143,6	246,8	100,2	201,3	37,8	78,9	44,4	92,0	22,6	49,1

H_s = 1.5 m Wave direction 165^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1,5	5	120,0	256,8	76,1	211,9	25,3	86,7	27,7	99,5	6,4	60,0
	6	116,3	251,3	72,3	206,4	27,5	83,8	25,3	99,4	0,0	61,4
	7	118,6	255,2	73,3	210,1	24,3	86,2	30,8	96,1	9,1	62,8
	8	124,2	255,0	80,1	211,8	30,0	84,1	33,8	101,0	12,4	70,1
	9	131,4	248,1	87,3	202,5	31,5	81,9	36,8	93,1	14,6	62,7
	10	132,5	248,6	88,4	203,0	33,0	82,1	37,9	92,8	17,3	59,6
	11	133,8	251,3	90,2	205,3	33,4	81,3	39,8	93,8	18,1	58,2
	12	136,6	250,3	93,4	204,8	34,2	82,6	40,3	93,8	19,4	52,4
	13	139,1	249,4	95,3	203,4	36,4	81,3	42,2	93,7	19,8	51,8

H_s = 2.0 m Wave direction 165^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
2	6	99,7	258,3	56,3	213,7	20,5	87,1	19,9	106,8	0,0	67,0
	7	99,3	273,4	53,8	230,3	11,6	87,6	23,4	117,6	0,0	72,5
	8	104,7	261,8	60,0	218,1	18,3	87,0	26,7	107,4	5,4	75,2
	9	111,0	278,4	66,2	235,1	22,5	90,2	23,9	113,0	3,2	80,7
	10	123,2	253,6	78,7	207,8	27,2	85,7	31,1	100,2	10,4	72,7
	11	125,2	255,1	81,8	208,5	30,9	84,0	35,3	98,8	13,6	66,1
	12	129,5	252,8	86,5	207,1	30,9	85,5	36,3	95,8	15,7	63,3
	13	132,8	255,1	89,1	208,4	34,5	82,5	38,7	95,5	16,9	60,2

H_s = 2.5 m Wave direction 165^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
2,5	6	70,6	360,3	26,5	314,6	6,9	103,9	0,0	169,9	0,0	85,8
	7	68,9	302,0	22,1	259,0	7,8	108,3	8,3	135,4	0,0	98,7
	8	72,6	331,1	28,0	282,6	7,2	107,7	0,0	190,9	0,0	96,2
	9	80,9	285,9	35,8	242,3	18,1	103,1	13,6	114,8	2,6	86,6
	10	107,9	274,8	63,7	231,3	23,2	91,9	24,1	112,7	0,0	81,2
	11	106,1	258,0	62,6	210,5	25,0	86,6	25,0	105,0	8,6	74,7
	12	119,4	266,5	76,5	223,8	27,6	86,6	32,2	100,6	12,4	70,7
	13	124,6	257,7	80,4	210,3	30,7	85,9	32,5	98,7	13,1	66,7

H_s = 3.0 m Wave direction 165^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
3	7	55,6	337,0	10,7	291,8	3,0	117,4	0,0	159,4	0,0	86,9
	8	66,1	321,5	20,6	277,7	9,8	104,2	1,7	151,5	0,0	97,2
	9	45,5	300,4	0,5	256,8	0,0	96,9	0,0	126,9	0,0	87,6
	10	89,0	285,7	43,2	241,6	17,5	100,5	15,8	122,5	0,0	80,7
	11	74,9	284,3	29,7	239,2	11,7	95,3	15,0	121,1	0,0	73,6
	12	103,9	278,7	61,1	235,9	21,5	88,0	27,3	105,3	5,7	75,4
	13	114,9	269,3	70,8	225,7	26,2	88,7	24,5	102,9	9,5	77,2

H_s = 0.5 m Wave direction 180^0

Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
0,5	3	146,9	242,1	102,8	197,7	39,4	77,2	45,3	90,5	23,1	51,0
	4	145,4	241,5	101,4	197,1	36,7	77,4	43,8	90,1	21,9	49,5
	5	145,2	241,7	101,3	197,3	35,4	77,5	43,5	90,1	21,9	48,9
	6	145,9	241,7	101,8	197,3	36,2	77,0	44,0	90,1	21,2	47,8
	7	146,1	241,9	102,2	197,4	35,8	76,8	44,3	90,0	21,6	48,5
	8	147,2	241,8	103,0	197,3	36,6	76,6	45,2	89,9	22,9	48,6
	9	147,8	241,9	103,7	197,4	37,2	76,5	45,1	90,0	23,3	48,0
	10	147,4	241,7	103,3	197,3	38,0	76,4	46,3	90,0	23,7	47,8
	11	147,9	242,4	104,0	197,8	37,8	76,4	46,6	90,2	23,8	47,3
	12	147,6	241,7	103,6	197,2	38,9	76,9	46,4	90,1	23,8	47,6
	13	149,0	242,9	105,1	198,2	39,2	76,7	47,0	90,4	24,6	47,3

H_s = 1.0 m Wave direction 180^0

Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1	4	136,8	249,4	93,4	205,0	33,7	80,4	39,6	98,1	16,3	55,4
	5	136,4	243,6	92,9	199,1	30,0	77,7	32,8	91,4	17,2	52,5
	6	137,8	244,4	93,7	199,5	30,6	78,2	39,6	91,8	18,3	51,5
	7	139,1	244,0	95,7	199,1	31,8	78,6	39,5	92,5	18,4	50,8
	8	141,4	243,8	97,7	199,0	34,1	79,5	41,9	90,8	20,1	50,1
	9	144,3	244,1	100,1	199,2	35,1	80,2	42,2	91,0	20,9	49,7
	10	142,3	243,6	98,3	198,8	35,7	80,0	43,9	90,9	21,4	49,8
	11	144,4	245,0	100,7	199,9	36,2	80,6	45,1	91,5	22,2	49,8
	12	142,9	243,5	98,9	198,7	37,0	78,1	44,1	91,0	21,5	48,6
	13	146,6	246,2	103,0	200,9	37,8	78,0	45,6	91,5	23,5	48,9

H_s = 1.5 m Wave direction 180^0

Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1,5	5	123,5	256,1	80,0	211,7	22,1	84,1	24,5	98,1	8,7	59,4
	6	114,5	250,7	70,6	206,3	27,2	83,6	27,4	97,7	2,6	55,8
	7	128,4	248,6	84,0	204,5	29,3	82,5	34,7	96,8	13,2	53,0
	8	137,2	246,4	93,1	201,6	30,8	81,0	37,7	92,6	17,2	52,2
	9	137,5	246,8	93,4	201,5	32,6	81,1	37,7	92,6	17,3	52,2
	10	135,6	247,5	91,6	202,6	34,0	83,7	39,6	92,4	18,3	51,5
	11	139,8	247,6	96,4	202,1	33,9	82,7	43,1	93,6	19,7	51,1
	12	136,9	245,5	93,0	200,4	35,1	79,6	41,4	91,7	18,8	50,0
	13	143,8	249,5	100,4	203,7	36,5	82,3	44,1	92,7	22,5	51,5

H_s = 2.0 m Wave direction 180^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
2	6	110,1	255,1	66,3	210,3	17,8	88,0	24,3	101,1	0,0	64,2
	7	117,2	252,0	72,1	206,6	29,3	86,3	24,6	95,3	0,0	61,3
	8	124,4	248,1	79,7	203,3	28,8	82,8	30,8	95,6	5,2	60,8
	9	127,3	253,9	83,4	208,3	30,0	87,7	33,7	95,5	14,3	59,9
	10	119,6	252,0	75,5	206,7	31,3	88,8	32,5	95,4	12,3	54,4
	11	133,8	251,6	90,6	205,9	31,5	84,7	39,3	94,7	17,0	52,2
	12	122,7	248,9	79,2	203,6	33,0	84,4	33,6	93,1	15,7	51,5
	13	139,9	253,4	96,0	207,0	35,2	83,0	39,8	95,0	21,2	52,7

H_s = 2.5 m Wave direction 180^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
2,5	6	96,7	284,5	52,7	240,2	19,5	101,5	17,0	109,2	0,0	70,8
	7	105,7	254,5	61,4	209,2	27,5	87,8	24,0	99,9	0,0	66,7
	8	109,0	259,5	65,2	214,8	22,4	90,8	26,9	106,8	6,0	72,1
	9	113,6	257,0	71,1	211,8	27,8	87,8	29,1	98,6	4,4	59,5
	10	112,3	256,1	69,5	210,4	27,3	85,6	30,0	96,4	9,3	59,1
	11	125,4	253,3	82,5	206,8	30,1	84,6	35,1	96,0	13,6	54,4
	12	113,7	251,0	70,5	205,3	30,1	86,2	27,4	94,3	12,0	53,4
	13	127,8	255,2	84,1	208,8	32,1	85,1	37,5	95,8	16,5	53,8

H_s = 3.0 m Wave direction 180^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
3	7	112,1	264,2	66,5	219,1	20,1	94,3	24,4	111,3	0,0	74,8
	8	96,4	278,0	51,6	234,1	22,3	93,4	22,3	125,2	2,7	68,4
	9	98,1	264,2	54,9	218,8	16,0	91,1	21,4	99,4	5,5	67,8
	10	99,4	259,3	54,7	212,9	22,2	87,6	26,9	100,6	1,7	65,3
	11	113,5	256,0	71,0	209,3	23,8	85,8	28,5	96,3	2,5	60,2
	12	102,5	257,4	59,6	211,3	24,3	86,4	21,4	99,9	0,7	58,4
	13	122,6	258,6	79,1	211,1	28,3	86,0	33,5	96,7	11,1	54,2

H_s = 0.5 m Wave direction 195^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
0,5	3	145,3	242,5	101,2	198,1	38,6	77,5	45,4	90,7	22,8	49,8
	4	144,3	242,0	100,4	197,6	36,7	77,8	43,8	90,4	22,5	49,9
	5	145,6	242,3	101,7	197,8	35,1	77,5	44,4	90,3	21,9	48,5
	6	145,2	242,0	101,2	197,5	35,4	77,1	44,4	90,3	21,7	48,4
	7	144,6	242,3	100,9	197,8	34,6	76,9	44,3	90,3	22,3	49,0
	8	144,9	242,5	101,4	197,8	36,5	77,2	44,9	90,2	22,4	48,7
	9	146,0	242,8	102,2	198,1	36,6	76,7	45,3	90,3	23,0	48,6
	10	144,8	243,0	101,2	198,3	36,9	77,0	46,1	90,3	23,3	48,5
	11	145,6	242,9	101,9	198,2	37,4	77,3	46,1	90,3	23,5	49,0
	12	147,1	242,7	103,2	198,1	37,8	77,3	46,1	90,4	23,8	48,0
	13	146,3	243,1	102,7	198,4	38,7	76,8	46,2	90,5	24,3	47,7

H_s = 1.0 m Wave direction 195^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1	4	136,3	247,5	92,6	202,1	34,1	83,2	40,9	97,7	18,5	55,7
	5	133,4	243,9	89,7	199,0	28,1	79,1	37,1	91,9	16,3	52,9
	6	136,1	244,7	92,4	199,9	29,0	78,9	38,5	91,8	17,5	52,6
	7	138,5	245,0	94,7	200,0	31,4	79,4	39,8	91,9	19,5	51,1
	8	136,9	245,3	93,9	200,4	31,1	80,7	40,9	92,1	20,0	52,2
	9	139,0	246,4	95,4	201,1	33,8	80,3	41,3	92,3	20,0	51,1
	10	136,3	246,5	93,1	201,4	32,1	81,1	41,1	92,1	20,2	53,2
	11	136,1	245,9	92,5	200,7	34,2	80,6	42,1	91,9	19,9	52,4
	12	141,6	247,4	97,9	202,4	35,6	83,5	43,4	92,7	21,4	50,9
	13	140,3	246,7	97,2	201,7	36,0	80,3	42,8	93,1	20,8	51,0

H_s = 1.5 m Wave direction 195^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1,5	5	121,0	255,0	77,4	211,0	20,0	86,7	30,0	99,3	3,5	57,9
	6	123,5	255,7	79,6	210,3	24,3	82,6	34,3	96,1	7,3	55,1
	7	119,6	253,0	76,6	207,5	26,9	83,6	30,2	96,8	5,4	54,6
	8	122,7	254,9	79,9	210,0	23,9	85,7	32,6	96,6	14,1	56,0
	9	121,8	251,5	78,3	206,6	26,5	82,7	34,8	96,4	13,2	56,5
	10	104,0	254,3	60,5	209,4	23,8	87,1	25,0	96,4	14,4	60,3
	11	121,2	253,8	78,3	208,6	24,2	84,5	33,8	96,2	15,1	62,6
	12	119,3	252,7	75,8	207,7	31,3	86,6	33,2	94,1	13,9	58,1
	13	132,3	251,6	89,8	205,9	33,4	86,6	35,6	95,5	19,3	53,1

H_s = 2.0 m Wave direction 195^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
2	6	107,9	259,5	64,9	214,0	20,8	93,0	22,6	102,1	0,0	62,0
	7	118,4	255,3	73,9	210,2	23,5	87,2	29,5	99,0	6,7	63,8
	8	94,8	254,7	51,2	209,9	15,5	88,4	21,5	99,1	9,4	63,3
	9	55,9	272,1	13,0	226,4	6,1	90,6	7,4	107,2	0,0	72,0
	10	77,5	269,1	34,0	223,4	11,1	96,9	10,0	106,8	4,1	70,6
	11	82,4	271,0	40,0	225,0	11,5	91,4	20,0	111,0	4,1	74,3
	12	102,7	268,5	59,5	222,8	24,4	95,8	26,6	98,2	10,2	64,3
	13	100,7	257,5	58,0	211,6	24,3	87,2	21,5	97,8	11,9	59,9

H_s = 2.5 m Wave direction 195^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
2,5	6	74,9	283,4	34,5	237,1	6,4	100,2	10,8	118,5	0,0	83,4
	7	91,8	262,8	48,8	217,0	16,7	96,8	20,3	104,8	0,0	70,6
	8	43,4	284,3	0,5	237,9	0,0	98,7	0,0	111,4	0,0	78,5
	9	43,4	306,8	1,3	259,9	0,0	99,2	0,8	125,4	0,0	84,5
	10	42,7	278,5	0,5	232,2	0,0	95,4	0,0	112,0	0,0	77,6
	11	55,6	287,1	14,0	240,8	3,0	98,6	6,9	123,1	0,0	81,7
	12	67,0	288,6	24,9	242,4	10,1	107,8	14,3	106,2	1,9	74,3
	13	72,9	272,5	30,7	228,0	13,3	88,8	13,3	103,5	3,5	67,9

H_s = 3.0 m Wave direction 195^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
3	7	76,3	292,3	33,5	246,7	5,9	98,2	10,9	118,5	0,0	78,2
	8	41,2	286,3	0,4	237,8	0,0	110,4	0,0	116,6	0,0	84,1
	9	40,6	335,8	0,5	287,6	0,0	118,5	0,0	139,4	0,0	82,0
	10	40,7	313,3	0,4	267,1	0,0	115,9	0,0	144,9	0,0	83,2
	11	49,4	287,7	8,3	241,6	2,8	108,7	4,8	123,4	0,0	80,3
	12	42,0	303,9	0,5	255,9	0,0	130,2	0,0	127,4	0,0	82,9
	13	46,7	290,1	4,7	245,4	1,9	93,2	2,7	114,3	0,0	77,2

Lift through Wave Zone - Short Crested Waves

H_s = 0.5 m Wave direction 165^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
0,5	3	144,2	241,6	100,2	197,3	37,9	76,5	44,3	90,3	22,3	49,7
	4	143,0	241,4	98,9	197,1	35,7	76,4	43,0	90,1	21,5	50,4
	5	143,8	241,6	99,9	197,2	35,2	77,0	43,1	90,2	20,9	50,0
	6	142,3	242,6	98,7	198,0	34,4	77,2	42,4	90,3	21,9	48,3
	7	143,1	243,0	99,3	198,3	36,2	77,0	43,6	90,5	22,6	49,5
	8	141,5	243,4	98,0	198,6	36,5	77,2	43,8	90,5	22,8	48,9
	9	142,5	244,3	99,0	199,3	36,9	77,2	44,6	90,7	23,2	48,3
	10	143,9	244,0	100,4	199,1	37,1	78,6	45,1	90,7	23,4	50,0
	11	143,0	244,4	99,6	199,6	38,0	77,6	44,9	90,9	23,9	48,7
	12	145,1	243,9	101,4	199,1	37,6	78,0	45,2	90,9	23,7	48,2
	13	145,8	243,8	101,9	199,0	37,9	78,5	45,8	90,8	24,4	48,4

H_s = 1.0 m Wave direction 165^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1	4	131,9	251,8	88,4	207,3	31,2	83,7	22,8	97,9	14,2	59,1
	5	132,2	246,2	88,7	201,5	31,5	80,9	34,8	94,2	17,4	53,3
	6	133,3	246,4	90,3	201,1	32,4	78,7	38,0	92,3	19,0	53,1
	7	127,0	246,6	82,8	201,4	29,3	80,5	33,7	92,8	19,0	51,6
	8	129,6	247,0	86,7	201,8	32,8	81,5	37,5	92,3	20,1	51,7
	9	131,7	249,0	88,4	203,2	33,5	81,2	39,5	92,7	19,7	52,5
	10	134,4	252,0	91,3	207,9	34,0	84,7	36,0	93,6	18,9	61,2
	11	134,9	252,5	92,1	206,5	33,8	83,0	40,2	94,4	19,2	58,1
	12	136,7	257,4	93,3	212,3	34,6	86,5	41,6	95,0	20,2	51,5
	13	138,5	249,7	95,0	204,3	33,4	82,2	41,7	92,7	21,8	50,6

H_s = 1.5 m Wave direction 165^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1,5	5	112,6	251,3	69,7	206,6	27,3	85,0	18,4	98,2	6,5	56,7
	6	118,4	255,1	73,7	210,8	24,9	85,4	27,4	100,9	3,0	62,0
	7	102,2	258,3	58,2	213,6	22,5	85,9	21,8	104,4	0,0	64,4
	8	85,4	268,7	42,5	224,6	12,6	84,4	14,2	100,2	4,6	75,3
	9	81,5	268,6	36,7	224,8	12,7	86,8	15,1	101,1	3,0	62,9
	10	101,3	283,9	57,3	239,1	20,3	89,5	12,1	115,8	7,7	74,1
	11	108,0	278,2	63,1	233,5	24,2	87,7	10,4	112,9	12,3	70,4
	12	120,7	267,5	77,6	222,5	27,3	87,4	30,7	104,4	12,9	61,9
	13	120,7	258,1	77,1	211,9	26,0	86,1	16,9	97,8	14,5	53,5

H_s = 2.0 m Wave direction 165^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
2	6	91,3	283,5	48,1	238,2	14,3	90,2	14,3	119,7	0,0	79,1
	7	67,7	289,6	22,8	243,6	9,2	94,9	2,5	121,4	0,0	72,8
	8	45,5	325,5	0,5	280,5	0,0	103,4	0,0	127,7	0,0	88,0
	9	45,8	292,6	1,4	248,4	0,2	90,5	0,0	120,1	0,0	70,8
	10	50,8	322,0	8,1	276,5	2,7	99,2	0,0	135,3	0,0	85,2
	11	58,3	314,9	16,7	270,0	5,7	108,5	0,0	135,8	1,2	79,9
	12	89,5	303,3	44,9	257,9	20,4	98,6	15,1	124,4	6,5	69,8
	13	96,8	271,2	53,5	226,3	22,1	96,7	0,0	102,8	0,0	60,8

H_s = 2.5 m Wave direction 165^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
2,5	6	45,1	340,4	0,5	293,6	0,0	108,6	0,0	184,4	0,0	95,1
	7	43,2	328,4	0,5	284,2	0,0	118,6	0,0	147,6	0,0	104,0
	8	41,3	411,1	0,5	366,6	0,0	129,2	0,0	202,6	0,0	124,7
	9	41,5	361,8	0,4	312,2	0,0	124,5	0,0	165,8	0,0	104,5
	10	42,0	348,5	0,5	303,8	0,0	104,0	0,0	146,5	0,0	91,9
	11	41,3	361,4	0,4	316,1	0,0	120,7	0,0	155,7	0,0	96,1
	12	64,4	318,8	20,4	273,0	9,2	121,7	0,0	138,8	0,0	79,2
	13	75,2	289,9	30,6	244,5	14,4	104,9	0,0	113,0	0,0	69,5

H_s = 3.0 m Wave direction 165^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
3	7	41,2	387,6	0,4	343,3	0,0	136,6	0,0	200,6	0,0	114,5
	8	40,9	416,5	0,4	371,8	0,0	143,3	0,0	186,3	0,0	119,1
	9	41,2	377,6	0,0	334,3	0,0	149,4	0,0	157,4	0,0	119,0
	10	40,9	479,4	0,4	435,9	0,0	140,6	0,0	220,3	0,0	144,1
	11	42,5	364,0	0,5	316,0	0,0	133,2	0,0	185,0	0,0	104,4
	12	43,5	352,8	0,5	306,8	0,0	127,4	0,0	161,6	0,0	90,1
	13	43,9	311,9	0,6	266,3	0,0	116,7	0,0	125,8	0,0	78,2

H_S = 0.5 m Wave direction 180^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
0,5	3	145,1	241,5	101,0	197,2	37,5	76,9	44,7	90,2	22,3	51,8
	4	143,2	241,2	99,3	196,9	37,3	77,0	44,3	89,9	22,0	49,4
	5	143,9	241,7	99,9	197,2	35,3	77,1	43,2	90,1	21,3	50,1
	6	143,3	242,2	99,4	197,7	35,9	77,3	43,6	90,3	21,7	49,5
	7	143,7	242,7	100,0	198,1	35,8	77,0	44,0	90,2	21,9	49,2
	8	144,6	243,2	100,9	198,5	36,7	77,1	44,5	90,3	22,8	48,6
	9	144,0	243,6	100,3	198,8	36,8	77,3	44,4	90,6	22,7	48,5
	10	142,3	243,9	99,0	199,1	36,3	77,4	45,0	90,7	23,1	48,7
	11	144,1	244,3	100,6	199,4	37,9	77,5	44,9	91,0	23,8	48,0
	12	144,4	244,3	100,8	199,4	37,7	79,9	45,0	91,0	23,2	48,4
	13	145,8	244,1	102,1	199,4	38,0	78,8	46,0	91,1	23,9	49,0

H_S = 1.0 m Wave direction 180^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1	4	136,8	248,4	93,0	203,8	35,4	80,4	34,0	96,5	7,1	57,9
	5	129,9	246,5	86,3	201,9	31,7	81,1	37,0	92,3	13,0	55,9
	6	136,5	245,2	93,2	200,1	31,6	78,8	39,0	91,3	13,7	54,8
	7	135,0	247,3	91,3	202,1	31,7	79,8	39,1	92,4	16,7	51,7
	8	136,9	248,7	93,1	203,4	33,3	79,9	39,1	92,0	19,7	52,6
	9	134,5	248,7	90,9	203,3	32,5	81,3	38,6	92,2	19,1	53,2
	10	121,4	252,3	77,7	206,5	28,9	87,0	31,1	99,1	18,5	56,8
	11	136,3	249,5	93,3	204,0	34,2	83,6	41,2	93,5	18,0	54,6
	12	136,0	250,5	92,4	204,5	31,0	83,5	40,6	96,9	17,3	51,2
	13	138,4	251,7	95,0	206,1	35,6	82,1	41,1	93,3	18,7	51,2

H_S = 1.5 m Wave direction 180^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1,5	5	112,4	251,8	68,5	207,2	23,5	86,6	15,2	98,5	0,0	58,1
	6	117,2	252,1	73,5	207,1	22,3	83,7	29,0	100,1	1,0	64,7
	7	119,1	263,7	75,1	219,2	26,9	85,4	23,0	99,5	3,4	72,7
	8	102,6	270,9	58,9	226,0	23,5	84,2	18,9	101,5	0,3	73,1
	9	108,1	271,6	63,1	227,0	24,8	88,2	23,0	105,6	2,3	67,5
	10	59,3	298,5	16,0	254,0	6,9	94,3	9,2	125,9	0,0	68,9
	11	97,2	276,5	54,0	232,3	23,7	90,3	23,2	108,4	10,5	69,4
	12	113,5	262,5	68,6	217,7	26,2	95,6	19,2	97,8	13,6	59,9
	13	121,1	262,9	77,3	216,3	27,9	85,7	20,5	97,3	15,5	53,6

H_s = 2.0 m Wave direction 180^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
2	6	59,9	277,0	16,0	230,9	7,3	101,5	6,1	106,6	0,0	65,0
	7	44,2	280,6	0,6	237,3	0,0	93,8	0,2	113,6	0,0	74,2
	8	42,5	289,8	0,4	245,1	0,0	97,4	0,0	126,4	0,0	85,1
	9	45,5	294,9	1,6	249,8	0,2	97,3	0,0	121,2	0,0	82,3
	10	41,9	339,0	0,4	294,2	0,0	102,8	0,0	141,6	0,0	79,5
	11	55,3	316,9	12,4	272,4	5,7	97,4	5,1	130,0	0,4	81,8
	12	81,2	278,8	38,3	234,7	17,4	107,6	3,6	111,6	0,6	72,7
	13	81,8	276,3	38,1	228,9	17,6	95,8	0,0	103,3	13,3	62,3

H_s = 2.5 m Wave direction 180^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
2,5	6	59,7	297,3	15,3	251,3	4,7	114,2	0,0	129,7	0,0	88,1
	7	42,5	342,1	0,5	297,0	0,0	113,0	0,0	149,2	0,0	100,6
	8	42,0	381,9	0,4	337,0	0,0	120,9	0,0	164,7	0,0	100,4
	9	42,2	384,7	0,5	339,0	0,0	126,7	0,0	157,5	0,0	102,9
	10	40,3	331,7	0,4	286,0	0,0	122,1	0,0	135,5	0,0	86,3
	11	42,9	356,7	0,5	312,0	0,0	119,5	0,0	148,0	0,0	91,3
	12	42,2	325,8	0,6	280,4	0,0	111,2	0,0	129,9	0,0	82,8
	13	72,4	287,2	29,4	241,9	14,3	103,8	0,0	114,1	0,9	77,9

H_s = 3.0 m Wave direction 180^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
3	7	38,5	412,4	0,3	355,3	0,0	173,5	0,0	202,2	0,0	114,5
	8	40,8	378,6	0,4	333,6	0,0	138,2	0,0	179,4	0,0	165,9
	9	40,3	456,9	0,4	402,8	0,0	155,3	0,0	272,0	0,0	123,0
	10	41,0	435,7	0,4	392,1	0,0	167,9	0,0	194,2	0,0	132,1
	11	42,2	358,1	0,5	314,2	0,0	112,1	0,0	159,2	0,0	117,0
	12	42,0	349,1	0,5	303,5	0,0	117,1	0,0	144,0	0,0	110,7
	13	43,4	309,6	0,8	265,7	0,3	113,1	0,0	126,2	0,0	85,1

H_s = 0.5 m Wave direction 195^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
	3	144,7	242,0	100,7	197,6	38,6	77,7	45,3	90,5	22,2	52,1
	4	145,5	241,6	101,6	197,2	37,6	77,2	43,8	90,2	22,3	49,0
	5	141,5	242,1	97,7	197,6	35,0	76,6	42,8	90,2	19,5	49,8
	6	143,7	242,4	99,9	197,8	36,0	77,2	43,5	90,3	21,8	48,6
	7	141,6	243,7	97,9	198,9	35,8	78,4	43,8	90,6	22,2	50,0
0,5	8	139,4	246,3	96,4	201,1	35,9	78,5	43,8	91,6	23,1	49,1
	9	142,1	246,2	98,8	201,0	35,7	77,9	44,1	91,4	22,5	48,9
	10	142,9	245,2	99,5	200,1	35,9	77,8	44,6	91,0	22,9	50,1
	11	143,8	244,0	100,3	199,2	37,5	78,1	45,4	90,8	24,0	48,6
	12	144,7	243,7	101,2	198,9	37,5	78,8	45,5	90,8	23,9	49,7
	13	145,1	244,7	101,4	200,1	38,1	79,4	46,0	91,5	24,0	49,4

H_s = 1.0 m Wave direction 195^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
	4	135,4	244,0	91,6	200,2	32,5	79,4	33,5	93,9	16,3	54,6
	5	134,3	246,9	90,6	202,1	31,3	80,2	37,2	93,1	15,1	52,8
	6	132,1	246,0	88,4	200,8	30,9	81,1	38,8	91,6	16,7	53,2
	7	124,8	250,5	80,4	205,0	31,4	82,3	30,1	93,7	14,7	53,8
1	8	85,0	253,7	40,7	209,2	19,1	88,4	18,8	96,4	5,0	54,2
	9	101,9	255,3	58,0	209,1	25,3	85,1	30,2	96,9	6,7	55,6
	10	117,3	256,2	73,7	211,9	28,5	87,6	36,1	94,9	11,8	54,1
	11	135,1	250,4	92,1	204,8	32,7	87,6	39,5	93,6	18,9	51,7
	12	132,9	248,7	89,1	203,6	32,4	81,8	41,3	95,9	16,6	51,5
	13	138,4	251,9	94,3	206,4	33,2	81,0	43,1	94,9	17,9	52,8

H_s = 1.5 m Wave direction 195^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
	5	119,6	254,3	76,3	210,3	26,2	85,5	23,9	100,8	0,0	60,0
	6	110,2	254,2	66,7	210,4	25,6	88,9	21,6	104,0	0,0	59,7
	7	97,1	266,3	53,4	222,1	14,5	87,8	17,7	103,7	9,4	66,8
	8	45,3	291,2	1,7	244,1	0,1	96,1	0,9	119,1	0,0	71,9
1,5	9	44,0	292,9	0,7	247,0	0,0	95,0	0,3	110,3	0,0	80,0
	10	69,7	274,1	26,3	229,2	11,7	91,4	10,5	102,0	0,0	65,8
	11	103,0	273,0	58,1	228,5	20,5	104,9	16,0	104,5	9,5	69,8
	12	115,6	259,1	70,8	215,1	26,0	90,5	21,5	99,5	7,9	63,4
	13	125,4	260,9	82,1	214,6	25,4	85,3	27,9	98,6	14,3	60,1

H_s = 2.0 m Wave direction 195^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
2	6	87,7	275,9	43,5	231,8	14,1	89,7	10,0	120,3	0,0	70,8
	7	43,0	328,6	0,5	283,4	0,0	105,9	0,0	127,5	0,0	89,2
	8	43,4	307,0	0,5	262,2	0,0	107,5	0,0	147,1	0,0	83,9
	9	40,9	316,0	0,5	269,8	0,0	98,5	0,0	133,2	0,0	91,1
	10	44,1	312,5	0,7	266,9	0,0	97,8	0,0	115,6	0,0	76,3
	11	59,0	309,3	17,4	263,8	7,4	98,7	3,7	119,2	0,0	84,2
	12	73,3	297,1	30,2	253,2	14,3	97,6	3,9	116,7	0,0	72,5
	13	88,8	279,7	45,1	235,0	15,9	91,3	11,2	108,0	6,1	73,5

H_s = 2.5 m Wave direction 195^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
2,5	6	44,3	313,0	0,5	265,7	0,0	112,2	0,0	153,5	0,0	144,0
	7	42,1	363,4	0,5	314,1	0,0	137,8	0,0	168,7	0,0	130,7
	8	40,4	547,3	0,4	493,8	0,0	232,0	0,0	281,7	0,0	161,3
	9	40,9	379,5	0,4	336,1	0,0	136,1	0,0	209,8	0,0	126,5
	10	41,6	336,3	0,4	289,5	0,0	131,8	0,0	142,5	0,0	98,9
	11	40,1	356,4	0,4	311,2	0,0	108,2	0,0	140,0	0,0	95,4
	12	40,6	329,8	0,4	285,5	0,0	109,4	0,0	133,4	0,0	80,5
	13	44,2	304,1	1,1	258,9	0,0	95,4	0,0	119,5	0,0	82,4

H_s = 3.0 m Wave direction 195^0											
Sea state		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
H_s [m]	T_p [s]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
3	7	41,2	541,3	0,4	486,4	0,0	192,1	0,0	287,5	0,0	175,5
	8	38,7	495,8	0,0	438,5	0,0	208,2	0,0	350,4	0,0	179,0
	9	39,4	462,3	0,4	406,8	0,0	185,8	0,0	250,8	0,0	180,6
	10	40,1	439,7	0,4	394,6	0,0	134,1	0,0	192,3	0,0	130,2
	11	40,4	364,0	0,4	319,0	0,0	146,2	0,0	147,9	0,0	101,5
	12	39,4	354,5	0,4	308,2	0,0	137,2	0,0	150,4	0,0	96,9
	13	40,4	342,6	0,4	297,0	0,0	122,1	0,0	142,2	0,0	100,7

Combined Wind Sea and Swell Study

Case 1

Wind sea direction 165^0											
Swell		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
T [s]	Dir. [°]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
8	180	130,5	248,2	87,3	203,0	32,3	82,6	37,7	93,4	14,5	53,5
	165	128,8	249,0	85,6	203,9	30,1	80,4	35,7	94,1	14,3	56,3
	150	125,7	252,0	82,5	206,5	30,6	80,6	34,5	95,6	14,8	56,9
	135	127,9	249,5	84,8	204,2	31,8	80,6	35,6	95,0	13,6	56,6
	120	130,1	247,8	85,7	203,1	28,4	81,6	35,2	94,2	12,5	53,6
	105	119,0	252,9	75,2	208,2	25,3	85,8	25,5	102,5	5,2	57,9
	90	108,7	255,2	64,0	210,5	22,5	88,8	24,2	107,7	1,1	61,0
9	180	130,9	248,9	87,9	204,0	32,7	81,7	37,1	93,9	18,4	52,2
	165	131,5	247,0	88,3	201,9	32,7	81,6	38,2	92,3	16,2	57,1
	150	131,0	247,8	87,8	202,4	32,6	80,5	38,1	93,3	13,4	60,2
	135	131,1	247,4	87,6	202,7	32,7	80,5	38,8	95,0	13,9	62,0
	120	128,6	248,9	85,0	204,0	31,4	80,4	37,4	96,2	10,2	62,7
	105	122,3	253,0	78,5	209,0	27,0	81,3	31,5	99,9	6,7	62,4
	90	112,9	260,6	68,3	216,5	22,9	82,9	19,8	99,5	4,0	61,8
10	180	130,9	248,2	88,1	203,4	32,9	80,3	36,7	93,7	16,2	51,8
	165	134,8	246,3	91,7	201,0	32,4	81,3	37,2	92,3	17,5	54,5
	150	135,1	246,6	91,5	201,6	32,1	81,2	34,1	94,8	13,4	62,3
	135	132,6	249,3	89,5	204,0	31,2	80,8	37,1	95,2	12,6	66,4
	120	128,9	252,2	86,0	207,9	28,7	85,5	33,3	98,2	7,2	67,1
	105	112,6	272,1	67,9	228,1	23,9	90,0	20,7	106,1	2,0	75,0
	90	98,0	277,0	53,5	233,1	21,7	91,0	13,7	108,7	2,6	74,0
11	180	134,0	248,1	90,9	202,6	32,4	80,3	38,9	92,5	16,7	51,9
	165	134,7	247,9	90,6	203,1	31,7	80,6	37,4	95,0	18,9	55,5
	150	130,7	249,9	86,7	204,2	31,7	81,9	36,1	94,7	16,8	53,1
	135	126,8	253,0	82,8	207,5	29,9	80,8	34,7	96,5	15,1	59,1
	120	120,6	267,0	76,8	223,2	27,3	89,7	30,6	100,8	8,2	64,3
	105	108,4	268,0	63,2	223,5	21,2	95,0	15,4	105,9	6,9	69,5
	90	95,9	279,3	50,9	234,3	12,6	106,5	4,3	105,3	3,1	70,9
12	180	131,8	249,0	89,1	203,7	31,8	79,3	36,9	93,7	19,3	51,9
	165	130,5	248,3	87,9	202,8	32,4	80,3	37,0	92,9	19,5	54,4
	150	129,1	249,1	86,6	203,6	32,2	82,0	36,9	94,7	18,8	54,8
	135	127,5	250,3	84,9	204,9	31,8	82,6	35,8	95,9	14,9	57,6
	120	123,1	252,7	80,6	207,1	30,4	82,2	34,3	95,7	17,5	54,1
	105	116,7	264,0	74,4	218,5	29,3	87,1	31,8	98,1	7,7	64,2
	90	116,2	259,7	74,0	214,1	28,0	84,8	31,2	98,7	12,9	58,5
13	180	133,4	246,4	90,4	201,1	31,9	79,9	38,1	92,3	18,6	53,2
	165	133,1	248,4	90,2	202,9	32,0	82,8	38,1	93,3	19,5	52,3
	150	133,0	251,6	90,1	206,4	32,1	83,1	38,3	95,8	19,5	53,7
	135	132,9	255,9	90,1	210,5	32,1	86,1	38,5	98,0	19,2	53,6
	120	132,8	258,9	90,0	213,9	31,9	88,3	36,8	100,4	18,5	54,4
	105	133,0	260,0	90,2	214,2	31,7	88,4	38,4	101,9	16,6	56,3
	90	133,4	275,1	89,8	229,4	31,6	96,8	37,3	100,6	17,4	56,8
14	180	132,7	246,7	89,8	201,4	32,1	78,9	36,9	92,4	18,7	52,6
	165	132,5	246,6	89,6	201,2	32,2	78,9	36,9	92,3	18,6	52,4
	150	132,4	246,5	89,5	201,1	32,2	79,0	36,9	92,4	18,7	52,1
	135	132,4	246,5	89,6	201,1	32,2	78,9	36,8	92,5	19,1	51,9
	120	132,5	246,6	89,7	201,3	32,2	79,5	36,6	92,7	18,0	51,8
	105	132,7	246,9	89,9	201,8	32,0	80,8	36,6	92,6	15,7	51,5
	90	132,9	247,3	90,1	201,9	31,8	80,6	36,6	92,2	13,8	52,2

Wind sea direction 180^0											
Swell		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
T [s]	Dir. [°]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
8	180	133,2	246,2	89,7	201,2	32,4	83,0	37,5	93,4	10,2	59,9
	165	131,6	248,4	87,8	204,6	32,3	84,7	36,9	92,8	10,2	56,3
	150	128,7	252,1	85,1	208,3	31,8	88,1	36,3	98,3	5,5	55,1
	135	131,0	248,4	87,2	203,3	32,0	82,2	37,4	93,1	8,3	54,5
	120	131,5	248,1	87,3	203,1	31,1	82,4	37,2	93,2	5,9	54,5
	105	112,5	252,2	67,4	206,9	25,3	82,7	14,0	98,8	5,5	59,6
	90	110,8	261,2	66,3	217,3	18,8	90,0	10,6	104,1	7,8	59,1
9	180	133,5	247,1	90,3	201,9	32,8	80,3	38,3	92,7	11,5	54,1
	165	134,5	246,3	90,9	201,4	31,7	81,8	37,3	92,7	10,3	55,3
	150	133,6	247,5	89,6	202,5	31,1	83,2	36,6	95,4	14,2	58,0
	135	134,4	247,7	90,8	202,9	30,8	82,2	37,1	93,7	12,5	59,4
	120	133,5	250,5	90,2	205,3	30,1	83,5	34,0	94,5	13,4	60,8
	105	118,9	265,1	74,1	220,9	27,1	90,5	26,2	104,1	9,9	63,6
	90	102,5	261,4	57,8	217,1	23,3	89,4	21,6	101,6	11,4	66,3
10	180	134,3	246,8	91,2	201,4	32,4	81,0	37,9	92,4	16,3	52,6
	165	136,8	246,2	93,1	201,5	31,1	80,4	38,6	92,1	12,9	56,0
	150	135,6	246,9	91,6	202,1	30,6	81,7	37,9	94,3	13,3	57,7
	135	133,8	248,6	89,8	203,2	30,1	81,7	36,7	93,8	11,5	59,1
	120	129,3	255,3	85,9	211,3	27,1	86,3	34,7	97,7	8,1	63,2
	105	118,8	279,3	73,9	235,9	25,8	89,5	30,3	111,5	7,3	70,5
	90	110,1	272,9	65,0	229,0	25,2	88,4	21,3	113,6	5,5	71,6
11	180	135,1	246,8	92,1	201,9	31,1	81,1	37,8	92,2	15,2	53,4
	165	135,0	247,5	92,1	202,2	32,2	79,8	38,3	93,0	16,3	52,9
	150	132,3	248,8	88,7	203,1	32,3	81,0	36,9	92,7	13,6	57,9
	135	127,8	255,4	84,0	211,8	30,1	83,1	35,9	98,9	6,5	60,1
	120	117,1	257,2	72,4	212,8	27,2	89,6	22,7	106,4	11,5	64,1
	105	100,8	275,0	56,1	230,4	20,4	103,8	19,1	111,2	9,7	66,0
	90	90,3	279,8	46,6	235,6	16,1	96,8	10,1	109,5	9,4	68,7
12	180	134,9	246,2	91,8	201,1	31,8	79,6	38,3	92,1	14,5	54,5
	165	134,0	248,2	91,0	203,7	31,9	79,5	37,6	93,7	15,1	57,8
	150	132,8	247,5	89,9	202,1	31,5	79,7	36,8	93,7	18,0	55,2
	135	131,2	249,2	88,3	203,6	30,9	84,2	35,7	94,7	17,1	53,8
	120	128,8	252,3	86,1	207,0	31,3	85,6	34,3	96,4	17,2	53,4
	105	125,7	258,8	83,1	213,1	31,5	86,4	26,2	98,4	14,5	55,3
	90	124,2	263,0	81,8	217,2	30,9	85,8	25,2	100,8	12,0	55,9
13	180	135,5	246,4	92,3	201,1	31,0	79,7	37,8	92,1	12,5	55,2
	165	135,3	248,9	92,2	203,5	30,7	80,8	37,7	93,0	12,7	55,5
	150	135,2	253,3	92,1	207,7	30,3	82,9	37,6	95,2	12,0	55,3
	135	135,2	258,4	92,2	212,7	30,1	87,6	37,5	99,8	11,3	55,7
	120	135,1	253,2	92,2	208,2	30,3	85,2	37,3	97,5	10,6	55,3
	105	133,6	259,4	89,5	213,4	29,2	87,0	33,2	100,3	17,2	56,8
	90	122,8	267,9	78,9	221,0	30,0	89,1	28,6	103,0	16,2	63,7
14	180	135,3	246,3	92,2	201,4	32,0	78,3	38,3	92,1	11,2	55,3
	165	135,1	246,2	92,0	201,3	32,2	79,1	38,2	92,1	12,9	55,7
	150	134,9	246,3	91,8	201,0	32,3	78,5	38,2	91,9	13,8	57,3
	135	134,9	246,8	91,8	201,6	32,1	80,7	38,1	92,1	13,7	57,8
	120	134,9	246,8	91,9	201,5	31,9	79,2	38,1	92,2	13,3	58,0
	105	135,2	246,6	91,6	201,3	31,9	82,0	38,0	92,0	11,6	56,9
	90	134,6	247,1	91,0	201,7	32,1	80,1	37,7	91,9	10,6	54,8

Wind sea direction 195^0											
Swell		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
T [s]	Dir. [°]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
8	180	116,5	246,3	72,6	201,3	23,3	80,7	32,9	92,2	13,9	53,2
	165	123,7	250,1	79,5	205,0	31,1	81,1	26,6	94,5	13,9	56,2
	150	122,7	251,8	78,0	206,6	29,3	82,5	25,5	94,5	12,2	57,8
	135	128,6	249,9	84,4	205,0	31,5	81,4	29,7	94,5	13,8	54,0
	120	128,7	249,6	84,7	204,7	30,3	80,8	32,3	94,8	10,7	54,3
	105	109,6	252,7	64,7	209,1	23,3	89,2	19,1	102,6	1,9	61,6
	90	92,7	255,9	47,9	212,4	18,0	90,6	14,8	102,6	4,3	61,8
9	180	132,6	247,1	88,5	202,3	32,7	83,6	35,6	92,3	15,6	51,8
	165	128,3	246,2	84,7	201,3	32,1	83,3	33,9	92,6	14,1	55,6
	150	125,8	247,0	82,3	201,9	31,6	82,7	33,9	92,7	14,7	57,2
	135	126,7	247,2	83,2	201,8	28,3	83,1	34,4	92,2	10,3	57,1
	120	110,3	249,2	65,6	204,0	25,1	81,9	26,5	93,8	6,1	57,7
	105	91,0	259,2	46,5	215,6	23,8	82,1	18,5	104,0	7,3	66,7
	90	80,2	268,9	36,0	225,4	14,3	86,0	15,5	112,4	6,2	69,5
10	180	133,7	246,8	89,6	201,5	31,7	81,7	36,8	94,3	17,3	52,7
	165	131,3	247,4	87,7	202,4	32,4	81,4	37,6	92,6	16,7	53,5
	150	127,9	248,0	84,5	202,8	28,2	82,0	37,4	93,1	15,4	55,2
	135	123,5	249,2	79,4	203,8	22,5	83,2	36,2	93,6	14,1	56,1
	120	104,8	251,1	60,7	205,6	16,4	86,1	28,4	94,8	3,0	62,2
	105	106,3	270,0	61,9	226,3	22,0	88,3	14,1	106,4	7,7	67,5
	90	103,9	289,7	59,0	246,1	21,2	90,0	14,4	114,8	1,8	70,3
11	180	128,8	247,9	85,4	202,6	29,7	81,4	31,6	92,3	16,6	54,3
	165	131,5	249,8	88,1	204,2	31,5	82,4	38,2	92,3	15,9	51,6
	150	127,7	249,3	84,1	203,7	30,4	80,9	36,6	93,5	9,1	55,2
	135	123,1	252,2	79,6	206,7	27,0	84,3	31,6	95,5	9,0	58,1
	120	98,0	264,1	53,1	219,7	21,3	94,6	18,7	104,1	5,1	65,4
	105	94,5	270,1	49,7	225,7	20,1	94,6	7,9	108,3	3,6	60,6
	90	89,4	283,3	44,6	239,6	18,2	108,1	4,5	115,3	1,9	66,4
12	180	129,8	248,2	86,3	202,7	27,6	81,8	35,6	92,7	17,5	54,4
	165	128,4	248,8	85,0	203,2	29,0	80,2	34,5	93,5	17,4	53,3
	150	126,8	249,8	83,5	204,6	28,1	83,9	36,6	94,0	16,0	55,3
	135	124,3	250,7	81,2	205,3	26,2	83,2	35,0	94,2	15,1	54,5
	120	122,4	254,3	79,0	208,1	28,9	92,1	26,2	98,5	13,7	54,1
	105	116,3	262,4	73,2	216,7	28,1	85,8	24,1	99,9	12,1	55,6
	90	115,6	256,7	72,7	211,4	26,6	93,5	25,6	99,4	12,6	57,6
13	180	133,2	247,9	89,4	202,5	32,2	80,7	39,4	92,4	17,0	52,4
	165	133,2	250,4	89,4	204,9	32,1	82,7	39,4	94,0	17,1	52,4
	150	133,4	255,9	89,6	211,6	32,0	94,7	39,3	98,9	17,3	54,4
	135	133,7	256,7	90,0	211,4	32,0	87,1	39,2	101,6	17,0	58,0
	120	134,4	256,0	90,6	209,7	31,8	89,3	30,5	97,0	15,7	54,7
	105	135,5	260,9	91,7	213,8	31,6	89,1	34,9	101,3	15,3	57,5
	90	136,1	263,2	91,7	217,3	31,1	87,1	34,4	102,5	14,2	58,2
14	180	133,0	246,6	89,2	201,3	32,1	80,6	38,1	91,9	15,9	52,4
	165	132,9	246,8	89,1	201,6	32,2	80,9	38,1	91,8	15,9	52,5
	150	132,8	246,9	89,0	201,8	32,3	81,0	38,0	92,9	15,8	52,4
	135	132,4	247,2	88,6	202,2	32,3	80,8	37,8	93,3	15,6	52,9
	120	131,9	247,6	88,1	202,7	32,3	79,3	37,6	94,4	15,3	51,8
	105	131,4	247,6	87,6	202,6	32,2	81,1	37,6	93,7	15,1	52,4
	90	130,9	247,3	87,3	201,9	32,1	80,5	38,0	92,5	15,2	52,1

Case 2

Wind sea direction 165^{0}											
Swell		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
T [s]	Dir. [°]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
8	180	126,5	252,2	83,3	207,2	27,3	83,7	35,0	95,7	8,7	56,7
	165	116,1	252,6	70,8	207,2	26,4	84,7	23,8	101,9	13,3	68,8
	150	103,2	258,8	58,3	214,3	22,2	87,7	19,1	108,9	9,6	67,5
	135	117,5	251,1	74,3	206,1	27,6	83,7	27,0	102,3	12,6	63,4
	120	116,9	252,7	72,5	207,8	25,3	86,6	26,8	100,0	8,0	63,6
	105	62,0	300,4	17,1	255,9	7,6	102,2	2,5	119,5	0,0	78,9
	90	50,5	304,6	6,3	260,4	1,6	110,2	3,9	120,8	0,0	62,3
9	180	128,4	249,5	85,5	204,5	30,5	84,4	34,7	94,6	16,6	54,2
	165	128,5	247,4	85,2	202,8	30,3	83,5	30,1	97,1	14,3	58,3
	150	119,6	253,8	75,1	209,0	27,7	83,6	12,0	105,3	11,8	64,7
	135	121,1	258,1	77,5	214,2	26,3	84,3	16,3	102,9	11,7	65,9
	120	110,2	263,4	65,2	219,8	19,7	83,5	30,4	100,4	2,2	66,3
	105	54,3	288,5	10,2	244,2	4,4	93,5	0,0	121,8	0,0	77,4
	90	47,8	307,9	3,0	263,3	1,0	97,0	0,0	127,9	0,0	78,0
10	180	128,7	251,7	86,1	206,7	32,1	82,2	34,7	95,5	16,2	54,0
	165	135,8	247,5	91,7	202,9	32,6	81,8	36,1	96,3	12,3	63,9
	150	114,4	262,6	70,4	219,1	30,4	85,6	26,1	106,8	6,2	68,2
	135	119,6	267,4	74,6	223,5	24,3	87,6	26,6	112,7	3,2	72,3
	120	93,5	296,5	48,3	253,0	21,8	94,1	12,3	121,7	0,0	75,7
	105	56,6	309,7	11,3	266,0	4,5	100,0	2,7	127,2	0,0	81,1
	90	45,3	320,8	0,5	277,1	0,0	98,2	0,0	132,6	0,0	89,2
11	180	132,6	249,4	89,2	203,8	31,5	81,2	38,2	92,9	15,3	52,4
	165	132,4	249,4	88,3	203,9	31,1	82,1	33,4	94,7	18,2	51,4
	150	123,1	253,6	79,2	207,5	27,1	86,1	32,3	98,6	12,2	58,4
	135	111,2	282,8	67,9	238,0	22,2	107,4	21,8	107,8	5,6	66,0
	120	74,9	302,3	30,1	258,1	12,6	102,7	3,2	117,5	0,0	78,1
	105	48,2	323,0	2,9	278,7	1,3	116,9	0,0	141,0	0,0	89,3
	90	45,3	334,4	0,5	290,1	0,0	118,7	0,0	151,0	0,0	93,8
12	180	130,7	249,3	87,8	204,0	28,2	80,3	35,4	93,4	15,5	51,6
	165	127,9	250,4	85,7	205,7	29,0	81,7	32,1	94,8	18,5	52,6
	150	124,8	253,6	82,8	207,6	26,2	86,6	23,9	95,9	18,1	54,9
	135	120,7	255,2	78,5	209,5	25,7	84,3	29,0	99,7	17,0	59,1
	120	109,1	271,1	67,2	225,2	23,1	97,1	12,3	104,6	11,7	70,3
	105	104,1	275,5	62,4	228,6	23,1	97,7	12,4	102,9	6,6	67,2
	90	106,9	301,4	63,9	254,3	22,5	114,9	19,4	109,9	6,6	66,3
13	180	133,6	248,2	90,6	203,6	31,8	83,2	37,9	93,4	18,7	52,9
	165	133,3	255,1	90,5	209,5	32,0	84,6	38,0	96,5	18,5	54,0
	150	133,2	262,3	90,5	216,2	31,6	86,4	38,2	99,8	17,9	55,8
	135	133,2	269,2	90,6	221,9	31,0	92,5	38,5	101,3	17,4	60,8
	120	131,8	265,1	88,1	217,7	28,0	89,2	26,3	99,3	14,2	54,5
	105	125,3	271,6	80,7	223,5	28,0	95,4	23,2	102,3	11,2	57,4
	90	120,4	272,7	75,6	225,8	27,7	94,0	26,3	106,8	14,1	59,6
14	180	132,2	247,1	89,4	201,7	31,8	79,3	35,8	93,0	18,5	52,0
	165	131,9	247,7	89,2	202,2	32,1	78,9	35,9	93,1	18,5	52,3
	150	131,7	247,8	89,0	202,3	31,6	79,3	35,8	93,9	17,5	52,0
	135	131,7	247,9	88,7	202,3	30,8	80,1	35,6	93,9	16,3	52,3
	120	131,4	248,9	88,5	203,2	30,3	81,0	35,3	93,0	14,1	53,1
	105	130,6	249,3	87,4	203,7	30,5	82,3	35,1	93,6	11,7	52,6
	90	130,2	249,8	86,6	204,2	31,4	83,2	35,2	94,0	9,6	52,1

Wind sea direction 180^0											
Swell		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
T [s]	Dir. [°]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
8	180	129,1	248,7	84,5	204,3	31,4	85,0	29,9	94,9	8,8	62,1
	165	117,9	251,1	74,8	206,0	27,1	83,8	29,3	97,7	8,8	60,2
	150	107,8	267,5	64,3	223,1	21,5	86,0	14,8	108,8	2,2	70,6
	135	118,3	251,0	75,3	206,7	26,2	83,8	27,0	104,1	7,8	59,0
	120	112,3	253,8	67,5	210,5	26,2	84,1	21,9	102,1	4,3	60,6
	105	48,7	289,5	3,6	245,7	1,2	92,2	0,0	115,7	0,0	78,6
	90	45,1	300,2	0,7	256,1	0,0	96,3	0,0	133,1	0,0	83,3
9	180	130,3	251,8	87,1	207,4	32,2	83,8	36,1	95,1	11,5	56,1
	165	121,8	247,1	77,6	202,8	29,4	83,9	28,9	95,3	13,7	57,1
	150	105,6	255,2	61,5	211,6	26,4	83,7	25,2	104,9	12,8	67,8
	135	112,0	256,8	68,0	212,3	29,4	84,2	26,3	105,6	14,1	66,3
	120	98,4	271,1	53,3	227,4	21,9	89,5	21,9	106,5	9,1	74,7
	105	47,5	287,7	2,8	244,7	1,1	98,3	0,0	129,6	0,0	72,4
	90	48,5	308,2	3,8	264,7	1,1	102,2	2,3	137,9	0,0	78,8
10	180	132,5	251,0	89,3	206,3	31,6	85,4	36,2	96,0	17,7	54,9
	165	130,2	247,6	86,1	202,1	31,4	81,3	38,1	95,5	11,4	58,0
	150	117,6	253,7	73,2	209,9	28,7	84,7	23,4	111,0	10,0	63,0
	135	121,1	270,4	77,2	227,4	25,8	92,6	30,8	116,0	2,6	71,4
	120	98,1	286,1	52,0	242,9	16,4	95,8	13,3	120,1	0,0	74,6
	105	50,5	319,5	5,4	275,7	1,5	106,0	0,0	135,4	0,0	84,7
	90	45,5	328,6	0,9	285,2	0,0	108,7	0,0	132,9	0,0	84,1
11	180	133,3	249,8	90,5	204,2	31,0	80,6	36,4	93,1	14,8	52,4
	165	132,3	250,3	89,7	204,5	30,4	89,4	37,5	94,1	15,0	54,7
	150	123,5	262,0	79,6	217,8	27,0	95,0	34,1	100,6	10,7	61,3
	135	92,7	274,2	47,8	230,1	21,0	104,3	10,0	105,2	0,0	67,3
	120	46,0	302,0	1,1	257,7	0,0	100,5	0,0	126,7	0,0	74,0
	105	46,4	330,3	3,7	286,7	1,4	118,7	0,0	143,9	0,0	85,1
	90	44,3	338,7	0,5	295,2	0,0	131,7	0,0	147,4	0,0	86,6
12	180	133,6	247,7	90,2	202,2	31,2	80,9	37,5	92,6	12,7	55,2
	165	132,1	251,0	89,0	205,3	27,6	85,4	33,4	95,2	17,5	52,5
	150	116,4	251,9	72,5	206,4	19,2	87,7	28,3	95,9	17,2	52,9
	135	116,4	258,1	72,4	212,3	20,1	85,6	28,6	99,5	13,7	57,5
	120	120,6	266,5	76,7	221,4	26,9	93,0	23,6	103,3	13,9	60,4
	105	111,6	271,5	69,0	225,2	25,0	92,9	17,7	104,6	8,4	61,5
	90	107,3	308,9	64,8	262,9	24,2	114,9	16,9	112,9	11,1	63,5
13	180	133,9	250,9	91,0	206,0	30,3	82,3	36,5	95,8	10,8	55,3
	165	133,8	257,0	91,0	211,0	29,4	89,8	36,1	96,7	11,8	56,5
	150	133,7	266,2	91,0	221,2	29,2	94,3	35,9	101,1	16,5	56,7
	135	133,6	262,6	91,0	217,0	29,1	93,8	35,7	102,0	13,0	57,9
	120	132,7	263,4	88,2	217,4	27,7	88,9	35,6	101,0	15,7	61,0
	105	118,8	285,1	74,2	236,7	27,2	100,6	32,0	105,5	11,8	59,0
	90	126,2	282,1	82,2	233,7	25,4	98,0	28,4	108,3	10,5	60,2
14	180	134,4	247,4	91,3	202,5	31,9	79,0	37,4	92,7	10,7	55,4
	165	134,0	247,2	90,9	202,2	31,7	79,0	37,3	92,3	11,4	58,1
	150	133,9	247,6	90,6	202,2	31,5	80,1	37,2	92,3	13,6	60,4
	135	133,5	247,7	90,2	202,2	31,3	82,1	37,1	93,4	13,1	61,3
	120	132,9	247,7	89,6	202,3	29,8	81,0	26,5	92,6	17,5	55,7
	105	131,7	249,6	88,1	204,6	28,2	82,5	31,7	94,1	16,8	53,9
	90	131,3	250,0	87,9	204,3	30,3	83,7	34,4	94,9	15,3	54,5

Wind sea direction 195^0											
Swell		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
T [s]	Dir. [°]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
8	180	115,0	253,8	71,2	210,0	20,9	88,8	25,7	97,8	8,4	58,7
	165	104,1	251,0	58,8	206,0	21,9	84,8	20,0	100,3	8,8	67,4
	150	89,5	257,4	44,6	212,8	18,4	86,1	12,1	107,6	5,4	71,5
	135	101,4	252,9	57,2	207,6	24,9	86,2	18,8	100,8	6,2	67,4
	120	102,4	261,7	57,8	218,0	20,4	84,0	20,4	107,3	1,8	64,8
	105	45,6	296,3	0,9	252,4	0,0	103,2	0,0	126,0	0,0	75,9
	90	45,0	322,3	0,5	278,4	0,0	120,6	0,0	125,2	0,0	70,7
9	180	127,6	251,1	83,7	206,1	30,9	84,4	29,3	95,1	11,2	54,8
	165	120,5	247,3	76,6	202,4	29,2	84,6	28,8	102,8	9,6	64,5
	150	111,8	257,0	68,2	213,5	27,0	85,3	18,8	109,4	9,4	63,6
	135	112,4	255,6	67,9	211,6	26,8	87,8	21,6	105,0	7,2	69,2
	120	89,3	267,8	44,6	224,7	23,2	84,8	13,4	109,5	2,1	68,7
	105	45,0	289,7	0,5	246,2	0,0	93,0	0,0	122,4	0,0	77,4
	90	44,6	305,2	0,5	261,5	0,0	96,0	0,0	130,9	0,0	80,1
10	180	127,5	249,2	84,4	204,9	30,9	82,6	34,0	95,1	14,2	54,5
	165	128,0	249,4	84,5	203,7	32,7	82,8	36,2	93,2	14,2	58,6
	150	118,0	255,6	74,6	212,2	24,5	87,3	30,3	102,1	12,2	66,5
	135	115,9	268,8	71,8	225,6	23,0	91,0	25,3	113,8	7,9	68,5
	120	72,3	302,7	29,0	259,4	14,1	99,5	7,9	127,2	0,0	79,5
	105	46,7	314,1	0,8	270,4	0,0	97,6	0,0	136,6	0,0	83,0
	90	43,8	325,1	0,5	281,3	0,0	108,3	0,0	152,7	0,0	88,2
11	180	119,0	249,6	75,5	204,4	30,7	80,9	24,0	96,1	16,0	53,9
	165	129,3	264,7	85,5	220,5	30,3	89,9	37,2	99,9	15,2	53,2
	150	119,9	255,3	74,6	209,8	24,7	89,1	30,7	99,8	6,0	63,4
	135	101,1	277,9	56,0	232,5	24,3	108,4	16,8	109,9	1,0	64,7
	120	65,0	285,5	19,7	242,2	8,9	112,4	0,0	119,9	0,0	75,1
	105	45,0	325,8	0,5	282,2	0,0	107,5	0,0	140,9	0,0	90,0
	90	43,4	337,6	0,5	294,4	0,0	112,5	0,0	150,1	0,0	97,2
12	180	125,3	250,3	81,6	204,6	30,4	82,0	30,6	93,7	16,1	54,6
	165	124,3	250,2	81,2	204,9	30,6	83,4	35,3	96,6	15,4	51,6
	150	120,0	254,3	77,3	209,1	26,2	83,8	19,2	97,9	9,3	53,7
	135	114,5	257,9	71,5	211,7	25,5	84,8	17,5	105,0	10,1	54,4
	120	103,0	263,5	60,1	218,3	26,3	91,9	14,0	101,2	9,0	60,8
	105	86,4	279,3	43,7	233,7	21,5	102,3	8,6	107,2	1,4	66,4
	90	82,2	299,8	39,7	253,2	19,6	120,2	7,5	106,6	2,5	61,8
13	180	134,2	249,1	90,3	203,6	31,8	82,4	39,9	94,3	14,7	53,7
	165	134,2	256,5	90,4	210,7	31,5	85,4	39,6	100,0	13,7	54,2
	150	134,6	263,4	90,8	217,0	30,9	86,6	39,2	101,5	15,4	58,1
	135	135,3	261,6	91,5	214,4	30,3	87,5	38,8	101,1	11,1	59,5
	120	134,6	266,7	90,8	222,0	28,2	94,1	33,4	100,2	15,6	57,0
	105	113,3	271,2	68,3	224,5	25,5	91,3	19,6	103,7	14,6	58,3
	90	104,9	274,9	60,5	228,8	20,9	95,9	19,8	106,1	13,6	70,1
14	180	130,8	247,5	87,2	202,6	32,3	80,4	37,4	92,5	15,0	52,4
	165	130,6	247,6	87,0	202,2	32,5	81,0	37,2	92,2	14,9	52,2
	150	130,2	248,3	86,5	203,1	32,4	80,8	37,0	94,1	14,8	54,4
	135	129,4	248,7	85,8	203,6	32,1	81,6	36,7	92,9	14,6	51,9
	120	128,3	248,6	84,7	202,9	30,2	82,2	36,6	94,1	14,2	52,3
	105	118,6	250,6	74,6	206,8	26,4	82,1	20,9	97,3	14,0	52,9
	90	115,9	252,6	72,2	208,7	26,3	82,1	20,3	99,6	13,1	55,0

Case 3

Wind sea direction 165⁰											
Swell		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
T [s]	Dir. [°]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
8	180	141,6	244,7	97,4	200,4	34,3	81,0	38,5	95,4	10,4	50,9
	165	132,4	248,3	87,6	203,4	30,7	83,6	36,2	93,5	13,5	58,7
	150	122,2	248,9	77,7	203,9	29,1	81,5	27,6	96,7	15,4	62,7
	135	133,3	248,8	89,7	204,6	32,7	82,2	35,5	97,0	16,3	56,2
	120	134,5	248,8	90,3	203,5	32,3	80,5	37,6	97,4	8,8	60,4
	105	86,0	281,2	40,8	237,6	15,5	93,4	11,6	116,2	0,8	72,4
	90	68,9	294,7	24,2	250,2	7,9	103,4	8,0	115,2	1,4	58,8
9	180	141,0	246,2	97,2	201,4	30,9	81,2	42,2	92,9	19,3	52,2
	165	132,0	245,7	88,1	201,3	27,6	83,9	34,0	92,9	17,3	54,6
	150	133,0	247,3	88,7	203,1	30,2	84,8	28,2	95,4	17,2	57,2
	135	135,9	245,1	92,2	200,7	34,3	81,8	36,2	95,6	13,8	56,5
	120	127,2	255,4	82,3	211,9	29,6	82,5	34,9	95,3	6,6	65,6
	105	89,1	277,7	44,1	234,0	19,3	86,2	10,9	114,6	0,6	66,7
	90	70,1	283,5	25,1	239,5	11,9	88,5	3,3	111,6	0,1	72,2
10	180	141,6	246,4	98,0	201,6	36,1	81,6	41,1	92,3	17,4	51,9
	165	141,8	246,3	97,6	201,4	35,4	81,2	39,7	92,1	15,7	52,7
	150	135,5	246,9	91,4	202,2	33,7	82,6	35,5	96,0	17,3	52,6
	135	129,7	251,2	85,7	206,0	30,5	83,7	27,4	96,6	10,0	57,4
	120	99,1	260,0	53,6	214,2	25,8	91,8	13,9	102,7	5,9	69,4
	105	72,0	277,9	26,0	234,5	10,8	96,8	8,9	123,1	0,0	74,9
	90	66,6	286,2	21,4	242,6	9,1	96,1	5,9	123,1	0,0	76,5
11	180	141,6	244,7	97,9	199,7	34,9	78,4	40,8	91,2	21,3	50,2
	165	137,6	247,3	94,6	201,9	32,6	81,5	41,9	92,5	20,9	52,5
	150	130,3	256,6	87,8	211,7	30,1	87,2	37,1	96,6	19,2	57,5
	135	128,2	266,9	84,8	222,0	28,7	99,0	24,6	101,4	12,3	60,8
	120	104,3	269,0	58,9	225,6	20,8	92,6	19,2	113,8	4,5	77,5
	105	77,1	297,0	32,1	253,6	11,5	101,5	7,1	128,2	0,0	79,6
	90	62,1	318,9	17,3	275,2	6,5	101,4	0,0	134,8	0,0	86,2
12	180	141,2	244,7	97,8	199,9	36,6	78,4	41,9	91,2	20,9	49,5
	165	138,3	245,9	95,2	201,0	35,2	80,0	41,7	92,1	20,8	50,9
	150	135,7	247,6	92,8	202,6	34,0	82,3	41,5	92,7	20,2	51,2
	135	131,4	251,7	88,8	206,7	31,3	81,7	39,7	96,5	18,0	54,1
	120	125,6	267,2	83,1	221,9	28,8	90,6	34,7	97,7	15,2	56,3
	105	113,9	280,9	71,6	235,7	27,1	99,6	27,3	102,0	13,4	63,6
	90	111,7	289,7	69,4	243,3	26,3	103,2	28,4	109,8	10,1	62,3
13	180	142,2	246,9	98,7	202,2	35,9	80,0	42,5	92,9	20,8	51,4
	165	141,5	252,9	97,8	207,4	35,5	83,3	42,6	95,0	20,6	51,3
	150	140,5	263,5	96,9	218,6	35,2	88,0	42,6	97,8	20,4	54,6
	135	139,5	267,5	96,2	221,5	34,9	88,0	42,3	100,1	20,1	57,5
	120	137,4	262,6	94,3	216,7	34,6	88,5	41,8	99,8	19,5	58,7
	105	136,0	272,3	93,0	225,6	34,4	96,6	41,1	106,7	19,2	59,0
	90	135,6	285,7	91,7	238,3	33,1	100,6	40,9	108,9	17,2	59,4
14	180	140,3	243,7	96,6	198,9	36,1	77,2	42,1	91,0	20,0	49,7
	165	140,4	243,9	96,8	199,1	35,6	77,0	42,2	91,1	20,6	48,7
	150	140,3	244,3	96,7	199,4	35,5	77,2	42,4	91,4	21,0	50,0
	135	139,6	244,8	96,1	200,0	35,0	77,6	42,3	92,5	21,0	50,9
	120	138,6	245,4	95,1	200,4	34,3	79,1	41,9	92,2	20,6	49,7
	105	138,0	245,9	94,6	201,0	34,1	79,8	41,4	92,5	20,0	50,0
	90	138,2	247,1	94,8	202,2	34,0	80,6	41,3	92,9	19,4	51,9

Wind sea direction 180^0											
Swell		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
T [s]	Dir. [°]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
8	180	139,4	244,2	95,4	199,8	36,5	80,8	41,2	91,7	19,3	52,2
	165	132,1	245,8	87,5	201,6	33,8	81,6	36,1	93,7	18,4	57,9
	150	122,9	250,1	78,3	204,9	30,2	81,8	26,9	96,1	15,4	59,5
	135	132,6	244,8	89,0	200,2	34,1	80,9	35,1	92,8	16,1	54,9
	120	134,7	248,2	89,6	203,0	33,1	81,5	34,2	94,0	11,1	57,4
	105	72,8	275,1	28,1	231,6	11,7	89,1	4,8	114,2	0,0	66,7
	90	57,8	278,6	12,9	234,7	5,7	97,5	0,3	119,6	0,0	73,6
9	180	141,0	246,3	97,2	201,3	36,5	82,1	43,6	92,1	18,3	52,8
	165	137,7	244,2	93,7	200,0	31,6	83,3	34,2	92,2	17,9	52,1
	150	132,2	244,7	88,1	200,6	32,7	82,9	34,1	95,9	16,8	56,3
	135	138,2	243,9	94,0	199,6	35,0	80,8	38,0	93,6	14,6	63,1
	120	129,3	250,4	84,7	205,1	29,9	85,4	35,3	94,8	12,4	61,7
	105	98,5	268,4	53,5	224,8	20,0	85,6	16,7	112,5	1,8	67,2
	90	75,9	286,8	31,0	242,9	13,5	85,9	2,5	120,9	0,0	67,6
10	180	142,5	244,2	98,6	199,3	34,1	80,9	42,7	91,6	21,0	51,8
	165	143,8	243,9	100,2	199,1	37,3	79,2	42,8	91,4	20,3	51,2
	150	138,9	251,4	94,7	207,3	34,4	83,0	34,9	98,0	17,7	55,4
	135	132,9	250,5	88,1	206,0	30,6	83,5	34,5	96,5	9,4	58,5
	120	109,2	270,1	64,0	223,6	26,1	98,3	12,2	106,4	2,6	63,6
	105	90,3	286,5	45,3	242,0	16,0	91,8	8,5	123,8	0,0	76,0
	90	73,4	287,0	27,2	243,4	10,0	101,0	1,1	124,6	0,0	81,0
11	180	141,6	247,2	98,3	202,3	36,5	80,1	44,0	93,0	21,3	51,0
	165	137,6	246,9	94,8	201,7	35,2	81,8	42,3	92,3	20,1	51,2
	150	133,4	255,7	90,2	210,8	26,5	90,5	40,4	96,0	19,6	55,2
	135	123,1	256,7	80,4	212,8	29,1	85,9	35,5	101,1	12,7	56,6
	120	100,9	270,2	55,6	226,6	19,8	97,1	15,9	107,8	6,3	68,9
	105	69,4	303,1	25,5	259,2	11,9	121,0	4,8	124,2	0,0	81,3
	90	60,4	317,4	15,5	273,4	8,0	109,5	0,0	134,5	0,0	84,0
12	180	140,9	244,7	97,5	199,8	36,6	77,9	43,8	91,0	20,7	50,0
	165	139,0	246,4	95,9	201,4	35,6	79,7	43,1	92,0	20,2	50,0
	150	137,1	248,3	94,2	203,6	33,3	82,3	42,2	93,0	19,8	51,8
	135	134,3	255,4	91,3	210,2	31,6	86,8	40,9	95,1	19,1	53,4
	120	126,8	264,6	84,2	219,2	30,1	92,8	37,9	98,0	17,6	57,1
	105	116,1	279,5	73,8	233,8	27,0	99,7	28,6	101,7	9,9	57,1
	90	117,6	281,9	75,3	235,7	27,9	100,3	28,5	102,5	9,6	61,3
13	180	142,7	246,3	99,2	201,5	36,4	80,1	43,6	92,7	20,7	50,6
	165	142,1	254,9	98,7	209,6	36,1	85,6	43,4	95,5	20,2	53,6
	150	141,5	260,4	98,2	214,8	35,9	86,7	43,3	97,4	19,7	56,2
	135	140,7	260,9	97,5	214,9	35,8	88,4	43,0	102,2	19,2	57,2
	120	139,7	261,5	96,7	215,2	34,7	87,6	42,3	99,9	18,6	59,6
	105	138,3	272,4	95,4	226,0	30,8	90,6	41,1	103,1	18,1	57,9
	90	137,8	301,5	95,0	253,5	34,3	109,0	40,8	116,1	19,2	62,2
14	180	141,2	243,5	97,7	198,7	36,0	77,8	43,0	90,8	22,0	49,2
	165	142,0	243,5	98,6	198,8	36,2	77,6	43,0	90,9	22,2	50,0
	150	142,0	244,0	98,5	199,2	36,5	77,7	43,0	91,1	22,1	50,2
	135	141,5	244,3	98,1	199,5	36,2	78,8	42,8	91,2	21,9	50,8
	120	140,7	244,9	97,4	199,9	35,9	80,6	42,4	91,9	21,7	49,9
	105	138,4	245,5	95,2	200,7	35,6	81,8	42,0	92,2	21,2	50,4
	90	136,9	246,8	93,7	201,8	35,6	82,4	41,7	92,4	20,9	51,1

Wind sea direction 195^0

Swell		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
T [s]	Dir. [°]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
8	180	139,9	243,6	95,9	199,0	34,3	82,0	40,0	91,9	17,0	51,2
	165	132,4	248,5	87,8	203,5	30,1	82,0	36,9	94,6	15,4	56,7
	150	120,5	249,7	75,9	204,5	31,0	83,6	26,7	104,2	13,6	59,4
	135	134,6	244,2	90,5	199,9	34,2	82,1	35,0	95,3	12,7	56,4
	120	135,4	251,8	91,3	208,2	32,2	80,7	35,4	97,5	11,2	58,6
	105	79,2	280,7	34,0	236,7	14,0	86,9	11,0	114,7	1,8	68,4
	90	44,8	277,7	0,8	233,6	0,0	89,2	0,3	113,3	0,0	70,9
9	180	141,8	246,5	98,1	201,5	36,3	81,4	39,7	93,6	17,9	52,7
	165	136,2	246,1	92,0	201,9	34,7	83,2	36,4	98,2	18,4	53,6
	150	126,4	249,9	82,2	206,1	31,7	82,6	31,7	98,3	17,4	54,9
	135	136,6	244,1	92,5	199,5	35,4	80,7	38,8	94,1	17,0	57,1
	120	131,8	253,1	87,1	209,3	31,2	86,0	33,5	96,4	8,5	63,6
	105	82,3	270,6	37,5	227,1	15,8	85,4	8,6	111,0	1,6	65,1
	90	84,7	273,5	40,0	230,0	15,4	86,6	6,0	115,1	0,0	66,4
10	180	143,1	245,3	99,5	200,5	36,4	80,4	43,1	93,1	20,9	52,7
	165	144,1	244,2	100,5	199,5	36,9	78,4	43,5	91,3	18,3	51,4
	150	138,9	246,1	94,5	201,2	34,9	81,6	37,8	94,5	15,8	54,6
	135	127,0	251,3	82,1	205,8	32,3	83,5	30,3	99,3	10,2	58,7
	120	113,3	263,2	67,9	216,2	23,1	94,5	17,1	105,2	5,7	69,8
	105	92,4	287,8	47,0	244,3	11,3	101,0	15,6	122,4	0,0	72,3
	90	71,1	298,8	25,5	254,6	7,1	97,4	6,8	125,6	0,0	77,1
11	180	143,1	245,3	99,3	200,3	36,8	79,6	43,9	91,4	22,1	50,7
	165	141,5	247,3	98,1	202,1	31,7	81,5	43,3	92,3	22,0	51,6
	150	134,7	252,0	91,7	206,1	28,4	87,9	41,3	96,8	18,8	53,0
	135	112,3	260,4	67,3	216,1	25,7	90,5	31,1	99,4	9,8	60,7
	120	91,3	272,0	46,3	227,9	17,1	93,9	15,7	116,0	3,0	70,6
	105	68,3	306,1	23,4	262,3	8,2	104,4	2,5	125,5	0,0	78,5
	90	58,5	311,7	13,9	267,9	5,4	112,8	2,7	129,4	0,0	83,6
12	180	143,4	244,7	99,9	199,8	36,5	78,5	43,0	91,3	21,1	49,6
	165	141,5	246,1	98,3	201,1	36,0	81,5	42,8	92,8	21,3	52,4
	150	139,5	248,5	96,6	203,6	33,8	82,1	42,7	93,9	15,8	51,3
	135	137,3	255,6	94,7	210,5	30,4	86,6	42,0	98,2	13,7	55,7
	120	132,9	261,5	89,9	216,5	31,2	90,9	39,4	97,8	8,0	56,8
	105	129,2	275,1	86,3	229,5	29,4	94,1	34,1	102,5	11,5	60,1
	90	124,1	267,5	81,3	221,7	27,1	92,5	30,3	103,5	10,2	61,8
13	180	143,1	246,7	99,7	201,9	36,8	80,5	43,0	92,7	21,8	50,9
	165	142,3	254,2	99,0	209,1	36,7	84,6	42,9	96,6	21,7	52,9
	150	141,5	259,4	98,3	213,3	36,1	85,3	43,0	99,8	21,4	55,9
	135	140,6	266,2	97,5	219,3	35,6	90,6	42,8	100,3	21,1	56,0
	120	139,7	264,3	96,7	217,2	35,4	87,6	42,4	99,5	20,9	55,4
	105	138,5	270,6	95,6	223,2	34,4	88,5	42,2	103,4	20,2	60,0
	90	138,0	292,8	95,2	245,1	34,4	104,5	41,7	113,9	19,1	61,3
14	180	143,1	244,0	99,5	199,2	36,8	78,0	43,0	91,0	22,0	50,0
	165	143,8	244,2	100,3	199,4	36,9	78,0	43,2	91,1	21,6	50,0
	150	143,5	244,5	100,0	199,7	36,8	77,7	43,0	91,3	21,1	50,4
	135	143,1	244,9	99,7	200,0	36,6	78,1	42,8	91,4	21,0	50,2
	120	142,4	245,3	99,0	200,4	36,4	79,0	42,7	92,1	21,2	50,1
	105	141,6	245,9	98,3	200,9	34,4	81,5	42,7	92,2	21,7	51,2
	90	140,7	246,6	97,5	201,5	32,7	80,6	42,4	93,0	21,0	50,7

Case 4

Wind sea direction 195^0											
Swell		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
T [s]	Dir. [°]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
8	180	139,9	243,6	95,9	199,0	34,3	82,0	40,0	91,9	17,0	51,2
	165	132,4	248,5	87,8	203,5	30,1	82,0	36,9	94,6	15,4	56,7
	150	120,5	249,7	75,9	204,5	31,0	83,6	26,7	104,2	13,6	59,4
	135	134,6	244,2	90,5	199,9	34,2	82,1	35,0	95,3	12,7	56,4
	120	135,4	251,8	91,3	208,2	32,2	80,7	35,4	97,5	11,2	58,6
	105	79,2	280,7	34,0	236,7	14,0	86,9	11,0	114,7	1,8	68,4
	90	44,8	277,7	0,8	233,6	0,0	89,2	0,3	113,3	0,0	70,9
9	180	141,8	246,5	98,1	201,5	36,3	81,4	39,7	93,6	17,9	52,7
	165	136,2	246,1	92,0	201,9	34,7	83,2	36,4	98,2	18,4	53,6
	150	126,4	249,9	82,2	206,1	31,7	82,6	31,7	98,3	17,4	54,9
	135	136,6	244,1	92,5	199,5	35,4	80,7	38,8	94,1	17,0	57,1
	120	131,8	253,1	87,1	209,3	31,2	86,0	33,5	96,4	8,5	63,6
	105	82,3	270,6	37,5	227,1	15,8	85,4	8,6	111,0	1,6	65,1
	90	84,7	273,5	40,0	230,0	15,4	86,6	6,0	115,1	0,0	66,4
10	180	143,1	245,3	99,5	200,5	36,4	80,4	43,1	93,1	20,9	52,7
	165	144,1	244,2	100,5	199,5	36,9	78,4	43,5	91,3	18,3	51,4
	150	138,9	246,1	94,5	201,2	34,9	81,6	37,8	94,5	15,8	54,6
	135	127,0	251,3	82,1	205,8	32,3	83,5	30,3	99,3	10,2	58,7
	120	113,3	263,2	67,9	216,2	23,1	94,5	17,1	105,2	5,7	69,8
	105	92,4	287,8	47,0	244,3	11,3	101,0	15,6	122,4	0,0	72,3
	90	71,1	298,8	25,5	254,6	7,1	97,4	6,8	125,6	0,0	77,1
11	180	143,1	245,3	99,3	200,3	36,8	79,6	43,9	91,4	22,1	50,7
	165	141,5	247,3	98,1	202,1	31,7	81,5	43,3	92,3	22,0	51,6
	150	134,7	252,0	91,7	206,1	28,4	87,9	41,3	96,8	18,8	53,0
	135	112,3	260,4	67,3	216,1	25,7	90,5	31,1	99,4	9,8	60,7
	120	91,3	272,0	46,3	227,9	17,1	93,9	15,7	116,0	3,0	70,6
	105	68,3	306,1	23,4	262,3	8,2	104,4	2,5	125,5	0,0	78,5
	90	58,5	311,7	13,9	267,9	5,4	112,8	2,7	129,4	0,0	83,6
12	180	143,4	244,7	99,9	199,8	36,5	78,5	43,0	91,3	21,1	49,6
	165	141,5	246,1	98,3	201,1	36,0	81,5	42,8	92,8	21,3	52,4
	150	139,5	248,5	96,6	203,6	33,8	82,1	42,7	93,9	15,8	51,3
	135	137,3	255,6	94,7	210,5	30,4	86,6	42,0	98,2	13,7	55,7
	120	132,9	261,5	89,9	216,5	31,2	90,9	39,4	97,8	8,0	56,8
	105	129,2	275,1	86,3	229,5	29,4	94,1	34,1	102,5	11,5	60,1
	90	124,1	267,5	81,3	221,7	27,1	92,5	30,3	103,5	10,2	61,8
13	180	143,1	246,7	99,7	201,9	36,8	80,5	43,0	92,7	21,8	50,9
	165	142,3	254,2	99,0	209,1	36,7	84,6	42,9	96,6	21,7	52,9
	150	141,5	259,4	98,3	213,3	36,1	85,3	43,0	99,8	21,4	55,9
	135	140,6	266,2	97,5	219,3	35,6	90,6	42,8	100,3	21,1	56,0
	120	139,7	264,3	96,7	217,2	35,4	87,6	42,4	99,5	20,9	55,4
	105	138,5	270,6	95,6	223,2	34,4	88,5	42,2	103,4	20,2	60,0
	90	138,0	292,8	95,2	245,1	34,4	104,5	41,7	113,9	19,1	61,3
14	180	143,1	244,0	99,5	199,2	36,8	78,0	43,0	91,0	22,0	50,0
	165	143,8	244,2	100,3	199,4	36,9	78,0	43,2	91,1	21,6	50,0
	150	143,5	244,5	100,0	199,7	36,8	77,7	43,0	91,3	21,1	50,4
	135	143,1	244,9	99,7	200,0	36,6	78,1	42,8	91,4	21,0	50,2
	120	142,4	245,3	99,0	200,4	36,4	79,0	42,7	92,1	21,2	50,1
	105	141,6	245,9	98,3	200,9	34,4	81,5	42,7	92,2	21,7	51,2
	90	140,7	246,6	97,5	201,5	32,7	80,6	42,4	93,0	21,0	50,7

Wind sea direction 210^0											
Swell		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
T [s]	Dir. [°]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
8	180	141,6	244,1	97,4	199,8	35,9	82,2	40,1	92,3	20,2	50,8
	165	132,9	247,6	88,3	204,0	32,2	82,2	32,7	95,1	16,7	60,3
	150	121,5	250,6	77,2	206,9	28,6	84,3	25,7	98,8	11,9	62,2
	135	134,6	245,7	90,5	201,1	35,1	81,9	32,7	94,2	14,2	56,1
	120	126,4	249,9	81,7	206,5	33,9	82,3	23,2	97,8	8,3	61,9
	105	78,9	275,9	33,8	232,2	14,6	90,7	0,0	112,6	3,1	69,5
	90	56,6	281,9	12,2	237,9	5,1	92,0	2,2	118,3	0,0	73,1
9	180	139,6	246,7	95,8	201,9	33,6	84,1	39,8	93,1	20,4	53,4
	165	136,7	247,4	92,8	202,7	32,5	84,4	38,1	94,9	19,5	53,9
	150	136,7	246,9	92,5	202,9	31,9	83,2	28,5	92,6	16,3	57,5
	135	136,7	246,1	92,7	202,2	35,3	80,7	20,7	94,8	15,7	57,2
	120	100,4	249,8	55,6	205,4	25,1	84,1	12,9	96,2	5,7	58,2
	105	89,0	270,5	44,1	227,0	18,2	85,3	5,2	112,8	1,7	70,9
	90	71,1	283,7	26,3	239,8	12,2	87,5	2,5	121,6	0,1	72,5
10	180	142,3	245,7	98,9	200,7	34,9	80,7	41,9	93,2	21,5	52,9
	165	143,6	245,1	99,7	200,2	36,9	79,2	44,4	92,5	17,9	50,9
	150	139,6	247,1	96,1	202,1	35,6	82,4	37,6	94,9	15,7	57,9
	135	134,8	252,7	90,9	207,5	32,8	87,6	36,2	97,3	13,7	57,1
	120	115,8	264,7	70,8	219,8	28,7	95,1	23,7	105,9	6,2	65,4
	105	65,2	281,6	20,1	237,1	10,1	96,3	2,7	120,1	0,0	76,4
	90	55,5	305,5	10,5	261,0	4,1	101,0	0,0	127,1	0,0	77,3
11	180	142,0	245,5	98,6	200,5	36,5	79,8	43,4	91,9	22,1	52,1
	165	140,9	248,5	97,8	203,0	35,9	81,3	43,9	93,0	22,0	50,2
	150	135,9	253,2	93,4	208,8	26,5	88,0	42,0	96,4	20,1	54,8
	135	124,7	258,5	80,9	212,3	26,9	85,0	36,5	101,1	10,3	63,8
	120	86,7	268,3	41,6	223,2	17,4	91,0	17,3	112,7	2,2	70,6
	105	57,3	298,5	12,4	254,7	6,7	107,6	0,0	124,7	0,0	75,8
	90	57,4	308,7	12,6	264,5	5,2	110,1	0,2	130,7	0,0	84,4
12	180	142,7	245,2	99,2	200,3	36,4	79,0	43,6	91,9	21,5	49,4
	165	141,0	246,7	97,7	201,6	35,2	80,5	43,3	92,4	20,9	52,4
	150	139,0	249,3	95,8	203,8	33,7	84,5	43,1	94,5	20,2	51,7
	135	136,0	253,0	93,3	207,7	31,9	82,7	42,3	98,9	19,2	53,7
	120	131,3	265,8	88,7	220,4	29,2	91,9	39,4	99,7	13,7	55,4
	105	119,1	274,3	74,9	228,9	28,4	96,0	26,4	101,1	11,2	64,7
	90	125,4	277,0	82,3	230,9	26,3	92,0	33,1	102,1	9,4	63,2
13	180	142,9	246,5	99,2	201,6	36,3	80,2	43,8	92,8	21,5	50,6
	165	142,3	253,7	98,8	208,5	35,9	83,7	43,6	95,1	21,4	54,1
	150	141,6	259,3	98,3	213,6	35,4	87,0	43,2	97,7	21,4	54,3
	135	141,0	263,5	97,8	217,6	35,0	92,0	42,7	100,9	21,0	56,5
	120	140,4	260,6	97,3	214,2	34,3	88,1	42,2	102,0	20,3	55,1
	105	138,6	270,6	95,3	224,2	33,7	92,1	41,6	103,8	19,3	60,3
	90	136,5	286,4	93,4	239,2	33,7	102,1	41,3	117,4	19,4	59,7
14	180	144,0	245,0	100,4	200,1	36,9	78,5	43,9	91,6	22,0	50,3
	165	143,6	245,2	100,0	200,2	36,5	78,3	43,8	91,6	22,0	50,3
	150	142,7	245,5	99,1	200,6	36,1	78,4	43,7	91,7	21,8	50,1
	135	142,2	246,0	98,6	201,0	35,5	78,2	43,6	92,0	21,8	51,3
	120	142,1	246,5	98,7	201,4	35,2	78,2	43,5	92,3	21,8	51,3
	105	141,3	247,0	97,9	202,0	34,7	81,3	43,5	92,3	21,5	51,3
	90	140,7	247,3	97,5	202,2	34,3	82,0	43,4	93,2	21,0	50,7

Wind sea direction 225⁰											
Swell		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
T [s]	Dir. [°]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
8	180	138,7	244,5	94,8	200,1	35,5	83,7	39,3	93,3	20,1	54,6
	165	129,9	246,7	85,9	201,7	27,9	84,8	35,6	94,1	16,9	55,9
	150	113,1	249,0	68,6	203,9	28,3	84,9	24,2	98,2	10,5	66,0
	135	130,2	245,2	86,1	201,0	31,0	83,0	33,1	93,5	13,9	56,0
	120	134,2	248,4	89,1	204,8	33,5	81,8	27,0	96,3	11,0	57,7
	105	77,5	279,3	32,9	235,4	14,2	94,7	10,3	116,2	0,5	70,9
	90	44,9	278,6	0,8	234,6	0,0	94,8	0,3	118,6	0,0	66,2
9	180	136,3	247,4	92,8	202,6	32,1	84,2	35,1	94,8	17,0	56,6
	165	132,5	248,9	88,7	204,4	32,3	83,1	36,4	94,0	18,0	54,2
	150	133,2	246,3	88,9	202,2	35,8	84,1	36,7	94,1	18,6	55,2
	135	136,7	245,6	92,2	200,9	34,1	83,7	37,7	93,8	16,8	60,0
	120	122,6	256,2	77,7	212,4	30,4	84,7	33,3	103,3	10,1	60,4
	105	85,1	271,3	40,2	227,6	15,5	86,4	10,7	113,2	3,8	66,9
	90	79,1	277,3	34,8	233,4	14,8	87,2	7,3	111,0	0,0	72,8
10	180	138,5	246,3	95,2	201,4	32,3	81,5	39,3	92,9	20,3	52,1
	165	142,1	245,3	98,3	200,4	35,9	79,2	42,6	91,8	17,7	52,6
	150	138,9	247,7	95,3	202,6	35,0	81,0	37,7	94,9	18,0	54,5
	135	132,9	251,8	88,5	206,2	31,3	87,9	36,2	98,1	11,4	57,9
	120	108,6	266,6	64,1	221,7	20,5	94,4	24,5	107,0	0,0	66,1
	105	63,7	281,9	18,5	237,6	8,7	98,9	4,7	118,8	0,0	74,0
	90	51,2	301,1	6,5	256,6	2,0	99,0	2,8	120,7	0,0	84,9
11	180	140,1	246,6	96,7	201,5	36,1	80,7	40,9	92,1	20,4	53,3
	165	138,2	249,0	95,3	203,4	35,1	81,9	42,5	92,9	20,7	50,6
	150	134,8	254,0	92,4	209,5	29,1	89,9	41,3	95,8	19,2	54,8
	135	127,4	267,5	82,1	222,9	29,1	94,5	37,0	101,2	11,0	62,5
	120	100,7	266,0	55,6	222,4	20,4	100,2	20,8	108,1	0,0	67,5
	105	57,7	287,1	14,9	243,3	5,5	108,3	4,3	122,0	0,0	78,0
	90	53,8	299,2	9,0	255,4	2,8	105,1	0,0	129,2	0,0	83,4
12	180	139,5	245,5	96,2	200,5	35,7	80,8	41,4	91,9	21,4	50,0
	165	137,9	247,5	94,9	202,2	34,8	80,6	41,1	93,4	21,5	50,3
	150	136,2	249,4	93,5	204,0	33,8	82,9	41,0	94,5	19,5	51,7
	135	134,0	253,7	91,5	208,5	32,2	86,6	40,2	97,9	19,8	55,0
	120	130,5	259,3	87,8	214,0	31,3	87,8	38,2	98,6	14,6	57,5
	105	127,2	286,0	83,9	240,1	28,0	98,5	32,7	105,0	8,1	66,0
	90	123,2	278,2	80,0	232,1	25,7	99,6	30,0	101,8	11,5	58,0
13	180	140,4	246,7	97,0	201,8	36,1	80,4	42,5	92,5	21,1	50,6
	165	139,6	251,7	96,3	206,8	35,5	85,2	42,3	94,3	21,1	55,0
	150	138,5	261,0	95,2	214,5	34,9	89,2	41,9	98,1	21,0	56,4
	135	137,6	263,8	94,4	216,9	34,3	87,2	41,5	99,9	21,1	56,7
	120	136,5	261,6	93,3	215,6	33,3	87,7	41,0	101,9	20,8	56,9
	105	135,5	268,2	92,5	221,8	32,2	88,9	40,5	103,3	20,6	56,0
	90	135,6	280,7	92,8	233,9	31,6	96,4	39,4	107,8	19,2	58,6
14	180	139,0	244,9	95,7	200,0	35,5	79,7	41,0	91,4	20,5	49,4
	165	139,0	244,9	95,7	200,0	35,5	79,1	41,1	91,6	20,5	50,2
	150	138,9	245,0	95,6	200,2	35,2	78,8	41,2	91,7	20,6	50,8
	135	138,7	245,5	95,4	200,6	35,0	78,9	41,3	91,8	20,7	51,4
	120	138,3	246,1	95,0	201,1	35,0	78,7	41,4	92,1	20,6	51,5
	105	138,1	246,6	94,9	201,5	35,2	79,5	41,5	92,8	20,4	51,1
	90	138,3	247,3	95,1	202,2	35,1	81,6	41,5	93,6	20,3	51,6

Case 5

Wind sea direction 225^0											
Swell		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
T [s]	Dir. [°]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
8	180	138,7	244,5	94,8	200,1	35,5	83,7	39,3	93,3	20,1	54,6
	165	129,9	246,7	85,9	201,7	27,9	84,8	35,6	94,1	16,9	55,9
	150	113,1	249,0	68,6	203,9	28,3	84,9	24,2	98,2	10,5	66,0
	135	130,2	245,2	86,1	201,0	31,0	83,0	33,1	93,5	13,9	56,0
	120	134,2	248,4	89,1	204,8	33,5	81,8	27,0	96,3	11,0	57,7
	105	77,5	279,3	32,9	235,4	14,2	94,7	10,3	116,2	0,5	70,9
	90	44,9	278,6	0,8	234,6	0,0	94,8	0,3	118,6	0,0	66,2
9	180	136,3	247,4	92,8	202,6	32,1	84,2	35,1	94,8	17,0	56,6
	165	132,5	248,9	88,7	204,4	32,3	83,1	36,4	94,0	18,0	54,2
	150	133,2	246,3	88,9	202,2	35,8	84,1	36,7	94,1	18,6	55,2
	135	136,7	245,6	92,2	200,9	34,1	83,7	37,7	93,8	16,8	60,0
	120	122,6	256,2	77,7	212,4	30,4	84,7	33,3	103,3	10,1	60,4
	105	85,1	271,3	40,2	227,6	15,5	86,4	10,7	113,2	3,8	66,9
	90	79,1	277,3	34,8	233,4	14,8	87,2	7,3	111,0	0,0	72,8
10	180	138,5	246,3	95,2	201,4	32,3	81,5	39,3	92,9	20,3	52,1
	165	142,1	245,3	98,3	200,4	35,9	79,2	42,6	91,8	17,7	52,6
	150	138,9	247,7	95,3	202,6	35,0	81,0	37,7	94,9	18,0	54,5
	135	132,9	251,8	88,5	206,2	31,3	87,9	36,2	98,1	11,4	57,9
	120	108,6	266,6	64,1	221,7	20,5	94,4	24,5	107,0	0,0	66,1
	105	63,7	281,9	18,5	237,6	8,7	98,9	4,7	118,8	0,0	74,0
	90	51,2	301,1	6,5	256,6	2,0	99,0	2,8	120,7	0,0	84,9
11	180	140,1	246,6	96,7	201,5	36,1	80,7	40,9	92,1	20,4	53,3
	165	138,2	249,0	95,3	203,4	35,1	81,9	42,5	92,9	20,7	50,6
	150	134,8	254,0	92,4	209,5	29,1	89,9	41,3	95,8	19,2	54,8
	135	127,4	267,5	82,1	222,9	29,1	94,5	37,0	101,2	11,0	62,5
	120	100,7	266,0	55,6	222,4	20,4	100,2	20,8	108,1	0,0	67,5
	105	57,7	287,1	14,9	243,3	5,5	108,3	4,3	122,0	0,0	78,0
	90	53,8	299,2	9,0	255,4	2,8	105,1	0,0	129,2	0,0	83,4
12	180	139,5	245,5	96,2	200,5	35,7	80,8	41,4	91,9	21,4	50,0
	165	137,9	247,5	94,9	202,2	34,8	80,6	41,1	93,4	21,5	50,3
	150	136,2	249,4	93,5	204,0	33,8	82,9	41,0	94,5	19,5	51,7
	135	134,0	253,7	91,5	208,5	32,2	86,6	40,2	97,9	19,8	55,0
	120	130,5	259,3	87,8	214,0	31,3	87,8	38,2	98,6	14,6	57,5
	105	127,2	286,0	83,9	240,1	28,0	98,5	32,7	105,0	8,1	66,0
	90	123,2	278,2	80,0	232,1	25,7	99,6	30,0	101,8	11,5	58,0
13	180	140,4	246,7	97,0	201,8	36,1	80,4	42,5	92,5	21,1	50,6
	165	139,6	251,7	96,3	206,8	35,5	85,2	42,3	94,3	21,1	55,0
	150	138,5	261,0	95,2	214,5	34,9	89,2	41,9	98,1	21,0	56,4
	135	137,6	263,8	94,4	216,9	34,3	87,2	41,5	99,9	21,1	56,7
	120	136,5	261,6	93,3	215,6	33,3	87,7	41,0	101,9	20,8	56,9
	105	135,5	268,2	92,5	221,8	32,2	88,9	40,5	103,3	20,6	56,0
	90	135,6	280,7	92,8	233,9	31,6	96,4	39,4	107,8	19,2	58,6
14	180	139,0	244,9	95,7	200,0	35,5	79,7	41,0	91,4	20,5	49,4
	165	139,0	244,9	95,7	200,0	35,5	79,1	41,1	91,6	20,5	50,2
	150	138,9	245,0	95,6	200,2	35,2	78,8	41,2	91,7	20,6	50,8
	135	138,7	245,5	95,4	200,6	35,0	78,9	41,3	91,8	20,7	51,4
	120	138,3	246,1	95,0	201,1	35,0	78,7	41,4	92,1	20,6	51,5
	105	138,1	246,6	94,9	201,5	35,2	79,5	41,5	92,8	20,4	51,1
	90	138,3	247,3	95,1	202,2	35,1	81,6	41,5	93,6	20,3	51,6

Wind sea direction 240^0											
Swell		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
T [s]	Dir. [°]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
8	180	139,6	247,9	95,5	203,5	34,9	81,6	36,9	94,8	21,1	52,7
	165	125,3	247,5	80,5	203,9	30,7	84,4	35,6	97,1	14,0	57,5
	150	114,2	249,1	69,8	203,8	27,8	82,1	28,7	99,3	7,6	59,9
	135	132,3	248,6	88,2	204,4	33,5	81,0	33,1	96,0	15,5	56,8
	120	133,3	249,3	88,4	204,3	30,4	82,4	30,9	97,0	12,7	58,0
	105	82,5	279,2	37,5	235,6	15,4	92,5	7,7	117,0	2,4	70,3
	90	48,4	285,6	3,8	241,7	1,4	103,6	0,0	117,3	2,2	60,6
9	180	140,8	248,1	97,0	203,2	34,8	83,8	38,4	92,7	17,4	54,5
	165	135,6	247,6	91,4	202,8	31,9	83,4	34,7	96,2	18,7	53,6
	150	134,1	245,4	89,8	201,0	34,2	84,4	36,8	94,1	15,0	61,2
	135	135,0	245,3	90,7	200,7	34,3	81,6	32,7	92,9	14,9	58,5
	120	128,9	250,9	83,8	205,6	29,3	84,5	30,8	94,4	10,3	61,5
	105	82,7	266,5	37,7	223,0	14,4	84,8	15,4	106,6	0,0	65,6
	90	45,5	271,8	0,9	228,2	0,0	88,0	0,4	111,9	0,0	77,6
10	180	139,8	248,6	96,5	203,5	34,9	82,0	41,8	93,0	21,8	52,8
	165	142,4	245,7	98,4	200,7	35,7	79,6	42,9	91,7	18,8	52,3
	150	138,5	248,1	93,7	204,2	34,1	82,6	37,4	97,1	17,8	53,6
	135	132,9	258,9	87,8	213,6	32,7	88,2	34,9	100,4	16,7	59,3
	120	110,7	266,4	65,0	222,7	22,4	96,0	23,7	112,3	1,9	67,4
	105	79,0	281,0	34,0	236,7	11,8	92,1	8,7	124,8	0,0	75,9
	90	53,1	295,0	8,4	250,8	2,2	101,7	1,6	131,4	0,0	79,7
11	180	138,6	245,7	95,0	200,6	34,5	83,3	38,7	91,8	21,5	52,1
	165	139,1	248,9	95,9	203,4	35,5	82,5	41,0	93,0	21,0	50,5
	150	135,2	254,9	92,5	208,6	29,2	84,0	37,9	97,7	18,2	52,1
	135	120,1	273,9	75,0	229,3	27,2	102,1	30,2	105,6	8,6	60,2
	120	82,5	273,0	39,8	229,5	13,6	95,5	14,4	108,3	3,1	66,5
	105	68,2	287,8	23,3	243,9	9,5	101,3	0,0	122,5	0,0	74,4
	90	56,4	301,5	11,5	256,1	5,6	113,9	1,2	131,6	0,0	85,7
12	180	140,3	245,5	96,9	200,5	35,4	79,4	41,9	92,1	21,2	51,0
	165	139,0	247,4	95,9	202,2	35,7	81,5	41,5	96,8	20,6	50,6
	150	137,6	248,6	94,7	203,7	34,6	84,7	41,2	95,4	20,0	54,2
	135	134,4	256,9	91,5	211,4	32,2	86,4	40,1	98,2	19,2	54,2
	120	122,8	258,8	80,2	212,7	28,7	89,3	36,1	100,0	13,4	57,1
	105	114,2	273,9	71,9	227,5	27,3	96,5	29,3	100,1	9,6	61,2
	90	117,9	298,3	75,3	252,0	26,3	113,0	29,3	105,2	8,5	58,7
13	180	140,2	246,6	96,5	201,6	35,6	80,3	42,6	92,6	21,0	51,3
	165	138,8	252,7	95,3	207,5	34,8	83,6	42,1	94,9	20,7	52,1
	150	138,0	257,9	94,5	212,2	34,3	85,4	41,3	98,2	20,6	55,3
	135	137,4	266,3	94,1	220,5	34,2	92,2	40,8	99,2	20,5	54,2
	120	136,6	271,4	93,4	225,1	34,2	97,8	40,8	100,9	20,0	57,3
	105	136,6	270,4	93,3	223,4	34,0	98,0	40,8	102,9	19,0	56,0
	90	136,7	296,3	93,7	247,5	33,0	100,3	40,9	121,8	16,0	63,2
14	180	141,3	244,8	97,8	200,0	35,8	79,1	41,5	91,7	21,0	52,2
	165	140,9	245,1	97,4	200,2	35,9	78,7	41,6	91,8	21,3	52,1
	150	140,5	245,2	97,1	200,3	35,9	79,1	41,7	92,0	21,6	52,3
	135	140,3	245,3	96,9	200,3	35,7	78,7	41,7	92,1	21,6	51,8
	120	140,1	245,8	96,9	200,9	35,6	77,9	41,6	92,4	21,1	51,1
	105	140,2	247,0	96,9	202,0	35,3	81,1	41,7	93,1	20,7	51,6
	90	140,2	247,8	96,8	202,8	34,9	79,2	41,7	94,1	20,7	51,0

Wind sea direction 255^0

Swell		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
T [s]	Dir. [°]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
8	180	138,1	247,1	94,3	202,6	35,3	81,7	36,0	95,9	20,7	52,8
	165	128,9	247,0	85,5	202,1	31,9	83,8	26,2	97,5	17,8	55,7
	150	121,1	249,3	76,8	204,0	28,8	83,0	24,1	96,1	14,2	62,8
	135	131,3	245,8	87,6	201,7	33,8	83,3	29,5	95,2	18,1	54,5
	120	131,5	250,1	86,2	204,9	32,4	82,1	32,9	99,5	14,4	58,2
	105	68,9	276,1	24,5	232,5	9,3	95,7	2,4	108,4	1,5	66,6
	90	79,1	283,7	34,2	239,5	11,7	101,4	7,6	111,8	4,8	60,2
9	180	135,1	248,2	91,5	203,5	34,5	83,5	35,0	93,2	21,9	52,6
	165	134,3	245,7	90,3	201,1	32,8	84,0	36,7	93,4	18,7	53,8
	150	118,5	246,3	74,0	201,7	32,0	82,5	28,0	94,1	14,6	54,6
	135	129,0	246,7	84,4	202,9	33,0	82,7	34,8	99,9	16,7	61,2
	120	116,4	256,8	71,8	213,3	30,2	85,4	23,3	102,2	10,2	60,8
	105	94,2	266,9	49,2	223,4	17,4	86,5	22,7	109,5	3,3	69,2
	90	60,1	280,3	15,5	236,5	5,7	87,7	8,2	115,2	0,0	71,9
10	180	139,1	245,7	95,7	200,7	30,8	81,2	40,5	95,2	21,4	53,1
	165	139,1	245,6	94,9	200,6	35,6	79,5	40,8	93,0	19,2	52,3
	150	134,1	249,3	90,8	204,1	34,0	83,5	38,5	94,6	16,0	56,0
	135	133,8	259,2	90,7	214,0	31,3	89,7	37,8	102,1	14,5	59,1
	120	116,1	271,3	71,2	225,1	26,4	99,7	26,2	104,2	4,1	67,0
	105	77,6	274,8	32,5	230,3	10,1	90,6	7,2	122,7	2,9	73,9
	90	65,1	286,7	20,0	242,9	7,7	105,1	5,7	123,1	0,0	75,3
11	180	139,7	246,1	96,3	201,0	35,5	80,6	41,3	92,3	21,2	51,3
	165	136,3	248,8	93,4	203,4	34,8	80,7	41,7	93,2	20,7	50,1
	150	132,0	252,1	89,2	206,1	26,5	84,7	40,1	96,2	19,2	55,4
	135	121,3	268,3	76,2	221,8	25,6	96,3	32,6	106,4	5,3	60,7
	120	82,8	265,0	39,8	219,6	14,9	93,1	11,3	106,9	0,0	69,7
	105	55,2	294,1	10,3	248,9	3,7	105,6	0,0	123,2	0,0	85,0
	90	51,2	306,1	5,6	262,0	2,5	115,9	0,0	130,3	0,0	86,4
12	180	138,8	245,6	95,7	200,6	34,8	79,3	42,2	91,9	21,6	49,5
	165	136,9	247,7	94,0	202,7	34,2	80,2	41,3	92,9	21,5	50,3
	150	135,1	251,1	92,5	205,6	33,0	83,4	40,5	93,8	21,3	51,1
	135	133,4	253,2	90,7	207,5	30,6	84,0	39,5	98,5	20,6	56,6
	120	120,7	259,1	76,1	212,5	28,5	89,5	29,1	100,0	16,3	55,1
	105	123,6	273,9	80,8	227,8	26,8	96,5	30,0	101,1	10,2	59,9
	90	119,1	280,6	76,7	235,3	27,9	104,5	27,6	104,5	10,4	62,1
13	180	140,4	247,0	96,9	202,0	36,0	80,2	42,3	93,1	20,5	50,9
	165	139,6	253,7	96,2	207,9	35,6	82,6	42,0	96,0	20,4	53,4
	150	138,8	260,5	95,4	214,0	35,1	85,1	41,5	98,5	20,6	62,5
	135	137,7	263,6	94,5	217,7	34,6	87,9	41,1	99,5	20,3	56,1
	120	136,4	262,9	93,3	216,7	34,0	88,9	40,4	103,9	19,1	56,4
	105	134,5	271,0	90,9	224,6	33,2	94,9	39,2	106,4	18,4	57,8
	90	131,2	287,8	87,7	240,3	32,9	100,9	37,8	118,7	19,0	59,9
14	180	136,6	245,3	93,1	200,3	34,4	78,6	42,1	91,8	21,5	49,2
	165	136,2	245,7	92,7	200,7	34,2	78,6	42,3	92,0	21,6	49,8
	150	135,5	246,2	92,0	201,1	34,0	78,8	42,1	92,2	21,6	49,7
	135	135,1	246,5	91,7	201,3	33,8	78,2	41,9	92,8	21,4	51,9
	120	135,2	246,9	91,8	201,8	33,4	78,7	41,3	92,8	21,4	51,4
	105	135,2	247,2	91,8	201,9	33,6	79,9	40,7	92,6	21,2	51,7
	90	134,7	247,8	91,5	202,6	33,7	79,4	40,2	93,2	20,5	51,6

Case 6

Wind sea direction 225⁰											
Swell		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
T [s]	Dir. [°]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
8	180	71,2	254,3	27,1	208,5	9,8	93,2	11,3	101,2	4,6	76,1
	165	44,0	355,7	0,4	311,3	0,0	117,7	0,0	160,0	0,0	111,1
	150	40,7	439,3	0,2	381,9	0,0	138,8	0,0	194,9	0,0	141,0
	135	42,9	350,8	0,5	305,7	0,0	97,8	0,0	148,4	0,0	111,2
	120	44,4	380,1	0,5	338,8	0,0	114,3	0,0	164,8	0,0	114,4
	105	32,3	945,2	0,0	870,1	0,0	443,1	0,0	332,6	0,0	262,9
	90	30,1	784,7	0,0	723,2	0,0	442,7	0,0	434,4	0,0	298,0
9	180	78,9	264,0	36,5	218,2	13,6	91,8	15,6	99,2	5,4	64,4
	165	44,9	289,5	0,5	244,9	0,0	103,4	0,0	116,7	0,0	84,1
	150	44,0	345,9	0,5	300,2	0,0	105,3	0,0	160,4	0,0	116,3
	135	47,7	332,5	2,3	289,6	0,7	105,8	0,6	137,0	0,0	110,1
	120	43,9	398,6	0,5	357,2	0,0	121,1	0,0	170,0	0,0	125,0
	105	44,1	712,2	0,0	648,4	0,0	339,9	0,0	317,6	0,0	212,3
	90	31,6	872,2	0,0	839,7	0,0	441,9	0,0	360,4	0,0	276,0
10	180	111,0	286,6	70,0	238,5	22,5	96,5	27,7	106,2	13,9	59,8
	165	114,2	279,6	69,9	232,2	24,8	95,9	27,7	106,3	1,6	62,4
	150	64,2	319,1	18,6	277,0	7,5	99,9	2,4	135,7	0,0	93,6
	135	45,2	407,3	0,5	364,9	0,0	112,8	0,0	170,1	0,0	119,9
	120	43,5	490,2	0,0	443,7	0,0	190,4	0,0	227,9	0,0	161,2
	105	29,3	863,3	0,0	779,1	0,0	359,3	0,0	398,6	0,0	332,1
	90	30,4	1037,0	0,0	953,6	0,0	387,4	0,0	460,6	0,0	425,0
11	180	128,0	261,4	85,2	214,4	26,4	88,9	34,4	99,3	12,7	56,7
	165	122,8	285,3	79,8	240,0	27,3	105,5	26,9	106,6	16,3	57,7
	150	53,9	378,7	8,8	335,3	1,7	174,6	4,1	163,9	0,0	99,6
	135	42,3	418,7	0,4	377,1	0,0	146,7	0,0	200,1	0,0	133,9
	120	32,7	618,3	0,0	555,0	0,0	231,5	0,0	306,7	0,0	311,7
	105	26,7	915,5	0,0	844,5	0,0	312,0	0,0	450,5	0,0	472,4
	90	25,2	1057,3	0,0	981,5	0,0	331,7	0,0	515,9	0,0	577,2
12	180	126,5	256,8	84,4	210,1	32,5	85,3	34,3	96,2	17,2	53,4
	165	121,4	277,9	80,7	230,8	28,3	94,1	35,4	104,9	17,1	56,7
	150	108,9	299,1	66,8	251,1	22,7	106,4	23,4	116,6	5,5	71,3
	135	58,6	307,2	14,0	259,6	5,1	122,8	5,4	131,8	0,0	73,2
	120	40,9	358,6	0,4	312,1	0,0	128,5	0,0	148,0	0,0	97,0
	105	40,3	422,8	0,4	378,0	0,0	147,4	0,0	183,9	0,0	136,0
	90	42,1	436,9	0,4	391,9	0,0	145,4	0,0	204,4	0,0	201,2
13	180	128,0	263,9	85,4	218,0	31,2	86,9	36,0	111,5	18,7	57,1
	165	112,1	274,4	70,5	226,2	25,5	90,6	29,9	103,7	16,4	60,6
	150	116,8	300,0	75,8	251,9	28,2	109,5	30,2	111,2	17,4	61,3
	135	117,1	294,7	75,2	245,5	27,7	102,7	31,4	110,4	12,7	63,9
	120	114,6	313,0	70,3	266,2	24,8	108,1	29,8	123,0	7,3	75,8
	105	76,7	281,5	32,4	234,5	14,6	98,1	11,2	111,5	3,5	72,4
	90	68,9	278,7	24,7	231,7	11,0	89,5	6,4	109,2	2,3	74,7
14	180	130,0	251,7	87,8	205,6	31,8	82,4	38,4	93,9	18,7	50,8
	165	122,6	252,2	80,7	205,9	30,6	79,6	33,3	94,1	17,2	49,9
	150	118,3	255,3	75,4	209,3	25,7	82,0	33,8	96,2	16,0	54,2
	135	120,8	256,4	79,3	210,0	29,6	83,8	32,7	96,8	18,4	53,9
	120	123,1	258,9	81,1	211,8	29,3	84,0	32,3	99,2	17,0	55,9
	105	124,0	278,8	81,9	231,9	30,0	96,2	33,6	103,8	12,9	65,7
	90	116,4	279,3	74,4	231,3	28,1	98,1	32,5	114,9	0,0	73,4

Wind sea direction 240⁰											
Swell		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
T [s]	Dir. [°]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
8	180	65,4	253,1	21,6	207,7	7,8	90,6	10,4	100,3	3,5	75,6
	165	44,1	356,1	0,4	312,3	0,0	118,9	0,0	162,0	0,0	112,0
	150	40,3	437,4	0,2	380,6	0,0	134,7	0,0	195,5	0,0	139,2
	135	42,4	349,9	0,4	304,7	0,0	97,2	0,0	146,6	0,0	111,8
	120	44,2	384,4	0,5	343,3	0,0	110,1	0,0	165,5	0,0	113,5
	105	33,7	943,5	0,0	870,4	0,0	428,6	0,0	342,9	0,0	294,1
	90	30,5	857,8	0,0	793,3	0,0	440,2	0,0	433,5	0,0	297,0
9	180	79,8	264,1	37,3	218,4	13,7	91,6	17,9	99,9	5,8	64,3
	165	44,9	299,1	0,5	255,0	0,0	99,8	0,0	118,1	0,0	87,2
	150	44,1	344,8	0,5	300,1	0,0	102,2	0,0	161,3	0,0	118,8
	135	48,8	332,8	3,5	289,7	1,5	104,6	0,2	135,7	0,0	107,8
	120	44,0	398,2	0,5	356,8	0,0	120,2	0,0	170,9	0,0	124,9
	105	42,3	708,6	0,0	645,9	0,0	346,1	0,0	321,7	0,0	220,7
	90	31,8	846,1	0,0	805,1	0,0	421,7	0,0	337,4	0,0	280,5
10	180	108,5	284,0	67,1	235,1	21,7	93,5	24,3	105,4	12,1	59,7
	165	113,0	280,7	68,9	233,2	24,9	95,5	27,7	107,9	7,4	61,9
	150	64,0	317,9	18,4	275,6	7,3	101,8	2,8	135,5	0,0	92,3
	135	45,2	418,5	0,5	374,8	0,0	115,3	0,0	171,6	0,0	118,7
	120	43,4	491,8	0,0	450,5	0,0	187,4	0,0	234,1	0,0	160,4
	105	29,6	846,2	0,0	769,0	0,0	398,5	0,0	391,8	0,0	349,1
	90	28,4	1028,1	0,0	945,0	0,0	390,3	0,0	361,3	0,0	424,6
11	180	114,9	262,2	73,3	215,2	21,9	88,9	33,4	99,1	12,4	57,5
	165	122,0	286,6	79,2	241,3	25,7	107,1	26,9	106,7	16,0	58,2
	150	51,5	398,6	6,8	354,3	0,9	190,7	4,2	161,7	0,0	99,8
	135	42,3	421,8	0,4	380,9	0,0	153,8	0,0	200,5	0,0	138,5
	120	30,7	609,7	0,0	544,7	0,0	228,0	0,0	310,5	0,0	311,0
	105	26,8	955,6	0,0	880,1	0,0	319,5	0,0	432,1	0,0	473,9
	90	25,0	1063,8	0,0	985,7	0,0	326,7	0,0	510,5	0,0	571,4
12	180	122,3	256,7	80,7	210,0	30,2	85,1	34,9	95,9	18,7	53,6
	165	116,7	273,7	76,0	227,1	26,0	93,9	31,6	104,0	17,5	57,4
	150	111,1	297,2	68,0	249,5	23,1	110,0	21,0	114,7	9,3	68,6
	135	52,8	314,7	8,3	267,0	3,2	126,0	4,6	132,4	0,0	72,3
	120	41,0	361,3	0,4	314,9	0,0	131,2	0,0	145,4	0,0	99,5
	105	40,1	419,4	0,4	374,7	0,0	148,7	0,0	181,0	0,0	137,2
	90	42,3	445,2	0,4	401,1	0,0	146,0	0,0	202,7	0,0	202,6
13	180	114,1	267,0	72,1	222,0	27,8	94,3	28,8	106,0	18,5	56,1
	165	123,3	275,4	81,6	227,4	30,6	92,1	34,2	103,5	18,0	60,4
	150	117,8	304,0	76,7	254,8	28,8	110,8	31,7	112,9	16,7	62,3
	135	115,3	283,2	74,0	235,1	26,3	96,3	31,6	106,0	13,6	63,0
	120	112,2	301,1	67,7	251,2	23,1	102,2	27,6	122,3	7,2	70,8
	105	83,0	280,5	39,1	233,6	16,1	98,6	14,3	111,7	4,0	73,9
	90	67,5	281,1	23,2	233,8	10,1	91,2	6,6	109,0	1,3	74,3
14	180	123,8	251,8	81,6	205,7	31,9	82,5	33,4	94,2	18,7	50,7
	165	122,7	252,0	80,7	205,9	31,9	79,7	32,9	94,2	18,3	50,0
	150	118,2	254,7	76,5	208,7	29,9	81,8	31,9	95,8	18,0	53,9
	135	120,4	256,2	78,9	209,9	29,1	83,2	31,3	97,1	18,6	53,9
	120	120,0	259,5	78,5	212,5	30,2	84,3	32,4	99,1	17,2	55,0
	105	117,3	272,1	75,5	225,3	29,1	93,0	31,8	107,3	10,1	60,4
	90	118,0	281,0	75,7	231,8	30,1	98,1	29,8	115,2	7,6	66,1

Wind sea direction 255^0											
Swell		Crane w. tension [kN]		Pennant tension [kN]		Sling 1 tension [kN]		Sling 2 tension [kN]		Sling 3 tension [kN]	
T [s]	Dir. [°]	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
8	180	69,4	253,4	25,4	208,9	8,6	91,5	11,3	101,7	4,4	76,1
	165	43,8	358,0	0,4	314,0	0,0	117,5	0,0	160,8	0,0	113,8
	150	40,9	425,1	0,1	369,6	0,0	136,0	0,0	186,6	0,0	138,6
	135	42,4	348,4	0,4	303,2	0,0	97,7	0,0	146,8	0,0	111,9
	120	44,1	379,1	0,5	337,8	0,0	112,5	0,0	164,4	0,0	112,4
	105	33,3	907,8	0,0	844,8	0,0	458,2	0,0	327,4	0,0	231,8
	90	30,2	786,7	0,0	736,8	0,0	441,4	0,0	434,1	0,0	292,5
9	180	80,8	266,4	38,6	220,7	13,9	91,3	19,4	99,1	6,0	66,6
	165	45,1	291,8	0,5	247,6	0,0	99,1	0,0	115,4	0,0	89,6
	150	44,2	342,8	0,5	296,1	0,0	103,7	0,0	155,0	0,0	119,6
	135	48,7	334,4	3,1	291,6	1,0	104,6	1,1	138,3	0,0	110,3
	120	43,7	407,8	0,4	366,1	0,0	119,9	0,0	173,4	0,0	127,5
	105	43,4	706,7	0,0	647,5	0,0	349,9	0,0	330,6	0,0	200,8
	90	32,9	842,7	0,0	811,0	0,0	417,6	0,0	374,5	0,0	268,0
10	180	101,2	285,2	60,3	236,6	19,9	94,2	25,0	105,2	12,9	59,6
	165	112,8	280,4	68,7	233,0	24,3	93,4	25,8	108,9	9,1	65,7
	150	64,2	319,2	18,6	276,9	8,6	100,4	2,4	132,9	0,0	93,7
	135	45,1	410,3	0,5	365,7	0,0	112,6	0,0	170,4	0,0	117,4
	120	43,7	495,8	0,5	451,3	0,0	185,8	0,0	229,0	0,0	154,6
	105	29,6	847,9	0,0	769,1	0,0	360,8	0,0	364,2	0,0	324,4
	90	28,8	1014,0	0,0	934,9	0,0	398,9	0,0	419,4	0,0	420,6
11	180	121,3	261,2	79,5	214,1	23,5	89,1	32,8	99,1	13,8	57,1
	165	122,9	285,2	79,2	239,9	26,7	105,4	28,6	110,7	16,4	59,9
	150	48,6	391,9	3,7	347,3	0,5	186,2	2,8	159,8	0,0	92,5
	135	42,5	428,0	0,4	386,9	0,0	146,6	0,0	197,6	0,0	142,6
	120	31,4	608,2	0,0	546,2	0,0	228,6	0,0	310,8	0,0	309,9
	105	27,0	953,2	0,0	875,6	0,0	323,4	0,0	418,8	0,0	480,1
	90	25,0	1023,3	0,0	969,6	0,0	327,1	0,0	498,5	0,0	578,2
12	180	121,8	256,9	79,8	210,3	29,1	83,9	33,1	95,9	18,5	53,9
	165	116,1	275,8	75,3	229,2	27,2	94,0	31,4	105,8	16,0	57,9
	150	110,6	295,2	68,8	247,4	22,5	105,4	19,9	114,7	0,9	69,3
	135	56,0	311,4	11,5	263,6	4,0	120,5	7,7	133,6	0,0	72,1
	120	41,4	358,2	0,4	311,9	0,0	129,9	0,0	148,2	0,0	94,2
	105	40,0	422,0	0,4	377,5	0,0	149,8	0,0	181,3	0,0	137,9
	90	41,8	437,5	0,4	392,4	0,0	144,1	0,0	202,5	0,0	200,3
13	180	120,4	267,8	78,0	221,1	29,3	86,5	32,1	106,3	18,5	56,2
	165	105,4	282,1	64,1	233,5	25,7	92,7	26,9	107,0	15,6	63,4
	150	121,9	295,5	80,8	246,0	30,2	96,8	33,3	120,9	19,0	62,3
	135	120,7	286,3	78,6	238,3	27,1	98,2	32,1	113,1	14,5	64,2
	120	109,3	297,5	67,4	248,7	23,7	105,7	26,4	111,0	6,4	64,4
	105	82,6	280,8	38,4	233,9	13,0	97,7	15,1	109,0	3,3	73,8
	90	61,4	281,3	17,3	234,1	7,6	90,5	4,3	109,9	1,3	73,6
14	180	127,6	252,4	85,1	206,3	32,8	82,7	36,5	94,4	18,2	50,7
	165	107,2	252,6	65,1	206,3	25,5	79,8	27,6	94,3	15,3	50,1
	150	126,3	255,2	84,5	208,9	31,5	82,0	35,0	96,4	18,0	54,6
	135	119,9	256,9	78,5	210,3	29,9	83,6	33,5	96,6	18,1	54,4
	120	120,3	259,0	78,9	212,1	29,3	84,3	32,0	99,4	13,7	54,6
	105	117,3	268,8	75,3	222,5	30,4	92,0	31,7	110,1	13,2	61,9
	90	117,3	299,5	75,5	253,0	30,3	117,7	30,7	118,0	4,4	70,4