Global Response Analysis for Semisubmersible Offshore Platform

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CONTENT

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ABBREVIATIONS

API	American Petroleum Institute
COG	Centre/s of gravity
DNV	Det Norske Veritas
FE	Finite Element
FEA	Finite Element Analysis
FPSO	Floating Production Storage and Offloading Ship
FSU	Floating Storage Unit
ISO	International Organization for Standardization
LRFD	Load Resistance Factor Design
MODU	Mobile offshore drilling units
OS	Offshore Standard
RAOs	Response Amplitude Operators
RP	Recommended practice
UF	Utilization factor
ULS	Ultimate Limit Strength
US	United States
WSD	Workable Stress Design

ABSTRACT

As we are moving to the deeper and harsher environments in search of oil and gas resources, it has been more challenging to ensure the structural integrity of the offshore platform being capable of withstanding the extreme environmental loading. For such deep and harsh environmental conditions the wave induced loads constitute the major part of overall loading on the offshore structure. Therefore, it is important to quantify wave-induced load effects to ensure a reasonable, safe and robust design of the offshore systems. One of the approaches to accomplish this task is by performing a global response analysis with the extreme hydrodynamic loading on the offshore floating platform.

The main objective of the thesis has been to present a case study of performing a global response analysis for a semisubmersible platform which is one of the common offshore floating structures in the industry. The approach of the case study has been to model a global structural model of the platform and perform the global response analysis with the applied hydrodynamic loading of the waves recommended by the offshore design codes, checking the impact of the wave induced loading on the structural integrity in extreme environmental loading conditions in the critical structural members of pontoon and column sub assembly exposed to the wave loading. The structural response is evaluated in terms of motions response of the platform and stress distribution on terms of element average Von mises stress on to the structural components due to the load effects induced by these environmental loads.
A global structural model of semisubmersible platform consisting of beam and shell finite elements has been used to perform the required global response analysis of the structure. For the structural modeling and analysis of the semisubmersible platform under consideration a standard finite element modeling software named SESAM GeniE has been used. Moreover to perform the hydrodynamic response analysis another software tool, HydroD Wadam has been used which is a general purpose hydrodynamic analysis program based on 3D potential theory for calculation of wave loading and wave induced responses.

To evaluate the wave induced loads for the semisubmersible platform a comparative study regarding the strength analysis concepts following two different design philosophies namely LRFD and WSD methods has also been discussed in this master thesis. This study has been performed by reviewing the different offshore codes & standards requirement for extreme environmental loading by the classification societies like DNV, ISO & API for the offshore floating column stabilized structure.

The results of the analysis have been presented as the motion response of the global structural model and checking for the structural integrity in terms yield utilization or stress distribution of the structural components exposed to wave loading. This allows us to identify the critical highly stressed region for the platform and to suggest about these critical zones requiring further detailed local analysis for the assurance of robust design. Moreover it has been concluded with the analysis performed that among WSD and LRFD methods, which is more conservative design approach for the Ultimate Limit State with application of extreme environmental loading for the case study of semisubmersible platform.

1. INTRODUCTION

1.1 Overview

The Offshore Structures has been playing a vital role to fulfill the increasing demands of fuels and energy in today's world. In Figure 1 the contribution of amount of oil and gas production from offshore fields has been shown along with forecast for coming years. We can comprehend the offshore oil & gas production has roughly doubled in the past few decades.

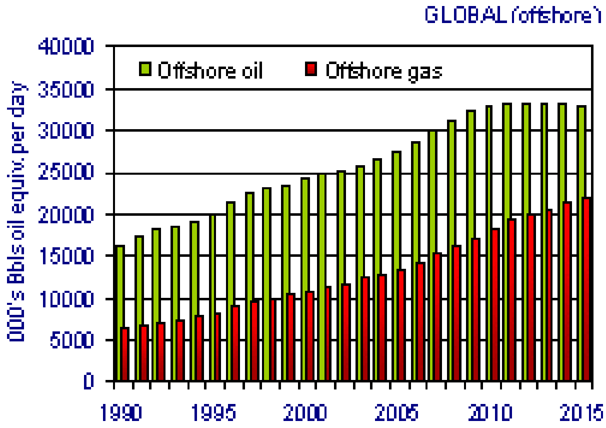


Figure 1 Offshore oil & gas production in 1000'sBpd between 1990 and 2015 (Source: www.marinetalk.com)

Considering the fact that we are moving to deeper and harsher environments in looking for more hydrocarbon resources, the emphasis is on novel and robust design concepts of offshore floating structures from the initial concepts of fixed platforms. In Figure 2 we have shown a data of the number of installed units of established offshore floating structures used for exploration and storage of the oil/gas in recent past. This database signifying the rise in the demand of the offshore floating productions/exploration units have been more than double during 1995 to 2005 and with a trend of further gradual rise.

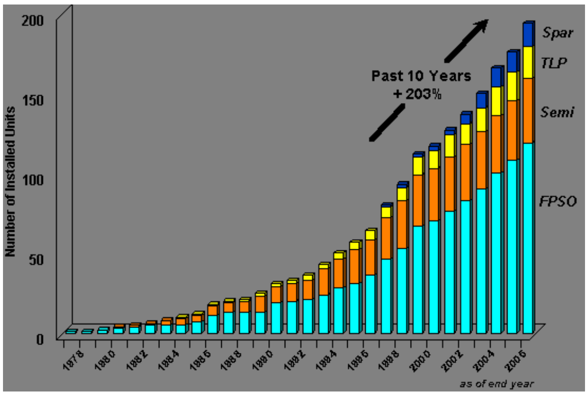


Figure 2 Numbers of Installed Units of Typical Offshore Floating Platforms in between1978-2005 (Source: www.imastudies.com)

Each and every set up facilities for offshore exploration/production has a huge risk involved in terms of health, safety and environmental challenges apart from the enormous amount of economic investment vested into the project. Hence it becomes really important to ensure the structural integrity and successful operation of the offshore structure. To give an idea in Figure 3 we have shown the economic investment for the past decade in the global offshore industry region-wise.

Figure 3 Global Spending in Offshore Industry between the years 2003 to 2012
(Source: www.energyandcapital.com)

However the analysis, design and construction of offshore floating structure is arguably one of the most demanding sets of tasks faced by the engineering profession considering innovations and technologies required to explore and supply oil/gas from deeper harsher environments of oil fields. As we are moving further to the extreme climates in search of oil and gas requirements the environmental loading becomes the major part of the loading on the offshore floating structure used for operations. Therefore, it is important to quantify wave-induced load effects which are one of the key sources of the environmental loading to ensure a reasonable, safe and robust design of the offshore systems. One of the ways to accomplish this task is by performing a global response analysis with the extreme hydrodynamic loading and studying its effects on the structural integrity offshore platform using the tools developed on the theoretical grounds recommended by the classification societies.

The response of the offshore floating structure to these extreme environmental loading and the structural integrity of the offshore floating structure needs to be verified accordingly for each of the failure limit states. One of the key failure modes for the offshore structure is the Ultimate Limit State. For offshore floating structure designed for extreme environmental loads, the global response analysis with hydrodynamic loading with is one of the key preliminary analyses model to verify the structural integrity of the system and locate the critical zones requiring local structural analysis for further detailed investigations.

1.2 Objective

The main objective of the thesis has been to present a case study of performing a global response analysis for a semisubmersible platform which is one of the common offshore floating structures in the industry for exploration/production of offshore oil and gas resources. Using the global analysis performed for a sample semisubmersible structure the motive was to analyze the motion response and quantify the hydrodynamic induced load effects to locate the critical zones requiring local structural analysis for further detailed investigations. The semisubmersible platform under consideration was a typical twin pontoon structure supported with 6 column legs having the length of the structure as 92.3m and the total width being 74.1m.

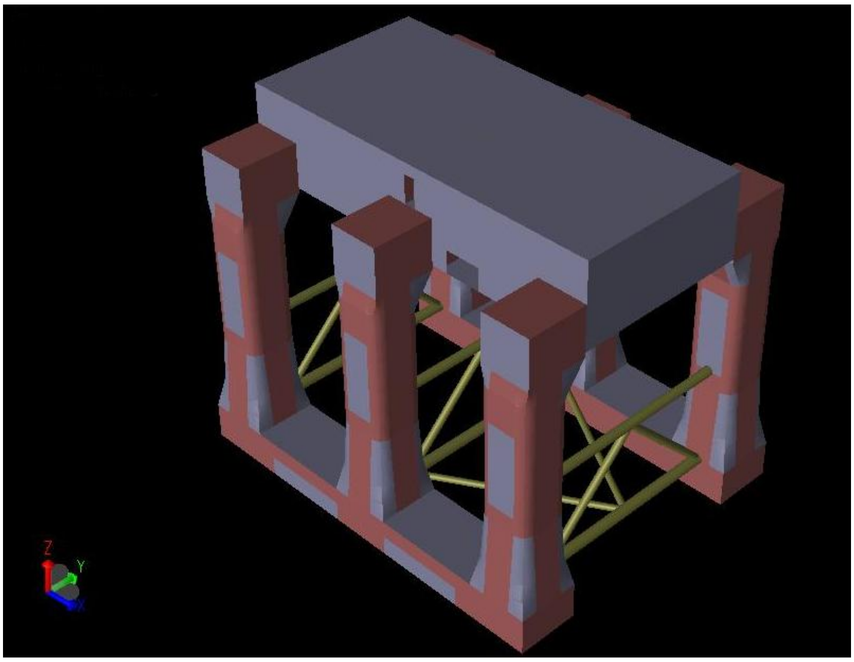


Figure 4 Semisubmersible Structural Model Analysed

The approach of the case study has been to model a global structural model of the semisubmersible platform and perform the global response analysis with the applied hydrodynamic loading of the waves recommended by the offshore design codes.

The extreme environmental wave loading chosen for the case study has been taken for one of the most rough and harsh oilfields locations of central North Sea. The design wave selected was a 100 year return period wave as recommended by the offshore codes and standards for ultimate limit state design for the offshore floating structure. Other components of the environmental loading like currents and wind loading were not included in the current scope of work.

The response of the structure was analyzed for a set of wave frequencies and heading to evaluate the most critical motion behavior and subsequent structural response of the platform. The motion response of the platform was studied in terms of the RAOs of the vessel and analyzing the most critical motion out of the 6 possible degrees of freedom.
With the global response analysis performed in such an extreme environmental condition, the structural response of the semisubmersible platform was analyzed in terms of yield utilization for the structural members due to the wave induced load effects. These checks were performed to investigate for the structural members for which excessive yielding are possible modes of failure with the requirement of the element average von Mises equivalent design stress for plated structures not exceeding the design resistance of the material. The focus was to evaluate the stress distribution in the key sub assemblies of pontoon and column structural components exposed to the environmental loading.

To perform this structural capacity check, the analysis models for two different strength design philosophies namely LRFD (Load Resistance Factor Design) and WSD (Workable Stress Design) has been investigated as recommended by the Offshore Design Codes/Standards for mobile offshore units like semisubmersibles. The key difference between these design approaches has been investigated in the way the safety factor has to be applied to the environmental induced loading on the structure for its robust and optimized design. It was concluded with this study that which of the two design approaches among WSD & LRFD produced more conservative design results in terms of yield utilization of the structural elements for the Ultimate Limit State design with extreme environmental loading.

A composite beam and shell finite element model in terms of the global structural strength model of semisubmersible have been used to perform the required global response analysis of the structure. For the structural modeling and analysis of the semisubmersible platform under consideration a standard finite element modeling software program named SESAM GeniE developed by DNV has been used. Moreover to perform the hydrodynamic response analysis part, another in house DNV Software tool SESAM HydroD: Wadam package has been used. It is a general purpose hydrodynamic analysis program based on 3D potential theory for calculation of wave loading and wave induced responses of fixed and floating marine structures with zero or low forward speed. The global motion response of the structure was analyzed using a post-processing program named POSTRESP and for the analyzing the hydrodynamic effects a software tool named XTRACT was used.

1.3 Thesis Organisation

This master thesis report has been composed of nine section and a references section. After this introductory chapter, Chapter 2 presents a brief overview of the offshore structures, different types of offshore structures, their basis of applications and operation. In chapter 3 the description about the Semisubmersible platform which is the offshore floating structure used as a case study for the current master thesis has been given. It contains a brief overview, classification and characteristic features of the semisubmersible platform. Chapter 4 discusses all the relevant offshore design codes criteria and recommendations that have been used as design guideline to perform the required global response analysis of the platform. It also briefly describes the concept of safety factor and its usage in global structural design. The two major design approaches suggested for offshore floating structure design, namely WSD and LRFD. Chapter 5 briefs the analysis methodology and the software tools used to perform the analysis work. Chapter 6 presents the global structural modeling of the semisubmersible platform studied in detail. It discusses about the key sub-assemblies of the platform modeled as finite element model to perform the subsequent analysis.

Chapter 7 discusses about the characteristic hydrodynamic and structural response that are expected for the global response analysis of semisubmersible platform. Moreover a detailed overview of hydrodynamic analysis set up for the platform and subsequent global motion response that has been mentioned for the given set of extreme environmental loading conditions. The final section of this chapter describes the quasi-static structural analysis performed to quantify the wave induced load effect in the structural elements of the semisubmersible platform.

Chapter 8 has been used to present the calculation and results of the global response analysis in terms of the yield utilization of structural components of the semi submersible platform.

Chapter 9 discusses about the salient conclusion that could be made from the current set of global response analysis performed and also presents some of the recommendations for future set of work on the topic. Following chapter 9 all the references that has to useful to compile the current piece of work has been listed in the Reference. An additional chapter of appendix has been added summing up the some key analysis run and output files from the global response analysis performed.

2. OFFSHORE STRUCTURES: BRIEF DESCRIPTION

Humankind has become highly dependent upon large quantities of fuel for their everyday's need from transportation of goods and people, operating machinery, to electricity needs and more. As the population increases exponentially and demands for inexpensive energy solutions continue to rise, the readily available reservoirs of energy rich fossil fuels have rapidly declined. In order to meet these demands, fossil fuel exploration and production is forced into more and more inhospitable conditions such as the extreme deep sea. The expenses associated with fixed production platforms at this depth are no longer within a feasible range making a floating production platform design a far more economical choice. The development of the offshore industry started with the use of fixed structures. As development accelerated with the discovery of oil and gas in deeper waters, the use of floating structures became commonplace. The Figure 5 shown below gives a typical overview about different types of structures used in the offshore Industry

Figure 5 Types of Offshore oil and gas structures (from left to right) : 1, 2) conventional fixed platforms 3) compliant tower (4, 5) vertically moored tension leg and mini-tension leg platform 6) Spar (7,8) Semisubmersibles 9) Floating production, storage, and offloading facility; 10) sub-sea completion and tie-back to host facility (Source:www.oceanexplorer.noaa.gov)

2.1. Factors Governing Selection of the Offshore Structures

Typically, the offshore production/exploration facilities to be selected have to be matched to the field requirements so it is necessary to examine some of the characteristics that influence concept selection of platform. The main factors of selecting an offshore structure at a particular reservoir fields are as follows

- production volumes
- environment loading
- water depth (influences fixed versus floating, mooring and riser systems selection)
- distance to shore or infrastructure (pipeline or tanker off loading)
- the number of drilling centers required to drain the reservoir
- reservoir fluid
- the well intervention (work-over) frequency
- risk to personnel

Steel braced jacket structures are by far the most common production platforms. However, as developments moved to deeper waters we had to consider the following points:

- The cost associated with jacket type platforms
- The floating structure offers earlier oil production.
- The floater offers a lower risk solution when the nature of the field is uncertain.
- The floater may provide oil storage

As discussed below the floating platforms have both advantages and disadvantages in these various roles. For instance:

- One of the advantages of using floating platforms is that the well testing phase can be extended and overlapped with the production phase, in order to obtain a better idea of the long term production rates without committing to the large risk of a field specific platform.
- A disadvantage is that many types of floating platform move too much in larger waves so that drilling or production operations may have to be suspended during storms.

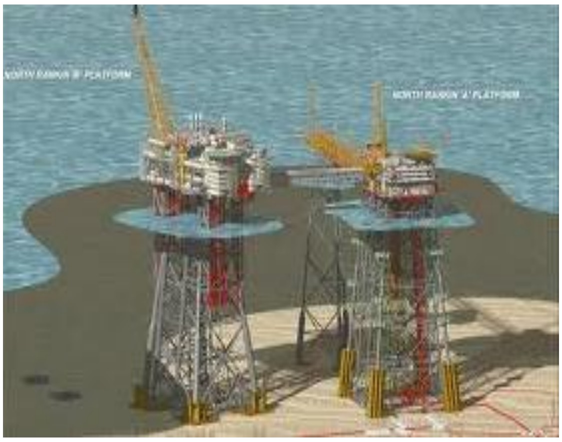
Considering the points mentioned above, depending upon the field requirement and environmental conditions the offshore platform is selected.

2.2. Common Types of Offshore Structures

The most common platforms used in today's offshore industry have been described briefly with their key features in the section below.

Jacket platforms are built on steel legs anchored directly onto the seabed, supporting a deck with space for drilling rigs, production facilities and crew quarters. These platforms are preferable to floating production systems for large fields in small-medium water depths. The long term lower operating costs and probably better reliability compensate for the possibly greater initial costs and time to first oil. However for deep water (greater than about 150 m) or more marginal fields (field life less than 10years) these fixed platforms are not economical. Where no oil storage is required then the fixed platform may be a jacket type. When oil storage is required then a gravity platform or jacket plus FSU may be used. As the water depth increases a stiff jacket structure with natural surge periods less than 3-4 seconds becomes difficult to design and it becomes better to place the surge periods at greater than about 30 seconds to avoid the large amounts of wave energy between 10 and 25 seconds.

A Gravity Based Structure can either be steel or concrete and is usually anchored directly onto the seabed. Steel GBS are predominantly used when there is no or limited availability of crane barges to install a conventional fixed offshore platform, for example in the Caspian Sea. There are several steel GBS in the world today (e.g. offshore Turkmenistan Waters (Caspian Sea) and offshore New Zealand). Steel GBS do not usually provide hydrocarbon storage capability. These structures are generally feasible in shallow water depth till 100 m although the deepest GBS being used at Troll field in Norway at water depth of 303 m.



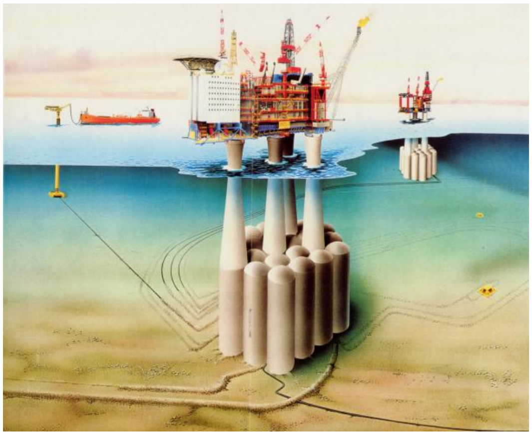


Figure 6 Jacket Fixed Platform (Left: Steel Jacket type Rankin Platforms, Source: www.project.connect.com.au), Gravity-based structure (Right, Source: Prof: Tadeusz Graczyk Lectures at ZUT)

Compliant tower are platforms that consist of slender flexible towers and a pile foundation supporting a conventional deck for drilling and production operations. It is most suited to a field requiring a high number of wells drilled from one location. However, due to long development schedule and the fact that the wells must be drilled sequentially from the compliant tower to capitalize on its capabilities, there tends to be a long period between the capital investment and the revenue which may hurt the field economics. Compliant towers work best at intermediate water depths, 400-700 meters where the steel weight is still not too high and installation is somewhat easier. Since they have no storage capability, they are most likely to be economic when a relatively short pipeline connection to export route is possible

Semisubmersibles are a common type of floating structure used in the exploration and production of offshore hydrocarbons. These platforms have hulls of sufficient buoyancy to cause the structure to float, but the structural/equipment weight of the platform and the mooring system keeps the structure upright. Typically, four to eight vertical, surface piercing columns are connected to these pontoons. The columns themselves may have cross and horizontal bracing to provide structural strength and triangulated rigidity for the platform. The minimal water plane area contributed by the vertical columns results in long heave, pitch and roll natural periods and the hydrodynamic loading can be minimised at the dominant wave period by careful selection of pontoon volume and water plane area. These features lead to good response characteristics in typical operating weather conditions. Semisubmersibles can be used in water depths from 200 to 12,000 feet. A more detailed description of this type of offshore platforms has been discussed in the Chapter 3 of this thesis.

Figure 7 Compliant Tower (Left, Source: www.budowle.pl), Semisubmersible (Right: www.gazprom.com)

Jack up is an offshore drilling structure that is self-elevating with the legs which are stationed on ocean floor and the drilling equipment is jacked up above the water's surface. Providing a very stable drilling environment, in comparison to other offshore drilling rigs, jackups can drill in waters up to 400-500 feet deep. They are designed to move and then anchor by deploying the legs to the seabed using a rack and pinion gear system on each leg.

A drillship is a marine vessel that's been modified to drill oil and gas wells. While drillships look similar to a tanker or cargo vessel, there are a couple of major differences. Drillships are equipped with a drilling derrick and moon pool. It is most often used for exploratory drilling of new oil or gas wells in deep water but can also be used for scientific drilling. Most drillship is outfitted with a dynamic positioning system to maintain position over the well. They can drill in water depths up to 12,000 ft Drillships are used predominantly in areas with long periods of calm weather due to their poor heave response characteristics.

The spars are floating platforms that can support drilling, production and storage operations consisting of a large vertical cylinder bearing topsides with equipment. The spar has more inherent stability since it has a large counterweight at the bottom and does not depend on the mooring to hold it upright. It also has the ability, by adjusting the mooring line tensions, to move horizontally and to position itself over wells at some distance from the main platform location. . The first production spar was Kerr-McGee's Neptune, anchored in 1,930 ft (590 m) in the Gulf of Mexico; however, spars were previously used as FSOs.

Figure 8 Jack-up drilling rigs (Left, Source: www.worldmaritimenews.com), Drill ships (Middle, Source: www.dft.gov.uk), Spar Platform (Right, Source: www.marineinsight.com)

Floating Production Storage and Offloading vessels, or FPSOs, are offshore production facilities that house both processing equipment and storage for produced hydrocarbons. The basic design of most FPSOs encompasses a ship-shaped vessel, with processing equipment, or topsides, aboard the vessel's deck and hydrocarbon storage below in the double hull. After processing, an FPSO stores oil or gas before offloading periodically to shuttle tankers or transmitting processed petroleum via pipelines. These platforms are moored to a location for extended periods, and do not actually drill for oil or gas. Some variants of these applications, called FSO (floating storage and offloading system) or FSU (floating storage unit), are used exclusively for storage purposes. However, as a result of its large displaced volume close to the waterline, the wave induced response of these structures is quite significant. Therefore, the station keeping and dependent systems such as risers must be designed to accommodate these motions. The riser systems therefore need to be flexible. However, the recent advances in flexible riser technology have permitted ship-shaped vessels to be used as production platforms even in harsh environments in recent years.

TLPs are floating platforms tethered to the seabed in a manner that eliminates most vertical movements of the structure. TLPs are used in water depths up to about 6,000 feet (2,000 m). The conventional TLP is a 4-column design which looks similar to a semisubmersible. TLP’s have sensitivity to payload through its effect on tether tensions. Excessive deck load may result in slack tether conditions in large waves. They are therefore not used for oil storage.

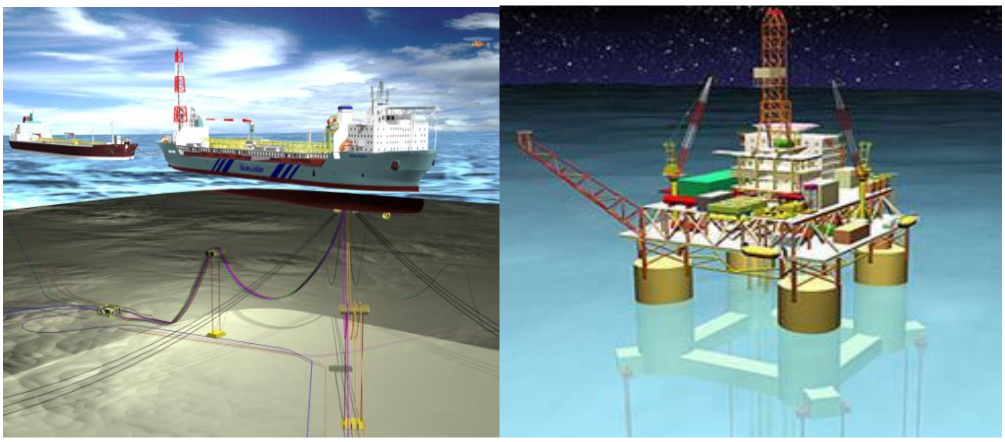


Figure 9 FPSO’s Vessel (Left, Source: www.bluewater.com),TLP Platform (Right, Source: www.rigzone.com)

3. DESCRIPTION OF STRUCTURE ANALYSED: SEMI SUBMERSIBLE

3.1. Introduction

As introduced in the previous section semisubmersible is a specialized marine vessel used in a number of specific offshore roles such as offshore drilling rigs, safety vessels, oil production platforms, and heavy lift cranes. Although the most common role for the structure is as a MODU designed with a platform-type deck that contains drilling equipment and other machinery supported by pontoon-type columns that are submerged into the water. They are one of the most stable types of floating rig, chosen for harsh conditions because of their ability to withstand rough waters. Its deep draft enable waves to pass through the unit with minimal energy without exciting it to excessive roll, pitch, sway, surge, heave, and yaw. With the work deck above the wave crests and the factors listed above, this design is a very capable work platform in severe environments. During the design of a semi, hull motion analysis in relation to waves crashing into the upper deck is critical. In addition, heave, roll, pitch, sway, yaw, and surge need to be analyzed in terms of the upper limits of motion in which crews and equipment can operate.

3.1.1 Evolution of Semisubmersibles

The semisubmersible design was first developed for offshore drilling activities dated way back in the 1950's. Mr. Bruce G. Collip, a naval architect working for Shell USA is regarded as the inventor of the initial semisubmersible drilling rig design, with co-workers Ronald Geer and Douwe Devries. During their service with Shell oil, the first semisubmersible rig Bluewater I was converted from existing 4 columns submersible in 1961 for operation in the Gulf of Mexico. It paved the way for the creation of a new generation of mobile drilling vessels capable of operating in deeper and deeper waters.

Figure 10 BluewaterI: First Semisubmersible (Source: www.fng.com)

3.1.2 Classification and Applications

One of the bases of classification of the semisubmersible rigs is based on the year of built and the operating water depth capability of the platform. As discussed in the section above the first generation of the semisubmersible rigs was developed in the early 1960's with operating water depth capacity of about 200 meters. With the evolution of the design concept and technical development, mankind has been able to produce seventh generation drilling rig facility that could be used in ultra deep operating water depth of around 4000m.

Figure 11 Frigstad Deepwater Rig 1 7th Generation semisubmersible drilling unit (Source: www.offshore.frigstad.com)

Based on another parameter of the way the platform is submerged in the water, there are two main types of semisubmersibles:

- bottle-type semisubmersibles
- column-stabilized semisubmersibles

Bottle-type semisubmersibles consist of bottle-shaped hulls below the drilling deck that can be submerged by filling the hulls with water. The first incarnation of this type of drilling rig, bottle-type semisubmersibles originally were conceived as submersible rigs. As a submersible, the bottles below the rig were completely submerged, resting on the ocean floor. But, as time progressed, naval architects realized that the rig would maintain its stabilization if the bottles were only partially submerged, but be able to drill in deeper waters. Mooring lines are then used to keep the semisubmersible in place, and these anchors are the only connection the rig has with the sea floor. Eventually, these bottle-type rigs were designed to only serve as semisubmersibles.

As a semisubmersible, the rig offered exceptional stability for drilling operations, and rolling and pitching from waves and wind was great diminished. In addition to occasional weather threats, such as storms, cyclones or hurricanes, some drilling locations are always harsh with constant rough waters. Being able to drill in deeper and rougher waters, semisubmersibles opened up a new avenue for exploration and development operations.

A more popular design for semisubmersible rigs is the column-stabilized semisubmersible. Here, two horizontal hulls are connected via cylindrical or rectangular columns to the drilling deck above the water. Smaller diagonal columns are used to support the structure. Submerging this type of semisubmersible is achieved by partially filling the horizontal hulls with water until the rig has submerged to the desired depth. Mooring lines anchor the rig above the well, and dynamic positioning can help to keep the semi sub on location, as well. Further the column stabilized semisubmersible units design can be classified as follows

- Ring Pontoon Semisubmersibles: Ring pontoon designs normally have one continuous lower hull (pontoons and nodes) supporting 4-8 vertical columns. The vertical columns are supporting the upper hull (deck).
- Twin Pontoon Semisubmersibles: Twin pontoon designs normally have two lower hulls (pontoons), each supporting 2-4 vertical columns. The 4-8 vertical columns are supporting the upper hull (deck). In addition it may be strengthened with diagonal braces supporting the deck and horizontal braces connecting the pontoons or columns.

Figure 12 Column Stabilized Semisubmersibles (Left: Ring Pontoon Design, Right: Twin Pontoon Design, Source: Petrowiki)

Although the major application of the semisubmersibles structures is as MODUs for drilling for offshore oil and gas, they are also used for other key functions across the offshore industries in the form of Semisubmersible crane vessels (SSCV), offshore support vessels (OSV), offshore production platforms.

3.1.3 Mooring and Transportation Operations

Semisubmersible platforms can be moved from place to place; can be ballasted up or down by altering the amount of flooding in buoyancy tanks; they are generally anchored by combinations of chain, wire rope or polyester rope, or both, though they can also be kept in place by the use of dynamic positioning. There are basically two ways of keeping the unit in position, the first being mooring by anchor lines (passive mooring system) and the second as dynamic positioning by thrusters (active mooring system).A combination of these methods is also utilized in some applications. Passive mooring system uses to multiple anchors and a number of spread mooring patterns are used to keep the floating rig in place including symmetric six-line, symmetric eight-line, symmetric twelve-line etc. These mooring spreads are chosen depending on the shape of the vessel being moored and the sea conditions in which it will be moored. However for the semisubmersibles platforms operating in deeper water depths a Dynamic Positioning (DP) system are generally economical, especially for very long wells and development projects.

Since semisubmersibles can float on the top of the water, transporting these rigs from location to location is made easier. Some semis are transported via outside vessels, such as tugs or barges, and some have their own propulsion method for transport.

Figure 13 Left: Spread Mooring System of platform (Source: Offshore Technology), Right: One of the modes of Semisubmersible Platform Transportation, (Source: Dockwise)

3.2. Semisubmersible Platform Analyzed

In the current piece of work a simplified model of a twin pontoon column stabilized semisubmersible with 6 sets of columns legs and cross-bracing connecting the legs semi submersible has been chosen to perform the set of global response analysis. It has three decks at different heights; the weather deck is at the top, the intermediate deck is the middle and the main deck is the lowest. In Figure 14 the graphical view of a similar existing model of the semisubmersible platform have been shown

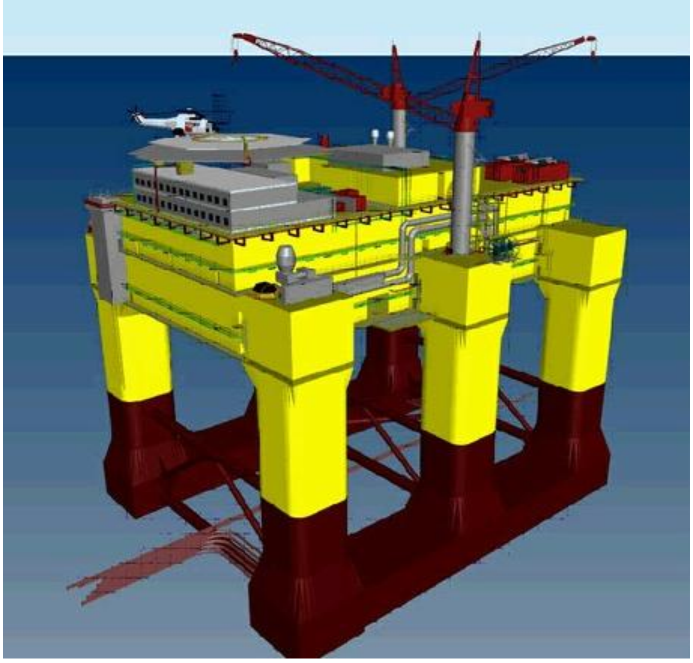


Figure 14 Similar Semisubmersible Platform Model (Source: Aibel)

The platform main technical dimensions are listed below in Table 1

Table 1 Main Dimensional Parameter for Semisubmersible Analyzed

Parameters	**Technical data**
Length of pontoon	92.3m
Height of pontoon	8.45m
Width of pontoon	14.3m
Height (Deck Structures)	19.5m
Height of each Column Leg	52.5 m
Overall Width of the Structure	74.1m

The characteristic length of the structure is been defined as the distance between the longitudinal end points of the pontoon i.e. 92.3 m

4. OFFSHORE STANDARDS AND SAFETY FACTOR CONCEPT

4.1 Design Codes

Offshore codes/standards are the reference documents that provide requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose to serve the offshore industry.

There are many of the organizations which provide these codes and standards for different processes like design, manufacturing, operation, installation, transportation and decommissioning services, namely API (American Institute of Petroleum), DNV (Det Norske Veritas), ISO (International Standard Organization) and NORSOK (Norwegian Standard).

DNV is an autonomous and independent foundation with the objectives of safeguarding life, property and the environment, at sea and onshore. DNV undertakes classification, certification, and other verification and consultancy services relating to quality of ships, offshore units and installations, and onshore industries worldwide, and carries out research in relation to these functions.

DNV Offshore Codes consist of a three level hierarchy of documents:

- Offshore Service Specifications: Provide principles and procedures of DNV classification, certification, and verification and consultancy services.
- Offshore Standards: Provide technical provisions and acceptance criteria for general use by the offshore industry as well as the technical basis for DNV offshore services.
- Recommended Practices: Provide proven technology and sound engineering practice as well as guidance for the higher level Offshore Service Specifications and Offshore Standards.

ISO (International Organization for Standardization) is the world's largest developer of voluntary International Standards. ISO gives state of the art specifications for products, services and good practice, helping to make industry more efficient and effective.

API codes are written by the American Petroleum Institute. API is the largest US trade association for the oil and natural gas industry

The Norsok standards are developed by the Norwegian petroleum industry to ensure adequate safety, value adding and cost effectiveness for petroleum industry developments and operations. Furthermore, Norsok standards are as far as possible intended to replace oil company specifications and serve as references in the authorities' regulations.

In the current piece of work, we have concentrated on the Mobile Offshore Drilling platforms like semisubmersibles; hence we have referred to the offshore standards and codes primarily meant for such offshore floating platforms.

In the following section we have discussed about some of the Offshore Codes/Standards which have been a key source of references for the development of this project.

Table 2 Main Design Codes

Number	**Revisions**	**Title**
DNV-OS-C101	April 2011	Design of offshore steel structures (LRFD method)
DNV-OS-C103	October 2012	Structural design of column stabilized units (LRFD method)
DNV-OS-C201	October 2010	Structural design of offshore units(WSD method)
DNV-RP-C103	April 2012	Column-stabilized units
DNV-RP-C205	October 2010	Environmental conditions and environmental loads
ISO19904_1	First edition 2006-11-01	Petroleum and natural gas industries Floating offshore structures – Part 1: Monohulls, Semisubmersibles and Spars
ISO19902	First edition 2007-12-01	Petroleum and natural gas industries – Fixed steel offshore structures
ISO19901	First edition 2005-11-15	Petroleum and natural gas industries -Met ocean design and operating considerations
API RP 2A-WSD	21st edition (2000)	Planning, designing and constructing Fixed offshore platforms-Working Stress Design.
API RP 2FPS	2nd edition (2011).	Planning, designing, and constructing Floating Production Systems.
NORSOK -N-001	Edition 8, September 2012	Integrity of offshore structures
NORSOK -N-003	Edition 2, September 2007	Actions and action effects

4.2 Safety Factor Concept: Theoretical Background

To study the global response analysis and impact of the hydrodynamic loading the key point concluded from the comparative study of the above mentioned standards was found out to be the way the standard recommended the usage of strength design philosophies for the offshore platform units. Basically the codes worked around two different strength design philosophies namely, the WSD (Workable Stress Design) or the LRFD (Load Resistance Factor Design) methods. In the section following we have discussed the way these two methodologies differ in applying the safety factor to hydrodynamic wave loading induced from the global response analysis in extreme environmental conditions for the Ultimate Limit State of the structure. However, prior to that description the concept of safety factor has been presented.

As we know every structure has a non-zero probability of failure. It can be measured on an annual basis or may be related to particular operations. The probability of failure though may vary through the life of the structure. It is also not possible to design a structure to eliminate this probability of failure. One important objective of design is to reduce the probability of failure to an acceptable level. The concept of safety factors in design is one of the most important considerations for a strength analysis of a structure.
Simply once the mode of failure of a structure is understood, the greater the safety factors the smaller the probability of failure but on the other hand the greater the safety factor, the greater the cost of producing the structure. Hence the fundamental need for optimization between cost and safety is required. Identifying this need for optimization, safety factors have been modified over the years primarily by trial and error. Also as greater physical understanding led to increased confidence in the performance of structures, safety factors changed to account for the better knowledge. Major catastrophes provided data on the performance limits of the designs which again helped refine the safety factors. Indeed, the safety factor approach is the basis for most codes, guidelines, recommended practices and regulations applied not only to offshore structures but also every other sphere of structural design

.

Early codes tended to put the safety factor on the material strength, so leading to the concept of working or allowable stress design (WSD). An alternative was to put the safety factor on the loads. Since the 1950s a considerable amount of work has been directed towards the rational derivation of safety factors.

This has demonstrated that the most sensible approach is to apply a load factor, essentially to account for the uncertainty in the load and a material factor to account for the uncertainty in the strength. These methods are known as load and resistance factor design (LRFD) or partial safety factor methods (PSF). Current designs tend to use the traditional WSD or LRFD approaches but with additional probabilistic analysis techniques to assist in optimization and to achieve uniform safety levels.
It was studied that main difference between the various Offshore Codes/Standards has been observed based on the approach for the safety factor that is used. The DNV and ISO standards advocates LRFD approach for column stabilized semisubmersible platform however they also have standards and codes which provide guidance for WSD approach as alternative.

It was also noted that the NORSOK N-004 (Design of steel structures) does not include special design provisions for Semisubmersibles as an Offshore Platform considered here in this initial research as case study for strength analysis, as it does for other types of floaters. However, the generic action and material factors recommended for steel structures in the N-001 is identical with those given in the ISO requirements.

It is still generally impossible to precisely quantify reliability so it is usual to calibrate the safety factors against experience with existing designs. It is argued that this leads to LRFD/PSF designs having a more uniform level of reliability across structure types and loading regimes than would be obtained from a structure designed using WSD allowable stresses. As noted in this report, even in Limit State Design philosophy, the load/action factors and resistance factors ensure the safety of the structure under extreme environmental conditions. It should also be noted that the LRFD method allows yielding to be reached or exceeded in such a way that the structure is still capable of resisting further loads but may encounter high levels of deformation without reaching an unstable mechanism.

However we would keep our design interest for this study primarily on the concept of safety factors and WSD/LFRD approach defined by the various codes/standards of DNV, API, ISO and Norsok applicable for semisubmersible global response in ultimate limit state with extreme environmental loading. The mathematical approach to the WSD & LRFD method applicable has been discussed in the following section below.

4.3 Limit State and Safety Factors by Offshore standards

A limit state refers to a state of loading condition of a structure beyond which it no longer fulfills the relevant design criteria for structural integrity, fitness for use, durability or other design requirements for a structure under consideration.The general standard, applicable to all offshore structures, requires that the structural design be performed with reference to a specified set of limit states. For each limit state, design situations are required to be determined and an appropriate calculation model be established. DNV OS-C 101 based on general LRFD design concept divides the limit states into four categories:

- Ultimate limit states (ULS)
- Serviceability limit state (SLS)
- Fatigue limit states (FLS)
- Accidental limit states (ALS)

On similar analogy the standard DNV OS –C201 based on the WSD design concepts requires the analysis check for the structural members of an offshore column stabilized platform for the following loading conditions

- functional loads
- maximum combination of environmental loads and associated functional loads
- accidental loads and associated functional loads
- annual most probable value of environmental loads and associated functional loads after credible failures, or after accidental events
- annual most probable value of environmental loads and associated functional loads in a heeled condition corresponding to accidental flooding

In the current scope of work we have limited our investigation to the ultimate limit state with extreme environmental loading as per the LRFD or maximum combination of environmental loads associated with functional loads as per the WSD concept which has been taken as synonymous description of the loading scenario. It should be noted that the considered loading has been referred generally as ultimate limit state with extreme environmental loading scenario or ULS-b in the thesis work. However various simplifications for this design state have been assumed to limit the scope of work and focus on the objective of analyzing the case study of the extreme wave induced load effects on the semisubmersible platform as presented later in Chapter 7 of the thesis.

As per the design standard for offshore structures DNV OS C 101 the example of the ultimate limit state can be given as

- loss of structural resistance in terms of excessive yielding and buckling
- failure of components due to brittle fracture
- loss of static equilibrium of the structure, or of a part of the structure
- failure of critical components caused by exceeding the ultimate resistance in cases reduced by repeated loads or the ultimate deformation of the components
- transformation of the structure into a mechanism of collapse or excessive deformation

In the present case one of the above mentioned example of the ultimate limit state has been studied by evaluating an approximate value of the yield utilization (for excessive yield check) and stress distribution of the structural components constituting the global structural model for the semisubmersible platform due to the extreme environmental loading applied. As discussed in the section below the safety level in LRFD design concepts primarily depends on two key factors, one being the load factor for the applied load effect and other related to material resistance property. The load factors for the applied loading effects accounts for the following

- Possible unfavorable deviations of the loads from the characteristic values
- The reduced probability that various loads acting together will act simultaneously at their characteristic value
- Uncertainties in the model and analysis used for determination of load effects.

The material factor based on the material resistance property of the structure accounts for

- possible unfavorable deviations in the resistance of materials from the values
- possible reduced resistance of the materials in the structure, as a whole, as compared with the characteristic values deduced from test specimens

However in the WSD format the safety level is achieved by taking a combined effect of the load and material factors of the structural member in terms of usage factors. On similar grounds the usage factors accounts for

- Possible unfavourable deviations of the loads
- The reduced probability that various loads acting together will act simultaneously
- Uncertainties in the model and analysis used for determination of load effects
- Possibleunfavourable deviations in the resistance of materials
- Possible reduced resistance of the materials in the structure, as a whole, as compared with the valuesdeduced from test specimen

4.3.1 Load and resistance factor design format (LRFD)

The utilization of LRFD/Limit States Design allows the allocation of different safety factors to the different types of loadings depending on the degree of uncertainty associated with each type of loading. This method is advantageous considering the account of variability in the load and resistance, uniform level of safety and risk assessment based on theory. However one of the limitations of this method being it requires availability of statistical data. The level of safety of a structural element is considered to be satisfactory if the design load effect (S_d) does not exceed the design resistance (R_d). The equation: $S_d = R_d$, defines a limit.

$$S_d <= R_d \tag{1}$$

A design load is obtained by multiplying the characteristic load by a given load factor

$$F_d = \gamma_f F_k \tag{2}$$

A design load effect is the most unfavorable combined load effect derived from the design loads, and can be expressed by one single quantity as:

$$S_d = q(F_{d1},....,F_{dn}) \tag{3}$$

If the relationship between the load and the load effect is linear, the design load effect may be determined by multiplying the characteristic load effects by the corresponding load factors:

$$S_d = \sum_{i=1}^{n} (\gamma_{fi} S_{di}) \tag{4}$$

The design resistance (R_d) is determined as follows:

$$R_d = \varphi R_k \tag{5}$$

The resistance factor relate to the material factor γ_M can be mathematically given as:

$$\Phi = 1/\gamma_M \tag{6}$$

However for a typical value of the material factor for general steel structures is about 1.15.
In Table 3, load factors (γ_f) applicable to the Ultimate Limit State and for each combination of action categories to be considered in a design check.

Table 3 Load factors (γf) the Ultimate Limit State (Source: DNV OS -101 TableD1)

Combination of design loads	**Load Categories**		
	G	Q	E
ULS a	1.3	1.3	0.7
ULS b	1.0	1.0	1.3
G= Permanent Loadings Q= Variable Functional Loads E= Environmental Loads			

4.3.2 Working stress design format

The Working/Allowable Stress Design (WSD/ASD) methodology combines all load types with a single safety factor applied on the calculated combined stress. The advantage of using this method is its simplistic application. However there are some limitations for application of this method, for e.g. inadequate account of variability, stress not being a good measure of resistance, safety factor being subjective, no risk assessment based on reliability theory.

The WSD format is an approach whereby a design value of combined action effects is directly compared with the corresponding design value of strength. In Table 4, the action combination factors applicable to the WSD format are listed for ULS and for each combination of action categories to be considered in a design check.

Table 4 WSD Action Effects (γ_f) the Ultimate Limit State (Source: ISO 19904_1 Table 5)

Limit state	**Action combination factor**		
	Action category		
	G	Q	E
ULS a	1.0	1.0	-
ULS b	1.0	1.0	1.0
G= Permanent Loadings Q= Variable Functional Loads E= Environmental Loads			

In WSD the target component safety level is achieved by comparing the calculated stress for different loading conditions with maximum permissible stress defined by multiplication of the characteristic strength or capacity of the structural member with permissible usage factors.

The permissible usage factors are a function of loading condition, failure mode and importance of strength member. The basic permissible usage factor for different loading conditions has been given in the Table 5

Table 5 Usage factors (η_0) for ULS loading condition (Source: DNV OS C-201 TableE1)

Loading Conditions	a)	b)
Usage factor	0.60	0.80
a) functional loads = Equivalent to ULS (a) *b)* maximum combination of environmental loads and associated functional loads= Equivalent to ULS (b)		

5. ANALYSIS METHODOLOGY & SOFTWARE PROGRAMS USED

5.1 Analysis Methodology

Keeping in mind the key points from the study of the codes and standards mentioned in the prior section, the focus of this section of the work has been defining the approach for the global strength analysis of the platform. As discussed, primarily when we mention about strength analysis we would be concentrating on the global structural analysis in terms of yield utilization of global structural model with the application hydrodynamic loading from extreme environmental condition. We could say that the global performance and strength analysis of a semisubmersible platform is a complex task, with requirements to analyze several loading conditions representing the most unfavorable realistic load combinations. In the analysis we have assumed several simplifications that have been made in order to limit the scope of work to a manageable level within available resources. For the current analysis we have investigated the structure with one set of extreme environmental loading condition. By one set of environmental loading condition we mean that we would be applying one set of wave approaching from different directions on our structure and analyze the pressure load generated by the loading in different sections of the structure. Here a 100 year return period wave with certain wave height, time period recommended by the offshore standards as extreme environmental loading [Ref: Chapter 7.2] has been applied to obtain various set of pressure loading on the structure which would be further used in the quasi-structural analysis.

The approach has been discussed in detail in Chapter 7 of the report. Moreover, we would be focusing on the main structures of the semisubmersible i.e. pontoon, column and deck. The other components of the structure such as the bracing, derrick and other topsides details are the aspects of the structural design related to local design and fatigue strength has not been discussed in the current scope of work.

As discussed we have approached the analysis in two major parts as mentioned follows:

- Hydrodynamic Analysis: For calculating the wave load and platform response analysis. The main output for this part of analysis would be to calculate the RAOs for the semisubmersible platform and the wave pressure loads in long crested wave
- Global Structural Analysis: Analyzing the global strength of the platform. The main output from this analysis would be to verify the global strength of the structure with respect to the yielding utilization factors

5.2 Software Program Used

The software program used to perform the sets of analysis defined in the methodology section has been SESAM which is a complete strength assessment system for engineering of ships, offshore structures and risers based on the finite element methodology, developed by DNV. This software program has various modules suiting different analysis requirements however for the current study of global response analysis of the semisubmersible the following modules used has been selected.

5.2.1 Sesam Genie

For the structural modeling and analysis of semisubmersible platform under consideration a standard finite element modeling software program package GeniE has been selected.
GeniE is a tool for designing and analyzing, the offshore and maritime structures made of beams/shells. Modeling, analysis and results processing are performed in the same graphical user environment. The feature of concept technology makes the Sesam GeniE software highly efficient for integrating stability, loading, strength assessment and CAD exchanges.
Sesam GeniE is software for modeling of floating offshore structure like semisubmersible platforms as it allows efficient modeling of the key components that are required for modeling in terms of plates, stiffeners, volume to impart buoyancy, compartment to carry liquid or solid ballast etc. For floating structures, the Sesam GeniE software can also perform static and dynamic linear analysis for structures subjected to wave, wind, current, and ballast and equipment layout.
Genie also has the feature to check the code compliance for the plate and beam structure. Code compliance of beams may be performed according to API, Norsok or Euro code. The results may be reported graphically or by using standard report layouts. Similarly, for plated structures (stiffened as well as un-stiffened) they may be checked against recommended rules like DNV (RP C201.1) and API.

5.2.2 Sesam HydroD-Wadam

The Sesam HydroD software is a tool for hydrostatic and hydrodynamic analysis which includes the capability of analyzing a hydrodynamic model of the floating structure like semisubmersible platform. The possibility of importing the FEA model to generate the different sub assemblies of the model is very convenient and time saving feature allowed by HydroD program. This feature has been used in the current set of hydrodynamic analysis performed for the semisubmersible platform by using the FEA model generated in GeniE package.

For the hydrodynamic part of analysis a sub module included in the HydroD package named as Wadam has been used. Wadam is a general purpose hydrodynamic analysis program for calculation of wave loading and wave induced responses of fixed and floating marine structures with zero or low forward speed. These analyses in Wadam are normally performed in the frequency domain, but it is also possible to do it in time domain. For an analysis performed in Wadam, typically airy wave theory is applied with various available options of wave spectrum and results are presented as complex transfer functions or as deterministic results for specified phases of the wave.

The software is based on widely accepted linear methods for marine hydrodynamics, the 3-D radiation-diffraction theory employing a panel model and Morison equation in linear form employing a beam model (created by Sesam GeniE).

The former method is appropriate for voluminous structural parts (having typical dimensions greater than 1/5 of the wavelength). The latter method will predict drag (viscous) forces more accurately and is therefore suitable for more slender structural parts.

For the structure comprised of both slender and voluminous parts like in the present case of global structural model of the semisubmersible platform the two methods have been used in combination by establishing the so-called composite models. The Sesam GeniE Wadam software will automatically apply the appropriate method based on the ratio of the structural dimension (diameter) to wavelength. The radiation-diffraction part of Wadam is based on software developed by Massachusetts Institute of Technology.

5.2.3 Postresp & Xtract: Analysis Post Processing Tool

The Postresp software have been used to do statistical post-processing of general responses given as transfer functions in the frequency domain analysis performed for global response of the semisubmersible platform. The transfer functions have been generated by the hydrodynamic program HydroD Wadam as discussed in the earlier section. The main parameters analyzed using the Postresp program has been the response variables in terms of Surge, Sway, Heave, Roll, Pitch and Yaw motion. They have been plotted as dimensionless quantities with respect to the wave spectrum applied at different heading and frequencies. Other key parameters analyzed using Postresp has been the added mass coefficients, the excitation forces and the second order horizontal drift forces. This tool has been really helpful in evaluating the global motion response of the semisubmersible platform. The results from the program have been discussed in the Chapter 7 and 8.

Advanced high-speed graphics makes the Xtract software from Sesam the ideal tool for examining the structural models at any level of detail with or without analysis results. In the current piece of work this program tool has been used to analyze the hydrostatic pressure, hydrodynamic pressure and wave induced loading on the semisubmersible platform analyzed at element and node level. Interactive zooming, rotating, panning and cutting features has allowed to achieve the best view of the model for performing the quasi-static structural analysis for global structural model. The software is helpful to visualize all relevant points belonging to an integrated hydrodynamic analysis like e.g. the finite element model (e.g. several super elements), the water pressure, the displacements (structure and water) and the stresses. The capability of having animated response is another characteristic of the program. The Xtract's database browser also enables the user to easily navigate across the super element hierarchy, result cases, result attributes with components (displacements, stresses, etc.) and sets.

6. STRUCTURAL MODELLING

The objective of the global structural modeling has been to develop the Panel, Morison and global structural finite element models of the twin pontoon semisubmersible with bracings to enable the assessment of responses resulting from global loads from extreme environmental wave loading. A global structural model is a structural model representing the stiffness of the actual structure. It is modeled as a volumetric, thin-walled three-dimensional finite element model. In the current study the thin-walled model has been modeled in shell finite elements with combination of beam elements as recommended for the twin pontoon semisubmersible model by the offshore codes. The structural connections in the model have been modeled with adequate stiffness by ensuring sufficient detail of connections at key locations for pontoon/column and column/deck in order to represent the actual stiffness such that the resulting global responses are appropriate for the design. The panel model takes into account the finite elements exposed to the action of hydrodynamic wave loading as wet elements and the drag forces acting on the braces are considered by the Morison model.

This model has been analyzed for a set of extreme environmental loading to evaluate the global response of the structure in different conditions and to perform the subsequent quasi-static structural analysis dependent on these global responses. The simplified model of the structure has been prepared to analyze the most basic geometry and avoid any complication during the analysis.

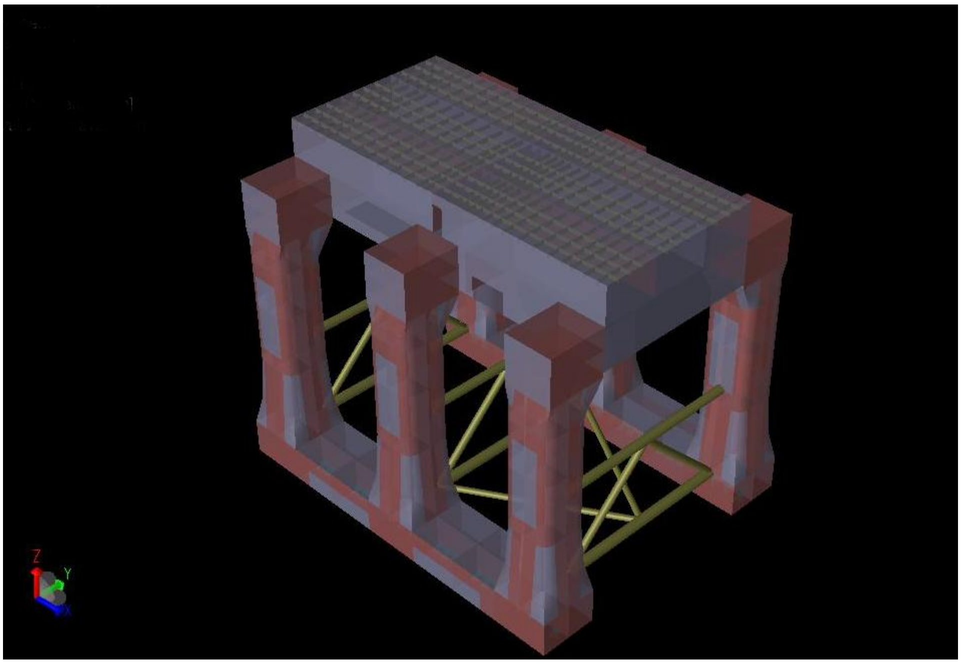


Figure 15 Global Structural Model (Transparent View)

6.1 Modelling Set Up

The global coordinate system has been defined in accordance with the recommended practices prescribed for the offshore column stabilised units like semisubmersible platform as follows

- X-direction coinciding with the unit's longitudinal centre line, where positive direction is pointing in forward direction and negative in the aft direction of the semisubmersible platform The model have been moved in longitudinal direction, so that the longitudinal centre of buoyancy is around x=0.
- Y-direction has been taken as the platform's transverse centre line with positive y-direction being towards port side.
- Z-axis has been taken vertical direction with positive z in upward direction. Z=0 at pontoon base line.

The SI-units has been used to set up the modelling with the key dimensional units given as follows:

- Mass = [kg]
- Length = [m]
- Time = [s]

The outputs in terms of forces and stresses from the global response analysis have been evaluated in the following units:

- Force = [N]
- Stress = [Pa] or [MPa]

The material used for the structural modelling of the semisubmersible is high strength steel of grade NV 36D as given by the structural technical drawings provided by the DNV. The material has been taken as a linear isotropic model along with the following material properties

Table 6 Material Properties of the Structural Model [Source: DNV OS-B101 April 2009]

Material Property	Value	Units
Yield Stress	3.55×10^{8}	Pa
Density	7850	kg/m^{3}
Young's Modulus	2.1×10^{11}	Pa
Poisson's Ratio	0.3	-
Thermal Coefficient	1.2×10^{-5}	$W/(m.C^{-1})$
Damping Coefficient	0.03	N.s/m

6.2 Geometrical Modelling

The geometrical modelling of the semisubmersible offshore platform under study has been performed in accordance to the requirement of analysing the structural global strength of the semisubmersible model comprising of sub assemblies like pontoon, columns, deck, and bracing. The modelling work has been done by using the finite element structural modelling package SESAM GeniE [Ref: Chapter5.2.1].

As being mentioned the global model is a coarse model of the unit, which represents the global stiffness of the unit. In order to represent the global stiffness of the semisubmersible, as per the offshore codes/standards the structural components which contribute to the global stiffness have been included in the design as mentioned follows:

- the longitudinal stiffness of the pontoons,
- the stiffness of the braces in axial direction,
- the stiffness in vertical direction of the columns
- and the stiffness of the main bulkheads as well as the shear and bending stiffness of the upper hull

The global structural model has been designed as a simplified structural model to avoid any complexities in the analysis. Moreover the stiffeners and girders have not been included unless they effect the overall stiffness of the structure in a significant manner for e.g. Girder System at the Upper Deck, Bracing has been included.

Smaller openings such as doors, man holes, pipe penetrations have not been modelled as their effect on the global stiffness of the system is minimal. However the larger openings in the deck assembly has been modelled as plate elements cut outs, as the stiffness of the area is reduced due to these opening.

The overall modelling process has been done by modelling the sub-assemblies of the structure with the help of structural drawing provided by DNV for the H3 Type semisubmersible under study. The details of the modelling have been avoided to ensure the confidentiality of the data provided by the organisation.

In the following section we have discussed about the modelling of the key structural sub-assemblies of the semisubmersible platform studied for this global response analysis

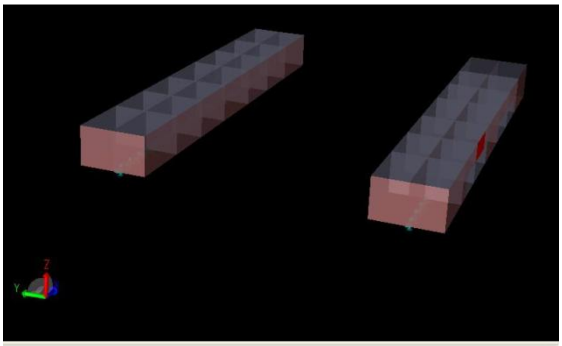
6.2.1 Pontoons

The pontoon sub-assembly has been created with shell elements and mostly as flat plates in accordance to the rectangular design of the pontoon elements. The structural components in longitudinal direction have been included in the model of the pontoons as they contribute significantly to the global stiffness of the model. This implies that longitudinal bulkheads and pontoon shells are the key components for the pontoon global stiffness model. The longitudinal bulkhead has been modelled as a flat plate which runs along the longitudinal central axis of each of the pontoon.

In the pontoon the transverse watertight bulkheads has been modelled, in order to achieve geometric stiffness between pontoon's vertical shell sides and the longitudinal bulkhead. If this stiffness is omitted the pontoon was found to deflect incorrectly depending on the distribution of the load on the pontoon and the length of the free span between the columns.

In the current pontoon model, the water tight bulkheads have been modelled as flat plates of occurring at regular specified distance as shown in the Figure 16 below

The local reinforcements such as longitudinal girders covering over short distances, frames has been neglected as their contribution to the global stiffness of the structure is minimal



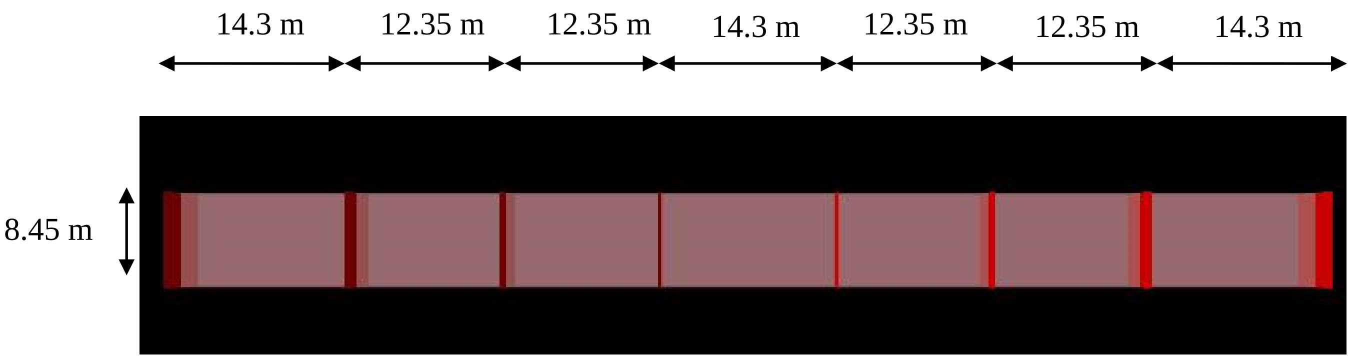


Figure 16 Pontoon Global Structural Model & Bulkheads

6.2.2 Columns

The column structural assembly in vertical direction is highly important for the global stiffness. Hence, transverse and longitudinal bulkheads and column shell plates in the vertical direction have been included in the global structural model. At the top part of the columns the deck connection is a critical region and has also been modelled. It is not strictly necessary, but the stress peaks from the structural model were found to be reduced by modelling these structures. Another advantage was that the steel weight was observed to be more correctly distributed. The column structure is a more complex structure than the pontoon design as it consists of curved shells at the top and the bottom as shown below in Figure 17. These curved shells regions for the column were the possible critical region for stress concentration in the structural analysis model and were the key connection areas with other sub assemblies of the structure like pontoon, bracing and the deck structure.

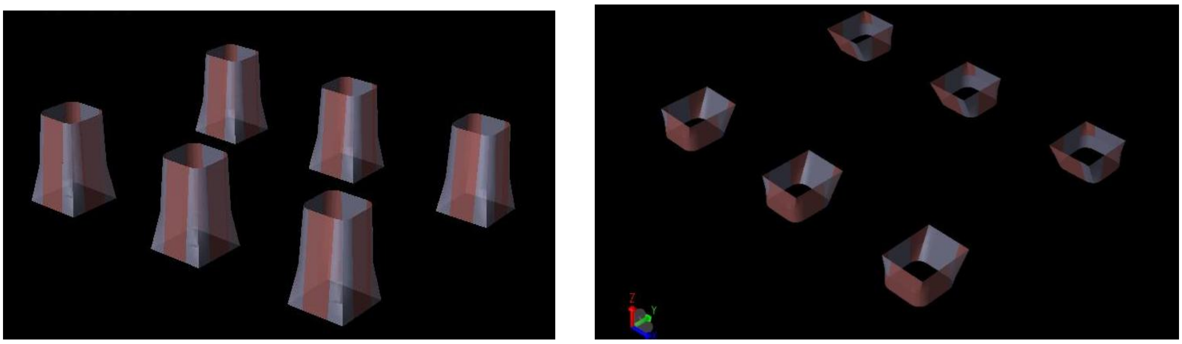


Figure 17 Column Bottom (Left) & Top Part (Right) Curved Shell sub-assembly

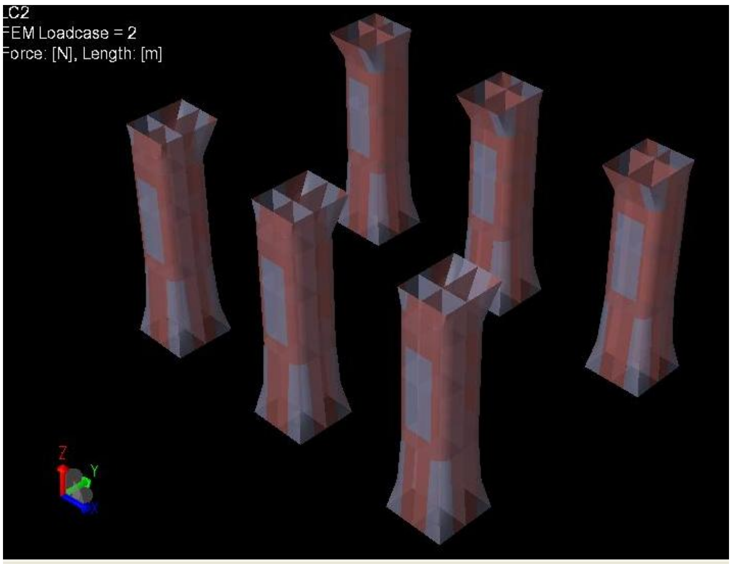


Figure 18 Column Sub-Assembly

6.2.3 Upper Deck

The global model of the upper hull was observed to be a complex task to design with provision of so many actual structural components in the deck structure. Although with the guidance to the offshore codes/standards about the key structural member useful for global stiffness of the overall semisubmersible platform were included in the model.

The deck structure had been divided at the three levels in the semisubmersible structure analyzed namely main deck, intermediate deck and the upper deck. The main deck is the deck part defining the connection region with the column sub-assembly.

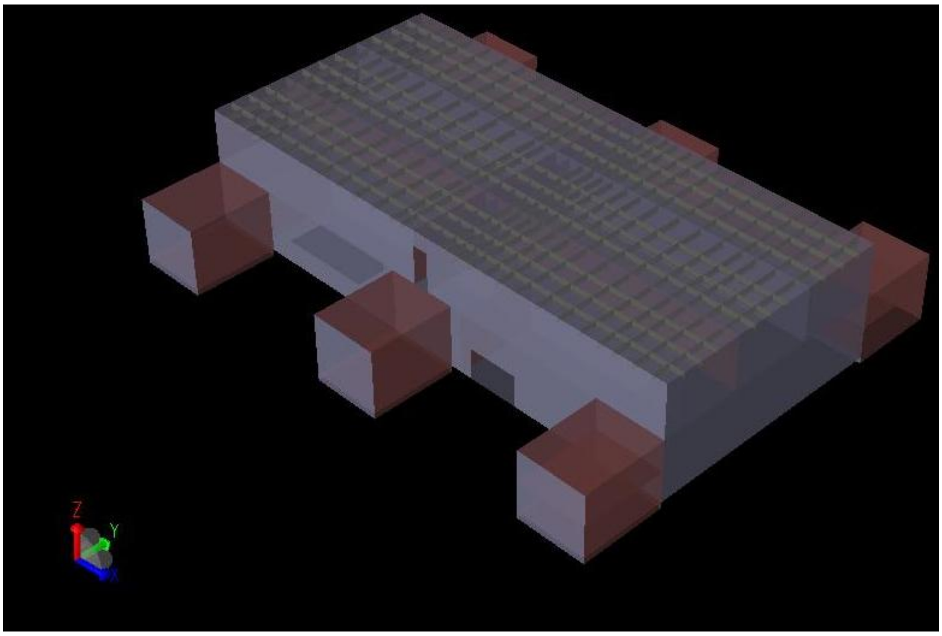


Figure 19 Deck Sub-Assembly

The bulkheads running across the transversal and longitudinal direction were found to be important for the global structural model along with the outer deck shell member.

The bulkheads act as girder webs, while the upper hull decks act as flanges in these cases and hence their contribution to global stiffness of the structure is critical. In addition, the decks represent the shear stiffness of the upper hull even though the thickness may be small.

Local details such as brackets, buckling stiffeners, smaller cut-outs such as doors etc. has been neglected in the global model as these structural members don't contribute significantly to the global strength of the semisubmersible platform.

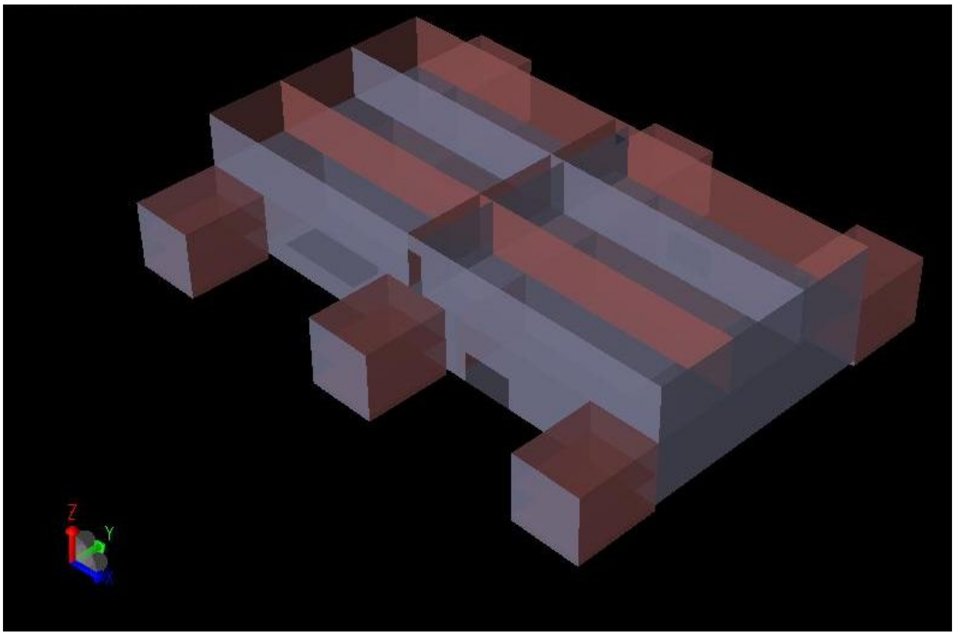


Figure 20 Deck Bulkhead Structure (Upper Deck Plate Removed for the Better View)

The girders and the framing system to the upper deck shell were modelled using T-section beam elements as per the technical structural drawings. It should be also noted that for the upper hull, the other girders as long as they do not contribute to the global stiffness have been omitted. One of the reasons of modelling the deck framing system was to ensure correct deflection of the upper deck. The structural components of the deck framing structure important for the global stiffness of the semisubmersible platform has been given in the Figure 21 below

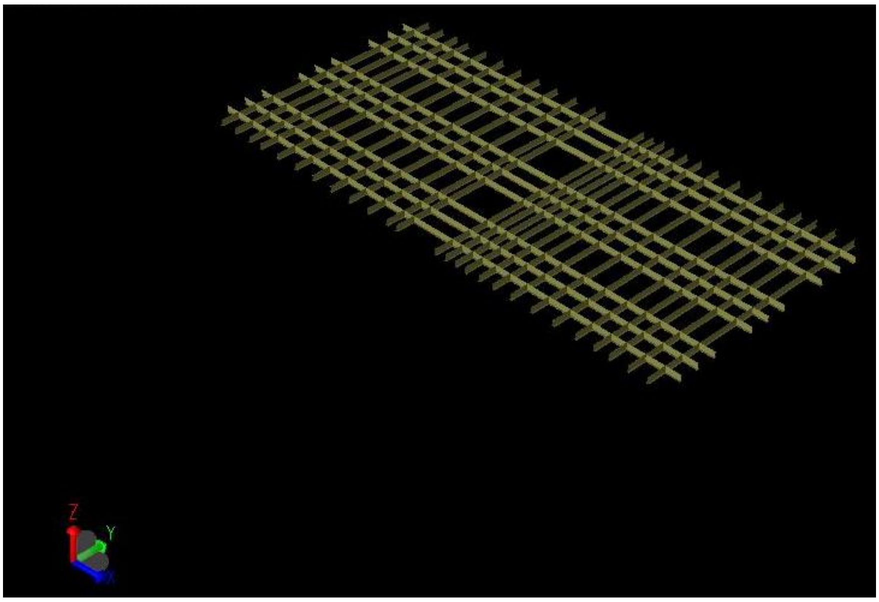


Figure 21 Upper Deck Framing Systems

6.2.4 Bracings

The cross bracing system is used to interconnect the columns-pontoons assembly of the port and starboard side. In the global structural model it has been designed without the bulkheads/ring stiffeners as they do not contribute to the global strength. The weight of these items is small compared to the brace shell itself, so that the mass distribution is expected to be represented in a sufficiently accurate manner.

These structures have been modelled using a pipe section with geometrical diameter and thickness of the bracing. It consists of the various different pipe models in the current design which has been taken from the design drawing of the semisubmersible platform provided by the DNV. The various pipe section used for design of the structure has been shown below using schematic figures from the FE modelling tool GeniE.

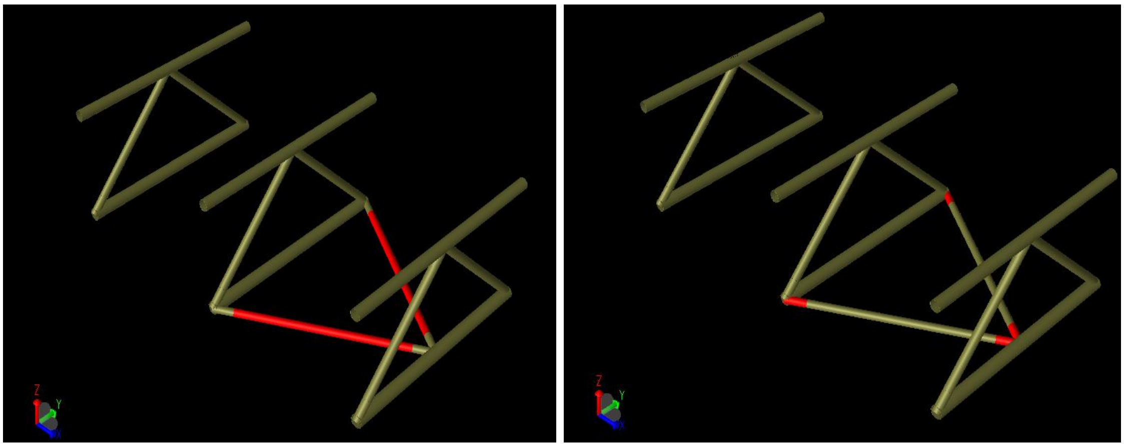


Figure 22 Bracing Pipe Section 150020(Left), Pipe Section 15025(Right)

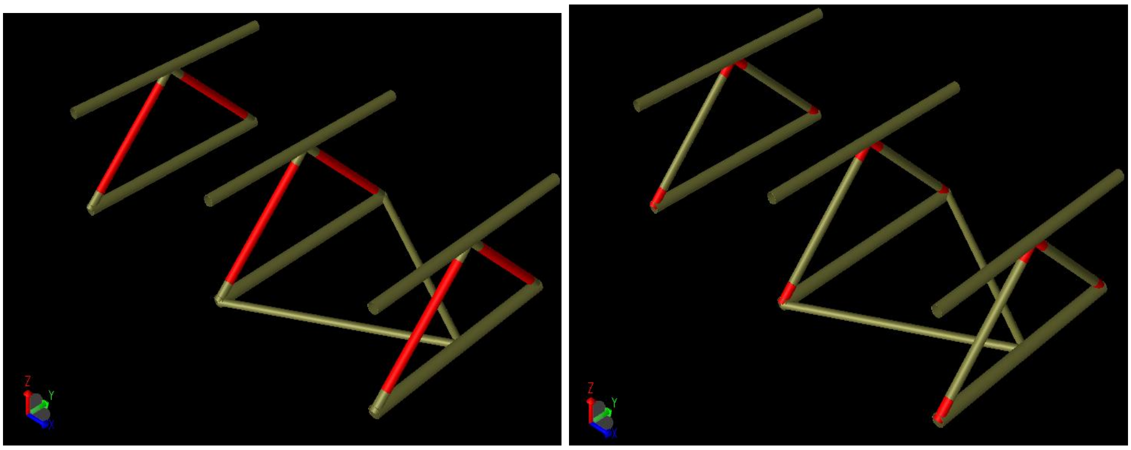
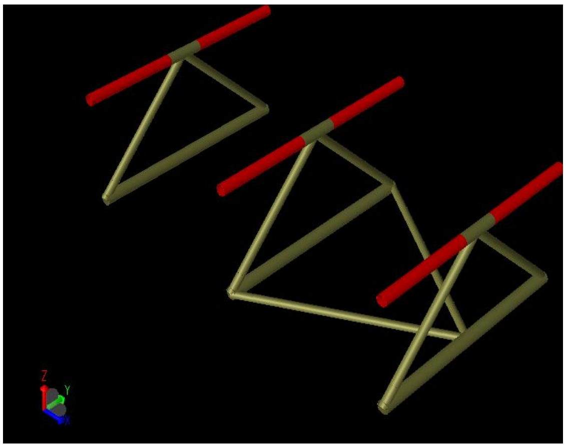


Figure 23 Bracing Pipe Section 170035(Left), Pipe Section 170040(Right)



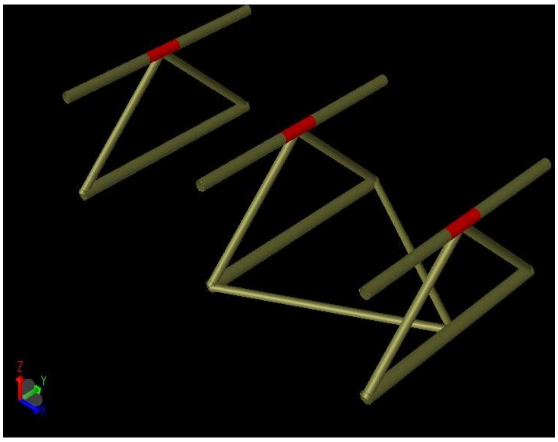
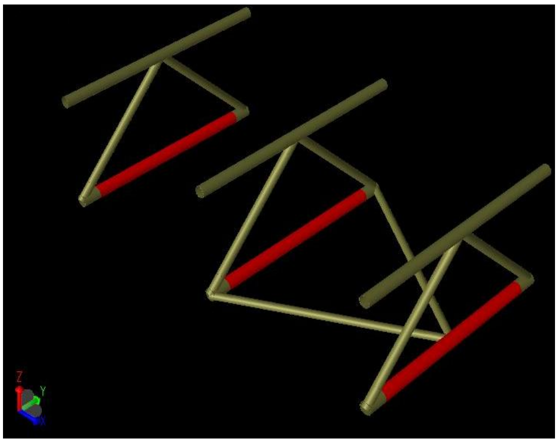


Figure 24 Bracing Pipe Section 220035(Left), Pipe Section 220040(Right)



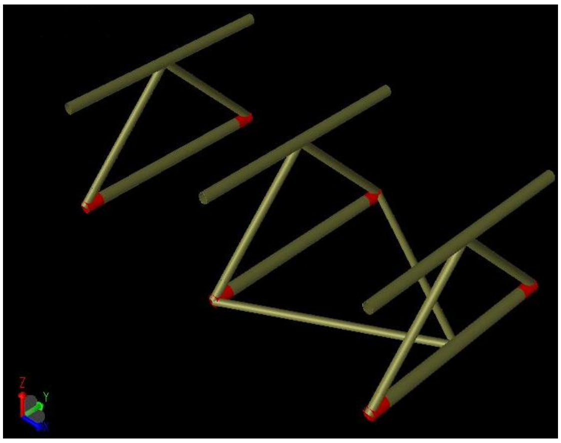


Figure 25 Bracing Pipe Section 250035(Left), Pipe Section 250040(Right)

Table 7 Pipe Section Geometry for Cross-Bracing Modelling

Bracing Pipe Section	Geometrical Diameter (in m)	Thickness(in m)
Section 150020	2.5	0.040
Section 150025	2.5	0.035
Section 175035	2.2	0.040
Section 175040	2.2	0.035
Section 220035	1.75	0.040
Section 220040	1.75	0.035
Section 250035	1.5	0.040
Section 250040	1.5	0.035

6.2.5 Key Connection Regions

The key locations in the global structural design of the semisubmersible platform are expected to be the connections between the upper-hull/columns, column/braces and column pontoons as per the design codes. In this area it has been ensured to include bulkheads, decks frames, and stringers as they contribute to the global stiffness. Since if only a part of the foundation is modelled, the stress would be expected to be of approximate distribution in these key connection regions. Moreover these regions are recommended to be analysed by a detailed local structural finite element analysis to provide a more precise stress distribution.

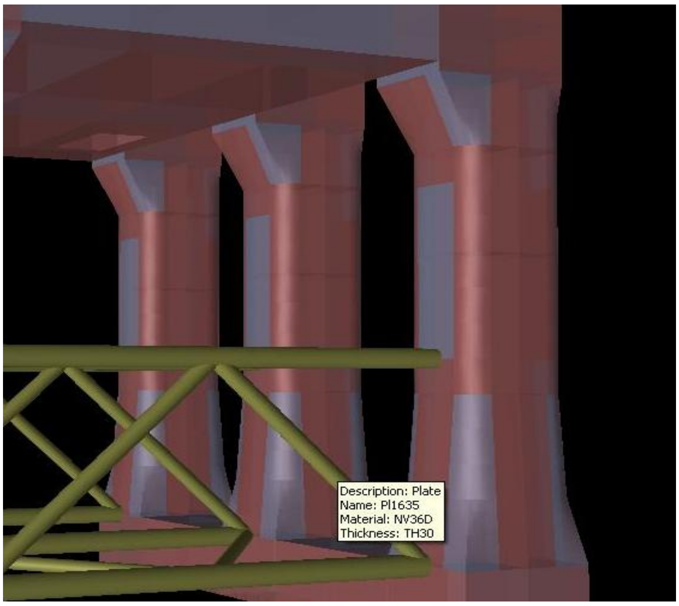


Figure 26 Bracing Column Pontoon Connections

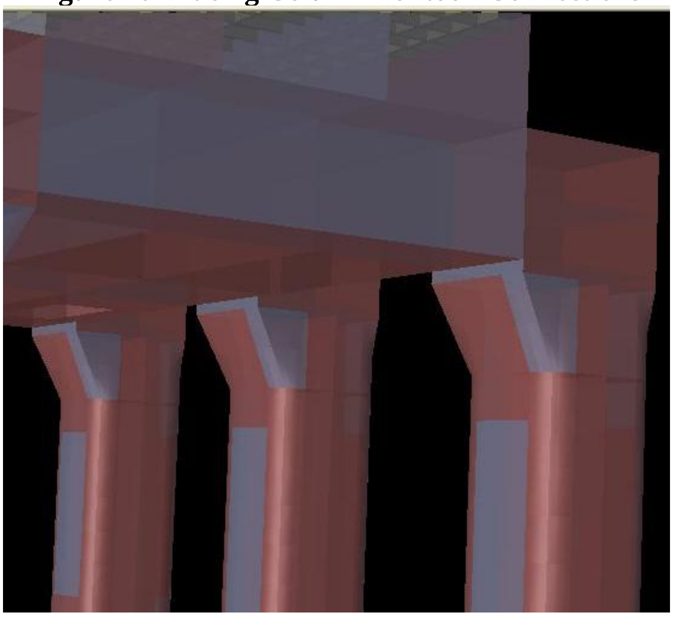


Figure 27 Column Deck Connections

6.4.6 Boundary conditions

According to the recommended practices by the design codes for the semisubmersible platforms there are two ways to define the boundary condition for the global analysis. Fixed boundary conditions may be used for a statically determined set of boundary conditions while spring stiffness is more appropriate to avoid stress concentration around support points.
Figure 28 illustrates a set of boundary conditions with spring stiffness as per DNV-RP-C103 which has been used as a concept in the current global structural model of the semisubmersible.

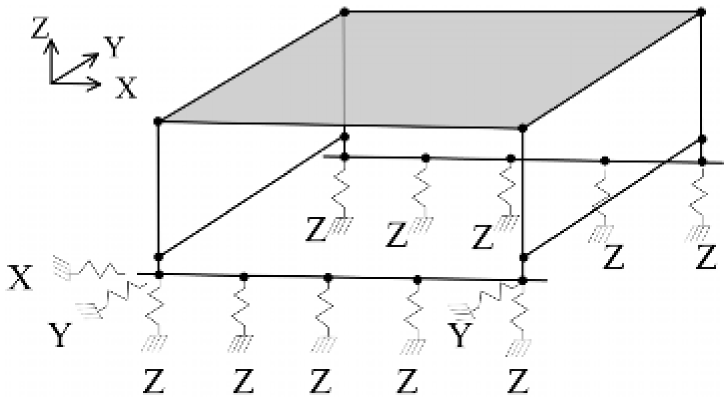


Figure 28 Semisubmersible boundary condition support with springs (Ref: DNV RP-C103)

The total vertical stiffness has been calculated according to the water plane area of the semisubmersible structure under operating conditions. The spring stiffness has been applied at significant number of distributed region to minimize the stress concentration in the pontoon shells and to minimize the unbalance of the force. Moreover these springs have been applied at "strong" points in the model (for e.g. intersection of the bulkheads etc.) so as to limit the effect of unphysical support reactions as per the offshore design code DNV RP-C103.The springs have been attached to the pontoon base line below the column. The spring stiffness of the water plane area is calculated as

$$k = \rho * g * A_w \tag{7}$$

Where ρ = density of water = 1025 Kg/m^3

g= gravity of 9.81m/s2,

A_w = water plane area of the structure.

The water plane area has been calculated for one of the column leg of the semisubmersible and been multiplied by 6 to obtain the total water plane area of the structure assuming 0 trim loading condition at operating draft

Based on the above formulation for the number of the spring systems applied and minimisation of the unbalance of the reaction force due to structural weight loading we have calculated that the vertical stiffness of spring to be about 80000 N/m.

In addition, in one of the nodes a spring in the global x- and y- direction and in one of the nodes a spring in global y-direction has been defined with the stiffness of these springs are to be set roughly about 1% of the vertical stiffness. The rotational stiffness in the entire three axes for the springs has been assumed to be zero.

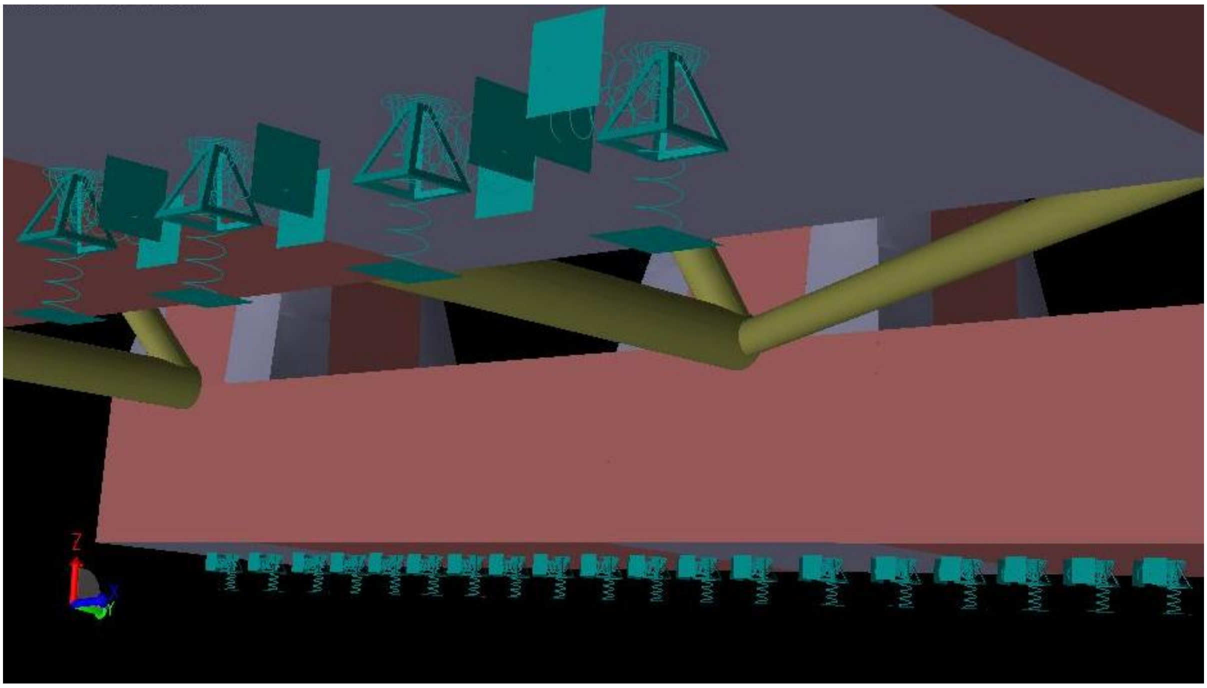


Figure 29 Spring stiffness applied along the longitudinal axis of the pontoon

6.3 Meshing

The finite element modelling of the structure was required for setting up of the global response analysis of the semisubmersible platform. Three different finite element meshing models were required to perform the hydrodynamic analysis part of the global response namely the Panel model, the Morison model and the Structural model. These meshing models and the approach/key points considered for the required meshing has been described below.
The element mesh largely depends on the geometry of the unit. A typical maximum size of the quadrilateral shaped elements approximately 3m by 3m for a semisubmersible is recommended by the offshore codes/standard and has been used generally in our analysis as well. However, the size is often smaller at some regions due to changes in plate thickness, internal structure such as bulkheads and frames etc. Moreover, triangular shaped elements have been allowed in places where quadrilateral elements do not fit properly. Another aspect is to have as rectangular elements as possible with a length to breadth ratio of less than 5:1. Before starting the modelling of the global structure we have considered an overview of the internal structure and the changes in plate thickness. The element distribution has been decided by the internal structure in the column such as longitudinal and transverse bulkheads, trunk, plate thickness etc. A usual number of elements for the rounded corners have been kept as 3-4. It was then to be verified that the chosen mesh was suitable for the pontoon and upper deck structure. In order to avoid unnecessary many elements compromises were made with respect to thickness changes etc.

In the current approach, generally for the finite element modelling 8-noded elements have been used for the structure using the second order element approach. 6-noded triangular elements have been used sporadically in areas, where the element meshes of 8-noded shell elements do not fit. The triangular elements are stiffer and therefore have been avoided in general.3-noded beam elements have been to be used for the modelling of stiffeners etc. as for the mass model 3-noded will be sufficient.4-noded shell elements have been avoided as these elements give to high stresses if they are wrapped to simplify the meshing and node count. With the above mentioned modelling techniques extra attention has been taken in cases, where e.g. bulkheads are modelled. The sub-assemblies of the structure have been divided into sets, which make the design modifications and the post-processing of the model easier. Rational set division techniques have been used for e.g. longitudinal/ transverse bulkheads shell plating forward, aft, port and starboard side, decks, columns, pontoons, wet-surface etc.

6.3.1. Panel model

The structural model of the shell structures of pontoons, columns exposed to the water surface have been used for the panel model. The set of the elements, which are wet, i.e. one side is wet and one side is dry has been used to define the panels which would be affected by the hydrodynamic pressure of the wave loading. In the modelling of panel model a dummy hydrodynamic pressure load is applied the wetted panels. However during the hydrodynamic analysis the set applies for the panel elements below the still water line and it separates out the dry elements with defined hydrodynamic pressure. Simple meshing techniques have been used to create the panel model. 8 node 2nd order meshing properties have been applied to the panels with 6 node elements in areas where the 8-noded elements do not fit. The mesh elements length for simplicity has been kept uniform and of order of 3 m by 3m.
The meshed panel model used for further analysis is as shown in the Figure 30 below.
As shown no internal structural components and bulkheads were taken in the panel model as they are not exposed to the hydrodynamic pressure. The top super element number for the panel model was taken as 1. The summary of the panel model defined for the global response and load transfer analysis has been given in the Chapter Appendix A discussing with summary of model properties.

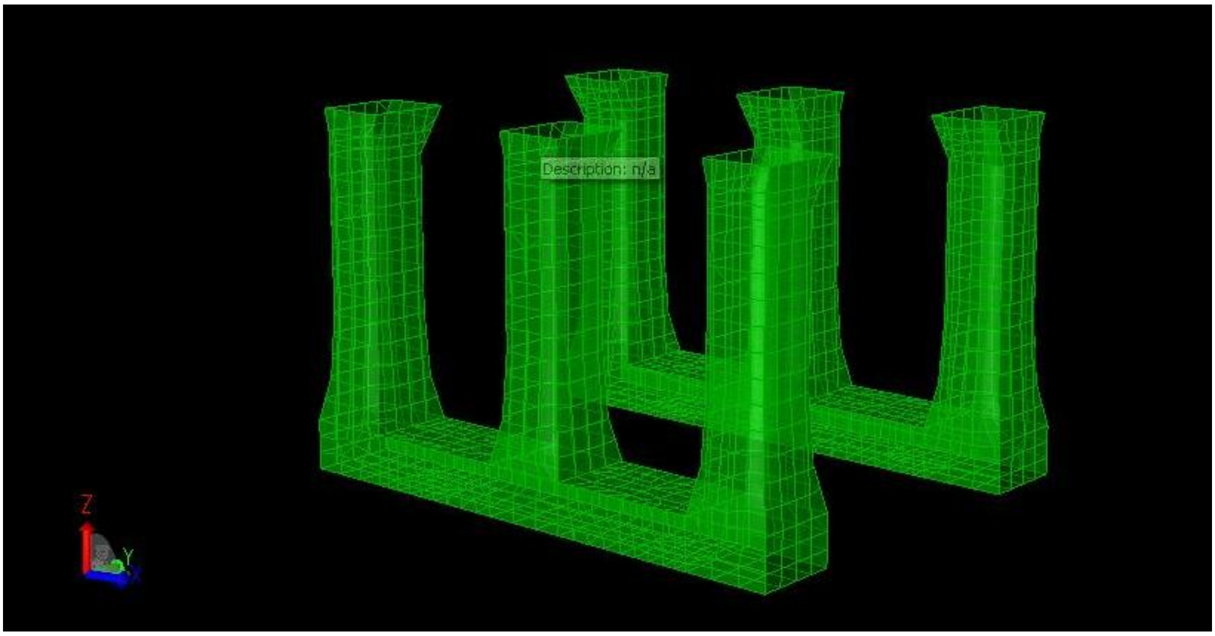


Figure 30 Panel Meshing Model

6.3.2 Morison Model

The Morison model is a structural finite element model that consists of the cross bracing beam elements. The cross connecting bracing are pipe sections that connects the pontoon-column assembly of the starboard and port side of the semisubmersible.

The Morison model was generated by simply meshing the cross bracing pipe section. It is an important part of the hydrodynamic model as its response to the extreme environmental wave loading affects the global response of the semisubmersible platform in terms of drag due applied wave loading. The drag coefficients assigned to the various pipe sections constituting the bracing were assumed as a uniform numerical value of 0.7 in the horizontal and vertical axes of the semisubmersible platform for the hydrodynamic analysis.

A default value of meshing element length was used to create the mesh model of the Morison elements. The ends of the Morison elements getting connected to the column and pontoon sub-assemblies have been defined as pressure elements. The top super element number for the Morison model was taken as 2. The Morison model has been shown using the Figure 31 below.

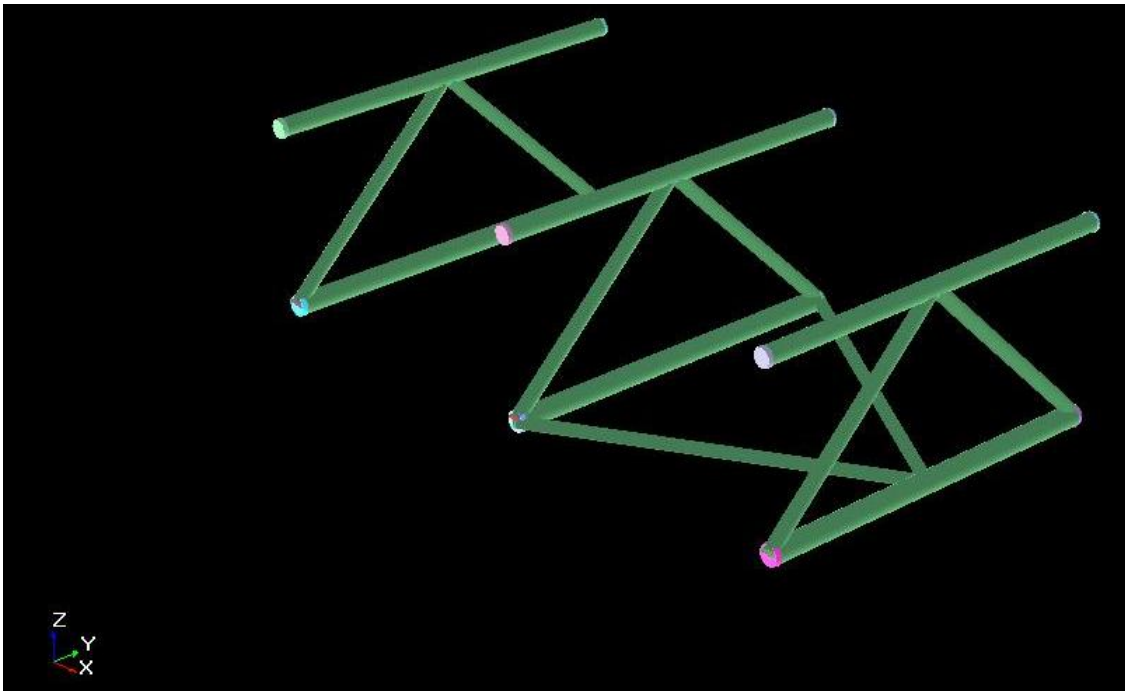


Figure 31 Morison Meshing Model

6.3.4 Structural Mesh Model

The structural mesh model is finite element model of the entire global structural model of the semisubmersible. It is a complex structure for meshing as it includes all the structural components including the bulkheads, the girders, bracings and other key structural connections of the semisubmersible platform. The meshing for the internal structural components and bulkheads had to be ensured to be uniform and gradual to avoid any hot spot generation during the analysis. The element size of the mesh in critical locations like connections between columns, deck, pontoons and bracing had to be refined to a finer model for smooth stress transition/deformation in the analysis. This structural model included the panel and the Morison model along with the finite element assembly of the deck structure and single node spring elements. The mesh model for the entire global structural model has been shown as below in Figure 32.

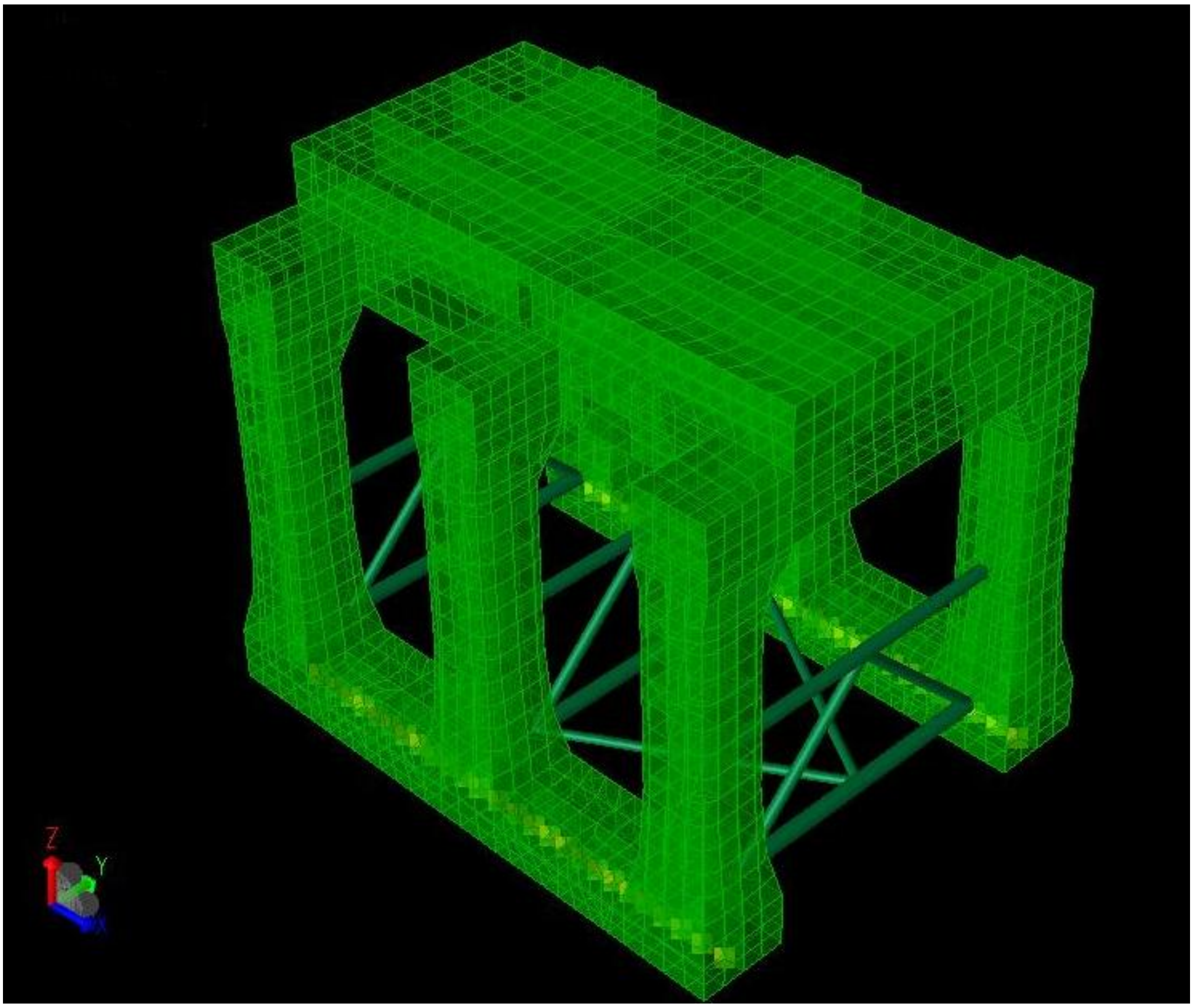


Figure 32 Structural Mesh Model

7. GLOBAL RESPONSE ANALYSIS

The global response wave load analysis has been set up using the 3D potential theory program SESAM HYDRO-D Wadam package, which calculates RAO's for motions and loads in long crested waves. As discussed in Chapter 5.2.2 WADAM is a general purpose hydrodynamic analysis program for calculation of wave loading and wave induced responses of fixed and floating marine structures with zero or low forward speed. WADAM computations take place in the frequency domain which is a recommended method to evaluate the global response of the semisubmersible. Two types of calculations were carried out using WADAM:

- Hydrostatic calculations, in which the hydrostatic and inertia properties of the structure are calculated, together with the loading from weight and buoyancy. This loading is important for equilibrium and has been included in the subsequent structural analysis
- Load calculations, in which the detailed pressure distribution on an element level is calculated. These pressures are transferred to the structural FEM model for subsequent quasi-static structural analysis.

To perform the hydrodynamic analysis on the global structure of the semisubmersible platform a hydro model was created in HYDRO-D software as shown in the Figure 33 below. This hydro model mainly consisted of the finite element model of the structure namely panel, Morison, and structural model.

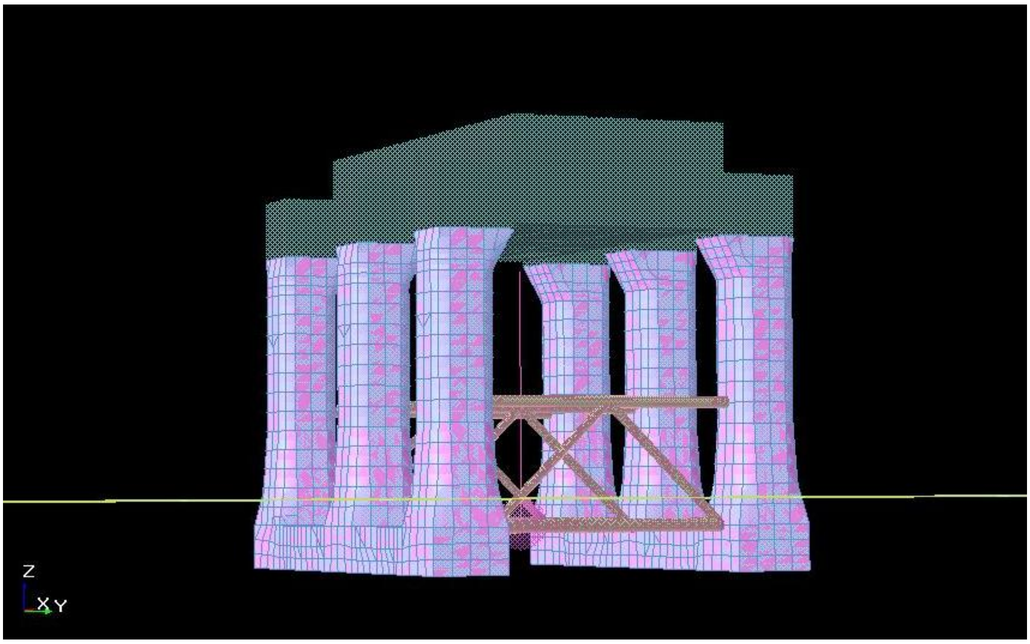


Figure 33 Hydro Model of the Semisubmersible platform

7.1 Equation of Motion and Characteristic global response of the semi submersible

With the help of theoretical study for dynamics of rigid body, the equation of motion of the platform centre of gravity have been studied in this section. The mathematical equations has been given in this section to summarize the platform motion variables with respect to applied regular wave loads from its incident, diffracted and radiated components.

$$[M]\{\ddot{x}\} = \{F(t)\}=\{F\}\, e^{iwt} \tag{8}$$

Where M is the mass matrix of the model, and F(t) is the vector of fluid loads on platform which exclude the still water buoyant

The fluid loads acting on the platform surface can be divided into the hydrostatic restoring loads F_s (t) induced by the displacement of the platform from the mean position, and the hydrodynamic loads F_d (t) depended on the waves and platform motions, namely

$$\{F(t\}) = \{F_s\,(t\})+ \{F_d\,(t)\} \tag{9}$$

The hydrostatic restoring loads can be written as follows where *[K]* is matrix of hydrostatic restoring force

$$\{\, F_s\,(t)\}=-[K]\, x \tag{10}$$

The hydrodynamic loads can be obtained by integrating the hydrodynamic pressures on the wet surface of the platform. According to the division of the velocity potential of flow, the hydrodynamic loads can be decomposed into incident wave force, diffraction wave force and radiation force which can be written as

$$\{F_t(t)\} = \{F^I\,(t)\}+ \{F^D\,(t\})+ \{F^R\,(t)\} \tag{11}$$

The incident wave force and diffraction wave force could be written into the combined form as the so-called wave excitation loads mentioned above

$$\{F_E\,(t)\} = \{F^I\,(t)\}+ \{F^D\,(t)\} \tag{12}$$

The radiation force could be summarized as follows where *[A] and [C]* are three dimensional hydrodynamic coefficients corresponding to added mass and damping respectively.

$$\{F^R\,(t)\} = -\,[A]\,\ddot{x}\; -\,[C]\,\dot{x} \tag{13}$$

Hence using the series of mathematical equation 9 to equation 13, we can summarize the equation of platform motion can be given as

$$([M]+[A])\{\ddot{x}\}+[C]\,\dot{x} + [K]\,x = \{F_t(t)\} \tag{9}$$

With the background of the mathematical model of equation of motion for semisubmersible platform presented above it could be stated that the static response for the semisubmersible platform is caused by the permanent loads (lightship weight), variable functional loads, and deformation loads.

As per the offshore design codes and standards the motion responses due to hydrodynamic loading of the platform is critical factor governing the global strength of the unit. The characteristics hydrodynamic responses of a typical twin pontoon semisubmersible unit with diagonal braces between column and pontoons have been illustrated on see Figure 34.The key components for these responses has been listed as follows

- F_S: The split force generated between pontoons due to hydrodynamic loading in the transverse direction of the semisubmersible
- M_t: There is the torsion moment generated about the transverse horizontal axis of the unit which is another significant response generated due to hydrodynamic loading.
- F_L :Another critical response of the unit is the Longitudinal shear force between the pontoons along its longitudinal axis
- a_L: Apart from the force and moment response, the acceleration of the deck mass in the longitudinal direction is another important hydrodynamic response.
- a_T : The transverse acceleration of deck mass
- a_V : Vertical acceleration of deck mass,

A schematic figure consisting of the characteristic response from a hydrodynamic environment has been shown below

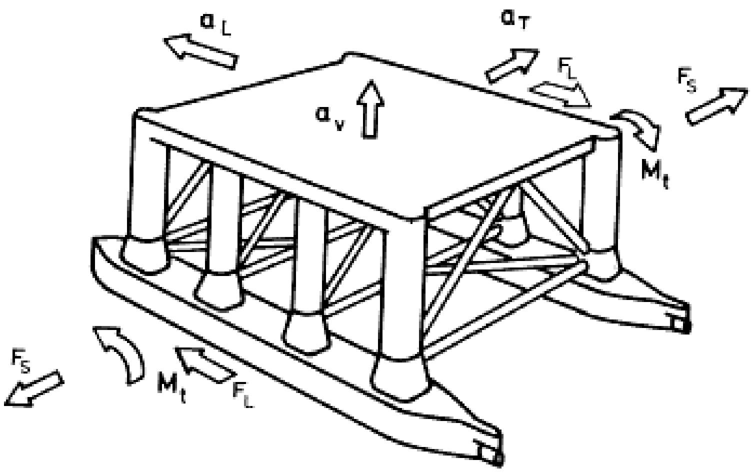


Figure 34 Characteristic hydrodynamic responses of semisubmersible (Source: DNV RP C-103)

7.2 Environmental Loading Criteria: Design Wave Selection

Environmental loads are loads which may vary in magnitude, position and direction during the period under consideration, and which are related to operations and normal use of the installation. Examples of environmental loading can be given as follows

- hydrodynamic loads induced by waves and current
- inertia forces
- wind
- earthquake
- tidal effects
- marine growth
- Snow and ice.

In the current piece of work a stochastic design wave analysis method with frequency domain analysis was applied to account for the environmental loading from the hydrodynamic analysis to evaluate the global response of the semisubmersible platform.

The analysis performed was set up with the defining the environmental design wave parameters in terms of wave frequency, wave heading, significant wave height, peak wave period, water depth of the field etc.

In this analysis study only one environmental scenario, the extreme 100-yr hurricane condition (ULS-b), and one mass distribution were analyzed. The draft of model has been taken from the operating design condition i.e. 13.33m vertically up from the pontoon base as given by the technical drawing of the structures from DNV.

In the WADAM analysis the semisubmersible model has been analyzed as a free floating body, without considering the coupling effect of the mooring lines and risers on the structure motion response. It is assumed that this simplification leads to more conservative results; however this effect is assumed to have little significance.

The design wave parameter have been selected based on one of most extreme climates i.e. in the North Sea with 100 year return period found for the current operating locations of mobile offshore units like semisubmersible platforms as given in the Table 8 below.

Table 8 Indicative values of met ocean parameters in central North Sea sites [Ref: [ISO 19901-1]

Met ocean parameter	Return Period				
	1	5	10	50	100
Significant wave height (m)	9.8	11.2	11.8	13.1	13.6
Spectral peak period a (s)	13.6	14.6	15.0	15.7	16

In accordance to the offshore standard code API 2 A, several design sea-states (varying wave height and period) from several directions has been analyzed to ensure that the wave causing the highest dynamic loads in a primary strength member is bracketed. Linear harmonic wave theory has been used to investigate the variations in dynamic loads due to passage of a wave. A design wave approach has been chosen as recommended for structural stress analysis of floating platforms like semisubmersibles to calculate maximum stress. This design wave approach preserves the merits of the stochastic approach by using the maximum expected stochastic values of some characteristic response parameters in the selection of design wave parameters. The wave spectrum applied has been discussed in the further section of this chapter. The schematic wave headings considered to evaluate the most extreme response of the vessel due to applied hydrodynamic loading has been shown below.

\

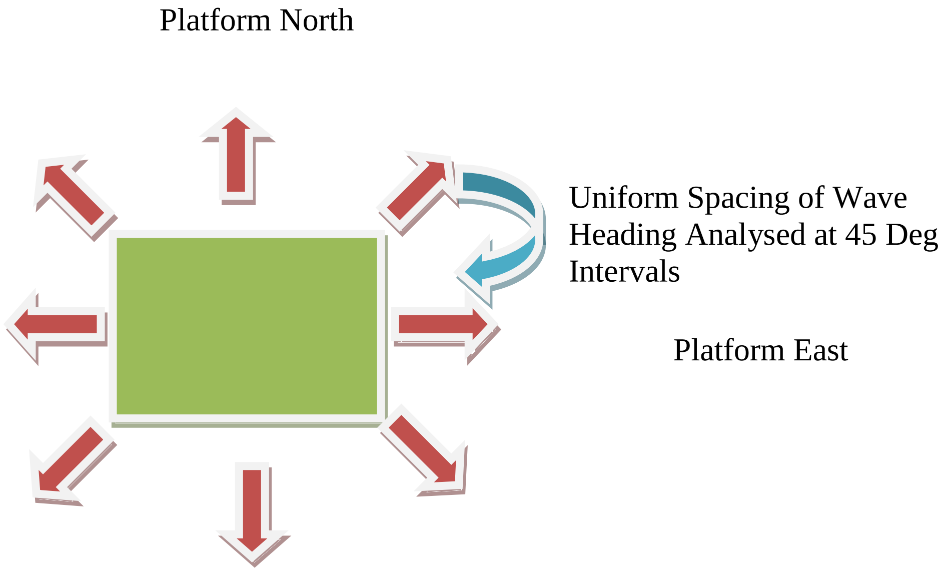


Figure 35 Wave Heading Direction for different load cases analysed

7.3 Analysis Set Up

The coordinate system used for the hydrodynamic analysis has been taken the same as the global structural modelling discussed in the Chapter 6.1 except for the fact that the entire hydrodynamic model (constituting of the Panel, Morison and the structural model) was translated in the vertical direction by -13.33 m which has been taken as the operating draft of the platform to ensure that mean sea level is around z= 0 as per recommendation of the software manuals. This operating draft of 13.33m allows an acceptable balance of net buoyancy and static forces acting on the semisubmersible model analysed with minimal trim and heel condition.

However for the setting up the analysis, the first step has been taken as defining the design wave spectrum and the sea state to which the semisubmersible platform was exposed has been defined in the HydroD Wadam package. The analysis was set up as frequency domain analysis for checking the motion response and the transferring the global loads on the structure due to wave loading.

The water depth of the location was assumed to be uniform 300 m which is in coherence with the range of water depth expected in the central North Sea region and typical water depth for operation of semi submersible platform in that region. The sea state was defined for the duration of 3 hour according to the recommended practices in the offshore design codes. The wave start and main heading was assumed to be 45 degrees with respect to the platform longitudinal axis for the sea state. The drag effects of the incident waves were calculated using the drag linearization by stochastic methods. The drift forces in the hydrodynamic analysis were calculated using the far field integration methods. To generate the wave field the off-body points were taken in the (x, y) plane to calculate the hydrodynamic parameters at relevant points in the wave field. The range for the off-body points was taken as a grid system between (250m, 200m) to (-250m, -200m) with an interval of 25m in x axis and 20m in y axis.

The various time periods for which the response was analysed were taken in the range of 4 seconds to 24 seconds with an interval of 2 seconds in coherence to the spectral range defined in the standard DNV-RP-C-205. The load-cases based on combination of wave direction and wave frequency analysed for different loading conditions has been mentioned as follows

Table 9 Load Cases Analyzed, Wave Heading, Wave Period

Load Case	**Heading**	**Period**		**Load Case**	**Heading**	**Period**		**Load Case**	**Heading**	**Period**
2_1	0	4		**4_9**	90	20		**7_6**	225	14
2_2	0	6		**4_10**	90	22		**7_7**	225	16
2_3	0	8		**4_11**	90	24		**7_8**	225	18
2_4	0	10		**5_1**	135	4		**7_9**	225	20
2_5	0	12		**5_2**	135	6		**7_10**	225	22
2_6	0	14		**5_3**	135	8		**7_11**	225	24
2_7	0	16		**5_4**	135	10		**8_1**	270	4
2_8	0	18		**5_5**	135	12		**8_2**	270	6
2_9	0	20		**5_6**	135	14		**8_3**	270	8
2_10	0	22		**5_7**	135	16		**8_4**	270	10
2_11	0	24		**5_8**	135	18		**8_5**	270	12
3_1	45	4		**5_9**	135	20		**8_6**	270	14
3_2	45	6		**5_10**	135	22		**8_7**	270	16
3_3	45	8		**5_11**	135	24		**8_8**	270	18
3_4	45	10		**6_1**	180	4		**8_9**	270	20
3_5	45	12		**6_2**	180	6		**8_10**	270	22
3_6	45	14		**6_3**	180	8		**8_11**	270	24
3_7	45	16		**6_4**	180	10		**9_1**	315	4
3_8	45	18		**6_5**	180	12		**9_2**	315	6
3_9	45	20		**6_6**	180	14		**9_3**	315	8
3_10	45	22		**6_7**	180	16		**9_4**	315	10
3_11	45	24		**6_8**	180	18		**9_5**	315	12
4_1	90	4		**6_9**	180	20		**9_6**	315	14
4_2	90	6		**6_10**	180	22		**9_7**	315	16
4_3	90	8		**6_11**	180	24		**9_8**	315	18
4_4	90	10		**7_1**	225	4		**9_9**	315	20
4_5	90	12		**7_2**	225	6		**9_10**	315	22
4_6	90	14		**7_3**	225	8		**9_11**	315	24
4_7	90	16		**7_4**	225	10				
4_8	90	18		**7_5**	225	12				

The wave spectrum was modelled as Bretschneider spectrum which is denoted as a 2 parameter Pierson-Moskowitz spectrum with the significant wave height being 13.6m and peak period being 16 sec as taken for the design wave from the Table 8.

The mathematical equation for the Pierson Moskowitz wave spectrum in terms of significant wave height and peak time period have been mentioned below

$$S_n(f) = [\{5*H_s^2* \exp(-5/4T_p^4*f^4)\}/(16*f^5*T_P^4)\}] \quad (14)$$

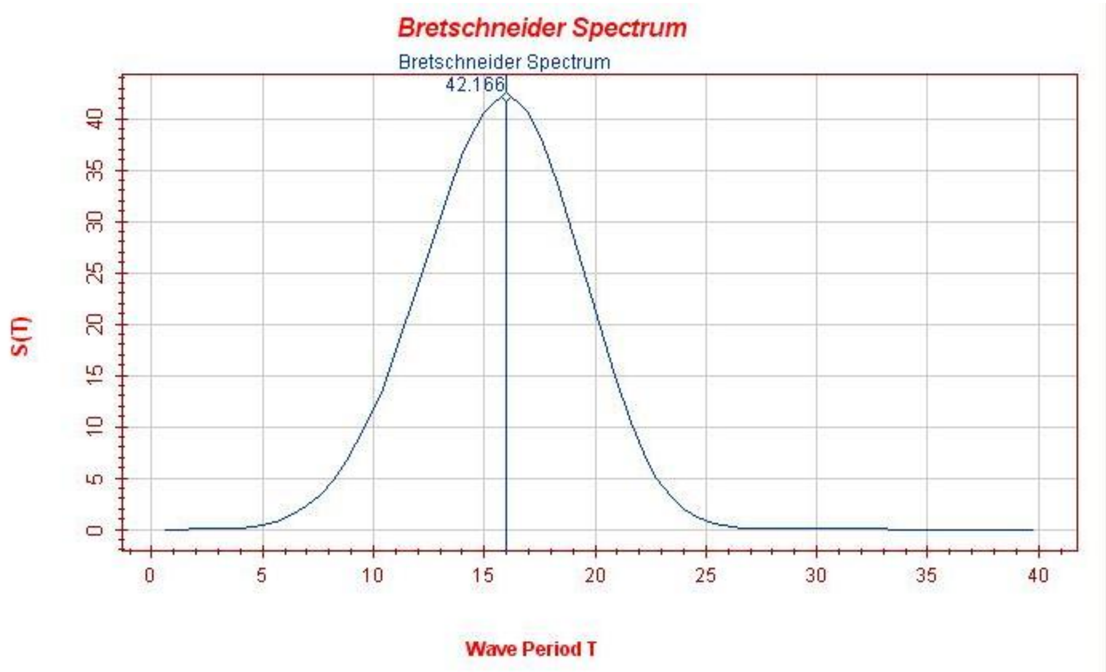


Figure 36 Wave spectrums for design wave

As mentioned the mass model of the structure was generated as user defined option from the homogenous density panel model and fill from buoyancy tools of HydroD Wadam programme in the global coordinate system. Since an absolute ideal situation of net balance of buoyancy and static forces is difficult to attain for the analysis set up, a draft of 13.33m which gives a net vertical force of $4.23x10^7$ was accepted as it is the order of the typical force which is managed by the mooring system of the semisubmersible platform.

For the loading state with no heel and trim of the platform, the vertical centre of gravity was assumed to be matching with the vertical centre of buoyancy of the structure. The schematic snapshot from the analysis has been shown below to represent the mass model denoted by the ball shaped symbol.

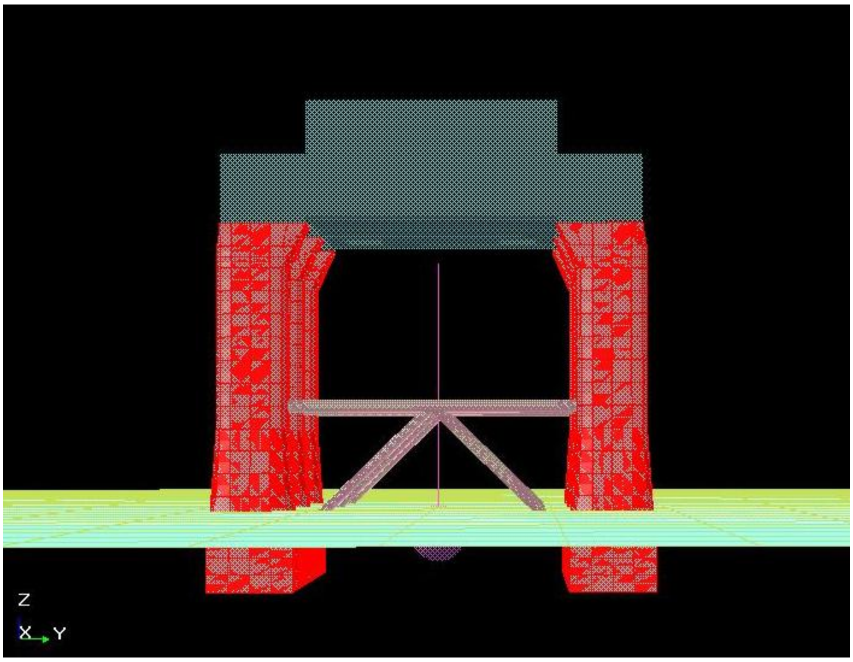


Figure 37 Mass Model of the Semisubmersible Platform

The key parameters for the Mass Model and the stability of the platform have been given in the coordinate system of the hydrodynamic model which is the same as the coordinate system defined in Chapter 6.1 except for the translation of the vertical axis to ensure the mean sea level at the origin of the hydrodynamic model (z axis translated by -13.33m).

Table 10 Mass Model for the Hydrodynamic Analysis

Parameter	Value	Units
Mass of the Global Structure Model	9.77×10^6	Kg
Buoyancy Volume	9.54×10^3	m^3
Centre of Buoyancy in coordinate(x,y,z)	(0, 0, -3.52m)	m
Centre of Gravity in coordinate (x,y,z)	(0.3, 0, -4.77m)	m
Radius of Gyration for Roll, Pitch, Yaw (x,y,z)	(36.6, 40.6, 48.13)	m

Once these parameters were defined in the analysis and the run was completed, the output was extracted in terms of the global motion response and the hydrodynamic loading on the semisubmersible platform. The hydrodynamic load transfer calculations for the composite beam-shell global structure included the effects due to static load, dynamic gravity, and restoring pressure. Among the various load-cases the objective was to extract the responses in terms of hydrodynamic pressure loading and hydrostatic loading for the platform which has portrayed in the analysis results below via contour plots. The reference for the summary of the hydro model has been discussed in Chapter Appendix A.

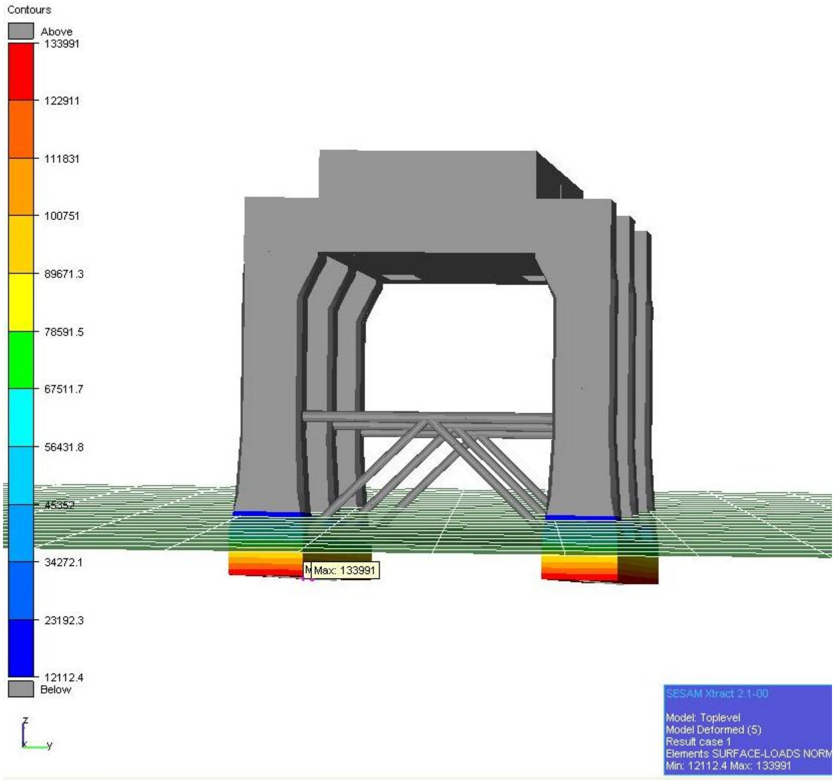


Figure 38 Hydrostatic pressure distributions on the structure elements

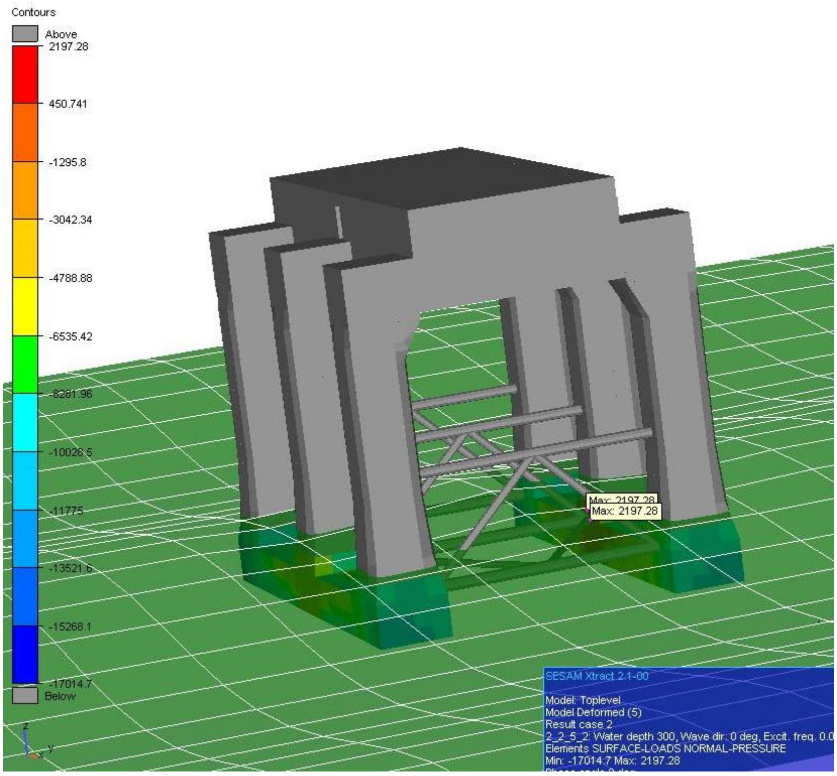


Figure 39 Hydrodynamic Pressure Distributions on the structure element (Load Case 2_5)

7.4 Global Motion Response Analysis

The first set of output from the hydrodynamic analysis performed has been analysed in the form of motion response of the semisubmersible platform under the action of the extreme environmental wave loading applied. The frequency domain analysis approach was taken up to set up the hydrodynamic analysis as explained earlier and the response of the platform was measured in terms of its Response Amplitude Operators (RAOs) for the 6 degree of freedom.
A schematic response of a vessel has been shown below to define the Surge, Sway, Heave, Roll, Pitch and Yaw motions.

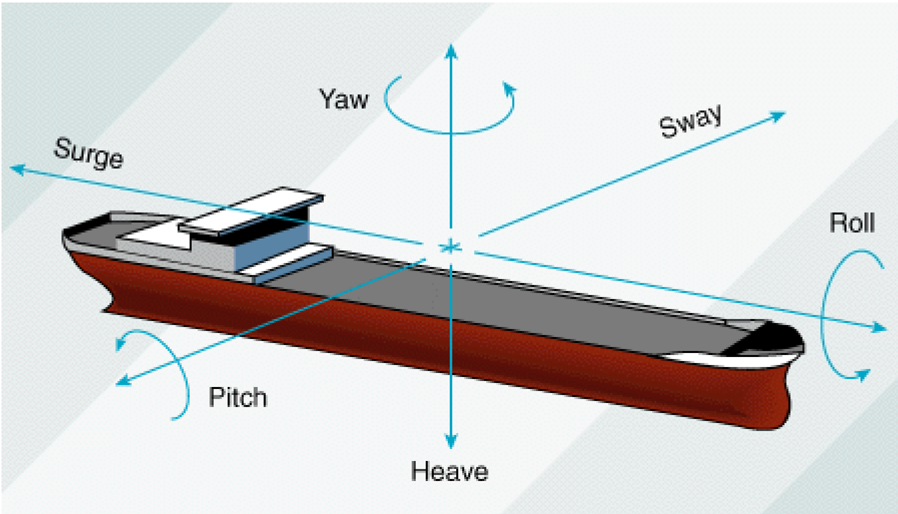


Figure 40 Surge, Sway, Heave, Roll, Pitch, Yaw Motions of a Vessel.

In accordance to the general convention surge, sway, heave is the translational motions response along the longitudinal, transverse and the vertical axis of the semisubmersible platform respectively. Similarly roll, pitch, and yaw have been considered as the rotational motion along the longitudinal, transverse and the vertical axis respectively.

In the present global motion analysis, some significant response variables like the excitation forces and 2nd order horizontal drift forces have also been studied to see the study the effect of extreme wave conditions on the structure.
The most important results to analyze from the global motion response are the platform's translational and rotational response which has been plotted with the application of wave loading corresponding to wave of different direction and time period.

The translational response variables have being plotted in the form of the dimensional-less quantities i.e. for translational motion the response have been measured in terms of (meters/meters) and for the rotational motion the response has been measured in terms of (deg-meters/meters) to the wave loading applied.

It is known that the heave motion response of the semisubmersible platform is one of the most critical motions as it affects a lot of installation and operation works on the functional rig. The critical motion under head sea conditions with wave coming at a heading of 180 degrees with respect to positive longitudinal axis of the platform has been plotted for the different degrees of freedom and wave periods below in Figure 41. In the ULS condition, positive clearance between the deck structure and the wave crest, including relative motion and interaction effects, should normally be ensured which largely depends on the heave motion of the structure.

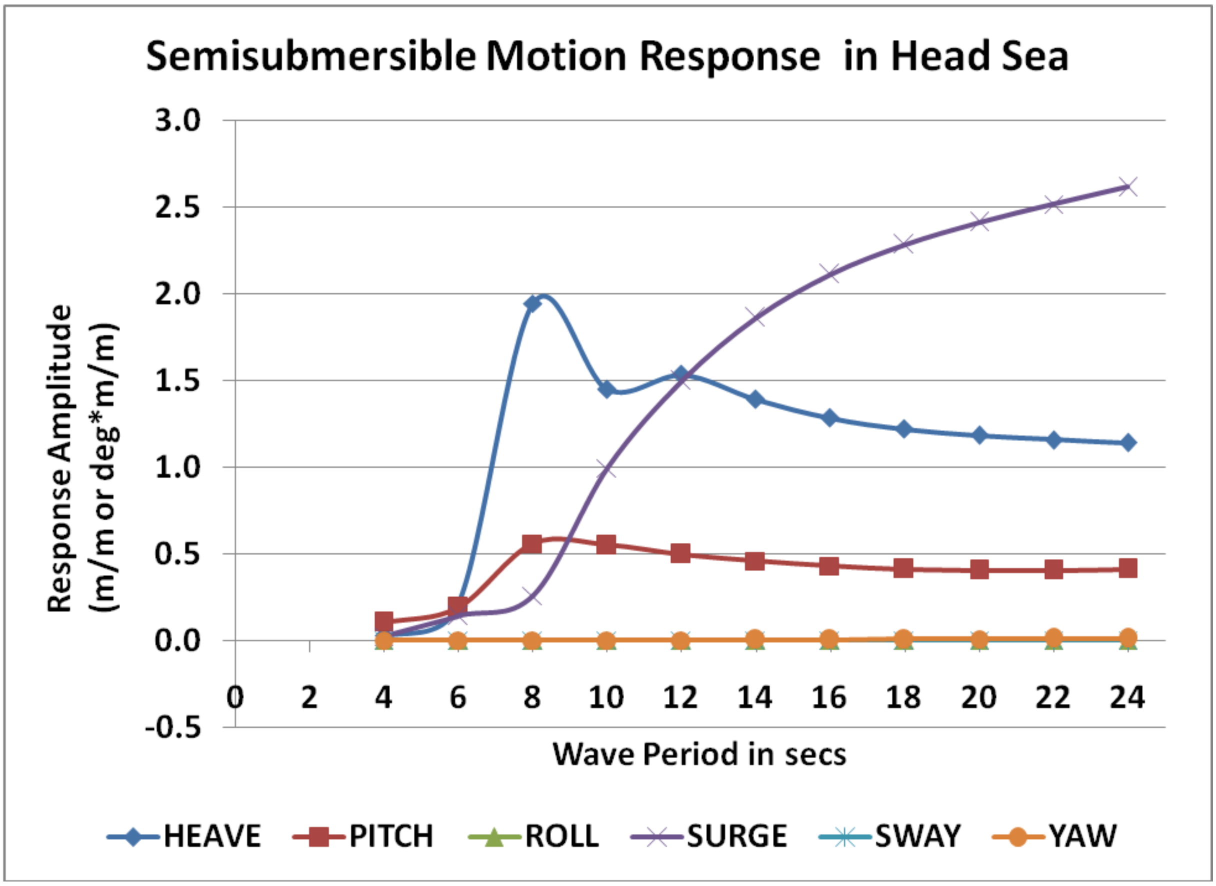


Figure 41 Response Amplitude Operators (RAOs) of semisubmersible platform in Head Sea Wave

The motion responses corresponding to each translational and rotational dof's are plotted as follows

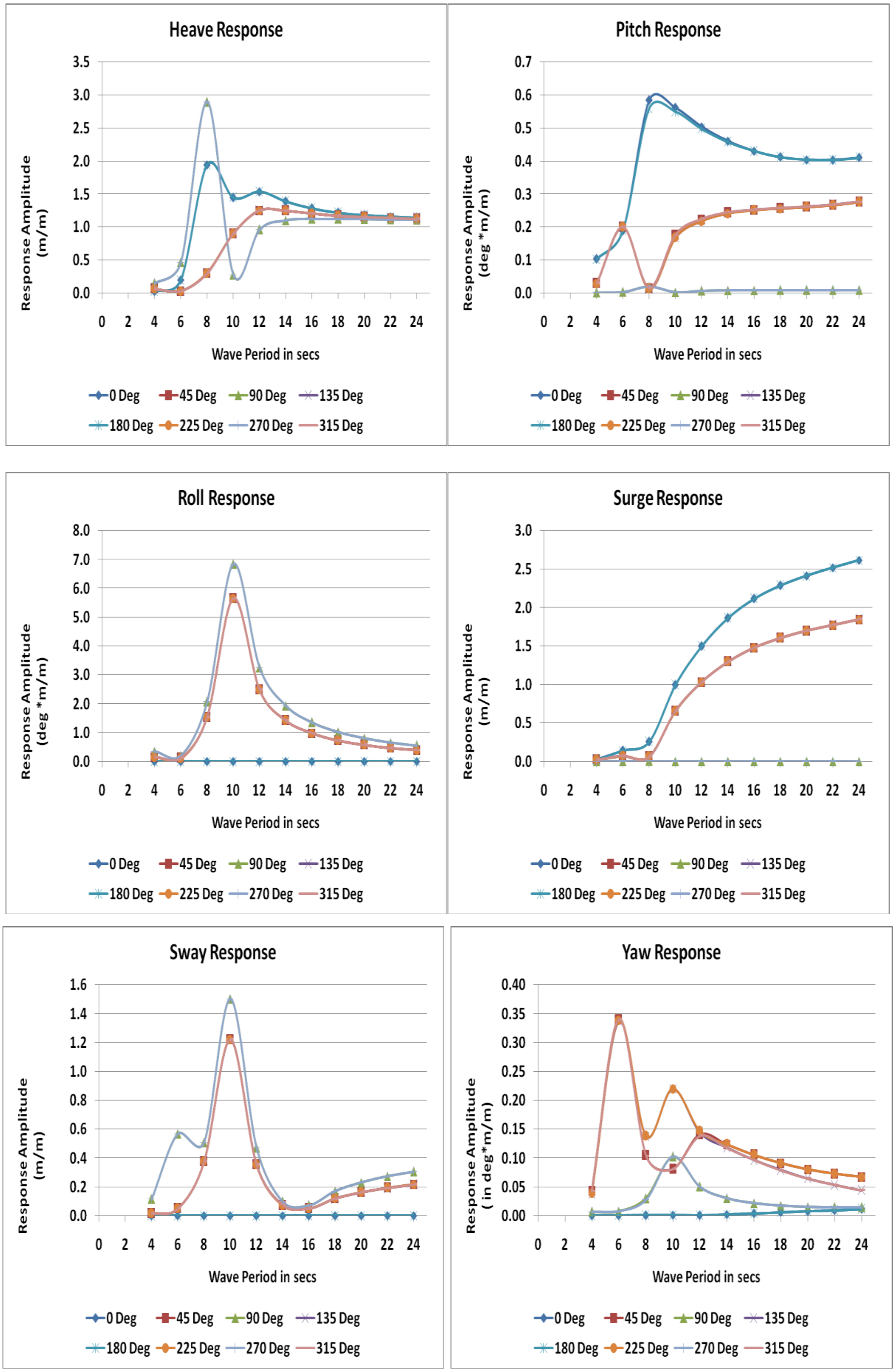


Figure 42 Global motions response of semisubmersible platform (RAO's)

It is analyzed via these plots that the heave motion is experienced to its maximum value during the head or the following seas when the wave action is along the longitudinal axis.
These observations are in accordance to the theoretical motion response for similar platforms.
One interesting observation that we can infer from these plots were that the maximum global characteristic response is not necessarily occurring for environmental conditions that are associated with the period for the characteristic largest wave height. In such cases wave period and associated wave steepness parameters have found to be the governing factors for the extreme responses as suggested in the code DNV RP-C103.
The head sea response of the platform shown in the figure 41, we can observe that the roll and yaw motions are negligible because the semisubmersible has been subjected submitted to head sea waves, so the excitation is significant in the longitudinal direction of the platform.
It can also be inferred that for the heave motion RAO coefficient tends to zero for low wave lengths because for low wavelength(and low time period) the heave motion is negligible (Characteristic length L is much larger than wave length λ), and for high λ the platform moves with the same amplitude than the wave (λ>L).
As mentioned the platform response was also analyzed in terms of first order excitation forces and moments acting on the platform with the extreme environmental loading applied.
The first order hydrodynamics forces represent forces of the linear effects of incident & diffracted wave potentials. These forces are typically sinusoidal and have a time-average value equal to zero. Mathematically, the excitation force component can be decomposed in the equation form as

$$F= F_1 (\omega) + F_2 (2\omega)= F_1 sin(\omega t + \alpha_1) + F_2+ F_2 sin(2\omega t+\alpha_2) \qquad (15)$$

Here F_1 component of the excitation forces denote the 1st order excitation forces and F_2 denotes the drift forces correspond to the second order forces and are related to the added resistance caused by the water displaced by the floating structure. The drift forces in general terms can be said as time-independent second order forces acting on ship-structure subjected to the wave field. The plots for the 1st order excitation forces and moments have been mentioned below with the convention as FORCE1 first order excitation force in x-direction, FORCE2 first order excitation force in y-direction, FORCE3 first order excitation force in z-direction, FORCE4 first order excitation moment about x-axis, FORCE5 first order excitation moment about y-axis and FORCE6 first order excitation moment about z-axis

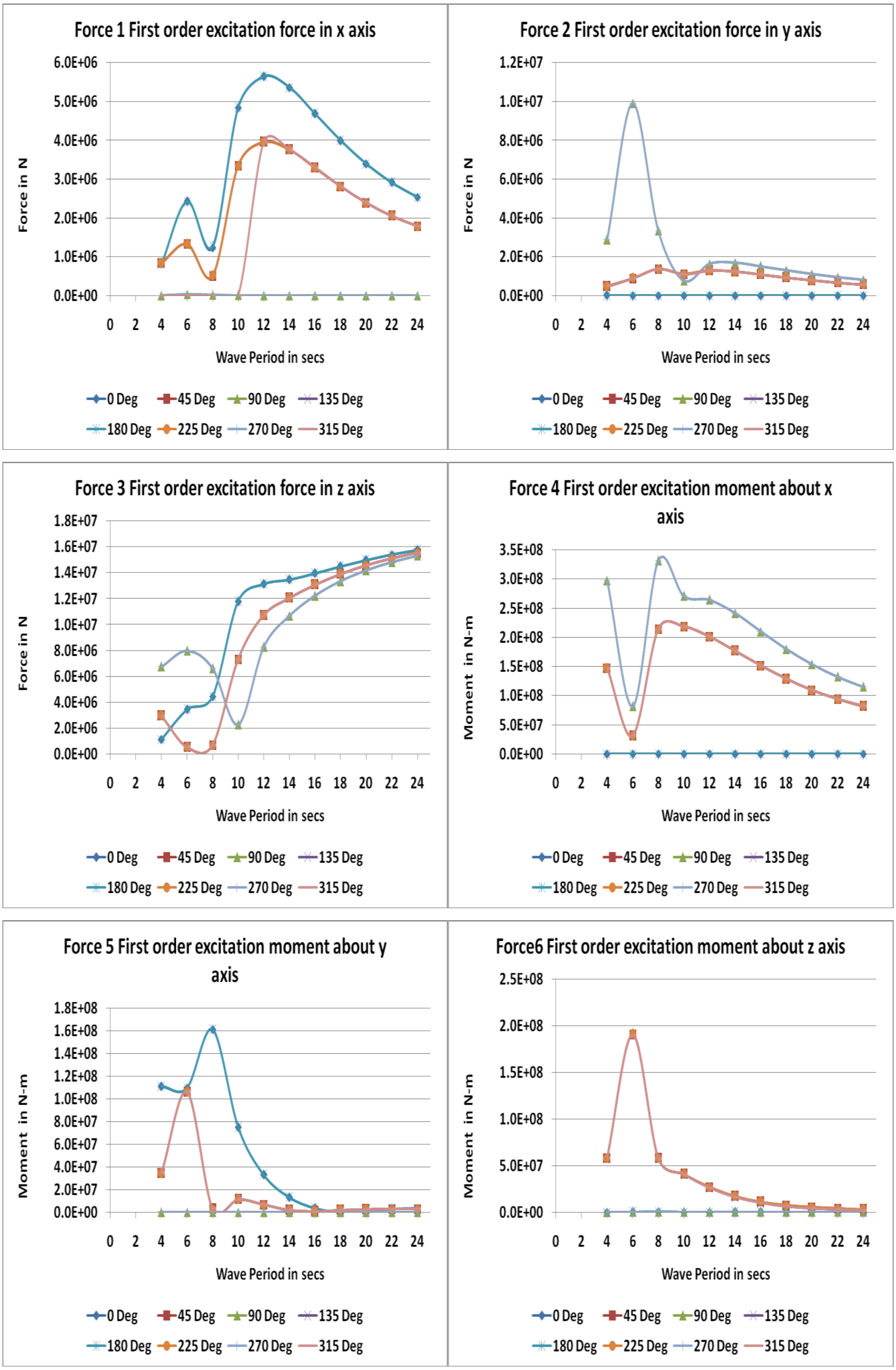


Figure 43Global Motions Response 1st Order Excitation Force & Moments (Force1, Force 2, Force3, Force 4, Force 5, Force 6)

Similarly the output in terms of 2nd order time independent horizontal drift forces for the semisubmersible response was also analyzed. The convention used for the plotting being HDRFT1 Second order horizontal mean drift force in x-direction, HDRFT2 Second order horizontal mean drift force in y-direction and HDRFT6 Second order horizontal mean drift moment about x- direction.

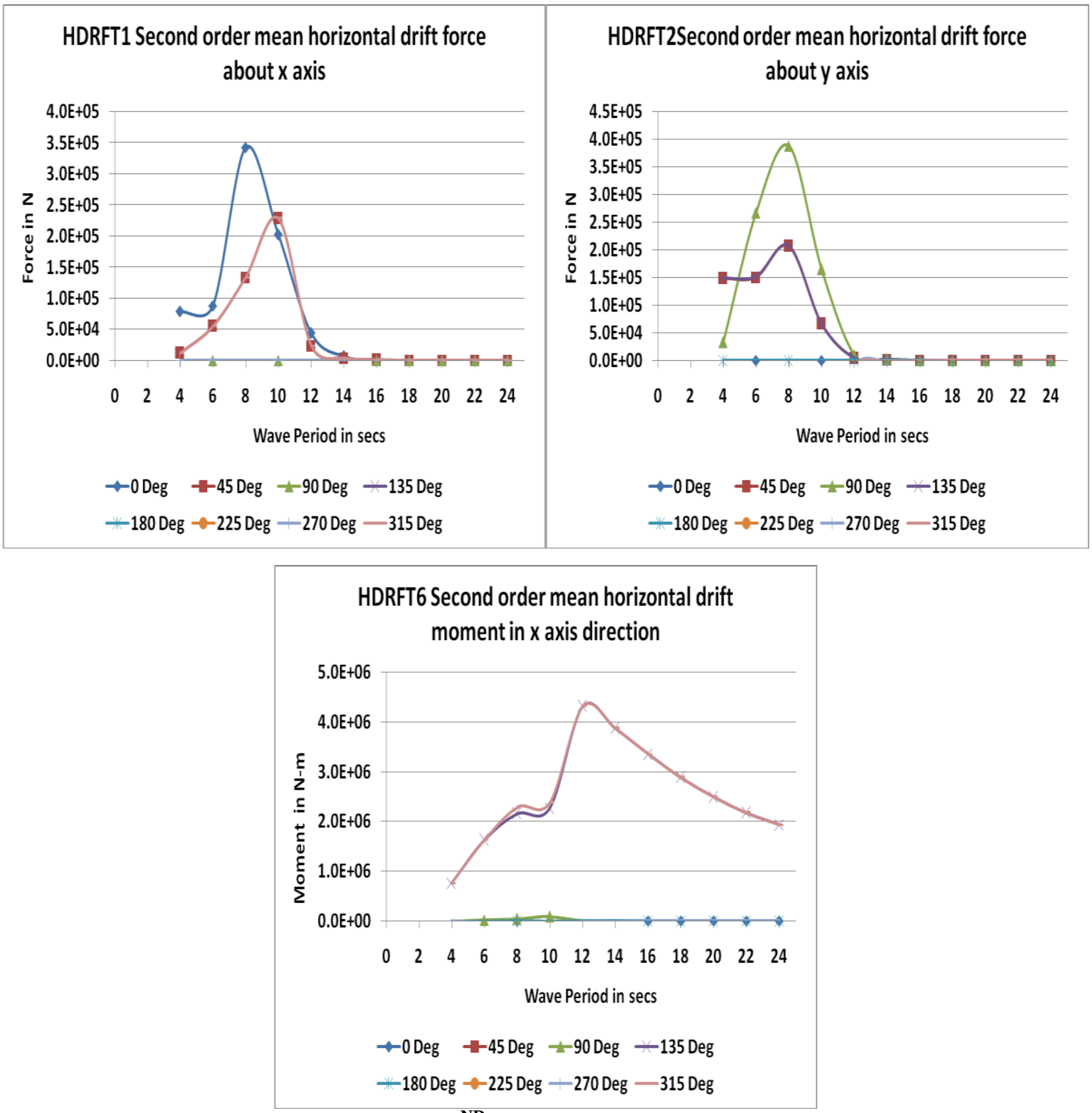


Figure 44 Global Motions Response 2ND Order Horizontal Mean Drift Forces & Moments

As it can be analyzed from the plots the maximum response for second order horizontal mean drift force in x axis occurred during following sea with wave heading of 0 degrees with the platform longitudinal axis, whereas in the y axis it occurred for beam sea condition with 90 degree wave heading. For the drift moment about x axis, the maximum response occurred at quarter-sea with wave heading of 315 degrees.

The theoretical way to evaluate the resonance period in heave of the platform for the head sea is calculated to verify that the peak in Figure 41 is around the correct period.

The natural heave period resulting in resonance for the unit can be mathematically given as

$$Tn_3 = \frac{\sqrt{(M+A33)}}{\sqrt{(\rho * g * Aw)}} x 2\pi = 7.95 \text{ sec} \qquad (16)$$

In the equation M is the mass of the global structural model taken from the mass model given in Table 10. A33 is the added mass coefficient in the vertical direction due to vertical motion response of the semisubmersible unit in applied wave conditions. Although the added mass coefficient varies with various wave frequency as shown in the Figure 45 below but it has been found to be in the range of 1.5 x 10^7 to 3.2 x10^7. The of added mass coefficient for heave for the most probable wave period range of 8-12 sec has been used in this formulation as an average value of 1.7 x10^7. A_w in the above equation corresponds to the water plane area of the hydrodynamic model which has been found out to be 1662 m2 as given in the Chapter Appendix A. Using in these values the theoretical natural resonance heave period is found out to be 7.95 seconds which is coherence with the peak response for the heave motion in head sea condition as shown in Figure 41.

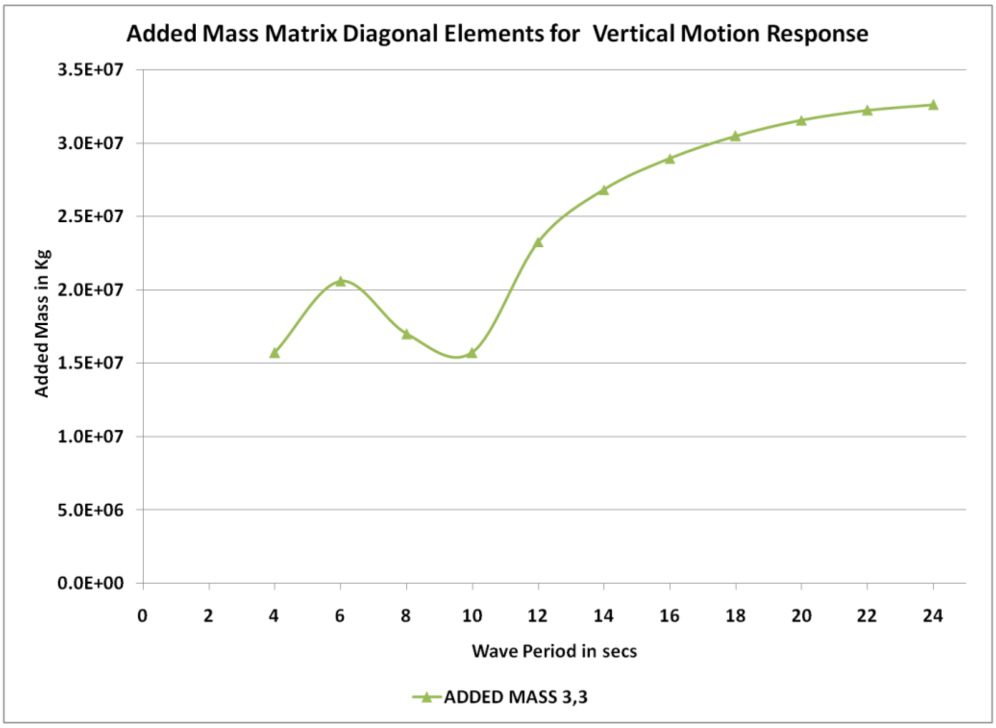


Figure 45 Added Mass Coefficient for Heave Response

7.5 Global structural strength analysis

To evaluate the overall structural strength and to estimate the magnitude of the extreme environmental loading on the semisubmersible platform the hydrodynamic pressure loads obtained from the hydrodynamic analysis were transferred to the structural FEM model for the subsequent quasi-static structural analysis.All hydrodynamic loads developed in addition to the mass inertia loads, have been applied to the structural model to study the overall wave induced stress in the panels.

Structural strength analysis in our case study has been limited in this study to the global strength analysis of the semisubmersible platform with key sub assemblies like pontoon, columns and deck structure. In the analysed configuration the semisubmersible platform consisted of two pontoons with 6 columns supporting the topside deck structure. Structural integrity was checked with respect to yielding of the structure. Yield checks have been performed based on shell von Mises stress (element average), checked against allowable stress limits specified in the offshore standards. In the current study no consideration was given to the code checking of the beam members in the bracing section as beam utilization formulae has been out of the scope of the work presented in this thesis.

As mentioned in the Chapter 6 the global structural FEA model of the semisubmersible platform was generated using the standard FE tool SESAM GeniE.
The rigid body motions of the model were restrained by means of applying 1 node spring elements to provide the required balance of forces to the structural loading. The balance of the global loads and the reaction forces was checked and confirmed to be in the acceptable range tending to zero.

The major loads applied to the structural model were as follows:

- Gravity acceleration
- Static pressure (on the outer shell)
- Dynamic wave loads (pressures and inertia loads from WADAM analysis)

The local effect of the wind and current loads on the structure is considered negligible compared to extreme wave loading of 100 year return period; therefore these loads were not applied to the model.

The overview of the structural model has been mentioned below

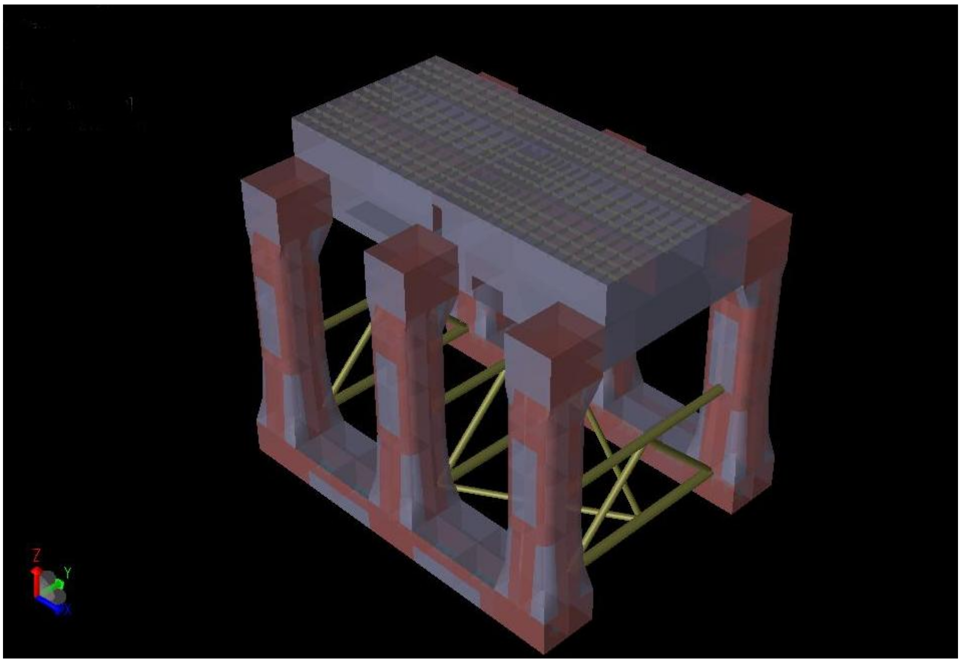


Figure 45 Structural Model of the Semisubmersible Platform

The Structural strength analysis was analysed to evaluate the most extreme response in terms of von Mises element average stress in the panel due to above mentioned loading scenarios.
The quasi- static structural analysis were observed for different wave frequencies and wave heading. Among them the most extreme response in form of contour plot for the Von Mises Element average stress has been shown in the figure below.
An interesting observation was made using the analysis performed that all the extreme responses in a particular wave heading occurred for the same wave frequency of, f = 0.0833 Hz corresponding to the wave period of 12 sec which is different from the peak period of the wave spectrum. This can be explained in coherence with the global motion response and the excitation force response for the global structure as they also show their peak responses at the similar wave frequency.
The tabulated results for each of the extreme structural response has been presented in the next chapter to estimate and verify the yield utilisation of the structural components for the extreme environmental loading

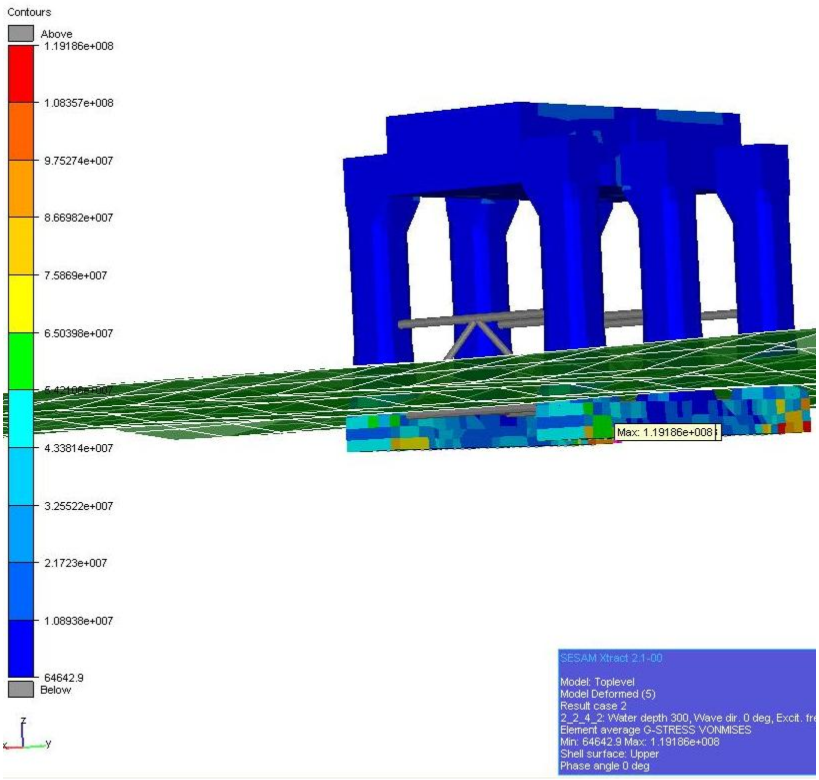


Figure 46 Max Von Mises element average stress Contour Plot Following Sea (Load case 2_4)

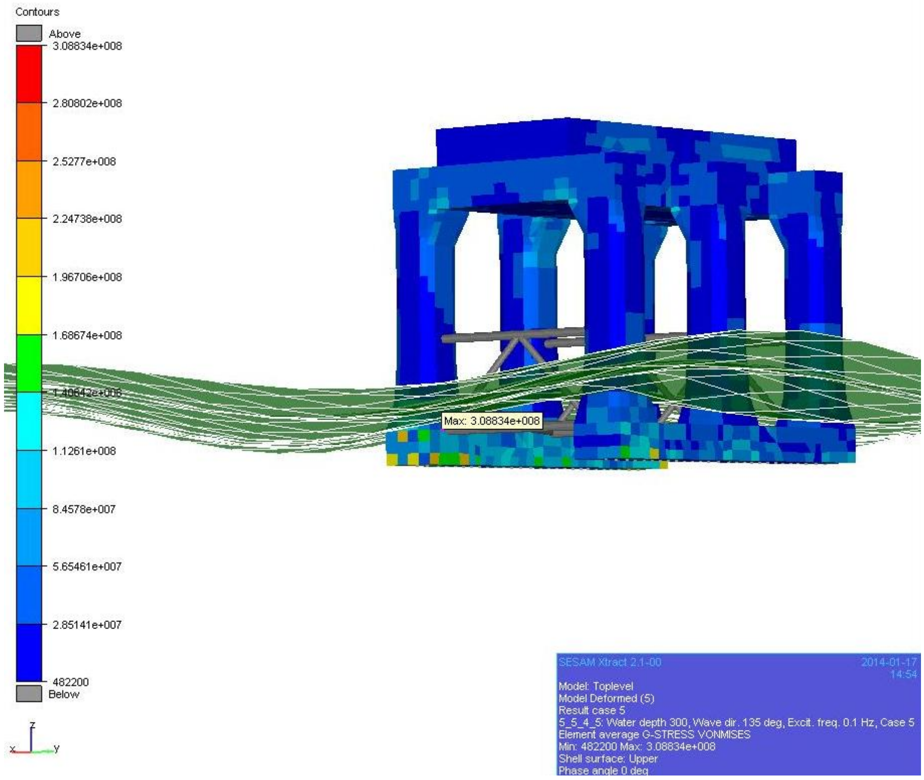


Figure 47 Max Von Mises element average stress Contour Plot Quarter Sea (Load case 5_4)

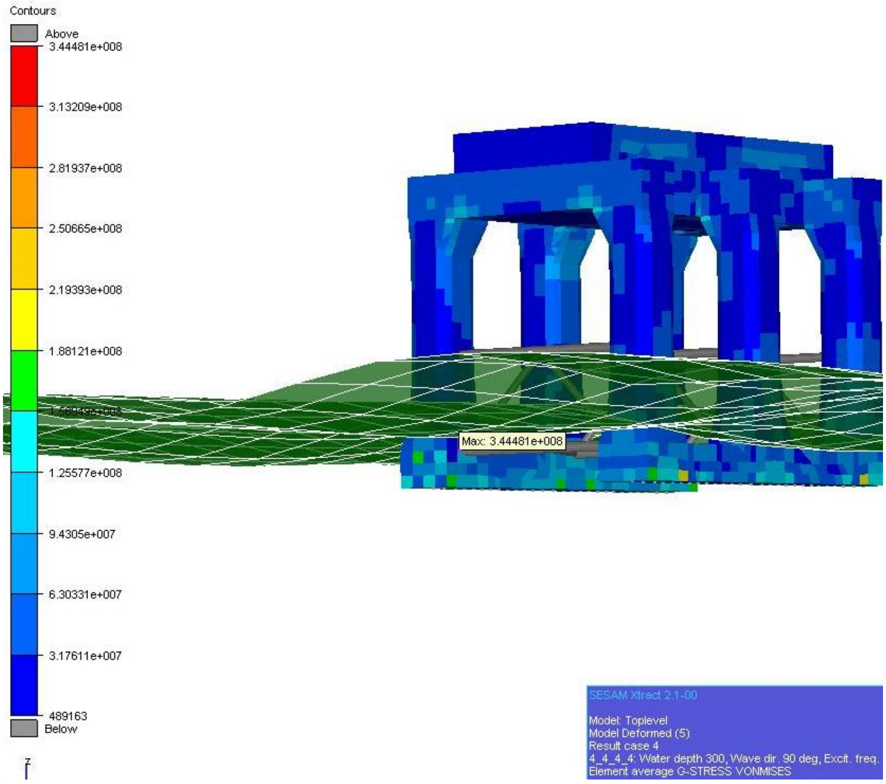


Figure 48 Max Von Mises element average stress Contour Plot Beam Sea (Load case 4_4)

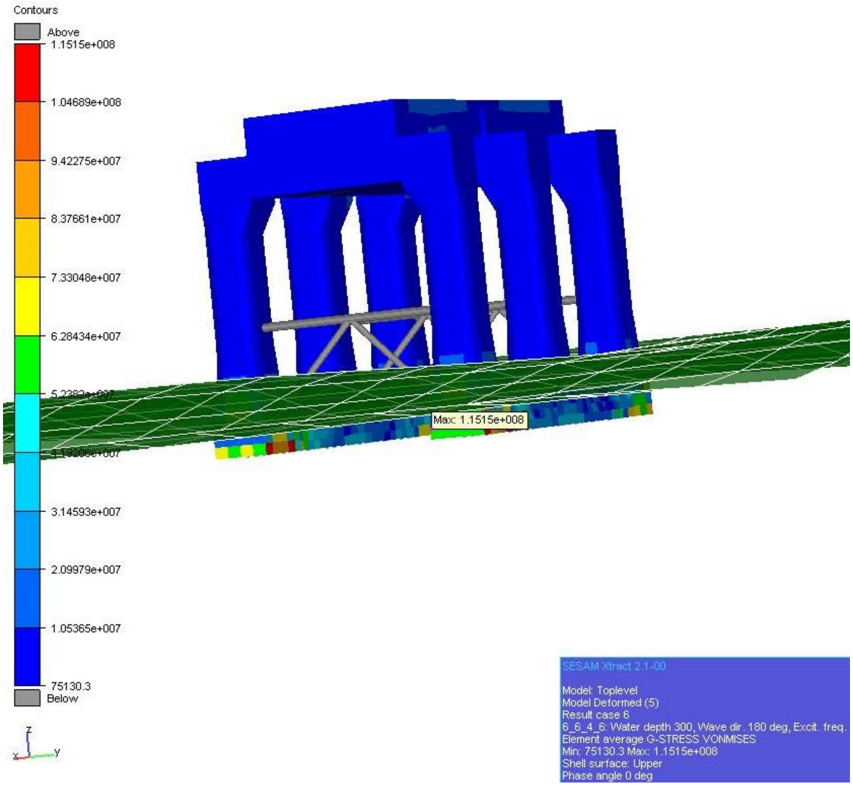


Figure 49 Max Von Mises element average stress Contour Plot Head Sea (Load case 6_4)

8. RESULTS AND CALCULATION

A yield check was performed based on the shell von Mises stresses (element average) induced in the structural elements of the semisubmersible platform analyzed with extreme wave induced load effects. The focus of the yield utilization and the stress distribution has been kept for the sub assembly of columns, pontoons, and bracing connections as it is the region exposed in the range of impact of the wave loading. The structural loading due to wave induced effects for various load cases were scanned in order to find the maximum element average Von Mises stress. The results are presented for the panels for each of the three key sub assembly of the semisubmersible platform namely the pontoon, column and deck assembly. However it has been observed that due to various structural simplifications of the FEA model and assumptions adopted during the analysis set up, the yield utilization at some of the elements has been close or higher than the yield strength of the structural material and it has been presented as it is in this section. It should also be noted that stress distribution regions around the yield strength determined by the current set of global response analysis just gives an indication of the actual stress distribution. However, a non-linear local finite element method analysis needs to be carried out in order to trace the full extent of the plastic zone or region with stress distribution close to the ultimate yield strength in the semisubmersible platform. Moreover with the current global structural model the maximum stresses may have indicated the local stress concentrations (caused by the modeling simplifications or lack of the local reinforcements added to the structure) and may not represent the precise stress level in the actual structure.

Recalling the action or the load factor from Chapter 4, applied for the ULS-b limit state for WSD and LRFD method we can rewrite the equation of utilization factor for the structural elements under the wave induced loading in extreme environmental conditions as

$$UF_{WSD} = (\sigma v - m)/(\sigma y/1.67) * 1.33) \quad (17)$$

$$UF_{LFRD} = (\sigma v - m) * 1.3/(\sigma y/1.15 \ ) \quad (18)$$

Where $\sigma v - m$ is the Von Mises Element Average Stress, σy is the yield stress of the structural material of high strength steel

Table 11 presents result set of the comparison of the von Mises stresses. It can be seen, that the utilization calculated based on the maximum observed stress is slightly higher for the LRFD runs Comparison of the utilizations calculated based on the stresses in the middle of the panel yielded close correlation between the results for WSD and LRFD utilizations (about 16%).It is worth mentioning, that the comparison is based on one sample loading condition only – extreme 100-yr wave loading for the central North Sea region (ULS-b for the LRFD method) and is only reflective of the magnitudes of the static and dynamic loadings on this structure.

The results set has been given for the subassemblies of the pontoon, column and deck structure under different wave heading cases for head, following, beam and quartering seas state with respect to the north of the semisubmersible platform.

Table 11 Indicative values of Element Average Von Mises Stress in the Semisubmersible Platform

Wave Heading	**Panel**	**Quasi-Static Structural Stress [MPa]**	**Yield Utilisation**		**Load Case Description**
			WSD	**LRFD**	
Head Sea (Wave 180 Deg)	Pontoon	115.55	0.41	0.49	6_3
	Column	62.84	0.22	0.26	6_3
	Deck	52.38	0.19	0.22	6_3
Following Sea(Wave 0 Deg)	Pontoon	119.19	0.42	0.50	2_3
	Column	65.04	0.23	0.27	2_3
	Deck	54.21	0.19	0.23	2_3
Beam Sea (Wave 90 Deg)	Pontoon	281.94	1.00	1.19	4_3
	Column	344.48	1.22	1.45	4_3
	Deck	156.84	0.55	0.66	4_3
Quarter Sea(Wave 45 Deg)	Pontoon	252.77	0.89	1.06	3_3
	Column	308.83	1.09	1.30	3_3
	Deck	140.642	0.50	0.59	3_3

9. CONCLUSION AND RECOMMENDATIONS

This study covers the scope of work of presenting the analysis procedures to perform a global response analysis for a twin pontoon type semisubmersible for evaluating the response to the extreme environmental wave loading on the structure. Various relevant offshore standards have been taken as a reference for modelling global structural model and performing the global response analysis.

The following salient conclusions have been made from the thesis work:

1. Global response analysis based on frequency domain set up is one of the preliminary methods to evaluate the response of the offshore floating structure to a given set of environment loading. This method can be used in the offshore structure industry as a front end engineering tool to predict the appropriate motion response for operations and estimating the effect of extreme environmental loading onto the structural integrity of the platform.

2. The motion response of the semisubmersible is a critical factor for a lot of operations and maintenance work during working of the drilling platform. It has been concluded that the heave is one of the most significant motion response for the offshore floating structure like semisubmersible for the deck clearance requirements and operations of drilling equipments. The heave response has been particularly found out critical in the case of head sea(wave heading 180 degrees to the platform longitudinal axis) or following sea situations (wave heading 0 degrees) and the peak response at 8 seconds is in coherence with the theoretical natural resonance period of 7.95 seconds.

3. Transferring the hydrodynamic loading on to the finite element structural model composed of beam and structural elements of the semisubmersible platform is one useful way to quantify the wave induced loading for initial estimation of design loads. It is particularly of importance when the platform is supposed to operating under harsh and extreme climatic conditions such as North Sea where the environmental loading is significantly higher than the other permanent or variable loads of the offshore structure. This thesis work has laid down the procedures to perform one such set of global response analysis under extreme conditions.

4. To check the impact of the environmental loading on semisubmersible platform, a formulation to calculate the yield utilization of structural components has been presented in the Chapter 8 of the master thesis. The results obtained using these formulation based on associated load and safety factors have been analyzed as the sub assembly of pontoon and column exposed to the wave loading near the mean sea level experiences the highest stress distribution range. However in some of the load-cases the yield utilization in some of structural components due to the wave induced loading has been estimated to be close or above the yield strength of the structure. This could be accounted for the assumptions and simplifications in the geometric modeling of the structure leading to some stress concentration.

5. The maximum stress level due to wave induced loading were found to be occurring at around similar wave frequency range for which the extreme motion response of the platform was investigated (f= 0.125-0.1 Hz or T= 8-10 sec).This result is in accordance with the theoretical behavior of structure under global loads as the natural resonance period of motion response of the vessel lies in this frequency range.

6. Offshore standards corresponding to design guidance of semisubmersibles platforms advocates two different design philosophies for the structural integrity strength of the structure, namely WSD and LRFD methods. The yield utilization in terms of Von Mises Element Average Stress in the elements for the hydrodynamic extreme wave loading of semisubmersible platform was observed to be about 16 % higher following LRFD approach as compared to the WSD approach. Therefore, it can be concluded that the WSD method can produce more conservative designs than the LRFD methodology for storm conditions when the stress due to environmental loading is significantly higher than that associated with well-defined dead loads or weights

7. In the current set of analysis the connection region between column and pontoons, bracing and column/pontoons have been found critical to wave loading. The worst case scenario in terms of stress distribution (344 MPa) has been observed to occur in beam sea scenario at the lower section of the column leg sub-assembly in connection with pontoons of the semisubmersible platform.

There have been also some points for recommendations based on this master thesis work, which are as follows

1. The global structural analysis based on the wave induced loading is a preliminary method for identifying the critical zones related to the structural integrity of the semisubmersible. However a more detailed local non- linear finite element analysis is recommended for more precise information regarding structural strength in these critical zones as in the global structural model stress concentration caused by the modeling simplifications or lack of the local reinforcements may not represent the actual state of stress distribution in the structural members.

2. More case studies of different environmental loading scenarios including wind, current effects would add considerable value to the current piece of work. Moreover it is recommended that the structure should also be analyzed for other limit states scenarios like accidental, fatigue and serviceability as given in the Chapter 4 of this thesis.

3. An additional study of the global response analysis with in depth specific calculations including the effects of mooring lines and riser system would be imparting further accuracy to the analysis. These effects have not been included in the current scope of work to allow completing the case study under the available resources limits.

4. Based on the similar set of theoretical concepts, the present work could be used as a platform to perform the global response analysis on other types of offshore floating structures like TLP, Spars and FPSO etc.

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10. Static and dynamic analysis of the Semisubmersible type floaters for Offshore wind turbine by C.Mayilvahanan and R.Panneer Selvam

Software Related

11. DNV Sesam GeniE Version 6.5-04 Software (2013) – GeniE user manual
12. DNV Sesam HydroD Version 4.5 Software (2013) – HydroD user manual
13. DNV Sesam Wadam Version 9.0 Software (2013) – Wadam user manual
14. DNV Sesam Xtract Version 9.0 Software (2013) – Xtract user manual
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Technical data

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Standard & Codes

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41. www.gazprom.com Picture for Semisubmersible
42. http://www.worldmaritimenews.com Picture for Jack-up drilling rigs
43. www.dft.gov.uk Picture for Drill ships
44. http://www.marineinsight.com Picture for Spar Platform
45. www.bluewater.com Picture for FPSO's Vessel
46. www.offshore.frigstad.com Picture Frigstad Deepwater Rig1 7th Generation semisubmersible drilling unit
47. www.offshore-technology.com/ Picture of mooring system of Semisubmersible
48. www.dockwise.com/Picture for One of the modes of Semisubmersible Platform Transportation

APPENDIX

The analysis run and output files have been added in support of the master thesis work in this section. These files have been added here on account to their larger size. The list of the analysis files added in this section are as follows

Table 12 List of run and output files from analysis

File Name	Description
Summary of Hydrodynamic Model	Summary of The hydrodynamic analysis file which accounts for setting up the wave induced loading on the semisubmersible platform for the extreme wave spectrum applied. This part has been taken from the Wadam run file.
RAOs	The Global Motion Response files which includes the response of the platform in terms of surge, sway, heave, roll, pitch, yaw motion. This file has been exported from the Postresp postprocessor

Appendix A Summary of Model Properties

ALL COORDINATES ARE GIVEN IN THE INPUT COORDINATE SYSTEM

THE RADII OF GYRATION AND CENTRIFUGAL MOMENTS OF THE MASS MATRIX AND THE RESTORING COEFFICIENTS ARE GIVEN RELATIVE TO THE MOTION REFERENCE POINT (ORIGIN OF THE GLOBAL COORDINATE SYSTEM).

UNITS DATA:

ACCELERATION OF GRAVITY G = 9.80665E+00 [L/T**2]

WATER DENSITY RHO = 1.02500E+03 [M/L**3]

GEOMETRY DATA:

CHARACTERISTIC LENGTH L = 9.23000E+01 [L]

VERTICAL COORDINATE OF STILL WATER LINE -ZLOC = 0.00000E+00 [L]

NUMBER OF NODES IN THE MORISON MODEL NMNOD = 318

NUMBER OF MORISON ELEMENTS NMELM = 7

7 PRESSURE AREA ELEMENTS

NUMBER OF MORISON SUBELEMENTS NMSEL = 7

NUMBER OF BASIC PANELS = 1088

NUMBER OF SYMMETRY PLANES IN THE PANEL MODEL = 0

TOTAL NUMBER OF PANELS = 1088

MASS PROPERTIES AND STRUCTURAL DATA:

MASS OF THE STRUCTURE M = 9.77198E+06 [M]

WEIGHT OF THE STRUCTURE M*G = 9.58304E+07 [M*L/T**2]
WATER PLANE AREA WPLA = 1.66268E+03 [L**2]

CENTRE OF GRAVITY
XG = 3.26393E-01[L]
YG = 6.62722E-15 [L]
ZG =-4.76885E+00 [L]

ROLL RADIUS OF GYRATION XRAD = 3.66785E+01 [L]

PITCH RADIUS OF GYRATION YRAD = 4.06848E+01 [L]

YAW RADIUS OF GYRATION ZRAD = 4.81304E+01 [L]

ROLL-PITCH CENTRIFUGAL MOMENT XYRAD = 5.61326E-04 [L**2]

ROLL-YAW CENTRIFUGAL MOMENT XZRAD = 5.91753E+01 [L**2]

PITCH-YAW CENTRIFUGAL MOMENT YZRAD = 5.50294E-02 [L**2]

HYDROSTATIC DATA

DISPLACED VOLUME VOL = 9.53789E+03 [L**3]

MASS OF DISPLACED VOLUME RHO*VOL = 9.77634E+06 [M]

WATER PLANE AREA WPLA = 1.66268E+03 [L**2]

CENTRE OF BUOYANCY
XCB = -1.10732E-07 [L]
YCB =-1.75096E-06 [L]
ZCB =-3.52451E+00 [L]

TRANSVERSE METACENTRIC HEIGHT GM4 = 1.60250E+02 [L]

LONGITUDINAL METACENTRIC HEIGHT GM5 = 3.41588E+00 [L]

HEAVE-HEAVE RESTORING COEFFICIENT C33 = 1.67130E+07 [M/T**2]

HEAVE-ROLL RESTORING COEFFICIENT C34 = 7.41873E+00 [M*L/T**2]

HEAVE-PITCH RESTORING COEFFICIENT C35 =-1.90932E+01 [M*L/T**2]

ROLL-ROLL RESTORING COEFFICIENT C44 = 1.53636E+10 [M*L**2/T**2]

PITCH-PITCH RESTORING COEFFICIENT C55 = 3.27491E+08 [M*L**2/T**2]

ROLL-PITCH RESTORING COEFFICIENT C45 = 6.91517E+03 [M*L**2/T**2]

ENVIRONMENTAL DATA

WATER DEPTH = 3.00000E+02 [L]
NUMBER OF WAVE LENGTHS = 11
NUMBER OF HEADING ANGLES = 8
WAVE SPECTRUM TYPE: PIERSON-MOSKOWITZ
Zero up crossing period (given): 11.36
Spectral peak period (calc): 15.99

	WAVE LENGTH	WAVE NUMBER	WAVE PERIOD	WAVE ANG. FREQUENCY
1	2.49724E+01	2.51605E-01	4.00000E+00	1.57080E+00
2	5.61880E+01	1.11824E-01	6.00000E+00	1.04720E+00
3	9.98897E+01	6.29012E-02	8.00000E+00	7.85398E-01
4	1.56078E+02	4.02568E-02	1.00000E+01	6.28319E-01
5	2.24752E+02	2.79561E-02	1.20000E+01	5.23599E-01
6	3.05910E+02	2.05394E-02	1.40000E+01	4.48799E-01
7	3.99495E+02	1.57278E-02	1.60000E+01	3.92699E-01
8	5.05112E+02	1.24392E-02	1.80000E+01	3.49066E-01
9	6.21422E+02	1.01110E-02	2.00000E+01	3.14159E-01
10	7.45838E+02	8.42433E-03	2.20000E+01	2.85599E-01
11	8.75123E+02	7.17977E-03	2.40000E+01	2.61799E-01

HEADING ANGLES (ANGLE BETWEEN POS. X-AXIS AND DIRECTION OF WAVE PROPAGATION):

	IN DEGREES	IN RADIANS
1	0.00000E+00	0.00000E+00
2	4.50000E+01	7.85398E-01
3	9.00000E+01	1.57080E+00
4	1.35000E+02	2.35619E+00
5	1.80000E+02	3.14159E+00
6	2.25000E+02	3.92699E+00
7	2.70000E+02	4.71239E+00
8	3.15000E+02	5.49779E+00

WAVE SPREADING FUNCTION: USER-DEFINED
Weight = 1 means long-crested

Direction	Weight
0.00	0.250
45.00	0.475
90.00	0.250
135.00	0.012
180.00	0.000
225.00	0.000
270.00	0.000
315.00	0.012

Appendix B Response amplitude operators (RAOs) of the semisubmersible

Name WaveDir	Period	RealVal	ImagVal	Amplitude	Phase
HEAVE 0	24	1.14E+00	-1.08E-03	1.14E+00	-0.054
	22	1.16E+00	-2.13E-03	1.16E+00	-0.105
	20	1.18E+00	-4.60E-03	1.18E+00	-0.223
	18	1.22E+00	-1.11E-02	1.22E+00	-0.519
	16	1.28E+00	-3.01E-02	1.28E+00	-1.343
	14	1.39E+00	-9.41E-02	1.39E+00	-3.884
	12	1.50E+00	-3.17E-01	1.53E+00	-11.923
	10	1.30E+00	-6.29E-01	1.45E+00	-25.77
	8	5.34E-01	-1.87E+00	1.94E+00	-74.033
	6	1.47E-01	1.39E-01	2.02E-01	43.546
	4	-9.15E-03	-2.27E-02	2.45E-02	-111.942
HEAVE 45	24	1.13E+00	-1.07E-03	1.13E+00	-0.054
	22	1.14E+00	-2.06E-03	1.14E+00	-0.104
	20	1.15E+00	-4.35E-03	1.15E+00	-0.217
	18	1.17E+00	-1.02E-02	1.17E+00	-0.499
	16	1.20E+00	-2.69E-02	1.20E+00	-1.282
	14	1.24E+00	-8.06E-02	1.25E+00	-3.714
	12	1.22E+00	-2.51E-01	1.25E+00	-11.598
	10	8.08E-01	-3.93E-01	8.99E-01	-25.927
	8	3.03E-01	-2.07E-02	3.03E-01	-3.908
	6	2.97E-02	5.18E-03	3.02E-02	9.885
	4	1.44E-02	6.23E-02	6.40E-02	77.033
HEAVE 90	24	1.11E+00	-1.09E-03	1.11E+00	-0.056
	22	1.11E+00	-2.03E-03	1.11E+00	-0.105
	20	1.12E+00	-4.17E-03	1.12E+00	-0.213
	18	1.12E+00	-9.50E-03	1.12E+00	-0.484
	16	1.12E+00	-2.43E-02	1.12E+00	-1.241
	14	1.10E+00	-7.01E-02	1.10E+00	-3.652
	12	9.43E-01	-2.03E-01	9.65E-01	-12.17
	10	2.00E-01	-1.93E-01	2.78E-01	-44.027
	8	-1.05E-01	2.90E+00	2.90E+00	92.07
	6	4.37E-02	4.65E-01	4.67E-01	84.638
	4	-9.79E-02	-1.08E-01	1.46E-01	-132.123
HEAVE 135	24	1.13E+00	-1.22E-03	1.13E+00	-0.062
	22	1.14E+00	-2.24E-03	1.14E+00	-0.113
	20	1.15E+00	-4.57E-03	1.15E+00	-0.228
	18	1.17E+00	-1.05E-02	1.17E+00	-0.513
	16	1.20E+00	-2.73E-02	1.20E+00	-1.3
	14	1.24E+00	-8.12E-02	1.25E+00	-3.74
	12	1.22E+00	-2.52E-01	1.25E+00	-11.634
	10	8.08E-01	-3.94E-01	8.99E-01	-25.995
	8	3.01E-01	-2.02E-02	3.01E-01	-3.836
	6	3.10E-02	4.42E-03	3.13E-02	8.11
	4	1.36E-02	6.20E-02	6.35E-02	77.609
HEAVE 180	24	1.14E+00	-1.30E-03	1.14E+00	-0.065
	22	1.16E+00	-2.40E-03	1.16E+00	-0.119

	20	1.18E+00	-4.95E-03	1.18E+00	-0.24
	18	1.22E+00	-1.15E-02	1.22E+00	-0.541
	16	1.28E+00	-3.07E-02	1.28E+00	-1.373
	14	1.39E+00	-9.52E-02	1.39E+00	-3.927
	12	1.50E+00	-3.19E-01	1.53E+00	-11.988
	10	1.30E+00	-6.32E-01	1.45E+00	-25.889
	8	5.18E-01	-1.87E+00	1.94E+00	-74.537
	6	1.45E-01	1.40E-01	2.02E-01	43.93
	4	-8.65E-03	-2.24E-02	2.40E-02	-111.079
HEAVE 225	24	1.13E+00	-1.21E-03	1.13E+00	-0.062
	22	1.14E+00	-2.23E-03	1.14E+00	-0.113
	20	1.15E+00	-4.57E-03	1.15E+00	-0.228
	18	1.17E+00	-1.05E-02	1.17E+00	-0.513
	16	1.20E+00	-2.73E-02	1.20E+00	-1.3
	14	1.24E+00	-8.12E-02	1.25E+00	-3.739
	12	1.22E+00	-2.52E-01	1.25E+00	-11.633
	10	8.08E-01	-3.94E-01	8.99E-01	-25.982
	8	3.03E-01	-2.11E-02	3.03E-01	-3.98
	6	3.09E-02	4.40E-03	3.13E-02	8.095
	4	1.44E-02	6.22E-02	6.38E-02	76.969
HEAVE 270	24	1.11E+00	-1.09E-03	1.11E+00	-0.056
	22	1.11E+00	-2.03E-03	1.11E+00	-0.104
	20	1.12E+00	-4.17E-03	1.12E+00	-0.213
	18	1.12E+00	-9.49E-03	1.12E+00	-0.484
	16	1.12E+00	-2.43E-02	1.12E+00	-1.24
	14	1.10E+00	-7.01E-02	1.10E+00	-3.651
	12	9.43E-01	-2.03E-01	9.65E-01	-12.168
	10	2.00E-01	-1.93E-01	2.78E-01	-44.011
	8	-1.05E-01	2.90E+00	2.90E+00	92.07
	6	4.37E-02	4.65E-01	4.68E-01	84.638
	4	-9.79E-02	-1.08E-01	1.46E-01	-132.112
HEAVE 315	24	1.13E+00	-1.06E-03	1.13E+00	-0.054
	22	1.14E+00	-2.05E-03	1.14E+00	-0.104
	20	1.15E+00	-4.35E-03	1.15E+00	-0.216
	18	1.17E+00	-1.02E-02	1.17E+00	-0.498
	16	1.20E+00	-2.69E-02	1.20E+00	-1.281
	14	1.24E+00	-8.06E-02	1.25E+00	-3.714
	12	1.22E+00	-2.51E-01	1.25E+00	-11.597
	10	8.08E-01	-3.93E-01	8.99E-01	-25.934
	8	3.01E-01	-1.98E-02	3.01E-01	-3.759
	6	2.98E-02	5.18E-03	3.02E-02	9.875
	4	1.37E-02	6.21E-02	6.36E-02	77.556
PITCH 0	24	1.02E-02	-4.10E-01	4.10E-01	-88.57
	22	1.07E-02	-4.03E-01	4.03E-01	-88.486
	20	1.17E-02	-4.04E-01	4.04E-01	-88.339
	18	1.40E-02	-4.12E-01	4.13E-01	-88.053
	16	1.91E-02	-4.30E-01	4.31E-01	-87.464
	14	3.04E-02	-4.59E-01	4.60E-01	-86.211
	12	5.68E-02	-5.01E-01	5.04E-01	-83.536
	10	1.16E-01	-5.49E-01	5.61E-01	-78.089
	8	1.87E-01	-5.54E-01	5.84E-01	-71.323

	6	1.21E-01	-1.46E-01	1.89E-01	-50.248
	4	-8.61E-02	-5.64E-02	1.03E-01	-146.792
PITCH 45	24	9.84E-03	-2.75E-01	2.76E-01	-87.954
	22	1.00E-02	-2.66E-01	2.67E-01	-87.842
	20	1.07E-02	-2.60E-01	2.61E-01	-87.651
	18	1.22E-02	-2.56E-01	2.56E-01	-87.278
	16	1.55E-02	-2.51E-01	2.52E-01	-86.481
	14	2.27E-02	-2.42E-01	2.43E-01	-84.66
	12	3.75E-02	-2.20E-01	2.24E-01	-80.339
	10	5.82E-02	-1.66E-01	1.76E-01	-70.693
	8	1.37E-02	-7.00E-03	1.54E-02	-27.077
	6	-1.41E-01	1.42E-01	2.00E-01	134.837
	4	-2.21E-02	1.96E-02	2.95E-02	138.536
PITCH 90	24	9.04E-03	1.06E-03	9.10E-03	6.668
	22	8.78E-03	9.77E-04	8.83E-03	6.355
	20	8.55E-03	8.96E-04	8.60E-03	5.982
	18	8.36E-03	7.94E-04	8.39E-03	5.429
	16	8.14E-03	6.22E-04	8.17E-03	4.368
	14	7.80E-03	2.32E-04	7.80E-03	1.701
	12	6.57E-03	-7.21E-04	6.61E-03	-6.26
	10	1.80E-03	-7.73E-04	1.96E-03	-23.255
	8	-1.16E-03	1.90E-02	1.91E-02	93.498
	6	2.44E-04	3.18E-03	3.19E-03	85.613
	4	-8.97E-04	-8.68E-04	1.25E-03	-135.929
PITCH 135	24	8.44E-03	2.77E-01	2.77E-01	88.254
	22	7.80E-03	2.68E-01	2.68E-01	88.331
	20	6.85E-03	2.62E-01	2.62E-01	88.5
	18	5.20E-03	2.57E-01	2.57E-01	88.842
	16	1.93E-03	2.52E-01	2.52E-01	89.56
	14	-5.07E-03	2.42E-01	2.42E-01	91.199
	12	-2.05E-02	2.18E-01	2.19E-01	95.387
	10	-4.67E-02	1.61E-01	1.68E-01	106.15
	8	-9.81E-03	6.62E-03	1.18E-02	145.998
	6	1.41E-01	-1.42E-01	2.00E-01	-45.08
	4	2.31E-02	-1.81E-02	2.93E-02	-38.11
PITCH 180	24	8.25E-03	4.10E-01	4.10E-01	88.847
	22	7.47E-03	4.03E-01	4.03E-01	88.938
	20	6.25E-03	4.04E-01	4.04E-01	89.112
	18	4.03E-03	4.12E-01	4.12E-01	89.44
	16	-5.42E-04	4.30E-01	4.30E-01	90.072
	14	-1.08E-02	4.58E-01	4.58E-01	91.355
	12	-3.61E-02	4.97E-01	4.98E-01	94.155
	10	-9.85E-02	5.40E-01	5.49E-01	100.334
	8	-1.80E-01	5.29E-01	5.59E-01	108.8
	6	-1.19E-01	1.48E-01	1.90E-01	128.942
	4	8.61E-02	5.62E-02	1.03E-01	33.15
PITCH 225	24	8.44E-03	2.75E-01	2.76E-01	88.244
	22	7.80E-03	2.66E-01	2.67E-01	88.322
	20	6.85E-03	2.60E-01	2.60E-01	88.492
	18	5.20E-03	2.56E-01	2.56E-01	88.836

	16	1.94E-03	2.51E-01	2.51E-01	89.558
	14	-5.07E-03	2.41E-01	2.41E-01	91.204
	12	-2.06E-02	2.17E-01	2.18E-01	95.42
	10	-4.74E-02	1.61E-01	1.68E-01	106.425
	8	-1.01E-02	6.78E-03	1.21E-02	146.034
	6	1.41E-01	-1.42E-01	2.00E-01	-45.065
	4	2.24E-02	-1.86E-02	2.91E-02	-39.698
PITCH 270	24	9.04E-03	-1.08E-03	9.11E-03	-6.779
	22	8.78E-03	-1.01E-03	8.84E-03	-6.558
	20	8.55E-03	-9.59E-04	8.61E-03	-6.401
	18	8.36E-03	-9.33E-04	8.41E-03	-6.373
	16	8.15E-03	-9.68E-04	8.20E-03	-6.773
	14	7.80E-03	-1.21E-03	7.90E-03	-8.776
	12	6.54E-03	-2.03E-03	6.84E-03	-17.217
	10	1.03E-03	-1.63E-03	1.93E-03	-57.773
	8	-1.39E-03	1.91E-02	1.92E-02	94.165
	6	1.20E-04	3.26E-03	3.26E-03	87.892
	4	-5.50E-04	-6.98E-04	8.88E-04	-128.226
PITCH 315	24	9.84E-03	-2.77E-01	2.77E-01	-87.964
	22	1.00E-02	-2.68E-01	2.68E-01	-87.853
	20	1.07E-02	-2.62E-01	2.62E-01	-87.663
	18	1.22E-02	-2.57E-01	2.58E-01	-87.291
	16	1.55E-02	-2.53E-01	2.53E-01	-86.496
	14	2.27E-02	-2.43E-01	2.44E-01	-84.681
	12	3.75E-02	-2.21E-01	2.24E-01	-80.386
	10	5.75E-02	-1.67E-01	1.76E-01	-70.954
	8	1.34E-02	-6.82E-03	1.51E-02	-26.908
	6	-1.41E-01	1.42E-01	2.00E-01	134.826
	4	-2.29E-02	1.92E-02	2.99E-02	140.06
ROLL 0	24	-5.64E-05	5.70E-05	8.01E-05	134.695
	22	-5.27E-05	6.44E-05	8.32E-05	129.277
	20	-4.95E-05	7.36E-05	8.87E-05	123.952
	18	-4.93E-05	8.47E-05	9.80E-05	120.191
	16	-5.44E-05	9.94E-05	1.13E-04	118.673
	14	-7.38E-05	1.26E-04	1.46E-04	120.287
	12	-1.14E-04	2.19E-04	2.47E-04	117.412
	10	3.28E-04	4.28E-04	5.39E-04	52.525
	8	1.82E-04	-5.73E-05	1.91E-04	-17.465
	6	-4.06E-05	7.28E-05	8.33E-05	119.139
	4	2.84E-04	2.01E-04	3.47E-04	35.297
ROLL 45	24	-5.43E-04	-3.90E-01	3.90E-01	-90.08
	22	-8.05E-04	-4.66E-01	4.66E-01	-90.099
	20	-1.37E-03	-5.73E-01	5.73E-01	-90.137
	18	-2.77E-03	-7.30E-01	7.30E-01	-90.217
	16	-7.19E-03	-9.77E-01	9.77E-01	-90.422
	14	-2.86E-02	-1.42E+00	1.42E+00	-91.155
	12	-2.43E-01	-2.47E+00	2.48E+00	-95.614
	10	-4.85E+00	-2.89E+00	5.65E+00	-149.226
	8	-1.50E+00	3.08E-01	1.54E+00	168.426

		6	6.60E-02	1.07E-01	1.26E-01	58.347
		4	-1.43E-01	6.94E-02	1.59E-01	154.06
ROLL	90	24	-2.99E-04	-5.49E-01	5.49E-01	-90.031
		22	-5.32E-04	-6.55E-01	6.55E-01	-90.047
		20	-1.09E-03	-8.04E-01	8.04E-01	-90.078
		18	-2.61E-03	-1.02E+00	1.02E+00	-90.146
		16	-7.59E-03	-1.35E+00	1.35E+00	-90.321
		14	-3.15E-02	-1.93E+00	1.93E+00	-90.935
		12	-2.66E-01	-3.24E+00	3.25E+00	-94.693
		10	-5.50E+00	-4.07E+00	6.84E+00	-143.509
		8	-2.02E+00	-4.22E-01	2.07E+00	-168.228
		6	7.49E-02	-1.84E-01	1.99E-01	-67.821
		4	-1.97E-01	2.92E-01	3.52E-01	124.051
ROLL	135	24	8.64E-05	-3.90E-01	3.90E-01	-89.987
		22	1.61E-05	-4.66E-01	4.66E-01	-89.998
		20	-2.36E-04	-5.73E-01	5.73E-01	-90.024
		18	-1.10E-03	-7.30E-01	7.30E-01	-90.086
		16	-4.51E-03	-9.77E-01	9.77E-01	-90.264
		14	-2.37E-02	-1.42E+00	1.42E+00	-90.957
		12	-2.32E-01	-2.47E+00	2.48E+00	-95.354
		10	-4.84E+00	-2.92E+00	5.66E+00	-148.891
		8	-1.51E+00	2.96E-01	1.54E+00	168.889
		6	4.42E-02	8.64E-02	9.70E-02	62.918
		4	-1.40E-01	6.94E-02	1.56E-01	153.596
ROLL	180	24	-5.43E-05	-5.67E-05	7.85E-05	-133.743
		22	-4.82E-05	-6.40E-05	8.01E-05	-126.979
		20	-4.06E-05	-7.27E-05	8.32E-05	-119.18
		18	-2.89E-05	-8.32E-05	8.81E-05	-109.186
		16	-6.45E-06	-9.61E-05	9.64E-05	-93.836
		14	4.85E-05	-1.20E-04	1.30E-04	-68.015
		12	1.99E-04	-2.38E-04	3.10E-04	-50.123
		10	-3.59E-04	-9.89E-04	1.05E-03	-109.96
		8	-3.08E-04	4.57E-05	3.12E-04	171.576
		6	9.70E-05	-1.13E-04	1.49E-04	-49.36
		4	-3.05E-04	-2.36E-04	3.86E-04	-142.303
ROLL	225	24	-1.98E-04	3.90E-01	3.90E-01	90.029
		22	-1.17E-04	4.66E-01	4.66E-01	90.014
		20	1.48E-04	5.73E-01	5.73E-01	89.985
		18	1.03E-03	7.30E-01	7.30E-01	89.919
		16	4.47E-03	9.77E-01	9.77E-01	89.738
		14	2.37E-02	1.42E+00	1.42E+00	89.041
		12	2.32E-01	2.47E+00	2.48E+00	84.64
		10	4.84E+00	2.92E+00	5.66E+00	31.099
		8	1.51E+00	-2.97E-01	1.54E+00	-11.121
		6	-4.38E-02	-8.60E-02	9.65E-02	-117.021
		4	1.40E-01	-6.92E-02	1.56E-01	-26.279
ROLL	270	24	1.84E-04	5.49E-01	5.49E-01	89.981
		22	4.25E-04	6.55E-01	6.55E-01	89.963
		20	9.93E-04	8.04E-01	8.04E-01	89.929
		18	2.51E-03	1.02E+00	1.02E+00	89.859

	16	7.50E-03	1.35E+00	1.35E+00	89.683
	14	3.15E-02	1.93E+00	1.93E+00	89.068
	12	2.66E-01	3.24E+00	3.25E+00	85.308
	10	5.50E+00	4.07E+00	6.84E+00	36.491
	8	2.02E+00	4.22E-01	2.07E+00	11.769
	6	-7.50E-02	1.84E-01	1.99E-01	112.193
	4	1.97E-01	-2.92E-01	3.52E-01	-55.95
ROLL 315	24	4.29E-04	3.90E-01	3.90E-01	89.937
	22	6.98E-04	4.66E-01	4.66E-01	89.914
	20	1.27E-03	5.73E-01	5.73E-01	89.873
	18	2.67E-03	7.30E-01	7.30E-01	89.791
	16	7.08E-03	9.77E-01	9.77E-01	89.585
	14	2.84E-02	1.42E+00	1.42E+00	88.851
	12	2.42E-01	2.47E+00	2.48E+00	84.392
	10	4.85E+00	2.89E+00	5.65E+00	30.782
	8	1.50E+00	-3.08E-01	1.54E+00	-11.563
	6	-6.62E-02	-1.07E-01	1.26E-01	-121.668
	4	1.42E-01	-6.96E-02	1.58E-01	-26.057
SURGE 0	24	6.82E-03	-2.62E+00	2.62E+00	-89.851
	22	1.06E-02	-2.52E+00	2.52E+00	-89.758
	20	1.76E-02	-2.41E+00	2.41E+00	-89.583
	18	3.03E-02	-2.29E+00	2.29E+00	-89.24
	16	5.39E-02	-2.11E+00	2.11E+00	-88.538
	14	9.72E-02	-1.86E+00	1.86E+00	-87.012
	12	1.70E-01	-1.49E+00	1.50E+00	-83.512
	10	2.45E-01	-9.64E-01	9.95E-01	-75.764
	8	1.09E-01	-2.34E-01	2.58E-01	-65.088
	6	-4.05E-02	1.36E-01	1.41E-01	106.654
	4	-1.57E-02	1.76E-02	2.36E-02	131.734
SURGE 45	24	5.55E-03	-1.84E+00	1.84E+00	-89.828
	22	8.29E-03	-1.77E+00	1.77E+00	-89.732
	20	1.32E-02	-1.70E+00	1.70E+00	-89.554
	18	2.21E-02	-1.60E+00	1.60E+00	-89.209
	16	3.83E-02	-1.48E+00	1.48E+00	-88.514
	14	6.64E-02	-1.29E+00	1.30E+00	-87.061
	12	1.06E-01	-1.03E+00	1.03E+00	-84.102
	10	1.11E-01	-6.48E-01	6.57E-01	-80.304
	8	1.18E-02	-6.26E-02	6.37E-02	-79.349
	6	-2.90E-02	-6.68E-02	7.29E-02	-113.492
	4	7.97E-03	-2.14E-02	2.28E-02	-69.557
SURGE 90	24	1.44E-03	1.47E-03	2.06E-03	45.538
	22	1.51E-03	1.43E-03	2.08E-03	43.489
	20	1.60E-03	1.41E-03	2.13E-03	41.288
	18	1.72E-03	1.38E-03	2.20E-03	38.759
	16	1.86E-03	1.35E-03	2.30E-03	36.007
	14	2.03E-03	1.32E-03	2.43E-03	32.99
	12	2.22E-03	1.29E-03	2.56E-03	30.147
	10	2.53E-03	9.55E-04	2.71E-03	20.662
	8	1.67E-03	3.80E-03	4.16E-03	66.302

	6	2.32E-03	4.13E-04	2.36E-03	10.087
	4	-1.04E-04	-3.24E-05	1.09E-04	-162.688
SURGE 135	24	-4.20E-03	1.85E+00	1.85E+00	90.131
	22	-7.02E-03	1.77E+00	1.77E+00	90.227
	20	-1.20E-02	1.70E+00	1.70E+00	90.406
	18	-2.11E-02	1.61E+00	1.61E+00	90.754
	16	-3.75E-02	1.48E+00	1.48E+00	91.453
	14	-6.59E-02	1.30E+00	1.30E+00	92.913
	12	-1.06E-01	1.03E+00	1.03E+00	95.898
	10	-1.12E-01	6.47E-01	6.56E-01	99.787
	8	-1.51E-02	6.21E-02	6.39E-02	103.695
	6	2.74E-02	6.65E-02	7.19E-02	67.626
	4	-7.13E-03	2.15E-02	2.27E-02	108.356
SURGE 180	24	-7.00E-03	2.62E+00	2.62E+00	90.153
	22	-1.11E-02	2.52E+00	2.52E+00	90.253
	20	-1.84E-02	2.41E+00	2.41E+00	90.437
	18	-3.16E-02	2.29E+00	2.29E+00	90.793
	16	-5.59E-02	2.11E+00	2.11E+00	91.516
	14	-1.00E-01	1.86E+00	1.86E+00	93.079
	12	-1.74E-01	1.49E+00	1.50E+00	96.659
	10	-2.52E-01	9.62E-01	9.94E-01	104.657
	8	-1.17E-01	2.30E-01	2.58E-01	116.981
	6	3.76E-02	-1.36E-01	1.41E-01	-74.516
	4	1.47E-02	-1.77E-02	2.30E-02	-50.387
SURGE 225	24	-4.20E-03	1.84E+00	1.84E+00	90.13
	22	-7.01E-03	1.77E+00	1.77E+00	90.227
	20	-1.20E-02	1.70E+00	1.70E+00	90.406
	18	-2.11E-02	1.60E+00	1.60E+00	90.754
	16	-3.75E-02	1.48E+00	1.48E+00	91.453
	14	-6.59E-02	1.29E+00	1.30E+00	92.915
	12	-1.06E-01	1.03E+00	1.03E+00	95.909
	10	-1.12E-01	6.46E-01	6.56E-01	99.866
	8	-1.49E-02	6.26E-02	6.43E-02	103.43
	6	2.72E-02	6.67E-02	7.20E-02	67.792
	4	-7.18E-03	2.15E-02	2.27E-02	108.45
SURGE 270	24	1.45E-03	-1.47E-03	2.06E-03	-45.463
	22	1.52E-03	-1.44E-03	2.09E-03	-43.359
	20	1.62E-03	-1.41E-03	2.15E-03	-41.073
	18	1.75E-03	-1.39E-03	2.23E-03	-38.435
	16	1.91E-03	-1.37E-03	2.35E-03	-35.525
	14	2.11E-03	-1.36E-03	2.51E-03	-32.742
	12	2.23E-03	-1.41E-03	2.64E-03	-32.296
	10	1.57E-03	-8.11E-04	1.77E-03	-27.313
	8	2.07E-03	3.21E-03	3.81E-03	57.22
	6	2.41E-03	8.72E-04	2.56E-03	19.938
	4	-1.02E-05	-1.87E-04	1.87E-04	-93.105
SURGE 315	24	5.55E-03	-1.85E+00	1.85E+00	-89.828
	22	8.30E-03	-1.77E+00	1.77E+00	-89.732
	20	1.32E-02	-1.70E+00	1.70E+00	-89.554
	18	2.22E-02	-1.61E+00	1.61E+00	-89.209

	16	3.83E-02	-1.48E+00	1.48E+00	-88.515
	14	6.64E-02	-1.30E+00	1.30E+00	-87.063
	12	1.06E-01	-1.03E+00	1.03E+00	-84.112
	10	1.10E-01	-6.48E-01	6.57E-01	-80.383
	8	1.20E-02	-6.21E-02	6.33E-02	-79.1
	6	-2.92E-02	-6.67E-02	7.28E-02	-113.657
	4	7.92E-03	-2.14E-02	2.28E-02	-69.657
SWAY 0	24	1.88E-06	-1.41E-03	1.41E-03	-89.924
	22	9.31E-06	-1.37E-03	1.37E-03	-89.612
	20	1.95E-05	-1.34E-03	1.34E-03	-89.167
	18	3.12E-05	-1.30E-03	1.30E-03	-88.625
	16	5.05E-05	-1.24E-03	1.24E-03	-87.661
	14	8.45E-05	-1.13E-03	1.14E-03	-85.728
	12	1.45E-04	-9.59E-04	9.70E-04	-81.38
	10	1.04E-04	-6.78E-04	6.86E-04	-81.311
	8	-8.97E-06	6.42E-05	6.48E-05	97.956
	6	-2.52E-04	3.49E-04	4.31E-04	125.806
	4	-2.32E-04	1.59E-04	2.82E-04	145.609
SWAY 45	24	-1.30E-04	-2.17E-01	2.17E-01	-90.034
	22	-1.58E-04	-1.94E-01	1.94E-01	-90.047
	20	-1.99E-04	-1.64E-01	1.64E-01	-90.07
	18	-2.32E-04	-1.20E-01	1.20E-01	-90.111
	16	-8.07E-05	-5.14E-02	5.14E-02	-90.09
	14	1.98E-03	7.15E-02	7.15E-02	88.415
	12	3.66E-02	3.51E-01	3.53E-01	84.048
	10	1.06E+00	6.02E-01	1.22E+00	29.57
	8	3.44E-01	-1.49E-01	3.75E-01	-23.436
	6	4.43E-02	-2.41E-02	5.04E-02	-28.587
	4	1.57E-02	-3.56E-03	1.61E-02	-12.801
SWAY 90	24	-1.21E-04	-3.06E-01	3.06E-01	-90.023
	22	-1.71E-04	-2.73E-01	2.73E-01	-90.036
	20	-2.49E-04	-2.30E-01	2.30E-01	-90.062
	18	-3.35E-04	-1.69E-01	1.69E-01	-90.114
	16	-2.28E-04	-7.25E-02	7.25E-02	-90.18
	14	2.03E-03	9.74E-02	9.74E-02	88.808
	12	4.01E-02	4.70E-01	4.72E-01	85.129
	10	1.20E+00	9.01E-01	1.50E+00	36.877
	8	4.62E-01	2.11E-01	5.08E-01	24.515
	6	-1.84E-01	5.38E-01	5.68E-01	108.83
	4	7.08E-02	-9.11E-02	1.15E-01	-52.162
SWAY 135	24	-4.37E-05	-2.15E-01	2.15E-01	-90.012
	22	-8.51E-05	-1.92E-01	1.92E-01	-90.025
	20	-1.55E-04	-1.62E-01	1.62E-01	-90.055
	18	-2.55E-04	-1.19E-01	1.19E-01	-90.123
	16	-2.62E-04	-4.96E-02	4.96E-02	-90.302
	14	1.39E-03	7.31E-02	7.31E-02	88.912
	12	3.47E-02	3.53E-01	3.55E-01	84.384
	10	1.06E+00	6.10E-01	1.22E+00	29.948
	8	3.46E-01	-1.46E-01	3.75E-01	-22.873
	6	4.52E-02	-2.11E-02	4.99E-02	-24.958
	4	1.46E-02	-3.10E-03	1.49E-02	-11.985

SWAY 180	24	-5.00E-06	1.41E-03	1.41E-03	90.203
	22	-9.77E-07	1.37E-03	1.37E-03	90.041
	20	8.80E-07	1.34E-03	1.34E-03	89.962
	18	-1.84E-06	1.30E-03	1.30E-03	90.081
	16	-1.34E-05	1.24E-03	1.24E-03	90.619
	14	-4.37E-05	1.13E-03	1.13E-03	92.216
	12	-1.19E-04	9.52E-04	9.60E-04	97.136
	10	-6.57E-05	7.86E-04	7.89E-04	94.779
	8	5.14E-05	-8.08E-05	9.58E-05	-57.566
	6	2.53E-04	-3.48E-04	4.30E-04	-54.024
	4	2.25E-04	-1.59E-04	2.75E-04	-35.264
SWAY 225	24	3.79E-05	2.17E-01	2.17E-01	89.99
	22	8.75E-05	1.94E-01	1.94E-01	89.974
	20	1.64E-04	1.64E-01	1.64E-01	89.943
	18	2.62E-04	1.20E-01	1.20E-01	89.875
	16	2.55E-04	5.14E-02	5.14E-02	89.715
	14	-1.43E-03	-7.15E-02	7.16E-02	-91.148
	12	-3.48E-02	-3.51E-01	3.53E-01	-95.66
	10	-1.06E+00	-6.09E-01	1.22E+00	-150.101
	8	-3.46E-01	1.46E-01	3.75E-01	157.091
	6	-4.53E-02	2.19E-02	5.03E-02	154.273
	4	-1.50E-02	3.54E-03	1.55E-02	166.765
SWAY 270	24	1.20E-04	3.06E-01	3.06E-01	89.978
	22	1.82E-04	2.73E-01	2.73E-01	89.962
	20	2.71E-04	2.30E-01	2.30E-01	89.933
	18	3.66E-04	1.69E-01	1.69E-01	89.876
	16	2.66E-04	7.25E-02	7.25E-02	89.79
	14	-1.99E-03	-9.74E-02	9.74E-02	-91.168
	12	-4.00E-02	-4.70E-01	4.72E-01	-94.866
	10	-1.20E+00	-9.01E-01	1.50E+00	-143.123
	8	-4.62E-01	-2.11E-01	5.08E-01	-155.49
	6	1.84E-01	-5.38E-01	5.68E-01	-71.169
	4	-7.08E-02	9.11E-02	1.15E-01	127.843
SWAY 315	24	1.31E-04	2.15E-01	2.15E-01	89.965
	22	1.76E-04	1.92E-01	1.92E-01	89.947
	20	2.33E-04	1.62E-01	1.62E-01	89.917
	18	2.85E-04	1.19E-01	1.19E-01	89.862
	16	1.62E-04	4.96E-02	4.96E-02	89.813
	14	-1.85E-03	-7.31E-02	7.31E-02	-91.451
	12	-3.64E-02	-3.52E-01	3.54E-01	-95.896
	10	-1.06E+00	-6.03E-01	1.22E+00	-150.381
	8	-3.44E-01	1.49E-01	3.75E-01	156.601
	6	-4.42E-02	2.33E-02	4.99E-02	152.196
	4	-1.52E-02	3.08E-03	1.55E-02	168.556
YAW 0	24	1.17E-02	-9.50E-06	1.17E-02	-0.047
	22	9.60E-03	-1.70E-05	9.60E-03	-0.101
	20	7.66E-03	-3.18E-05	7.66E-03	-0.238
	18	5.85E-03	-6.02E-05	5.85E-03	-0.59
	16	4.12E-03	-1.19E-04	4.12E-03	-1.651
	14	2.41E-03	-2.32E-04	2.42E-03	-5.504

		12	4.93E-04	-3.22E-04	5.89E-04	-33.165
		10	-1.32E-03	2.68E-04	1.35E-03	168.522
		8	-9.51E-04	2.69E-04	9.88E-04	164.186
		6	4.25E-04	-5.54E-04	6.99E-04	-52.479
		4	-5.85E-05	-1.13E-04	1.27E-04	-117.463
YAW	45	24	6.70E-02	-6.35E-03	6.73E-02	-5.421
		22	7.20E-02	-7.53E-03	7.24E-02	-5.967
		20	7.96E-02	-9.20E-03	8.02E-02	-6.592
		18	9.03E-02	-1.17E-02	9.10E-02	-7.378
		16	1.04E-01	-1.57E-02	1.06E-01	-8.542
		14	1.21E-01	-2.29E-02	1.23E-01	-10.688
		12	1.35E-01	-3.93E-02	1.41E-01	-16.22
		10	7.07E-02	-3.88E-02	8.07E-02	-28.726
		8	8.36E-02	6.26E-02	1.04E-01	36.815
		6	2.54E-01	2.28E-01	3.41E-01	41.843
		4	-4.35E-02	1.01E-03	4.35E-02	178.668
YAW	90	24	1.20E-02	-8.94E-03	1.50E-02	-36.714
		22	9.97E-03	-1.06E-02	1.45E-02	-46.67
		20	8.10E-03	-1.29E-02	1.52E-02	-57.805
		18	6.37E-03	-1.62E-02	1.74E-02	-68.583
		16	4.71E-03	-2.14E-02	2.19E-02	-77.608
		14	2.85E-03	-3.04E-02	3.05E-02	-84.643
		12	-2.19E-03	-5.03E-02	5.03E-02	-92.488
		10	-8.10E-02	-6.23E-02	1.02E-01	-142.424
		8	-2.90E-02	-8.64E-03	3.02E-02	-163.41
		6	5.02E-03	-5.99E-03	7.81E-03	-50.043
		4	-4.16E-03	5.55E-03	6.94E-03	126.844
YAW	135	24	-4.33E-02	-6.35E-03	4.38E-02	-171.65
		22	-5.24E-02	-7.52E-03	5.30E-02	-171.842
		20	-6.38E-02	-9.17E-03	6.45E-02	-171.83
		18	-7.81E-02	-1.16E-02	7.89E-02	-171.562
		16	-9.55E-02	-1.53E-02	9.67E-02	-170.89
		14	-1.16E-01	-2.18E-02	1.18E-01	-169.376
		12	-1.40E-01	-3.72E-02	1.45E-01	-165.067
		10	-2.14E-01	-4.99E-02	2.20E-01	-166.897
		8	-1.25E-01	-5.69E-02	1.38E-01	-155.561
		6	-2.53E-01	-2.24E-01	3.37E-01	-138.487
		4	3.82E-02	1.22E-03	3.83E-02	1.82
YAW	180	24	1.17E-02	-1.65E-05	1.17E-02	-0.081
		22	9.60E-03	-2.39E-05	9.60E-03	-0.143
		20	7.66E-03	-3.67E-05	7.66E-03	-0.274
		18	5.85E-03	-6.37E-05	5.85E-03	-0.624
		16	4.12E-03	-1.20E-04	4.12E-03	-1.668
		14	2.41E-03	-2.30E-04	2.42E-03	-5.452
		12	4.96E-04	-3.18E-04	5.89E-04	-32.616
		10	-1.33E-03	2.68E-04	1.36E-03	168.643
		8	-9.64E-04	2.94E-04	1.01E-03	163.029
		6	4.18E-04	-5.35E-04	6.79E-04	-51.969
		4	-5.77E-05	-1.23E-04	1.36E-04	-115.125
YAW	225	24	6.70E-02	6.32E-03	6.73E-02	5.395

		22	7.20E-02	7.47E-03	7.24E-02	5.925
		20	7.96E-02	9.10E-03	8.02E-02	6.517
		18	9.03E-02	1.15E-02	9.11E-02	7.231
		16	1.05E-01	1.51E-02	1.06E-01	8.22
		14	1.22E-01	2.14E-02	1.24E-01	9.939
		12	1.42E-01	3.67E-02	1.47E-01	14.463
		10	2.14E-01	5.01E-02	2.20E-01	13.162
		8	1.26E-01	5.71E-02	1.38E-01	24.476
		6	2.54E-01	2.25E-01	3.39E-01	41.487
		4	-3.83E-02	-1.46E-03	3.84E-02	-177.813
YAW	270	24	1.20E-02	8.92E-03	1.50E-02	36.628
		22	9.98E-03	1.05E-02	1.45E-02	46.533
		20	8.13E-03	1.28E-02	1.52E-02	57.593
		18	6.44E-03	1.61E-02	1.74E-02	68.237
		16	4.92E-03	2.12E-02	2.18E-02	76.949
		14	3.76E-03	3.00E-02	3.03E-02	82.857
		12	5.67E-03	4.98E-02	5.01E-02	83.502
		10	8.16E-02	6.22E-02	1.03E-01	37.317
		8	2.63E-02	8.42E-03	2.76E-02	17.75
		6	-5.75E-03	5.31E-03	7.82E-03	137.295
		4	3.92E-03	-5.43E-03	6.70E-03	-54.193
YAW	315	24	-4.33E-02	6.33E-03	4.37E-02	171.675
		22	-5.24E-02	7.49E-03	5.30E-02	171.866
		20	-6.38E-02	9.14E-03	6.45E-02	171.85
		18	-7.80E-02	1.16E-02	7.89E-02	171.556
		16	-9.53E-02	1.55E-02	9.66E-02	170.791
		14	-1.15E-01	2.25E-02	1.18E-01	168.979
		12	-1.33E-01	3.88E-02	1.38E-01	163.703
		10	-7.08E-02	3.90E-02	8.08E-02	151.147
		8	-8.32E-02	-6.23E-02	1.04E-01	-143.189
		6	-2.53E-01	-2.27E-01	3.40E-01	-138.135
		4	4.34E-02	-1.29E-03	4.34E-02	-1.696

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