University of
Stavanger

Faculty of Science and Technology

MASTER'S THESIS

<table>
<tr><td>Study program/ Specialization:

Offshore Technology
Marine and Subsea Technology</td><td>Spring semester, 2012

Open</td></tr>
<tr><td>Writer:
Alexey A. Ozorishin</td><td>…………………………………………
(Writer's signature)</td></tr>
<tr><td colspan="2">Faculty supervisor: Professor Ove Tobias Gudmestad

External supervisor(s): Professor Anatoly Borisovich Zolotukhin (Gubkin University)</td></tr>
<tr><td colspan="2">Titel of thesis:

FSO Concept for Shallow Waters in the Vietnam Offshore
Oilfield - Block Hanoi Trough - 02.</td></tr>
<tr><td colspan="2">Credits (ECTS):
30</td></tr>
<tr><td>Key words:

Shallow water, Floating Storage Offloading Unit, Stability, Moring System, Ansys Aqwa</td><td>Pages: 90

+enclosure: 122 + 4 video files

Stavanger, 15.06.2012
Date/year</td></tr>
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FSO Concept for Shallow Waters in the Vietnam Offshore

Oilfield - Block Hanoi Trough - 02.

Ozorishin, Alexey Alexandrovich, Master student.

Faculty of Science and Technology, University of Stavanger
Faculty of Oil and Gas Field Development, Gubkin Russian State University of Oil and Gas, Moscow

Abstract

Storage and offloading are integral parts of any oil and gas development project. This issue is more difficult and complex for offshore fields, because all or most parts of the equipment are located in the sea.

For Block Hanoi Trough - 02 there is no exception. All equipment is planned to be installed in the sea. However, FSO is the only floating unit in this oilfield. FSO is the cheapest solution, due to absence of the onshore infrastructure. However, cheapest solution does not mean the simplest one. Shallow water and severe weather conditions create challenges for a vessel. An unwanted development of events might have a catastrophic consequence.

The most input data regarding weather conditions and production rate are analyzed in the first part of the Thesis. Further general aspects of vessel such as types of hull, blocks of FSO, types of mooring systems are discussed in second part of the Thesis.

Last part is dedicated to engineering calculations. An FSO model is built using computer aided engineering systems *FastShip* and *Solidworks*. Model has natural sizes, including the volume of tanks and realistic mass properties. To evaluate wind loads a superstructure was build. Further model was exported to hydrodynamic system *Ansys Aqwa 14,* which is based on finite element model grids. Extreme weather data were the model input. Hydrostatic and hydrodynamic parameters of stability such as response amplitude operator were estimated. Also 2 possible mooring system designs were appreciate. Chains and anchor were calculated based on evaluating data. To reach the technical tasks international standards were used. All the necessary information about the weather data, area conditions and oilfield is provided by the oil company "Lukoil Overseas".

Conclusions summarize the obtained results, give a recommendation for increasing stability and reducing possible emergency situations.

Master thesis

Key words:
Shallow water, Floating Storage Offloading Unit, Stability, Moring System, Ansys Aqwa.

Acknowledgments

I would like to express thanks to my scientific supervisor from “University in Stavanger”, Professor Ove Tobias Gudmestad. I gained invaluable experience of the offshore industry from him. His courses “Marine Operations” and “Marine Technology” provide the basis for my Master thesis.

I am very grateful to my scientific advisor from “Gubkin Russian State University of Oil and Gas", Professor Anatoly Borisovich Zolotukhin for his good advices, creative approaches and responsive leadership.

I wish to give a special thanks to Senior Scientific Researcher from “Institute for Automation and Control Processes, Far Eastern Branch of the Russian Academy of Sciences”, Benjamin Mefodevich Dorozhko, who was my guide in the world of Computational Fluid Dynamics.

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1. Field Description

The offshore oilfield block Hanoi Through-02 (MVHN-02) is located on the shelf of the South China Sea in Northern Vietnamese waters, around 50 km to South East from Hai Phong Port, about 180 km from the planned Nghi Oil Refinery, approximately 550 km from Dung Quat Oil Refinery. The Oilfield Service center is located in Vung Tau about 1560 km south from the MVHN-02, transport takes 5 days sailing or 3 days by road.

The MVHN-02 area is 1185 m^2. Water depth is ranging from 0 to 20 m. The available territory above the oilfield (square foot allocation for field development) is around 250 000 Acres: this area is mainly offshore and is limited Onshore because of farming, seasonal rice paddies and villages. The MVHN-02 includes 3 structures: B31, B15+B28. The structures will development separately due to long distance between them (Fig. 1.1). Hereby only development of B31 is presented. Total reserves achieve 30 435 thousands TOE, average daily production rate is 462.8 TOE, Maximum production daily rate is 601. 3 TOE.

Development of B15+B28 is similar.

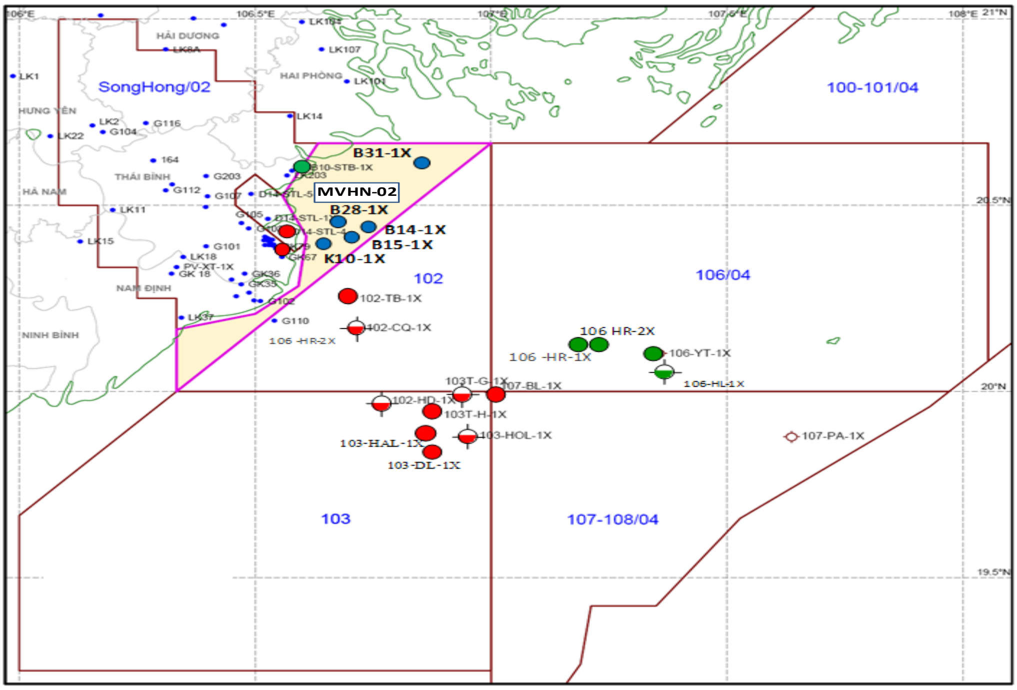


Figure 1.1 – Map of oilfields offshore Hai Phong, Northern Vietnam. This thesis relates to the development of B31-1X in Block MVHN-02

The development scheme includes a central mobile offshore production unit (MOPU), 14 satellite platforms and a floating storage and offloading unit (FSO). The MOPU will process dual phase fluid from all satellite platforms. The big number of satellites is determined by the small depth of the reservoirs (500-700m). Further processed oil will be transported to a FSO through a subsea pipeline. The FSO is located at 20 km from the MODU, where the depth is around 30m. The FSO is connected with the MODU by a pipeline. The oil product will be offloaded to shuttle tankers (Figure 1.2).

Associated gas will be used for the power system. Excesses gas will be injected back to the reservoir through 2 injection wells. Energy will be supplied to the FSO through cable. In case the cable will be broken, the FSO has diesel generators to support the working of the electrical centrifugal pump.

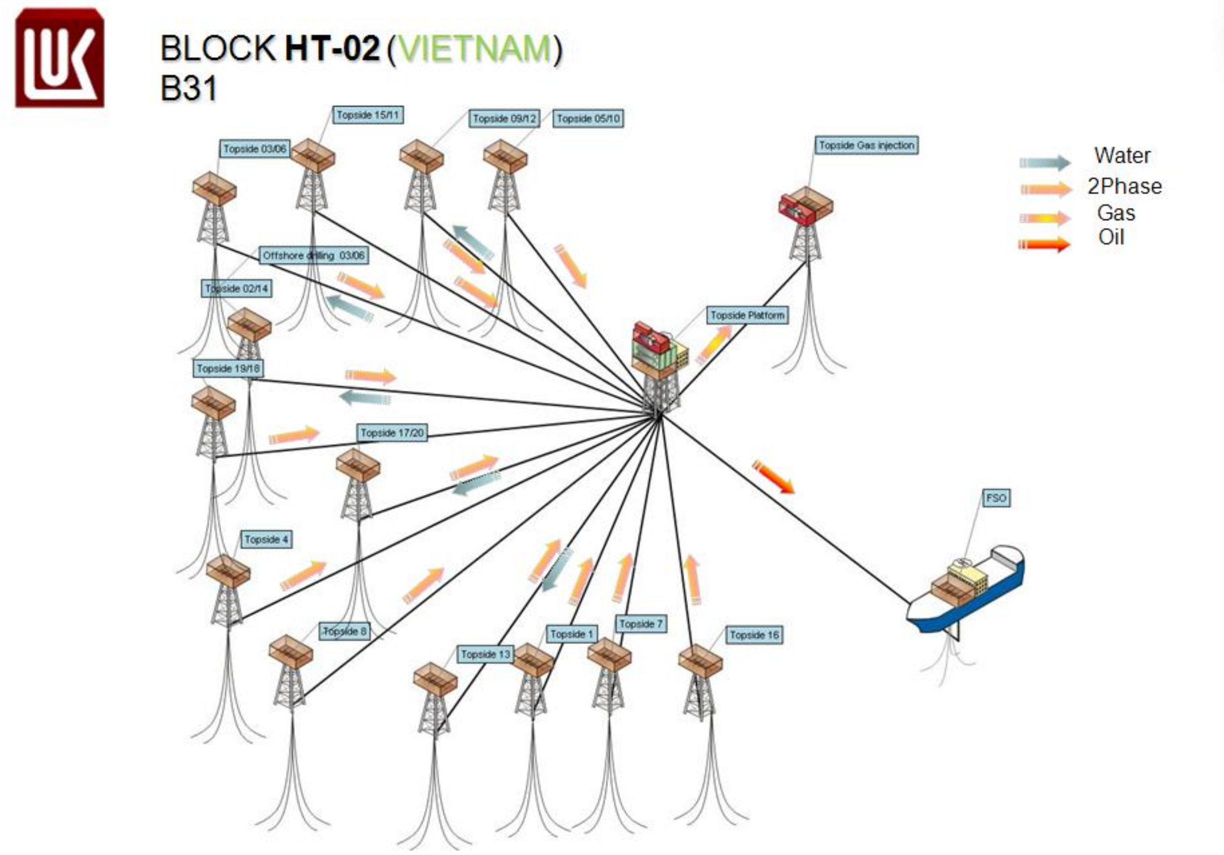


Figure 1.2 – Development scheme for field B31-1X in Block MVHN-02

The agreement between PetroVientam, Quad Energy S.A. and Lukoil Overseas was signed on 20.12.2007. Production period is 23 years and can be prolong to 28 years as by the agreement.

2. Metocean Data Analysis

2.1. Regional Overview

The meteorological and oceanographic conditions offshore Vietnam are generally dominated by monsoonal effects, with regional and local variations typically resulting from solar radiation, tidal currents and bathymetry. Squall and tropical storms are known to impact the area (Figure 2.1).

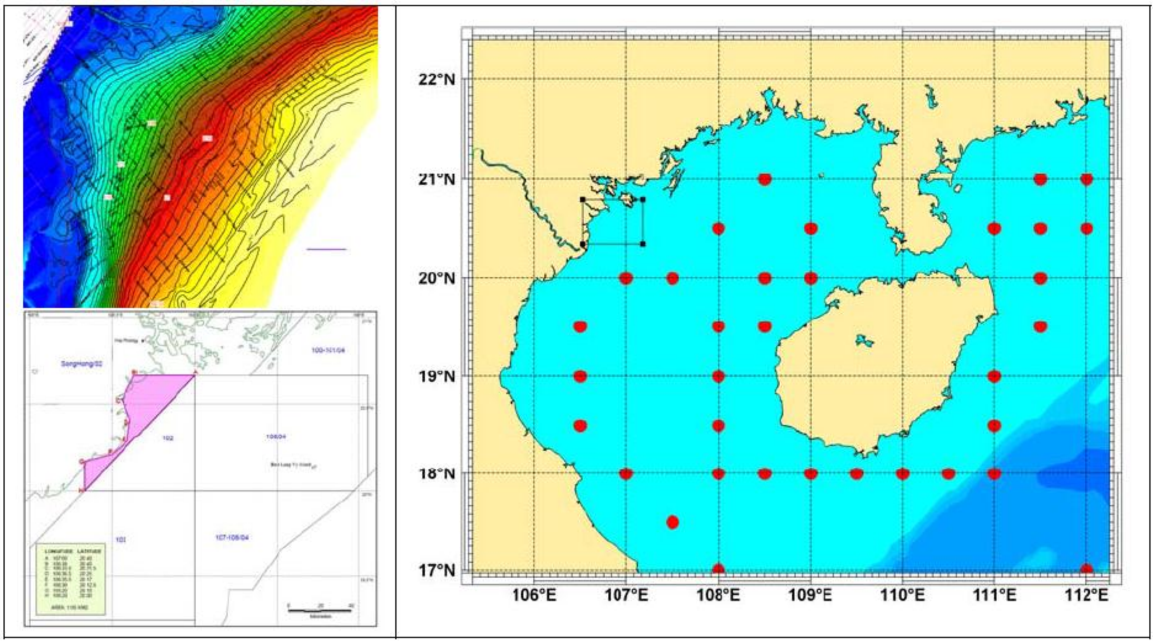


Figure 2.1 – Location of the Study [1].

2.2. Metocean Parameter Descriptions

Metocean parameters are to be described as given in Table 2.1

Table 2.1 Metocean parameter description

PARAMETER	UNITS	DESCRIPTION	COMMENTS
$Ws_{10\text{-}min}$	m/s	10-minute mean wind speed at 10m above sea level	Estimated using ISO relationships.
Hs	m	Significant wave height	Estimated from the wave energy spectrum, Hs = $4\sqrt{m_0}$. Equivalent to the mean height of the highest one-third of the waves in a sea-state.
Tp	s	Peak period	The period associated with the peak in the wave energy spectrum.
Tz	s	Mean zero-crossing period	Estimated from the wave energy spectrum, Tz = $\sqrt{m_0/m_2}$. The Tz values presented in this report are the associated zero-crossing period for the quoted Hs values.

Units and Conventions:

The following list describes the units and conventions used in this part.

- Wind speed is expressed in meters/second [m/s].
- Wind direction is expressed in compass points or degrees, relative to true North, and describes the direction from which the wind is travelling.
- Wave height is expressed in meters [m].
- Wave period is expressed in seconds [s].
- Wave direction is expressed in compass points or degrees, relative to true North, and describes the direction from which the waves were travelling.
- Current speeds are expressed in meters per second [m/s].
- Current direction is expressed in compass points or degrees, relative to true North, and describes the direction towards which the currents were flowing.

2.3. Currents

Most studies of the regional circulation in the Gulf of Tonkin have shown the north-easterly wind in the winter season forces a southward flow in the upper water column along the Vietnamese coast which is compensated by a northward flow in the interior and along the coast of Hainan [1]. This results in a cyclonic gyre across the entire basin. The flow pattern in the summer months is usually weaker but is generally accepted as weakly anti-cyclonic. However, some literature suggests that the flow remains weakly cyclonic in the summer owing to the flow through the Qiongzhou Strait, north of Hainan. Figure 2.2 shows the monthly distribution of the current speeds. Current speeds are low, below 0.25m/s for more than 93% of the year.

Current Speed at 0m (m/s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
> 0.45									0.10	0.09		
0.40–0.45	0.09								0.27	0.27	0.02	
0.35–0.40	0.22	0.17				0.06	0.16		0.33	0.45	0.77	0.22
0.30–0.35	1.37	0.57	0.23	0.26	0.78	2.55	1.87	1.96	0.86	1.12	2.52	1.65
0.25–0.30	5.38	3.46	2.14	3.58	4.22	6.33	6.73	5.90	3.45	3.27	4.48	4.22
0.20–0.25	7.20	8.42	7.71	7.67	9.10	8.41	9.28	10.77	8.60	8.18	8.61	7.97
0.15–0.20	13.16	14.20	13.35	13.72	12.88	14.79	14.38	14.15	16.06	14.38	14.82	13.70
0.10–0.15	21.10	21.22	22.57	23.84	23.67	26.80	26.67	25.46	24.05	23.91	22.23	22.29
0.05–0.10	30.69	31.75	35.06	33.92	30.57	31.39	29.52	31.51	31.44	30.61	30.28	29.28
0.00–0.05	20.81	20.21	18.94	17.00	18.77	9.68	11.39	10.25	14.84	17.73	16.27	20.67

Month

Figure 2.2 – Monthly occurrence of surface current [1].

2.4. Tropical Storms

Tropical revolving storms occur in the area of interest. The Joint Typhoon Warning Center database shows 72 storms since 1950 affecting the area within a radius of 100 nautical miles of the area of interest, Figure 2.3. The storms generally occur between May and November, Figure 2.4.

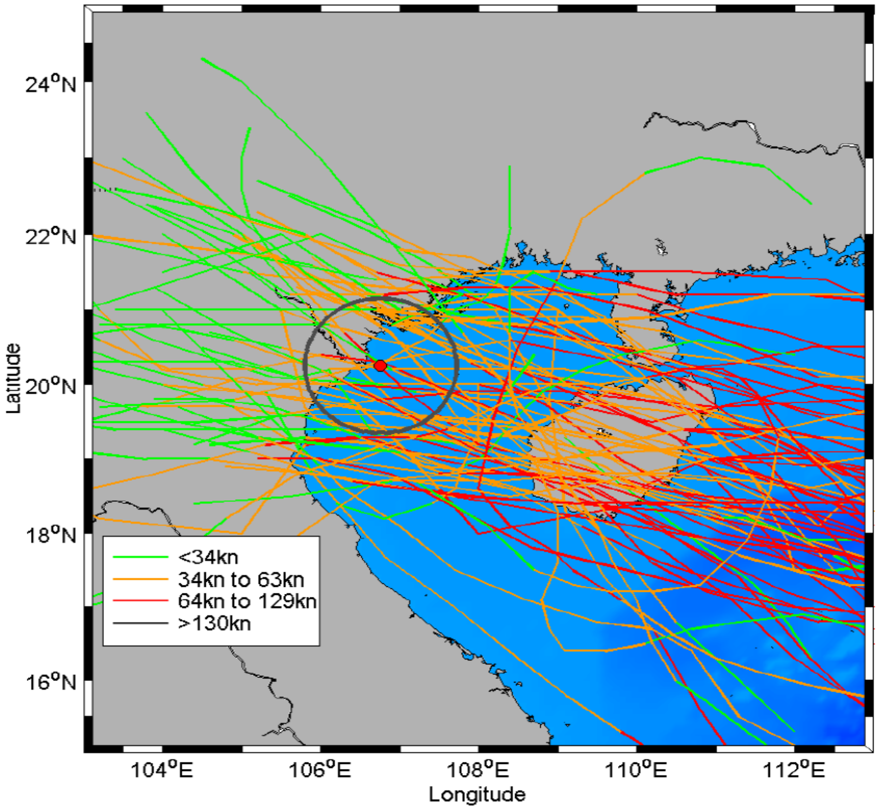


Figure 2.3 – Tropical storm track – within 100 km of the target location since 1950 [1]

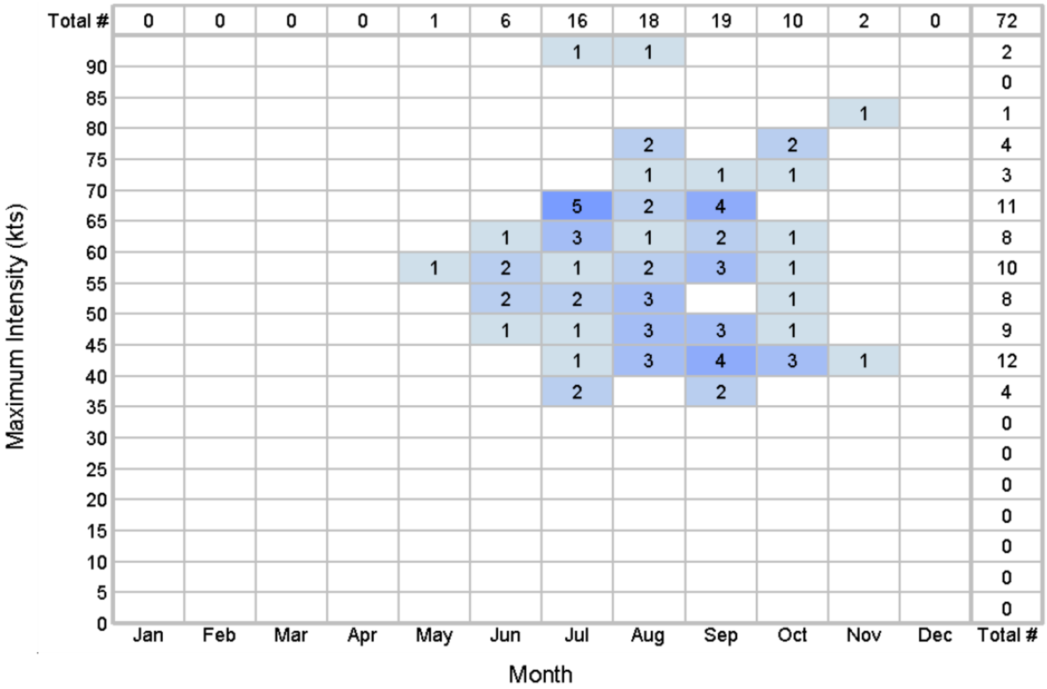


Figure 2.4 – Tropical storm occurrence [1]

2.5. Winds

Wind Speed and Direction for all year are shown in the figure 2.5 and 2.6.

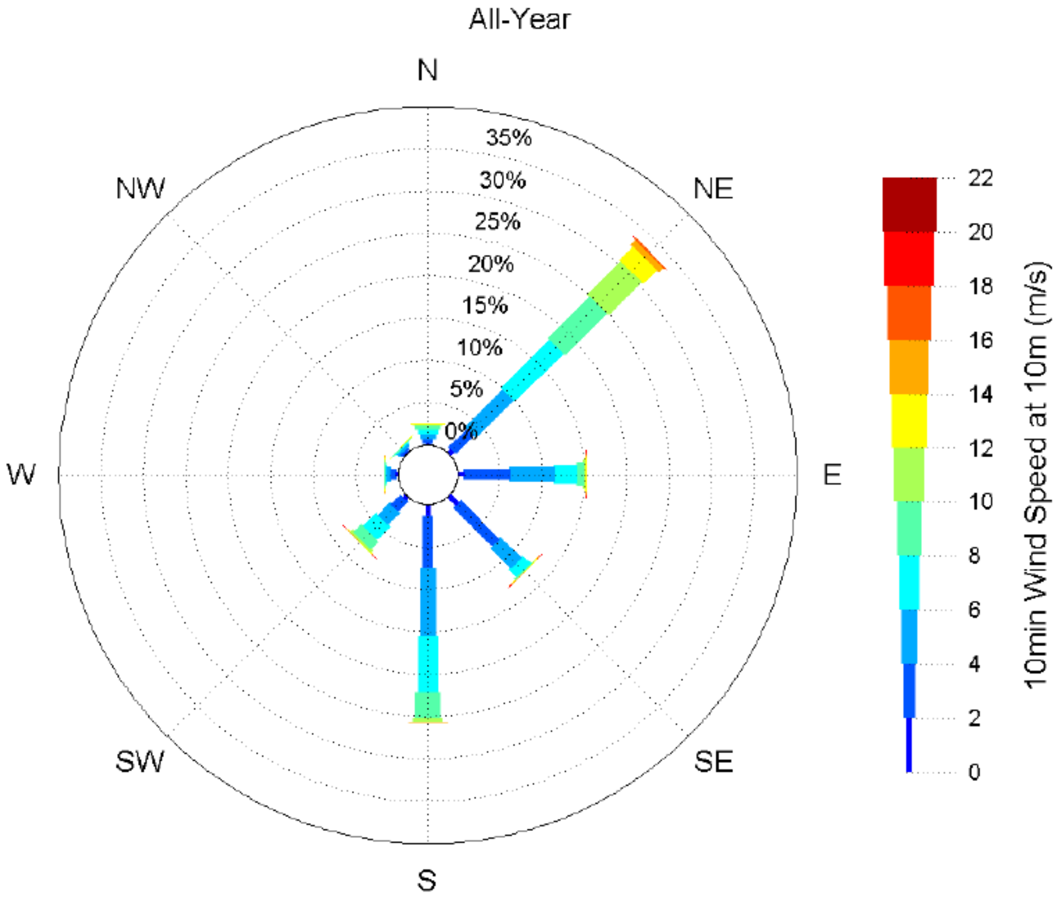


Figure 2.5 – Rose diagram Velocity and Direction [1]

All-Year

10min Wind Speed at 10m (m/s)	N	NE	E	SE	S	SW	W	NW	Total %	Exceed %
Total	2.54	33.54	15.18	12.60	25.75	7.77	1.59	1.02	100.00	
20+		<0.01							<0.01	
18–20										
16–18	<0.01	0.17	<0.01	<0.01		<0.01			0.20	0.21
14–16	0.05	0.73	0.02	0.02	0.02				0.83	1.04
12–14	0.09	2.29	0.04	0.02	0.07	0.04	<0.01		2.55	3.59
10–12	0.15	5.47	0.26	0.02	0.53	0.33	0.02	0.04	6.82	10.41
8–10	0.47	6.97	0.75	0.19	2.92	1.24	0.02	0.10	12.66	23.07
6–8	0.54	8.08	2.73	1.16	6.69	2.15	0.18	0.14	21.66	44.73
4–6	0.58	6.21	5.16	3.41	8.03	1.99	0.45	0.30	26.13	70.86
2–4	0.49	3.08	5.39	6.39	6.17	1.57	0.69	0.30	24.07	94.94
0–2	0.16	0.54	0.83	1.39	1.33	0.44	0.22	0.15	5.06	

10min Wind Direction at 10m (°T From)

Figure 2.6 Percentage occurrence, wind speed and direction [1]

Winds are principally from the north east during the months of September through to March with speeds of over 20 m/s.

2.6. Waves

Significant Wave Heights and Directions for all year are shown in figure 2.7

All-Year

Significant Wave Height (m)	N	NE	E	SE	S	SW	W	NW	Total %	Exceed %
Total	0.37	21.13	27.30	15.36	34.06	1.18	0.31	0.29	100.00	
3.75			<0.01	<0.01					0.01	0.01
3.50										0.01
3.25			<0.01	<0.01					0.01	0.03
3.00				<0.01					<0.01	0.03
2.75			0.02						0.02	0.05
2.50		0.01	0.04						0.05	0.11
2.25		0.03	0.04	<0.01	0.02	<0.01			0.11	0.22
2.00		0.08	0.03		0.04				0.16	0.38
1.75		0.27	0.07	0.01	0.04				0.39	0.77
1.50		0.80	0.12	0.05	0.26	<0.01			1.23	2.00
1.25		2.01	0.42	0.08	1.13	0.03			3.67	5.67
1.00		3.72	0.77	0.27	3.84	0.08	<0.01	<0.01	8.69	14.36
0.75	0.02	4.79	2.02	1.06	7.55	0.32	<0.01	<0.01	15.77	30.13
0.50	0.07	4.83	6.51	4.34	10.76	0.25	0.05	0.03	26.84	56.97
0.25	0.16	3.76	12.03	7.01	9.07	0.33	0.15	0.08	32.58	89.55
0.00	0.12	0.84	5.22	2.52	1.34	0.14	0.10	0.16	10.45	

Mean Wave Direction (°T From)

Figure 4.1.1 Rose Diagram Significant Wave Height and Direction – All Year

Figure 2.7 Percentage occurrence, significant wave height and direction [1]

Wave directions are also from the north east and east between September and March with significant wave heights of up to 3.9m and from the south and south east in April to August with wave heights of up to 2.5m in June.

Direction is more visually shown in the rose diagram – Figure 2.8

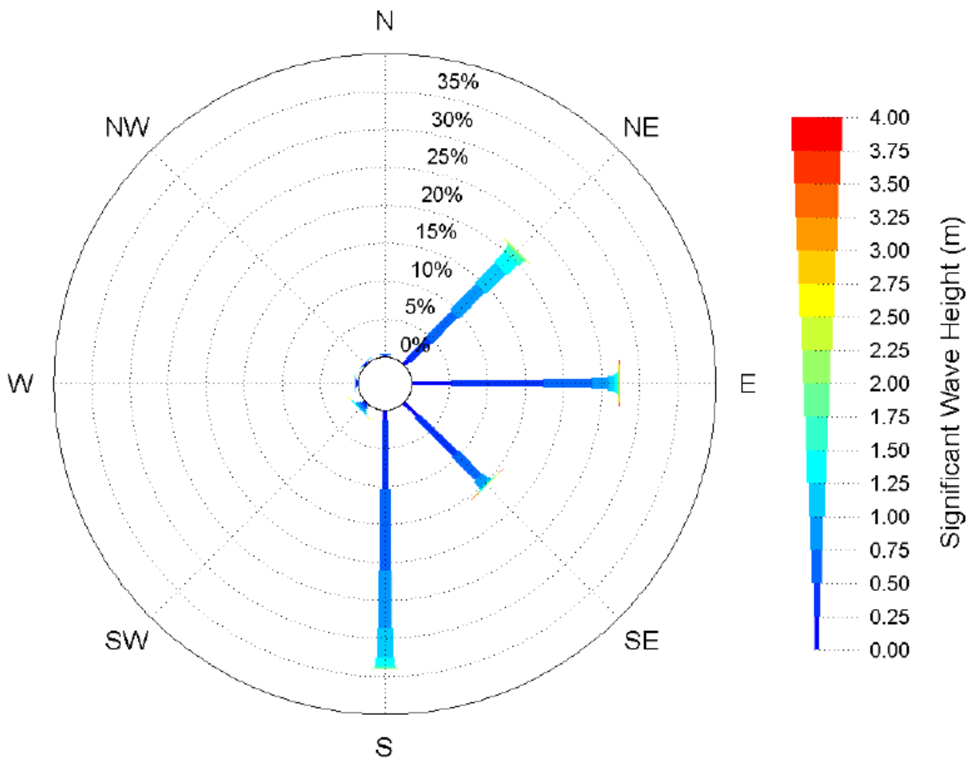


Figure 2.8 – Rose diagram significant wave height and direction [1]

Significant Wave Height and Peak Period for all year are shown in Figure 2.9

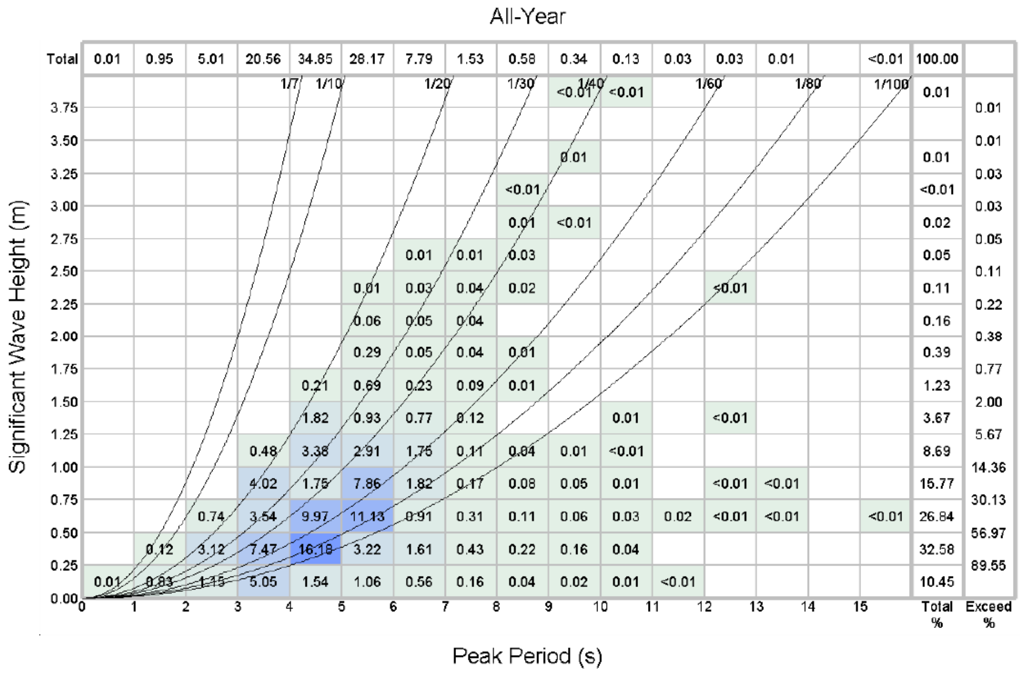


Figure 2.9 Significant wave heights and associate peak period [1]

2.7. Conclusion

E Evaluation of the weather data shows that waves and wind are dominated by North-East and South directions. It will be dependent on what parameter has the strongest influence.

Another important conclusion is the normal operational data:

- Significant wave height 0.5-1.25 m
- Peak period 5-6 s
- Wind speed 4-12 m/s
- Storm intensively 55-70 kts (28-36 m/s)
- Current velocity is small and will be neglected.

This data is the most important for offloading procedure from FSO to shuttle tanker. The extreme conditions are more important to consider because the FSO will be on location in the sea for all year during 25-28 years. They are presented in table 2.2

Table 2.2 – extrime metocean data [2]

Wave Data				
	Hs (m)	Hmax (m)	Ts (s)	Tz (s)
1yr Typhoon	8	13.5	10.4	8.6
10yr Typhoon	12.5	20.9	13.3	11.1
100yr Typhoon	14.9	24.9	14.7	12.2
1yr non-Typhoon	2.7	4.5	6.6	5.5
10yr non-Typhoon	5.1	8.5	8.8	7.3
100yr non-Typhoon	7.3	12.3	10.4	8.6
Wind Data			Current Data	
	Speed (m/s)	Direction	Speed (m/s)	Direction
1yr Typhoon	35.7	67.5	1.72	225
10yr Typhoon	55.4	67.5	2.32	247.5
100yr Typhoon	65.9	67.5	2.75	247.5
1yr non-Typhoon	21.9	45	0.57	225
10yr non-Typhoon	29.8	45	0.85	225
100yr non-Typhoon	33.7	45	1.1	225

3. Seabed Bathimetry

The seafloor sediments within the surveyed site are dominated by clay and sand. The seabed surrounding is featureless.

3.1. Soil Drilling Analysis

Results from sampling indicate that the subsoil encountered at MVHN02 location comprises generally of clays with increasing strength from mudline to the final depth of penetration of 30m except for a sand layer at depth 5.3m-6.0m and 25.8m-28.5m (table 3.1)

Table 3.1 – Soil stratigraphy [3]

Depth Below Sea Bed (meters)		Thickness (meters)	Description
From	To		
0	3.2	3.2	Very soft silty CLAY
3.2	5.3	2.1	Hard silty CLAY
5.3	6.0	0.7	Medium dense silty SAND
6.0	8.2	2.2	Hard silty CLAY
8.2	17.0	8.8	Stiff silty CLAY
17.0	25.5	8.5	Very stiff silty CLAY
25.5	28.5	3.0	Dense silty SAND
28.5	30.0	1.5	Hard silty CLAY

4. Double Hull vs. Single Hull Tankers

4.1. General Description

Double-hull (DH) tankers have an inner and outer hull separating cargo from the ocean. The space between the inner and outer hull is generally 2-3 meters wide and is also segregated into sections similar to the cargo tanks (Figure 4.1). These segregated spaces act as ballast tanks to carry water on unladed voyages. For an oil spill to occur from a DH tanker, both the outer and inner hull must be breached [5]. The main purpose of the DH is to reduce the probability of oil spills following a collision or grounding.

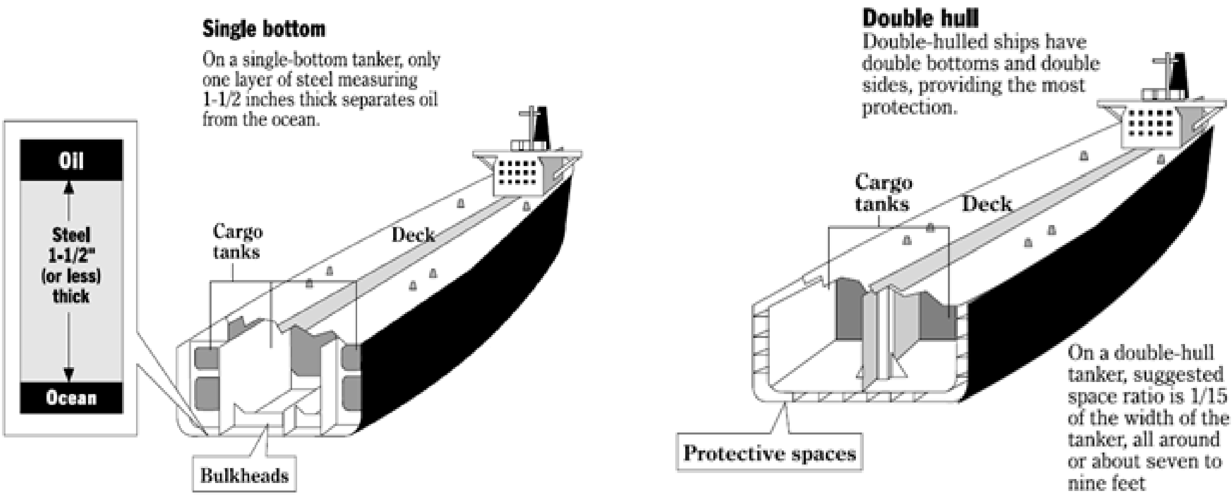


Figure 4.1 – Construction of SH and DH tankers [4].

Single-hull (SH) tankers have one hull and carry oil directly within the hull structure. Some SH tankers carry oil and ballast water within the same tanks (Figure 4.1). Whereas, some SH tankers have segregated ballast tanks within the hull. If a segregated ballast tank on a single-hull tanker is breached, no oil will be spilled unless the ballast water is contaminated. The segregated ballast tanks are still only protected from the ocean by one hull. Only a thin layer of steel, about 4 cm thick, separates the cargo of oil in a single-hulled tanker from the sea water outside. This layer can be easily punctured during collisions, groundings, so on [4].

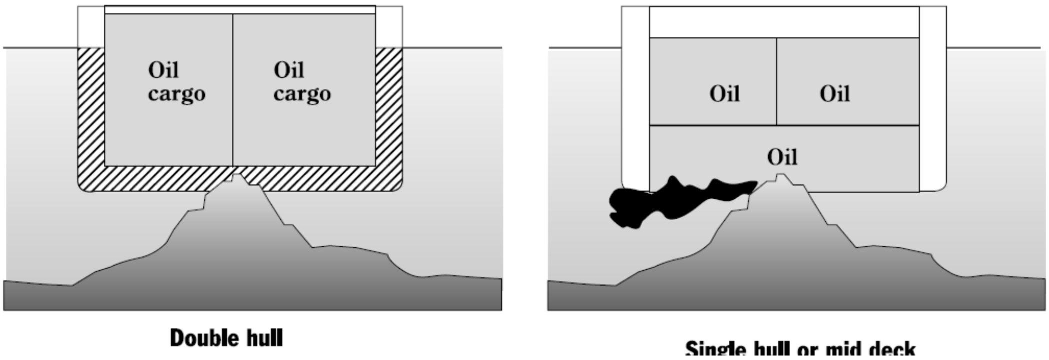


Figure 4.2 – Possible consequences after grounding.

Some ships have only double bottoms or double sides (Figure 4.3). These modifications protect only bottom or sides respectively. We don’t consider these options because it is just particular cases of DH, which are can’t provide protection from collisions, groundings or leakage of bottom and sides simultaneously.

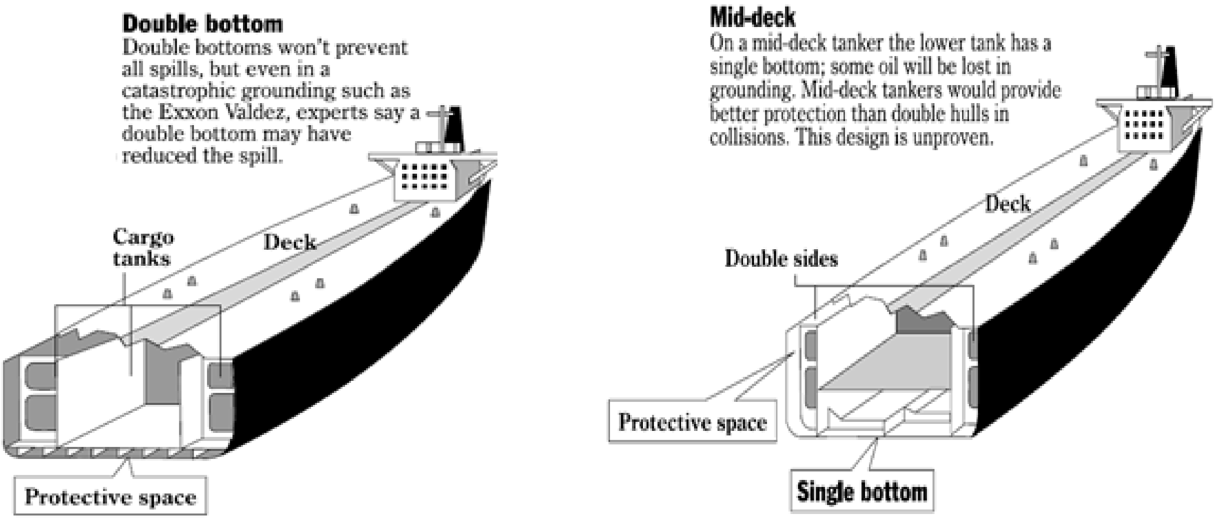


Figure 4.3 – Construction of double bottom and Mid-deck vessels [4]

Comparing design of DH and SH it is understandable that DH have serious construction advantages, however, the structural integrity of oil tanker hulls relies not only on good quality of initial design and construction but also on a program of inspection, maintenance and repair being conducted by the owner or his manager. We consider all these parameters briefly.

4.2. Maintenance

Proper maintenance is the responsibility of the ship owner and manager. Undetected corrosion has been an underlying cause of some of the more spectacular structural failures of tankers over the last few years. [6]

Failure to maintain the integrity of protective coatings and cathodic protection in ballast tanks in particular has led to leakage, pollution and fire. Maintenance of the ballast tanks of double hull tankers is just as essential, perhaps even more so since there is two to three times the surface area of internal structure to consider when compared to a single hull tanker. If coating failure of ballast tank structures happens before the end of the projected operational life, then there are significant difficulties associated with re-instating an effective coating system. [6]

However, the structure within the double hull ballast spaces is far more accessible than those in a single hull ship. Usually they will be between 2 and 3 meters wide allowing easy close up inspection, subject to the side tanks being fitted with side stringers to serve as inspection platforms at reasonable intervals. There should therefore be no reason for neglecting the inspection and maintenance of this structure and its coatings, subject to compliance with standard safety precautions prior to ballast tank entry. [6]

Cargo tank internal inspection on both single and double hull tankers remains problematic; however, with a lengthy process of tank washing, gas freeing and ventilation required before these tanks can be entered safely. [6]

4.3. Operations

DH tankers have two operational disadvantages in terms of stability comparing SH tankers. First, for a given depth of ship, adding a double bottom raises the ship's centre of gravity and thereby reduces the ship's reserves of stability. Second, free surface effects in cargo and ballast tanks during cargo operations may cause DH tankers to lose stability and suffer an angle of loll. The necessary operational procedures to maintain stability in such cases may restrict cargo operations to full cargo tanks. [6]

The most obvious potential hazard which all operators of double hull tankers need to guard against is that of cargo leakage into the ballast spaces. Leakage can arise from small fractures in bulkhead platings between cargo and ballast tanks caused by unpredicted local stress concentrations, fatigue, construction defects, or eventually corrosion through failure of the ballast spaces protective coating system. The structural design of double hull tankers renders them more susceptible to minor failures of this type than single hull ships. [6]

Sediment build up in ballast tanks has proved to be more of a problem for double hull than single hull tankers. The cellular nature of the double bottom ballast tanks can result in much greater retention of ballast water sediment, especially when ballast is taken on in estuarial waters, bringing an increase in the potential risks associated with the transfer of unwanted marine pests. [6]

Piping systems in double hull tankers can be fully segregated with cargo pipes able to be run almost exclusively through cargo tanks and ballast pipes through ballast tanks. This overcomes the problem with single hulled tankers whereby a leaking ballast pipe run through a cargo tank can sometimes become a potential source of pollution by contaminating the clean water ballast. [6]

Double hull tankers in general give improved cargo out turns over single hull ships. The smoother internal tank surfaces coupled with pump suctions recessed into wells in the double bottom make cargo discharge and tank washing much easier, giving an overall reduction in cargo residue retained within the cargo spaces. [6]

4.4. Construction

Modern shipyards adopt factory production line techniques to improve productivity and reduce ship construction times. This can put pressure on quality and an owner’s new building supervision team needs to be alert to several critical aspects of double hull tanker construction. [6]

Probably the most significant of these is the protection of the ballast tanks. The interiors of these compartments are the areas most prone to attack because of the extremely corrosive nature of salt water carried within them on unloded voyages. This aspect attains far greater significance in a DH tanker because of the increased surface area of the structure inside the ballast tanks. Because these tanks are much longer and narrower than those in single hull tankers, their surface area can be two to three times that of the ballast tanks in a single hull ship. Although protective coatings are an obligatory requirement of the major classification societies, it is left to the owner to choose the type, number of coats and ensure that they are properly applied, as well as making the decision on whether to fit anodes to help further reduce the potential for internal corrosion. [6]

The confined spaces of double hull ballast tanks, whether sides or bottom, are far more restrictive to work in than the comparatively spacious ballast tanks of the single hull tanker, so anything of this nature over above the yard standard is generally at the request and additional expense of diligent owners, because it adds production complications for the shipyard. [6]

4.5. Salvage

If a double hull tanker should run aground and rupture the outside shell, the available damage statistics suggest that the inner hull will, in most cases, not be breached. A single hull tanker, by contrast, would spill some cargo that would lighten the ship and make it easier to re-float. The size of the spill would largely depend upon the extent and location of the damage, resulting heel angle and associated tidal action. [6]

Damage to an 'L' shaped double bottom ballast tank on the other hand would cause flooding on one side resulting in a considerable list should the ship not come to rest on supporting ground, but remain free-floating. This may need to be corrected by the filling of an opposite tank. In any case, if the ship remains aground with damage to an 'L' shaped tank, then the consequent heel when the ship is floated free would need to be considered in the salvage plan. [6]

In the Prestige incident (19th November 2002), one side was flooded and the ballast tanks on the opposite side were filled to bring the ship upright, causing the hull stresses to exceed the design limits by some 68%. The relative merits of single and double hull designs in the event of a casualty will depend on the weather conditions at the time, as well as the availability and competency of the salvers but, in general, it will probably take longer to re-float a damaged double hull than a similarly damaged single hull tanker. [6]

4.6. Design

The tanker designs produced by today's shipbuilders, although approved by all the major classification societies, are based on the assumption that the owner will undertake all necessary repairs to the fabric during its lifetime. There is no such thing as a maintenance-free tanker. The design process therefore, although important, is not the sole factor in determining the long-term integrity of the structure. [6]

The difficulty of accurately predicting stress within the structure of a double hull tanker is compounded by the higher hull girder bending moments. Double hull tankers operate with global stress levels some 30% higher than those with single hulls because of the uniform distribution of cargo and ballast over the length of the ship. In a single hull tanker, the ballast tanks can be positioned to minimize longitudinal bending and shear stresses, resulting in values well below the acceptable maximum. [6]

The consequence is most likely to be small fatigue fractures in early years of service, especially in larger double hull tankers, unless great care is exercised in the design detail and supervision of workmanship during construction. [6]

Whilst these issues are important they are less relevant in existing designs of single hull tankers. From a practical perspective, particular attention has to be paid to the detection of fatigue cracks in the structure of double hull tankers to minimize the potential for cargo leakage into ballast tanks and the associated hazard presented by an accumulation of hydrocarbon gas within these confined spaces. [6]

4.7. Stability

The transverse stability—the ability of a ship to remain upright and a measure of its resistance either to take on a list or to capsize completely—of single hull tankers has never really been a problem. Single hull tankers need longitudinal bulkheads which run throughout the length of the cargo tanks to provide longitudinal strength. The transverse spacing of these bulkheads can be chosen to give tank sizes of approximately equal capacity and bottom support structure of manageable proportions. [6]

This is not the case with double hull tankers where the inner hull provides sufficient longitudinal strength without the need for additional longitudinal bulkheads for structural purposes, resulting in much wider cargo tanks with substantially increased free surface effects unless the tanks are fully filled up. [6]

The free surface effect is the degradation in transverse stability which occurs when there are slack surfaces—the liquid surface in any tank which is not filled so full that surface movement is effectively restricted by the deck structure in way of the tank hatch. [6]

When combined with the effect of the double bottom ballast tanks that effectively raise the centre of gravity of the cargo, there is a consequential large reduction in intact stability. [6]

In terms of damage stability, ensuring compliance owing to the intact stability issues referred to above is not easy and much more care needs to be taken in distributing the cargo on board a double hull than single hull tanker. Whilst this task is helped by the use of on board computers, it is underpinned by the need to provide an accurate and comprehensive trim and stability manual, ideally before the ship enters commercial service. [6]

4.8. Ventilation and Access

The cellular nature of the wing and double bottom tanks of double hull tankers makes the adequate ventilation of these spaces an important issue given personnel will be expected to regularly and safely enter them to check for corrosion, cargo leakage and ballast water sediment build up. [6]

Ease of access for close up structural inspection is an issue for all oil tankers, especially in the case of the comparatively large single hull tanker cargo and ballast tanks. Rafts, remotely controlled vehicles, both in and out of water, ladder access and staging are all used with varying degrees of success. [6]

In the case of double hull tankers, whilst the double bottom ballast spaces are easier to inspect, this may not be the case for the side tanks unless "inspection friendly" fore and aft stringers, horizontal structural members running the length of the tanks, are provided at convenient heights to serve as platforms for this purpose [6].

Cargo tanks on board double hull ships, being comparatively free of internal structure, need some provision for inspection of the deckhead areas, especially if heated cargoes are being carried when corrosion can be expected to be much more rapid because of the vacuum bottle or "Thermos" insulating effect stemming from the double hull design itself [6].

4.9. Conclusion

To sum up all aspects it is clear the DH construction has some advantage over the SH. The DH tankers are more safety. The DH construction decreases oil spills to minimum (Figure 4.4). But the DH vessel has more complex construction. And if to compare the DH and the SH tanker with poor maintenance, the DH will have more difficulties and problems related with operations and safety. Also it is important to understand that the DH helps to reduce oil spills, but does not decrease the likelihood of grounding or collision. Probably more than 80% of accidence is human factor. That's why to prevent or reduce accidents it is necessary to train crew, use electronic devices such as a global positioning system, up-to-date weather data and vessel traffic information.

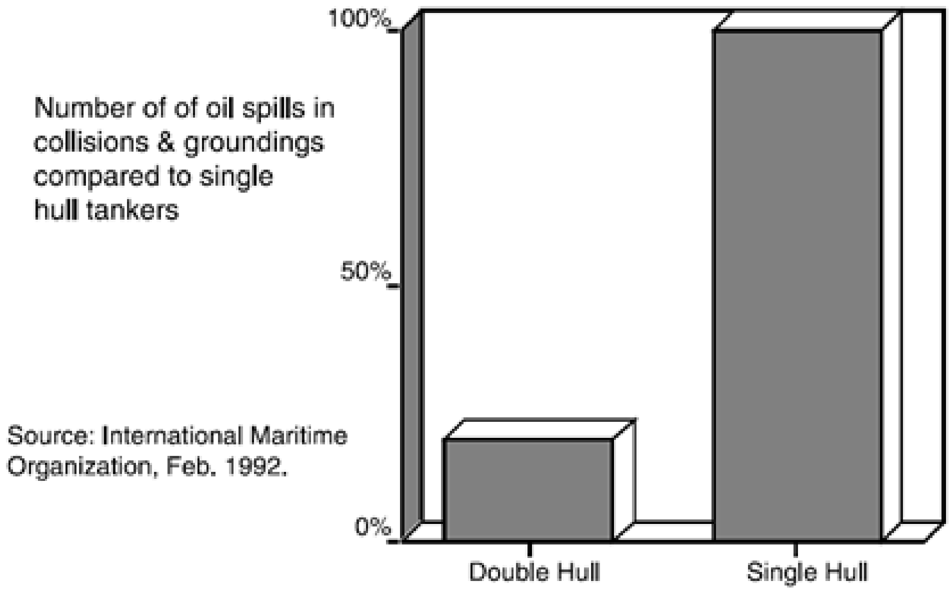


Figure 4.4 – Comparison of the number of oil spills in collisions and groundings of SH and DH [7]

In case of the FSO, a DH is the most suitable option as well since the ship will be in use for more than 25 years nonstop (excepting force-majeure). And it is easier to check the hull from the space between the inner and outer shields, detect and prevent leakage and repair if it is necessary.

5. FSO Design

Before describing of FSO design, necessary volume of storage tanks in FS0 shall be defined. Usually storage facility is equal 10 days production rate. Average daily production rate on a plato of block 31 is 4733,1 TOE. It means the necessary volume is 47331 TOE. Plus emergency storage shall be required 20-25% of total amount to prevent process shut down in case if shuttle tanker is delayed, WOW or other technical problems. Finally volume capacity equals 56850 TOE (or around 370000 Barrels).

Also transformation from tanker to FSO has to be taken into consideration. Additional equipment: turret, helicopter deck, power generators, etc. will increase light weight (weight of ship without cargo) on 10-20% aproximatelly. For e.g. let's take 5-10%. This mass shall be taken from gross tonnage. The light weight usually is around little bit less than gross tonnage consequently we can include this mass to gross tonnage. Finally gross tonnage equals about 62150 TOE

International tanker database was analyzed. List of acceptable tankers Vietnamese oilfield is shown in Table 5.1. Following criteria was used to choose tanker:

- Gross Tonnage 62150 TOE
- Availability
- Date of birth (The Newest tankers are the most eligible because after 15 years old tankers has additional surveys. More details are described in part "Vietnamese FSO Rules")
- Double hull type

Table 5.1 – acceptable tankers [8].

Vessel Name	LBP	Beam	Draft	Depth	DoB	Dwt	Gt	Owner
Moskovsky Prospect	239	44,03	15	21	01.09.2010	114100	62504	SOVCOMFLOT
United Honor	240	44,04	14,82	21	01.09.2010	112795	62775	Marine Management Services MC
Paramount Hatteras	239	44,03	14,8	21	01.10.2010	114700	62851	AET Inc Ltd
Primorsky Prospect	239	44,03	13,6	21	01.11.2010	113860	62504	SOVCOMFLOT
Paramount Halifax	239	44,03	14,8	21	01.11.2010	114062	62851	AET Inc Ltd
Paramount Hydra	239	44,03	14,8	21	01.01.2011	113968	62851	AET Inc Ltd
Suvorovsky Prospect	239	44,04	15	21	01.02.2011	113905	62504	SOVCOMFLOT
Phoenix Admiral	239	44,04	14,9	21	01.03.2011	114024	62234	Mitsui OSK Lines Ltd
Phoenix Advance	239	44,04	14,92	21	01.06.2011	114024	62234	Mitsui OSK Lines Ltd

All of these tankers have more or less similar parameters. Determinative factor will be economic attractiveness conditions and availability.

Let's define average parameters for analysis:

LBP = 240 m

Beam = 44 m

Draft = 15 m

Depth = 21m

Dwt = 114000 t

Additional equipment weight = 5300 t

Gt = 56850

5.1. General Design

The FSO vessel includes a floating storage, which provides a storage facility for the stock-tank oil with a volume of 370000 barrels and an offloading system (tandem or buoy) for transfer of the stored oil to a shuttle tanker as consistent with the development scheme.

The FSO requirements are as follows:

- The FSO vessel shall be a new build (or with a short period of operation).
- The preferred hull size is to be approximately 114000 DWT.
- The cargo capacity excluding slops tanks is 370000 bbls.
- All ballast tanks shall be segregated.
- All cargo tanks shall be smooth, have cathode protection , and equipped pumps.
- There are entrances in each tank for inspection and cleaning.
- The FSO power generation shall preferably be located on deck. Power generation located in the engine room is acceptable, but is less desirable.
- The FSO oil piping, tank and pump systems shall preferably meet oilfield standards rather than marine standards including double block and bleed isolation for cargo tank access.
- The FSO shall have living quarters with permanent beds.
- The FSO shall have davit launched survival crafts sufficient for the maximum personnel compliment. These crafts shall be accessible from the living quarters or shelters with minimal or no exposure to smoke or fire.
- The FSO shall have a davit launched Fast Rescue Craft (FRC).
- The FSO shall be equipped with two (2) offshore type cranes capable of covering the entire lay down area and supplying the living quarters. The cranes should be large enough to be able to assist in overhauling equipment that need repairing.

Necessary parts, superstructure and equipment of FSO:

· Living unit.

· Helicopter landing platform.

· Hawser handling and load sensor alarm system.

· Oil handling system: piping, cargo pumps and hydraulic systems.

· Oil inlet piping and inlet manifold.

· Oil offloading system: piping, export meter, prover and offloading manifold and offloading hose reel.

· Tank gauging.

· Inert gas system.

· Ballast pumping system.

· Marine growth inhibition system.

· Power generation system.

· Mechanical equipments.

· Electrical systems.

· Instrumentation and control system.

· Oily water treatment system.

· Cathodic protection system.

· Coating systems.

· Fire and safety systems.

· Navigation and communication systems.

· Material handling system.

· Hull monitoring system.

· Workshop.

Engineering and design work associated with the FSO vessel shall include, but hall not be limited to, the basic and detailed design and engineering of the above listed systems and components including primary steel work, all interconnecting pipe work, pipe supports, instrumentation, cabling supports and secondary steel work [9].

5.2. Mooring System

5.2.1. Mooring Systems Connection

Now a days several types of mooring system are used, hereby the most accessable systems for shallow water are evaluated:

- Spread moorings
- Single point mooring (SPM):
  - Internal Turret
  - External Turret

Spread Mooring

A spread mooring is a system with multiple mooring wires connected at the sea bed by normal anchors, piles or suction anchors (Figure 5.1). The other end of each line is attached to winches or stoppers on the vessel through fairleads as necessary.

Advantages of this system:

- It's the cheapest mooring solution
- Spread mooring
- Turret structure and bearing are not needed
- It can bear large loads

Spread mooring system has one serious disadvantage: fast disconnection is not possible.

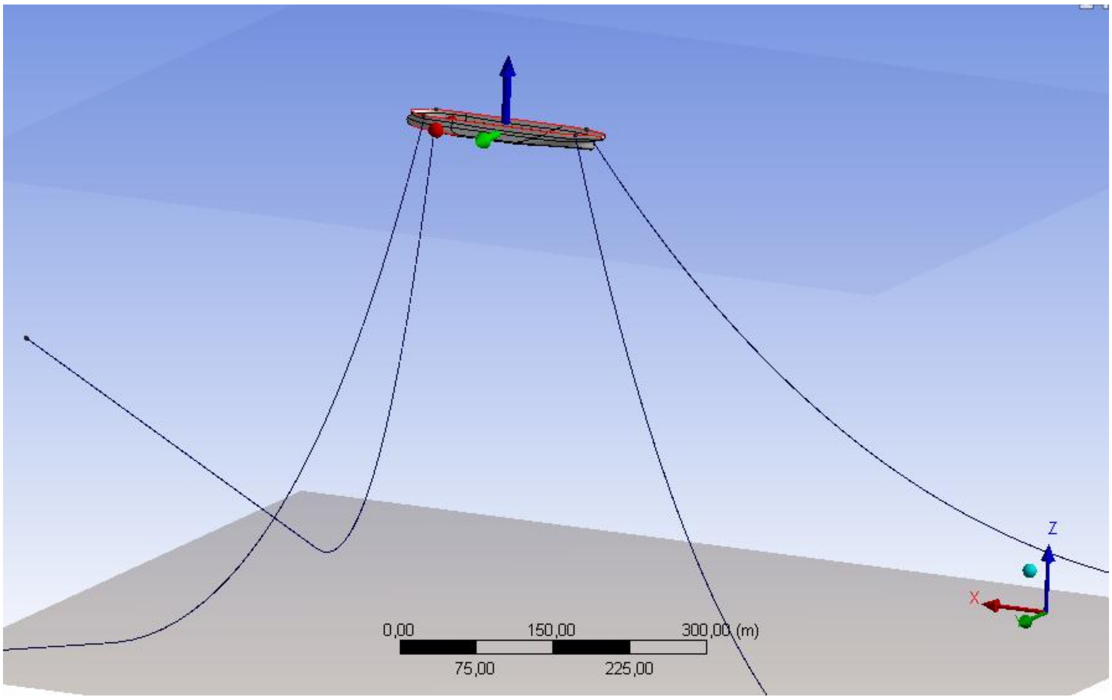


Figure 5.1 – Spread mooring system

Turret Mooring: Generally a turret mooring is separated on 2 parts: static part, which is attached mooring lines to a sea bottom through anchors (typically, a spread mooring) and rotating part (turret) is connected to the hull. Turret can be external and internal:

Internal Turret

The Internal Turret Mooring system is located in the front end of a vessel (Figure 5.2). The internal turret is supported by a large roller bearing in a moonpool. This can be found either at the bottom of the vessel, or at deck level. The outer race of the bearing is connected to the vessel, while the inner race is attached to the fixed part of the turret. The connection between the lower turret and the swivel stack is provided by a manifold structure above deck [1]. The position of internal turret is forced to increase hull length to safe volume of tanks. The price of modification is high.

One of the benefit of turret mooring systems is it allow vessels to change direction in accordance with dominant wave direction. This permits to work in the most severe environment conditions. Also internal turret allows easy translation of environmental load to the hull.

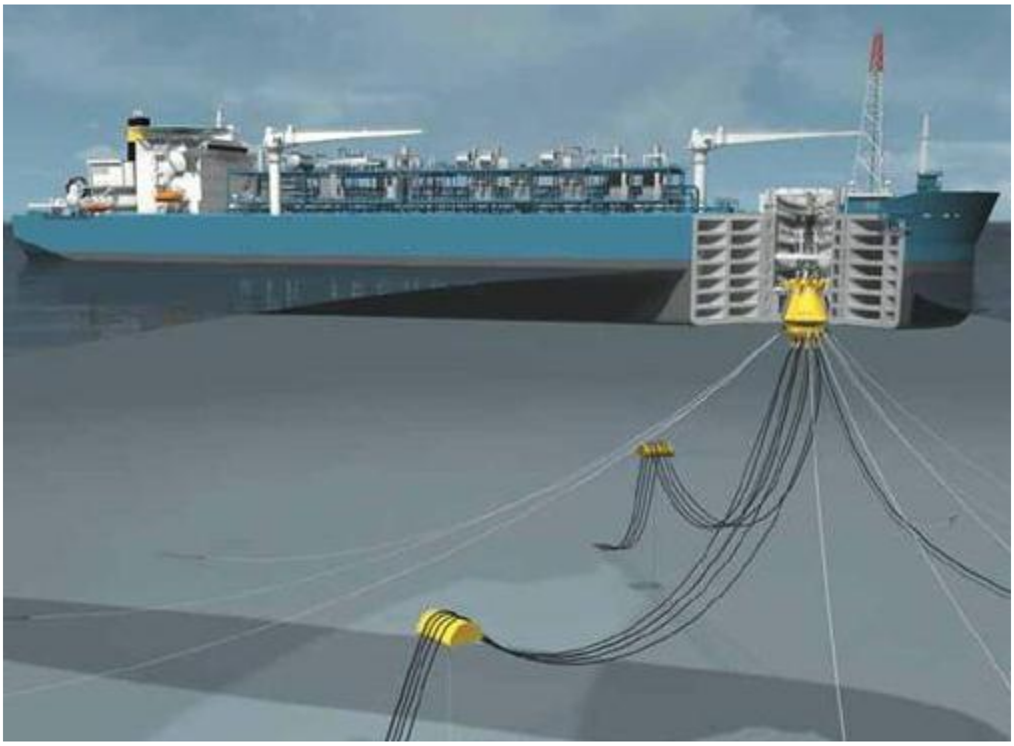


Figure 5.2 – Internal turret [11]

One of the modification of the internal turret is a disconnectable turret. In this case, an internal turret is integrated into the forward end of a tanker or barge. A large collet-type connector connects the turret to a mooring buoy. This has sufficient buoyancy to support the weight of the chain legs and risers. For reconnection it is sufficient to pull up the buoy under the ship. This is done with a wire rope hauled in on a drum winch. When the vessel leaves, the column remains on location [10].

External turret

Construction of an external turret is similar to an internal turret mooring. But the external turret is located outside the hull (Figure 5.3). It comprises a steal box located at the bow or stern of the vessel, which provides a foundation for the bearing and turret. The turret is mostly set-up above the waterline, but sometimes also under. The ship hull is needed less modification due to outside location of turret and as consequences less expenditures. As the chain table of an external turret mooring system is usually located above water level (in contrary to internal turrets), the system is suitable for shallow waters [10].

An external turret mooring can resist extreme sea conditions, as the vessel can "weathervane" freely over 360 degrees, just like the internal turret.

One advantage of the fabrication takes a shorter period of time.

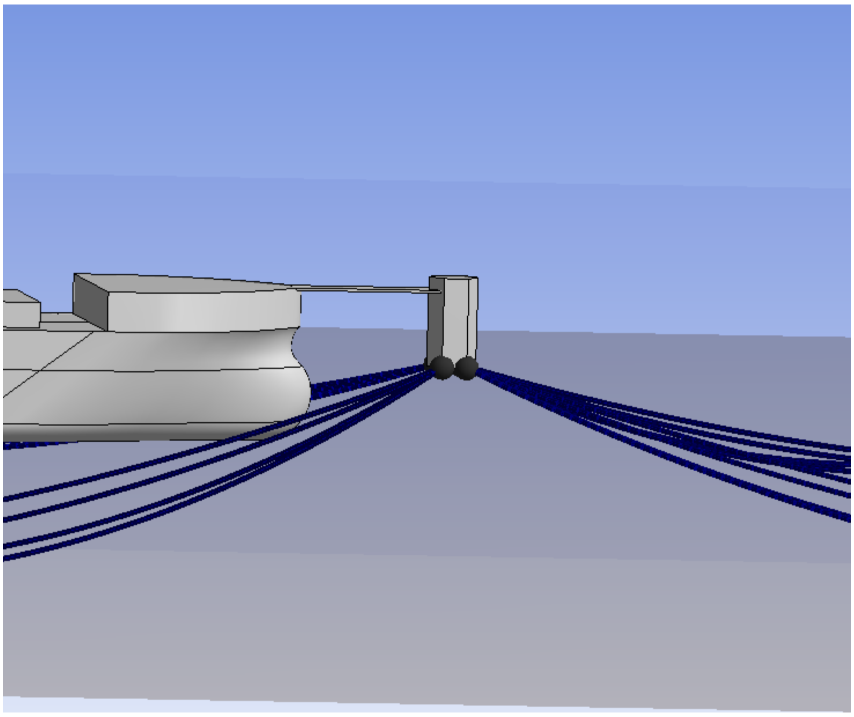


Figure 5.3 - External turret

The external turret also has a disconnectable modification.

An external disconnectable turret is mounted on the bow of a vessel. It disconnects automatically in two stages. During the first stage the risers are being isolated. Successively the riser column is being disengaged by a large hydraulically operated collet-type connectors. From the moment the tanker is disconnected it will sail away, while the column remains on location [10].

Three possible options of mooring system were described, the cheapest, the most simplified and reliable one is spread mooring. But experience of development of the similar projects in South Sea, such as Lufeng 22-1 (table 5.3.1) and Lufeng 13-1 shows that disconnection has to be available.

Table 5.2 – History of disconnections due to typhoons [12]

Typhoon name	Shutdown period	Description
Unknown	Oct 23th to 30th, 1998	STL dropped
Maggie	June 5th to 8th, 1999	STL dropped
SAM	Aug 20th to 24th, 1999	STL dropped
Dan	Oct 5th to 9th, 1999	STL dropped
Utor	July 4th to 7th, 2001	STL dropped
Imbudo	July 22nd to 25th, 2003	STL dropped
Sunvo	September 1st to 3rd, 2003	STL dropped
Damrey	Sept. 22nd to 25th, 2005	STL dropped
Chanchu	May 15th to 20th, 2006	STL dropped

From the remaining options an external disconnectable turret is more appropriate.

Internal turret is ready for more harsh conditions, but if we look at extreme environmental data without typhoons, especially in waves it is not big deal. if waves are higher 10 m ship will be disconnected and go way. Also it is not possible to use unternal turret in too shallow water (30 m) or special design shall be modeled for this conditions, which increases cost of mooring system.

Table 5.3 – extrime metocean data

Wave Data				
	Hs (m)	Hmax (m)	Ts (s)	Tz (s)
1yr Typhoon	8	13.5	10.4	8.6
10yr Typhoon	12.5	20.9	13.3	11.1
100yr Typhoon	14.9	24.9	14.7	12.2
1yr non-Typhoon	2.7	4.5	6.6	5.5
10yr non-Typhoon	5.1	8.5	8.8	7.3
100yr non-Typhoon	7.3	12.3	10.4	8.6
Wind Data			Current Data	
	Speed (m/s)	Direction	Speed (m/s)	Direction
1yr Typhoon	35.7	67.5	1.72	225
10yr Typhoon	55.4	67.5	2.32	247.5
100yr Typhoon	65.9	67.5	2.75	247.5
1yr non-Typhoon	21.9	45	0.57	225
10yr non-Typhoon	29.8	45	0.85	225
100yr non-Typhoon	33.7	45	1.1	225

In addition originally external turret has lower price than internal. The external turret needs less time period for manufacturing, installation and connection.

5.2.2. Types of Mooring Lines

Steel chain

Steel chain is the commonly used type of a mooring line. There are two types of chain, the studless and studded chain (Figure 5.4). The studless chain is mostly used for permanently moored platforms, while the studded chain is frequently used by drilling platforms. The steel chain is the heaviest mooring line, this weight makes it less suitable for deep water but it also gives the system more capacity to withstand forces. Any weak link of the chain and local wear are main disadvantages [14].

Figure 5.4 - Studless and studded chains respectively [13].

Steel wire

Further to the steel chain, the steel wire is used a lot in the mooring systems of floating platforms. The wire has the advantages of a higher elasticity (spring effect) and a lower weight. But it is sensitive to abrasion and corrosion. Unlike the steel in the circuit it has a parallel coupling [14].

Fiber rope

The latest development is the application of fiber ropes for mooring systems. Polyester and Aramid are the mostly used fibers. These fibers have a lower elasticity and breaking strength then the iron chain and wire, and they have a lower weight. Main lack is very sensitive to mechanical impact (for example cutting) [14].

Catenary mooring types shall be used to decrease tension in lines. Fiber rope and steel wire based more on the elasticity system and have minimal catenary effect. It means they will have huge loads in shallow water case (due to big environmental loads and limited offset) [14].

Fiber rope is not suitable in our situation, because the depth is shallow and we don't need special lightness. Also catenary system involves the interaction of the mooring lines from the seabed, which is detrimental to the rope.

6. Vessel Simulation

Nowadays simulation programs become more and more popular. Mathematical simulation is a new and necessary step in a pre-analysis, which cost is cheaper than physical simulation. Mathematical simulation allows to take into consideration different options in short time, without large expenditures needed to reconstruct the model. In case of multiphase flow simulation this becomes even more obvious, since not only the model of the analysed body has to be constructed but also several necessary environmental conditions should be taken into consideration. In addition, in computer simulation we can analyze a full scale model.

Hereby to estimate RAO, stability, environmental loads to FSO and mooring system is chosen Hydrodynamic software - Ansys Aqwa [15].

Aqwa consists from several programs. For the analysis presented here we need:

- AQWA-WAVE Used to transfer wave loads on fixed or floating structure calculated by AQWA-LINE to a finite element structure analysis package [15].
- AQWA-LINE Used to calculate the wave loading and response of bodies when exposed to a regular harmonic wave environment. The first order wave forces and second order wave drift forces are calculated in the frequency domain [15].
- AQWA-DRIFT Used to simulate the real-time motion of a floating body or bodies while operating in irregular waves. Wave frequency motions and low period oscillatory drift motions may be considered. Wind and current loading may also be applied to the body. If more than one body is being studied, coupling effects between bodies may be considered [15].
- AQWA-LIBRIUM Used to find the equilibrium characteristics of a moored or freely floating body or bodies. Steady state environmental loads may also be considered to act on the body (e.g. wind, wave drift and current) [15].

All these programs can be used separately, but they are combined in Ansys WorkBench:

- Hydrodynamic Diffraction (Aqwa-Wave and Aqwa-Line)

- Hydrodynamic Time Response (Aqwa-Drift and Aqwa-Librium)

Vessel simulation procedure could be separated in 4 stages:

- Ship construction
- Input Data
- Simulation
- Result analysis

6.1. Ship Construction.

Standard hull of tanker was taken from software FastShip. This model was corrected and modified in Solid Works software. External turret and superstructure were constructed (Figure 6.1). Size of hull was scaled to necessary parameters: LBP (length between perpendicular) = 240 m, breadth (for 100% load in waterline) = 44 m, depth = 21m.

Following mass properties are defined (Figure 6.1):

- Deck + superstructure =10 kt
- Hull + bulkheads, etc.=30 kt
- Machinery +equipment + ballast in bow and stern = 16.8 kt

3 options are analyzed:

1. 100% load
2. 50% load
3. 20% load

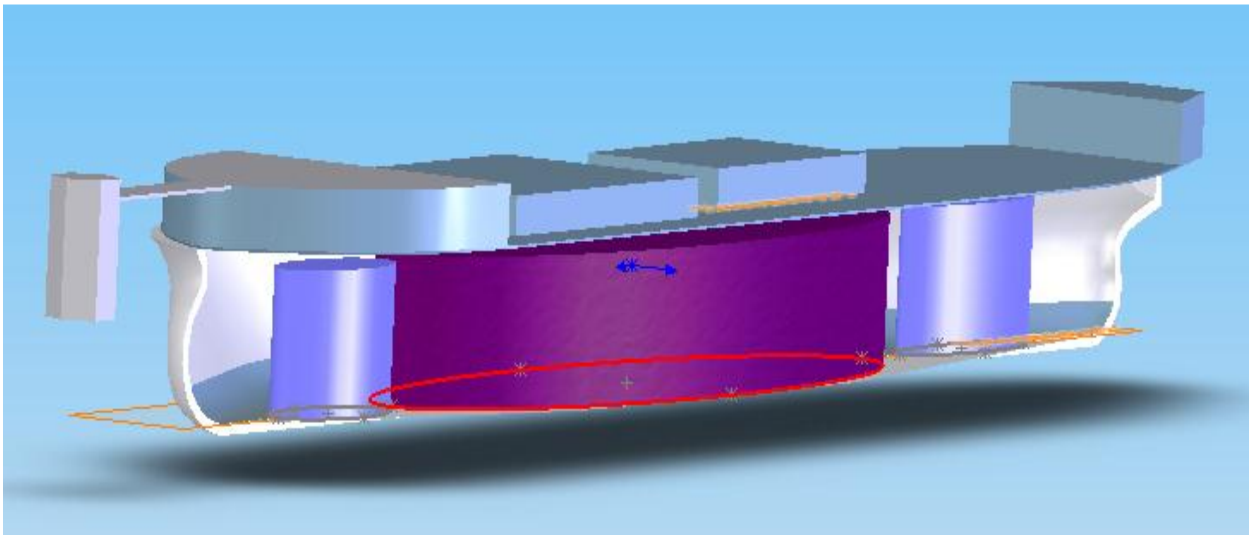


Figure 6.1 – Vessel Mass definition

Draft estimation for 2-nd and 3-rd options:

The draft of ship with tank load 20% =11400 t (it can be water ballast or oil) was calculated (Figure 5.2.1 final model of ship):

By Archimedes low:

$$\rho g V = \rho g d A$$

Tanker has a draft of 15 m with full load (114000 t):

$$\rho g \cdot 15 \cdot A = 114000$$

20% tanks load = (114000-56850)+56850*0,2 = 68520 t:

$$\rho g \cdot x \cdot A = 68520$$

We can define x from proportion:

$$\frac{\rho g \cdot 15 \cdot A}{\rho g \cdot x \cdot A} = \frac{114000}{68520}$$

$$x(\text{draft}) = 9.01\ m\ \approx 9\ m$$

In similar way 50% load is defined:

50% tanks load = (114000-56850)+56850*0,5 = 85575 t

$$\text{draft} = 11.26\ m\ \approx 11.3\ m$$

6.2. Input Data

Only for the first option the input data are discussed. For the 2-nd and 3-rd everything are similar with respectively data which are presented in Appendixes A and C.

First of all typical simulation scheme of Ansys is given in Figure 6.2:

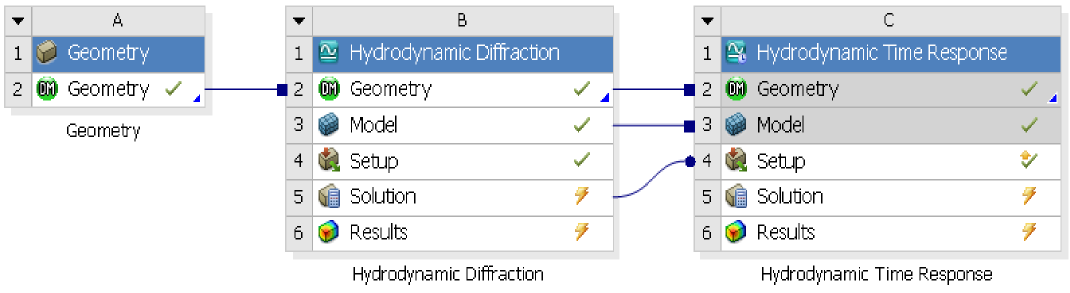


Figure 6.2 – Block-scheme of Ansys analysis

The model of the Vessel has to be empty with all thicknesses set to 0 m and with slice through waterline. It's necessary conditions. Because in Aqwa body has ideal non-compressible wall.

In Figure 6.3 solver tree is presented:

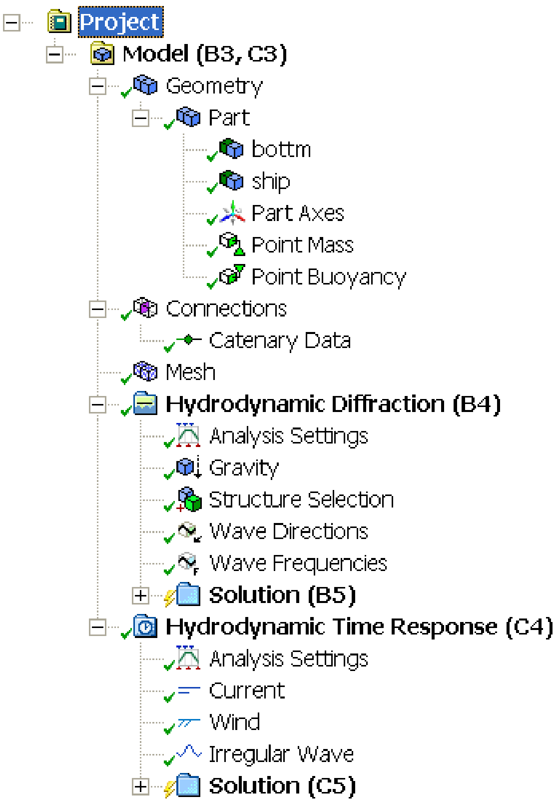


Figure 6.3 – Aqwa solver tree

Mass properties have to be set. The data are put to “Point Mass” and “Point buoyancy”. These characteristics are estimated in SolidWorks:

Center of gravity:

x=0.54 m

y=-0.01 m

z=-4.63 m

Inertia Moments:

Ixx = 71250004381.25 kg.m²

Iyy = 438216026946.44 kg.m²

Izz = 466944028712.96 kg.m²

Center of buoyancy:

x =0.75 m

y=0.00 m

z=-7.17 m

Submerged volume = 129231.06 m^3

Axe 0X is going parallel to ship longitude
Axe 0Y is going perpendicular to ship longitude
Plane 0XY lays in waterline area
Axe 0Z is going normal from waterline area to sky.

Next step is mesh construction, Figure 6.4. The size of the cell influence on the maximum allowed frequency. Also the calculation time and accurancy depend on the size of the cell (an ideal cell size has to be less than 1/7 of the wave length of the highest frequency). The most intresting data are from period 4 s (because one year return period is 5 s).

The wave length for 4 s equals :

$L = \frac{g}{2\pi} T^2 \tanh(kd)$ [2],

Where

g – gravity acceliration

T – wave period (4 s)

d – water depth (30 m)

K – number of waves $= \frac{2\pi}{L}$

$$L = \frac{g}{2\pi} T^2 \tanh\left(\frac{2\pi}{L} d\right) = 24.98\ m$$

Maximum cell size 3.5 m: 3.5 m*7 = 24.5 m.

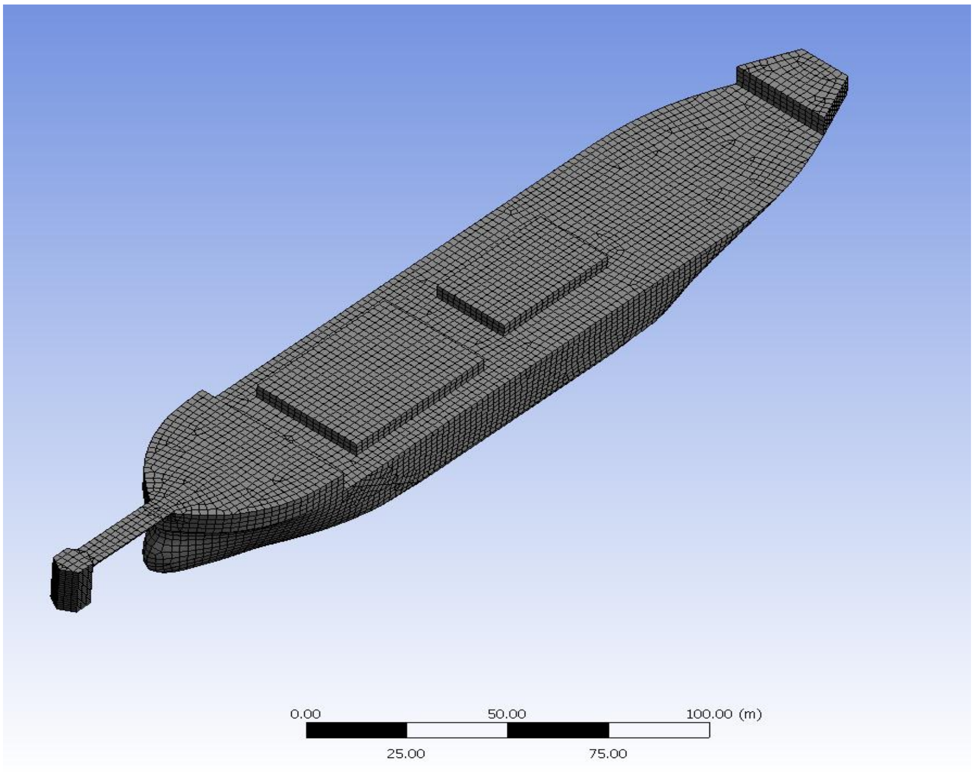


Figure 6.4 – The mesh on the vessel

6.3. Simulation

The simulation procedure is separated on the following 2 processes:

- Diffraction analisys
- Time response analysys

6.3.1 Diffraction Analisys

The Diffraction analysis is based on the linear algebraic equations of the harmonic response of a body in regular waves:

$$M(s)\ddot{X} + M(a)\ddot{X} + C\dot{X} + KX = F(d) + F(f) + F^{(2)},$$

The parameters in the equation of motion are:

K - Linear Stiffness Matrix with associated values of

- The Buoyancy Force at Equilibrium

- The Global Z coordinate of the Centre of Gravity at Equilibrium

and, for each frequency

M(a) - Added Mass Matrix

C - Radiation Damping Matrix

and, for each frequency and each direction

X - Response Motions (or RAOs)

$F(d)$ - Diffraction Forces

$F(f)$ - Froude Krylov Forces

$F^{(2)}$ Second Order Drift Forces

The first part of the diffraction analysis is Hydrostatic (For 100% loaded ship), Table 6.1:

Table 6.1 – Hydrostatic data

Structure	ship		
Hydrostatic Stiffness			
Centre of Gravity Position:	X: 0.54 m	Y: -1.e-2 m	Z: -4.6300001 m
	Z	RX	RY
Heave(Z):	96182808 N/m	16789.459 N/°	8695121. N/°
Roll(RX):	961965.19 N.m/m	1.62899e8 N.m/°	86898.43 N.m/°
Pitch(RZ):	4.98194e8 N.m/m	86898.445 N.m/°	5.90143e9 N.m/°
Hydrostatic Displacement Properties			
Actual Volumetric Displacement:	258240.81 m^3		
Equivalent Volumetric Displacement:	111219.52 m^3		
Centre of Buoyancy Position:	X: -1.5655e-2 m	Y: 1.0478e-4 m	Z: -7.1639204 m
Out of Balance Forces/Weight:	FX: 2.8547e-9	FY: -3.6185e-8	FZ: 1.321902
Out of Balance Moments/Weight:	MX: 2.3459e-2 m	MY: 1.2901852 m	MZ: -4.2282e-6 m
Cut Water Plane Properties			
Cut Water Plane Area:	9568.6992 m^2		
Centre of Floatation:	X:-4.6396546 m	Y: 1.4259e-6 m	
Principal 2nd Moment of Area:	X: 1582892.3 m^4	Y: 34036024 m^4	
Angle Principal Axis makes with X(FRA):	-3.7566e-5 °		
Small Angle Stability Parameters			
C.O.G. to C.O.B.(BG):	2.5339203 m		
Metacentric Heights (GMX/GMY):	3.5955997 m	129.26564 m	
COB to Metacentre (BMX/BMY):	6.1295199 m	131.79956 m	
Restoring Moments/Degree Rotations (MX/MY):	2843122. N.m/°	1.02213e8 N.m/°	

The most important data are marked by a frame. The metacentric height (GM) shows the initial stability of the ship and the capasity of the ship to return to the initail position when the outer force goes away. The GM > 0 if the metacenter is located above the center of gravity. 3 main values of GM are discussed:

- GM < 0 – unstable, in this case the uprighting moment is less than 0. The ship doesn't have initial stability and after environmental influence, the ship will be inclined an equilibrium position will be not be achived.
- GM = 0 – initial stable, uprighting moment = 0. In this case after external loads the ship will not return to initial position, because new position will be equilibrium.

- GM > 0 – stable, uprighting moment > 0. The ship will return to its initial position, before the restoring moment will be less than the capsizing moment.

By DNV standard GM has to be more than 0.3 m for open Sea. This condition is required.

A double hull ship is taken into consideration the full load ship has min GM. Hydrostatic parameters for 20% load and 50% load ship can be found in Appendixes A and C.

Next step is the analysis of the hydrodynamic data:

Response amplitude operators (RAOs). RAOs show the behavior of the ship in waves with different frequencies (periods). The RAO depends of the size (draft and area of waterline) and the mass properties of the ship, wave direction and period. RAOs are not physical parameters but they are calculated by linearized equations in different directions (based on Morison equation). RAOs could be separated in 2 parts: rotation and translation, the most dangerous motion is heave - translation and roll - rotational (Figure 6.5). Heave, roll and pitch are discussed in this part, all other RAOs you can find in Appendix A, C and E. Three wave's directions are analyzed: 0 degrees (Head Seas), 90 degrees (Beam Seas), and Quartering Seas (45 degrees).

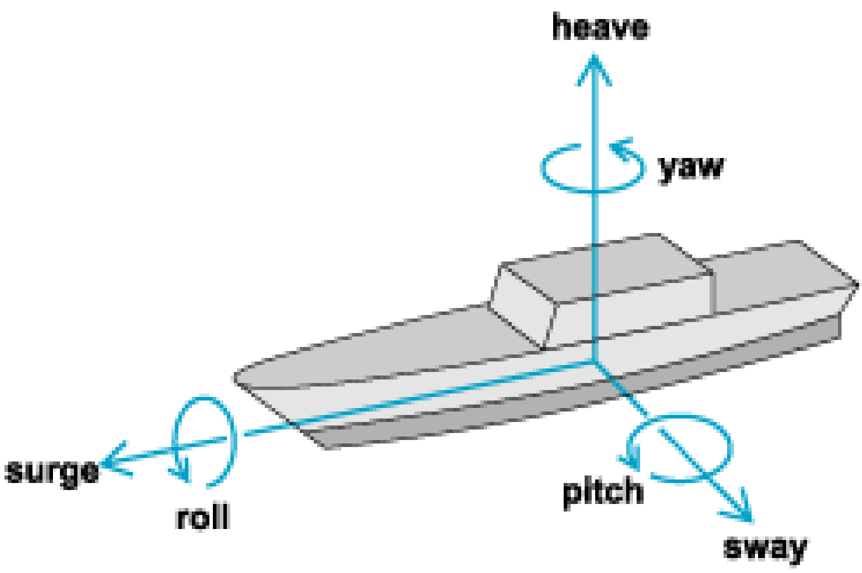


Figure 6.5 – Vessel six degree of freedom [16]

Translational motion: surge (X), sway (Y) and heave (Z)

Rotational motion: roll (RX), pitch (RY), yaw (RZ)

For roll, see Figure 6.6

Head seas:

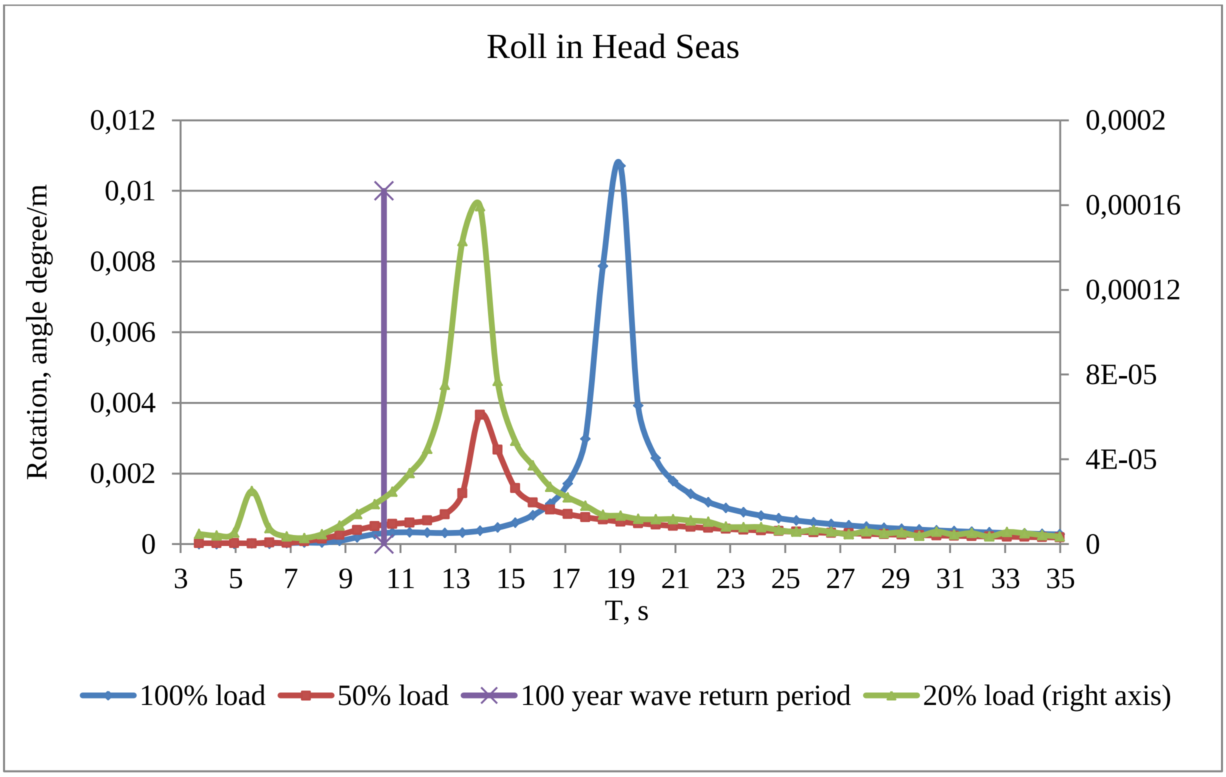


Figure 6.6 – Roll in Head Seas

First of all, when the peaks of the RAOs are not in line with the wave period, it means that the ship will not have resonance. For a RAO less then 0,002, the angle of inclination to 1 m of wave amplitude is small. It means that in a wave with height 7.3 m, the ship inclines to 0.002 * 7.3 / 2 = 0.0073 angle inclination. For one year wave return period the inclination is thus rather small. The vessel is stable.

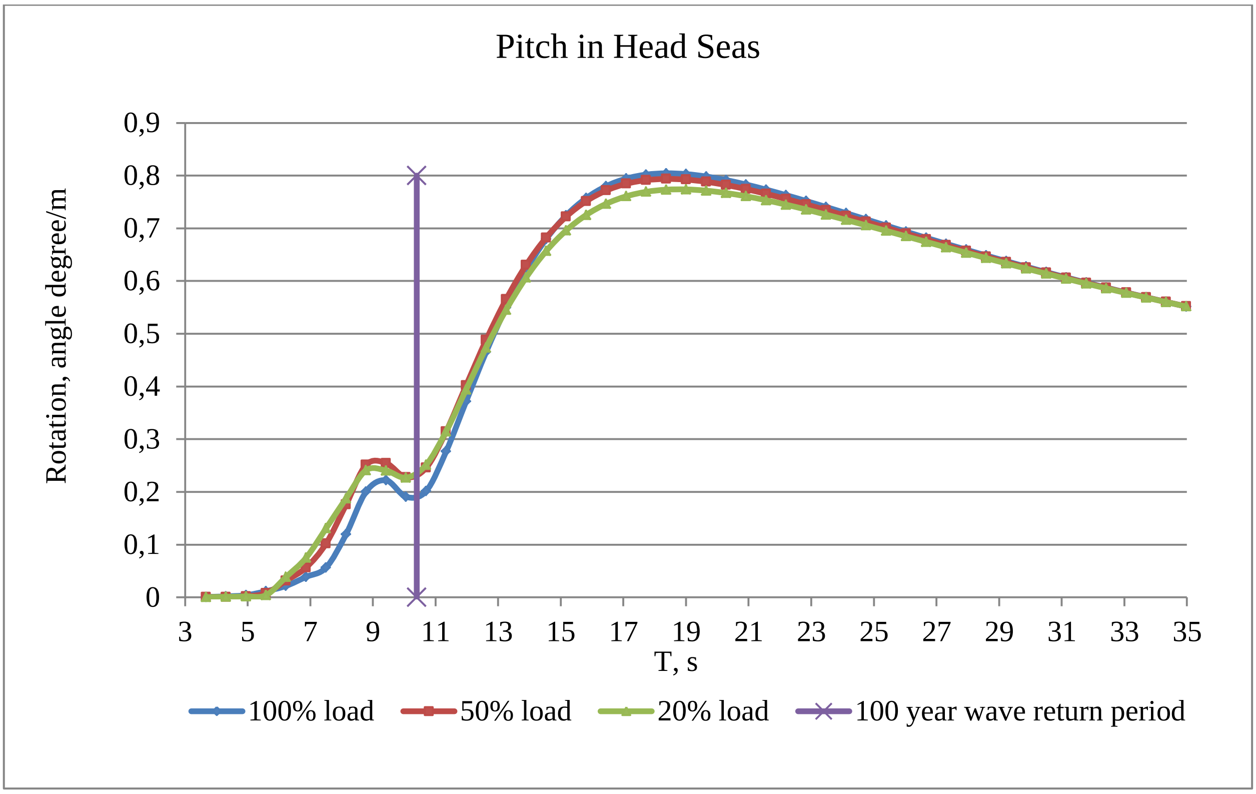


Figure 6.7 – Pitch in Head Seas

The same options have to be taken into consideration for pitch rotation, Figure 6.7. The peak period of the RAO is not in line with the wave period. The inclination equals less than 1.1 degree. It means that the bow raises to around 2.3 m or the stern goes down to 2.3 m. The minimum freeboard: 21 – 15 = 7 m. When the vessel is fully loaded: 7 - 2.3 = 4.7 m - freeboard when the vessel has max pitch inclination.

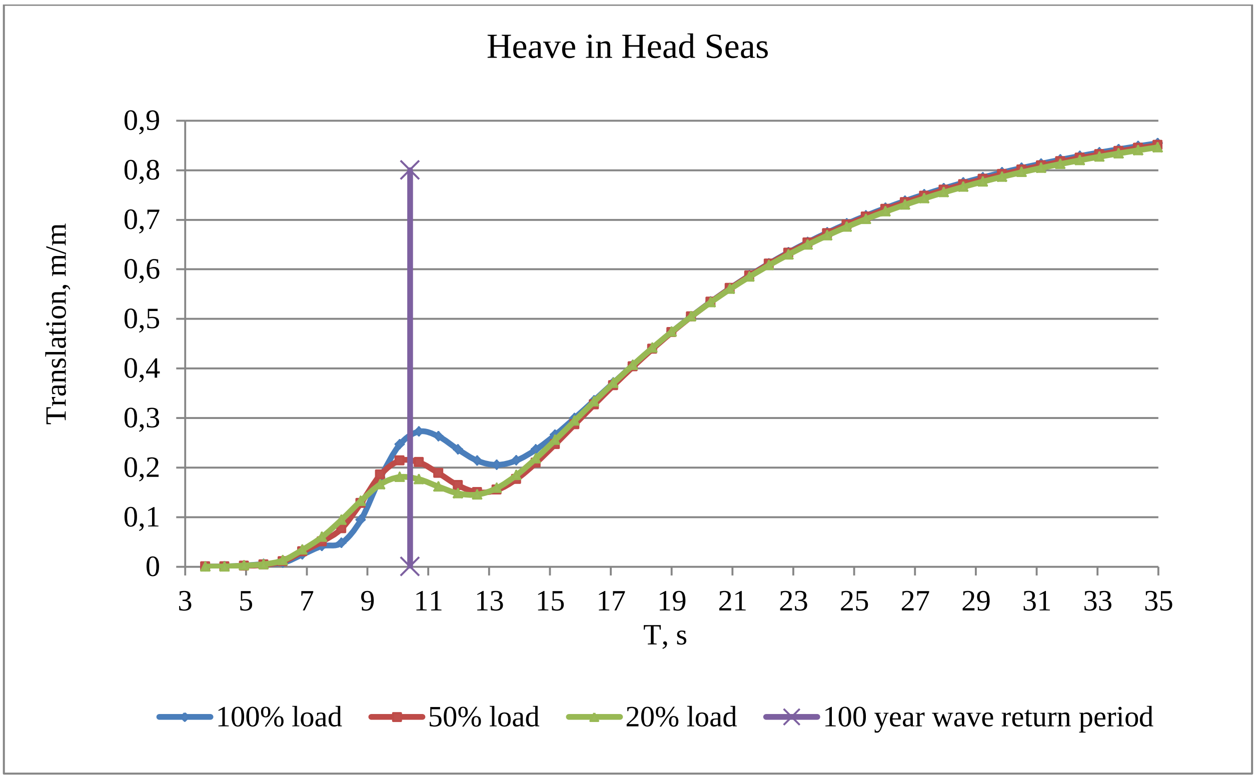


Figure 6.8 – Heave in Head Seas

Vessel heave motions (Figure 6.8) have resonance only in low wave frequencies, when the period of the wave is more than 17-18 s. Vessel translation in 100 year wave return period: 0.3 * 7.3 / 2 = 1 m.

In Beam Seas, the roll, heave and sway of the ship motions are considered, the pitch period will not be taken into consideration, because it is less than in head sea:

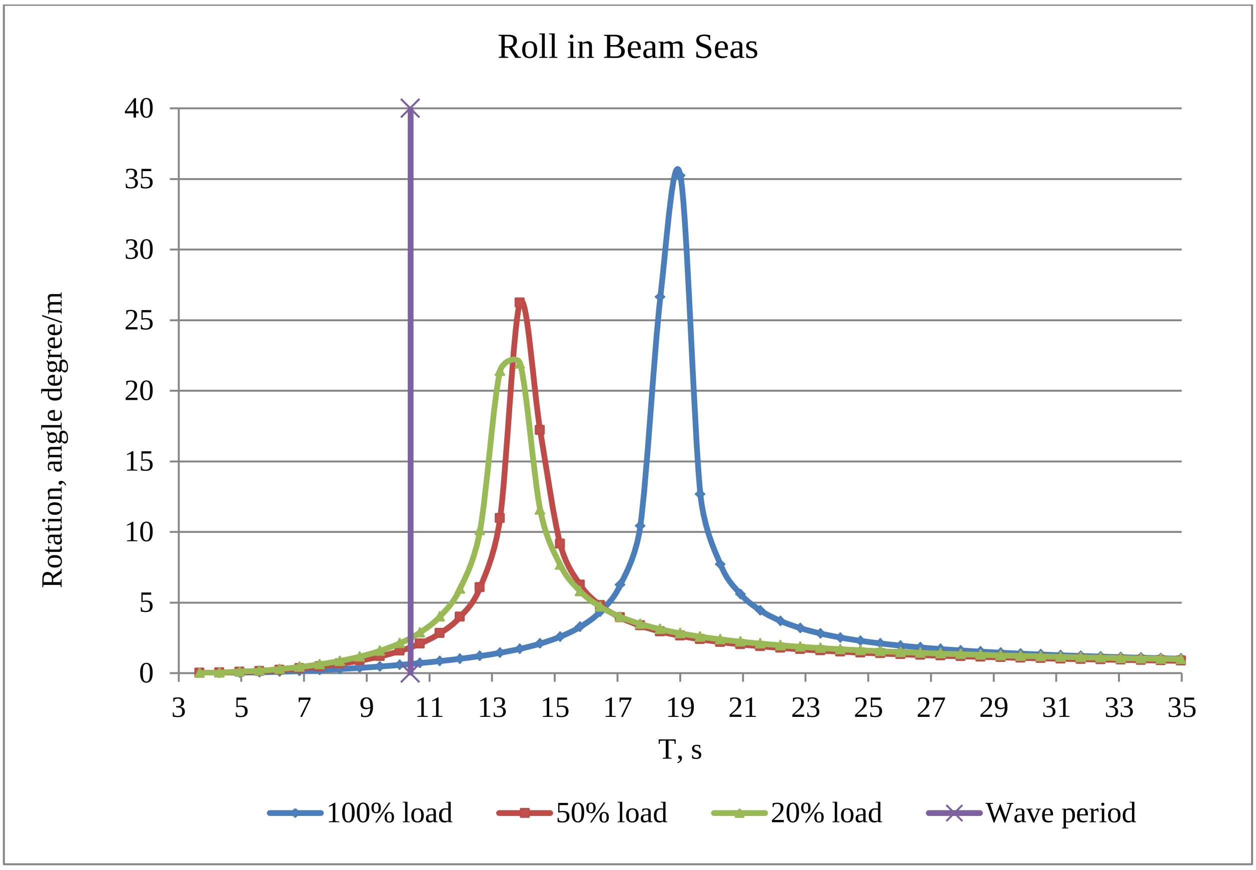


Figure 6.9 – Roll in Beam Seas

The roll motions in the beam sea, Figure 6.9, are the most dangerous inclination. However the vessel has resonance with in a wave with period more than 13 s. It is near, and if typhoon weather data are taken into consideration the vessel will go to resonance and sink. By the way 100 year wave return only is considered, because it is very difficult to forecast power of a typhoon and anyway the ship will disconnect and go away. The max angle inclination for a 20% load vessel = 2.8 angle degree/1 m of wave amplitude. It equals = 10.22 degrees. It's not too much, and vessel is stable. But it is not the operation conditions. The best solution is probably to stay in mooring position, and take max possible ballast.

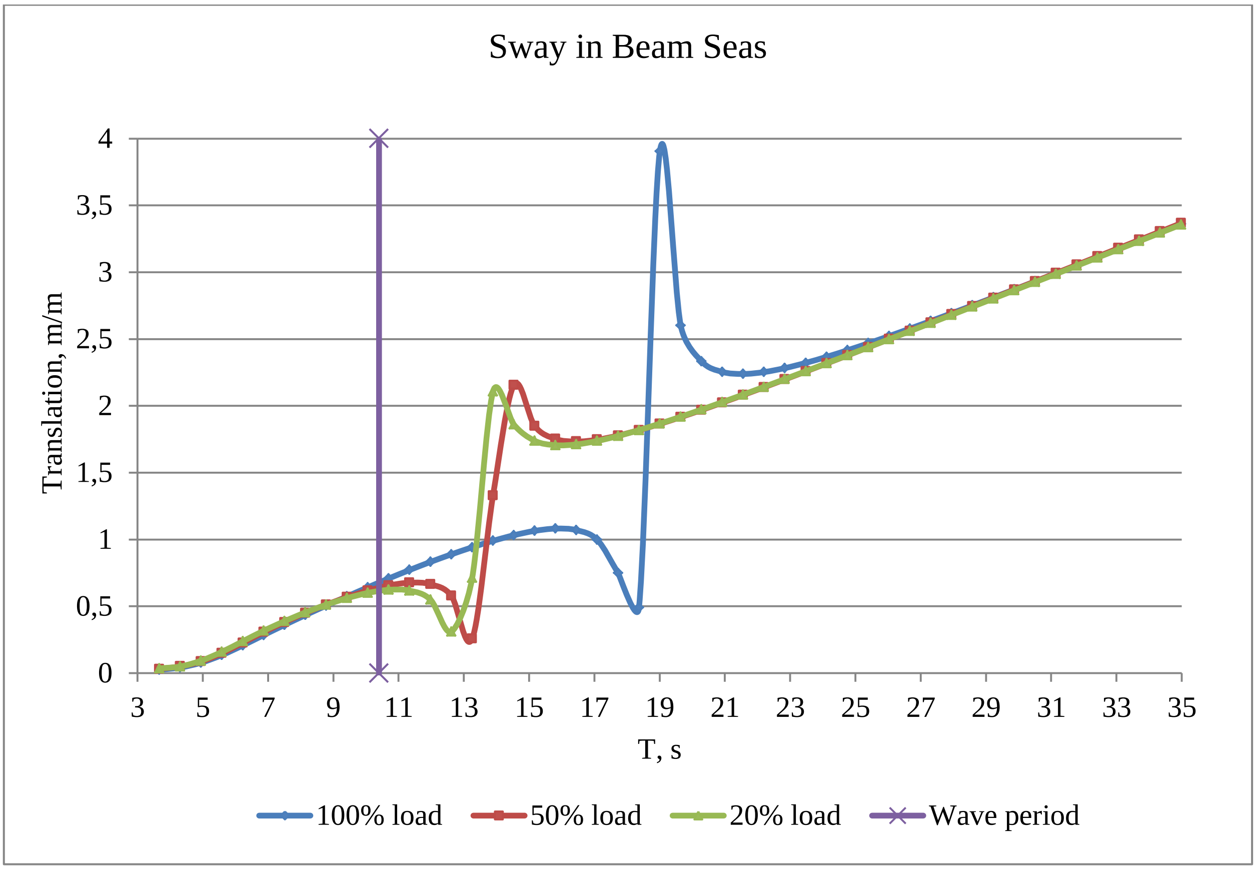


Figure 6.10 – Sway in Beam Seas

Sway motions, Figure 6.10, influence more on ship - handling quality than the stability. Small keels on the hull will reduce the sway. Anyway the value of sway is not big.

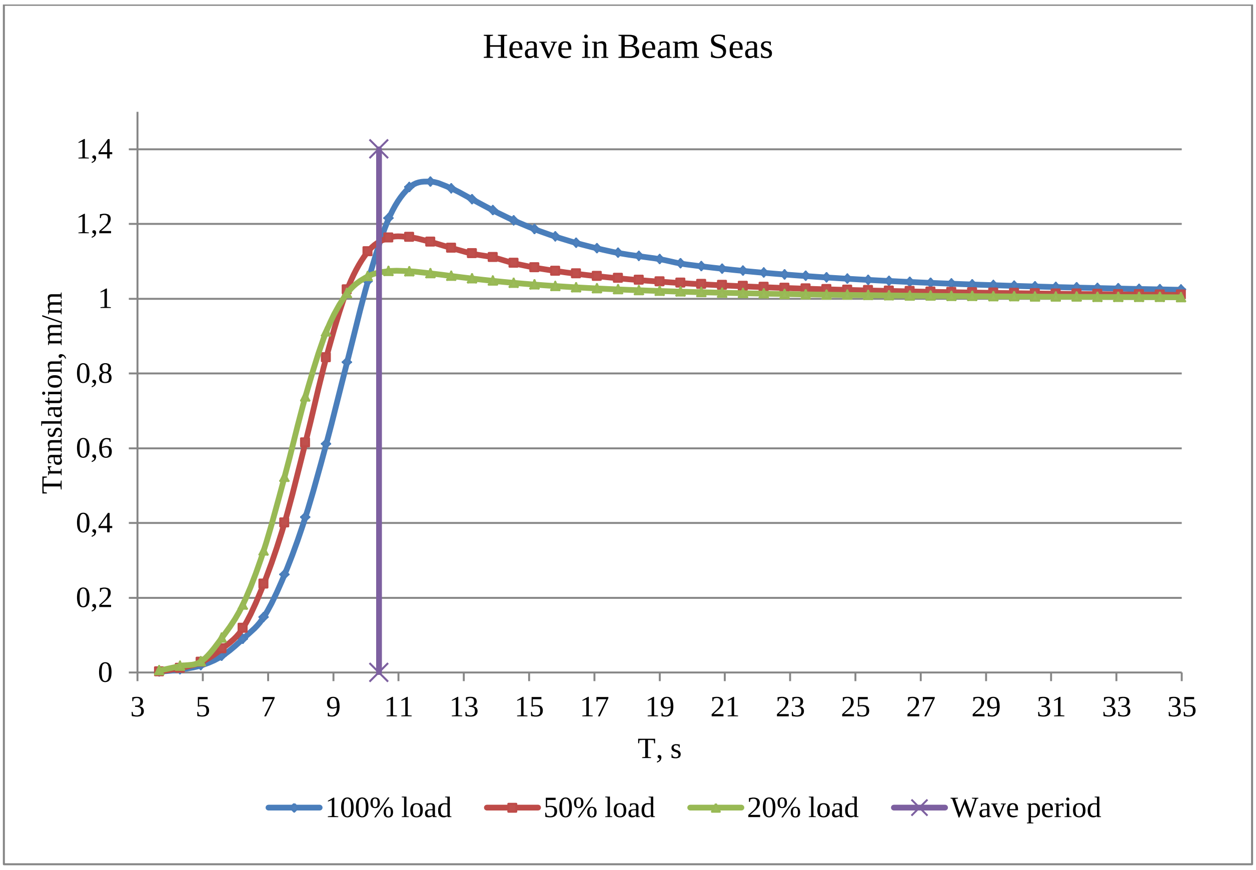


Figure 6.11 – Heave in Beam Seas

The value of the heave, Figure 6.11, is in absolute response: 1 * 7.3 / 2 = 3.65 m. The acceleration will cause high sea sickness for the ship crew. Keels on the sides of the hull will increase the additional mass and reduce the heave.

Quartering Seas (45 degree wave influence)

The most dangerous motion is roll in this wave direction, Figure 6.12.. Data for other RAOs could be found in Appendixes A, C and D.

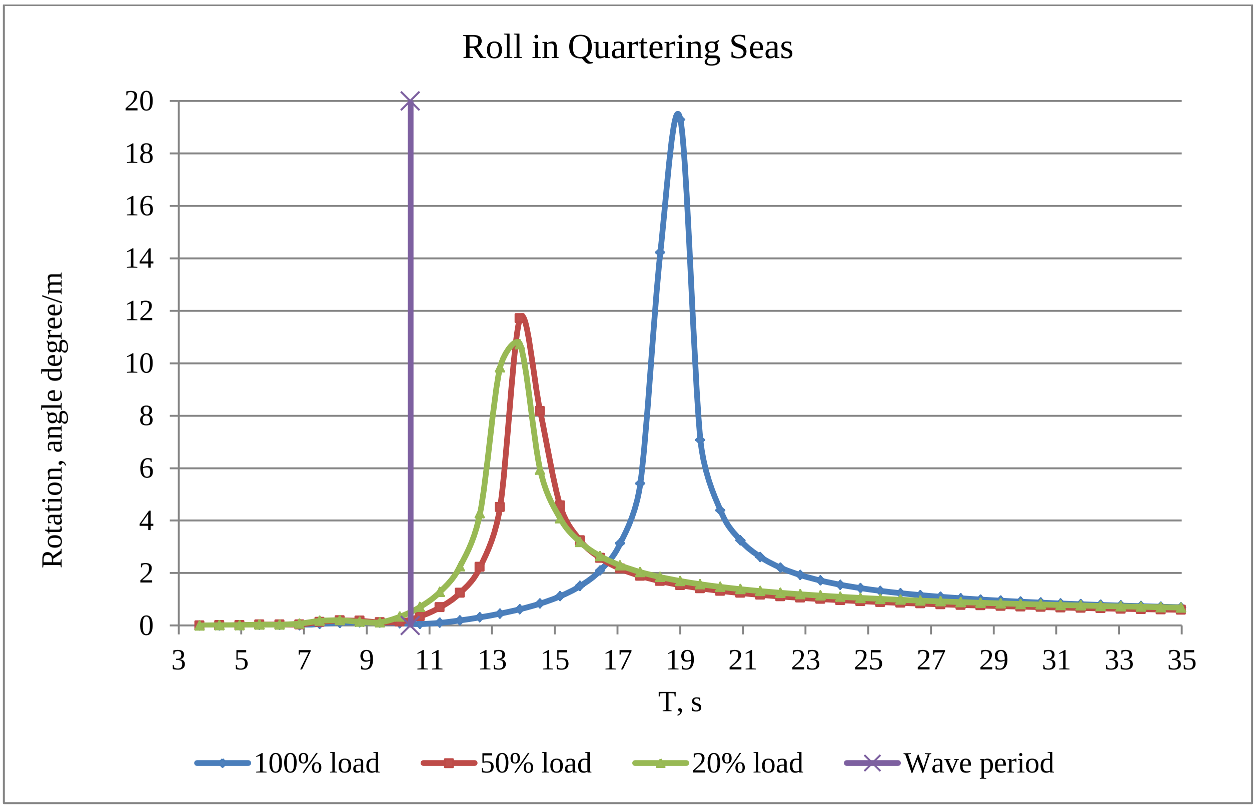


Figure 6.12 – Roll in Quartering Seas

The vessel is stable, but close to resonance is near.

In the next plot, Figure 6.13 is shown graphs of roll for different wave directions for 20% loaded ship, because this option has worst stability:

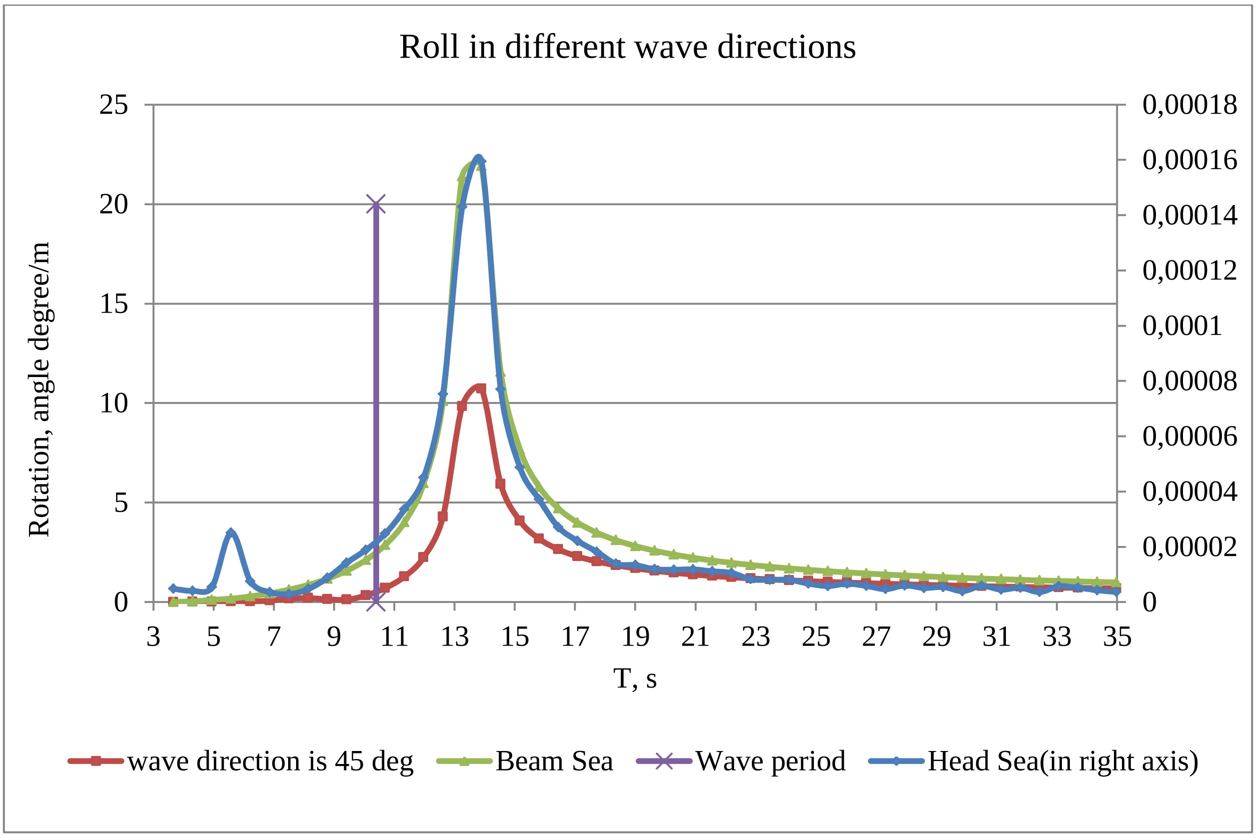


Figure 6.13 - Roll in different wave directions

The period of resonance in all directions is the same, but with different values. To get a complete understanding about dangerous directions for roll of the 20% loaded vessel, a 3D plot is created, Figure 6.14:

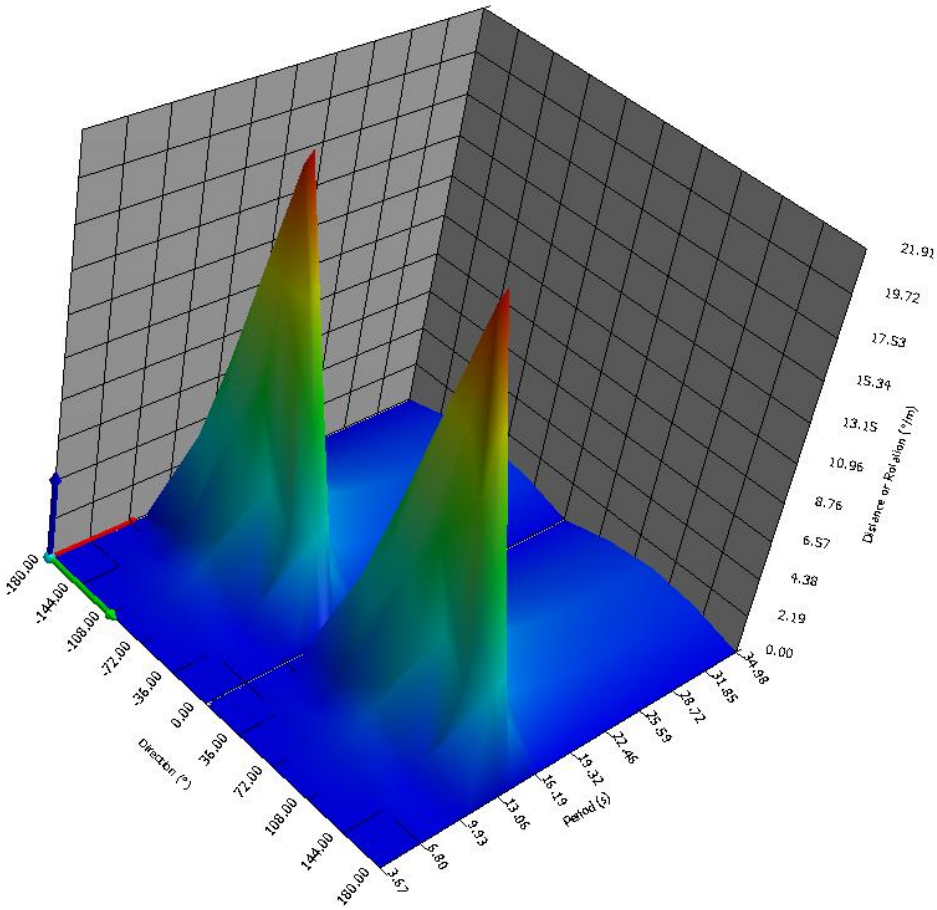


Figure 6.14 – Roll distribution depending on direction and period.

Next step is the structural analysis, which will be discussed very briefly.

On Figure 6.15 load distribution in the vessel due to head sea wave influence is shown. Loads vary according to the color (scale to the left). The maximum loads are found in the central part of hull. They increase from bottom to deck. This load distribution is created by long waves:

$$L = \frac{g}{2\pi} \cdot T^2 tanh\left(\frac{2\pi}{L} d\right) = \frac{9{,}81}{2\pi} \cdot 10{,}4^2 \tanh\left(\frac{2\pi}{L} \cdot 30\right) = 145 \text{ м}$$

The length of the FSO, 240m, is less than 2 wave length. It means that when the crest of the wave gets at the center part of the ship, the next crest will not be at stern or bow. This phenomenon induces big bending force in the hull. During modification of the ship to an FSO, the longitude bulkheads have to be stregthed.

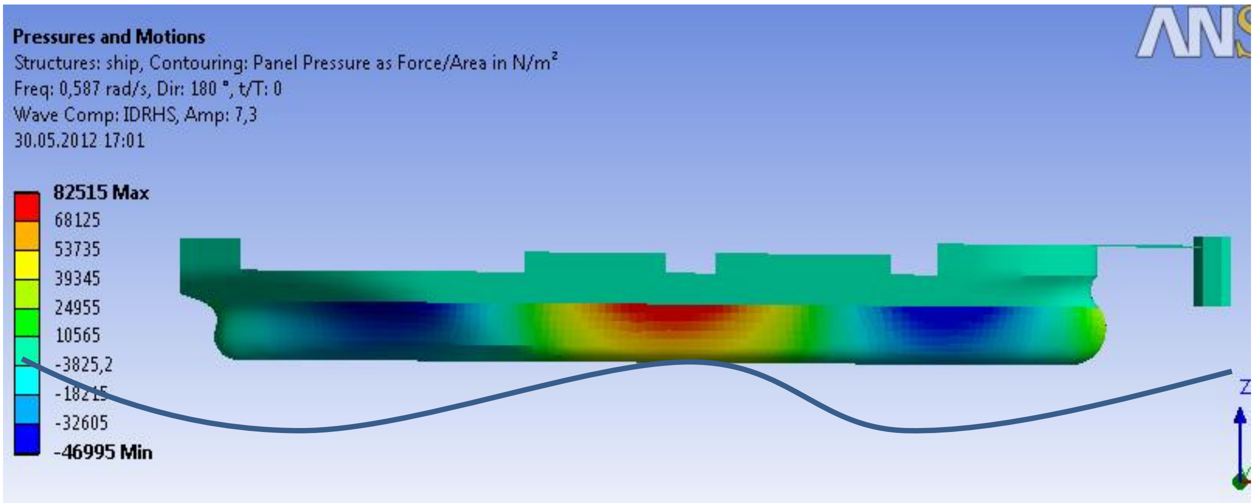


Figure 6.15 – Load distribution on the hull

6.3.2. Time Response Analysis

The diffraction model is transferred to a time response model. Wave, wind and current have to be defined additionally:

Wave

The Pierson-Moskowitz spectrum is chosen as irregular wave model:

$$S(\omega) = \frac{1}{2\pi} \cdot \frac{H_S^2}{4\pi T_Z^4} \cdot \left(\frac{2\pi}{\omega}\right)^2 e^{\left(\frac{1}{\pi T_Z^4}\right)} \cdot e^{\left(\frac{1}{\pi T_Z^4} \cdot \left(\frac{2\pi}{\omega}\right)\right)} \quad [15]$$

The Pierson-Moskowitz spectrum is a case for a fully developed sea. The Pierson-Moskowitz spectrum used in the AQWA program is formulated in terms of two parameters: the significant wave height (Hs=7.3 m) and the average (mean zero-crossing) wave period (Tz=8.6 s). This is considered of more direct use than the classic form, given in terms of the single parameter wind speed, or the form involving the peak frequency (T=10.4 s), where the spectral energy is a maximum. The spectral ordinate (S), at a frequency (ω, is given in rad/sec) [15]

Wind

The ISO wind spectrum is used for the wind distribution. This spectrum is defined in ISO 19901-1:2005(E).

Mean Profile

The mean profile for the wind speed averaged over 1 hour at elevation z, Uz, can be approximated by:

Uz=U10*[1 + C(ln(z/10)]

where:

U10 = wind speed averaged over 1 hour at reference elevation of 10 metres = 33.7 m/s

C = 0.0573*√(1+0.15*U10)

Wind spectrum:

$$S(f) = \frac{320 \cdot \left(\frac{U10}{10}\right)^2 \cdot \left(\frac{z}{10}\right)^{0.45}}{(1 + f^{0.486})^{3.561}}$$

f - frequency range from 0.00167 Hz $\leq$ f $\leq$ 0.5 Hz

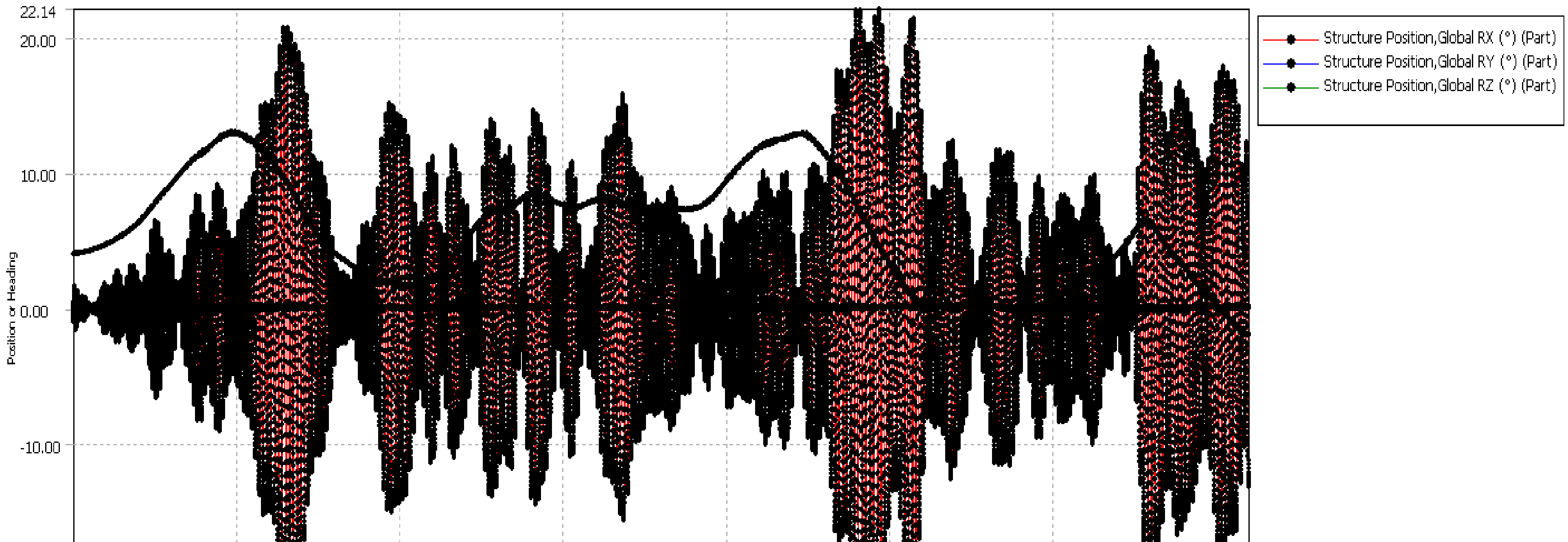
Current

Current is assumed to be constant. Velocity = 1.1 m/s at depth 10 m.

Table 6.2 - Weather simulation input parameters:

	Velocity, m/s	Period, s	Height, m	Position, m
Wave		10.4	7.3	
Wind	33.7			10
Current	1.1			-10

Simulation time has to be defined. For example 1 hour was simulated with a time step 0.1 s. The results of the rotational motions (RX – roll, RY – pitch and RZ – yaw) are presented in Figure 6.16. The maximum value (roll inclination = 22 degrees) is repeated around after 2000 s (1-st maximum value = 21 degrees is in the 600 s, 2-nd maximum value = 22 degree is in 2500 s). The extreme values do not vary a lot. 1000 s will be enough for simulation.



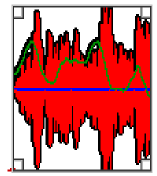


Figure 6.16 – roll-red line, pitch=blue line and yaw-green line motions in Beam Seas (1 hour simulation), degrees

A lot of cases have to be analyzed: different collinear weather loads + different non-linear weather loads + separate loads + coupled loads + non-extreme loads + so on and so on. But the time to prepare the Master thesis is limited. I have therefore taken into consideration the following options:

3 vessel options in beam seas and only the ship with 20% load in head seas and quartering seas (because this case has minimum stability as it was explained in the discussion of the diffraction analysis). Collinear weather loads will be analyzed because they have max loads.

20% loaded ship

Beam Seas.

Load distribution in sway direction (N), Figure 6.17

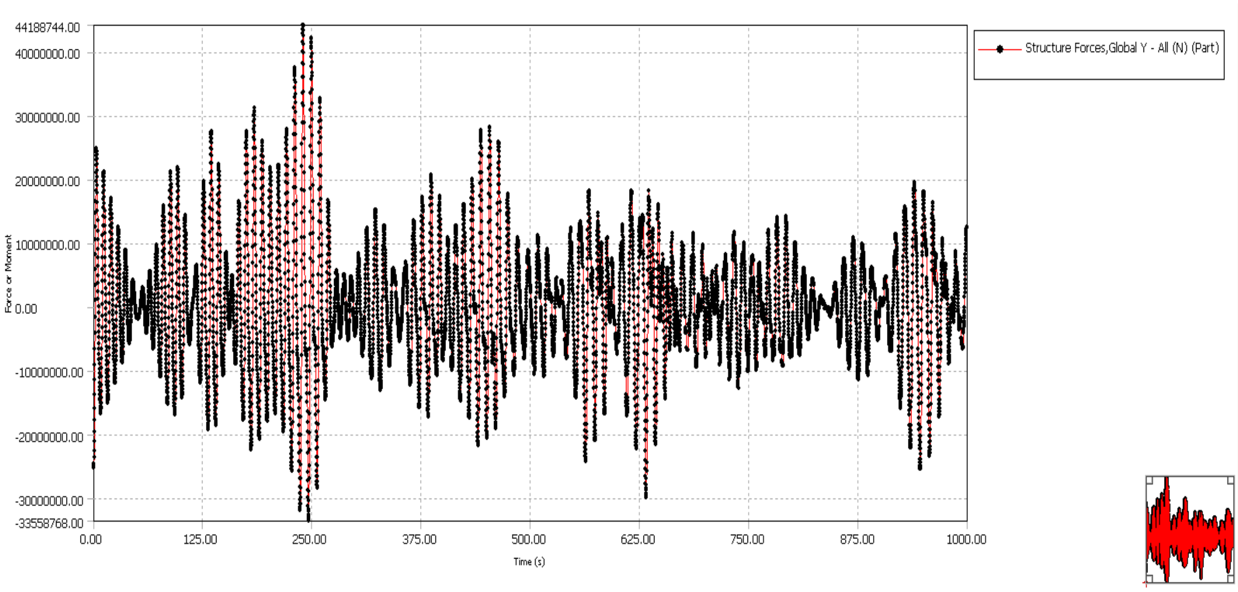


Figure 6.17 – Load distribution in sway direction, N

Roll and yaw motions (degrees), Figure 6.18*:*

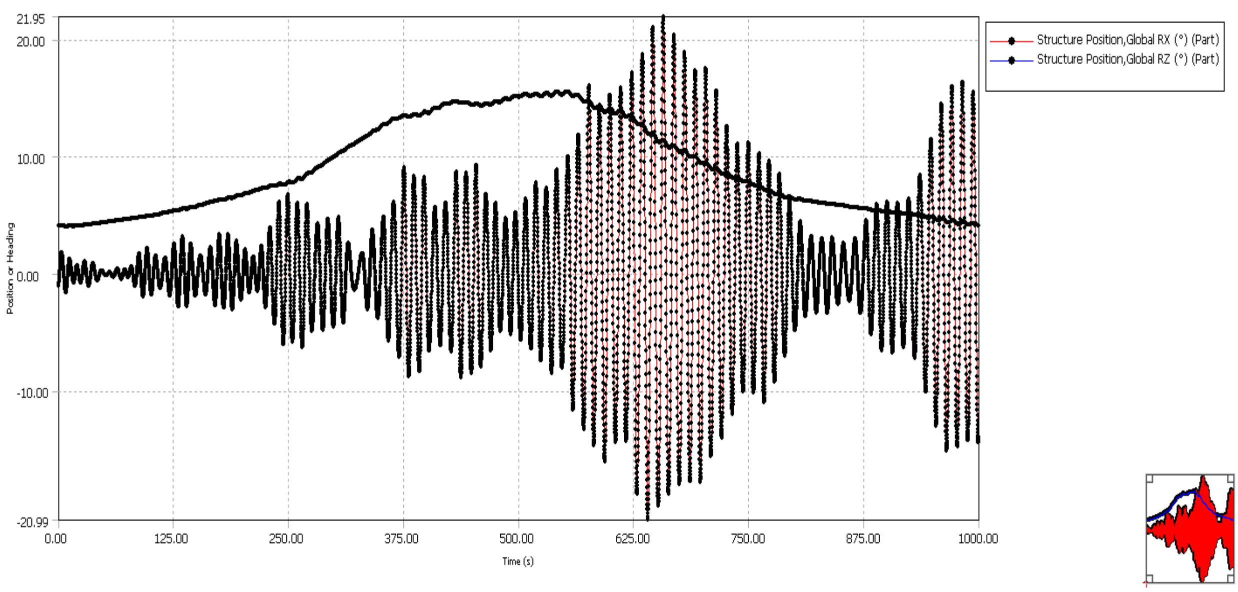


Figure 6.18 – Roll-red line and yaw-blue line motions in Beam Seas, degrees

An important conclusion can be derived from these graphs: roll and yaw are cumulative functions of loads. It's shown exactly in the plots. It means that maximum the value of the inclination of vessel is achieved not in the biggest wave or maximum loads moment. The vessel has maximum inclination after several waves. This phenomenon induces the risk of an emergency situation and decreases the chance to prevent the emergency situation because of the fact that it is not easily possible to identify lost stability.

Head Seas:

Load distribution in surge direction (N) , Figure 6.19*:*

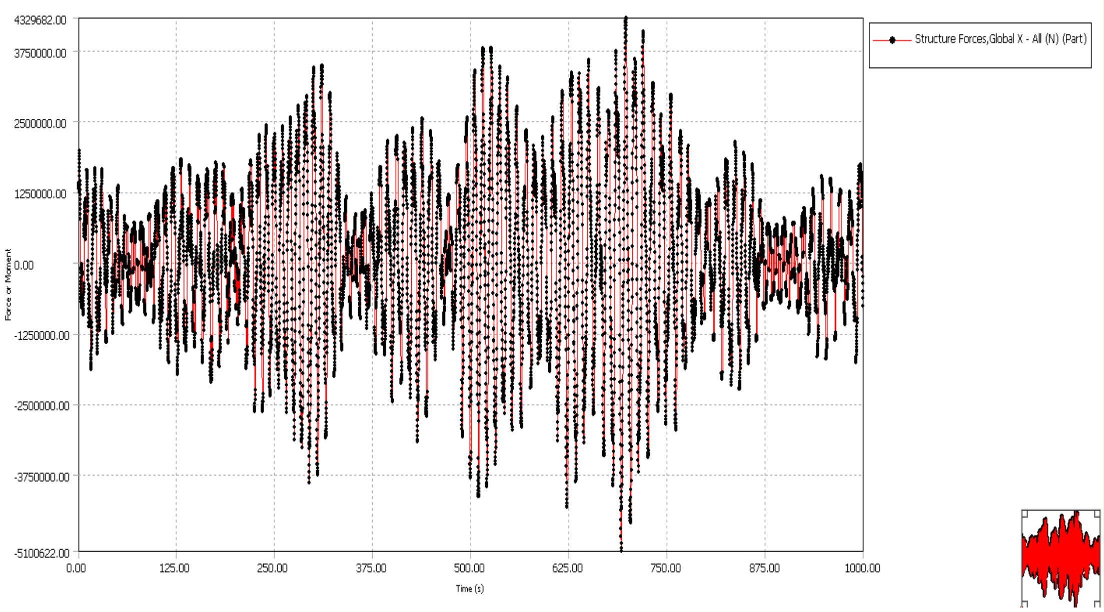


Figure 6.19 - Load distribution in surge direction, N

Pitch (degrees) and heave (m) motions, Figure 6.20*:*

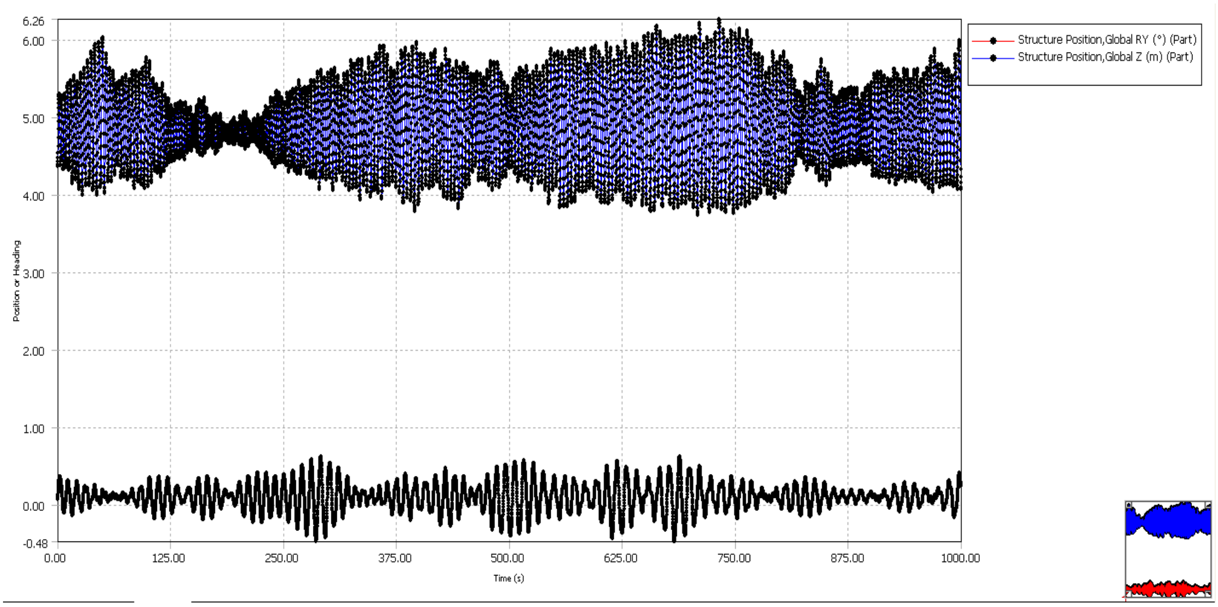


Figure 6.20 – Pitch-red line (degrees) and heave-blue line (m) motions in Head Seas

In Head seas loads are in 10 times less, pitch motion is small as well and doesn't present any hazard to the vessel. Pitch is twice lower than in Beam Sea. Under these conditions the ship has a good stability.

<u>Quartering Seas:</u>

Load distribution in surge and sway directions (N) , Figure 6.21*:*

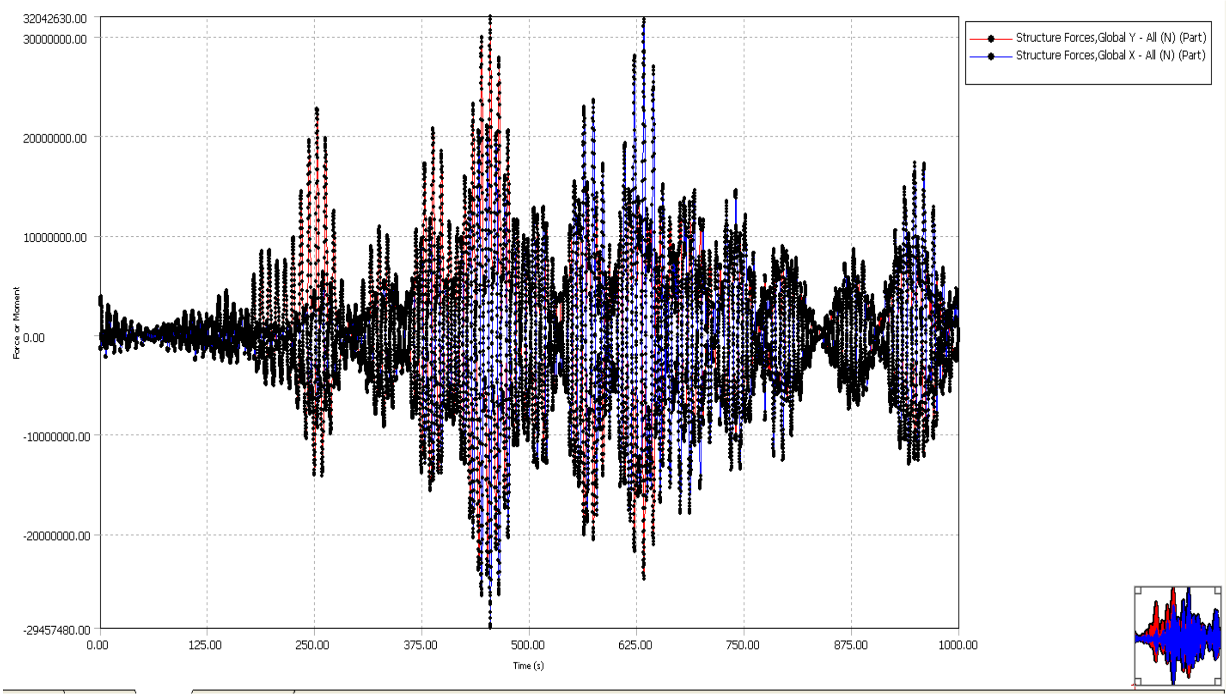


Figure 6.21 - Load distribution in surge-red line and sway-blue line directions in Quartering Seas, N

Roll and heave motions, Figure 6.22*:*

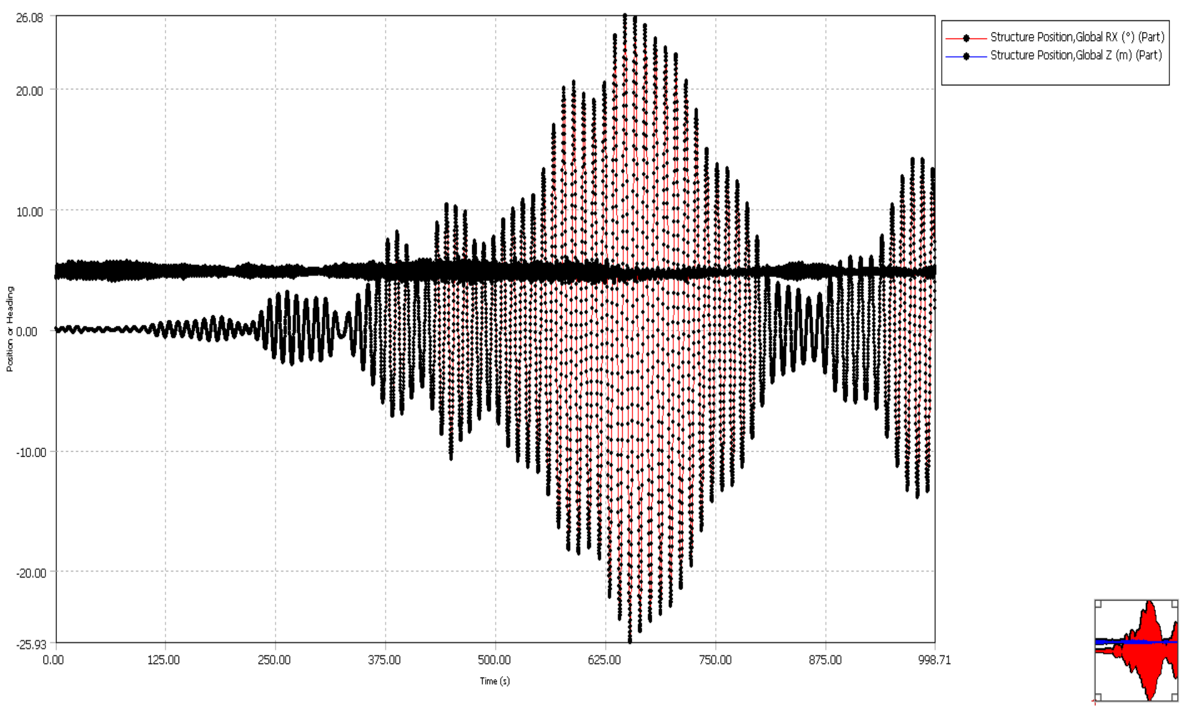


Figure 6.22 – Roll-red line (degrees) and heave-blue line (m) motions in Quartering Seas

Suddenly this option happened to show the worst output data, Figure 6.22: maximum roll motions (angle of inclination is more than 25 degree). Probability that the ship will sink is high. This result is difficult to explain by the fact that ship has very difficult trajectory of motions and load distributions. But it is understandable that comparing this case with the diffraction one with the same wave direction, we can consider that separate analysis without wind and current doesn't show a realistic picture.

Quartering Seas have to be considered for the 50% and 100% loaded vessel due to the results obtained from the previous case.

50% loaded vessel

One hour was simulated. The necessary time to obtain maximum loads and inclinations is increased because the vessel reaction to the weather factor is slow due to increasing mass of the ship (Figure 6.23).

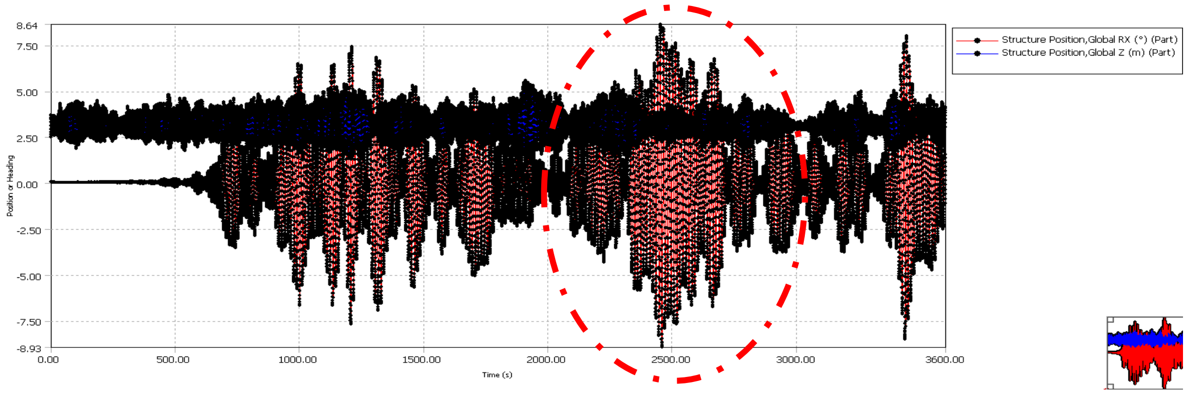


Figure 6.23 – One hour simulation to define maximum inclinations and loads, roll is red line (degrees), heave is blue line (m)

Therefore only time interval from to 2000 s to 3000 s is analyzed:

Load distribution in surge and sway direction (m), Figure 6.24*:*

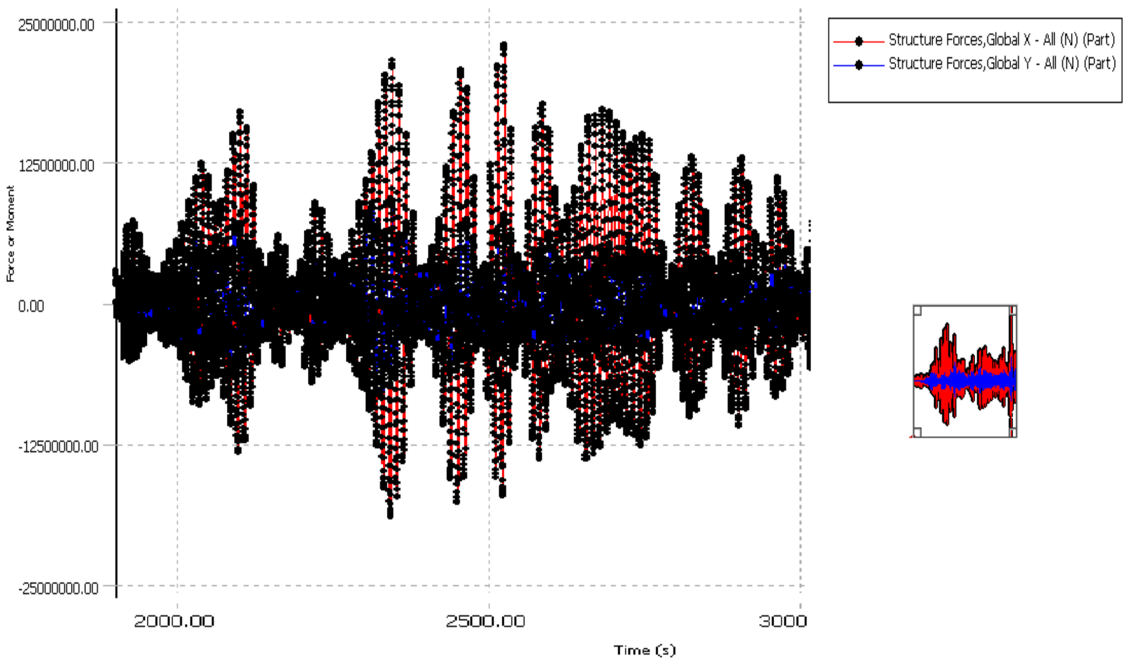


Figure 6.24 - Load distribution. Sway is red line, surge is blue line in Quartering Seas

Roll (degrees) and heave (m) motions, Figure 6.25*:*

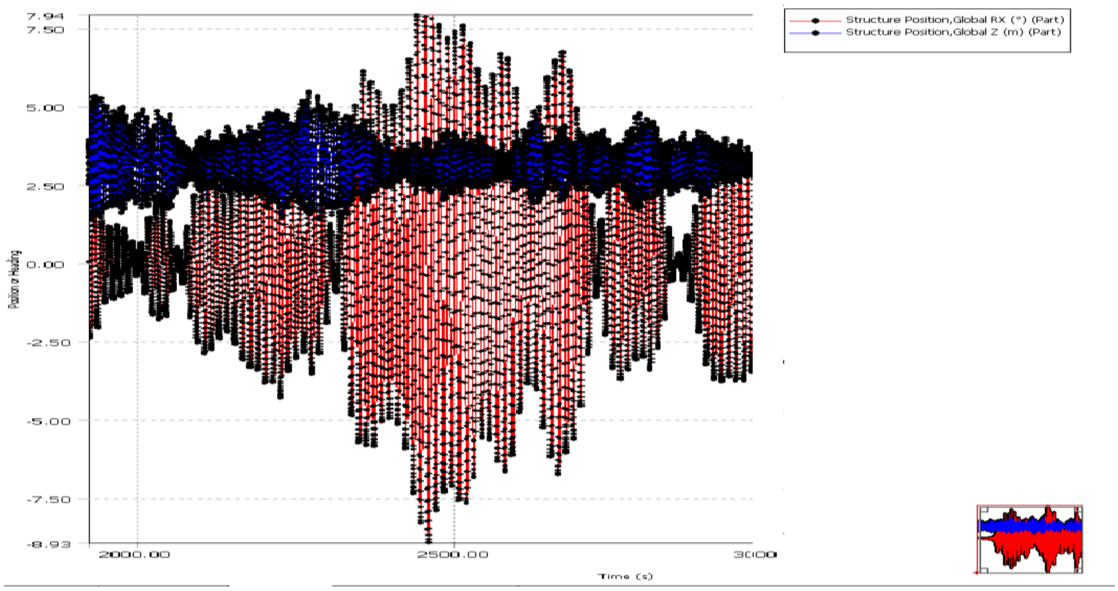


Figure 6.25 – Roll-red line (degrees) and heave-blue line (m) motions in Quartering Seas

This option of the vessel motion is more stable. Max angle of roll inclination is less than 10 degrees.

It’s understandable that in case the vessel has 100% load the maximum stability will be achieved. Therefore this option will not be taken into consideration. You can find the results in the Appendix D.

The mooring system is another challenge to be considered, Chapter 7.

7. Mooring System Simulation

Estimation of mooring system is found from in Aqwa program as well.

In the previous chapter the type of connection and the pattern of the mooring lines were defined – the ship has external turret mooring system with catenary lines. The effects of the chain mass and drag forces are considered; forces acting on the chain are time varying and have 'memory'. The chain will, in general, behave itself in a non-linear manner. The solution during a time history and the solution in the frequency domain are fully coupled, i.e. the cable tensions and motions of the vessel are considered to be mutually interactive where the chain affects vessel motion and vice versa.

The procedure has the following simplification:

1. Cables are semi-taut/taut during the analysis i.e. they have a minimum tension.

2. The sea bed will be considered at be horizontal at the location of the anchors.

3. The cable is modeled with a fixed number of elements.

4. 'Inline' dynamics (along the line of the cable) is included.

5. Sea bed friction is ignored.

The calculations are based on the following equations:

The static type solution:

K X = Fg + Fb +Fd + Fs,

where:

K = matrix of element tension stiffness

X = nodal displacement

Fg= gravity forces

Fb= buoyancy forces

Fd= drag forces due to steady current + current profile

Fs= sea bed reactions

Dynamic type solution:

$(-w^2 (Ms+Ma) -i\, C\, w + K)\, X = 0$

with a priori known X values applied at the fairlead,

where:

w = frequency (rad/sec)

Ms = structural mass

Ma = added mass

C = linearised damping

The linearised damping is obtained from the Morison drag relative velocity modulus directly for the single frequency solutions or for the multiple frequency solutions. Both solutions are necessarily iterative ones as the relative fluid velocity for each element is dependent on its motion [15].

Chain lines are based on catenary line geometry. Catenary line is described below. (Ozorishin A.A. Simplified calculations and analysis of FPSO mooring systems in the Kara Sea, [14]):

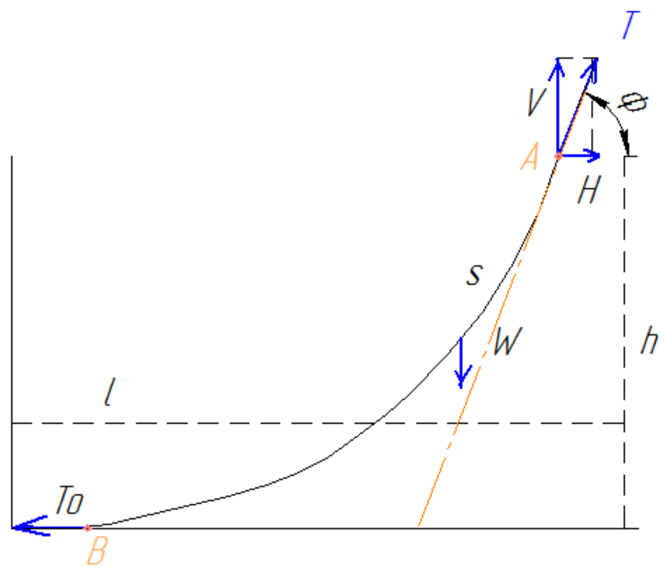


Figure 7.1 - Catenary geometry of the mooring line.

Let's assume that the mooring system has an ideal catenary geometry. In this case we can define the horizontal tension on the bottom (T_0), the length of the mooring line (S) and the necessary horizontal length from the connection point between the mooring system and the turret (A) to the touch down point (B), axial tension (T)

If we consider a piece of the mooring line we can determine the connection between the vertical tension and the horizontal one (Figure 7.2)

$$\frac{dy}{dx} = \frac{V}{H}$$

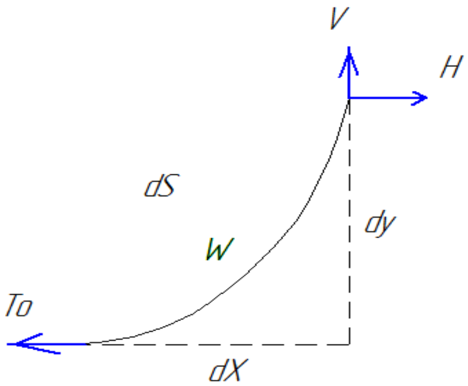


Figure 7.2 - Element of the mooring line

From this equation $\frac{dy}{dx} = \frac{V}{H}$ and the catenary equation $h = \frac{H}{W}\left(\cosh\left(\frac{w}{H}\right) - 1\right)$ we can find all necessary parameters:

The horizontal distance from the connection point between the mooring system and the submerged turret (A) to the touch down point (B):

$$L = \frac{H}{W}\operatorname{arccosh}\left(\frac{hW}{H} + 1\right);$$

Length of the mooring line (S):

$$S = \frac{H}{W}\sinh\left(\frac{W}{H}L\right);$$

Vertical Tension (V):

$$V = H\sinh\left(\frac{W}{H}L\right);$$

Axial tension (T):

$$T = \sqrt{V^2 + H^2};$$

Now we can check the chain:

$S_f \cdot T < B_L$,

where

S_f − safety factor

B_L − breaking load

Horizontal Tension on the bottom (B):

$$T^2 = T_0^2 + (WS)^2;$$

From this we obtain:

$$T_0 = \sqrt{T^2 - (WS)^2} = H;$$

Catenary line geometry is explained. By the way, it is difficult to define the horizontal load for 1 line due to the fact that the SPM is located behind the ship SPM has a small area and the stiffness of all lines influence each other. So the distance from the turret to the TDP (touch down point) is selected empirically. Two different geometries will be considered:

- 12 lines separated in 4 groups, Figure 7.4:

The mooring system is split into 4 groups (by 4 lines in each of them), the angle between the lines is 5 degrees, the length of each line is 315 m, the distance from turret to TDP is 312 m. This option is a standard solution.

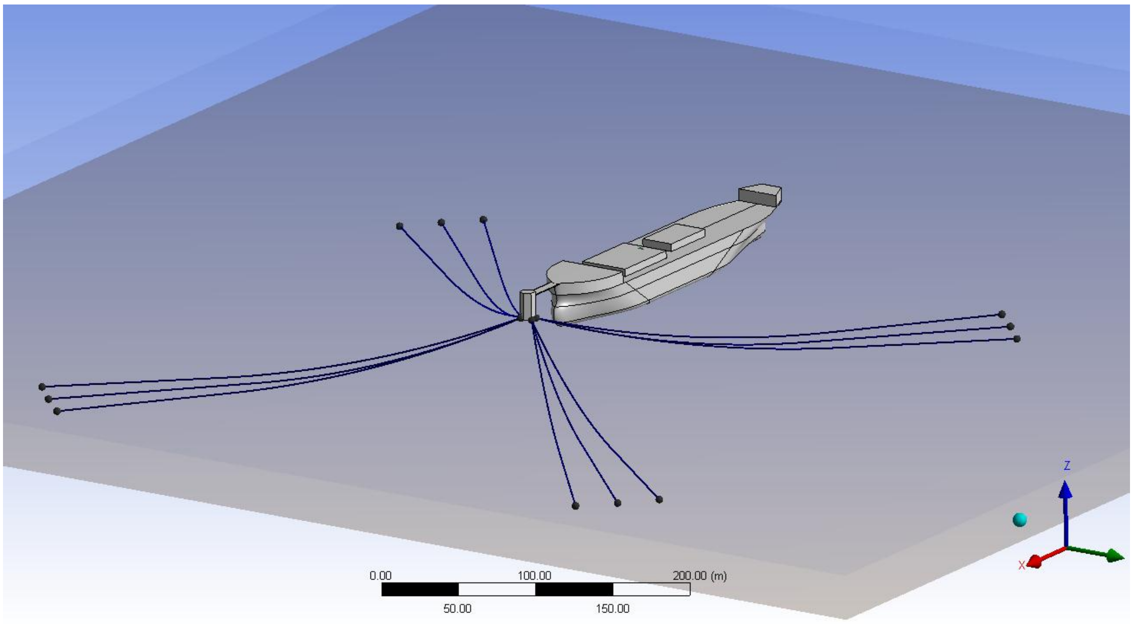


Figure 7.4 – Mooring design with 12 lines

- 12 lines with buoys separated in 4 groups, Figure 7.5:

Mooring system is separated into 4 groups (by 3 lines in each of them), the angle between the lines is 5 degrees. Two buoy systems with water displacement 70 000 kg are set in each line according to the following design: TDP - 105 m of chain – the buoy – 110m of chain – the buoy – 110 m of chain – the connection point is in the turret. The buoys allow us to increase the length of the lines which are equal to 325 m; the distance from the turret to the TDP is 312 m. This design could reduce the snap loads and the length of chain lying on the sea bottom.

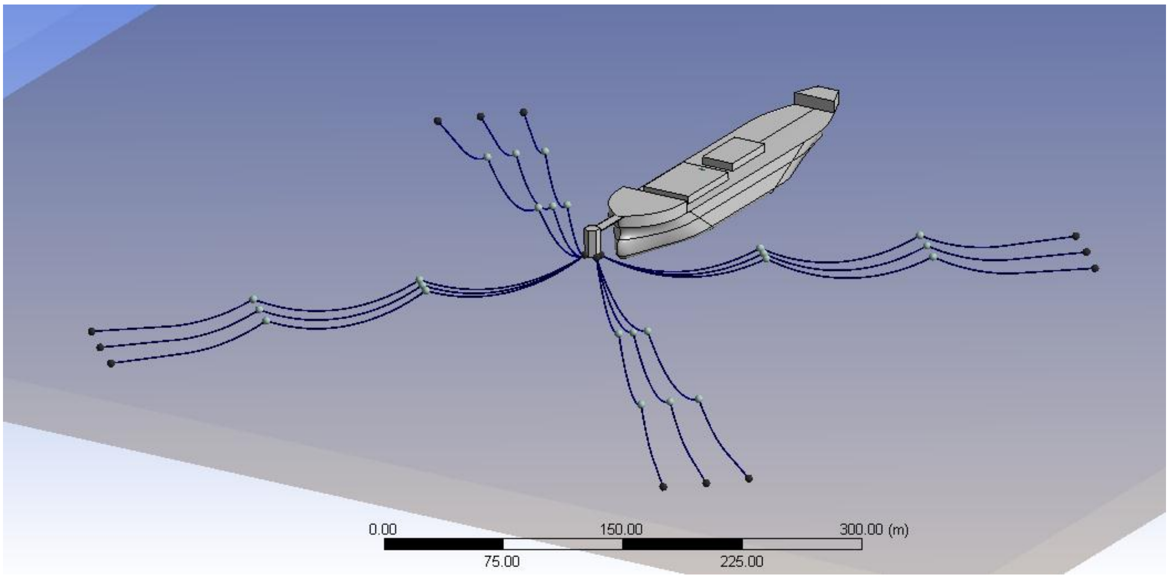


Figure 7.3 – Mooring design with 12 lines and buoys

Both systems have small area of lines projection. This decreases the risk of damage by trawlers and other vessels.

Usual options for the mooring simulation analysis are taken into consideration:

- Head Seas
- Collinear load direction is 15 degrees from the vessel bow
- Collinear load direction is 30 degrees from the vessel bow
- Collinear load direction is 45 degrees from the vessel bow

Four output parameters are the most important:

- Horizontal offset (a big offset is a challenge for the riser design). Offset in the surge direction will be discussed only in Head Seas due to limitations of the Aqwa program (Only the point of the center mass offset is estimated. In case of Head Seas offset, the turret is in line with the offset of the point of the center mass)
- Tension in lines to select chain grade
- Horizontal and uplift anchor forces to define anchor

- Length of chain lying on the sea bottom due to soft clay there is a risk of chain stucking

The fully loaded vessel is analyzed to evaluate the maximum parameters and to choose mooring system design. The 20% loaded vessel is discussed to check stability. The pre analysis shows that 1000 s simulation time is enough to show the maximum data.

The heaviest chain (686 kg/m) with Young modulus = 58490000 kN/m^2 and diameter = 0.177 m is selected to decrease the length of mooring lines due to ultra shallow water.

<u>Comparison of horizontal offset:</u>

Design with 12 lines, Figure 7.5:

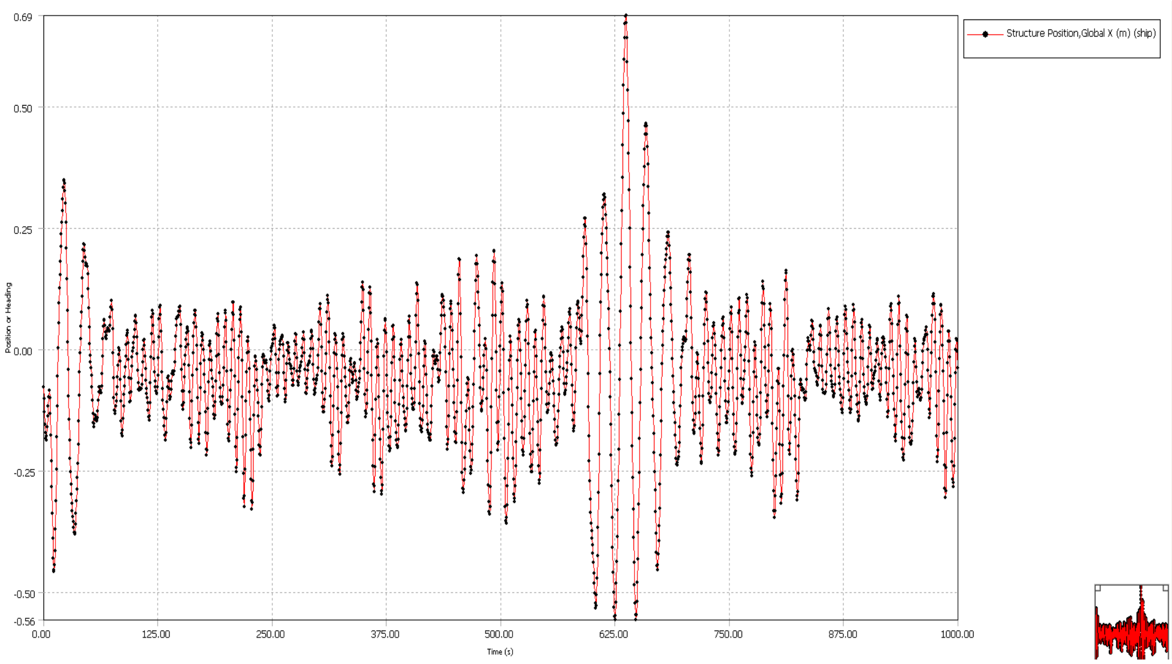


Figure 7.5 – Vessel horizontal offset (Design with 12 lines), m

Maximum offset is equal to 0.7 m. It is a very good result for the riser design.

Design with 12 lines and buoys, Figure 7.5:

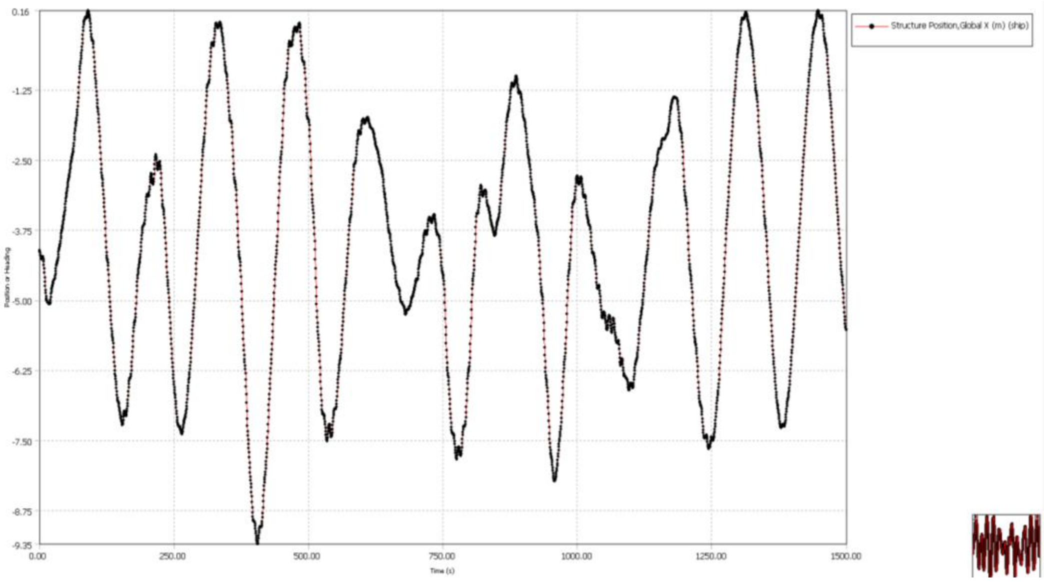


Figure 7.6 – Vessel horizontal offset (Design with 12 lines and buoys), m

The maximum offset is equal to 9.5 m. It is a big challenge for the riser design.

A numbering system for the lines has to be selected before continuing discussion,

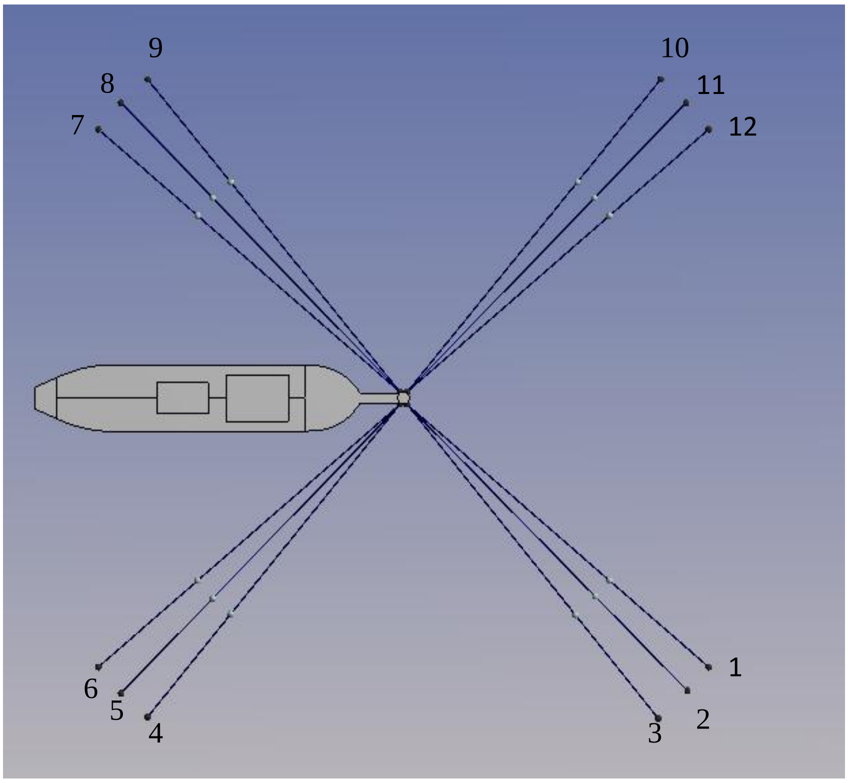


Figure 7.7 – Numbering of mooring lines

<u>Comparison of tension in lines:</u>

Design with 12 lines, Figure 7.8 (maximum tensions in lines are achieved in 30 degrees load direction)*:*

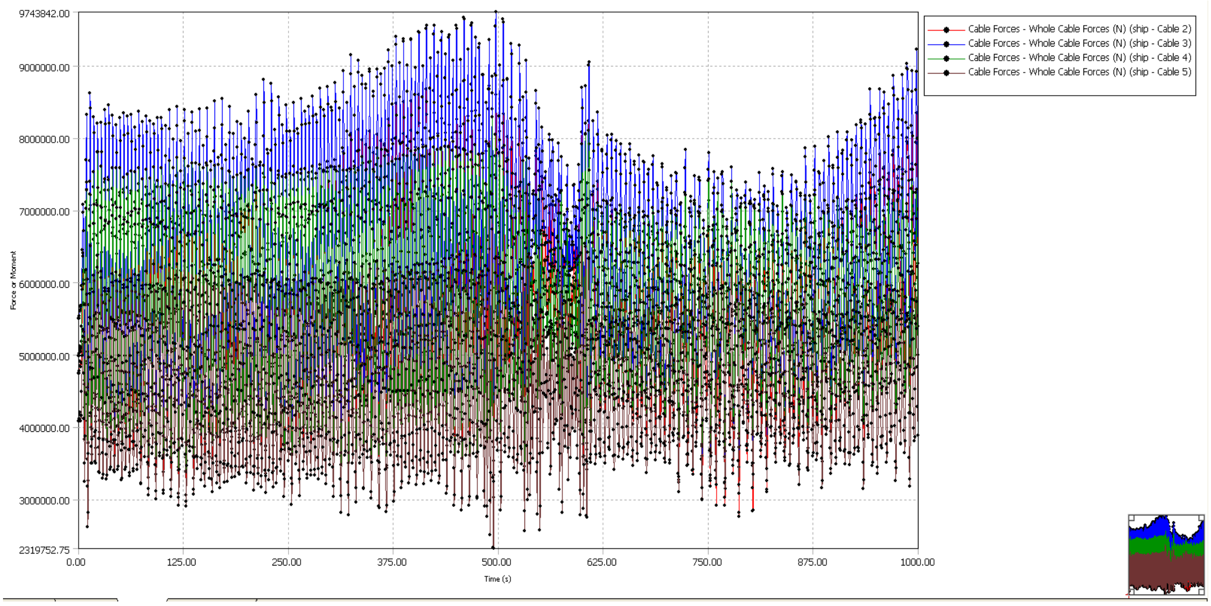


Figure 7.8 – Tension in lines, red plot is line 2, blue plot is line 3, green plot is line 4 and brown plot is line 5, N (Design with 12 lines)

The maximum load, 9.7 MN is in line 3. This load is huge and creates challenges for anchor and connection equipment on the turret. According to Vietnamese rules for FSO, the safety factor is equal to 1.67 (Table 7.1). The chain has to have a proof load at least 16 MN.

Table 7.1 – Factor of safety for anchoring lines [18]

		Factor of Safety
All Intact		
Dynamic Analysis	(DEC)	1.67
Quasi-Static	(DEC)	2.00
One broken Line (at New Equilibrium Position)		
Dynamic Analysis	(DEC)	1.25
Quasi-Static	(DEC)	1.43
One broken Line (Transient)		
Dynamic Analysis	(DEC)	1.05
Quasi-Static	(DEC)	1.18
Mooring Component Fatigue Life w.r.t. Design Service Life		
Inspectable areas		3.00
Non-inspectable and Critical Areas		10.00

Design with 12 lines and buoys, Figure 7.9 (maximum tension in lines are achieved in 15 degrees load direction)*:*

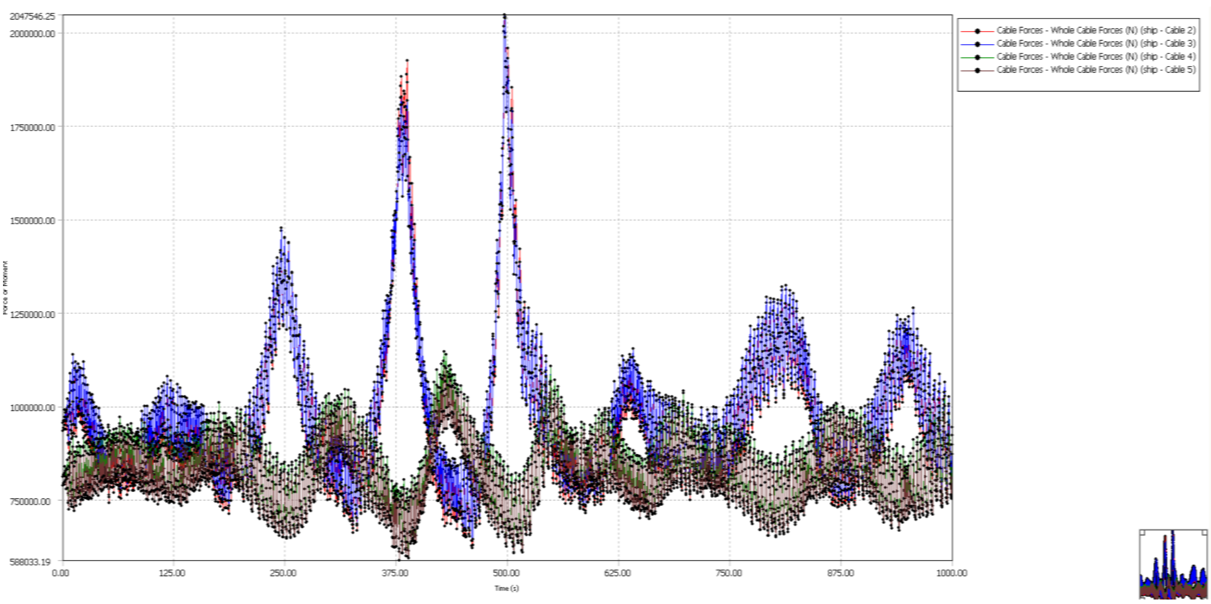


Figure 7.9 - Tension in lines, red plot is line 2, blue plot is line 3, green plot is line 4 and brown plot is line 5, N (Design with 12 lines and buoys)

The maximum load (2 MN) is in lines 2 and 3. The chain has to have a proof load of more than 3.7 MN (including safety factor). The lowest grade chain ORQ (Table 7.2) with a proof load of 13 MN is more than enough. Using lighter chain will increase offsets, uplift anchor forces and snap forces.

Table 7.2 – Chains and fittings [19]

Test Load	Proof Load											Weight	
Grade	ORQ	R3	NVR3	R3S Stud	R3S Stud-less	R4 Stud	R4 Stud-less	R4S Stud	R4S Stud-less	R5 Stud	R5 Stud-less		
C fac-tor	0,014	0,0148	0,0156	0,018	0,0174	0,0216	0,0192	0,024	0,0213	0,0251	0,0223	Stud	Stud-less
mm	kN	kN	kN								kN	kg/m	kg/m
127	7641	8078	8515	9824	9497	11789	10479	13099	11626	13700	12171	353	323
130	7950	8404	8858	10221	9880	12265	10903	13628	12095	14253	12663	370	338
132	8157	8623	9089	10488	10138	12585	11187	13984	12411	14625	12993	382	348
137	8682	9178	9674	11162	10790	13395	11906	14883	13209	15565	13829	411	375
142	9214	9741	10267	11847	11452	14216	12637	15796	14019	16520	14677	442	403
147	9753	10311	10868	12540	12122	15048	13376	16720	14839	17487	15536	473	432
152	10299	10887	11476	13241	12800	15890	14124	17655	15669	18464	16405	506	462
157	10850	11469	12089	13949	13484	16739	14879	18599	16507	19452	17282	540	493
162	11405	12056	12708	14663	14174	17596	15641	19551	17351	20447	18166	575	525
167	11963	12647	13330	15381	14869	18458	16407	20508	18201	21448	19056	611	558
172	12525	13240	13956	16103	15566	19324	17177	21471	19055	22455	19950	648	592
177	13088	13836	14584	16827	16267	20193	17949	22437	19912	23465	20847	686	627

Comparison of uplift anchor forces (only in lines with maximum tension) and length of chain lying on the sea bottom (for opposite lines with maximum tension), Table 7.3:

These parameters are given in the table due the fact that plots obtained in the simulation are not readable in a proper way

Table 7.3 – Comparison of uplift anchor forces and length of chain lying on the sea bottom

Design with 12 lines (15 degrees direction)	Design with 12 lines and buoys (45 degrees direction)
Uplift force in cable 3 = 265 KN	Uplift force in cable 3 = 35 KN
length of chain lying on the sea bottom 9 = 108 m	Laid length of cable 9 = 52 m

Summary: the design with 12 mooring lines has only one advantage, i.e. short offset (0.7 m), but due to high stiffness this option has huge tension in lines (9.7 MN) and big uplift force (265 KN). Also the probability that the chain will be stuck is in clay is also bigger, because the length of chain lying on the sea bottom (108 m) is twice bigger than in the second option. Option with 12 lines and buoys is selected.

In table 7.4 the maximum values for the case if one line is broken is given (all parameters can be found in Appendix F):

Table 7.4 – maximum values of parameters in case with one broken line (design with 12 lines and buoys)

Parameters	Values
Tension in the 2-nd cable, MN	2.75
Tension with safety factor, MN	3.43
Anchor uplifting force, kN	84
Horizontal offset, m	14
Laid length, m	51

The parameters do not change a lot except for anchor uplifting force (it will be discussed in the next chapter).

<u>The moored 20% loaded vessel's Stability in Quartering Seas 45 degrees (roll), Figure 7.10:</u>

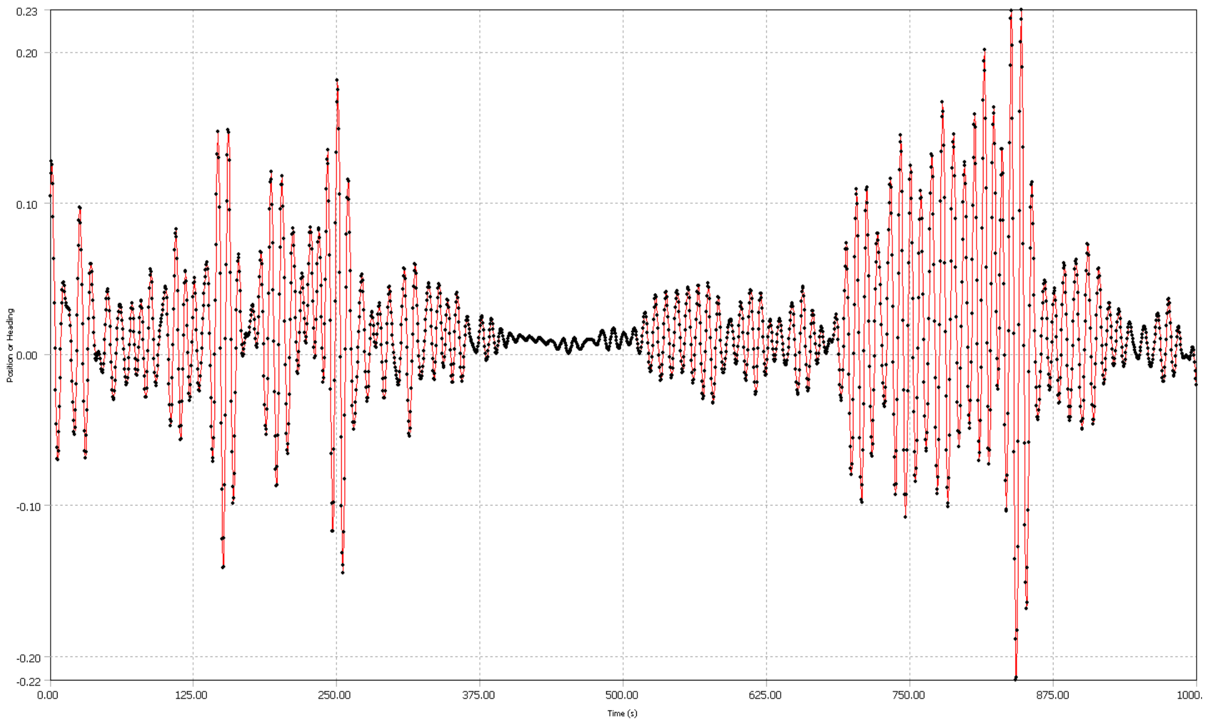


Figure 7.10 - The moored 20% load vessel Stability in Quartering Seas 45 degrees (roll), degrees

The maximum angle of inclination is equal to 0.23 degrees, the vessel is stable.

8. Anchor System

Types of anchor system:

Dead weight

The dead weight is the oldest type of anchor. The holding capacity is generated by the gravity force and by the friction between the anchor and the seabed. Common materials in use today for dead weights are steel and concrete [14].

Pile

The pile is a steel pipe that is installed into the seabed. The holding capacity of the pile is generated by the friction of the soil along the pile. The pile has to be installed to a great depth below the seabed to obtain the required holding capacity. The pile is capable of resisting both horizontal and vertical loads [14].

Drag embedment anchor

This is the most popular type of anchoring point today. The drag embedment anchor has been designed to penetrate into the seabed. The holding capacity is generated by the resistance of the soil in front of the anchor. The drag embedment anchor is suited for resisting horizontal loads, but not for large vertical loads [14].

Suction anchor

Like the pile, the suction anchor is a hollow steel pipe, although the diameter of the pipe is much larger than that of the pile. The suction anchor is forced into the seabed by means of a pump connected to the top of the pipe thus creating a pressure difference. When the pressure inside the pipe is lower than outside, the pipe is sucked into the seabed. After installation the pump is removed. The holding capacity of the suction anchor is generated by the friction of the soil along the suction anchor and lateral soil resistance. The suction anchor is capable of withstanding both horizontal and vertical loads [17].

Catenary type of mooring system is more accessible for shallow water (as was discussed in the previous chapter). Therefore the horizontal loads are dominating. To provide necessary resistance by using drag embedment anchor will be enough. The most reliable model of drag embedment anchor is possibly the Bruce FFTS MK4 anchor (Figure 8.1). Simplified selection (Figure 8.2) is chosen due to the fact that the exact parameters of the soil are unknown.

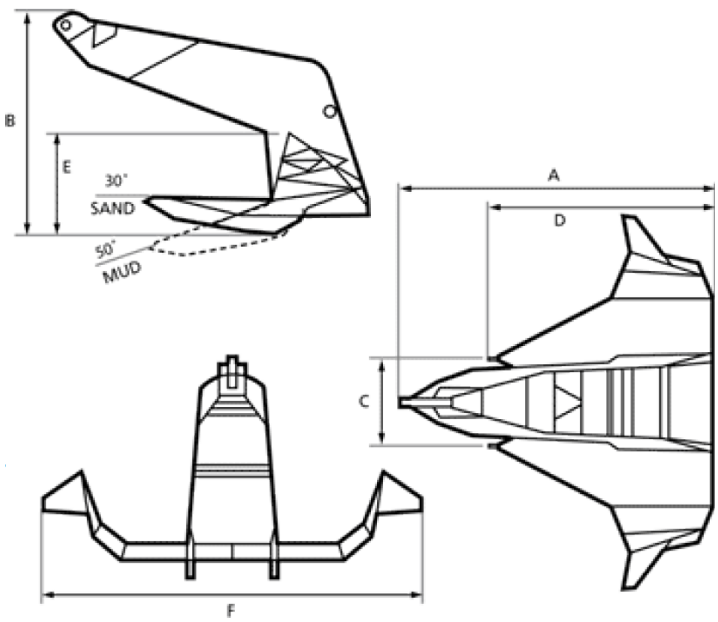


Figure 8.1 - Bruce FFTS MK4 anchor [20]

In the previous Chapter tension and uplifting forces were evaluated, Table 8.1:

Table 8.1 – maximum values of parameters in case with one broken line (design with 12 lines and buoys)

Parameters	Values
Tension in the 3-rd line, MN	2
Anchor uplifting force, kN (with 1 broken line)	35
Tension in the 2-nd line, MN (with 1 broken line)	2.75
Anchor uplifting force, kN (with 1 broken line)	84

The horizontal force could be estimated from the equation $T = \sqrt{H^2 + V^2}$, where V is Anchor uplifting force, H is the horizontal force. And $H = \sqrt{T^2 - V^2}$

Horizontal force $H_1 = \sqrt{2^2 - 0.035^2} = 1.99\ MN = 2MN$

Horizontal force with one broken line $H_2 = \sqrt{2.75^2 - 0.084^2} = 2.748\ MN = 2.75MN$

The safety factor for anchors is determined by the Vietnamese rules for FSO (Table 8.2)

Table 8.2 – Factor of safety for anchor holding capacity [18]

		Factor of Safety
Drag Anchors		
Intact Design	(DEC)	1.50
Broken Line Extreme	(DEC)	1.00
Vertically Loaded Anchors (VLAs)		
Intact Design	(DEC)	2.00
Broken Line Extreme	(DEC)	1.50
One broken Line (Transient)		
Dynamic Analysis	(DEC)	1.05
Quasi-Static	(DEC)	1.18
Pile Anchors		
Refer to API RP 2A, API RP 2T as applicable		
Suction Piles		
Intact Design	(DEC)	1.5 to 2.0*
Broken Line Extreme	(DEC)	1.2 to 1.5*

The horizontal force with safety factor (H_{1s}) is equal to 3MN, horizontal force with one broken line and safety factor (H_{2s}) is equal to 2.75 MN. H_{1s} is bigger than H_{2s} and will be taken into consideration. The holding capacity in t is equal to: 3MN / 9.81 m/s^2 = 306 t. From Figure 9.2, 9 t weight is required. Uplift force in t is equal to: 84 kN / 9.81 m/s^2 = 8.6 t. The own mass of anchor fits as well.

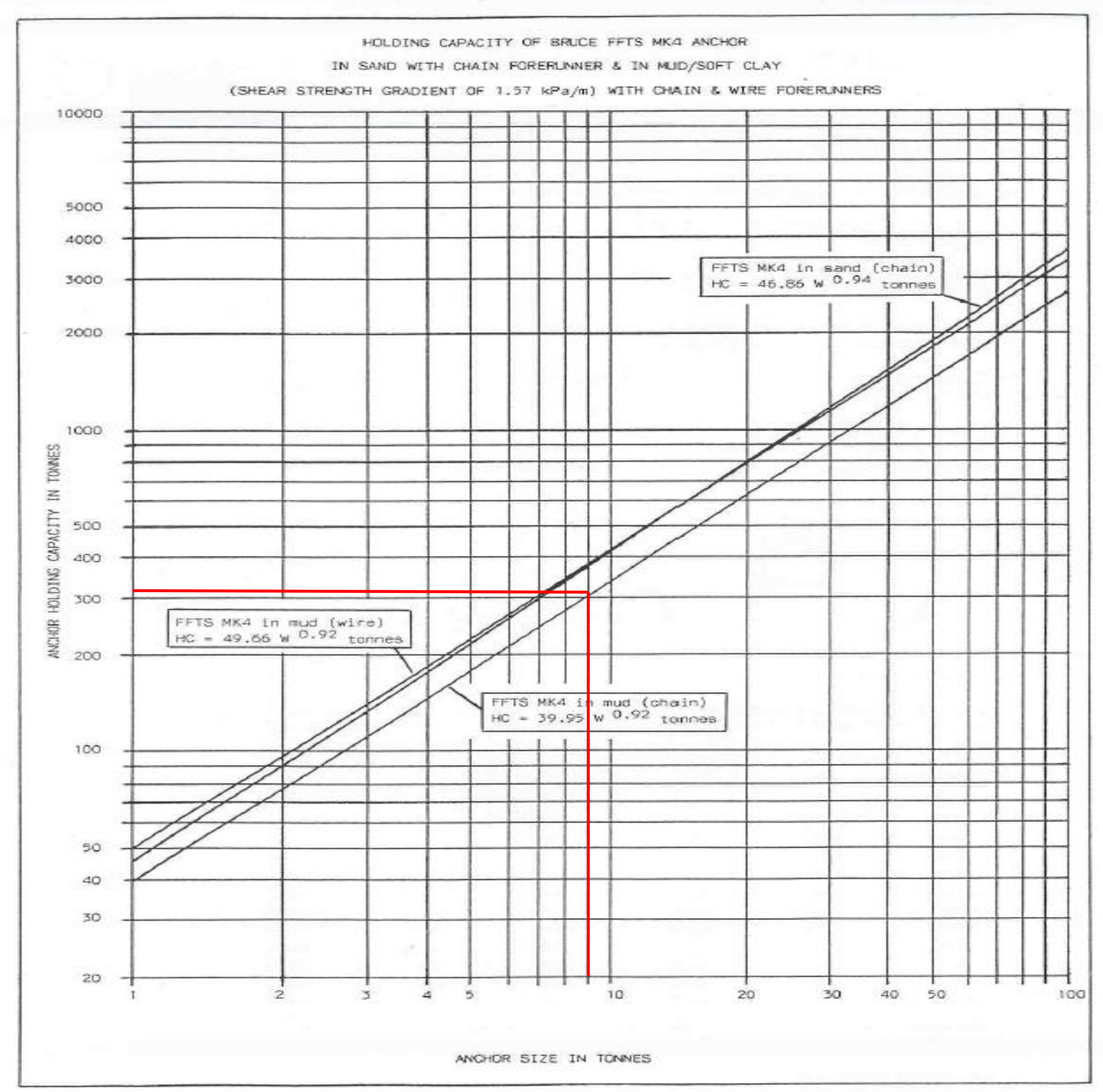


Figure 8.2 – Anchors holding capacity [20]

Conclusions

The FSO model has been evaluated in this Master thesis. The model has natural size and mass properties to represent a realistic solution. To appreciate the wind loads a superstructure was constructed. Hydrostatic outcomes have good values; all options of the loaded vessel are stable. RAOs were estimated in diffraction analysis. Roll motions of the 20% loaded vessel are more close to resonance with the waves expected at 100 year return period, but the vessel has good stability. Another important result is load distribution on the hull and analysis reveals that the construction of the central part of the hull has to be strengthened. Subsequent analysis in real time reveals that neglecting the wind and the current changes the results essentially: roll inclination of the empty vessel in Quartering Seas is equal to 26 degrees. The probability of the ship capsizing and sinking is high. The optimal solution is that the ship stays moored until ballast tanks are filled, and only after this the FSO has to go away. Other load cases options have good output results for all directions considered in this Master thesis.

Further, different types of mooring connection system were considered. External disconnectable system is the only one, which is possible to use in ultra shallow waters where there is a probability for typhoon storms. Two mooring line options were designed for external turret system. They are compared in several Quartering Seas. The system with 12 lines and buoys has the most acceptable values due to rather small line tensions (2 MN). The system with 12 lines and buoys has the following parameters: chain has grade stud ORQ with broken load 13 MN, lines have catenary geometry, length of line is 325 m, the distance from the connection point to the touch down point is 315 m, all lines are split into 4 groups (perpendicular to each other), the angle between lines is equal to 5 degrees, the maximum horizontal offset is 14 m (with one broken line). The riser design has to be optimized for this mooring system due to rather large offsets. The anchors type - Bruce FFTS MK 4 with weight 9 t is needed to restrain the FSO in the fixed position.

Further Work

To complete analysis the following procedure, the following has to be illuminated:

- To calculate accurate anchor parameters soil condition data has to be more precise.
- Riser design has to be taken into consideration, because it is a big challenge in shallow waters.
- Additional equipment such as dynamic positioning system and keels on the hull has to be analyzed. They can increase the stability and reduce loads on mooring system
- To provide economic Analysis is needed prior to investment decision.

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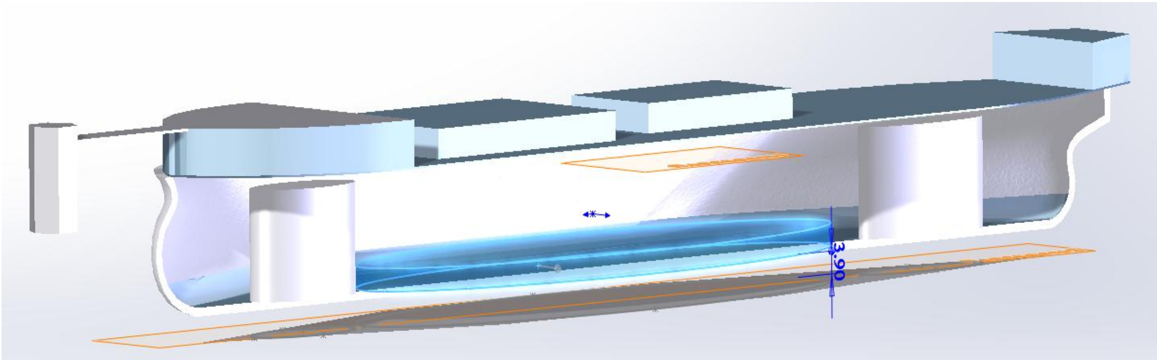
Appendix A – Simulation of 20% Loaded Vessel

Figure 1 - Vessel Mass definition



Units* (Units are the same in all Appendixes)

TABLE 1

Length	Meter
Mass	Kilograms
Rotational Velocity	Degrees
Force	Newton
Frequency	Radions per Second
Time	Second

Geometry*(Geometry is the same in all models)

TABLE 2 - Model (B3, C3, D3, E3, F3) > Geometry

Object Name	*Geometry*
State	Fully Defined
Sea Geometry	
Water Level	0 m
Water Depth	30 m
Water Density	1025 kg/m³
Water Size X	1000 m
Water Size Y	1000 m

TABLE 3 - Model (B3, C3, D3, E3, F3) > Geometry > Part

Object Name	*Part*
State	Fully Defined
Details of Part	
Total Structural Mass	68496468.78 kg
X Position of COG	0.9 m
Y Position of COG	0 m
Z Position of COG	0.48 m
Generate Internal Lid	No
Current Calculation Depth	0 m
Fixity Options	
Structure Fixity	Structure is Free to Move
Advanced Options	
Submerged Structure Detection	Program Controlled
Override Calculated GMX	No
Override Calculated GMY	No
Non-Linear Roll Damping	
Non-Linear Roll Damping	Excluded from Calculations

TABLE 4 - Model (B3, C3, D3, E3, F3) > Geometry > Part > Point Mass

Object Name	*Point Mass*
State	Fully Defined
Details of Point Mass	
X	0.9 m
Y	0 m
Z	0.48 m
Mass definition	Manual
Mass	68496468.78 kg
Define inertia values by	via Radius of Gyration
Kxx	18.5 m
Kyy	58 m
Kzz	62 m
Ixx	23442916439.955 kg.m²
Iyy	230422120975.92 kg.m²
Izz	263300425990.32 kg.m²

TABLE 5 - Model (B3, C3, D3, E3, F3) > Geometry > Part > Point Buoyancy

Object Name	*Point Buoyancy*
State	Fully Defined
Details of Point Buoyancy	
X	0 m
Y	0 m
Z	-4.3 m
Volume	74054.07 m³

Mesh* (Mesh is the same for all models)

TABLE 6 - Model (B3, C3, D3, E3, F3) > Mesh

Object Name	*Mesh*
State	Meshed
Details of Mesh	
Defeaturing Tolerance	1.5 m
Max Element Size	3.5 m
Max Allowed Frequency	1.713 rad/s
Meshing Type	Program Controlled
Generated Mesh Information	
Number of Nodes	9056
Number of Elements	9204
Number of Nodes (Diffracting Bodies)	2995
Number of Elements (Diffracting Bodies)	2920

Hydrodynamic Diffraction* (inputs data are the same in all models)

TABLE 7 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Diffraction (B4) > Gravity

Object Name	*Gravity*
State	Fully Defined
Details of Gravity	
Gravity, g	9.80665 m/s^2

TABLE 8 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Diffraction (B4) > Wave Direction

Object Name	*Wave Directions*
State	Fully Defined
Details of Wave Directions	
Type	Range of Directions, No Forward Speed
Required Wave Input	
Wave Range	-180° to 180° (-PI to PI)
Interval	45 °
Number of Intermediate Directions	7

TABLE 9 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Diffraction (B4) > Wave Frequency

Object Name	*Wave Frequencies*
State	Fully Defined
Frequency / Period definition	
Range	Program Controlled
Total Number of Frequencies	50
Equal Intervals Based Upon	Period

AQWA Hydrostatic Results

Structure	Part				
Hydrostatic Stiffness					
Centre of Gravity Position:	X: 0.9 m		Y: 0. m		Z: 0.48 m
	Z		RX		RY
Heave(Z):	89560720 N/		0.8330367 N/		1961436.8 N/
Roll(RX):	47.729485 N.		1.24138e8 N.		-42.156773 N.
Pitch(RZ):	1.12382e8 N.		-42.156773 N.		4.89911e9 N.
Hydrostatic Displacement Properties					
Actual Volumetric Displacement:	147883.47 m				
Equivalent Volumetric Displacement:	66825.828 m				
Centre of Buoyancy Position:	X: -1.4346e-3 m		Y: 1.7399e-5 m		Z: -4.295763 m
Out of Balance Forces/Weight:	FX: -3.64e-9		FY: 2.764e-8		FZ: 1.2129699
Out of Balance Moments/Weight:	MX: 3.5245e-5 m		MY: 1.9948415 m		MZ: 1.9949e-7 m
Cut Water Plane Properties					
Cut Water Plane Area:	8909.9043 m				
Centre of Floatation:	X: -0.3548141 m		Y: 5.3293e-7 m		
Principal 2nd Moment of Area:	X: 1413846.3 m		Y: 28617352 m		
Angle Principal Axis makes with X(FRA):	-2.9717e-5 °				
Small Angle Stability Parameters					
C.O.G. to C.O.B.(BG):	4.775763 m				
Metacentric Heights (GMX/GMY):	4.78478 m		188.73709 m		
COB to Metacentre (BMX/BMY):	9.5605431 m		193.51285 m		
Restoring Moments/Degree Rotations (MX/MY):	2166610.8 N.		85462616 N.		

TABLE 10 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrodynamic Graph Results

Object Name	*RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)*
State	Solved
Details of RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Frequency
Frequency or Period Scale	Period
Line A	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global X
Direction	-180 °
Position of Min in X	3.668
Position of Max in X	34.981
Minimum Value	0.002
Maximum Value	2.943
Line B	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global Y
Direction	-180 °
Position of Min in X	31.147
Position of Max in X	5.585
Minimum Value	0
Maximum Value	0
Line C	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global Z
Direction	-180 °
Position of Min in X	3.668
Position of Max in X	34.981
Minimum Value	0
Maximum Value	0.846

FIGURE 2 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Diffraction (B4) > Solution (B5) > RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)

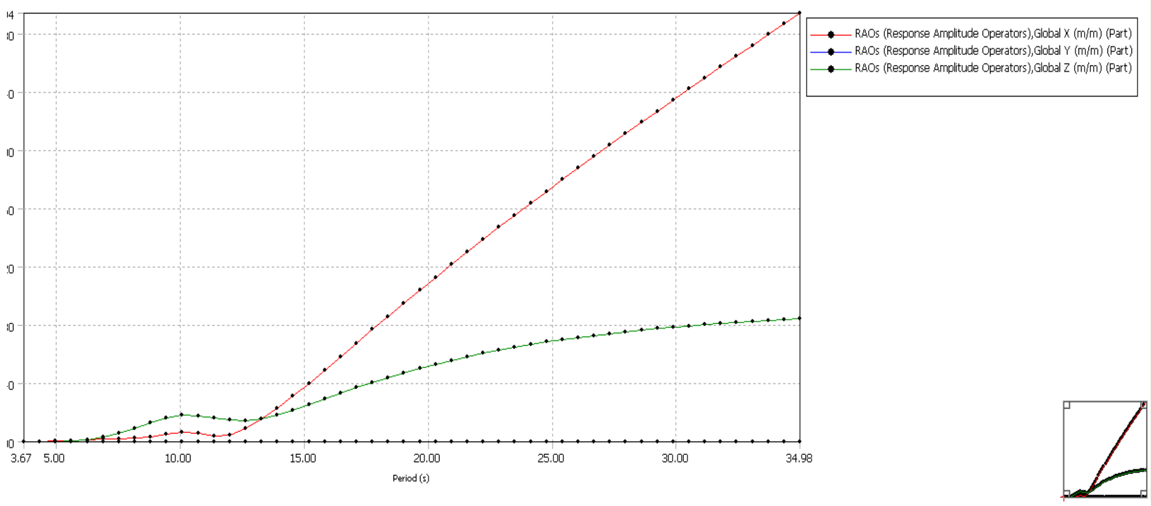


TABLE 11 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrodynamic Graph Results

Object Name	*RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)*
State	Solved
Details of RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Frequency
Frequency or Period Scale	Period
Line A	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global RX
Direction	-180 °
Position of Min in X	7.502
Position of Max in X	13.893
Minimum Value	0
Maximum Value	0
Line B	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global RY
Direction	-180 °
Position of Min in X	3.668
Position of Max in X	19.005
Minimum Value	0
Maximum Value	0.774
Line C	
Structure	Part
Type	RAOs (Response Amplitude Operators)

Component	Global RZ
Direction	-180 °
Position of Min in X	7.502
Position of Max in X	4.946
Minimum Value	0
Maximum Value	0

FIGURE 3 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Diffraction (B4) > Solution (B5) > RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)

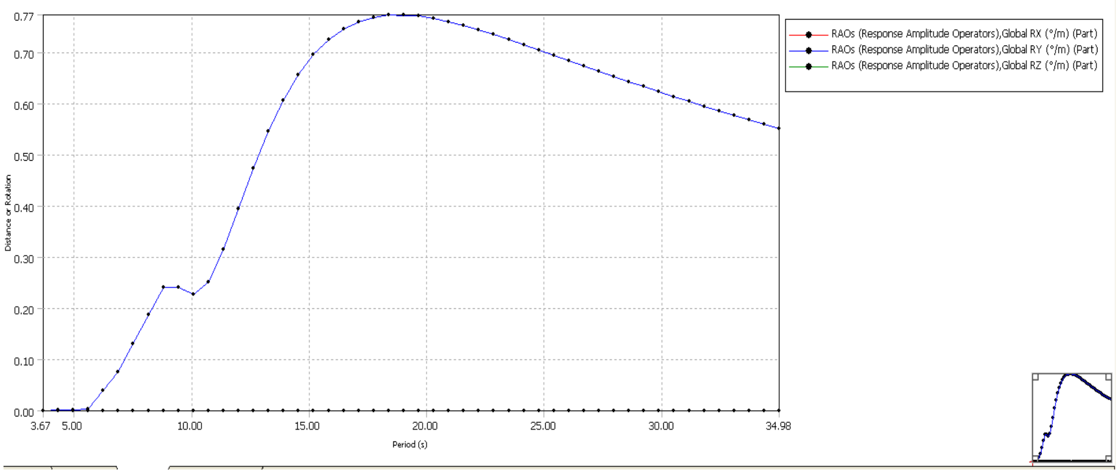


TABLE 12 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrodynamic Graph Results

Object Name	*RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)*
State	Solved
Details of RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Frequency
Frequency or Period Scale	Period
Line A	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global X
Direction	90 °
Position of Min in X	3.668
Position of Max in X	8.78
Minimum Value	0
Maximum Value	0.009
Line B	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global Y

Direction	90 °
Position of Min in X	3.668
Position of Max in X	34.981
Minimum Value	0.036
Maximum Value	3.356
Line C	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global Z
Direction	90 °
Position of Min in X	3.668
Position of Max in X	10.697
Minimum Value	0.005
Maximum Value	1.074

FIGURE 4 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Diffraction (B4) > Solution (B5) > RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)

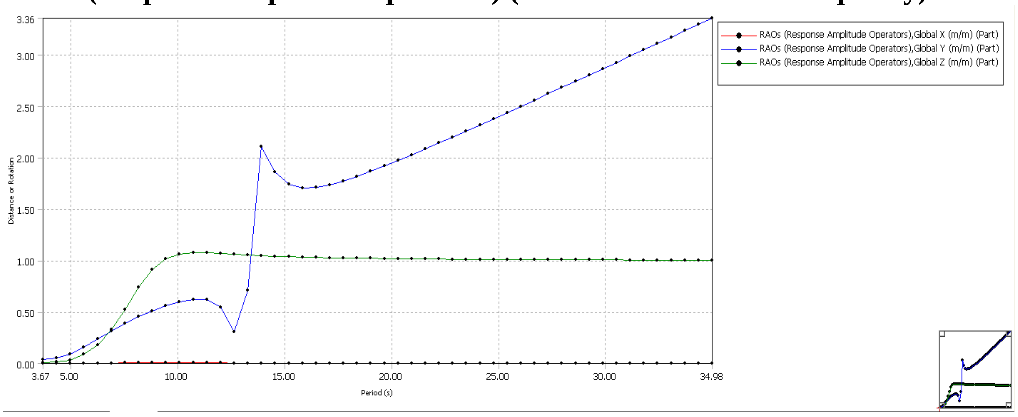


TABLE 13 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrodynamic Graph Results

Object Name	*RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)*
State	Solved
Details of RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Frequency
Frequency or Period Scale	Period
Line A	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global RX
Direction	90 °
Position of Min in X	3.668

Position of Max in X	13.893
Minimum Value	0.012
Maximum Value	21.912
Line B	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global RY
Direction	90 °
Position of Min in X	34.981
Position of Max in X	8.141
Minimum Value	0
Maximum Value	0.063
Line C	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global RZ
Direction	90 °
Position of Min in X	16.449
Position of Max in X	13.254
Minimum Value	0.004
Maximum Value	0.106

FIGURE 5 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Diffraction (B4) > Solution (B5) > RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)

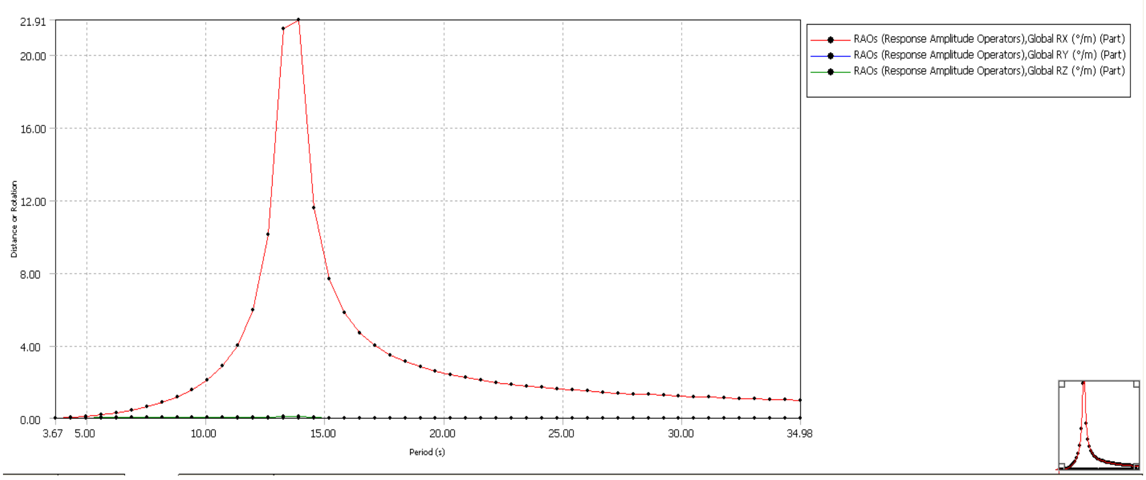


TABLE 14 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrodynamic Graph Results

Object Name	*RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)*
State	Solved
Details of RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Frequency
Frequency or Period Scale	Period
Line A	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global X
Direction	135 °
Position of Min in X	3.668
Position of Max in X	34.981
Minimum Value	0.002
Maximum Value	2.261
Line B	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global Y
Direction	135 °
Position of Min in X	3.668
Position of Max in X	34.981
Minimum Value	0.002
Maximum Value	2.171
Line C	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global Z
Direction	135 °
Position of Min in X	4.307
Position of Max in X	34.981
Minimum Value	0.003
Maximum Value	0.923

FIGURE 6 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Diffraction (B4) > Solution (B5) > RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)

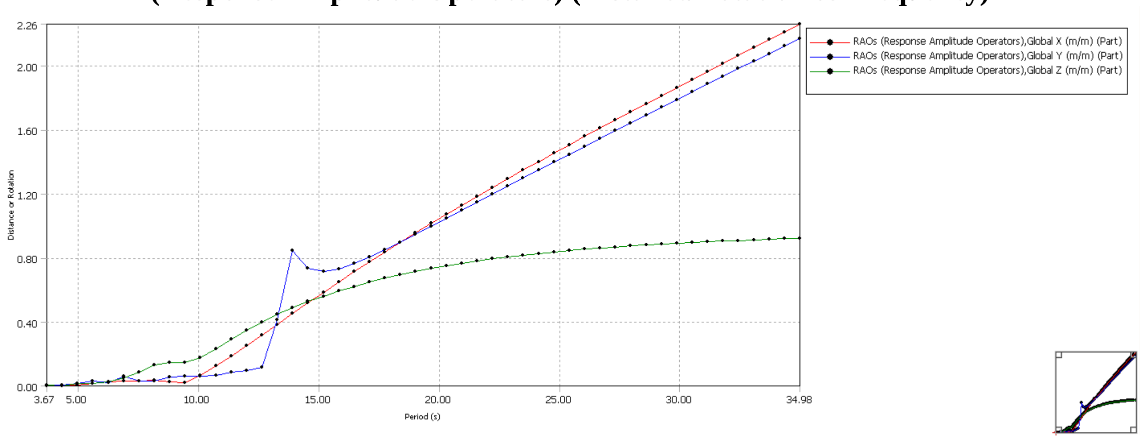


TABLE 15 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrodynamic Graph Results

Object Name	*RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)*
State	Solved
Details of RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Frequency
Frequency or Period Scale	Period
Line A	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global RX
Direction	135 °
Position of Min in X	3.668
Position of Max in X	13.893
Minimum Value	0.003
Maximum Value	10.718
Line B	
Type	RAOs (Response Amplitude Operators)
Component	Global RY
Direction	135 °
Position of Min in X	3.668
Position of Max in X	13.893
Minimum Value	0.003
Maximum Value	0.772
Line C	
Type	RAOs (Response Amplitude Operators)
Component	Global RZ
Direction	135 °
Position of Min in X	3.668
Position of Max in X	34.981
Minimum Value	0.006
Maximum Value	0.82

FIGURE 7 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Diffraction (B4) > Solution (B5) > RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)

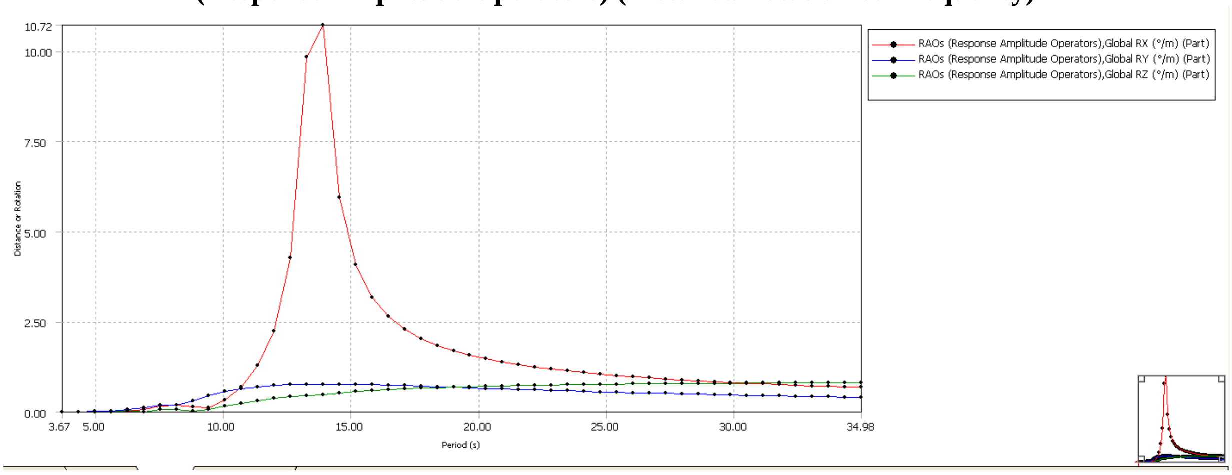
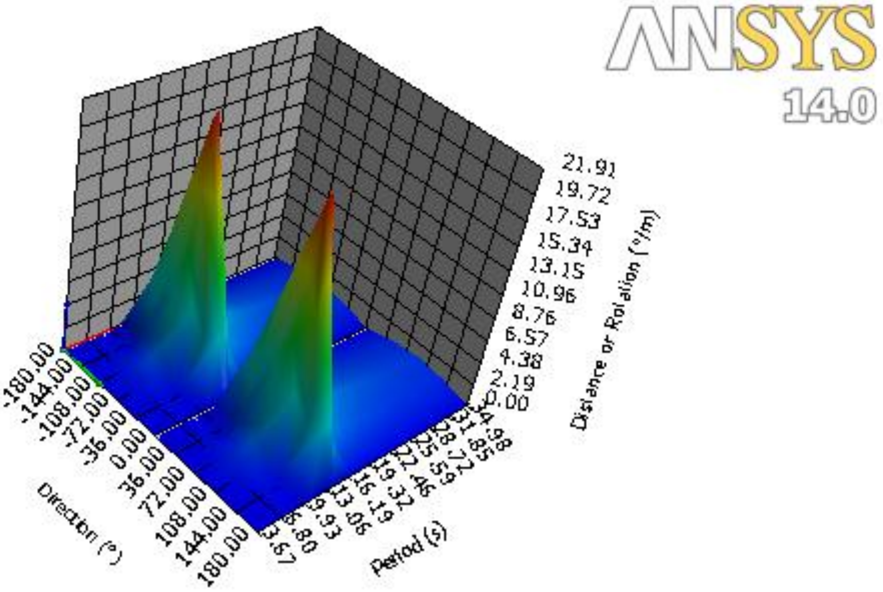


TABLE 16 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrodynamic Graph Results

Object Name	*RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency & Direction)*
State	Solved
Details of RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency & Direction)	
Presentation Method	Surface
Axes Selection	Distance/Rotation vs Frequency & Direction
Frequency or Period Scale	Period
Surface	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global RX
Position of Min in X	7.502
Position of Max in X	13.893
Position of Min in Y	0
Position of Max in Y	-90
Minimum Value	0
Maximum Value	21.912

FIGURE 8 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Diffraction (B4) > Solution (B5) > RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency & Direction)



Hydrodynamic Time Response (C4)

TABLE 17 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Time Response Specific Options	
Analysis Type	Irregular Wave Response with Slow Drift
Start Time	0 s
Time Step	0.1 s
Number of Steps	10001
Finish Time	1000 s
Starting Position	Program Controlled
Use Cable Dynamics	Yes

TABLE 18 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Irregular Wave

Object Name	*Irregular Wave*
State	Fully Defined
Wave Spectrum Details	
Wave Type	Pierson-Moskowitz
Direction of Spectrum	180 °
Seed Definition	Program Controlled
Omit Calculation of Drift Forces	No
Start Period	10.4 s
Finish Period	8 s
Significant Wave Height	7.3 m
Zero Crossing Period	8.6 s

TABLE 19 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Current

Depth (m)	Velocity (m/s)	Direction (°)
10	1.1	180

TABLE 20 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Wind

Object Name	*Wind*
State	Fully Defined
Wind Spectral Definition	
Spectra	ISO
Reference Height	10 m
Speed	33.7 m/s
Direction	180 °

Solution (C5)

TABLE 21 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Solution (C5) > Hydrodynamic Graph Results

Object Name	*Structure Position, Actual Response (Distance/Rotation vs Time)*
State	Solved
Details of Structure Position, Actual Response (Distance/Rotation vs Time)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Time
Line A	
Structure	Part
Type	Structure Position
SubType	Actual Response
Component	Global RY
Position of Min in X	230.7
Position of Max in X	226
Minimum Value	-0.507
Maximum Value	0.769
Line B	
Structure	Part
Type	Structure Position
SubType	Actual Response
Component	Global Z
Position of Min in X	767.9
Position of Max in X	350.5
Minimum Value	3.798
Maximum Value	6.12

FIGURE 9 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Solution (C5) > Structure Position, Actual Response (Distance/Rotation vs Time)

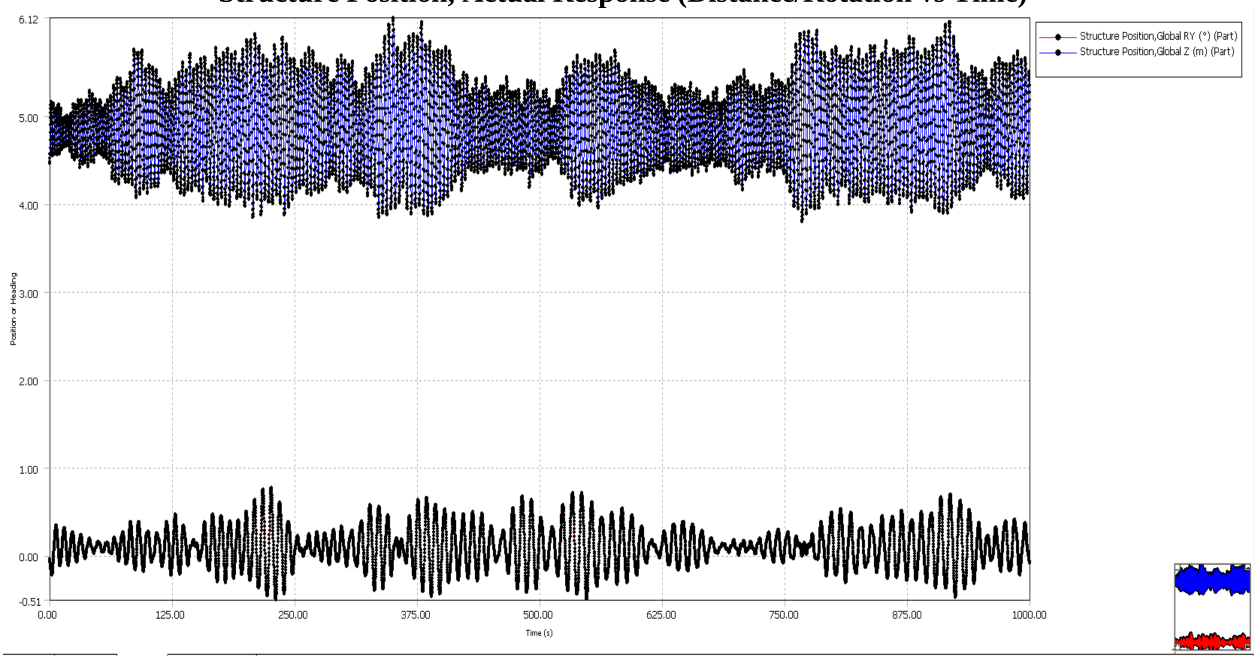
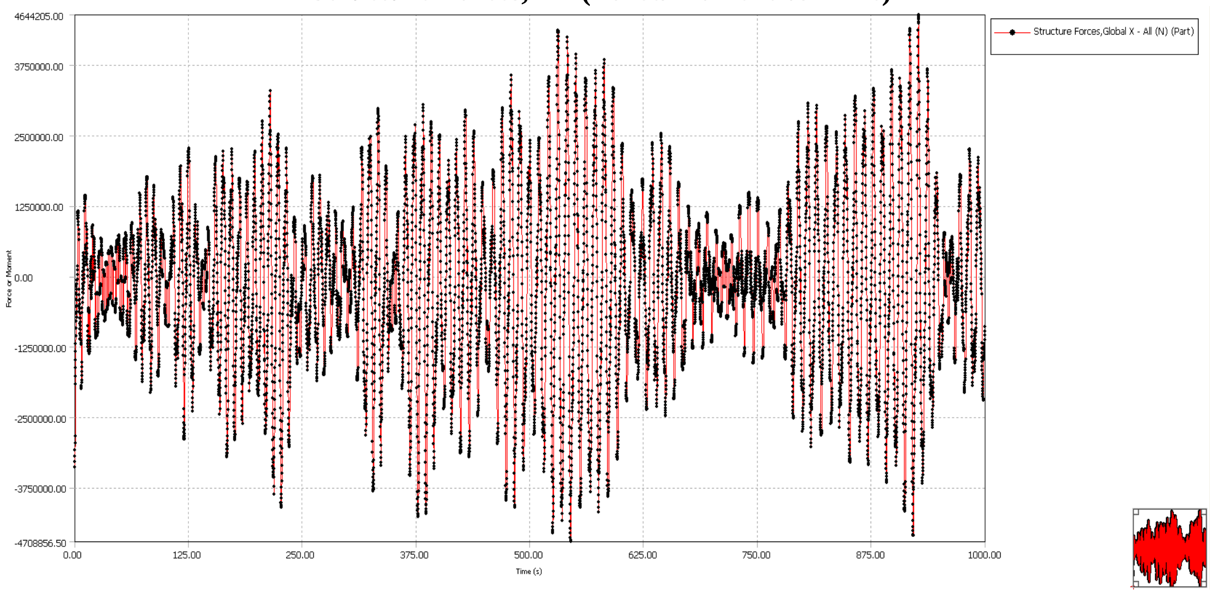


TABLE 22 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Solution (C5) > Hydrodynamic Graph Results

Object Name	*Structure Forces, All (Force/Moment vs Time)*
State	Solved
Details of Structure Forces, All (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	Part
Type	Structure Forces
SubType	All
Component	Global X
Position of Min in X	544.9
Position of Max in X	927.2
Minimum Value	-4708856.5
Maximum Value	4644205

FIGURE 10 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Solution (C5) > Structure Forces, All (Force/Moment vs Time)



Hydrodynamic Time Response 2 (D4)

TABLE 23 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Time Response Specific Options	
Analysis Type	Irregular Wave Response with Slow Drift
Start Time	0 s
Time Step	0.1 s
Number of Steps	10001
Finish Time	1000 s
Starting Position	Program Controlled
Use Cable Dynamics	Yes

TABLE 24 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Wind

Object Name	*Wind*
State	Fully Defined
Wind Spectral Definition	
Spectra	ISO
Reference Height	10 m
Speed	33.7 m/s
Direction	135 °

TABLE 25 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Irregular Wave

Object Name	*Irregular Wave*
State	Fully Defined
Wave Spectrum Details	
Wave Type	Pierson-Moskowitz
Direction of Spectrum	135 °
Seed Definition	Program Controlled
Omit Calculation of Drift Forces	No
Start Period	10.4 s
Finish Period	8 s
Significant Wave Height	7.3 m
Zero Crossing Period	8.6 s

TABLE 26 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Current

Depth (m)	Velocity (m/s)	Direction (°)
10	1.1	135

Solution (D5)

TABLE 27 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Solution (D5) > Hydrodynamic Graph Results

Object Name	*Structure Position, Actual Response (Distance/Rotation vs Time)*
State	Solved
Details of Structure Position, Actual Response (Distance/Rotation vs Time)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Time
Line A	
Structure	Part
Type	Structure Position
SubType	Actual Response
Component	Global RX
Position of Min in X	633.9
Position of Max in X	628.6
Minimum Value	-22.688
Maximum Value	21.93
Line B	
Structure	Part
Type	Structure Position
SubType	Actual Response
Component	Global Z
Position of Min in X	828.1
Position of Max in X	825.7
Minimum Value	3.461
Maximum Value	6.363

FIGURE 11 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Solution (D5) > Structure Position, Actual Response (Distance/Rotation vs Time)

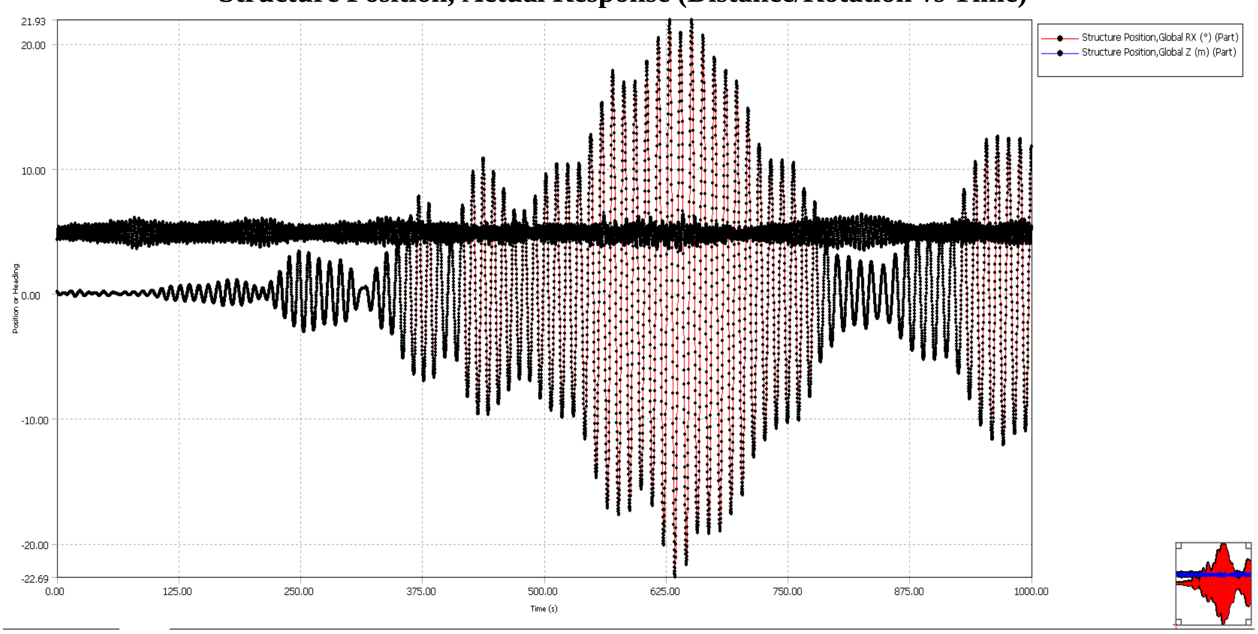
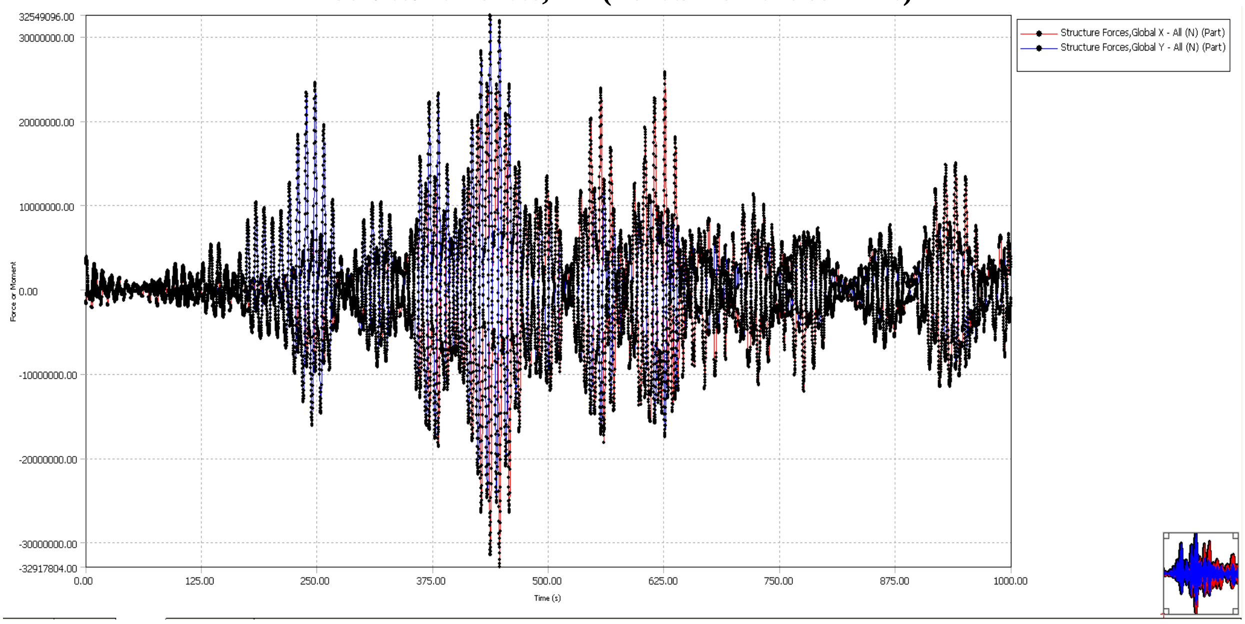


TABLE 28 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Solution (D5) > Hydrodynamic Graph Results

Object Name	*Structure Forces, All (Force/Moment vs Time)*
State	Solved
Details of Structure Forces, All (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	Part
Type	Structure Forces
SubType	All
Component	Global X
Position of Min in X	447.4
Position of Max in X	626.1
Minimum Value	-32917804
Maximum Value	25813964
Line B	
Structure	Part
Type	Structure Forces
SubType	All
Component	Global Y
Position of Min in X	443.9
Position of Max in X	437.2
Minimum Value	-25259384
Maximum Value	32549096

FIGURE 12 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Solution (D5) > Structure Forces, All (Force/Moment vs Time)



Hydrodynamic Time Response 3 (E4)

TABLE 29 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Time Response Specific Options	
Analysis Type	Irregular Wave Response with Slow Drift
Start Time	0 s
Time Step	0.1 s
Number of Steps	10001
Finish Time	1000 s
Starting Position	Program Controlled
Use Cable Dynamics	Yes

TABLE 30 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Wind

Object Name	*Wind*
State	Fully Defined
Wind Spectral Definition	
Spectra	ISO
Reference Height	10 m
Speed	33.7 m/s
Direction	90 °

TABLE 31 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Irregular Wave

Object Name	*Irregular Wave*
State	Fully Defined
Wave Spectrum Details	
Wave Type	Pierson-Moskowitz
Direction of Spectrum	90 °
Seed Definition	Program Controlled
Omit Calculation of Drift Forces	No
Start Period	10.4 s
Finish Period	8 s
Significant Wave Height	7.3 m
Zero Crossing Period	8.6 s

TABLE 32 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Current

Depth (m)	Velocity (m/s)	Direction (°)
10	1.1	90

Solution (E5)

TABLE 33 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Solution (E5) > Hydrodynamic Graph Results

Object Name	*Structure Position, Actual Response (Distance/Rotation vs Time)*
State	Solved
Details of Structure Position, Actual Response (Distance/Rotation vs Time)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Time
Line A	
Structure	Part
Type	Structure Position
SubType	Actual Response
Component	Global RX
Position of Min in X	640.4
Position of Max in X	657.4
Minimum Value	-20.986
Maximum Value	21.945
Line B	
Structure	Part
Type	Structure Position
SubType	Actual Response
Component	Global Z
Position of Min in X	622
Position of Max in X	445.6
Minimum Value	3.324
Maximum Value	6.303

FIGURE 13 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Solution (E5) > Structure Position, Actual Response (Distance/Rotation vs Time)

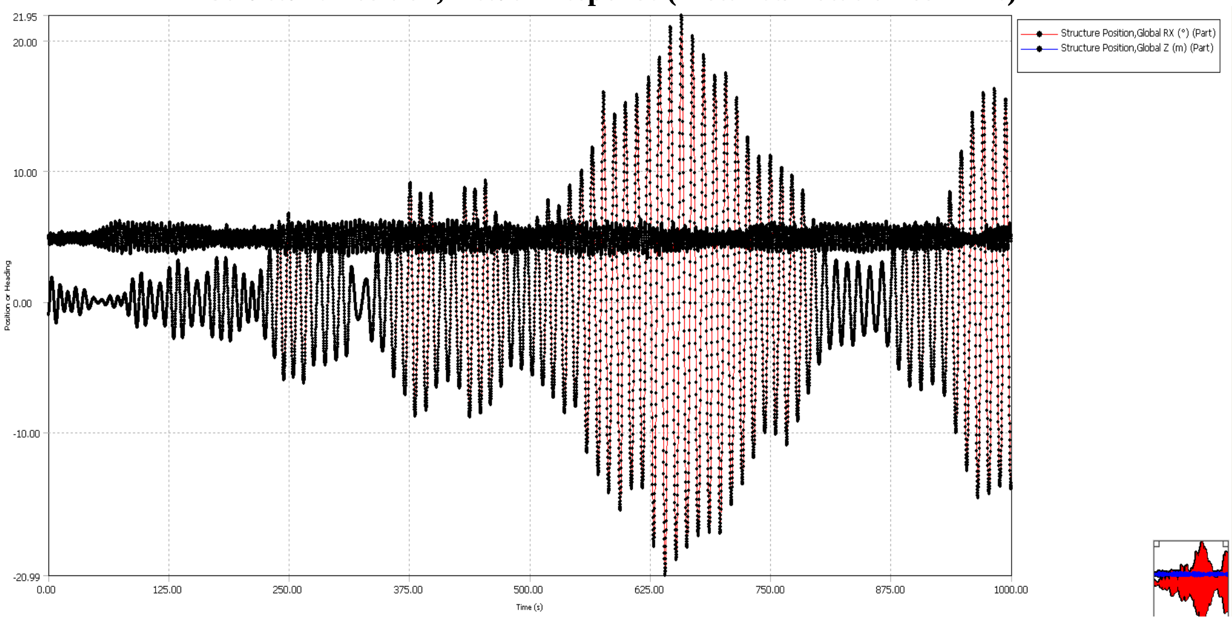
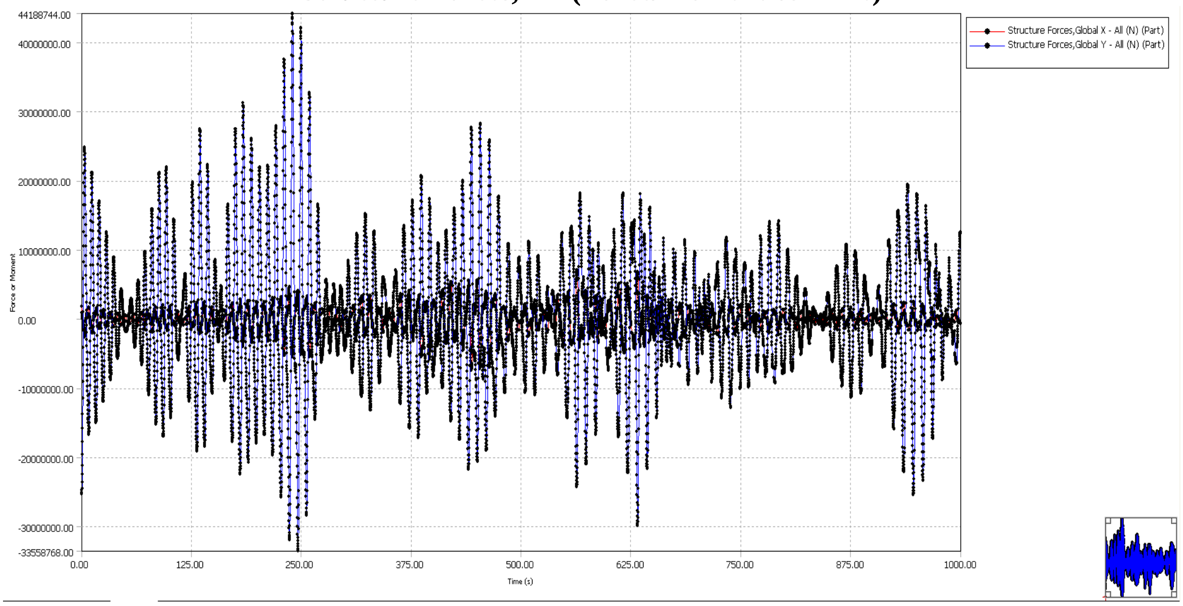


TABLE 34 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Solution (E5) > Hydrodynamic Graph Results

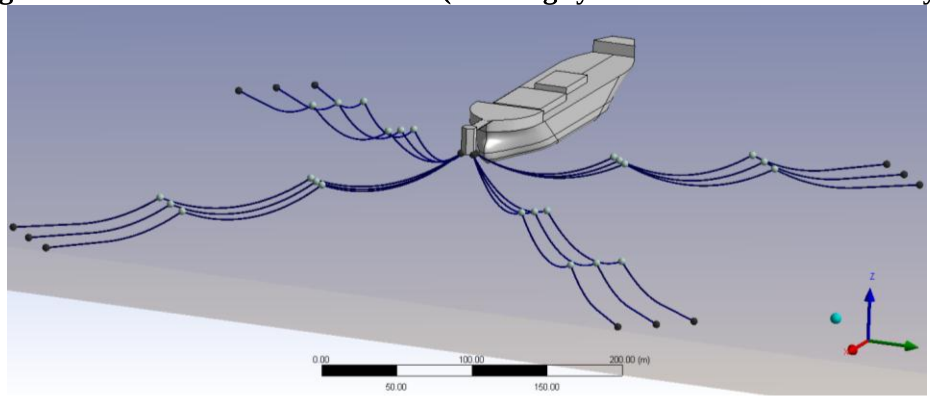
Object Name	*Structure Forces, All (Force/Moment vs Time)*
State	Solved
Details of Structure Forces, All (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	Part
Type	Structure Forces
SubType	All
Component	Global X
Position of Min in X	443.5
Position of Max in X	563.5
Minimum Value	-7399373
Maximum Value	7101143
Line B	
Structure	Part
Type	Structure Forces
SubType	All
Component	Global Y
Position of Min in X	246.1
Position of Max in X	239.8
Minimum Value	-33558768
Maximum Value	44188744

FIGURE 14 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Solution (E5) > Structure Forces, All (Force/Moment vs Time)



Appendix B – Simulation of 20% Loaded Moored Vessel (Mooring System with 12 Lines and Buoys)

Figure 1 - 20% loaded moored vessel (mooring system with 12 lines and buoys)



Connection points* (all moored models have the same connection points)

TABLE 1 - Model (B3, C3) > Geometry > Part > Connection Point

Object Name	*1*
State	Fully Defined
Details of 1	
Type	Attached to Structure
Structure	Part
Definition Of Position	Vertex Selection
Vertex	Vertex Selected (Part)
Vertex X	144.518276427541 m
Vertex Y	-4.3301269895491 m
Vertex Z	6.50000007603194 m
Postion Coordinates	
X Offset	0 m
Y Offset	0 m
Z Offset	0 m
X	144.518276427541 m
Y	-4.3301269895491 m
Z	6.50000007603194 m

TABLE 2 - Model (B3, C3) > Geometry > Part > Connection Point

Object Name	*2*
State	Fully Defined
Details of 2	
Type	Attached to Structure
Structure	Part
Definition Of Position	Vertex Selection
Vertex	Vertex Selected (Part)
Vertex X	139.518276427541 m
Vertex Y	-4.3301269895491 m
Vertex Z	6.5000000759811 m
Postion Coordinates	
X Offset	0 m
Y Offset	0 m
Z Offset	0 m
X	139.518276427541 m
Y	-4.3301269895491 m
Z	6.5000000759811 m

TABLE 3 - Model (B3, C3) > Geometry > Part > Connection Point

Object Name	*3*
State	Fully Defined
Details of 3	
Type	Attached to Structure
Structure	Part
Definition Of Position	Vertex Selection
Vertex	Vertex Selected (Part)
Vertex X	139.518276427541 m
Vertex Y	4.33012704829529 m
Vertex Z	6.50000007606014 m
Postion Coordinates	
X Offset	0 m
Y Offset	0 m
Z Offset	0 m
X	139.518276427541 m
Y	4.33012704829529 m
Z	6.50000007606014 m

TABLE 4 - Model (B3, C3) > Geometry > Part > Connection Point

Object Name	*4*
State	Fully Defined
Details of 4	
Type	Attached to Structure
Structure	Part
Definition Of Position	Vertex Selection
Vertex	Vertex Selected (Part)
Vertex X	144.518276427541 m
Vertex Y	4.33012704829529 m
Vertex Z	6.50000007616182 m
Postion Coordinates	
X Offset	0 m
Y Offset	0 m
Z Offset	0 m
X	144.518276427541 m
Y	4.33012704829529 m
Z	6.50000007616182 m

TABLE 5 - Model (B3, C3) > Geometry > Connection Point

Object Name	*Fixed Point 1*
State	Fully Defined
Details of Fixed Point 1	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	384 m
Y	-205 m
Z	-30 m

TABLE 6 - Model (B3, C3) > Geometry > Connection Point

Object Name	*Fixed Point 2*
State	Fully Defined
Details of Fixed Point 2	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	365 m
Y	-225 m
Z	-30 m

TABLE 7 - Model (B3, C3) > Geometry > Connection Point

Object Name	*Fixed Point 3*
State	Fully Defined
Details of Fixed Point 3	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	345 m
Y	-244 m
Z	-30 m

TABLE 8 - Model (B3, C3) > Geometry > Connection Point

Object Name	*Fixed Point 4*
State	Fully Defined
Details of Fixed Point 4	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	-61 m
Y	-244 m
Z	-30 m

TABLE 9 - Model (B3, C3) > Geometry > Connection Point

Object Name	*Fixed Point 5*
State	Fully Defined
Details of Fixed Point 5	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	-81 m
Y	-225 m
Z	-30 m

TABLE 10 - Model (B3, C3) > Geometry > Connection Point

Object Name	*Fixed Point 6*
State	Fully Defined
Details of Fixed Point 6	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	-100 m
Y	-205 m
Z	-30 m

TABLE 11 - Model (B3, C3) > Geometry > Connection Point

Object Name	*Fixed Point 7*
State	Fully Defined
Details of Fixed Point 7	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	-100 m
Y	205 m
Z	-30 m

TABLE 12 - Model (B3, C3) > Geometry > Connection Point

Object Name	*Fixed Point 8*
State	Fully Defined
Details of Fixed Point 8	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	-81 m
Y	225 m
Z	-30 m

TABLE 13 - Model (B3, C3) > Geometry > Connection Point

Object Name	*Fixed Point 9*
State	Fully Defined
Details of Fixed Point 9	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	-61 m
Y	244 m
Z	-30 m

TABLE 14 - Model (B3, C3) > Geometry > Connection Point

Object Name	*Fixed Point 10*
State	Fully Defined
Details of Fixed Point 10	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	345 m
Y	244 m
Z	-30 m

TABLE 15 - Model (B3, C3) > Geometry > Connection Point

Object Name	*Fixed Point 11*
State	Fully Defined
Details of Fixed Point 11	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	365 m
Y	225 m
Z	-30 m

TABLE 16 - Model (B3, C3) > Geometry > Connection Point

Object Name	*Fixed Point 12*
State	Fully Defined
Details of Fixed Point 12	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	384 m
Y	205 m
Z	-30 m

<u>Connections*</u>(the model in Appendix F has the same connections)

TABLE 17 - Model (B3, C3) > Connections > Catenary Data

Object Name	*Catenary Data*
State	Fully Defined
Details of Catenary Data	

TABLE 18 - Model (B3, C3) > Connections > Catenary Data > Catenary Section

Object Name	*Catenary Section 1*
State	Fully Defined
Section Properties	
Mass / Unit Length	686 kg/m
Equivalent Cross Sectional Area	0.0246 m²
Stiffness, EA	1439189678 N
Maximum Tension	20193000 N
Section Hydrodynamic Properties	
Equivalent Diameter	0.177 m
Longitudinal Drag Coefficient	0.025

TABLE 19 - Model (B3, C3) > Connections > Catenary Data > Catenary Joint

Object Name	*Catenary Joint 1 (Buoy)*
State	Fully Defined
Connection Joint Properties	
Select Joint Type	Buoy
Structural Mass	100 kg
Displaced Mass of Water	70000 kg
Added Mass	100 kg
Coefficient of Drag * Area	100 m²

TABLE 20 - Model (B3, C3) > Connections > Cable

Object Name	*Cable 1 - 12*
State	Fully Defined
Details of Cable 1	
Visibility	Visible
Suppressed	Not Suppressed
Connectivity	Fixed Point & Structure
Fixed Point	Fixed Point 1 (Fixed)
End Connection Point	1 (Part)
Type	Non-Linear Catenary
Cable Dynamics Properties	
Use Dynamics	Program Controlled
Number of Elements	100
Catenary Section Selection	
Section 1: Type	Catenary Section 1
Section 1: Length	105 m
Joint 1/2: Mass/Buoyancy	Catenary Joint 1 (Buoy)
Section 2: Type	Catenary Section 1
Section 2: Length	110 m
Joint 2/3: Mass/Buoyancy	Catenary Joint 1 (Buoy)
Section 3: Type	Catenary Section 1
Section 3: Length	110 m
Section 4: Type	None
Cable Properties	
Negative dZ Range	0 m
Positive dZ Range	1 m
Number of Vertical Partitions	15
Number of X Coordinates	40
Initial Cable Data	
Initial Cable Tension @ Start	692026.188 N
Initial Cable Tension @ End	822276.125 N

TABLE 21 - Model (B3, C3) > Connections > Cable 1 - 12

	Section 1	Joint 1-2	Section 2	Joint 2-3	Section 3
Type	Catenary Section 1	Catenary Joint 1 (Buoy)	Catenary Section 1	Catenary Joint 1 (Buoy)	Catenary Section 1
Section Length (m)	105	-	110	-	110
Mass / Unit Length (kg/m)	686	-	686	-	686
Equivilent CSA (m^2)	0.0246	-	0.0246	-	0.0246
Stiffness, EA (N)	1439189678	-	1439189678	-	1439189678
Maximum Tension (N)	20193000	-	20193000	-	20193000
Equivalent Diameter (m)	0.177	-	0.177	-	0.177
Longitudinal Drag Coefficient	0.025	-	0.025	-	0.025
Structural Mass (kg)	-	100	-	100	-
Displaced Mass of Water (kg)	-	70000	-	70000	-
Added Mass (kg)	-	100	-	100	-
Coefficient of Drag * Area (m^2)	-	100	-	100	-

Hydrodynamic Time Response 5 (C4)

TABLE 22 - Model (B3, C3) > Hydrodynamic Time Response 5 (C4) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Details of Analysis Settings	
Time Response Specific Options	
Analysis Type	Irregular Wave Response with Slow Drift
Start Time	0 s
Time Step	0.5 s
Number of Steps	2001
Finish Time	1000 s
Starting Position	Program Controlled
Use Cable Dynamics	Yes

TABLE 23 - Model (B3, C3) > Hydrodynamic Time Response 5 (C4) > Current

Depth (m)	Velocity (m/s)	Direction (°)
10	1.1	135

TABLE 24 - Model (B3, C3) > Hydrodynamic Time Response 5 (C4) > Wind

Object Name	*Wind*
State	Fully Defined
Details of Wind	
Visibility	Visible
Suppressed	Not Suppressed
Wind Spectral Definition	
Spectra	ISO
Reference Height	10 m
Speed	33.7 m/s
Direction	135 °

TABLE 25 - Model (B3, C3) > Hydrodynamic Time Response 5 (C4) > Irregular Wave

Object Name	*Irregular Wave*
State	Fully Defined
Wave Spectrum Details	
Wave Type	Pierson-Moskowitz
Direction of Spectrum	135 °
Seed Definition	Program Controlled
Omit Calculation of Drift Forces	No
Start Period	10.4 s
Finish Period	8 s
Significant Wave Height	7.3 m
Zero Crossing Period	8.6 s
Cross Swell Details	
Cross Swell Spectrum	None

Solution (C5)

TABLE 26 - Model (B3, C3) > Hydrodynamic Time Response 5 (C4) > Solution (C5) > Hydrodynamic Graph Results

Object Name	*Structure Position, Actual Response (Distance/Rotation vs Time)*
State	Solved
Details of Structure Position, Actual Response (Distance/Rotation vs Time)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Time
Line A	
Structure	Part
Type	Structure Position
SubType	Actual Response
Component	Global RX
Position of Min in X	842.5
Position of Max in X	847
Minimum Value	-0.216
Maximum Value	0.228

FIGURE 2 - Model (B3, C3) > Hydrodynamic Time Response 5 (C4) > Solution (C5) > Structure Position, Actual Response (Distance/Rotation vs Time)

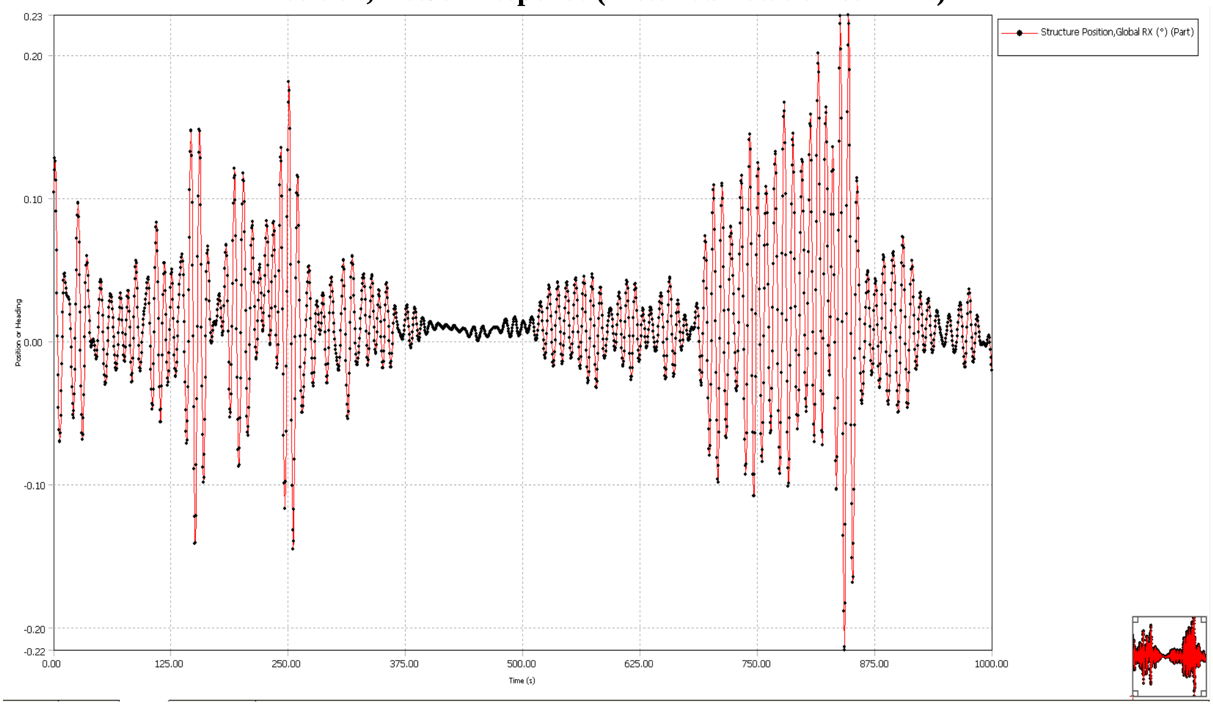


TABLE 27 - Model (B3, C3) > Hydrodynamic Time Response 5 (C4) > Solution (C5) > Hydrodynamic Graph Results

Object Name	*Cable Forces, Whole Cable Forces (Force/Moment vs Time)*
State	Solved
Details of Cable Forces, Whole Cable Forces (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	Part
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 3
Position of Min in X	591.5
Position of Max in X	406.5
Minimum Value	815741.688
Maximum Value	1421175.125

FIGURE 3 - Model (B3, C3) > Hydrodynamic Time Response 5 (C4) > Solution (C5) > Cable Forces, Whole Cable Forces (Force/Moment vs Time)

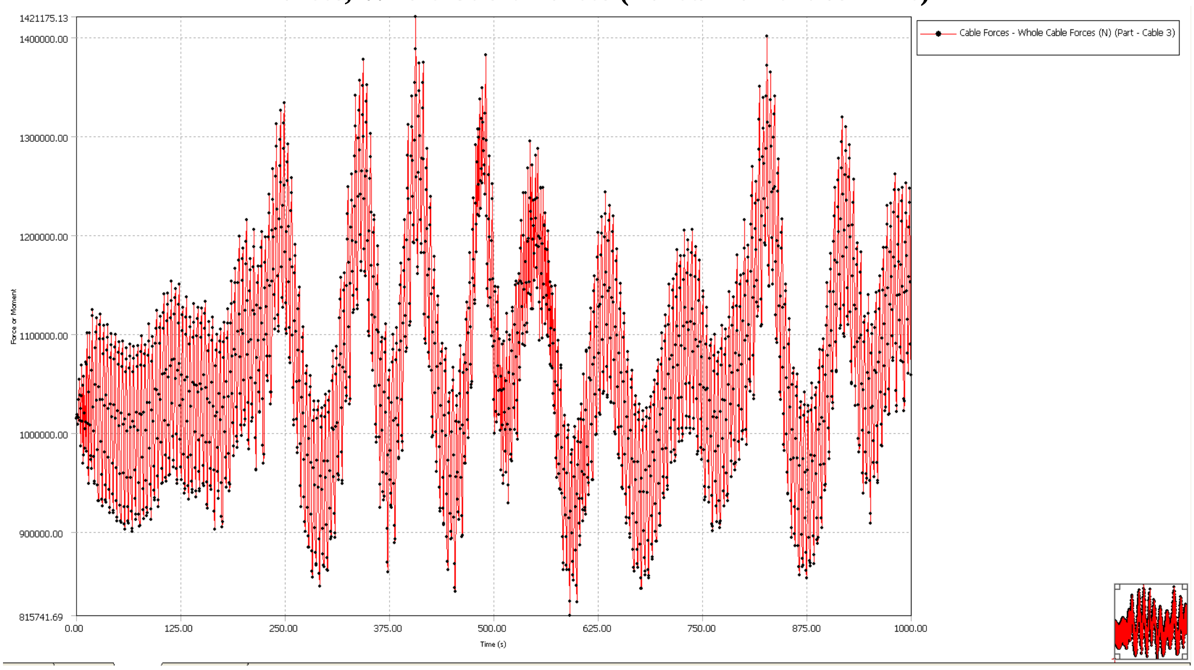
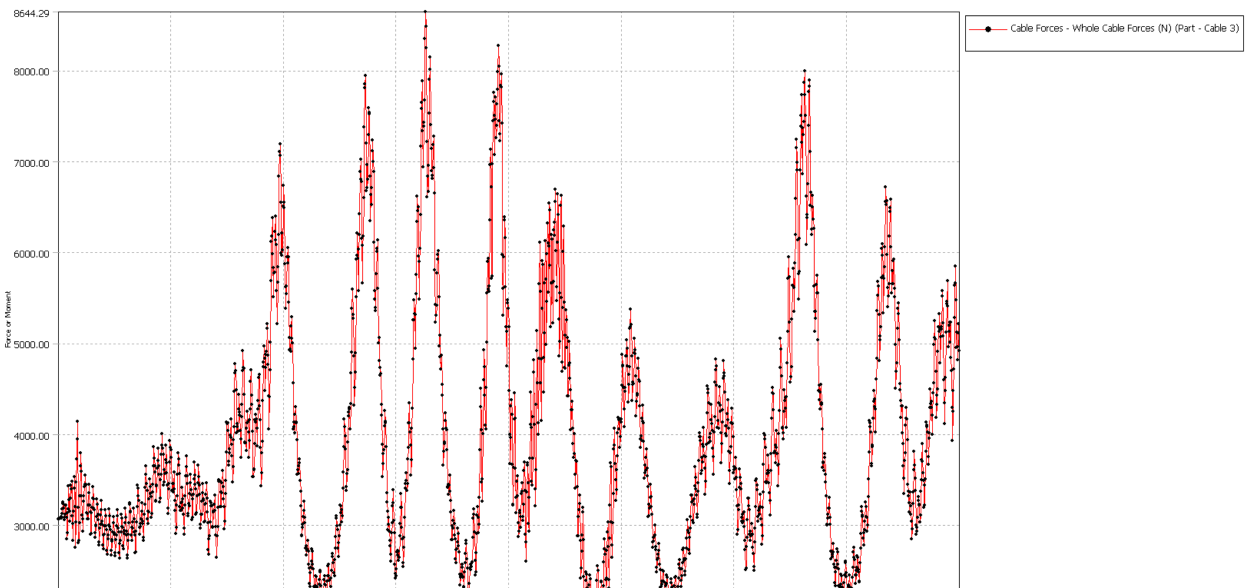
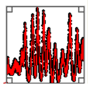


TABLE 28 - Model (B3, C3) > Hydrodynamic Time Response 5 (C4) > Solution (C5) > Hydrodynamic Results

Object Name	*Cable Forces, Whole Cable Forces (Force/Moment vs Time)*
State	Solved
Details of Cable Forces, Whole Cable Forces (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	Part
Type	Cable Forces
SubType	Whole Cable Forces
Component	Anchor Uplift
Connection	Cable 3
Position of Min in X	593
Position of Max in X	407.5
Minimum Value	1891.832
Maximum Value	8644.286

FIGURE 4 - Model (B3, C3) > Hydrodynamic Time Response 5 (C4) > Solution (C5) > Cable Forces, Whole Cable Forces (Force/Moment vs Time)





Appendix C –Simulation of 50% Loaded Vessel

FIGURE 1 – Vessel Mass definition

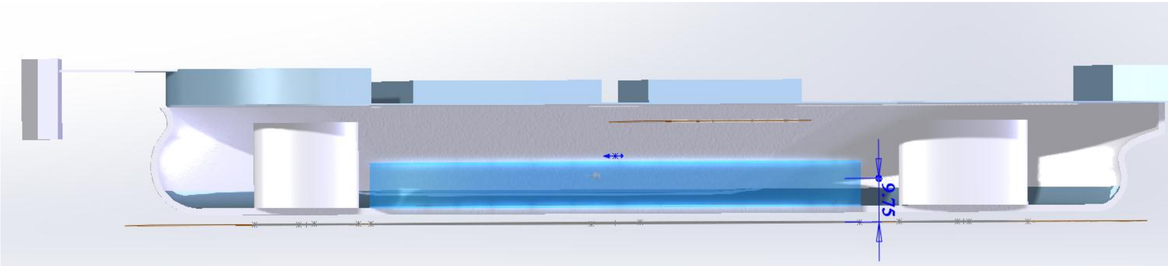


TABLE 1 - Model (B3, C3, D3, E3) > Geometry > Part

Object Name	*Part*
State	Fully Defined
Details of Part	
Part Visibility	Visible
Suppressed	Not Suppressed
Total Structural Mass	85519805.43 kg
X Position of COG	0.7 m
Y Position of COG	-0.01 m
Z Position of COG	-2.35 m
Fixity Options	
Structure Fixity	Structure is Free to Move

TABLE 2 - Model (B3, C3, D3, E3) > Geometry > Part > Axes

Object Name	*Part Axes*
State	Fully Defined
Details of Part Axes	
Visibility	Not Visible
Alignment Method	Global Axes
Rotation About Global Z	0 °
Rotation About Local Y	0 °
Rotation About Local X	0 °
Unit Vector X	[1, 0, 0]
Unit Vector Y	[0, 1, 0]
Unit Vector Z	[0, 0, 1]

TABLE 3 - Model (B3, C3, D3, E3) > Geometry > Part > Point Mass

Object Name	*Point Mass*
State	Fully Defined
Details of Point Mass	
Visibility	Visible
Suppressed	Not Suppressed
X	0.7 m
Y	-0.01 m
Z	-2.35 m
Mass definition	Manual
Mass	85519805.43 kg
Define inertia values by	via Radius of Gyration
Kxx	20 m
Kyy	60 m
Kzz	64 m
Ixx	34207922172 kg.m²
Iyy	307871299548 kg.m²
Izz	350289123041.28 kg.m²

TABLE 4 - Model (B3, C3, D3, E3) > Geometry > Part > Point Buoyancy

Object Name	*Point Buoyancy*
State	Fully Defined
Details of Point Buoyancy	
Visibility	Visible
Suppressed	Not Suppressed
X	0 m
Y	0 m
Z	-5.41 m
Volume	94764.87 m³

Hydrodynamic Diffraction (B4)

TABLE 5 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Gravity

Object Name	*Gravity*
State	Fully Defined
Details of Gravity	
Gravity, g	9.80665 m/s²

TABLE 6 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Wave Direction

Object Name	*Wave Directions*
State	Fully Defined
Details of Wave Directions	
Type	Range of Directions, No Forward Speed
Required Wave Input	
Wave Range	-180° to 180° (-PI to PI)
Interval	45 °
Number of Intermediate Directions	7

TABLE 7 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Wave Frequency

Object Name	*Wave Frequencies*
State	Fully Defined
Frequency / Period definition	
Range	Program Controlled
Total Number of Frequencies	50
Equal Intervals Based Upon	Period

Solution (B5)

TABLE 8 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrostatic Results

Object Name	*Hydrostatic*
State	Solved
Details of Hydrostatic	
Structure	Part
Graphical Representation	
Show Centre of Gravity	Yes
Show Centre of Buoyancy	Yes
Show Centre of Floatation	Yes

AQWA Hydrostatic Results

Structure Part

Hydrostatic Stiffness

Centre of Gravity Position:	X:	0.7 m	Y:	-1.e-2 m	Z:	-2.3499999 m

	Z	RX	RY
Heave(Z):	91480576 N/	15970.239 N/	2648199.3 N/
Roll(RX):	915027.31 N.	1.56262e8 N.	26509.139 N.
Pitch(RZ):	1.51731e8 N.	26509.139 N.	5.16089e9 N.

Hydrostatic Displacement Properties

Actual Volumetric Displacement:		189306.81 m³				
Equivalent Volumetric Displacement:		83433.961 m³				
Centre of Buoyancy Position:	X:	-6.9069e-2 m	Y:	3.2177e-6 m	Z:	-5.4044132 m
Out of Balance Forces/Weight:	FX:	-3.2744e-9	FY:	5.5669e-8	FZ:	1.268941
Out of Balance Moments/Weight:	MX:	2.27e-2 m	MY:	1.7449671 m	MZ:	-4.2449e-7 m

Cut Water Plane Properties

Cut Water Plane Area:		9100.9004 m²		
Centre of Floatation:	X:	-0.9586104 m	Y:	2.4224e-6 m
Principal 2nd Moment of Area:	X:	1468921.3 m⁴	Y:	29970486 m⁴
Angle Principal Axis makes with X(FRA):		1.3612e-5 °		

Small Angle Stability Parameters

C.O.G. to C.O.B.(BG):	3.0544133 m	
Metacentric Heights (GMX/GMY):	4.7050605 m	155.26259 m
COB to Metacentre (BMX/BMY):	7.7594738 m	158.317 m
Restoring Moments/Degree Rotations (MX/MY):	2727286. N.r	89997896 N.

TABLE 9 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrodynamic Graph Results

Object Name	*RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)*
State	Solved
Details of RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Frequency
Frequency or Period Scale	Period
Line A	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global X
Direction	-180 °
Position of Min in X	3.668
Position of Max in X	34.981
Minimum Value	0.001
Maximum Value	2.989
Line B	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global Y
Direction	-180 °
Position of Min in X	6.863
Position of Max in X	13.893
Minimum Value	0
Maximum Value	0
Line C	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global Z
Direction	-180 °
Position of Min in X	4.307
Position of Max in X	34.981
Minimum Value	0
Maximum Value	0.85

FIGURE 2 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)

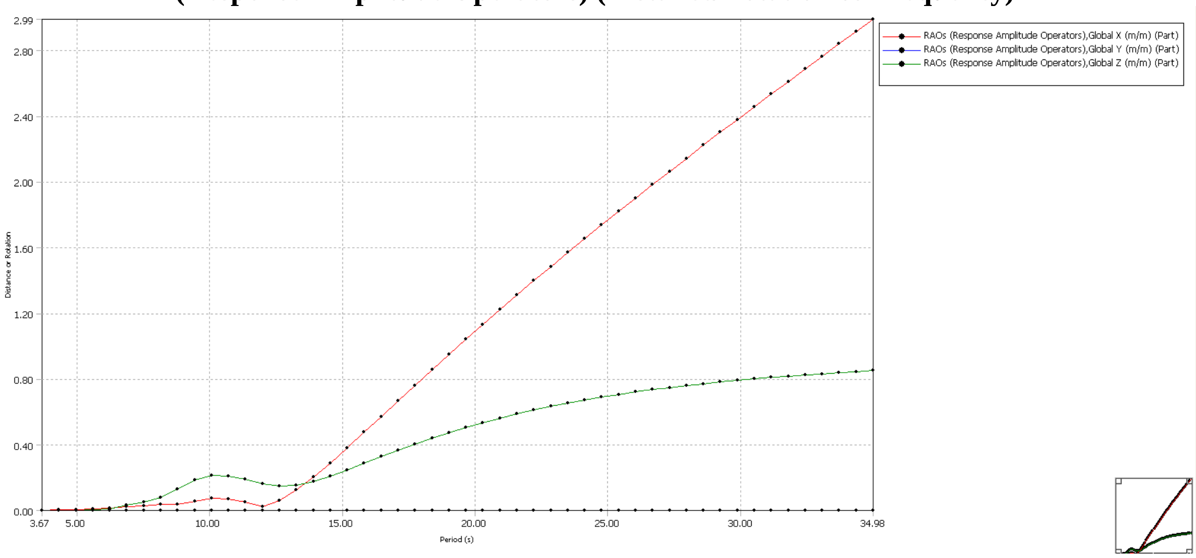


TABLE 10 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrodynamic Graph Results

Object Name	*RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)*
State	Solved
Details of RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Frequency
Frequency or Period Scale	Period
Line A	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global RX
Direction	-180 °
Position of Min in X	5.585
Position of Max in X	13.893
Minimum Value	0
Maximum Value	0.004
Line B	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global RY
Direction	-180 °
Position of Min in X	4.307
Position of Max in X	18.366
Minimum Value	0
Maximum Value	0.794
Line C	
Structure	Part

Type	RAOs (Response Amplitude Operators)
Component	Global RZ
Direction	-180 °
Position of Min in X	6.224
Position of Max in X	34.981
Minimum Value	0
Maximum Value	0

FIGURE 3 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)

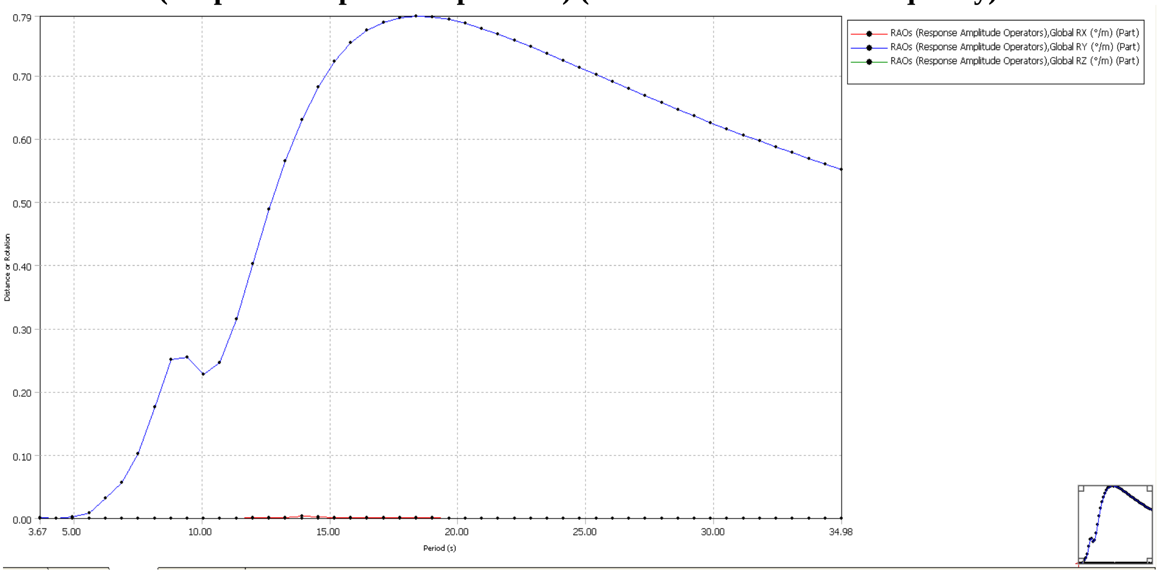


TABLE 11 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrodynamic Graph Results

Object Name	*RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)*
State	Solved
Details of RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Frequency
Frequency or Period Scale	Period
Line A	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global X
Direction	90 °
Position of Min in X	34.981
Position of Max in X	9.419
Minimum Value	0
Maximum Value	0.014
Line B	
Structure	Part

Type	RAOs (Response Amplitude Operators)
Component	Global Y
Direction	90 °
Position of Min in X	3.668
Position of Max in X	34.981
Minimum Value	0.031
Maximum Value	3.367
Line C	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global Z
Direction	90 °
Position of Min in X	3.668
Position of Max in X	11.337
Minimum Value	0.003
Maximum Value	1.165

FIGURE 4 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)

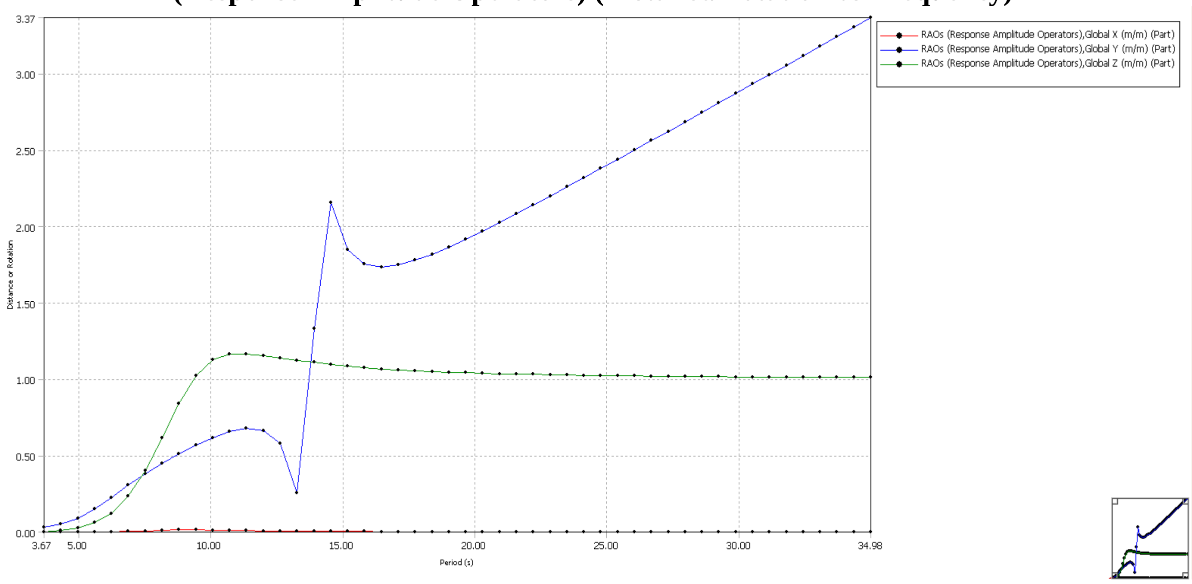


TABLE 12 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrodynamic Results

Object Name	*RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)*
State	Solved
Details of RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Frequency
Frequency or Period Scale	Period
Line A	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global RX
Direction	90 °
Position of Min in X	3.668
Position of Max in X	13.893
Minimum Value	0.009
Maximum Value	26.236
Line B	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global RY
Direction	90 °
Position of Min in X	3.668
Position of Max in X	8.78
Minimum Value	0
Maximum Value	0.093
Line C	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global RZ
Direction	90 °
Position of Min in X	3.668
Position of Max in X	13.893
Minimum Value	0.003
Maximum Value	0.061

FIGURE 5 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)

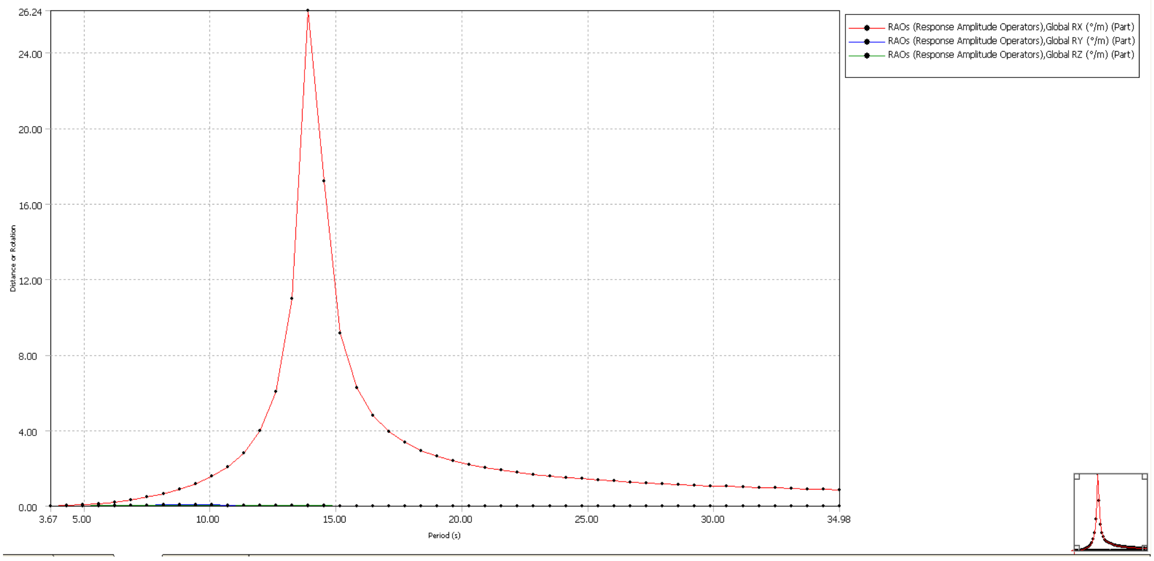


TABLE 13 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrodynamic Results

Object Name	*RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)*
State	Solved
Details of RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Frequency
Frequency or Period Scale	Period
Line A	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global X
Direction	135 °
Position of Min in X	3.668
Position of Max in X	34.981
Minimum Value	0.002
Maximum Value	2.3
Line B	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global Y
Direction	135 °
Position of Min in X	3.668
Position of Max in X	34.981
Minimum Value	0.002
Maximum Value	2.175
Line C	

Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global Z
Direction	135 °
Position of Min in X	3.668
Position of Max in X	34.981
Minimum Value	0
Maximum Value	0.928

FIGURE 6 -Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)

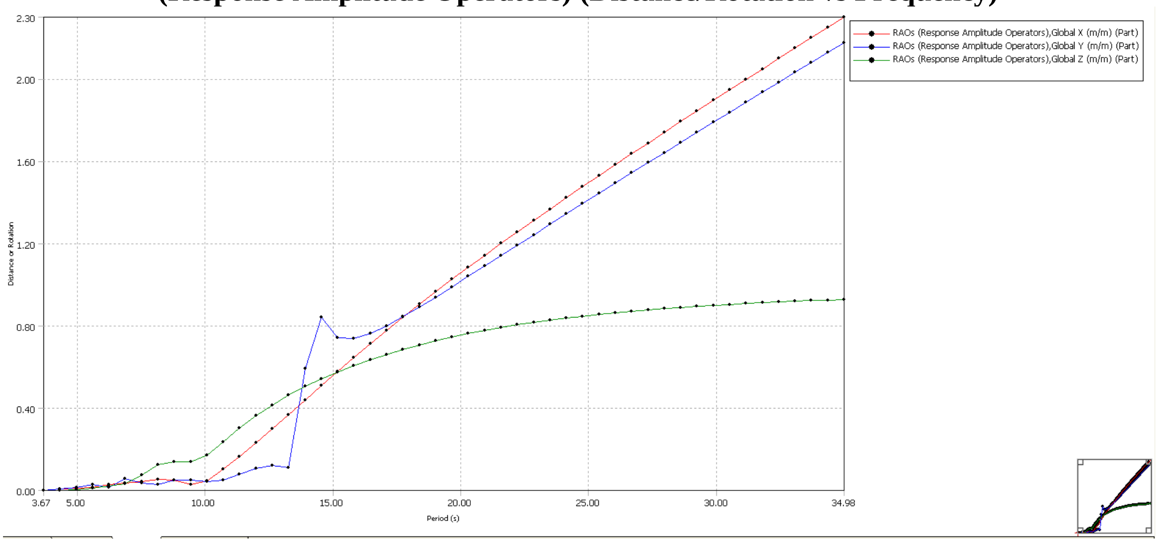


TABLE 14 -Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrodynamic Graph Results

Object Name	*RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)*
State	Solved
Details of RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Frequency
Frequency or Period Scale	Period
Line A	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global RX
Direction	135 °
Position of Min in X	3.668
Position of Max in X	13.893
Minimum Value	0.002
Maximum Value	11.716
Line B	

Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global RY
Direction	135 °
Position of Min in X	3.668
Position of Max in X	13.893
Minimum Value	0
Maximum Value	0.808
Line C	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global RZ
Direction	135 °
Position of Min in X	3.668
Position of Max in X	34.981
Minimum Value	0.005
Maximum Value	0.82

FIGURE 7 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)

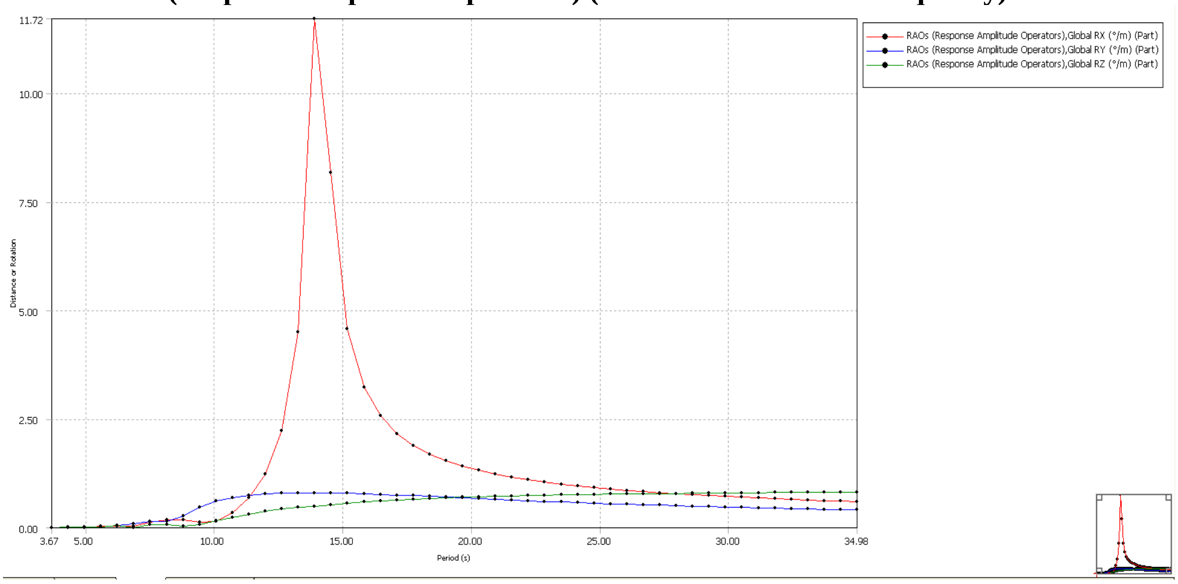
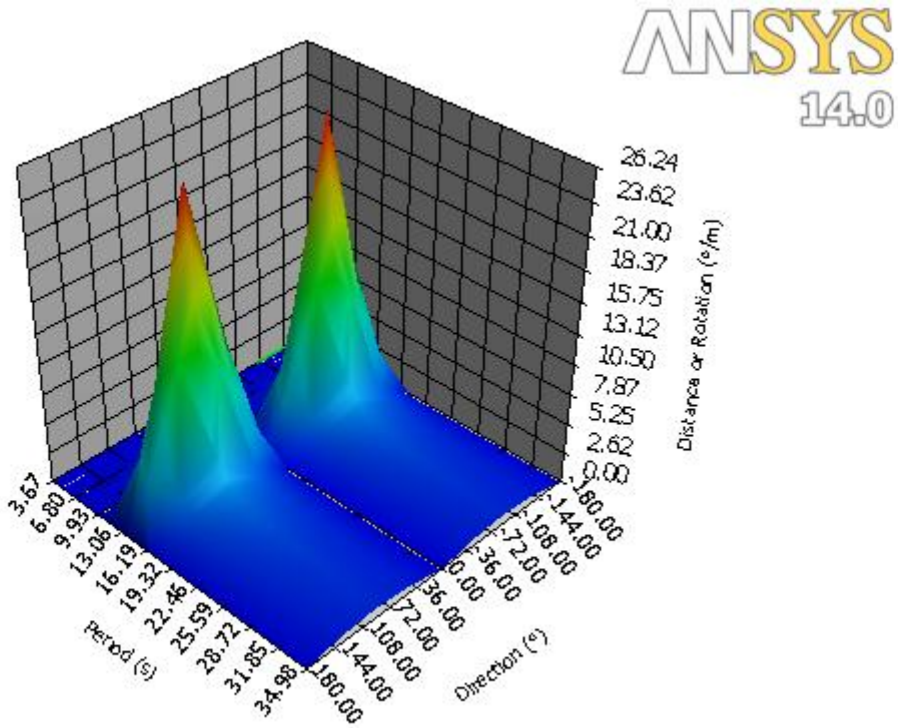


TABLE 15 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrodynamic Graph Results

Object Name	*RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency & Direction)*
State	Solved
Details of RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency & Direction)	
Presentation Method	Surface
Axes Selection	Distance/Rotation vs Frequency & Direction
Frequency or Period Scale	Period
Surface	
Structure	Part
Type	RAOs (Response Amplitude Operators)
Component	Global RX
Position of Min in X	3.668
Position of Max in X	13.893
Position of Min in Y	0
Position of Max in Y	-90
Minimum Value	0
Maximum Value	26.245

FIGURE 8 -Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency & Direction)



Hydrodynamic Time Response (C4)

TABLE 16 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Time Response Specific Options	
Analysis Type	Irregular Wave Response with Slow Drift
Start Time	0 s
Time Step	0.4 s
Number of Steps	9001
Finish Time	3600 s
Starting Position	Program Controlled
Use Cable Dynamics	Yes

TABLE 17 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Current

Depth (m)	Velocity (m/s)	Direction (°)
10	1.1	180

TABLE 18 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Wind

Object Name	*Wind*
State	Fully Defined
Details of Wind	
Visibility	Visible
Suppressed	Not Suppressed
Wind Spectral Definition	
Spectra	ISO
Reference Height	10 m
Speed	33.7 m/s
Direction	180 °

TABLE 19 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Irregular Wave

Object Name	*Irregular Wave*
State	Fully Defined
Wave Spectrum Details	
Wave Type	Pierson-Moskowitz
Direction of Spectrum	180 °
Seed Definition	Program Controlled
Omit Calculation of Drift Forces	No
Start Period	10.4 s
Finish Period	8 s
Significant Wave Height	7.3 m
Zero Crossing Period	8.6 s

Solution (C5)

TABLE 20 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Solution (C5) > Hydrodynamic Graph Results

Object Name	*Structure Position, Actual Response (Distance/Rotation vs Time)*
State	Solved
Details of Structure Position, Actual Response (Distance/Rotation vs Time)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Time
Line A	
Structure	Part
Type	Structure Position
SubType	Actual Response
Component	Global RX
Position of Min in X	2354
Position of Max in X	2359.6
Minimum Value	-9.613
Maximum Value	9.951
Line B	
Structure	Part
Type	Structure Position
SubType	Actual Response
Component	Global Z
Position of Min in X	3078.8
Position of Max in X	3581.6
Minimum Value	-0.292
Maximum Value	7.231

FIGURE 9 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Solution (C5) > Structure Position, Actual Response (Distance/Rotation vs Time)

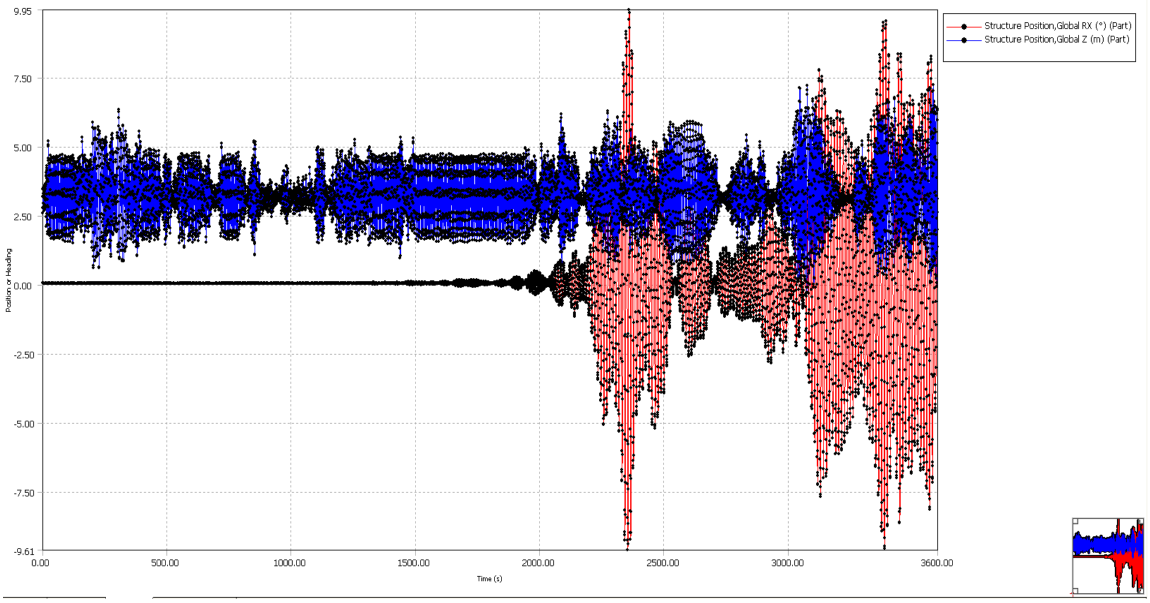
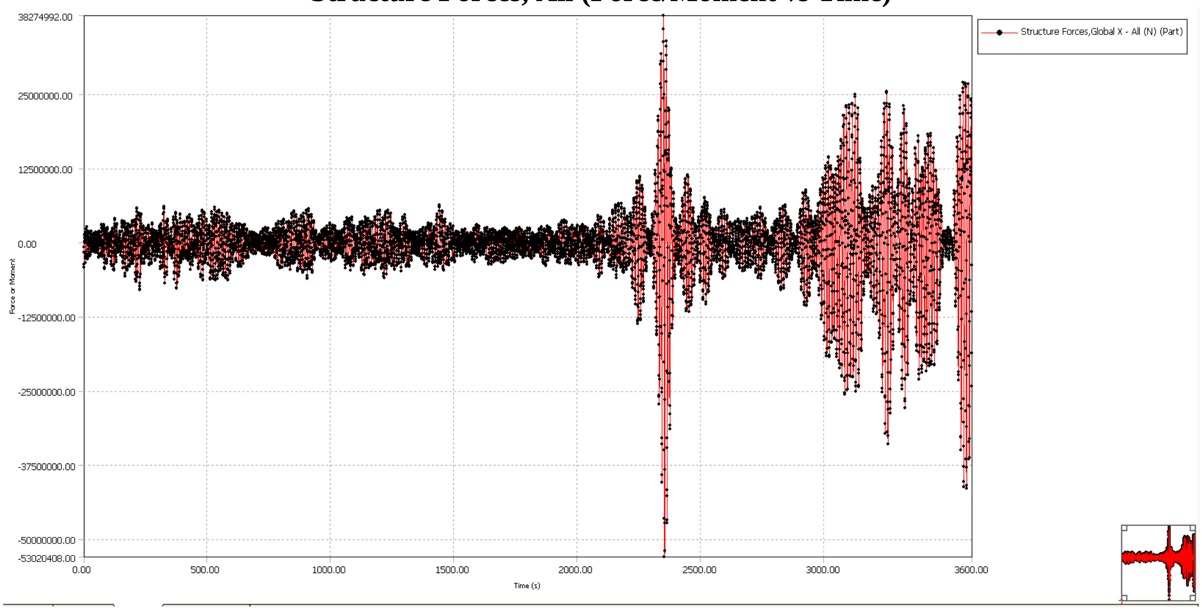


TABLE 21 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Solution (C5) > Hydrodynamic Graph Results

Object Name	*Structure Forces, All (Force/Moment vs Time)*
State	Solved
Details of Structure Forces, All (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	Part
Type	Structure Forces
SubType	All
Component	Global X
Position of Min in X	2353.6
Position of Max in X	2350
Minimum Value	-53020408
Maximum Value	38274992

FIGURE 10 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Solution (C5) > Structure Forces, All (Force/Moment vs Time)



Hydrodynamic Time Response 2 (D4)

TABLE 22 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Details of Analysis Settings	
Time Response Specific Options	
Analysis Type	Irregular Wave Response with Slow Drift
Start Time	0 s
Time Step	0.4 s
Number of Steps	9001
Finish Time	3600 s
Starting Position	Program Controlled
Use Cable Dynamics	Yes

TABLE 23 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Current

Depth (m)	Velocity (m/s)	Direction (°)
10	1.1	135

TABLE 24 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Wind

Object Name	*Wind*
State	Fully Defined
Wind Spectral Definition	
Spectra	ISO
Reference Height	10 m
Speed	33.7 m/s
Direction	135 °

TABLE 25 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Irregular Wave

Object Name	*Irregular Wave*
State	Fully Defined
Wave Spectrum Details	
Wave Type	Pierson-Moskowitz
Direction of Spectrum	135 °
Seed Definition	Program Controlled
Omit Calculation of Drift Forces	No
Start Period	10.4 s
Finish Period	8 s
Significant Wave Height	7.3 m
Zero Crossing Period	8.6 s

Solution (D5)

TABLE 26 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Solution (D5) > Hydrodynamic Graph Results

Object Name	*Structure Position, Actual Response (Distance/Rotation vs Time)*
State	Solved
Details of Structure Position, Actual Response (Distance/Rotation vs Time)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Time
Line A	
Structure	Part
Type	Structure Position
SubType	Actual Response
Component	Global RX
Position of Min in X	3430
Position of Max in X	2486
Minimum Value	-9.013
Maximum Value	8.705
Line B	
Structure	Part
Type	Structure Position
SubType	Actual Response
Component	Global Z
Position of Min in X	3081.2
Position of Max in X	338.4
Minimum Value	0.599
Maximum Value	6.48

FIGURE 11 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Solution (D5) > Structure Position, Actual Response (Distance/Rotation vs Time)

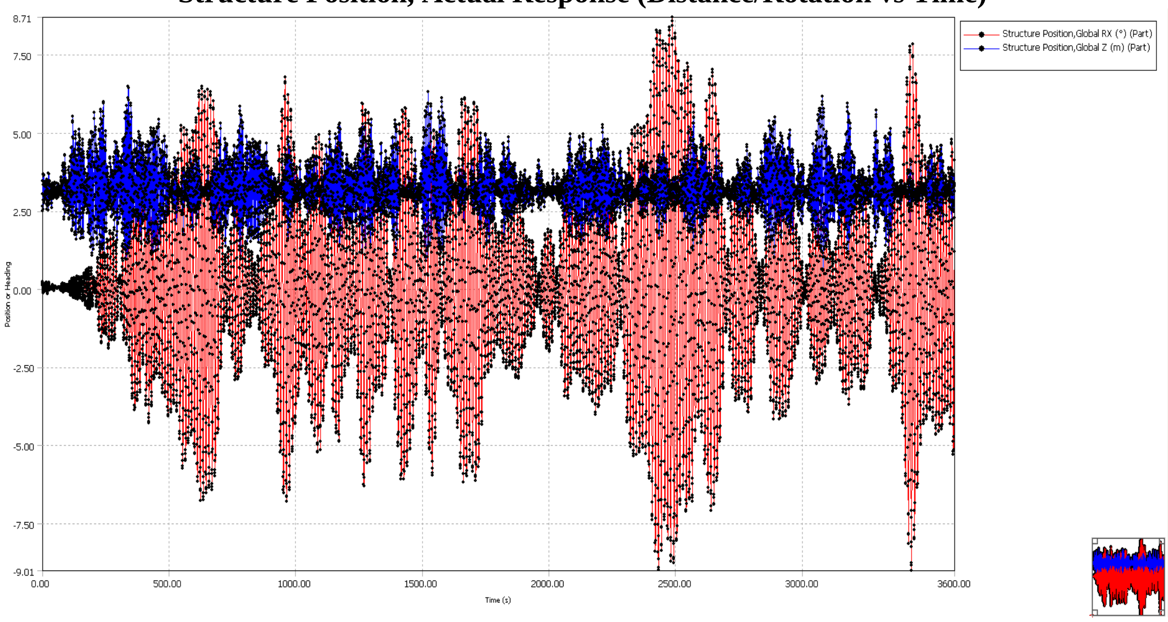
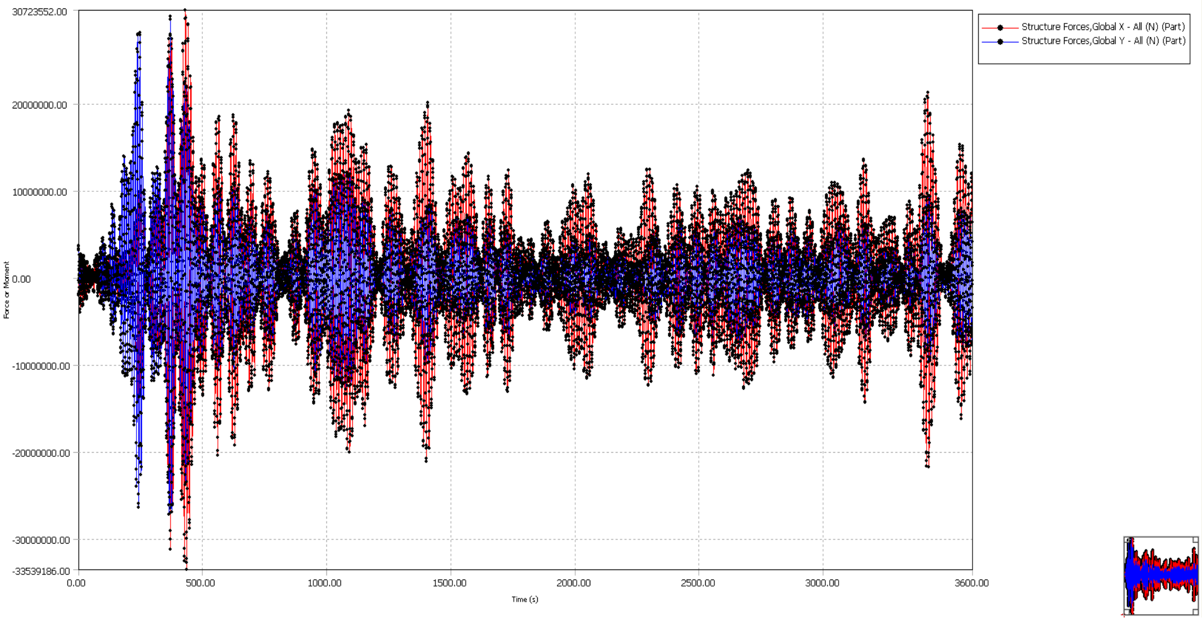


TABLE 27 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Solution (D5) > Hydrodynamic Graph Results

Object Name	*Structure Forces, All (Force/Moment vs Time)*
State	Solved
Details of Structure Forces, All (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	Part
Type	Structure Forces
SubType	All
Component	Global X
Position of Min in X	435.6
Position of Max in X	430.4
Minimum Value	-33539186
Maximum Value	30723552
Line B	
Structure	Part
Type	Structure Forces
SubType	All
Component	Global Y
Position of Min in X	364.8
Position of Max in X	369.2
Minimum Value	-27239288
Maximum Value	30034188

FIGURE 12 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Solution (D5) > Structure Forces, All (Force/Moment vs Time)



Hydrodynamic Time Response 3 (E4)

TABLE 28 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Time Response Specific Options	
Analysis Type	Irregular Wave Response with Slow Drift
Start Time	0 s
Time Step	0.4 s
Number of Steps	9001
Finish Time	3600 s
Starting Position	Program Controlled
Use Cable Dynamics	Yes

TABLE 29 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Current

Depth (m)	Velocity (m/s)	Direction (°)
10	1.1	90

TABLE 30 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Wind

Object Name	*Wind*
State	Fully Defined
Wind Spectral Definition	
Spectra	ISO
Reference Height	10 m
Speed	33.7 m/s
Direction	90 °

TABLE 31 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Irregular Wave

Object Name	*Irregular Wave*
State	Fully Defined
Wave Spectrum Details	
Wave Type	Pierson-Moskowitz
Direction of Spectrum	0 °
Seed Definition	Program Controlled
Omit Calculation of Drift Forces	No
Start Period	10.4 s
Finish Period	8 s
Significant Wave Height	7.3 m
Zero Crossing Period	8.6 s

Solution (E5)

TABLE 32 -Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Solution (E5) > Hydrodynamic Graph Results

Object Name	*Structure Position, Actual Response (Distance/Rotation vs Time)*
State	Solved
Details of Structure Position, Actual Response (Distance/Rotation vs Time)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Time
Line A	
Structure	Part
Type	Structure Position
SubType	Actual Response
Component	Global RX
Position of Min in X	2450
Position of Max in X	2443.6
Minimum Value	-8.938
Maximum Value	8.553
Line B	
Type	Structure Position
SubType	Actual Response
Component	Global Z
Position of Min in X	1175.6
Position of Max in X	2264.8
Minimum Value	0.512
Maximum Value	6.494

FIGURE 13 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Solution (E5) > Structure Position, Actual Response (Distance/Rotation vs Time)

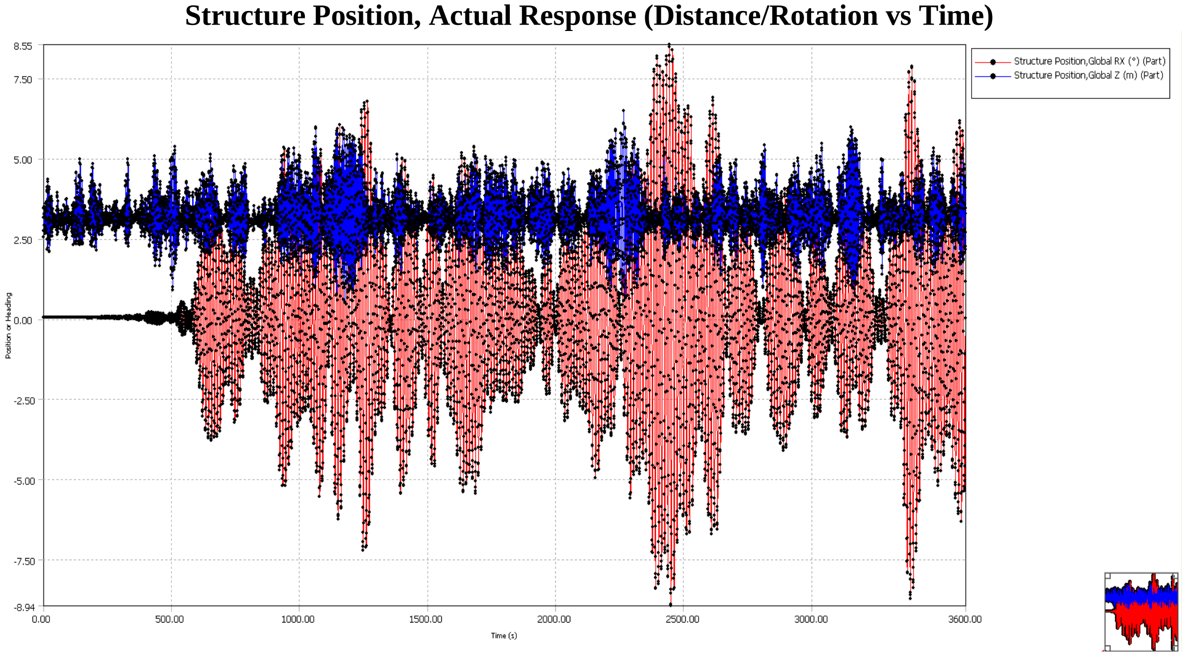
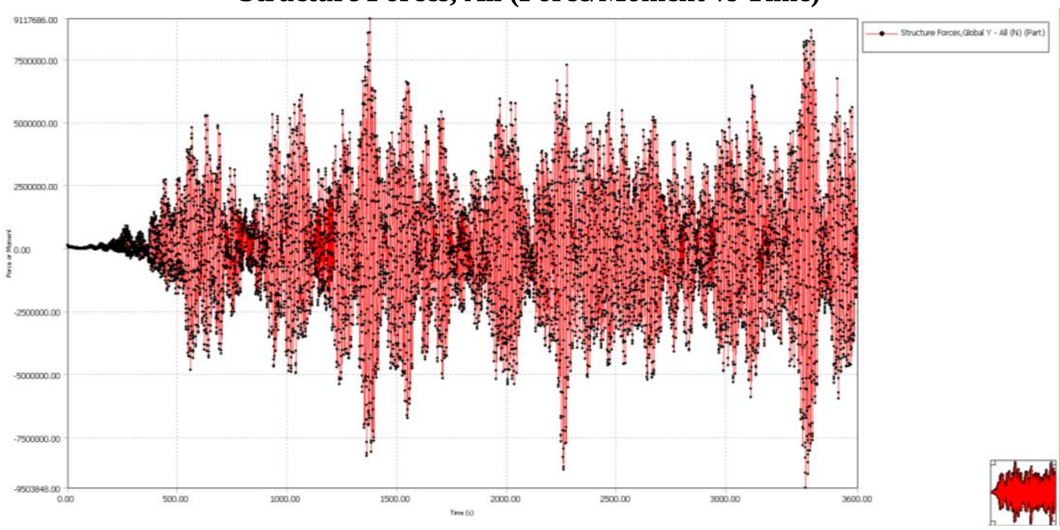


TABLE 33 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Solution (E5) > Hydrodynamic Graph Results

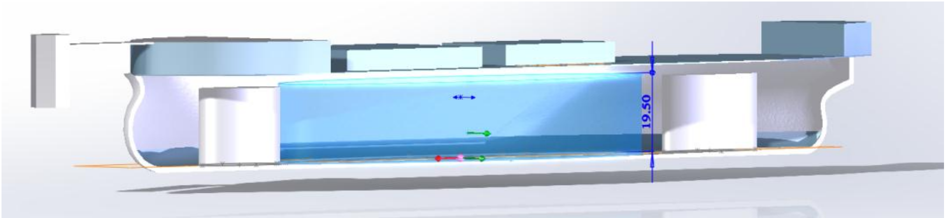
Object Name	*Structure Forces, All (Force/Moment vs Time)*
State	Solved
Details of Structure Forces, All (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	Part
Type	Structure Forces
SubType	All
Component	Global Y
Position of Min in X	3363.2
Position of Max in X	1378.4
Minimum Value	-9503848
Maximum Value	9117686

FIGURE 14 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Solution (E5) > Structure Forces, All (Force/Moment vs Time)



Appendix D – Simulation of 100% Loaded Vessel

FIGURE 1 - Vessel Mass definition



<u>Ship*</u>(All full loaded vesell models have the same parameters of the vessel)

TABLE 1 -Model (B3, C3, D3, E3) > Geometry > Part

Object Name	*ship*
State	Fully Defined
Details of ship	
Part Visibility	Visible
Suppressed	Not Suppressed
Total Structural Mass	114000007.01 kg
X Position of COG	0 m
Y Position of COG	0 m
Z Position of COG	-3.96 m
Generate Internal Lid	No
Current Calculation Depth	0 m
Fixity Options	
Structure Fixity	Structure is Free to Move

TABLE 2 - Model (B3, C3, D3, E3) > Geometry > ship > Axes

Object Name	*ship Axes*
State	Fully Defined
Details of ship Axes	
Visibility	Not Visible
Alignment Method	Global Axes
Rotation About Global Z	0 °
Rotation About Local Y	0 °
Rotation About Local X	0 °
Unit Vector X	[1, 0, 0]
Unit Vector Y	[0, 1, 0]
Unit Vector Z	[0, 0, 1]

TABLE 3 - Model (B3, C3, D3, E3) > Geometry > ship > Point Mass

Object Name	*Point Mass*
State	Fully Defined
Details of Point Mass	
Visibility	Visible
Suppressed	Not Suppressed
X	0 m
Y	0 m
Z	-3.96 m
Mass definition	Manual
Mass	114000007.01 kg
Define inertia values by	via Radius of Gyration
Kxx	25 m
Kyy	62 m
Kzz	64 m
Ixx	71250004381.25 kg.m²
Iyy	438216026946.44 kg.m²
Izz	466944028712.96 kg.m²

TABLE 4 - Model (B3, C3, D3, E3) > Geometry > ship > Point Buoyancy

Object Name	*Point Buoyancy*
State	Fully Defined
Details of Point Buoyancy	
Visibility	Visible
Suppressed	Not Suppressed
X	0.75 m
Y	0 m
Z	-7.17 m
Volume	129231.06 m³

Hydrodynamic Diffraction (B4)

TABLE 5 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Gravity

Object Name	*Gravity*
State	Fully Defined
Details of Gravity	
Gravity, g	9.80665 m/s²

TABLE 6 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Wave Direction

Object Name	*Wave Directions*
State	Fully Defined
Details of Wave Directions	
Type	Range of Directions, No Forward Speed
Required Wave Input	
Wave Range	-180° to 180° (-PI to PI)
Interval	45 °
Number of Intermediate Directions	7

TABLE 7 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Wave Frequency

Object Name	*Wave Frequencies*
State	Fully Defined
Frequency / Period definition	
Range	Program Controlled
Total Number of Frequencies	50
Equal Intervals Based Upon	Period

Solution (B5)

TABLE 8 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrostatic Results

Object Name	*Hydrostatic*
State	Solved
Details of Hydrostatic	
Structure	ship
Graphical Representation	
Show Centre of Gravity	Yes
Show Centre of Buoyancy	Yes
Show Centre of Floatation	Yes

AQWA Hydrostatic Results

Structure: ship

Hydrostatic Stiffness

Centre of Gravity Position:	X:	0. m	Y:	0. m	Z:	-3.96 m

	Z	RX	RY
Heave(Z):	96182816 N/	0.6643882 N/	7788625.5 N/
Roll(RX):	38.066639 N.	1.32544e8 N.	71.45343 N.r
Pitch(RZ):	4.46255e8 N.	71.45343 N.r	5.86216e9 N.

Hydrostatic Displacement Properties

Actual Volumetric Displacement:	258240.81 m
Equivalent Volumetric Displacement:	111219.52 m

Centre of Buoyancy Position:	X:	-1.5657e-2 m	Y:	1.0583e-4 m	Z:	-7.1639185 m
Out of Balance Forces/Weight:	FX:	2.8547e-9	FY:	-3.6185e-8	FZ:	1.321902
Out of Balance Moments/Weight:	MX:	2.4064e-4 m	MY:	3.6353e-2 m	MZ:	1.467e-7 m

Cut Water Plane Properties

Cut Water Plane Area:		9568.7002 m		
Centre of Floatation:	X:	-4.639658 m	Y:	3.9577e-7 m
Principal 2nd Moment of Area:	X:	1582888.6 m	Y:	34035992 m
Angle Principal Axis makes with X(FRA):		3.9422e-5 °		

Small Angle Stability Parameters

C.O.G. to C.O.B.(BG):	3.2039185 m	
Metacentric Heights (GMX/GMY):	2.9255877 m	128.5955 m
COB to Metacentre (BMX/BMY):	6.1295061 m	131.79942 m
Restoring Moments/Degree Rotations (MX/MY):	2313328.3 N.	1.01683e8 N.

TABLE 9 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrodynamic Graph Results

Object Name	*RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)*
State	Solved
Details of RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Frequency
Frequency or Period Scale	Period
Line A	
Structure	ship
Type	RAOs (Response Amplitude Operators)
Component	Global X
Direction	-180 °
Position of Min in X	3.668
Position of Max in X	34.981
Minimum Value	0
Maximum Value	3.015
Line B	
Structure	ship
Type	RAOs (Response Amplitude Operators)
Component	Global Y
Direction	-180 °
Position of Min in X	14.532
Position of Max in X	20.922
Minimum Value	0
Maximum Value	0
Line C	
Structure	ship
Type	RAOs (Response Amplitude Operators)
Component	Global Z
Direction	-180 °
Position of Min in X	3.668
Position of Max in X	34.981
Minimum Value	0
Maximum Value	0.854

FIGURE 2 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)

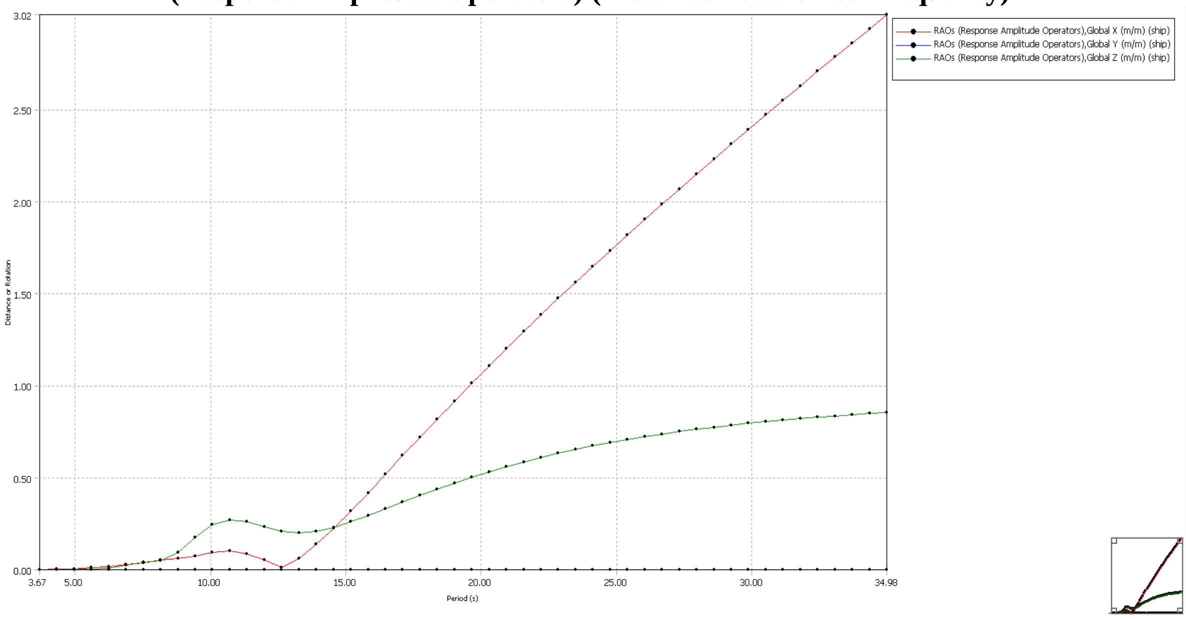


TABLE 10 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrodynamic Graph Results

Object Name	*RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)*
State	Solved
Details of RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Frequency
Frequency or Period Scale	Period
Line A	
Structure	ship
Type	RAOs (Response Amplitude Operators)
Component	Global RX
Direction	-180 °
Position of Min in X	34.342
Position of Max in X	20.922
Minimum Value	0
Maximum Value	0
Line B	
Structure	ship
Type	RAOs (Response Amplitude Operators)
Component	Global RY
Direction	-180 °
Position of Min in X	3.668
Position of Max in X	18.366
Minimum Value	0
Maximum Value	0.808
Line C	

Structure	ship
Type	RAOs (Response Amplitude Operators)
Component	Global RZ
Direction	-180 °
Position of Min in X	3.668
Position of Max in X	17.088
Minimum Value	0
Maximum Value	0

FIGURE 3 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)

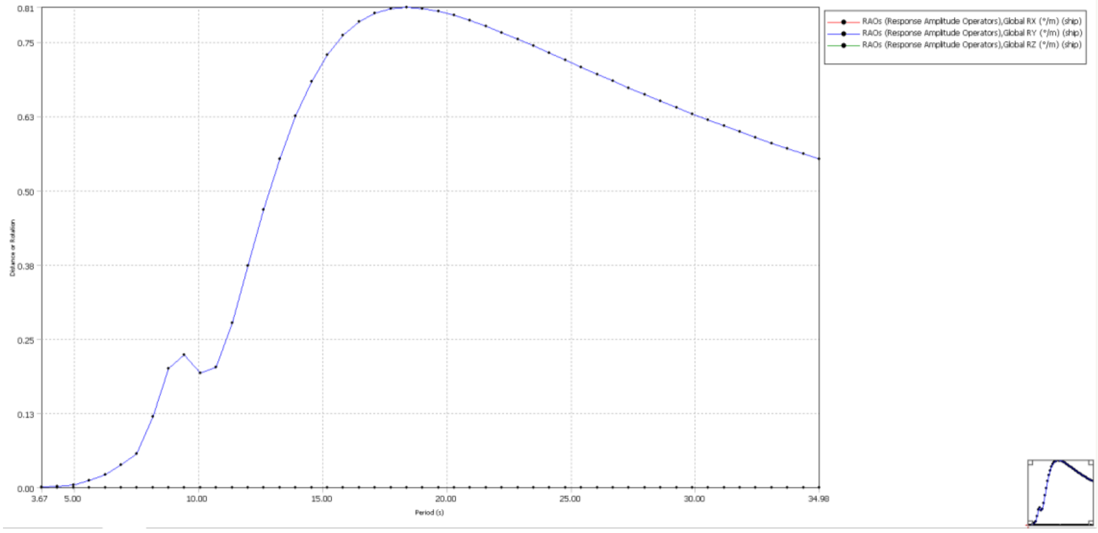


TABLE 11 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrodynamic Graph Results

Object Name	*RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)*
State	Solved
Details of RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Frequency
Frequency or Period Scale	Period
Line A	
Structure	ship
Type	RAOs (Response Amplitude Operators)
Component	Global X
Direction	90 °
Position of Min in X	28.59
Position of Max in X	10.058
Minimum Value	0
Maximum Value	0.042

Line B	
Structure	ship
Type	RAOs (Response Amplitude Operators)
Component	Global Y
Direction	90 °
Position of Min in X	3.668
Position of Max in X	20.922
Minimum Value	0.026
Maximum Value	4.822
Line C	
Structure	ship
Type	RAOs (Response Amplitude Operators)
Component	Global Z
Direction	90 °
Position of Min in X	3.668
Position of Max in X	11.976
Minimum Value	0.002
Maximum Value	1.313

FIGURE 4 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)

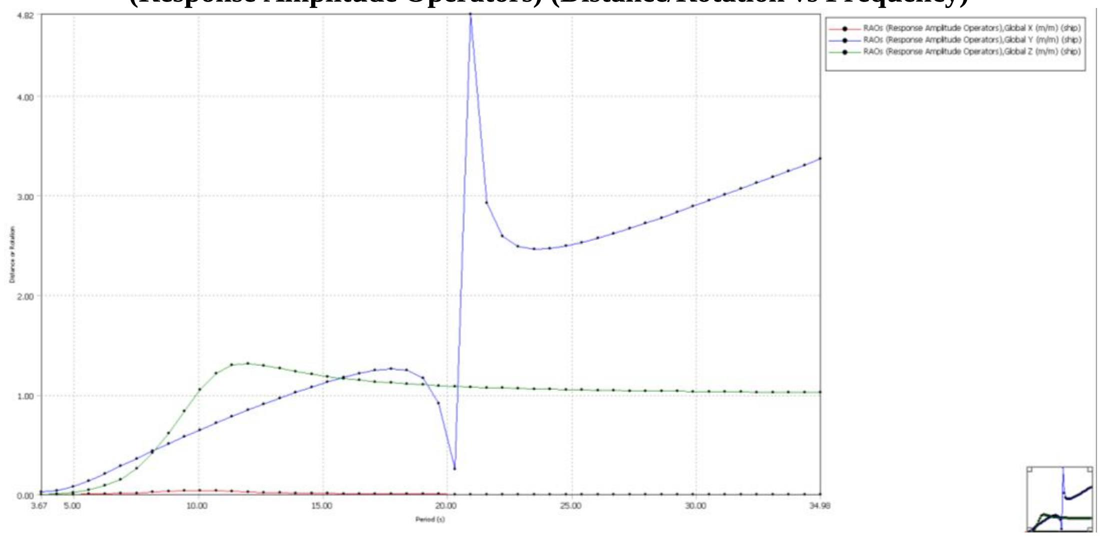


TABLE 12 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrodynamic Graph Results

Object Name	*RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)*
State	Solved
Details of RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Frequency
Frequency or Period Scale	Period
Line A	
Structure	ship
Type	RAOs (Response Amplitude Operators)
Component	Global RX
Direction	90 °
Position of Min in X	3.668
Position of Max in X	20.922
Minimum Value	0.007
Maximum Value	49.595
Line B	
Structure	ship
Type	RAOs (Response Amplitude Operators)
Component	Global RY
Direction	90 °
Position of Min in X	3.668
Position of Max in X	10.058
Minimum Value	0
Maximum Value	0.227
Line C	
Structure	ship
Type	RAOs (Response Amplitude Operators)
Component	Global RZ
Direction	90 °
Position of Min in X	11.337
Position of Max in X	20.922
Minimum Value	0.001
Maximum Value	0.35

FIGURE 5 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)

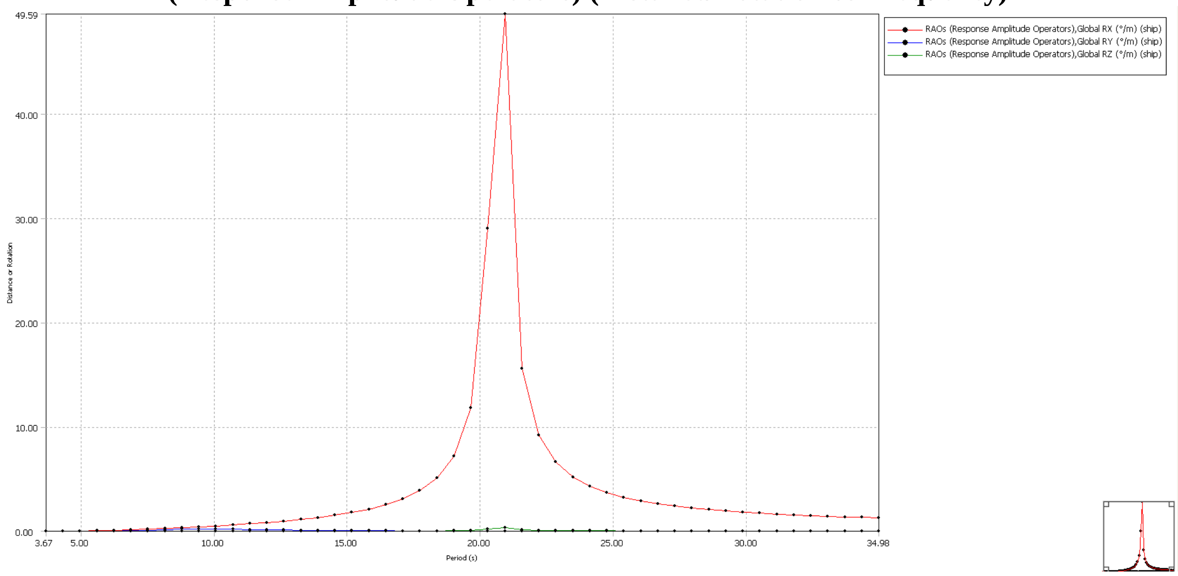


TABLE 13 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrodynamic Graph Results

Object Name	*RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)*
State	Solved
Details of RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Frequency
Frequency or Period Scale	Period
Line A	
Structure	ship
Type	RAOs (Response Amplitude Operators)
Component	Global X
Direction	135 °
Position of Min in X	3.668
Position of Max in X	34.981
Minimum Value	0.002
Maximum Value	2.327
Line B	
Structure	ship
Type	RAOs (Response Amplitude Operators)
Component	Global Y
Direction	135 °
Position of Min in X	3.668
Position of Max in X	20.922
Minimum Value	0.003
Maximum Value	2.703
Line C	
Structure	ship

Type	RAOs (Response Amplitude Operators)
Component	Global Z
Direction	135 °
Position of Min in X	3.668
Position of Max in X	34.981
Minimum Value	0
Maximum Value	0.937

FIGURE 6 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)

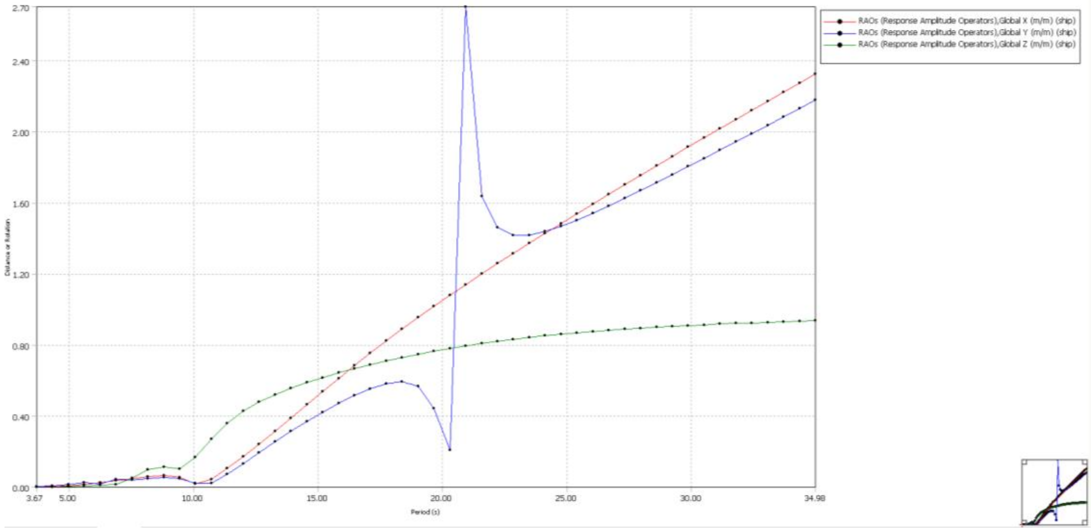


TABLE 14 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrodynamic Graph Results

Object Name	*RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)*
State	Solved
Details of RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Frequency
Frequency or Period Scale	Period
Line A	
Structure	ship
Type	RAOs (Response Amplitude Operators)
Component	Global RX
Direction	135 °
Position of Min in X	3.668
Position of Max in X	20.922
Minimum Value	0.002
Maximum Value	28.644
Line B	
Structure	ship
Type	RAOs (Response Amplitude Operators)

Component	Global RY
Direction	135 °
Position of Min in X	3.668
Position of Max in X	13.893
Minimum Value	0.001
Maximum Value	0.834
Line C	
Structure	ship
Type	RAOs (Response Amplitude Operators)
Component	Global RZ
Direction	135 °
Position of Min in X	3.668
Position of Max in X	20.922
Minimum Value	0.004
Maximum Value	0.864

FIGURE 7 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency)

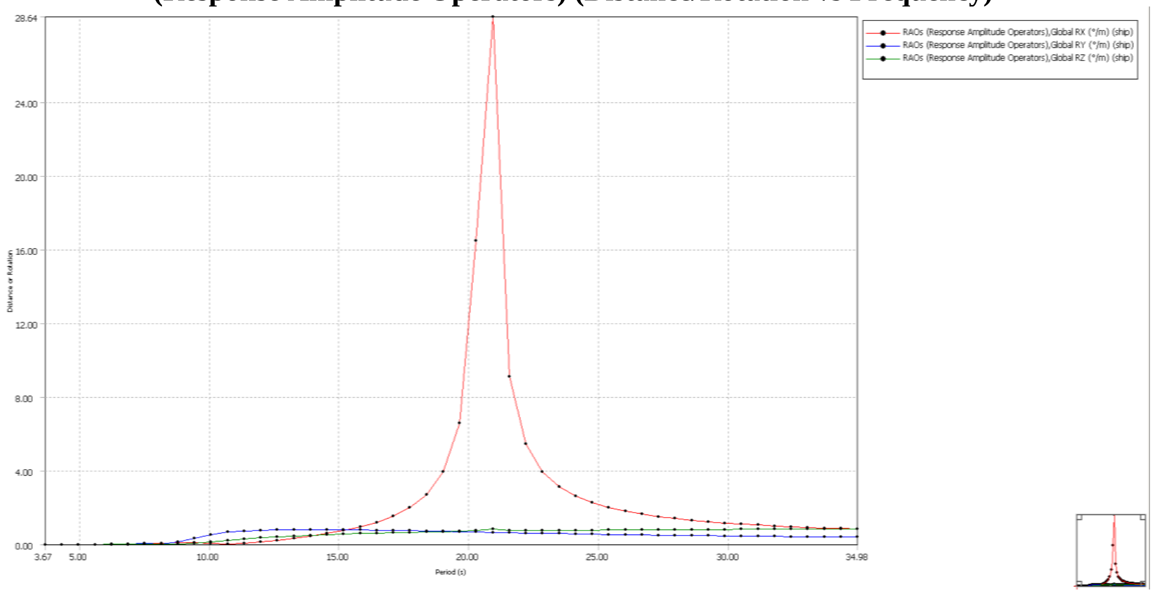
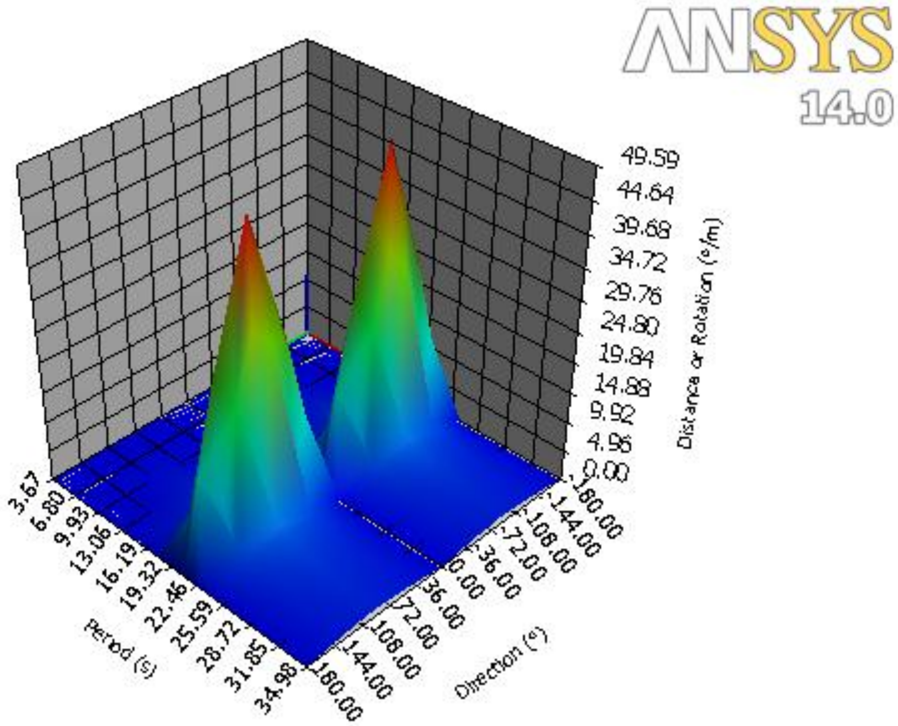


TABLE 15 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > Hydrodynamic Graph Results

Object Name	*RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency & Direction)*
State	Solved
Details of RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency & Direction)	
Presentation Method	Surface

Axes Selection	Distance/Rotation vs Frequency & Direction
Frequency or Period Scale	Period
Surface	
Structure	ship
Type	RAOs (Response Amplitude Operators)
Component	Global RX
Position of Min in X	3.668
Position of Max in X	20.922
Position of Min in Y	0
Position of Max in Y	90
Minimum Value	0
Maximum Value	49.595

FIGURE 8 - Model (B3, C3, D3, E3) > Hydrodynamic Diffraction (B4) > Solution (B5) > RAOs (Response Amplitude Operators) (Distance/Rotation vs Frequency & Direction)



Hydrodynamic Time Response (C4)

TABLE 16 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Details of Analysis Settings	
Time Response Specific Options	
Analysis Type	Irregular Wave Response with Slow Drift

Start Time	0 s
Time Step	0.4 s
Number of Steps	9001
Finish Time	3600 s
Starting Position	Based on Geometry
Use Cable Dynamics	Yes

TABLE 17 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Current

Depth (m)	Velocity (m/s)	Direction (°)
10	1.1	180

TABLE 18 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Irregular Wave

Object Name	*Irregular Wave*
State	Fully Defined
Details of Irregular Wave	
Visibility	Visible
Suppressed	Not Suppressed
Wave Range Defined by	Period
Wave Spectrum Details	
Wave Type	Pierson-Moskowitz
Direction of Spectrum	180 °
Seed Definition	Program Controlled
Omit Calculation of Drift Forces	Yes
Start Period	10.4 s
Finish Period	8 s
Significant Wave Height	7.3 m
Zero Crossing Period	8.6 s

TABLE 19 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Wind

Object Name	*Wind*
State	Fully Defined
Details of Wind	
Visibility	Visible
Suppressed	Not Suppressed
Wind Spectral Definition	
Spectra	ISO
Reference Height	10 m
Speed	33.7 m/s
Direction	180 °

Solution (C5)

TABLE 20 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Solution (C5) > Hydrodynamic Graph Results

Object Name	*Structure Position, Actual Response (Distance/Rotation vs Time)*
State	Solved
Details of Structure Position, Actual Response (Distance/Rotation vs Time)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Time
Line A	
Structure	ship
Type	Structure Position
SubType	Actual Response
Component	Global RY
Position of Min in X	5.2
Position of Max in X	9.6
Minimum Value	-1.377
Maximum Value	0.312
Line B	
Type	Structure Position
SubType	Actual Response
Component	Global Z
Position of Min in X	0
Position of Max in X	4
Minimum Value	-3.96
Maximum Value	9.711

FIGURE 9 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Solution (C5) > Structure Position, Actual Response (Distance/Rotation vs Time)

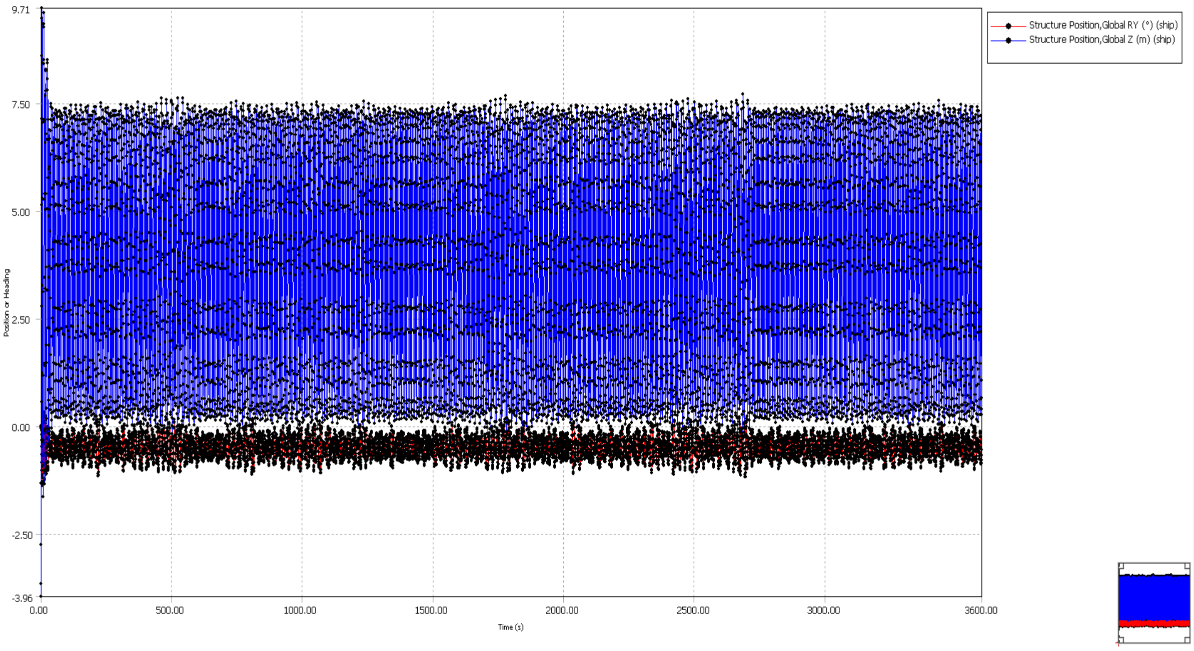
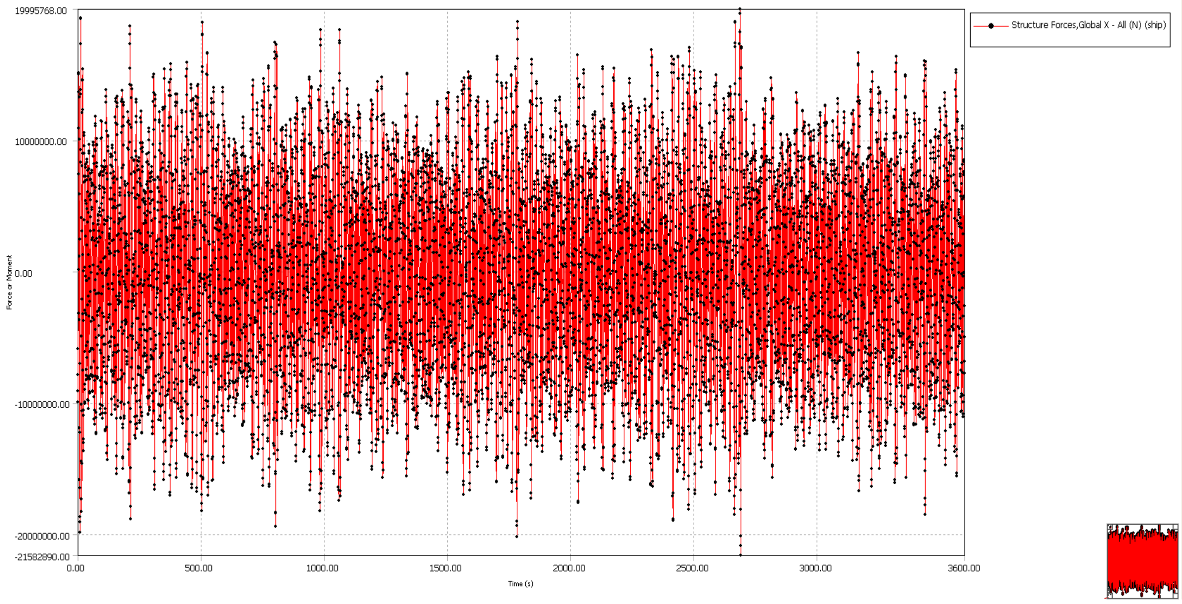


TABLE 21 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Solution (C5) > Hydrodynamic Graph Results

Object Name	*Structure Forces, All (Force/Moment vs Time)*
State	Solved
Details of Structure Forces, All (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	ship
Type	Structure Forces
SubType	All
Component	Global X
Position of Min in X	2691.2
Position of Max in X	2687.6
Minimum Value	-21582890
Maximum Value	19995768

FIGURE 10 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response (C4) > Solution (C5) > Structure Forces, All (Force/Moment vs Time)



Hydrodynamic Time Response 2 (D4)

TABLE 22 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Details of Analysis Settings	
Time Response Specific Options	
Analysis Type	Irregular Wave Response with Slow Drift
Start Time	0 s
Time Step	0.4 s
Number of Steps	9001
Finish Time	3600 s
Starting Position	Program Controlled
Use Cable Dynamics	Yes

TABLE 23 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Current

Depth (m)	Velocity (m/s)	Direction (°)
10	1.1	135

TABLE 24 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Wind

Object Name	*Wind*
State	Fully Defined
Wind Spectral Definition	
Spectra	ISO
Reference Height	10 m
Speed	33.7 m/s
Direction	135 °

TABLE 25 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Irregular Wave

Object Name	*Irregular Wave*
State	Fully Defined
Wave Spectrum Details	
Wave Type	Pierson-Moskowitz
Direction of Spectrum	0 °
Seed Definition	Program Controlled
Omit Calculation of Drift Forces	No
Start Period	10.4 s
Finish Period	8 s
Significant Wave Height	7.3 m
Zero Crossing Period	8.6 s

Solution (D5)

TABLE 26 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Solution (D5) > Hydrodynamic Graph Results

Object Name	*Structure Position, Actual Response (Distance/Rotation vs Time)*
State	Solved
Details of Structure Position, Actual Response (Distance/Rotation vs Time)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Time
Line A	
Structure	ship
Type	Structure Position
SubType	Actual Response
Component	Global RX
Position of Min in X	1160
Position of Max in X	1154
Minimum Value	-1.444
Maximum Value	0.748
Line B	
Structure	ship
Type	Structure Position
SubType	Actual Response
Component	Global Z
Position of Min in X	1058
Position of Max in X	1077.6
Minimum Value	0.592
Maximum Value	6.624

FIGURE 11 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Solution (D5) > Structure Position, Actual Response (Distance/Rotation vs Time)

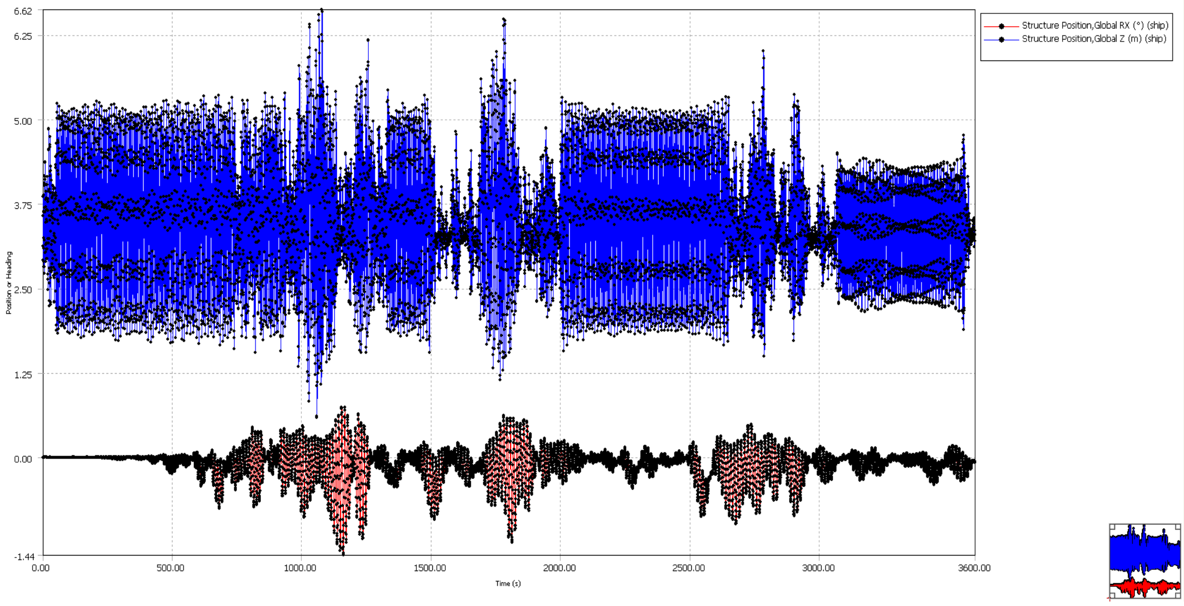
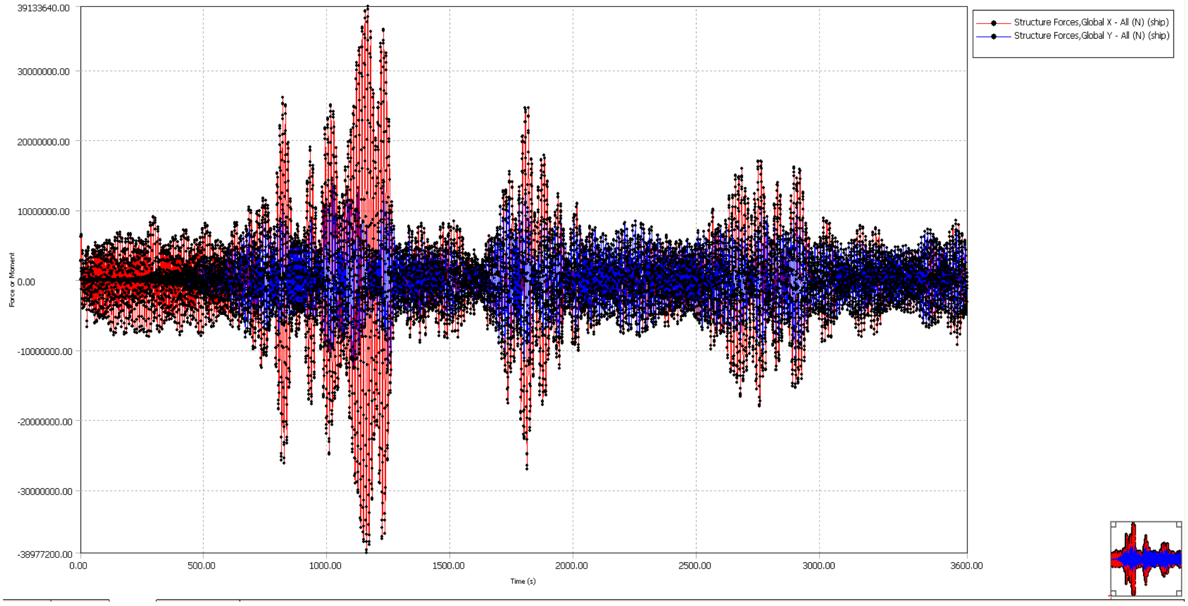


TABLE 27 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Solution (D5) > Hydrodynamic Graph Results

Object Name	*Structure Forces, All (Force/Moment vs Time)*
State	Solved
Details of Structure Forces, All (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	ship
Type	Structure Forces
SubType	All
Component	Global X
Position of Min in X	1160
Position of Max in X	1166
Minimum Value	-38977200
Maximum Value	39133640
Line B	
Structure	ship
Type	Structure Forces
SubType	All
Component	Global Y
Position of Min in X	1246.8
Position of Max in X	1021.6
Minimum Value	-13035451
Maximum Value	14573123

FIGURE 12 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 2 (D4) > Solution (D5) > Structure Forces, All (Force/Moment vs Time)



Hydrodynamic Time Response 3 (E4)

TABLE 28 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Time Response Specific Options	
Analysis Type	Irregular Wave Response with Slow Drift
Start Time	0 s
Time Step	0.4 s
Number of Steps	9001
Finish Time	3600 s
Starting Position	Program Controlled
Use Cable Dynamics	Yes

TABLE 29 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Current

Depth (m)	Velocity (m/s)	Direction (°)
10	1.1	90

TABLE 30 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Wind

Object Name	*Wind*
State	Fully Defined
Wind Spectral Definition	
Spectra	ISO
Reference Height	10 m
Speed	33.7 m/s
Direction	135 °

TABLE 31 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Irregular Wave

Object Name	*Irregular Wave*
State	Fully Defined
Wave Spectrum Details	
Wave Type	Pierson-Moskowitz
Direction of Spectrum	0 °
Seed Definition	Program Controlled
Omit Calculation of Drift Forces	No
Start Period	10.4 s
Finish Period	8 s
Significant Wave Height	7.3 m
Zero Crossing Period	8.6 s

Solution (E5)

TABLE 32 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Solution (E5) > Hydrodynamic Graph Results

Object Name	*Structure Position, Actual Response (Distance/Rotation vs Time)*
State	Solved
Details of Structure Position, Actual Response (Distance/Rotation vs Time)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Time
Line A	
Structure	ship
Type	Structure Position
SubType	Actual Response
Component	Global RX
Position of Min in X	1102.4
Position of Max in X	1108.4
Minimum Value	-1.655
Maximum Value	0.859
Line B	
Structure	ship
Type	Structure Position
SubType	Actual Response
Component	Global Z
Position of Min in X	2610.4
Position of Max in X	2602
Minimum Value	0.921
Maximum Value	6.361

FIGURE 13 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Solution (E5) > Structure Position, Actual Response (Distance/Rotation vs Time)

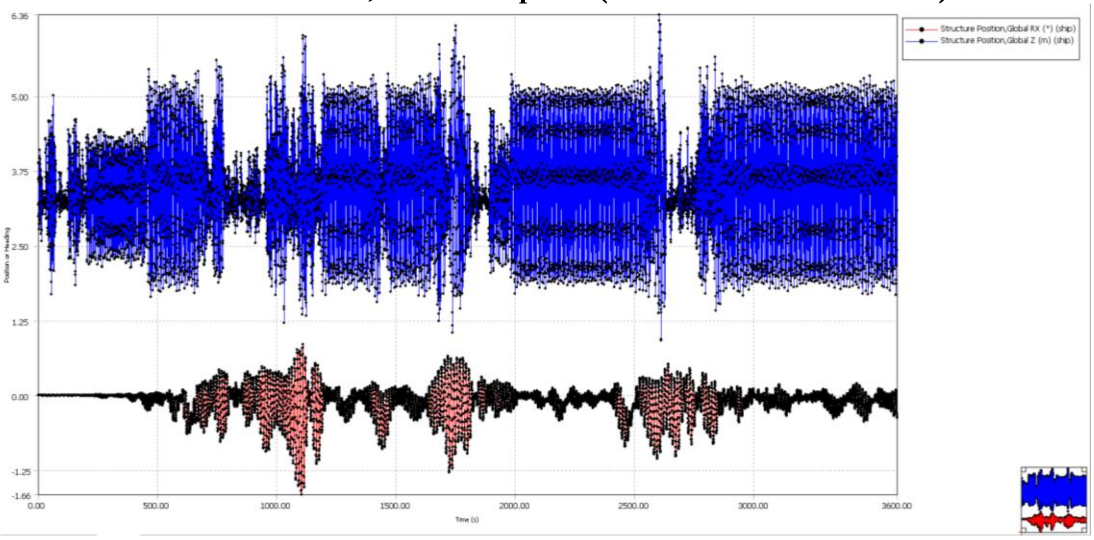
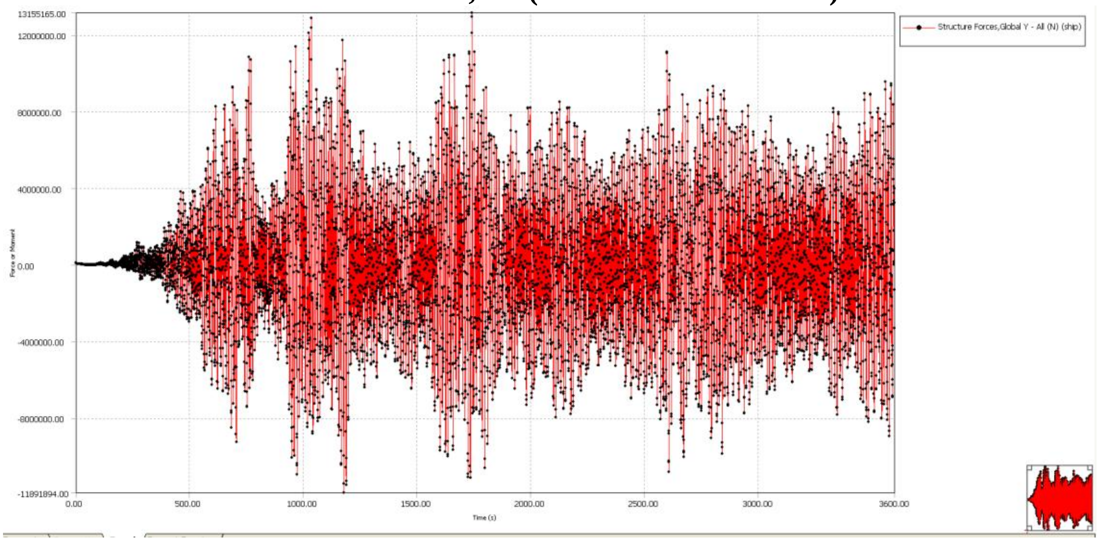


TABLE 33 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Solution (E5) > Hydrodynamic Graph Results

Object Name	*Structure Forces, All (Force/Moment vs Time)*
State	Solved
Details of Structure Forces, All (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	ship
Type	Structure Forces
SubType	All
Component	Global Y
Position of Min in X	1177.6
Position of Max in X	1742
Minimum Value	-11891894
Maximum Value	13155165

FIGURE 14 - Model (B3, C3, D3, E3) > Hydrodynamic Time Response 3 (E4) > Solution (E5) > Structure Forces, All (Force/Moment vs Time)



Appendix E – Simulation of 100% Loaded Moored Vessel (Mooring System with 12 Lines)

Figure 1 - 100% loaded moored vessel (mooring system with 12 lines)

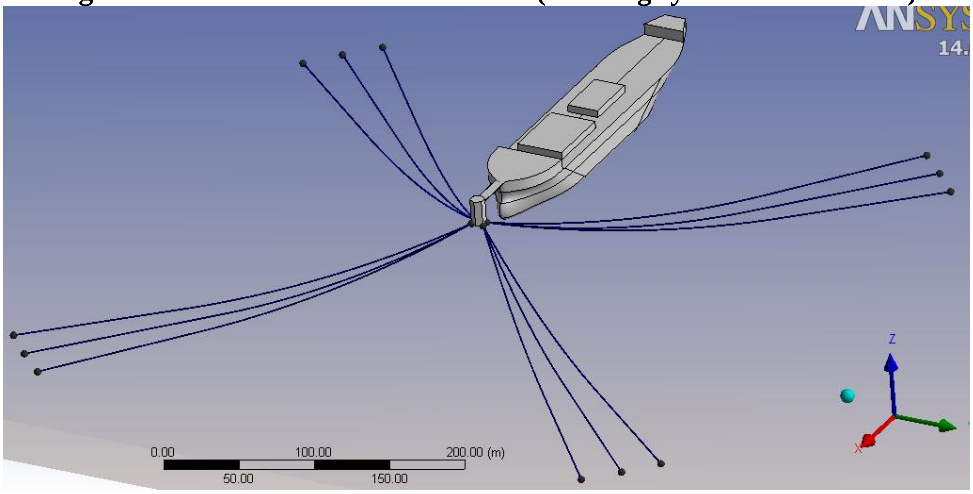


TABLE 1 - Model (B3, C3, D3, E3, F3) > Geometry > ship > Connection Point

Object Name	*Connection Point 1*
State	Fully Defined
Details of Connection Point 1	
Type	Attached to Structure
Structure	ship
Definition Of Position	Vertex Selection
Vertex	Vertex Selected (ship)
Vertex X	144.518276427541 m
Vertex Y	-4.3301269895491 m
Vertex Z	0.500000076031941 m
Postion Coordinates	
X Offset	0 m
Y Offset	0 m
Z Offset	0 m
X	144.518276427541 m
Y	-4.3301269895491 m
Z	0.500000076031941 m

TABLE 2 - Model (B3, C3, D3, E3, F3) > Geometry > ship > Connection Point

Object Name	*Connection Point 5*
State	Fully Defined
Details of Connection Point 5	
Type	Attached to Structure
Structure	ship
Definition Of Position	Vertex Selection
Vertex	Vertex Selected (ship)
Vertex X	139.518276427541 m
Vertex Y	-4.3301269895491 m
Vertex Z	0.5000000759811 m
Postion Coordinates	
X Offset	0 m
Y Offset	0 m
Z Offset	0 m
X	139.518276427541 m
Y	-4.3301269895491 m
Z	0.5000000759811 m

TABLE 3 - Model (B3, C3, D3, E3, F3) > Geometry > ship > Connection Point

Object Name	*Connection Point 9*
State	Fully Defined
Details of Connection Point 9	
Type	Attached to Structure
Structure	ship
Definition Of Position	Vertex Selection
Vertex	Vertex Selected (ship)
Vertex X	139.518276427541 m
Vertex Y	4.33012704829529 m
Vertex Z	0.500000076060136 m
Postion Coordinates	
X Offset	0 m
Y Offset	0 m
Z Offset	0 m
X	139.518276427541 m
Y	4.33012704829529 m
Z	0.500000076060136 m

TABLE 4 - Model (B3, C3, D3, E3, F3) > Geometry > ship > Connection Point

Object Name	*Connection Point 13*
State	Fully Defined
Details of Connection Point 13	
Type	Attached to Structure
Structure	ship
Definition Of Position	Vertex Selection
Vertex	Vertex Selected (ship)
Vertex X	144.518276427541 m
Vertex Y	4.33012704829529 m
Vertex Z	0.500000076161819 m
Postion Coordinates	
X Offset	0 m
Y Offset	0 m
Z Offset	0 m
X	144.518276427541 m
Y	4.33012704829529 m
Z	0.500000076161819 m

TABLE 5 - Model (B3, C3, D3, E3, F3) > Geometry > Connection Point

Object Name	*Fixed Point 2*
State	Fully Defined
Details of Fixed Point 2	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	384 m
Y	-205 m
Z	-30 m

TABLE 6 - Model (B3, C3, D3, E3, F3) > Geometry > Connection Point

Object Name	*Fixed Point 3*
State	Fully Defined
Details of Fixed Point 3	
Point Visibility	Visible
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	365 m
Y	-225 m
Z	-30 m

TABLE 7 - Model (B3, C3, D3, E3, F3) > Geometry > Connection Point

Object Name	*Fixed Point 4*
State	Fully Defined
Details of Fixed Point 4	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	345 m
Y	-244 m
Z	-30 m

TABLE 8 - Model (B3, C3, D3, E3, F3) > Geometry > Connection Point

Object Name	*Fixed Point 6*
State	Fully Defined
Details of Fixed Point 6	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	-61 m
Y	-244 m
Z	-30 m

TABLE 9 - Model (B3, C3, D3, E3, F3) > Geometry > Connection Point

Object Name	*Fixed Point 7*
State	Fully Defined
Details of Fixed Point 7	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	-81 m
Y	-225 m
Z	-30 m

TABLE 10 - Model (B3, C3, D3, E3, F3) > Geometry > Connection Point

Object Name	*Fixed Point 8*
State	Fully Defined
Details of Fixed Point 8	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	-100 m
Y	-205 m
Z	-30 m

TABLE 11 - Model (B3, C3, D3, E3, F3) > Geometry > Connection Point

Object Name	*Fixed Point 10*
State	Fully Defined
Details of Fixed Point 10	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	-100 m
Y	205 m
Z	-30 m

TABLE 12 - Model (B3, C3, D3, E3, F3) > Geometry > Connection Point

Object Name	*Fixed Point 11*
State	Fully Defined
Details of Fixed Point 11	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	-81 m
Y	225 m
Z	-30 m

TABLE 13 - Model (B3, C3, D3, E3, F3) > Geometry > Connection Point

Object Name	*Fixed Point 12*
State	Fully Defined
Details of Fixed Point 12	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	-61 m
Y	244 m
Z	-30 m

TABLE 14 - Model (B3, C3, D3, E3, F3) > Geometry > Connection Point

Object Name	*Fixed Point 14*
State	Fully Defined
Details of Fixed Point 14	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	345 m
Y	244 m
Z	-30 m

TABLE 15 - Model (B3, C3, D3, E3, F3) > Geometry > Connection Point

Object Name	*Fixed Point 15*
State	Fully Defined
Details of Fixed Point 15	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	365 m
Y	225 m
Z	-30 m

TABLE 16 - Model (B3, C3, D3, E3, F3) > Geometry > Connection Point

Object Name	*Fixed Point 16*
State	Fully Defined
Details of Fixed Point 16	
Type	Fixed
Definition Of Position	Coordinates
Postion Coordinates	
X	384 m
Y	205 m
Z	-30 m

Connections

TABLE 17 - Model (B3, C3, D3, E3, F3) > Connections > Catenary Data > Catenary Section

Object Name	*Catenary Section 1*
State	Fully Defined
Section Properties	
Mass / Unit Length	686 kg/m
Equivalent Cross Sectional Area	0.0246 m²
Stiffness, EA	1439189678 N
Maximum Tension	20193000 N
Section Hydrodynamic Properties	
Equivalent Diameter	0.177 m
Longitudinal Drag Coefficient	0.025

TABLE 18 - Model (B3, C3, D3, E3, F3) > Connections > Cable

Object Name	*Cable 1-12*
State	Fully Defined
Details of Cable 1	
Connectivity	Fixed Point & Structure
Fixed Point	Fixed Point 2 (Fixed)
End Connection Point	Connection Point 1 (ship)
Type	Non-Linear Catenary
Cable Dynamics Properties	
Use Dynamics	Program Controlled
Number of Elements	100
Catenary Section Selection	
Section 1: Type	Catenary Section 1
Section 1: Length	315 m
Section 2: Type	None
Cable Properties	
Negative dZ Range	0 m
Positive dZ Range	3 m
Number of Vertical Partitions	15

Number of X Coordinates	40
Initial Cable Data	
Initial Cable Tension @ Start	4074843.75 N
Initial Cable Tension @ End	4272408 N

TABLE 19 - Model (B3, C3, D3, E3, F3) > Connections > Cable 1-12

	Section 1
Type	Catenary Section 1
Section Length (m)	315
Mass / Unit Length (kg/m)	686
Equivilent CSA (m²)	0.0246
Stiffness, EA (N)	1439189678
Maximum Tension (N)	20193000
Equivalent Diameter (m)	0.177
Longitudinal Drag Coefficient	0.025

Hydrodynamic Time Response (C4)

TABLE 20 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response (C4) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Time Response Specific Options	
Analysis Type	Irregular Wave Response with Slow Drift
Start Time	0 s
Time Step	0.5 s
Number of Steps	2001
Finish Time	1000 s
Starting Position	Program Controlled
Use Cable Dynamics	Yes

TABLE 21 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response (C4) > Current

Depth (m)	Velocity (m/s)	Direction (°)
10	1.1	135

TABLE 22 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response (C4) > Irregular Wave

Object Name	*Irregular Wave*
State	Fully Defined
Wave Spectrum Details	
Wave Type	Pierson-Moskowitz
Direction of Spectrum	135 °
Seed Definition	Program Controlled
Omit Calculation of Drift Forces	Yes
Start Period	10.4 s
Finish Period	8 s
Significant Wave Height	7.3 m
Zero Crossing Period	8.6 s

TABLE 23 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response (C4) > Wind

Object Name	*Wind*
State	Fully Defined
Wind Spectral Definition	
Spectra	ISO
Reference Height	10 m
Speed	33.7 m/s
Direction	135 °

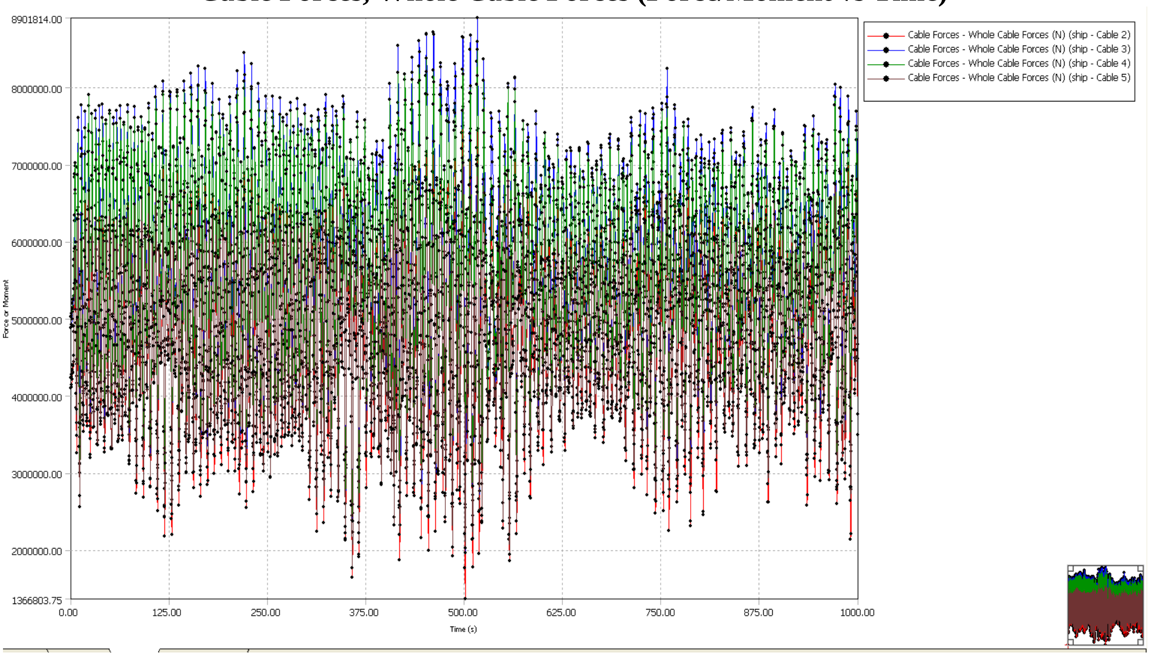
Solution (C5)

TABLE 24 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response (C4) > Solution (C5) > Hydrodynamic Graph Results

Object Name	*Cable Forces, Whole Cable Forces (Force/Moment vs Time)*
State	Solved
Details of Cable Forces, Whole Cable Forces (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 2
Position of Min in X	501
Position of Max in X	416
Minimum Value	1366803.75
Maximum Value	7522676
Line B	
Structure	ship

Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 3
Position of Min in X	501
Position of Max in X	516.5
Minimum Value	1963192.25
Maximum Value	8901814
Line C	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 4
Position of Min in X	557.5
Position of Max in X	516.5
Minimum Value	2414422.25
Maximum Value	8493424
Line D	
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 5
Position of Min in X	357.5
Position of Max in X	415.5
Minimum Value	1771966.375
Maximum Value	7248835

FIGURE 2 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response (C4) > Solution (C5) > Cable Forces, Whole Cable Forces (Force/Moment vs Time)



Hydrodynamic Time Response 2 (D4)

TABLE 25 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 2 (D4) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Time Response Specific Options	
Analysis Type	Irregular Wave Response with Slow Drift
Start Time	0 s
Time Step	0.5 s
Number of Steps	2001
Finish Time	1000 s
Starting Position	Program Controlled
Use Cable Dynamics	Yes

TABLE 26 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 2 (D4) > Current

Depth (m)	Velocity (m/s)	Direction (°)
10	1.1	150

TABLE 27 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 2 (D4) > Wind

Object Name	*Wind*
State	Fully Defined
Wind Spectral Definition	
Spectra	ISO
Reference Height	10 m
Speed	33.7 m/s
Direction	150 °

TABLE 28 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 2 (D4) > Irregular Wave

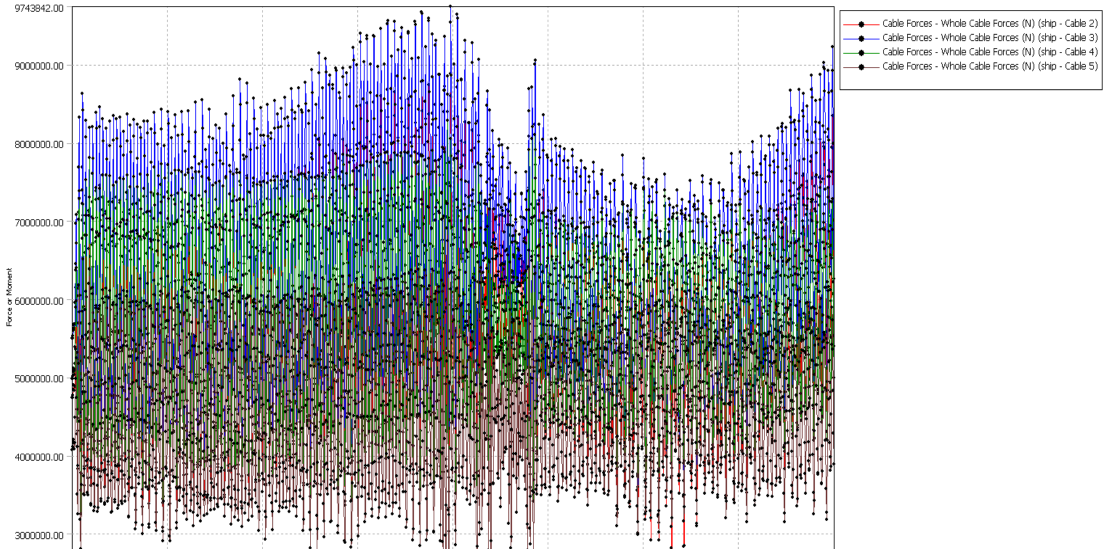
Object Name	*Irregular Wave*
State	Fully Defined
Wave Spectrum Details	
Wave Type	Pierson-Moskowitz
Direction of Spectrum	150 °
Seed Definition	Program Controlled
Omit Calculation of Drift Forces	No
Start Period	10.4 s
Finish Period	8 s
Significant Wave Height	7.3 m
Zero Crossing Period	8.6 s

Solution (D5)

TABLE 29 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 2 (D4) > Solution (D5) > Hydrodynamic Graph Results

Object Name	*Cable Forces, Whole Cable Forces (Force/Moment vs Time)*
State	Solved
Details of Cable Forces, Whole Cable Forces (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 2
Position of Min in X	787
Position of Max in X	496.5
Minimum Value	2756679.5
Maximum Value	8879587
Line B	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 3
Position of Min in X	787
Position of Max in X	497
Minimum Value	3444051
Maximum Value	9743842
Line C	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 4
Position of Min in X	494.5
Position of Max in X	492.5
Minimum Value	3024661.25
Maximum Value	8286696
Line D	
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 5
Position of Min in X	494.5
Position of Max in X	488.5
Minimum Value	2319752.75
Maximum Value	7060911.5

FIGURE 3 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 2 (D4) > Solution (D5) > Cable Forces, Whole Cable Forces (Force/Moment vs Time)



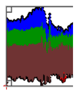


TABLE 30 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 2 (D4) > Solution (D5) > Hydrodynamic Graph Results

Object Name	*Cable Forces, Whole Cable Forces (Force/Moment vs Time)*
State	Solved
Details of Cable Forces, Whole Cable Forces (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Anchor Uplift
Connection	Cable 3
Position of Min in X	744
Position of Max in X	989
Minimum Value	2355.167
Maximum Value	265316.406

FIGURE 4 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 2 (D4) > Solution (D5) > Cable Forces, Whole Cable Forces (Force/Moment vs Time)

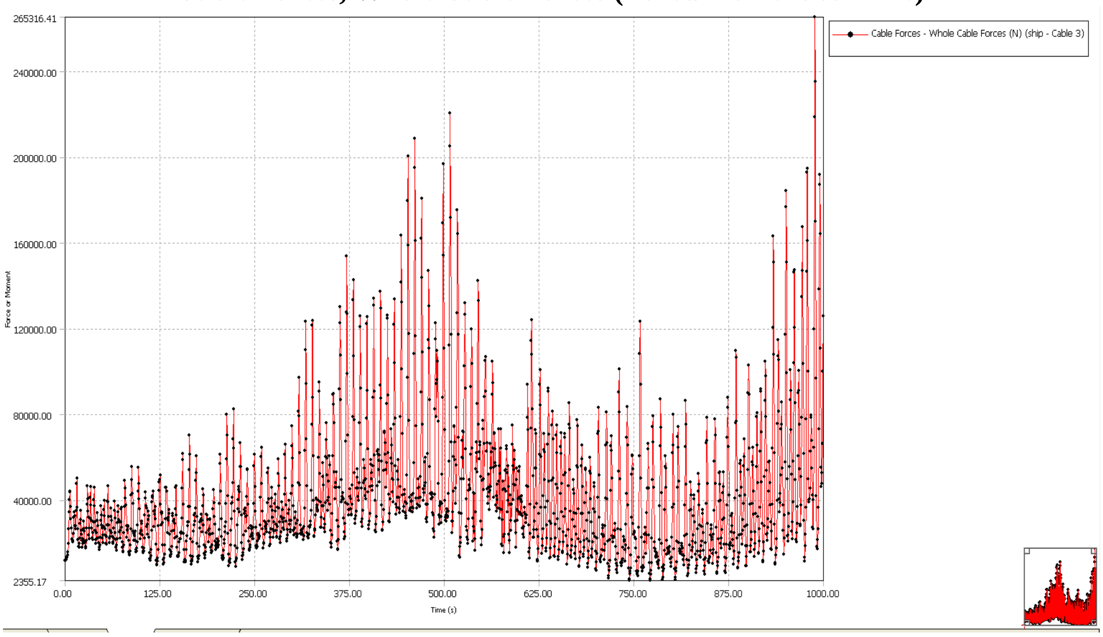
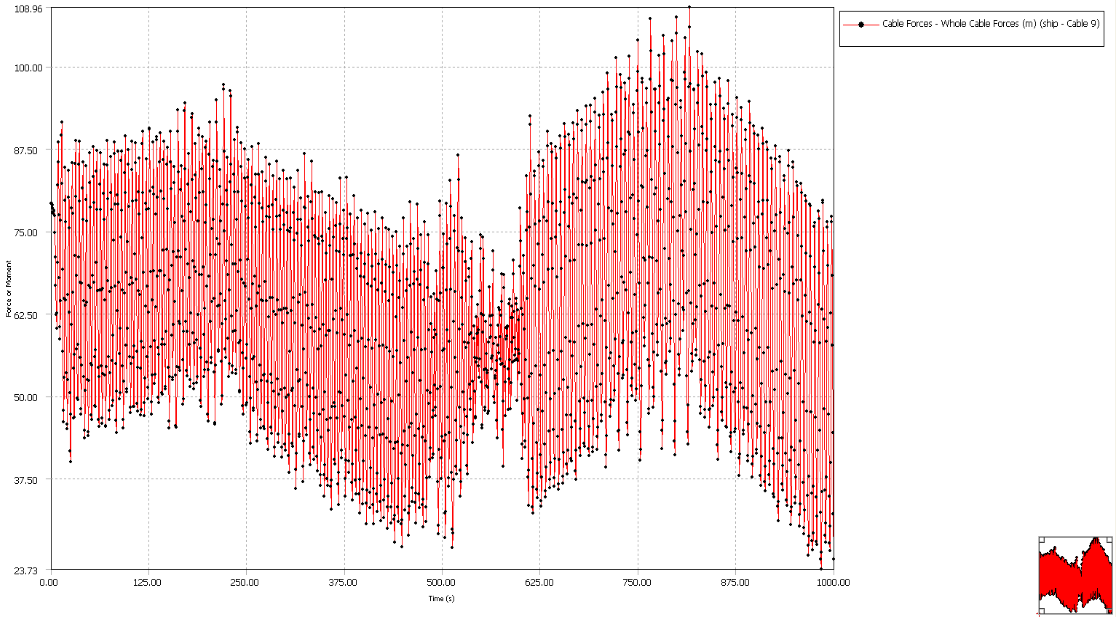


TABLE 31 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 2 (D4) > Solution (D5) > Hydrodynamic Graph Results

Object Name	*Cable Forces, Whole Cable Forces (Force/Moment vs Time)*
State	Solved
Details of Cable Forces, Whole Cable Forces (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Laid Length
Connection	Cable 9
Position of Min in X	984
Position of Max in X	815.5
Minimum Value	23.731
Maximum Value	108.959

FIGURE 5 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 2 (D4) > Solution (D5) > Cable Forces, Whole Cable Forces (Force/Moment vs Time)



Hydrodynamic Time Response 3 (E4)

TABLE 32 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 3 (E4) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Time Response Specific Options	
Analysis Type	Irregular Wave Response with Slow Drift
Start Time	0 s
Time Step	0.5 s
Number of Steps	2001
Finish Time	1000 s
Starting Position	Program Controlled
Use Cable Dynamics	Yes

TABLE 33 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 3 (E4) > Current

Depth (m)	Velocity (m/s)	Direction (°)
10	1.1	165

TABLE 34 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 3 (E4) > Wind

Object Name	*Wind*
State	Fully Defined
Wind Spectral Definition	
Spectra	ISO
Reference Height	10 m
Speed	33.7 m/s
Direction	165 °

TABLE 35 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 3 (E4) > Irregular Wave

Object Name	*Irregular Wave*
State	Fully Defined
Wave Spectrum Details	
Wave Type	Pierson-Moskowitz
Direction of Spectrum	165 °
Seed Definition	Program Controlled
Omit Calculation of Drift Forces	No
Start Period	10.4 s
Finish Period	8 s
Significant Wave Height	7.3 m
Zero Crossing Period	8.6 s

Solution (E5)

TABLE 36 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 3 (E4) > Solution (E5) > Hydrodynamic Graph Results

Object Name	*Cable Forces, Whole Cable Forces (Force/Moment vs Time)*
State	Solved
Details of Cable Forces, Whole Cable Forces (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 2
Position of Min in X	215
Position of Max in X	227
Minimum Value	2149594.75
Maximum Value	7867353.5
Line B	
Structure	ship

Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 3
Position of Min in X	771.5
Position of Max in X	458.5
Minimum Value	3246998.25
Maximum Value	8807521
Line C	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 4
Position of Min in X	12
Position of Max in X	769.5
Minimum Value	3043977.75
Maximum Value	8072940.5
Line D	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 5
Position of Min in X	215
Position of Max in X	20.5
Minimum Value	2144270.75
Maximum Value	7281257.5

FIGURE 6 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 3 (E4) > Solution (E5) > Cable Forces, Whole Cable Forces (Force/Moment vs Time)

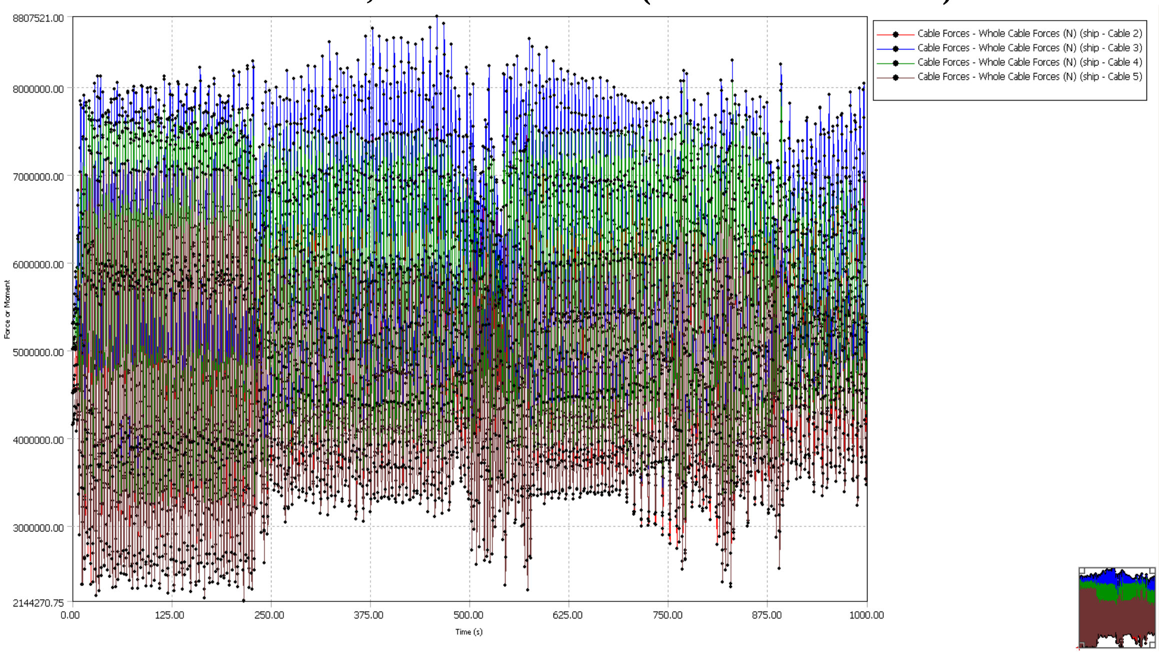
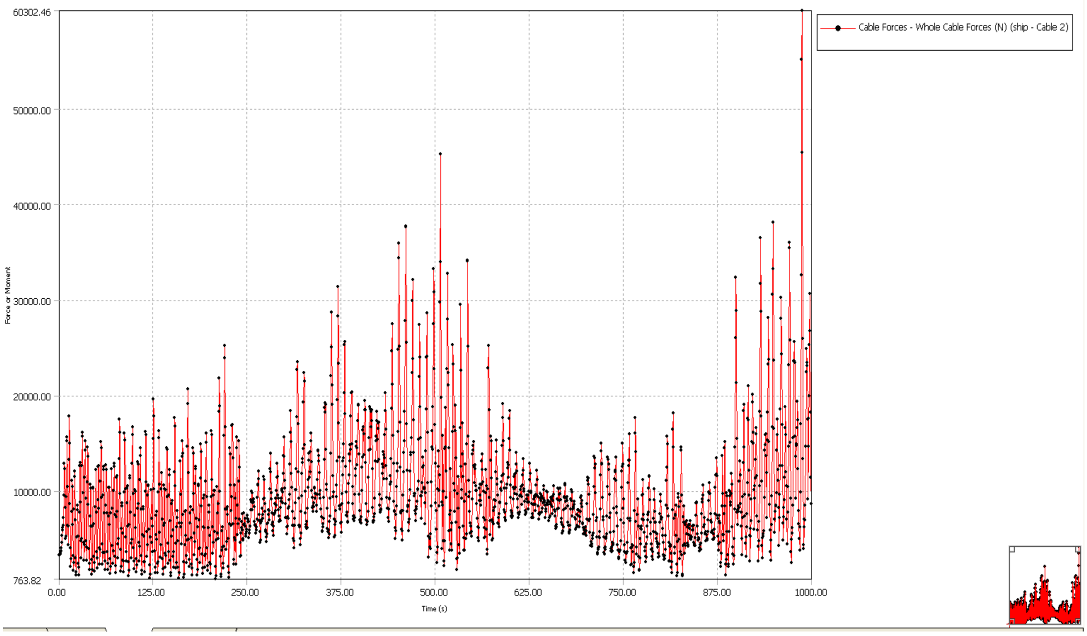


TABLE 37 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 3 (E4) > Solution (E5) > Hydrodynamic Graph Results

Object Name	*Cable Forces, Whole Cable Forces (Force/Moment vs Time)*
State	Solved
Details of Cable Forces, Whole Cable Forces (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Anchor Uplift
Connection	Cable 2
Position of Min in X	208
Position of Max in X	987.5
Minimum Value	763.82
Maximum Value	60302.461

FIGURE 7 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 3 (E4) > Solution (E5) > Cable Forces, Whole Cable Forces (Force/Moment vs Time)



Hydrodynamic Time Response 4 (F4)

TABLE 38 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 4 (F4) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Time Response Specific Options	
Analysis Type	Irregular Wave Response with Slow Drift
Start Time	0 s
Time Step	0.5 s
Number of Steps	2001
Finish Time	1000 s
Starting Position	Program Controlled
Use Cable Dynamics	Yes

TABLE 39 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 4 (F4) > Current

Depth (m)	Velocity (m/s)	Direction (°)
10	1.1	180

TABLE 40 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 4 (F4) > Wind

Object Name	*Wind*
State	Fully Defined
Wind Spectral Definition	
Spectra	ISO
Reference Height	10 m
Speed	33.7 m/s
Direction	180 °

TABLE 41 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 4 (F4) > Irregular Wave

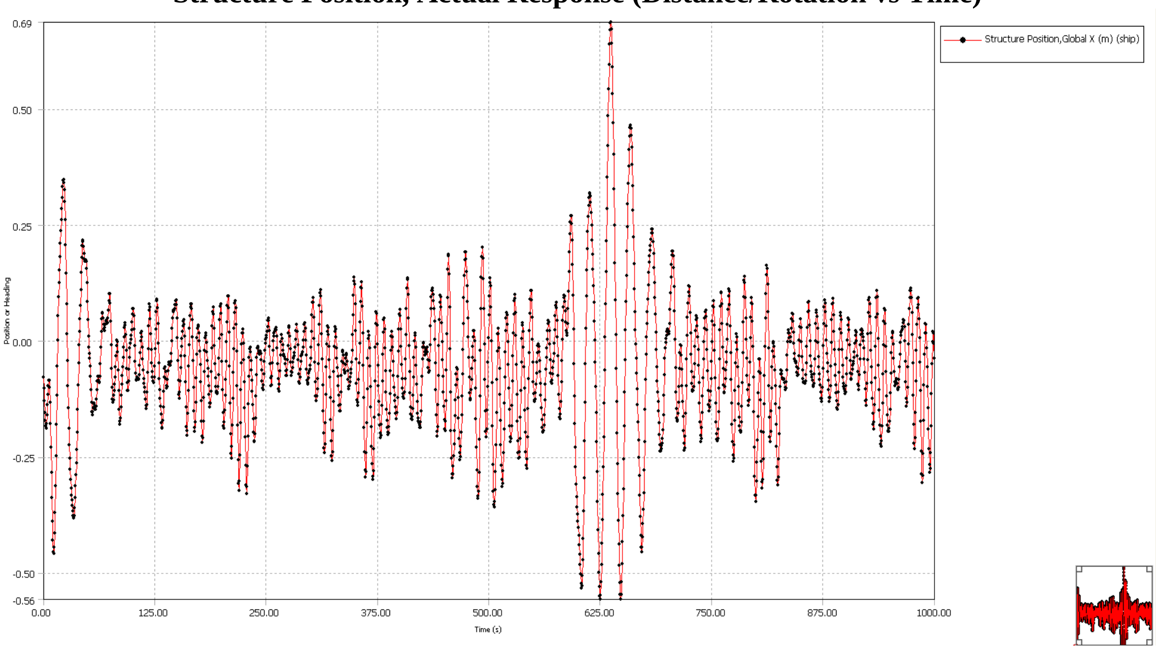
Object Name	*Irregular Wave*
State	Fully Defined
Wave Spectrum Details	
Wave Type	Pierson-Moskowitz
Direction of Spectrum	180 °
Seed Definition	Program Controlled
Omit Calculation of Drift Forces	No
Start Period	10.4 s
Finish Period	8 s
Significant Wave Height	7.3 m
Zero Crossing Period	8.6 s

Solution (F5)

TABLE 42 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 4 (F4) > Solution (F5) > Hydrodynamic Graph Results

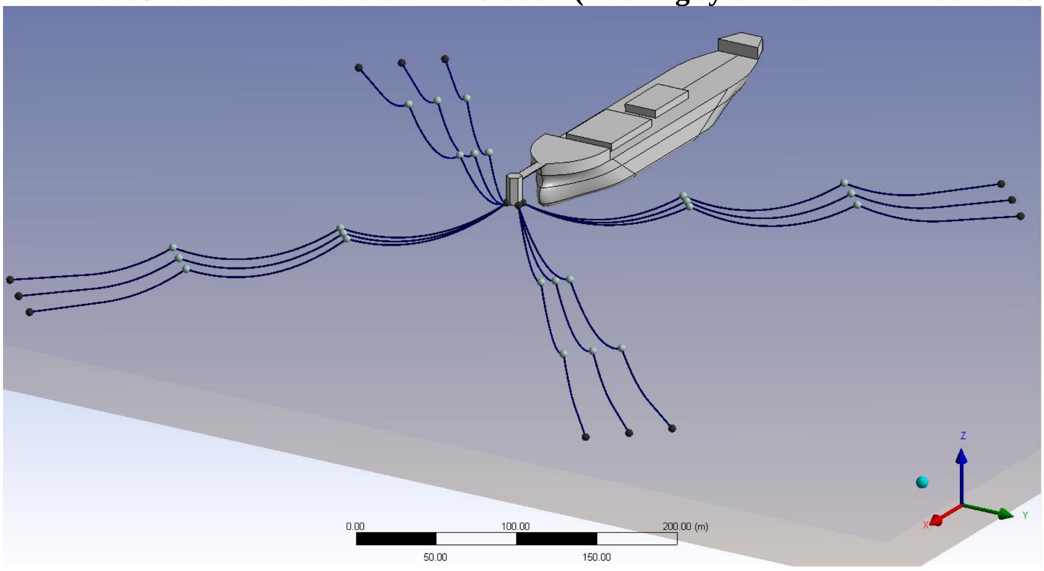
Object Name	*Structure Position, Actual Response (Distance/Rotation vs Time)*
State	Solved
Details of Structure Position, Actual Response (Distance/Rotation vs Time)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Time
Line A	
Structure	ship
Type	Structure Position
SubType	Actual Response
Component	Global X
Position of Min in X	625
Position of Max in X	637
Minimum Value	-0.557
Maximum Value	0.687

FIGURE 8 - Model (B3, C3, D3, E3, F3) > Hydrodynamic Time Response 4 (F4) > Solution (F5) > Structure Position, Actual Response (Distance/Rotation vs Time)



Appendix F – Simulation of 100% Loaded Moored Vessel (Mooring System with 12 Lines and Buoys)

Figure 1 - 100% loaded moored vessel simulation (mooring system with 12 lines and buoys)



Hydrodynamic Time Response (C4)

TABLE 1 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response (C4) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Details of Analysis Settings	
Time Response Specific Options	
Analysis Type	Irregular Wave Response with Slow Drift
Start Time	0 s
Time Step	0.5 s
Number of Steps	7201
Finish Time	3600 s
Starting Position	Program Controlled
Use Cable Dynamics	Yes

TABLE 2 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response (C4) > Current

Depth (m)	Velocity (m/s)	Direction (°)
10	1.1	135

TABLE 3 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response (C4) > Irregular Wave

Object Name	*Irregular Wave*
State	Fully Defined
Wave Spectrum Details	
Wave Type	Pierson-Moskowitz
Direction of Spectrum	135 °
Seed Definition	Program Controlled
Omit Calculation of Drift Forces	Yes
Start Period	10.4 s
Finish Period	8 s
Significant Wave Height	7.3 m
Zero Crossing Period	8.6 s

TABLE 4 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response (C4) > Wind

Object Name	*Wind*
State	Fully Defined
Wind Spectral Definition	
Spectra	ISO
Reference Height	10 m
Speed	33.7 m/s
Direction	135 °

Solution (C5)

TABLE 5 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response (C4) > Solution (C5) > Hydrodynamic Graph Results

Object Name	*Cable Forces, Whole Cable Forces (Force/Moment vs Time)*
State	Solved
Details of Cable Forces, Whole Cable Forces (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 1
Position of Min in X	198.5
Position of Max in X	748.5
Minimum Value	732189.25
Maximum Value	1177783.875
Line B	
Structure	ship

Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 2
Position of Min in X	198.5
Position of Max in X	748.5
Minimum Value	716531
Maximum Value	1136857.625
Line C	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 3
Position of Min in X	198.5
Position of Max in X	748.5
Minimum Value	737649.563
Maximum Value	1172787.875
Line D	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 4
Position of Min in X	250.5
Position of Max in X	532.5
Minimum Value	729629.438
Maximum Value	1090996.25

FIGURE 2 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response (C4) > Solution (C5) > Cable Forces, Whole Cable Forces (Force/Moment vs Time)

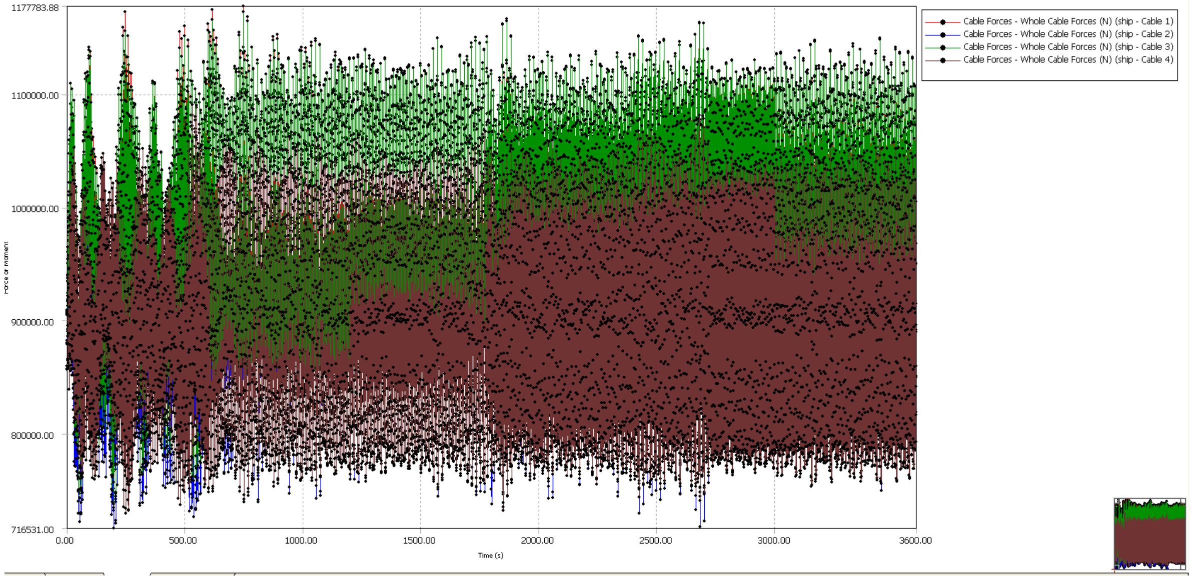
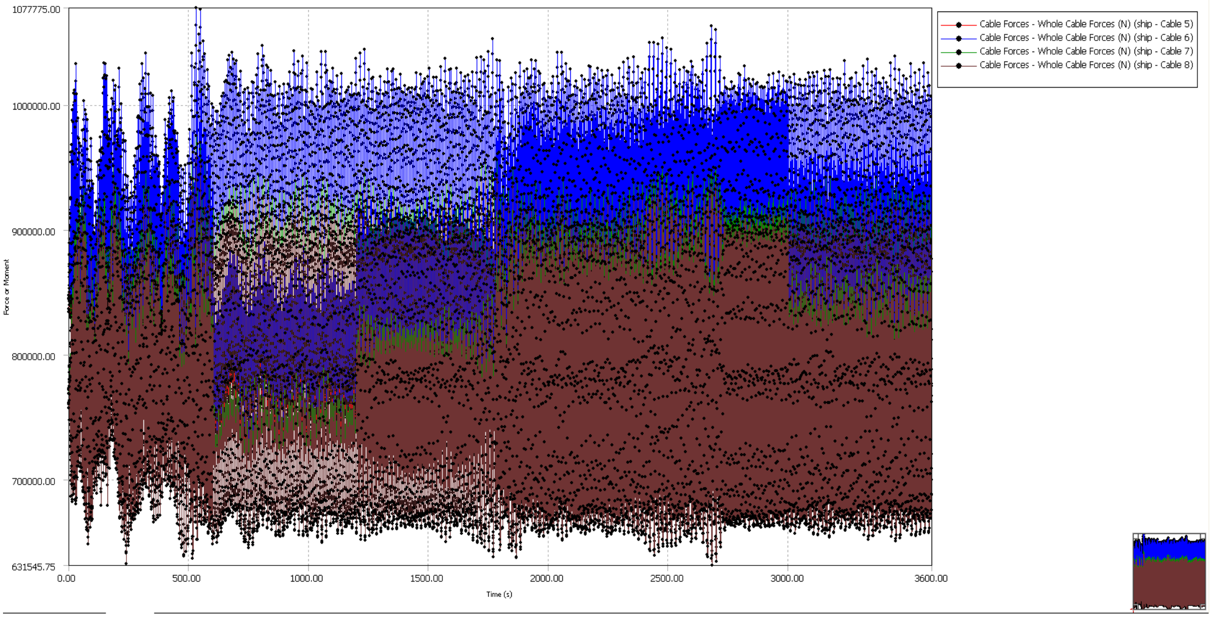


TABLE 6 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response (C4) > Solution (C5) > Hydrodynamic Graph Results

Object Name	*Cable Forces, Whole Cable Forces (Force/Moment vs Time)*
State	Solved
Details of Cable Forces, Whole Cable Forces (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 5
Position of Min in X	250.5
Position of Max in X	532.5
Minimum Value	708553.25
Maximum Value	1063951.75
Line B	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 6
Position of Min in X	250.5
Position of Max in X	532.5
Minimum Value	716979.625
Maximum Value	1077775
Line C	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 7
Position of Min in X	240
Position of Max in X	532.5
Minimum Value	642558.188
Maximum Value	975625.563
Line D	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 8
Position of Min in X	2683
Position of Max in X	532.5
Minimum Value	631545.75

Maximum Value	960648.938

FIGURE 3 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response (C4) > Solution (C5) > Cable Forces, Whole Cable Forces (Force/Moment vs Time)



Hydrodynamic Time Response 2 (D4)

TABLE 7 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 2 (D4) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Time Response Specific Options	
Analysis Type	Irregular Wave Response with Slow Drift
Start Time	0 s
Time Step	0.5 s
Number of Steps	2001
Finish Time	1000 s
Starting Position	Program Controlled
Use Cable Dynamics	Yes

TABLE 8 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 2 (D4) > Current

Depth (m)	Velocity (m/s)	Direction (°)
10	1.1	180

TABLE 9 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 2 (D4) > Wind

Object Name	*Wind*
State	Fully Defined
Wind Spectral Definition	
Spectra	ISO
Reference Height	10 m
Speed	33.7 m/s
Direction	180 °

TABLE 10 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 2 (D4) > Irregular Wave

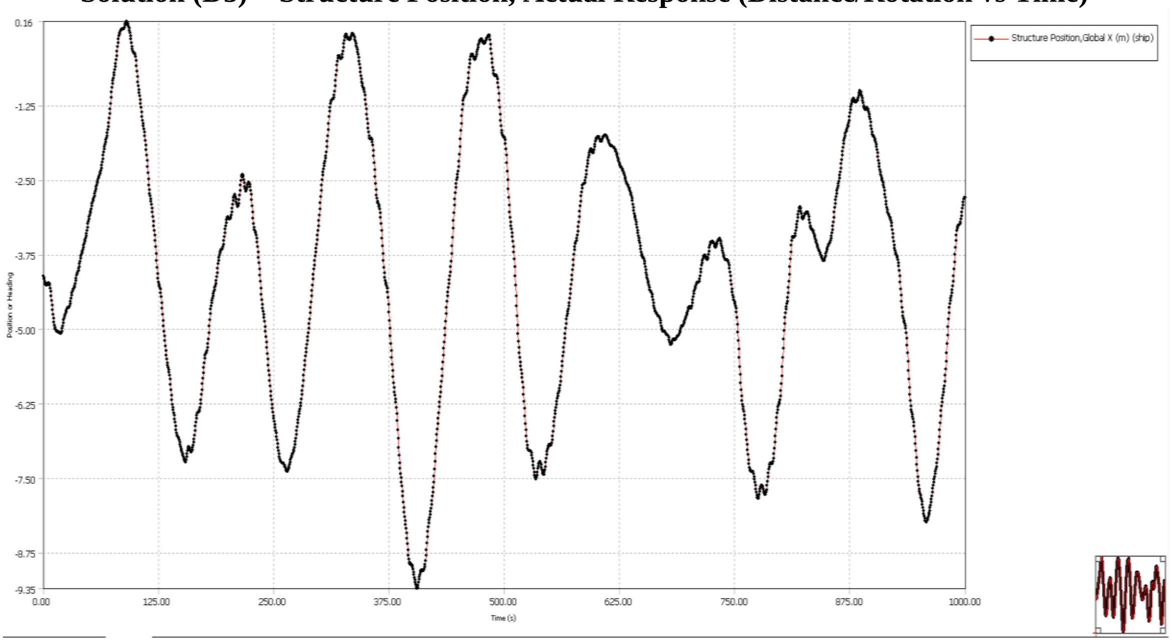
Object Name	*Irregular Wave*
State	Fully Defined
Wave Spectrum Details	
Wave Type	Pierson-Moskowitz
Direction of Spectrum	180 °
Seed Definition	Program Controlled
Omit Calculation of Drift Forces	No
Start Period	10.4 s
Finish Period	8 s
Significant Wave Height	7.3 m
Zero Crossing Period	8.6 s

Solution (D5)

TABLE 11 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 2 (D4) > Solution (D5) > Hydrodynamic Graph Results

Object Name	*Structure Position, Actual Response (Distance/Rotation vs Time)*
State	Solved
Details of Structure Position, Actual Response (Distance/Rotation vs Time)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Time
Line A	
Structure	ship
Type	Structure Position
SubType	Actual Response
Component	Global X
Position of Min in X	405.5
Position of Max in X	90
Minimum Value	-9.35
Maximum Value	0.164

FIGURE 4 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 2 (D4) > Solution (D5) > Structure Position, Actual Response (Distance/Rotation vs Time)



Hydrodynamic Time Response 3 (E4)

TABLE 12 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 3 (E4) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Time Response Specific Options	
Analysis Type	Irregular Wave Response with Slow Drift
Start Time	0 s
Time Step	0.5 s
Number of Steps	2001
Finish Time	1000 s
Starting Position	Program Controlled
Use Cable Dynamics	Yes

TABLE 13 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 3 (E4) > Current

Depth (m)	Velocity (m/s)	Direction (°)
10	1.1	150

TABLE 14 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 3 (E4) > Wind

Object Name	*Wind*
State	Fully Defined
Wind Spectral Definition	
Spectra	ISO
Reference Height	10 m
Speed	33.7 m/s
Direction	150 °

TABLE 15 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 3 (E4) > Irregular Wave

Object Name	*Irregular Wave*
State	Fully Defined
Wave Spectrum Details	
Wave Type	Pierson-Moskowitz
Direction of Spectrum	150 °
Seed Definition	Program Controlled
Omit Calculation of Drift Forces	No
Start Period	10.4 s
Finish Period	8 s
Significant Wave Height	7.3 m
Zero Crossing Period	8.6 s

Solution (E5)

TABLE 16 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 3 (E4) > Solution (E5) > Hydrodynamic Graph Results

Object Name	*Cable Forces, Whole Cable Forces (Force/Moment vs Time)*
State	Solved
Details of Cable Forces, Whole Cable Forces (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 2
Position of Min in X	280.5
Position of Max in X	353.5
Minimum Value	696593.313
Maximum Value	1804370.875

Line B	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 4
Position of Min in X	356
Position of Max in X	401.5
Minimum Value	691478.25
Maximum Value	1087360.875
Line C	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 5
Position of Min in X	356
Position of Max in X	401.5
Minimum Value	660240.875
Maximum Value	1043773.75

FIGURE 5 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 3 (E4) > Solution (E5) > Cable Forces, Whole Cable Forces (Force/Moment vs Time)

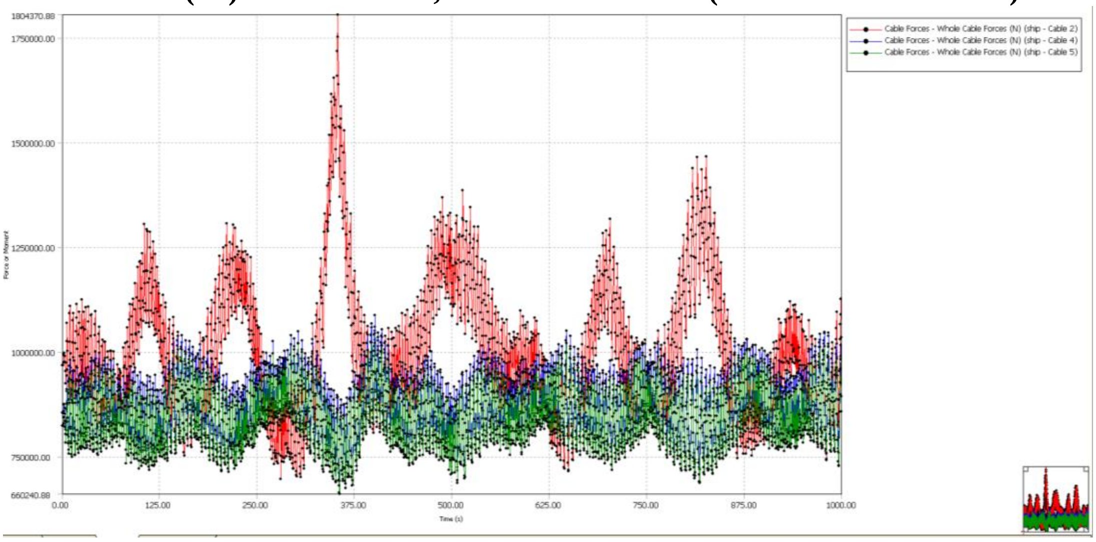
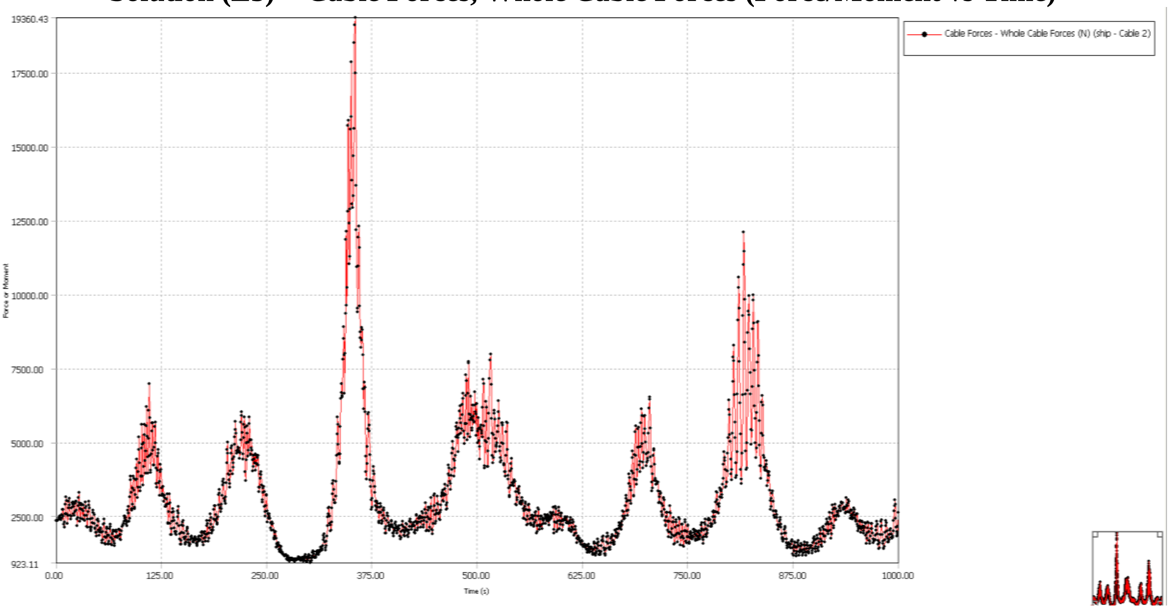


TABLE 17 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 3 (E4) > Solution (E5) > Hydrodynamic Graph Results

Object Name	*Cable Forces, Whole Cable Forces (Force/Moment vs Time)*
State	Solved
Details of Cable Forces, Whole Cable Forces (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Anchor Uplift
Connection	Cable 2
Position of Min in X	302
Position of Max in X	355
Minimum Value	923.113
Maximum Value	19360.43

FIGURE 6 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 3 (E4) > Solution (E5) > Cable Forces, Whole Cable Forces (Force/Moment vs Time)



Hydrodynamic Time Response 4 (F4)

TABLE 18 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 4 (F4) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Time Response Specific Options	
Analysis Type	Irregular Wave Response with Slow Drift
Start Time	0 s
Time Step	0.5 s
Number of Steps	2001
Finish Time	1000 s
Starting Position	Program Controlled
Use Cable Dynamics	Yes

TABLE 19 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 4 (F4) > Current

Depth (m)	Velocity (m/s)	Direction (°)
10	1.1	165

TABLE 20 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 4 (F4) > Wind

Object Name	*Wind*
State	Fully Defined
Wind Spectral Definition	
Spectra	ISO
Reference Height	10 m
Speed	33.7 m/s
Direction	165 °

TABLE 21 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 4 (F4) > Irregular Wave

Object Name	*Irregular Wave*
State	Fully Defined
Wave Spectrum Details	
Wave Type	Pierson-Moskowitz
Direction of Spectrum	165 °
Seed Definition	Program Controlled
Omit Calculation of Drift Forces	No
Start Period	10.4 s
Finish Period	8 s
Significant Wave Height	7.3 m
Zero Crossing Period	8.6 s

Solution (F5)

TABLE 22 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 4 (F4) > Solution (F5) > Hydrodynamic Graph Results

Object Name	*Cable Forces, Whole Cable Forces (Force/Moment vs Time)*
State	Solved
Details of Cable Forces, Whole Cable Forces (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 2
Position of Min in X	460.5
Position of Max in X	497
Minimum Value	621974.875
Maximum Value	2041119.75
Line B	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 3
Position of Min in X	460.5
Position of Max in X	496.5
Minimum Value	640306.063
Maximum Value	2047546.25
Line C	
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 4
Position of Min in X	378.5
Position of Max in X	428.5
Minimum Value	612156
Maximum Value	1146978.75
Line D	
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 5
Position of Min in X	378.5
Position of Max in X	428.5
Minimum Value	588033.188
Maximum Value	1107191.125

FIGURE 7 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 4 (F4) > Solution (F5) > Cable Forces, Whole Cable Forces (Force/Moment vs Time)

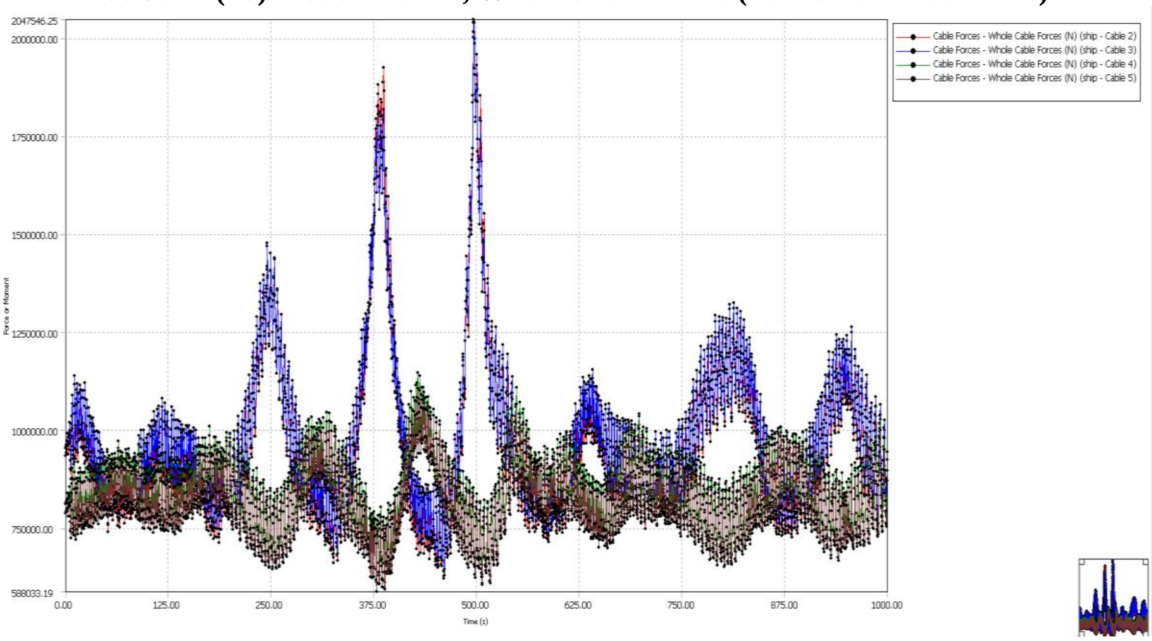


TABLE 23 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 4 (F4) > Solution (F5) > Hydrodynamic Graph Results

Object Name	*Cable Forces, Whole Cable Forces (Force/Moment vs Time)*
State	Solved
Details of Cable Forces, Whole Cable Forces (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Anchor Uplift
Connection	Cable 3
Position of Min in X	455.5
Position of Max in X	497.5
Minimum Value	582.978
Maximum Value	35001.512

FIGURE 8 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 4 (F4) > Solution (F5) > Cable Forces, Whole Cable Forces (Force/Moment vs Time)

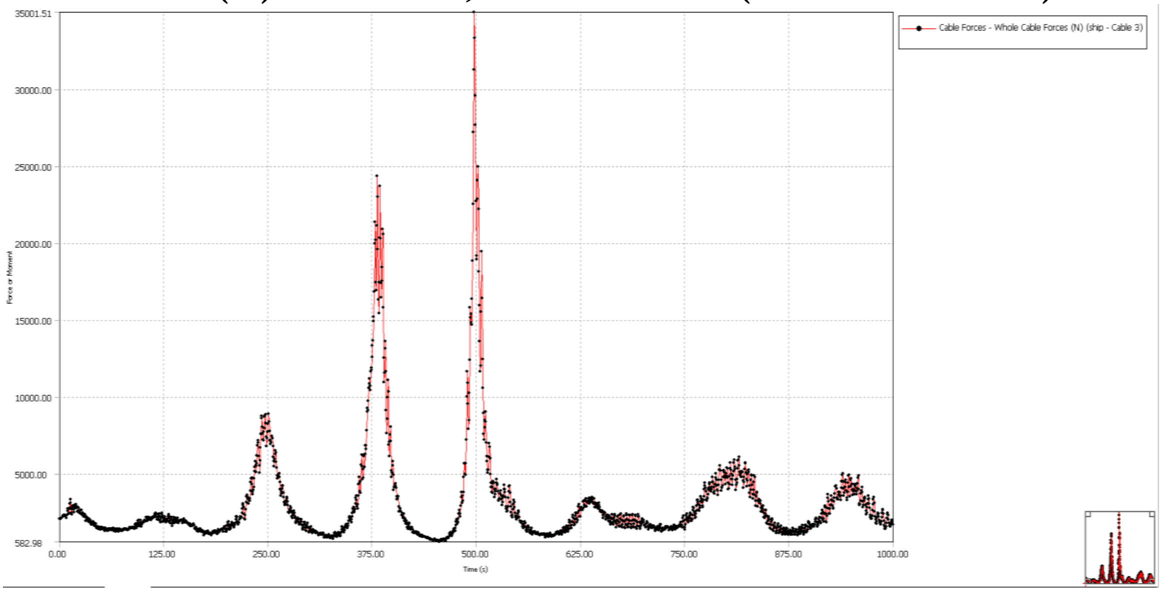
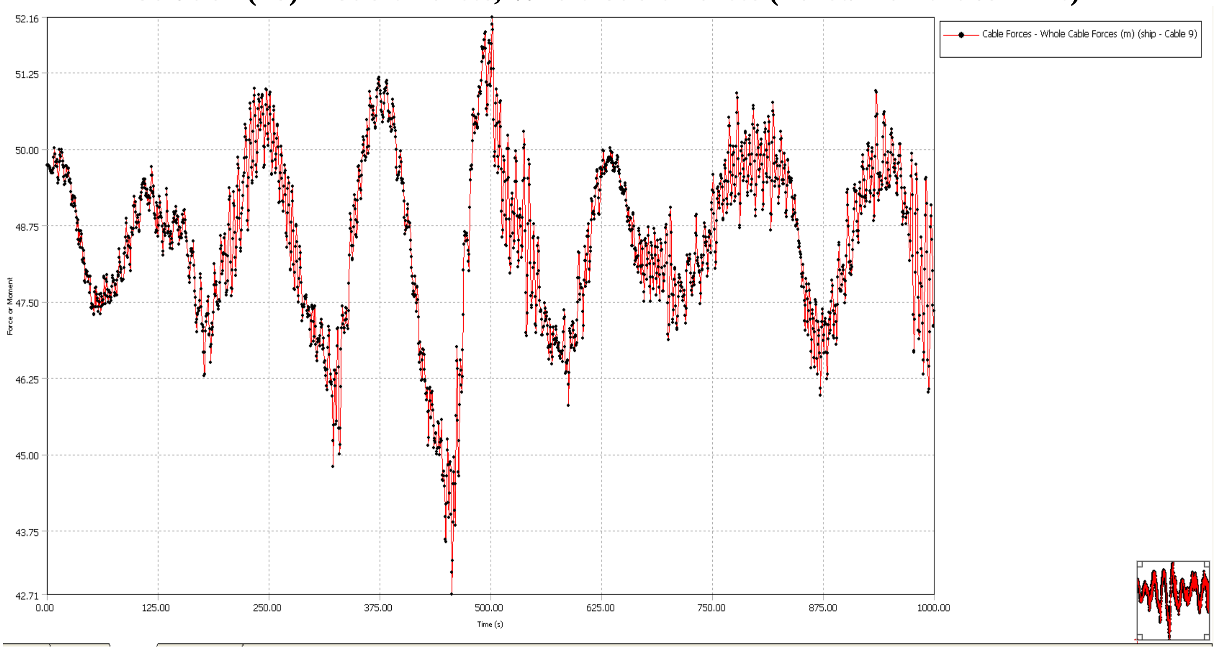


TABLE 24 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 4 (F4) > Solution (F5) > Hydrodynamic Graph Results

Object Name	*Cable Forces, Whole Cable Forces (Force/Moment vs Time)*
State	Solved
Details of Cable Forces, Whole Cable Forces (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Laid Length
Connection	Cable 9
Position of Min in X	456.5
Position of Max in X	502
Minimum Value	42.711
Maximum Value	52.156

FIGURE 9 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 4 (F4) > Solution (F5) > Cable Forces, Whole Cable Forces (Force/Moment vs Time)



Hydrodynamic Time Response 5 (G4)

TABLE 25 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 5 (G4) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Time Response Specific Options	
Analysis Type	Irregular Wave Response with Slow Drift
Start Time	0 s
Time Step	0.5 s
Number of Steps	2001
Finish Time	1000 s
Starting Position	Program Controlled
Use Cable Dynamics	Yes

TABLE 26 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 5 (G4) > Current

Depth (m)	Velocity (m/s)	Direction (°)
10	1.1	135

TABLE 27 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 5 (G4) > Wind

Object Name	*Wind*
State	Fully Defined
Wind Spectral Definition	
Spectra	ISO
Reference Height	10 m
Speed	33.7 m/s
Direction	135 °

TABLE 28 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 5 (G4) > Irregular Wave

Object Name	*Irregular Wave*
State	Fully Defined
Wave Spectrum Details	
Wave Type	Pierson-Moskowitz
Direction of Spectrum	135 °
Seed Definition	Program Controlled
Omit Calculation of Drift Forces	No
Start Period	10.4 s
Finish Period	8 s
Significant Wave Height	7.3 m
Zero Crossing Period	8.6 s

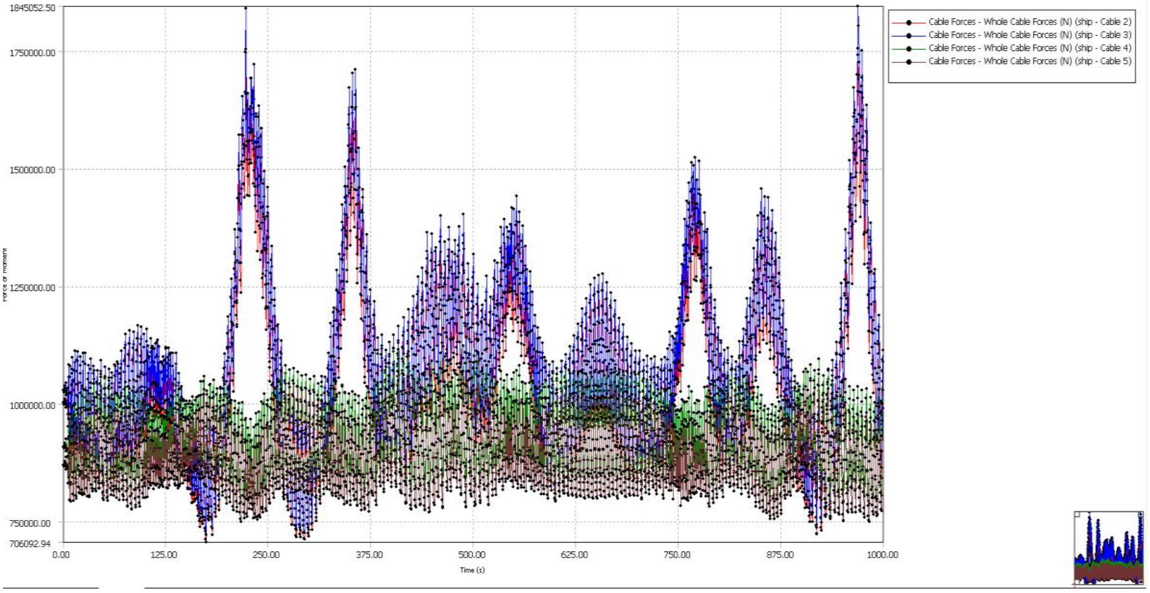
Solution (G5)

TABLE 29 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 5 (G4) > Solution (G5) > Hydrodynamic Graph Results

Object Name	*Cable Forces, Whole Cable Forces (Force/Moment vs Time)*
State	Solved
Details of Cable Forces, Whole Cable Forces (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 2
Position of Min in X	174
Position of Max in X	222.5
Minimum Value	706092.938
Maximum Value	1746892.75
Line B	

Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 3
Position of Min in X	174
Position of Max in X	969.5
Minimum Value	721627.938
Maximum Value	1845052.5
Line C	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 4
Position of Min in X	936
Position of Max in X	488
Minimum Value	788163.438
Maximum Value	1123374.5
Line D	
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 5
Position of Min in X	216.5
Position of Max in X	403
Minimum Value	748827.063
Maximum Value	1069031.5

FIGURE 10 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 5 (G4) > Solution (G5) > Cable Forces, Whole Cable Forces (Force/Moment vs Time)



Hydrodynamic Time Response 6 (H4)

TABLE 30 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 6 (H4) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Time Response Specific Options	
Analysis Type	Irregular Wave Response with Slow Drift
Start Time	0 s
Time Step	0.5 s
Number of Steps	2001
Finish Time	1000 s
Starting Position	Program Controlled
Use Cable Dynamics	Yes

TABLE 31 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 6 (H4) > Wind

Object Name	*Wind*
State	Fully Defined
Wind Spectral Definition	
Spectra	ISO
Reference Height	10 m
Speed	33.7 m/s
Direction	180 °

TABLE 32 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 6 (H4) > Current

Depth (m)	Velocity (m/s)	Direction (°)
10	1.1	180

TABLE 33 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 6 (H4) > Irregular Wave

Object Name	*Irregular Wave*
State	Fully Defined
Wave Spectrum Details	
Wave Type	Pierson-Moskowitz
Direction of Spectrum	180 °
Seed Definition	Program Controlled
Omit Calculation of Drift Forces	No
Start Period	10.4 s
Finish Period	8 s
Significant Wave Height	7.3 m
Zero Crossing Period	8.6 s

TABLE 34 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 6 (H4) > Cable Failure

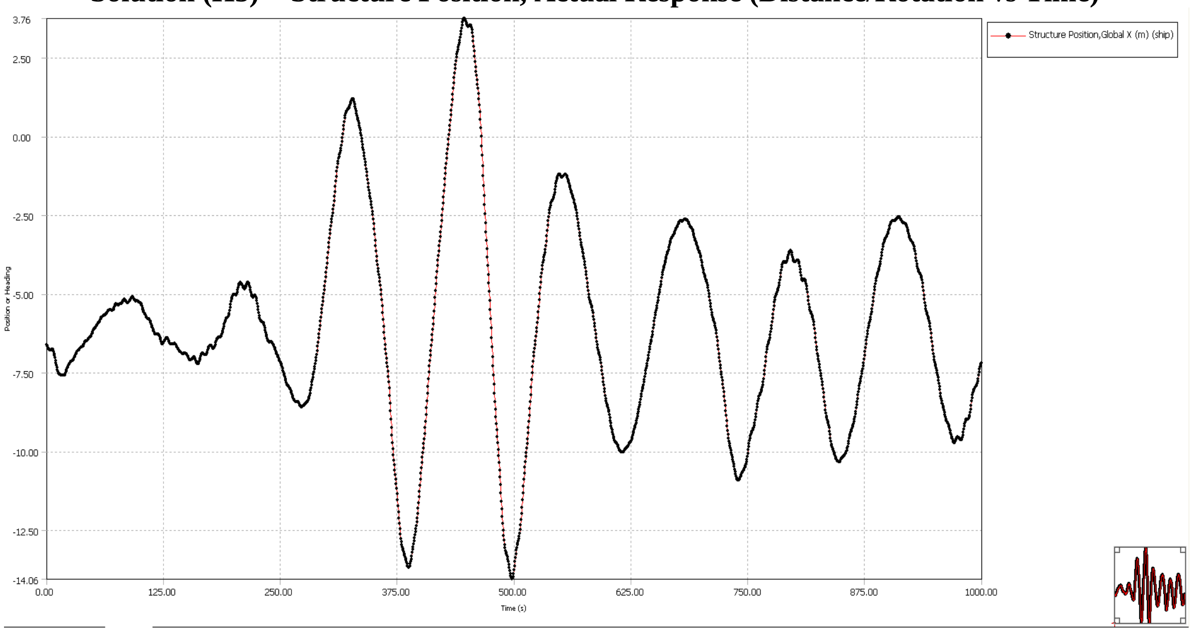
Object Name	*Cable Failure*
State	Fully Defined
Failure Definition	
Failing Cable	Cable 1
Failure Mode	At given time
Failure Time	0.5 s

Solution (H5)

TABLE 35 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 6 (H4) > Solution (H5) > Hydrodynamic Graph Results

Object Name	*Structure Position, Actual Response (Distance/Rotation vs Time)*
State	Solved
Details of Structure Position, Actual Response (Distance/Rotation vs Time)	
Presentation Method	Line
Axes Selection	Distance/Rotation vs Time
Line A	
Structure	ship
Type	Structure Position
SubType	Actual Response
Component	Global X
Position of Min in X	498
Position of Max in X	446.5
Minimum Value	-14.056
Maximum Value	3.755

FIGURE 11 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 6 (H4) > Solution (H5) > Structure Position, Actual Response (Distance/Rotation vs Time)



Hydrodynamic Time Response 7 (I4)

TABLE 36 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 7 (I4) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Time Response Specific Options	
Analysis Type	Irregular Wave Response with Slow Drift
Start Time	0 s
Time Step	0.5 s
Number of Steps	2001
Finish Time	1000 s
Starting Position	Program Controlled
Use Cable Dynamics	Yes

TABLE 37 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 7 (I4) > Current

Depth (m)	Velocity (m/s)	Direction (°)
10	1.1	165

TABLE 38 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 7 (I4) > Wind

Object Name	*Wind*
State	Fully Defined
Wind Spectral Definition	
Spectra	ISO
Reference Height	10 m
Speed	33.7 m/s
Direction	165 °

TABLE 39 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 7 (I4) > Irregular Wave

Object Name	*Irregular Wave*
State	Fully Defined
Wave Spectrum Details	
Wave Type	Pierson-Moskowitz
Direction of Spectrum	0 °
Seed Definition	Program Controlled
Omit Calculation of Drift Forces	No
Start Period	10.4 s
Finish Period	8 s
Significant Wave Height	7.3 m
Zero Crossing Period	8.6 s

TABLE 40 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 7 (I4) > Cable Failure

Object Name	*Cable Failure*
State	Fully Defined
Failure Definition	
Failing Cable	Cable 3
Failure Mode	At given time
Failure Time	0.5 s

Solution (I5)

TABLE 41 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 7 (I4) > Solution (I5) > Hydrodynamic Graph Results

Object Name	*Cable Forces, Whole Cable Forces (Force/Moment vs Time)*
State	Solved
Details of Cable Forces, Whole Cable Forces (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 2
Position of Min in X	817
Position of Max in X	859
Minimum Value	714226.125
Maximum Value	2749538.25
Line B	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Tension
Connection	Cable 4
Position of Min in X	94
Position of Max in X	959
Minimum Value	717051.688
Maximum Value	1187481.5

FIGURE 12 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 7 (I4) > Solution (I5) > Cable Forces, Whole Cable Forces (Force/Moment vs Time)

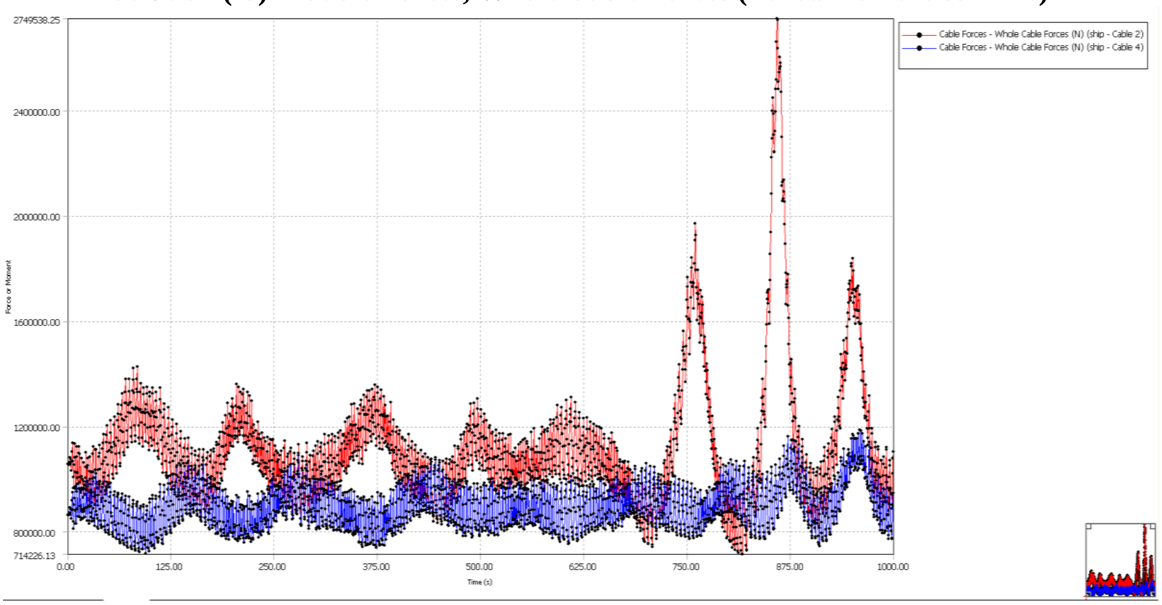


TABLE 42 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 7 (I4) > Solution (I5) > Hydrodynamic Graph Results

Object Name	*Cable Forces, Whole Cable Forces (Force/Moment vs Time)*
State	Solved
Details of Cable Forces, Whole Cable Forces (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Anchor Uplift
Connection	Cable 2
Position of Min in X	813
Position of Max in X	859
Minimum Value	972.507
Maximum Value	84009.844

FIGURE 13 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 7 (I4) > Solution (I5) > Cable Forces, Whole Cable Forces (Force/Moment vs Time)

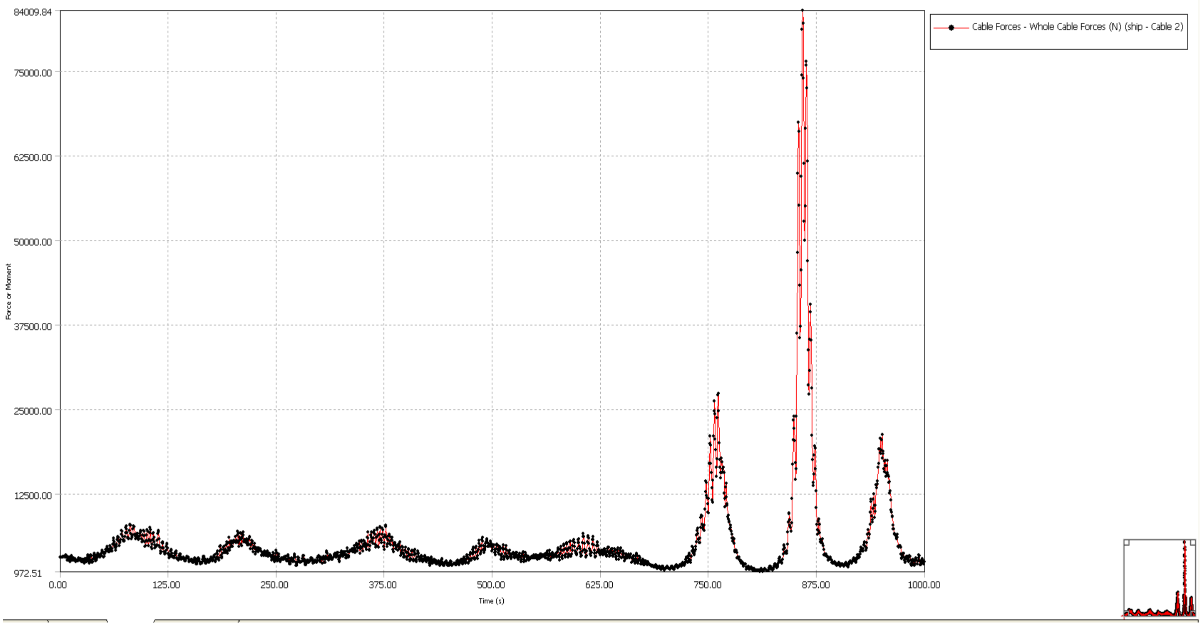


TABLE 43 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 7 (I4) > Solution (I5) > Hydrodynamic Graph Results

Object Name	*Cable Forces, Whole Cable Forces (Force/Moment vs Time)*
State	Solved
Details of Cable Forces, Whole Cable Forces (Force/Moment vs Time)	
Presentation Method	Line
Axes Selection	Force/Moment vs Time
Line A	
Structure	ship
Type	Cable Forces
SubType	Whole Cable Forces
Component	Laid Length
Connection	Cable 8
Position of Min in X	993.5
Position of Max in X	75.5
Minimum Value	43.101
Maximum Value	51.8

FIGURE 14 - Model (B3, C3, D3, E3, F3, G3, H3,) > Hydrodynamic Time Response 7 (I4) > Solution (I5) > Cable Forces, Whole Cable Forces (Force/Moment vs Time)