# DYNAMIC RESPONSE OF SPAR PLATFORM SECURED WITH MOORING SYSTEM USING ANSYS-AQWA

By

Syam Sundhara Rao

(15044)

Dissertation submitted in partial fulfillment of the requirement for the Bachelor of Engineering (Hons) Mechanical Engineering

January 2015

Universiti Teknologi PETRONAS,

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# CERTIFICATION OF APPROVAL

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Approved by:

__________________

(Ir. Dr. Mokhtar Awang)

Universiti Teknologi PETRONAS

Tronoh, Perak

January 2015

# CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and also that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(SYAM SUNDHARA RAO)

# ACKNOWLEDGEMENT

First and foremost I would like to express my most gratitude to the God Almighty for His blessings, as I managed to carry out my Final Year Project titled Dynamic Response of Spar Platform Secured with Mooring System Using Ansys-AQWA with success even though I did face several difficulties and obstruction throughout the project.

Deepest gratitude goes to Universiti Teknologi PETRONAS (UTP) for providing good facilities, the Mechanical Engineering Final Year Project coordinators for their guidance and other parties involved in making my project successful. A million of thanks to my supervisor, Ir. Dr. Mokhtar Awang as well as my co-supervisor Dr. Tamiru Alemu Lemma for their support and patience from the beginning to the end of the project. Their encouragement, advice and guidance made this project possible within the given time frame.

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# ABSTRACT

Oil and gas exploration has moved to deeper water in recent years and the type of offshore structures used are also changing. A spar has a deep draft cylindrical hull and is suitable for use in deep water regions. Since spar is a floating structure, it uses mooring lines to hold its position even though the wave and current loading will cause a motion response on the spar. To understand the motion as well as the tension loadings in the mooring lines, a dynamic analysis has been conducted in the time domain. The analysis uses a regular wave profile with 6m height and a period of 10s. The spar is secured with four mooring lines and is subjected to this wave loading and using the Linear Airy Wave Theory for computation. The forces acting on the spar and mooring lines is governed by the Morrison’s Equation. The responses of surge, heave, pitch and tension is then compared to a benchmark case obtained from previous study for validation purpose. Upon validation parametric study on the cross-sectional area of mooring lines and the number of mooring lines was performed. Simulation was performed using ANSYS AQWA finite element software and the results obtained are consistent with previous studies.

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# 1. INTRODUCTION

This research is focused on studying and understanding the dynamic response of spar platform secured with mooring lines which are being used in the oil and gas industry. The study will be helpful to the industry in various ways and will be further discussed.

## 1.1 Background

As the world's demand for fossil fuel increases, men find themselves moving into deeper water to meet the demand. With operations in deeper water regions the traditional oil platform can no longer be used and new technology is sought after. This causes more floating structure which are more economically sound to be used such as FPSO, Spar Platform, Tension Leg Platform(TLP) and many more. Malaysia's national oil company PETRONAS is also beginning to explore into deep water and have increased the use of spar platform as well as FPSO. A spar platform is a type of floating oil platform alternative that can support drilling, production and storage operations which is usually used in deep water region and are moored in place. This platform has been developed as an alternative to conventional fixed type platform. A spar platform consists of a large-diameter, single vertical cylinder supporting a deck. To lower the centre of gravity as well as to increase the stability of a spar platform, the cylinder is weighted at the bottom by filling the chamber with material that is denser than water. Spars are anchored to the seabed by way of a spread mooring system.

There are three types of spars, namely the original spar design, truss spars and cell spars. Consisting of a single cylindrical hull, the original design for spars was created in the mid '90s with the first developed for the Neptune field in the Gulf of Mexico. Next, the truss spar, which is similar to the original spar design, but the cylindrical hull, is shortened and a truss is incorporated below it. The truss usually includes horizontal plates that help to decrease vertical movement. The advantage of a truss spar is the cost which is far less compared to the original design because it requires less steel. This in turn also makes it lighter. The most recent variation of the spar is the cell spar, which is a scaled-down version of the original design. A cell spar has a large central cylinder surrounded by smaller cylinders of alternating lengths. At the bottom of the longer cylinders is the soft tank housing the heavy ballasting material, similar to a truss spar.

## 1.2 Problem Statement

Offshore operation involving the use of moored structure has made the study of the structures dynamic response all the more important. This is because in designing a platform, the more important question keeping in mind the economic feasibility of the place is the extent of operational downtime. The more the downtime of a platform is, the less revenue will be generated. One of the factors affecting the operational downtime is the motions of the structure or in this case the spar platform. With increasing motion, often the operations become more difficult and will slower the overall time taken. Eventually, if the motions become too large and unpredictable, the operations on the platform will have to be stopped. This will result in delay of operation. Things could get even worse when, due to occurring storm conditions, floating platform motions become so large that the risk of mooring lines will break increases. Therefore, the easiest solution to reduce the downtime one may consider bringing out more mooring lines, or pulling the vessel a bit tighter to the berth. However, this immediately raises the question of how many mooring lines to be used and how hard to pull? And if one pulls the spar platform harder, how does this affect the forces exerted in the mooring lines, is the seabed able to withstand the forces and how much motion of the vessel remains? The use of mooring lines is generally enough to contain the motion of the platform, but the location of mooring has to appropriate and also evenly distributed.

## 1.3 Objectives

To answer the questions in Section 1.2 is the primary objectives of this project are:

- To develop a finite element model of spar platform with mooring system and perform dynamic analysis.
- To assess the thickness impact of mooring lines on the tension build up in the lines.
- To investigate the relationship between the number of mooring lines and the spar motion.

## 1.4 Scope of Study

The core of a dynamic mooring analysis is formed by calculating how a floating body interacts with the environmental loads acting on it and how the loads exerted on the floating body are transferred to its mooring arrangement. This study focuses on the number on mooring lines and how will it affect the motion of the spar platform under the same environmental loads. The analysis will begin by first using two mooring lines. Eventually the number of mooring lines will be increased and it will be fixed symmetrically at the midpoint of the hull of the spar platform where the center of gravity of the structure is located. The next parametric study will include the thickness of the mooring lines and how it affects the tension build up in the mooring cables. The thickness will be varied from a minimum of 0.1 meter to 0.5 meters and the corresponding tension in the cable is reported. The height and period of the wave will be kept constant. The classic JIP spar has been chosen as spar model that will be simulated in ANSYS AQWA. This spar is chosen due to the simple modeling and the availability of data to compare the results obtained with such as the works of Islam (2011); Teng and Yang (2011). The dimensions of the spar that is modeled in ANSYS AQWA are provided in Table 3-1. All the analysis is performed using a regular wave with a height of 6m and a period of 10s. The direction of the wave is also unidirectional, where it is set to arrive from $0^{\circ}$ which parallel to the x-axis.

# 2. LITERATURE REVIEW

Oil and gas are the most widely used forms of energy that the world has ever known. To date, the discoveries of oil and gas fields have propelled and fueled the socio-economic development of the country and its people for a number of eras. With the ever increasing demand for fuel, exploration of oil and gas resources has been accelerated towards deeper waters further away from the continental shelf due to depletion of their reserve in shallow water depth.

More and more operation are going beyond the water depth of 1000m and some are also beginning to explore into ultra-deep water which has water depth of more than 3000m. As this phenomenon continues to increase in number day by day, traditional fixed types of offshore structures to explore these resources have become incongruous and companies have to resort to newer technology which better suits the new environment and is economically viable (Islam et al., 2011).

In search for new alternatives, various research have been conducted to come up with new technology that will enable mankind to tap into these reserves located in deeper water which will be more economical and suitable. Hence the exploration in deep sea conditions has resulted in development of series of flexible, compliant structures like the Tethered Buoy Tower (TBT), the Articulated Leg Platform (ALP), the Tension Leg Platform (TLP), and Spar Platform.

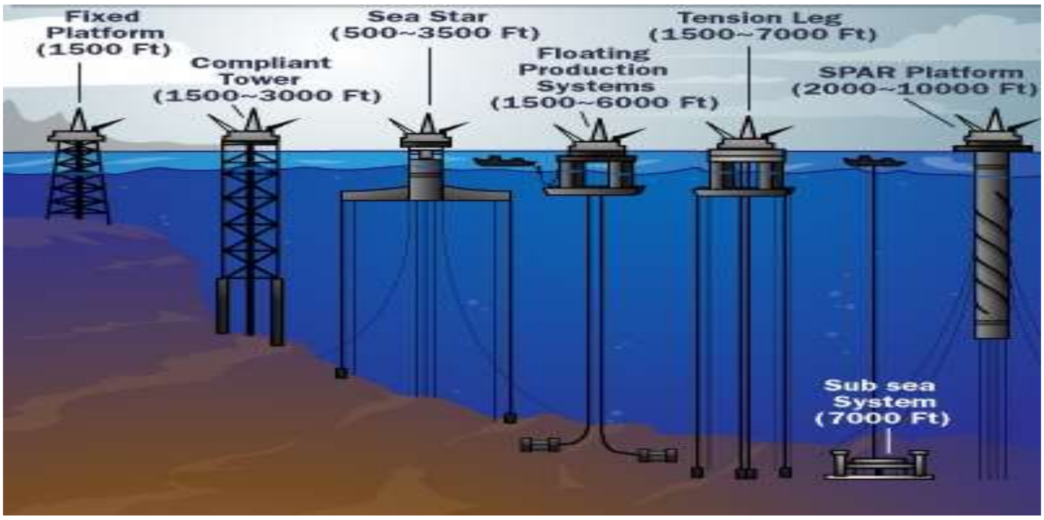


**Figure 2-1: Types of offshore production platform**

[Offshore Drilling Platform (2008)]

The need for FPSO has also increased since it is mobile and therefore can replace the need to have long pipelines for the transport of crude to the shore (Tahar and Kim, 2008). Spar platform is the latest among this new generation of compliant off-shore structures suitable for ocean drilling, production and storage of oil in deep water (Jameel, 2008).

These structures being used in deeper water are usually moored by mooring lines either to fixed structures or the seabed. Even the FPSO being used are moored to prevent the vessel or floating structure from drifting away. The primary driver for the mooring system and for the riser system is motion of the floating structure. Floating structure motions are driven by environmental forces, but are restrained by forces from the mooring and riser systems (Garett, 2005). Therefore the floating structure's motion is an important factor that determines the integrity and the stability of the moored system. The concern of this research is to determine the motion of the spar platform when subjected to hydrodynamic forces and the effect it has on the mooring lines. Parametric study such as the location of the mooring points and how it affects the spar platform's motion, the number of mooring lines suitable to be used and also the flexibility of the lines are also studied.

In performing a moored vessel dynamic analysis, traditionally computing the dynamic behaviour of a multi-component offshore structure due to environmental sea loads is a complex problem because of the inter relation between all the components. During the early phase of a project, it is a common practice to design each component of the system individually and taking into account subsystem interactions in a simplified way. This approach is usually referred to as an uncoupled analysis, in contrast to a fully coupled method wherein all the system components and their mutual interactions are computed simultaneously (Heurtier, 2001).

Kim et al. (2001a, b) showed that the conventional uncoupled or quasi-static analysis might produce unreliable results when deep water condition is selected. In the vessel motion computation, the mooring lines are represented by their corresponding stiffness's which may depend on the vessel position. These stiffness's values result from preliminary quasi-static computations. Using Finite Element Method, Static equilibrium is computed numerically while also taking into account the bending stiffness of the line. In the uncoupled analysis approach, the vessel motions are not influenced by the mooring lines and risers accelerations. The low frequency drift damping effect due to the lines is also neglected, although this phenomenon is essential to obtain accurate predictions for the roll motion and the dynamic behavior in extreme waves (Webster, 1995).

In this case, the coupled-dynamic analysis is a better choice of integrated approach so that all the interactions among platforms, mooring lines and risers can be fully evaluated. In current offshore industry, coupled dynamic analysis tools are being recommended more for deep water applications. Along this trend, Garrett (2005) has developed fully coupled dynamic analysis tools in time domain. In recent years, Kim et al. (2005) used the coupled dynamic analysis program for the global motion simulation of a turret-moored, tanker based FPSO. The numerical results are compared with the OTRC 1:60 model-testing results and they go along without much debate. Tahar and Kim (2008) developed a theory and numerical tool for coupled dynamic analysis of deep water floating platform with polyester mooring lines. In their paper, they made an extension to allow larger elongation and nonlinear stress–strain relationship, which is typical in polyester lines. Low and Langley (2008) presented a hybrid time/frequency domain approach for coupled analysis of vessel/mooring/riser. The method was found to be in good agreement with fully coupled time domain analysis, when used for relatively shallow water depths.

With all these recent studies, coupled analysis has been given much more consideration as it gives a much more accurate result due to the consideration of all the subsystems effect on one another. Such coupled effects have only recently received considerable attention, due to the large amount of CPU time required for their study. But with technology advancement and the ability of more powerful computers to complete the task within a shorter time period, coupled analysis is a better choice in conducting the dynamic analysis on vessels or any floating structure.

Generally the coupled analysis is also difficult to compute because the spar platform will have a six degree of freedom motion. Therefore the numerical method will be time consuming and a complex process. The motion of the floating structure is governed by the equation of motion:

$$\sum_{j=1}^{6} M_{kj}\ \ddot{x}_j = F_k^e$$

Where $M_{kj}$ , is the generalized mass matrix of the ship, $\ddot{x}_j$ is the generalized acceleration vector and $F_k^e$ is the external force vector.

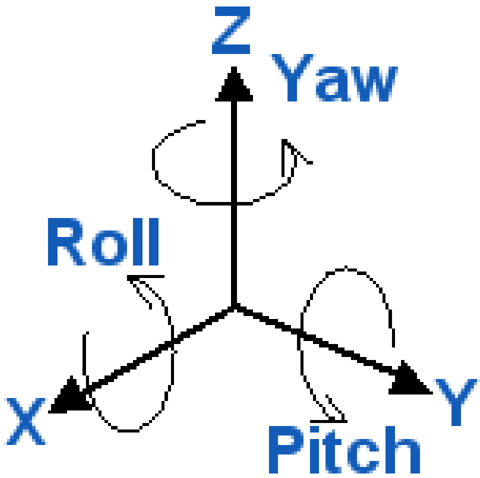


**Figure 2-2: The motions of a floating structure (6 DOF)**

In order to incorporate high degrees of non-linearities, an iterative time domain Newmark- β time integration scheme has been adopted for solving the coupled dynamic model (Islam et al., 2011). The equation of motion that describes the spar-mooring system equilibrium between inertia, damping, restoring and exciting forces can be shown as follows:

$$[M]\{\ddot{X}\} + [C]\{\dot{X}\} + [K]\{X\} = \{F(t)\}$$

Where, [M], [C] and [K] are the total mass, damping and stiffness matrices, of the spar-mooring system respectively. The 6 degrees of freedom (DOF) structural displacements are represented by {X} and the dot denotes differentiation with respect to time.

The dynamic responses of floating structures are determined by numerical method with the help of ANSYS – AQWA. ANSYS AQWA is an engineering analysis suite of tools for the investigation of the effects of wave, wind and current on floating and fixed offshore and marine structures, including spars, floating production storage and offloading (FPSO) systems, semi-submersibles, tension leg platforms (TLPs), ships, renewable energy systems and breakwater design.

To begin, a benchmark problem was selected to ensure the reliability of the programs results by performing the same problem done by Teng and Yang (2011) and checking if the results are the same before performing the selected case study for the project. Their project was selected because it was easy to understand and perform and also the dimensions are all provided for the spar model. The mechanical and geometrical property of the spar is shown in Table 3-1 and the hydrodynamic properties in Table 3-2.

In general, there are two basic approaches applicable for choosing the design wave environment of an offshore structure. Either a single wave method or wave spectrum can be used. Wave spectrum is used to represent the random sea state on a short term basis. Waves are normally in the form of random waves instead of ideal form. However, throughout this project, a single wave method or also known as regular wave is selected which is represented by a wave period and a wave height. Chakrabarti (1987) states the prediction of response of an offshore structure is generally made in regular wave because of the simplicity of the design analysis.

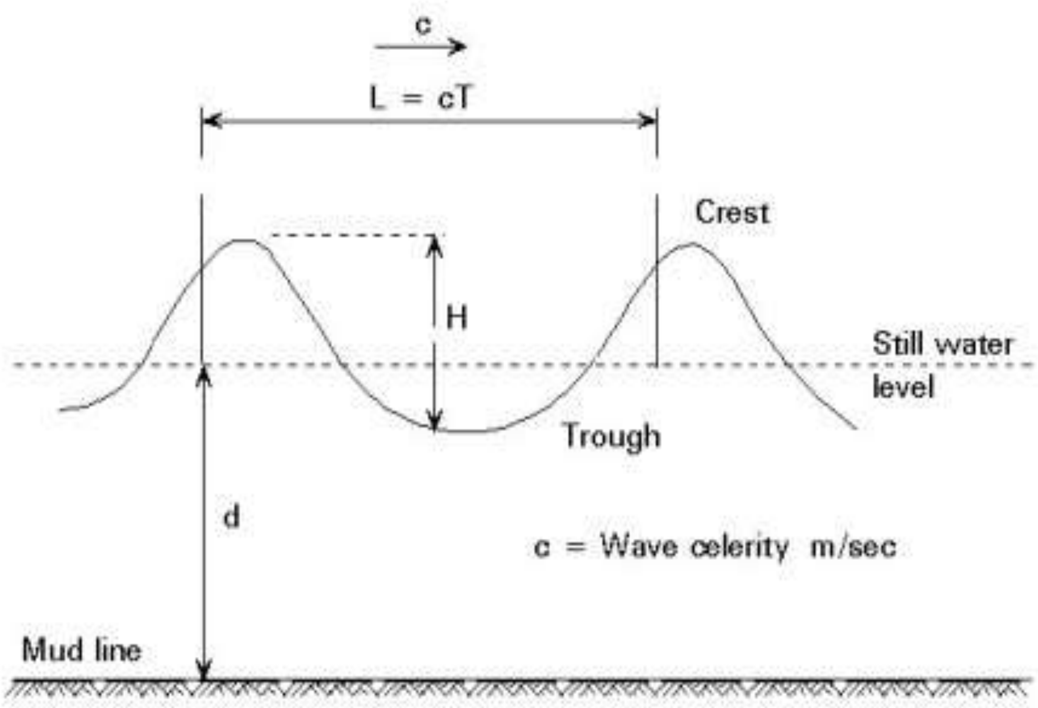


**Figure 2-3: Single wave design parameters**

**[Introduction and Environmental Loads (n.d.)]**

This simple, periodic wave propagating along the bottom may be characterized by wave height, H wave length, L and water depth, d, as shown in Figure 2-3, the highest point of the wave is crest and the lowest point is the trough. For linear or small amplitude wave, the wave height, H is the vertical distance from crest to trough. The wavelength, L is the horizontal distance between two identical points on two successive wave crests or two successive wave troughs. The time interval between two successive wave crests or troughs at a given point is the wave period, T. All these parameters are the key consideration in Linear Airy wave theory.

On the other hand, the load application on tubular members which are modeled in AQWA are handled and governed by this equation:

$$F = 0.5\rho C_d Du|u| + C_m \rho A a$$

Where:

| | | |
|---|---|---|
| F | = | Force per unit length |
| $C_d$ | = | Drag coefficient |
| ρ | = | The mass density of water |
| D | = | The member diameter |
| u | = | The instantaneous velocity resolved normal to the member |
| $C_m$ | = | The inertia coefficient |
| A | = | The cross-sectional area |
| a | = | Instantaneous acceleration resolved normal to the member |

Note: $C_m = 1 + C_a$

Where: $C_a$ is the added mass coefficient.

The user could also take into account the marine growth when inputting the diameter into the AQWA modeling.

For a more detail study on the catenary mooring lines, AQWA considers the catenary to be uniform with significant mass. A summary of the solution used in AQWA is presented where the equation expressed is in an axis system where the Z-axis is vertical. For catenaries which have zero slopes at the contact or attachment point on the seabed, we have the following equation:

$$H = AE\sqrt{\left(\frac{T}{AE}+1\right)^2 - \frac{2wZ}{AE}} - AE,$$

$$X = \frac{H}{w} sinh^{-1}\left(\frac{wL}{H}\right) + \frac{HL}{AE}$$

$$V = wL$$

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

Where:

| | | |
|---|---|---|
| L | = | Unstretched suspended length |
| w | = | Submerged weight per unit length |
| AE | = | Stiffness per length |
| X | = | Horizontal distance between fairlead point on structure to contact point on seabed |
| Z | = | Vertical distance between fairlead point on structure to contact point on seabed |
| H | = | Horizontal tension |
| V | = | Vertical tension force at the fairlead point |
| T | = | Total tension force at the fairlead point |

# 3. METHODOLOGY

The project is scheduled to be completed over a time span of two semesters or twenty eight (28) weeks. It was kick started by first selecting a project title to work on. After the selection process conducted by the course coordinator, the author was given the title Dynamic Response of Spar Platform with Mooring System using ANSYS AQWA. The projects methodology is presented in the flowchart below and the Gantt chart is included in Appendix A.

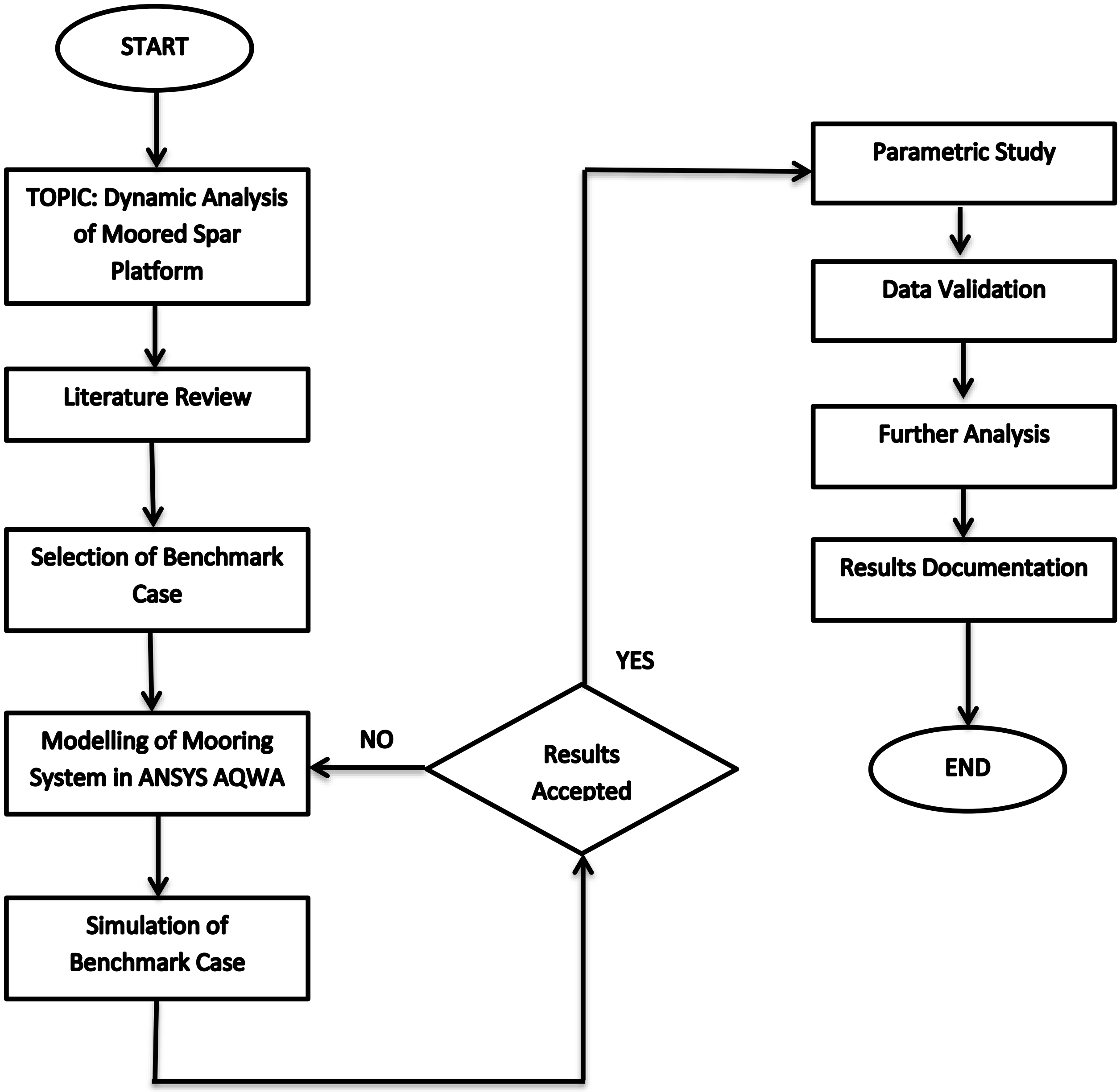


**Figure 3-1: Methodology flowchart of FYP**

To perform the dynamic analysis using ANSYS AQWA finite element software, the spar hull model is developed in the design modeler and meshed to a suitable mesh size. Next a hydrodynamic diffraction analysis is performed. During this step, the motion of the spar hull without any mooring system will be analyzed. Upon completion, the hydrodynamic time response analysis is performed. This is when the mooring system is included and analysis is performed using a wave height of 6m and a period of 10s. In hydrodynamic time response the analysis will incorporate the results from the hydrodynamic diffraction analysis completed earlier. Hence the dynamic analysis performed for this project is a coupled analysis performed in the time domain.

## 3.1 Literature Review

Literature review work involves the finding, reading, understand and comparing various existing literature on dynamic analysis of moored structures. The fundamental of the dynamic analysis, how mooring system behaves and the motion of the spar platform should be understood and studied. A new focus in the study has to be identified as well.

## 3.2 Acquisition of Benchmark Data

While various research papers have been reviewed, data for the modeling purpose was also found. The dimension of the spar platform that will be used as a benchmark case is obtained. Then the environmental forces such as wave height, current and wind speed was also gathered. For this project the research performed by B. Teng and M. D. Yang was chosen as the benchmark case and the corresponding dimensions of the spar platform are shown in Table 3-1 and Table 3-2.

**Table 3-1: Hydrodynamic properties**

| Structural element | Hydrodynamic coefficient | Value |
|---|---|---|
| Spar hull | Drag | 0.6 |
| | Inertia | 2.0 |
| | Added mass | 1.0 |
| Mooring lines | Drag | 1.0 |
| | Inertia | 2.2 |
| | Added mass | 1.2 |

**Table 3-2: Mechanical and geometrical properties of spar-mooring system**

| Element | Properties | Value |
|---|---|---|
| Spar hull | Length | 213.04 m |
| | Diameter | 40.54 m |
| | Draft | 198.12 m |
| | Mass | $2.592 \times 10^{8}$ kg |
| | Mooring point | -106.62 m |
| | Type of element | Rigid beam element |
| Mooring | Number of moorings | 4 |
| | Stiffness | $9.048 \times 10^{8}$ N |
| | Length | 600 m |
| | Mass | 79.17 kg/m |
| | Type of element | Non-linear catenary |
| | Diameter | 0.12 m |
| Sea water | Depth | 318.5 m |

## 3.3 Finite Element Modeling & Analysis

### 3.3.1 Modeling of Mooring System (Benchmark case)

Modeling work can be started once all the data required has been gathered. The model of a spar platform was modeled in ANSYS AQWA. All the mooring system was modeled as well taking into account the stiffness of the mooring lines, weight and also the pretension along the line. The model is a simple cylindrical design which resembles the hull of the spar platform. It is then modeled in two parts which is the overboard, the part which will be above the water line and the second part is the draft, the part of the hull which is submerged in the water.

The geometry for the spar model is obtained from the research paper of Teng and Yang (2011) since their paper is chosen as the benchmark case and the obtained data's are presented in Table 3-1 and Table 3-2.

The analysis on this model is performed based on the following condition and assumption:

1. The spar model is rigid beam element
2. The mass moment of inertia and the cylinder mass are defined at center of gravity
3. Non-linear catenary type element is used to model the mooring lines
4. Significant Wave Height is 6m and wave period equals 10s
5. The effect of wind is ignored
6. The wave is approaches the spar from the x-axis or considered 0 degrees

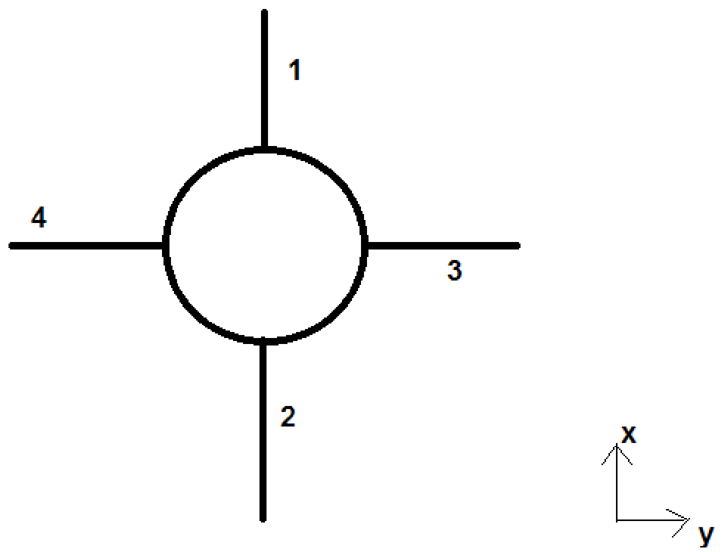


**Figure 3-2: Top view of mooring line configuration**

#### 3.3.1.1 Modeling spar hull

Calculations on the center of gravity and also the mass moment of inertia are performed, to be included as input data for the spar. The calculations are presented in the results and discussion section of this report. The spar is then modeled using the ANSYS AQWA design modeler as shown in Figure 3-3. Figure 3-4 shows the process where the input for hydrodynamic and environmental loads are performed.

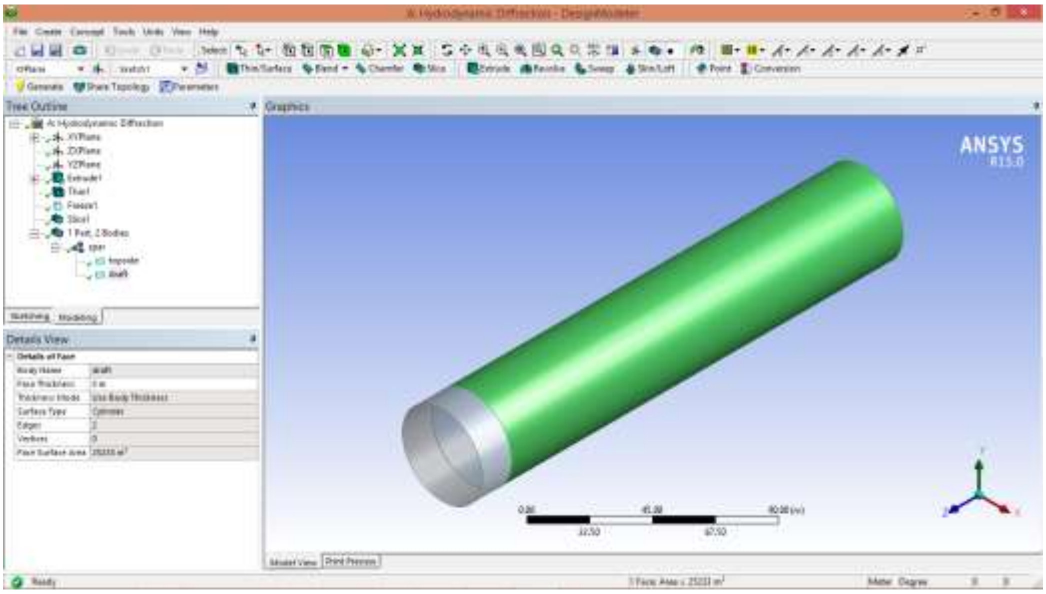

**Figure 3-3: Modeling Spar Geometry in Design Modeler**

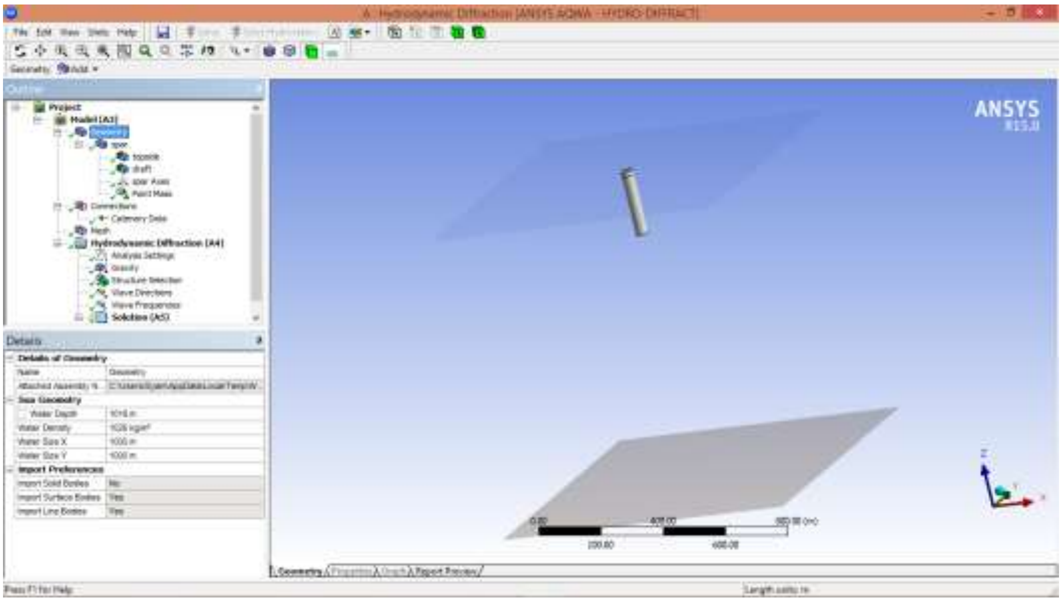

**Figure 3-4: Setting up the Hydrodynamic & Environmental Loads**

### 3.3.1.2 Hydrodynamic Diffraction

The next step would be the simulation process. The simulation of the benchmark case is performed first and the results obtained will be compared with previous works. The meshing of the model will need to be small to get a more accurate result but the duration of the simulation should also be taken into account as shown in Figure 3-5.

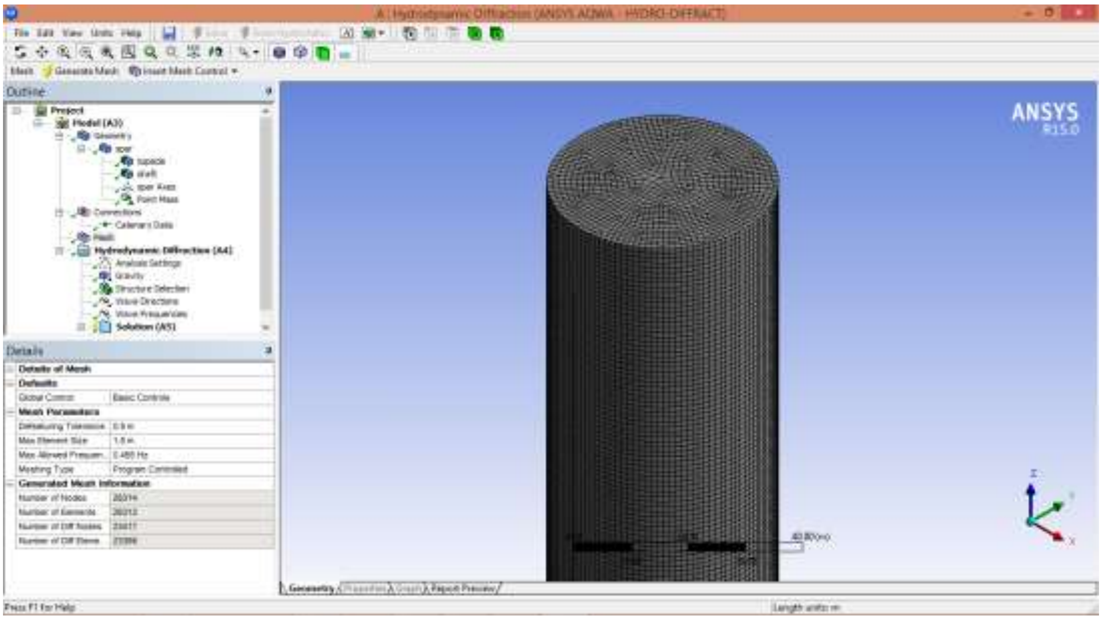


**Figure 3-5: Meshing the Spar Model**

Once meshing of the spar model has been completed, the next step would be to perform the hydrodynamic diffraction analysis on the spar. This analysis takes into account the wave height, period, and also the wave direction. Figure 3-6 shows the setting up for the hydrodynamic analysis in ANSYS AQWA.

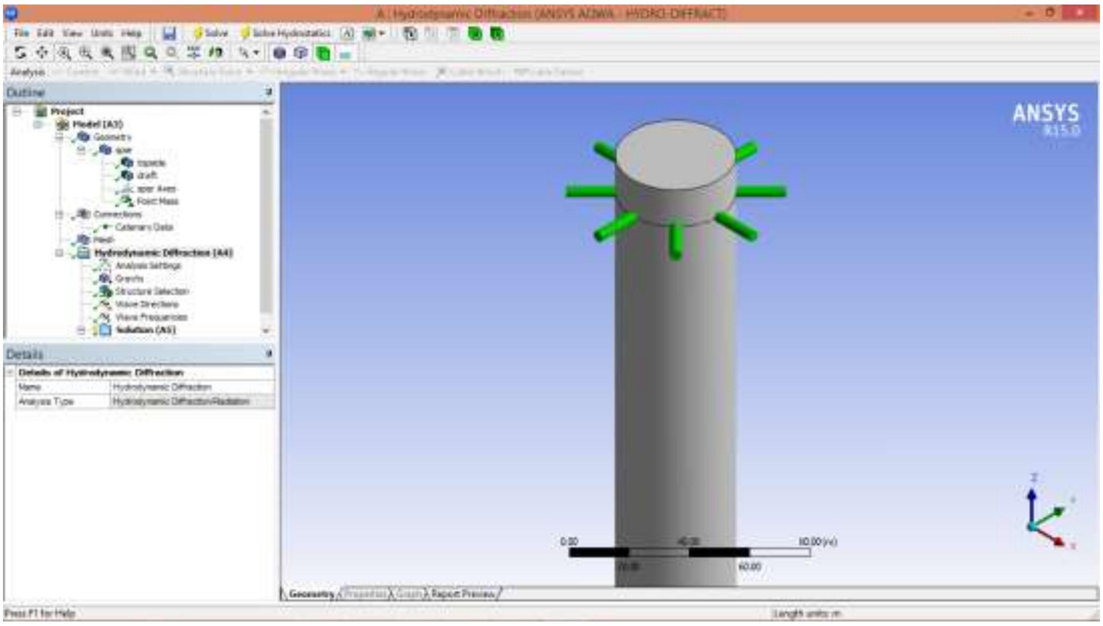


**Figure 3-6: Setting up the hydrodynamic diffraction analysis**

By performing this analysis, the motion of the spar without the presence of any mooring system will computed. The result is then incorporated in later stages when the mooring system has been completely modeled taking into account the interaction of spar hull and the mooring lines thus called coupled analysis.

#### 3.3.1.3 Including the mooring system

In this step, all the anchor location on the seabed and also the connection or fairlead point on the hull of the spar is determined in the coordinate system. The values are inserted into the program to set four fairlead locations and four anchor locations. Next the mooring lines, a non-linear catenary type is chosen and connected from the fairlead to the anchor point. Each mooring line connects only one fairlead to one anchor point. Upon completion, the spar with mooring system will be as shown in Figure 3-7.

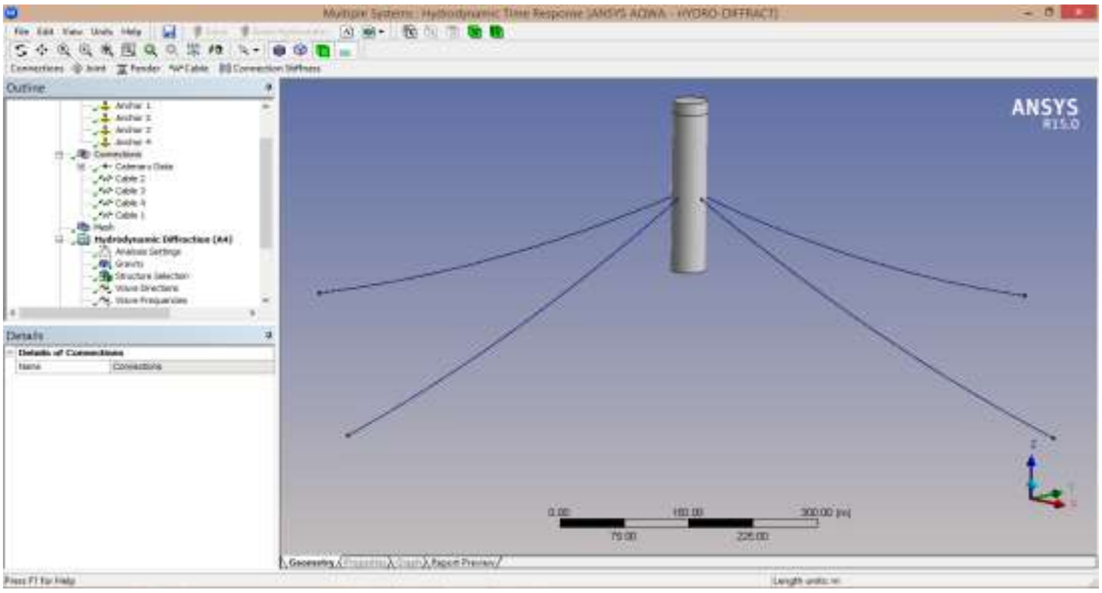


**Figure 3-7: Spar model with the mooring lines included**

#### 3.3.1.4 Hydrodynamic Time Response

Once all mooring lines have been attached, the model is set-up to undergo the hydrodynamic time response analysis. This is where the results of hydrodynamic diffraction which is performed earlier is incorporated to perform the coupled analysis of the spar taking into account the interaction of the mooring lines as well. The wave height is set at 6m and a period of 10 seconds. The direction of wave is set to come from the x-axis or 0 degrees. The simulation is performed for a total time of 1000 seconds. The setup of hydrodynamic time response analysis is shown in Figure 3-8 below.

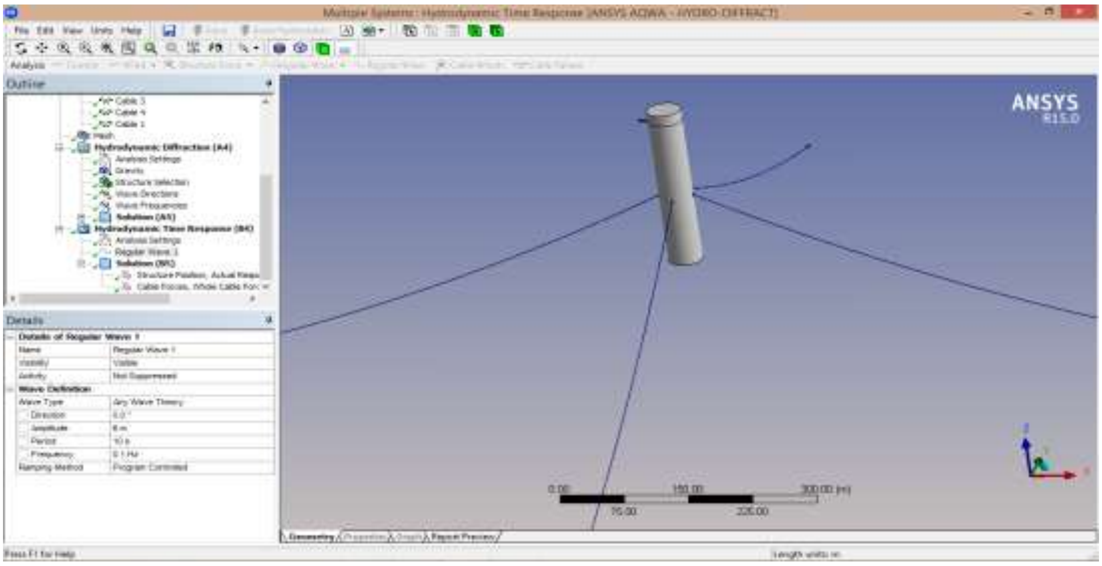


**Figure 3-8: Model set-up for the hydrodynamic time response analysis**

#### 3.3.1.5 Results and validation

From the hydrodynamic time response, the motion response of the spar is observed. The dynamic analysis of the classic JIP Spar is performed by considering motion of structure in six degrees of freedom at the COG which are surge, sway, heave, roll, yaw and pitch. However the most dominant are surge, heave and pitch while effect of the other motions are relatively small. Therefore these three responses will be taken into consideration and compared with the results obtained from the work of Teng and Yang (2011). Besides the responses, the tension in mooring lines is also one of the areas of concern. Tension values in all four mooring lines will be evaluated and discussed. Figure 3-9 shows the results window as shown in ANSYS AQWA and the required results will be extracted. The results should be comparable and as close as possible with the papers results to validate the model of spar in ANSYS AQWA.

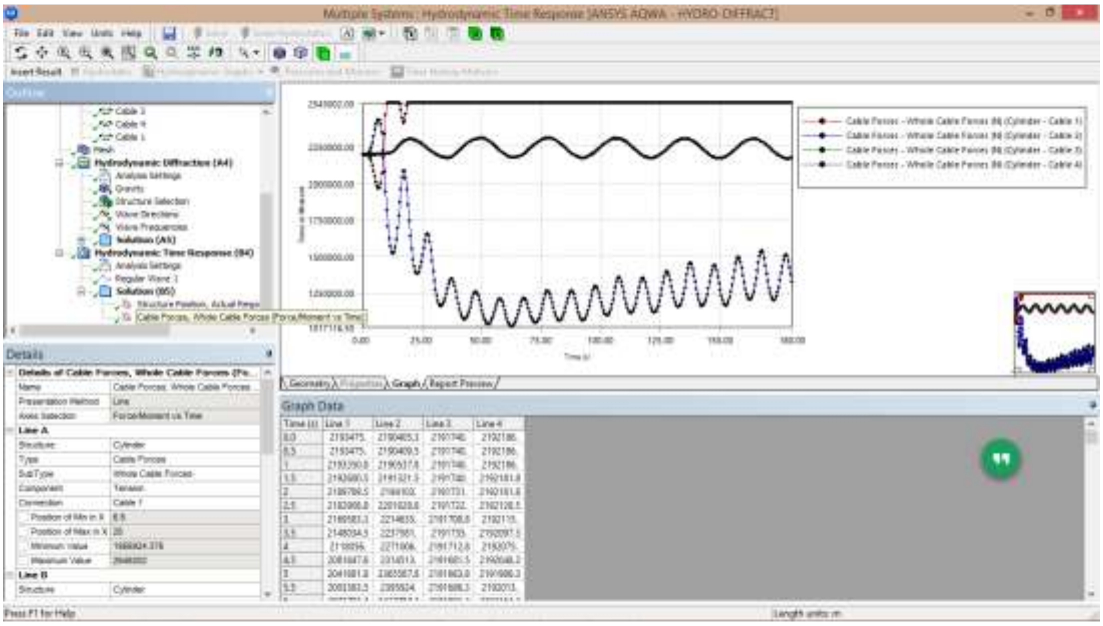

**Figure 3-9: Results displayed in ANSYS AQWA**

### 3.3.2 Parametric Study

Parametric study is conducted once the benchmark case is simulated and required results have been extracted. Here is where the focus of this study will be modeled and simulated. The existing model will be modified with small change for instance the location of mooring lines connection and the length of mooring lines. These changes effect on the system will be analyzed.

#### 3.3.2.1 Cross-sectional area of mooring lines

For this study the diameter of the mooring lines will be changed. The range of value of the diameter change is from 0.1 m to 0.5 m. by changing the diameter of the mooring line, the cross-sectional area of the mooring lines is also changed. The spar with changed cross-sectional area is subjected to same 6 m wave height and 10 seconds period from the 0 degrees direction. The effect of cross-sectional area of mooring lines on the motion of the spar as well as the tension in the mooring lines will be assessed.

#### 3.3.2.2 Number of mooring lines

The benchmark case has a mooring system that consists of four mooring lines. In this parametric study, the number of mooring lines will be varied. A total of three sets is performed where 2 mooring lines will be used for the first set. Next the usual 4 mooring lines system is analysed and finally a mooring system with 8 mooring lines will be used. The reason these numbers of mooring lines were chosen is due to the simplicity to determine its coordinate for the location of fairlead and the anchor point since it is an even set of mooring system. Besides that, it will also be symmetrical and will be more reliable when subjected to hydrodynamic loadings.

### 3.3.3 Further Simulation

If the results acquired are not satisfying, then further analysis has to be performed. Some changes on the model will be done and simulation will be carried out again until all results are satisfactory.

# 4.0 RESULTS AND DISCUSSION

In this section of the report, the result obtained from the dynamic analysis performed using ANSYS AQWA will be presented. Calculations on the mass moment of inertia are presented in Section 4.1 and it is needed as an input for the spar's hull characteristics. In Section 4.2 the motion response of surge, heave and pitch from the spar model is presented. These results were then compared to the benchmark case in Section 4.3. Following up is the tension values in each mooring line is assessed and presented. Finally the two parametric studies of cross-sectional area of mooring lines and also the effect of number of mooring lines is included in Section 4.5 of this report.

## 4.1 Moment of inertia

$$\text{Volume of the cylinder} = \pi r^2 h = \pi * \left(\frac{40.54}{2}\right)^2 * 213.04 = 274991.03\ m^3$$

Centroid/ CG = X, Y, Z = (0, 0, 106.52)

Moment Of Inertia using Parallel Axis Theorem

a) About the central axis

$$I = \frac{1}{2}MR^2 = \frac{1}{2} * 2.515 * 10^8 \left(\frac{40.54}{2}\right)^2 = 51667267175\ kg.m^2$$

b) About the central diameter

$$I = \frac{1}{4}MR^2 + \frac{1}{12}ML^2$$

$$I = \left(\frac{1}{4} * 2.515 * 10^8 * \left(\frac{40.54}{2}\right)^2\right) + \left(\frac{1}{12} * 2.515 * 10^8 * 213.04^2\right)$$

$$I = 977049422120.833\ kg.m^2$$

## 4.2 Surge, heave and pitch response

The classic JIP spar was subjected to 6m of wave height with a period of 10s. The dimension of the spar is presented in Table 3-1. All responses presented in this study were at the center of gravity of the spar. The Response-Amplitude Operator (RAO) obtained for surge, heave and pitch is 0.452, 0.006 and 1.669 respectively. These values represent the ratio amplitude of response to the amplitude of wave. Figure 4-1, 4-2 and 4-3 shows the surge heave and pitch response of the spar for 6 meter of wave height respectively.

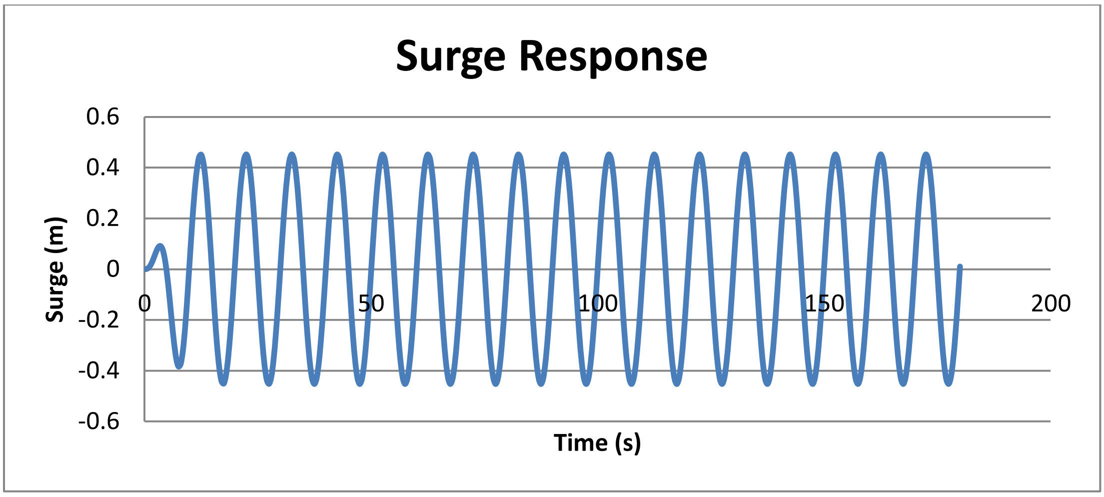


**Figure 4-1: Surge response in 6m wave height**

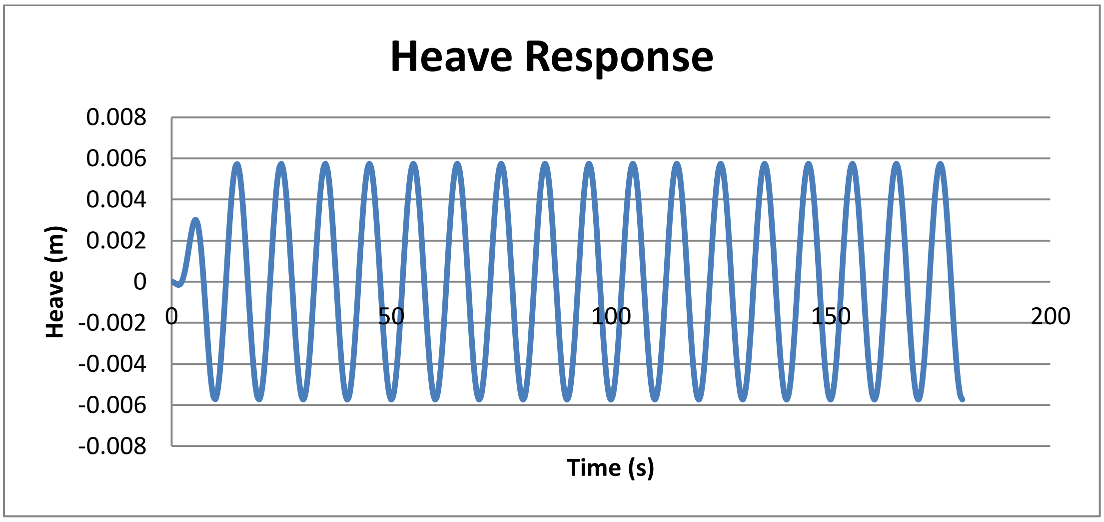


**Figure 4-2: Heave response in 6m wave height**

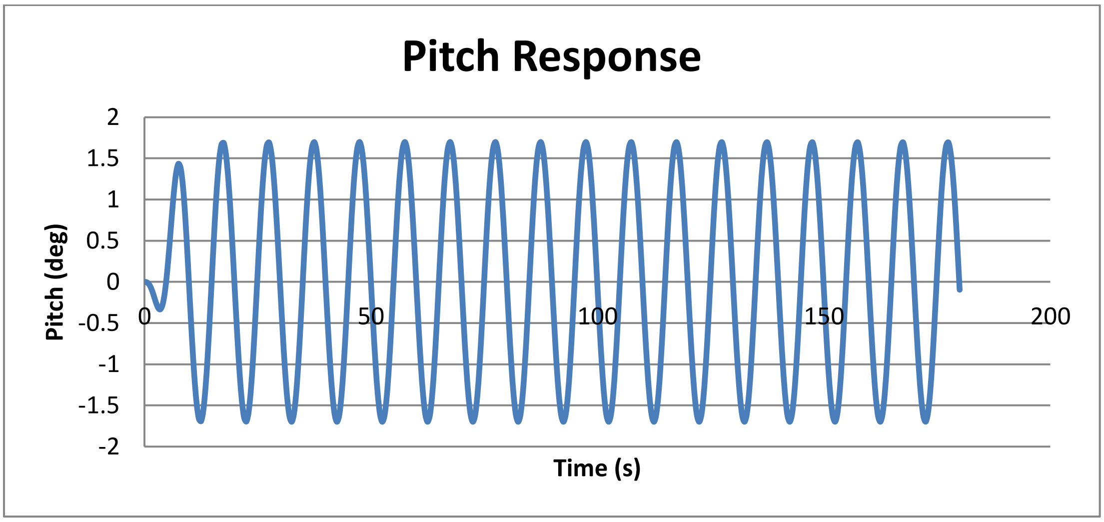


**Figure 4-3: Pitch response in 6m wave height**

Based on the above graphs, it can be observed that the surge, heave and pitch responses are in the form of sinusoidal which represent the regular wave effect. This is because the RAO values obtained are same throughout the time. Thus, the amplitude of response is also same throughout the time similar in behavior with the amplitude of regular wave profile.

Other than that, the surge response is highest compare to heave and pitch where the maximum deflection or offset is 2.76 m from the original position. The maximum value for heave and pitch response is 0.477 m and 3.54 degree respectively. The greater value for surge response which is the horizontal motion along x -axis is due to the wave is assumed to come from x -direction. Furthermore the horizontal wave forces itself is higher compare to the upward forces. Therefore, the impact on the structures movement for surge is greater due to larger amount of wave forces strike directly on the hull part. However, the surge response during this storm condition is considerable and will not affect the spar performance since displacement in x -direction is allowed up to 5m.

## 4.3 Results validation

The motion response of the spar in 318.5 m water depth has been validated by comparing the results obtained from the ANSYS AQWA with the work of Teng and Yang (2011). All the parameters used for the simulation in AQWA were obtained from this paper and was used as a benchmark case. The paper simulated the response of the spar in regular wave in the time domain using a self-developed program. It was simulated using two different numerical schemes: a coupled quasi-static approach (COUPLE_QS) and a coupled dynamic approach (COUPLE_DY). The difference between these two approaches is that the dynamic forces of mooring lines are included in COUPLE_DY but neglected in COUPLE_QS. The dynamic coupling effects between the spar and its mooring lines are investigated by the comparison of numerical simulations. For this project, we will compare results obtained from ANSYS AQWA with the results of COUPLE_DY since it is a coupled analysis taking into account the interaction of spar and mooring lines. The results from Teng and Yang (2011) are presented in Figure 4-4, 4-5 and 4-6.

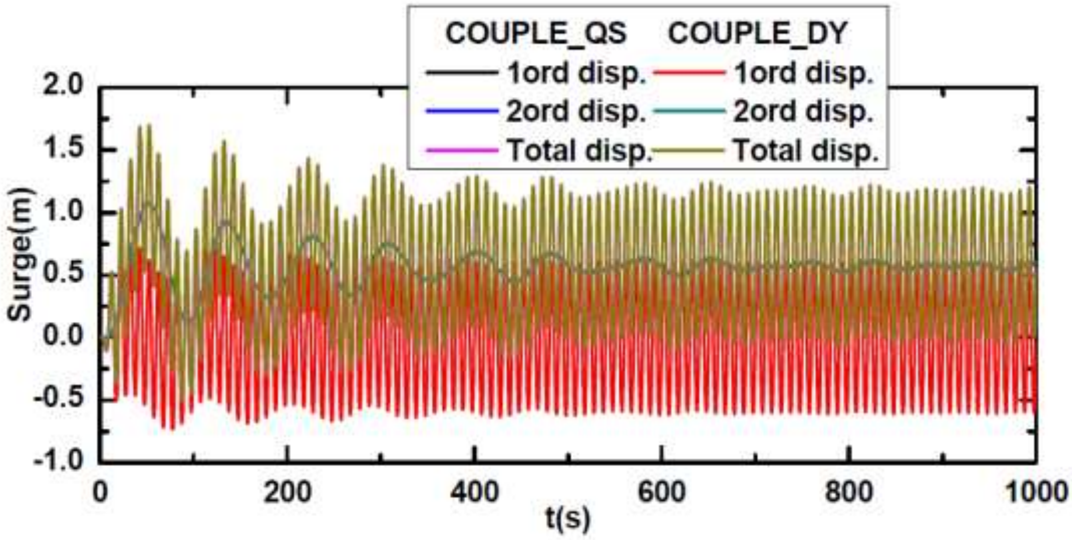


**Figure 4-4: Surge response of benchmark case**

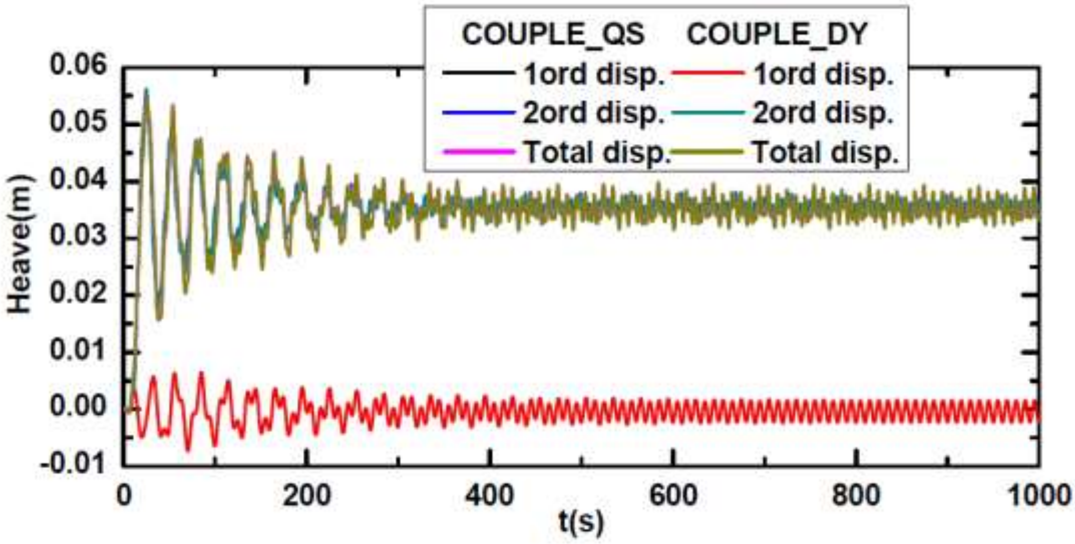


**Figure 4-5: Heave response of benchmark case**

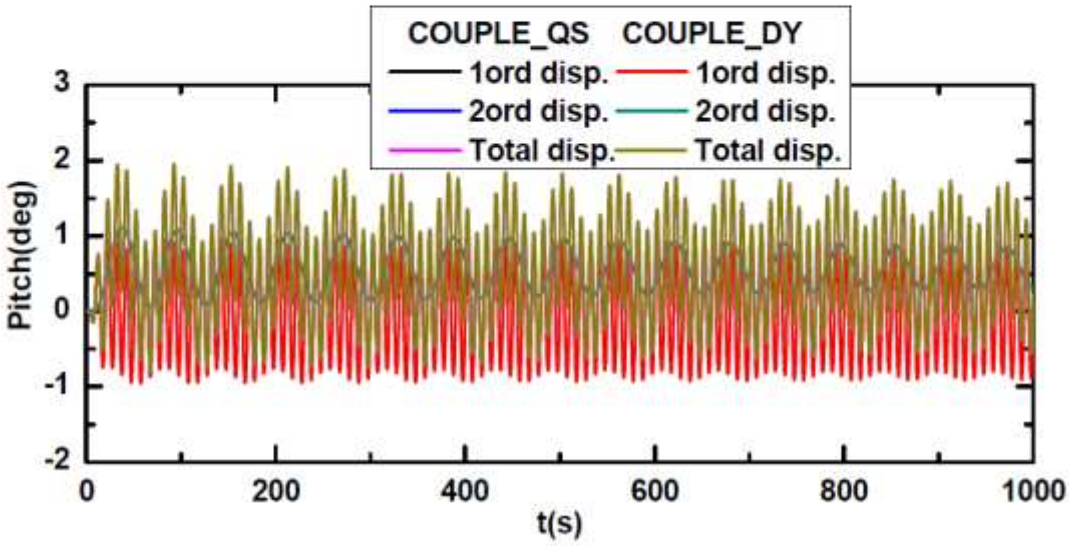


**Figure 4-6: Pitch response of benchmark case**

Based on the results from the benchmark case it can be seen that the results obtained from ANSYS AQWA have a similar pattern and the results corresponds well with the benchmark case. There still exists some level of tolerance of value. The results obtained is not exactly the same as the benchmark case results and this can be due to the difference in assumption and also the different method used. Table 4-1 below shows the difference in results obtained from this project using ANSYS AQWA compared to the benchmark case for all the motion response of surge, heave and pitch.

**Table 4-1: Comparison of results between Benchmark case and Project case**

| Response | Benchmark Case | Project Case |
|---|---|---|
| Surge (m) | +0.5 to -0.5 | +0.45 to -0.45 |
| Heave (m) | +0.006 to -0.006 | +0.006 to -0.006 |
| Pitch (deg) | +1.1 to -1.1 | +1.6 to -1.6 |

### 4.4 Tension in mooring cables

Tension in mooring lines plays an imperative character in the coupled dynamic analysis of the spar platform. The resulting tension in mooring lines 1, 2, 3 and 4 are shown in Figure 4-7, 4-8, 4-9 and 4-10 respectively.

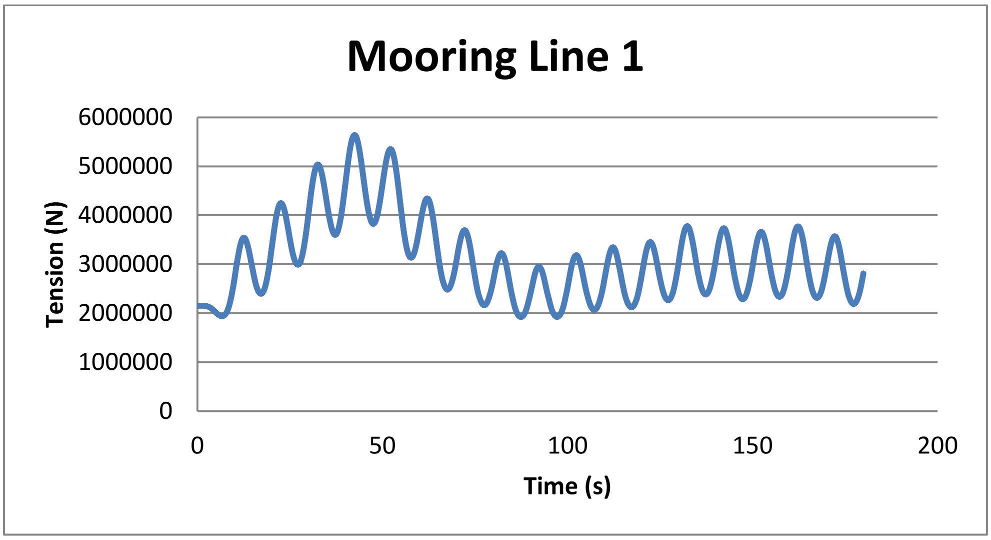


**Figure 4-7: Tension in mooring line 1**

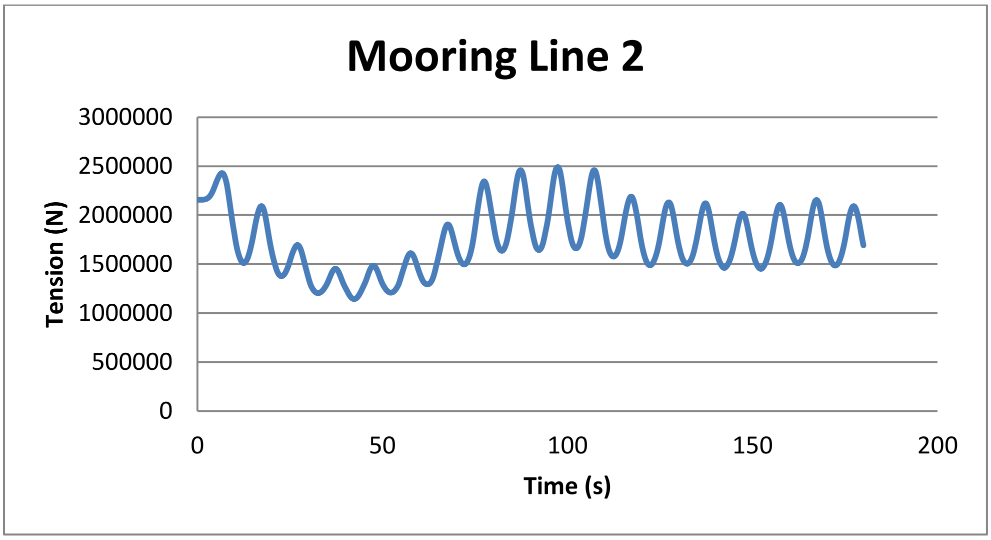


**Figure 4-8: Tension in mooring line 2**

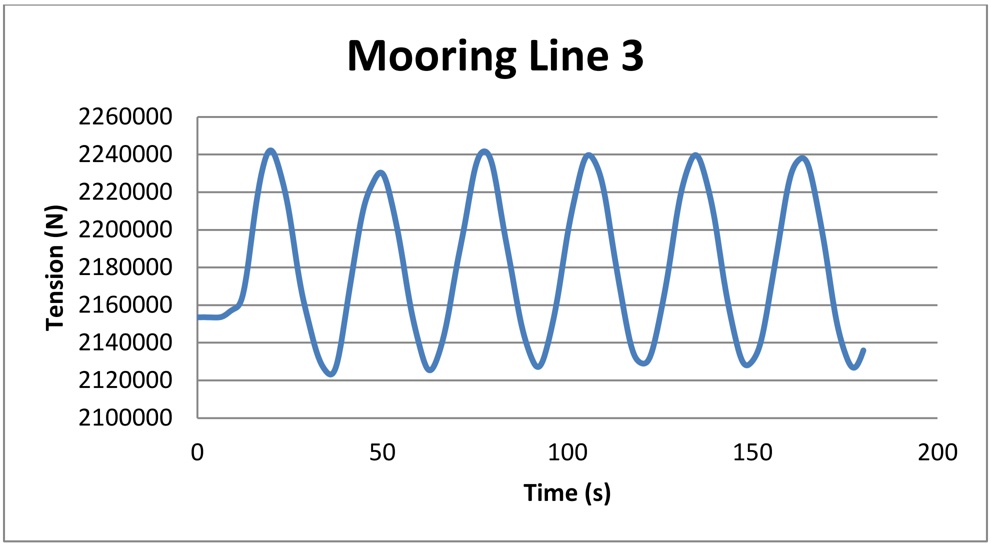


**Figure 4-9: Tension in mooring line 3**

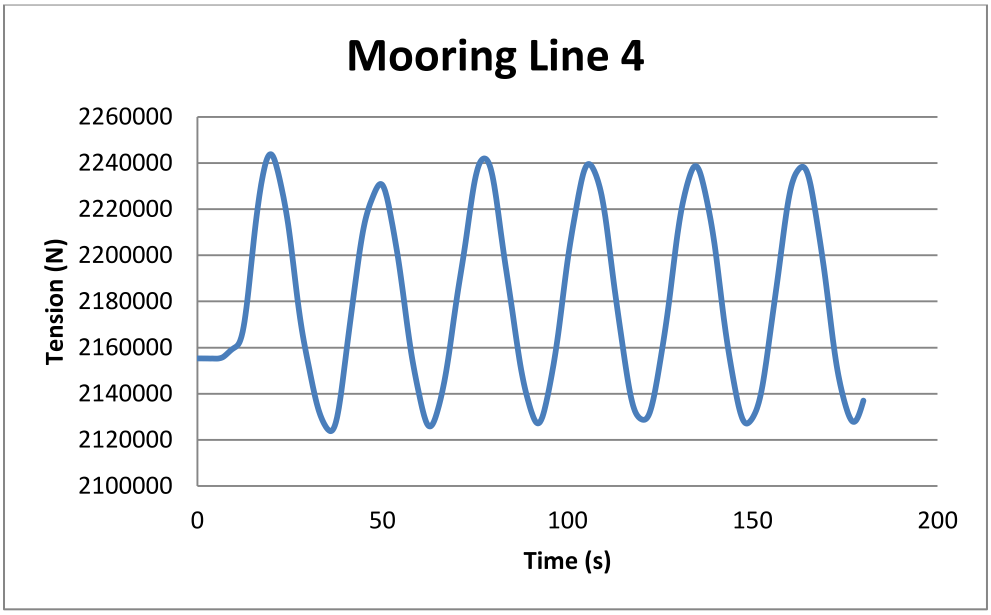


**Figure 4-10: Tension in mooring line 4**

Mooring line 1 shows the regular behavior of tension in direction of wave propagation. The results show that the maximum and minimum values of tension are 5637590.5 N and 1922266.5 N, respectively in mooring line 1. The tension time series of mooring line 2 is likewise regular in nature. However, there is slight fluctuation in magnitude. Mooring line 2 is also positioned in the direction of wave propagation. Mooring line 1 experiences the maximum tension to support surge in the forward direction, while mooring line 2 slackens, resulting in the reduction of pretension. Figure 4-7 shows the tension fluctuations when mooring line 1 stretches and Figure 4-8 shows mooring line 2 slackens due to surge response. Tension fluctuation is of complex periodic nature showing minor ripples near the peaks. For both of these mooring lines at the regular wave, periodic behavior is governed. The slack mooring line 2 remains in catenary shape with the reduction in tension. On the other hand, as for the mooring lines 3 and 4, they share the same tension since the position is in a symmetrical way from the direction of the wave approach. Figure 4-11 shows the comparisons of tension in all the mooring lines.

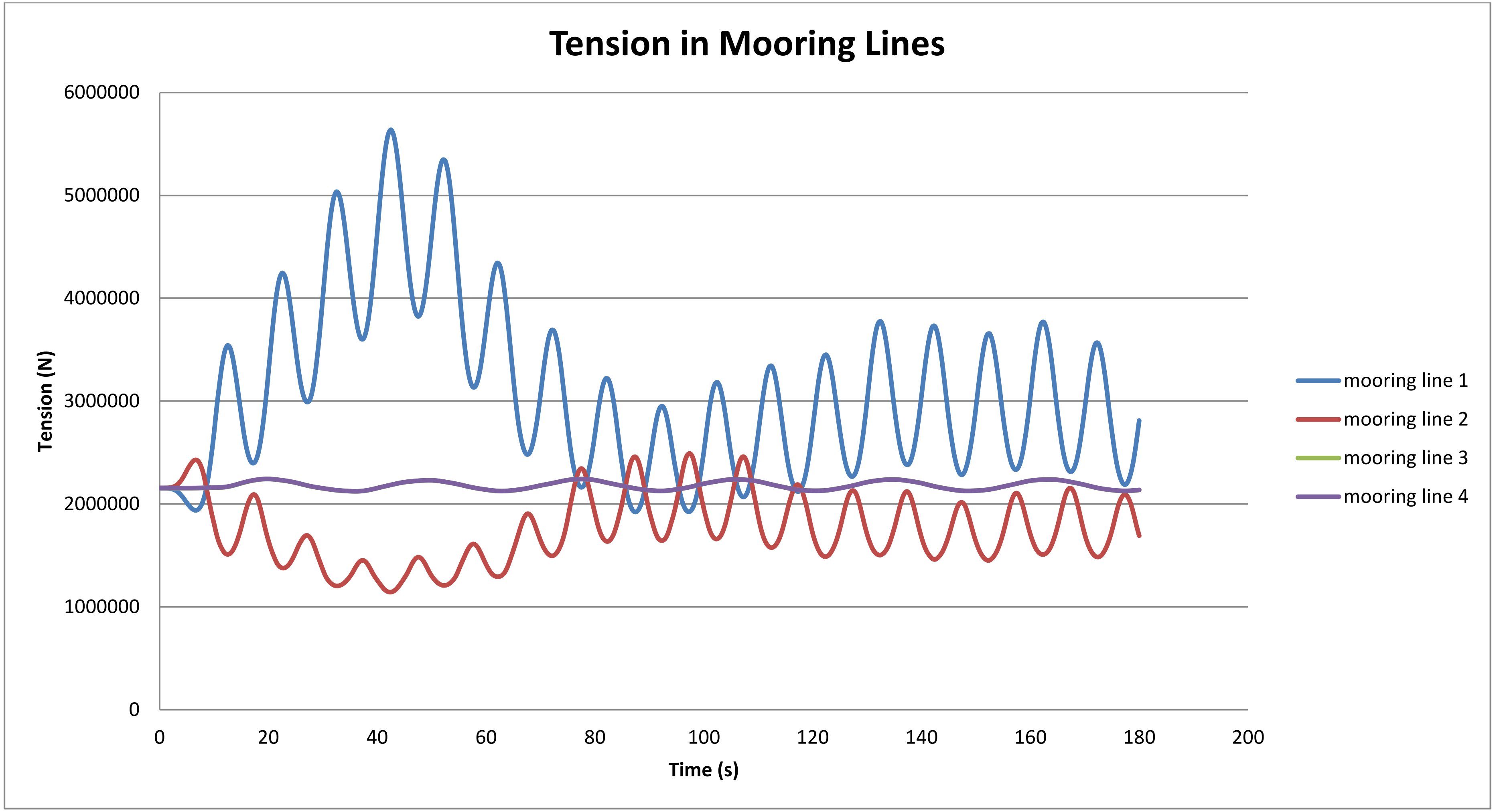


**Figure 4-11: Tension in all mooring lines**

## 4.5 Parametric Study

### 4.5.1 Cross-sectional area of mooring lines

The benchmark model has mooring lines with the diameter of 0.12 m. The diameter of mooring lines is then increased gradually up to 0.5 m to increase the cross-sectional area of the mooring lines and the equivalent tension build up in the mooring lines are investigated. The set of simulation was performed by using the Design of Experiment option available in ANSYS. This option enables the user to input the lower and upper bound value of input parameter. For this project the cross-sectional area of mooring lines is varied by using different diameter of mooring lines. The smallest diameter is 0.1m and increased up to 0.5m. The analysis can then be performed simultaneously using just one model file without the need to generate multiple model with different parameters. The results are then plotted to the best fit option and the critical conditions are also taken care of in the simulation via the design points. Figure 4-12 to Figure 4-15 below shows the maximum tension build up in mooring lines 1 to 4 respectively when the cross-sectional area of the mooring lines are varied.

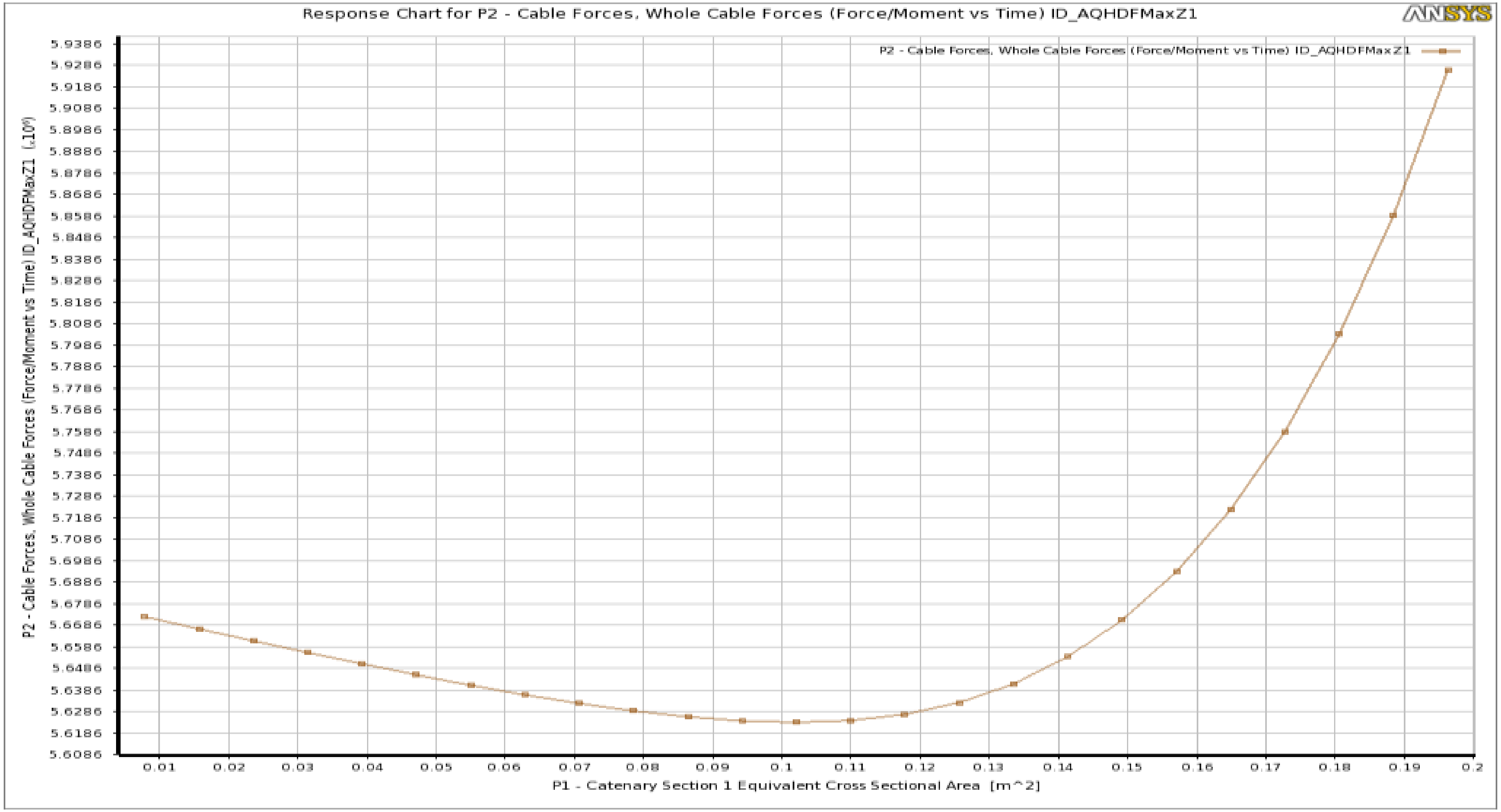


**Figure 4-12: Maximum tension VS cross-sectional area of mooring line 1**

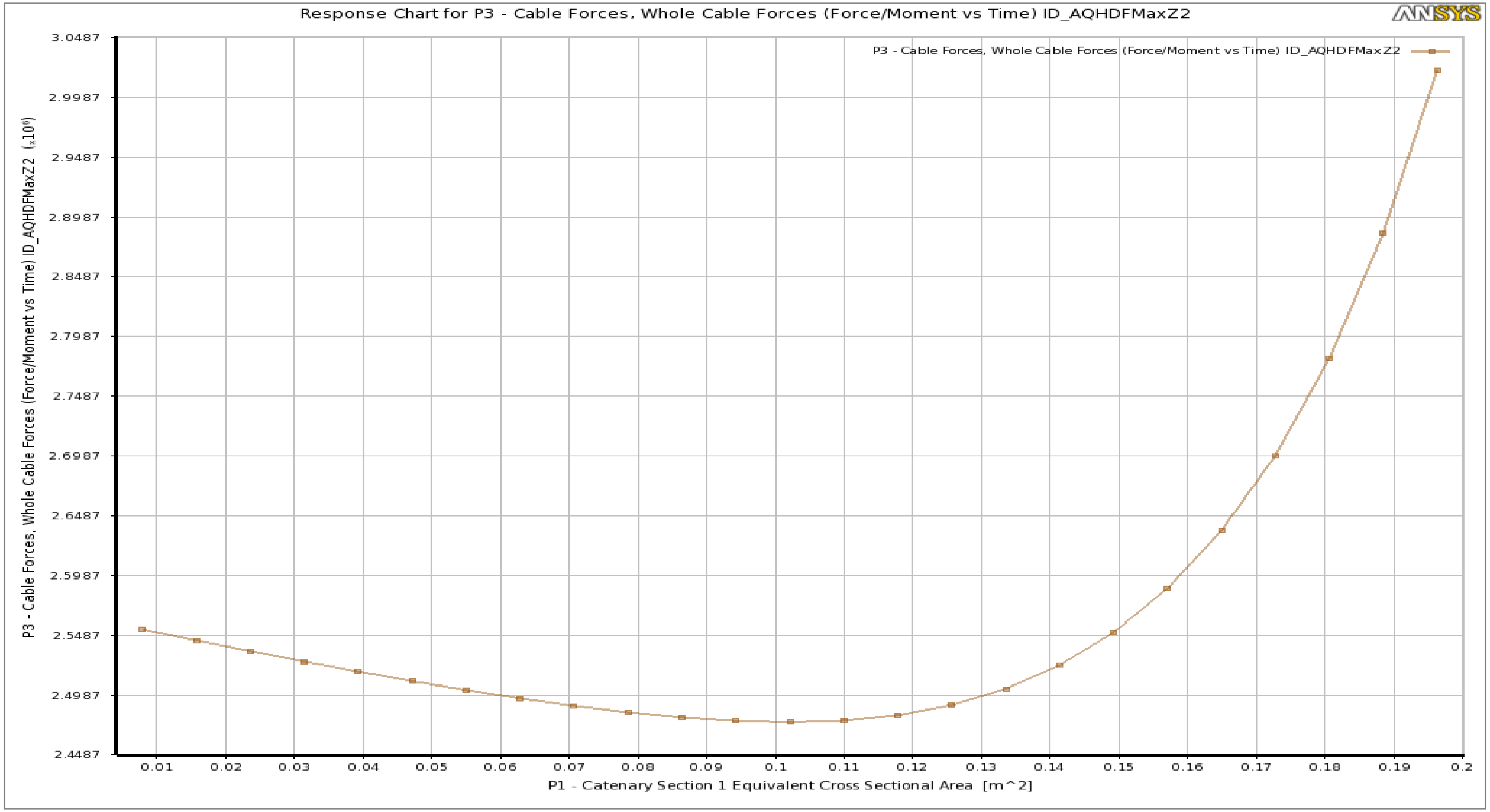


**Figure 4-13: Maximum tension VS cross-sectional area of mooring line 2**

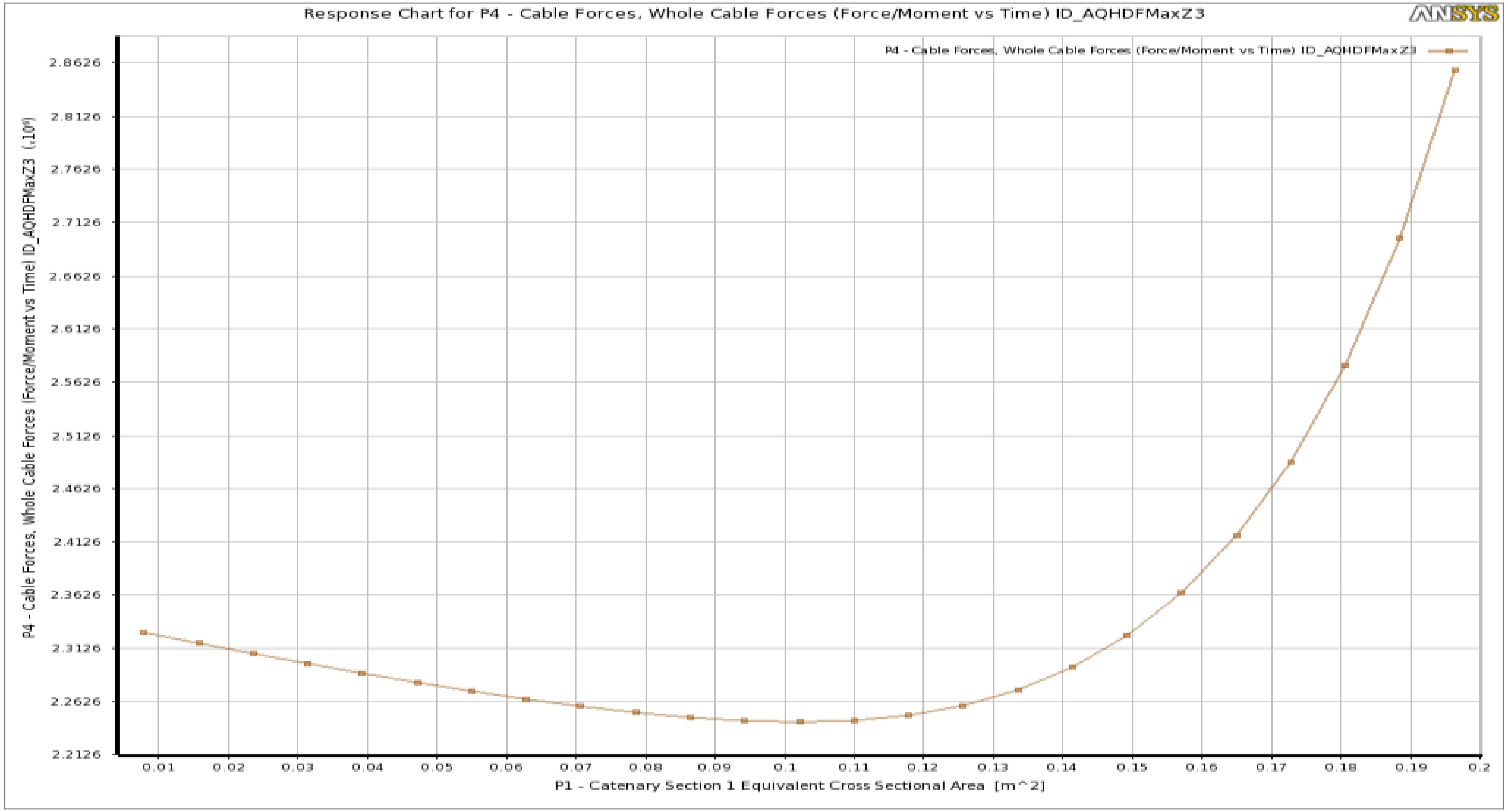


**Figure 4-14: Maximum tension VS cross-sectional area of mooring line 3**

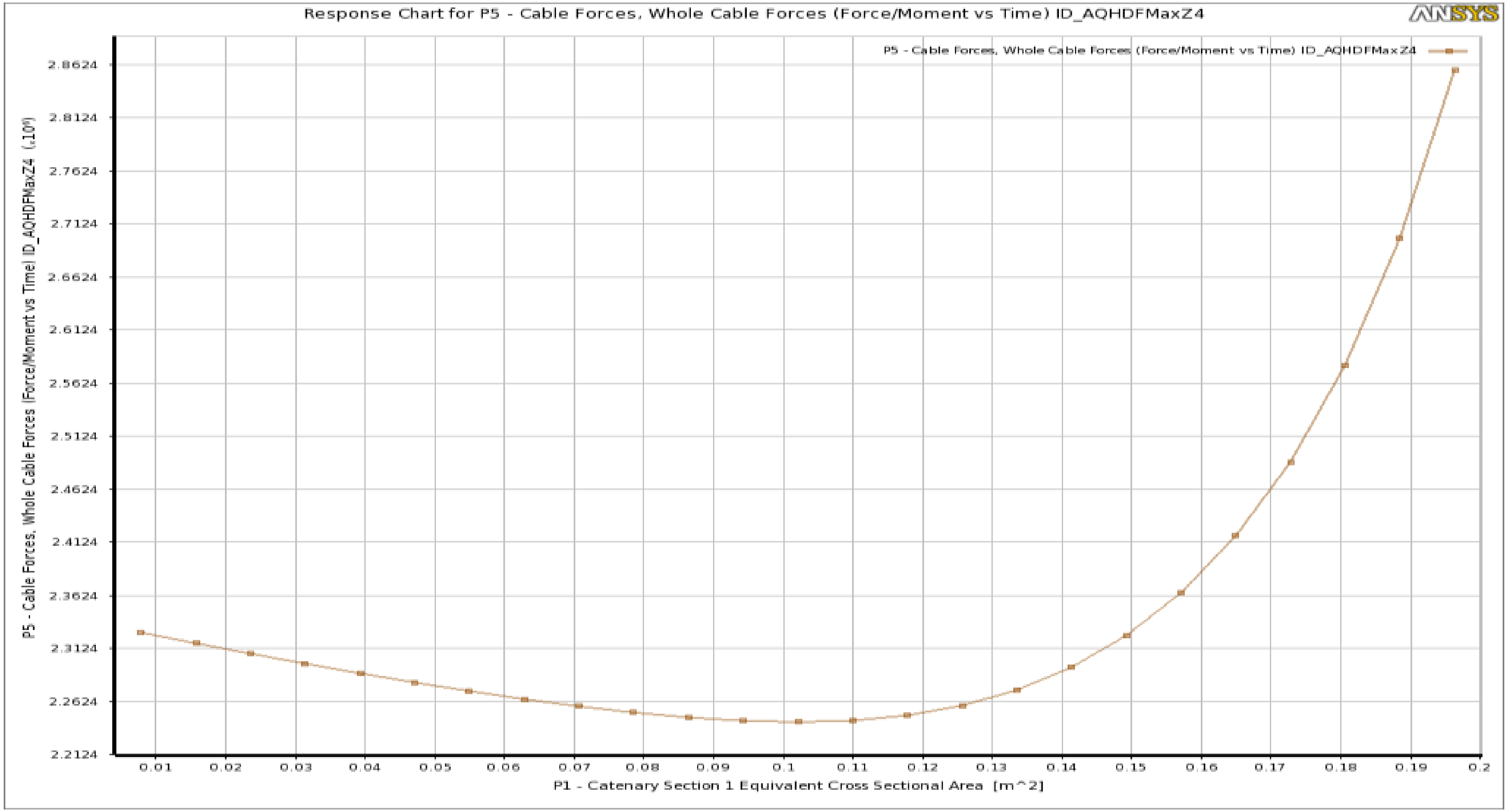


**Figure 4-15: Maximum tension VS cross-sectional area of mooring line 4**

Based on the graphs obtained from the simulation, it can be observed that mooring line 1 has the highest tension in all condition due to the direction of wave from its direction. Its opposite combination of mooring line 2 has the lowest tension due to the motion of the spar which is pushed by the waves and causes mooring line 2 to slacken thus reducing its tension. As usual mooring lines 3 and 4 show similar values of tension because of the symmetrical position to the wave direction. However, by theory when the cross-sectional area has been increased the tension should decrease but that is not the case here. This pattern is visible in among all mooring lines in the early stages but as the cross-sectional area is increased beyond $0.1m^2$ the tension begin to increase. One of the reasons for this phenomenon to occur is due to the buoyancy force action on the mooring cables. When the diameter is increased on the mooring lines, the volume of the mooring lines is also increased. In contrast, the mass of the mooring lines has been kept constant throughout the simulation. This will cause the density of the mooring line to decrease as well as increase the buoyancy force acting on the mooring lines. Buoyancy force is equals to the mass of water displaced, and since the increased mooring lines volume will displace more water, the buoyancy force increases. This will cause an upwards lift on the mooring lines and the tension will increase at the connection point because of the lift force. Therefore the results show an increase in tension even though the cross-sectional area of the mooring lines is increased.

### 4.5.2 Number of mooring lines

Another parametric study was performed in the number of mooring lines. Three separate models with two mooring lines, four mooring lines and eight mooring lines were modeled in ANSYS AQWA. The effect of mooring lines on the spar motion as well as the tension in the mooring lines is studied. All three models were subjected to a wave height of 6m and a period of 10 seconds.

#### 4.5.2.3 Two mooring line model

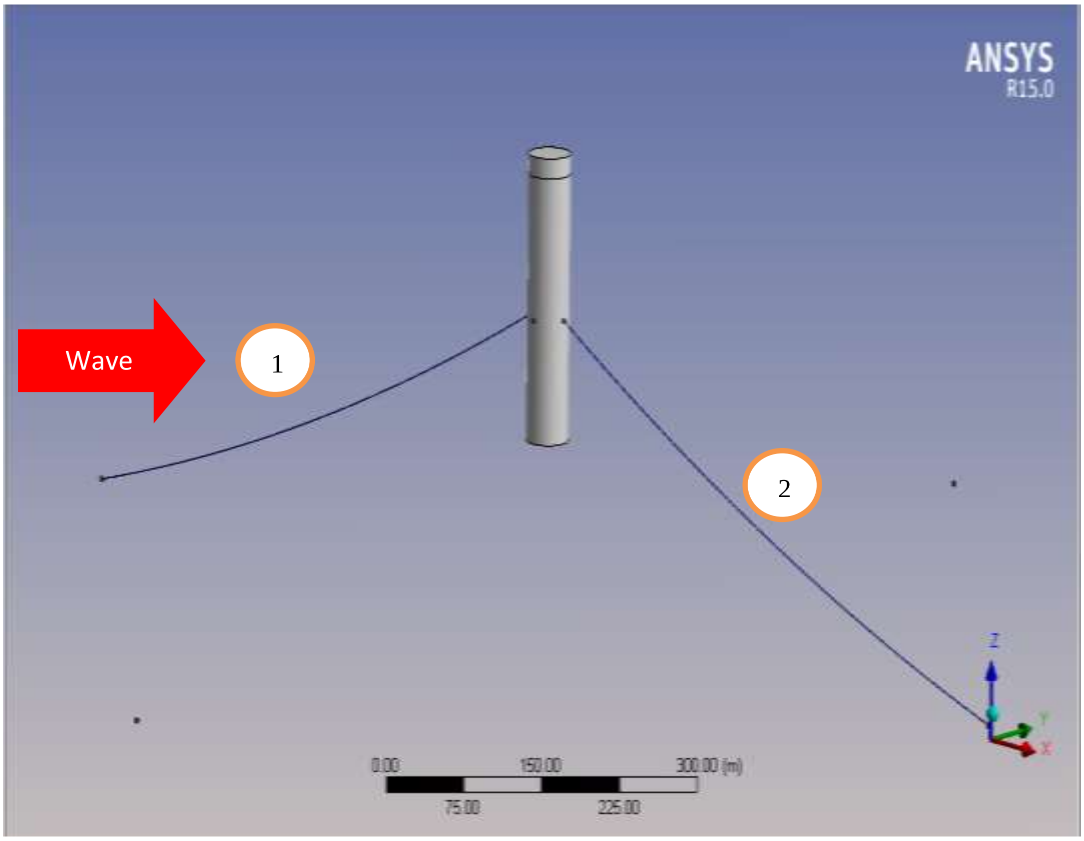


**Figure 4-16: Spar with two mooring lines model**

**Table 4-2: Results for spar with two mooring lines**

| Response | Surge (m) | | Heave (m) | Pitch (deg) |
|---|---|---|---|---|
| | 2.900 | | 0.482 | 3.540 |
| Mooring lines | Tension (N) | | | |
| | Maximum | | Minimum | |
| 1 | 5678567.5 | | 1936950.25 | |
| 2 | 2544933 | | 1154619.75 | |

#### 4.5.2.4 Four mooring line model

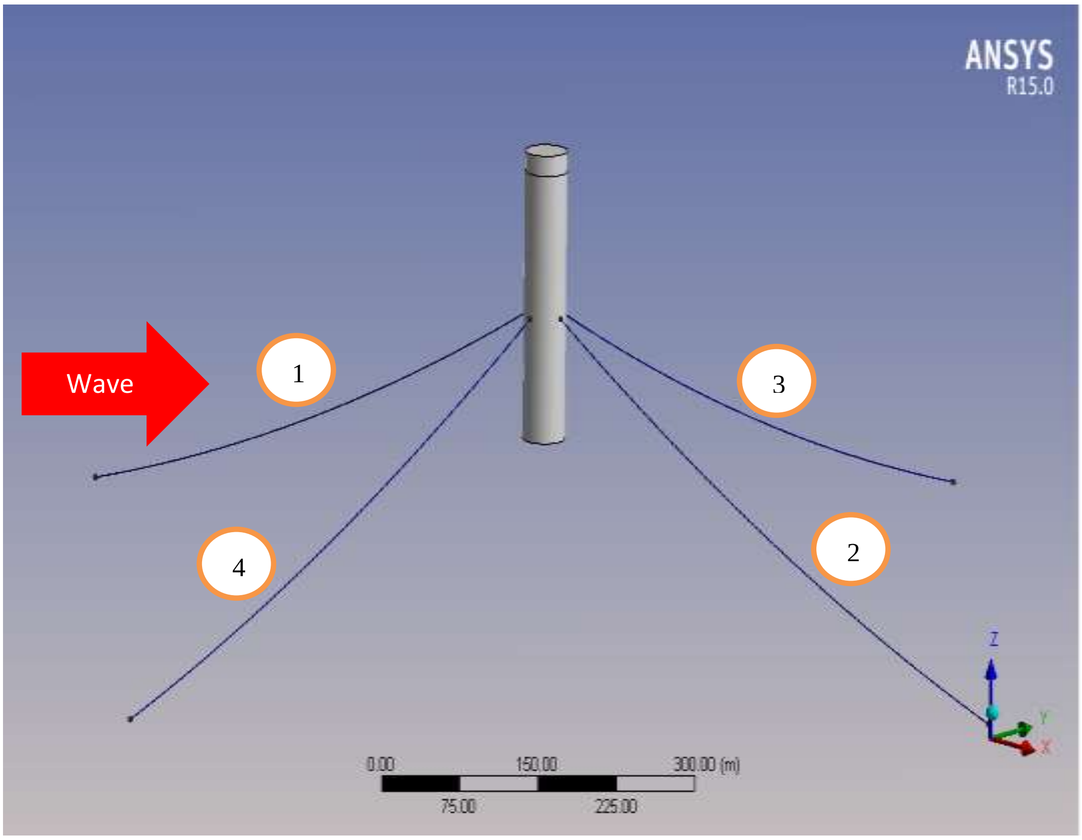


**Figure 4-17: Spar with four mooring lines model**

**Table 4-3: Results for spar with four mooring lines**

| Response | Surge (m) | | Heave (m) | Pitch (deg) |
|---|---|---|---|---|
| | 2.760 | | 0.477 | 3.540 |
| Mooring lines | Tension (N) | | | |
| | Maximum | | Minimum | |
| 1 | 5636323 | | 1922062.75 | |
| 2 | 2489257.25 | | 1143525.25 | |
| 3 | 2241810.75 | | 2122951.5 | |
| 4 | 2243518.5 | | 2123629.75 | |

4.5.2.5 Eight mooring line model

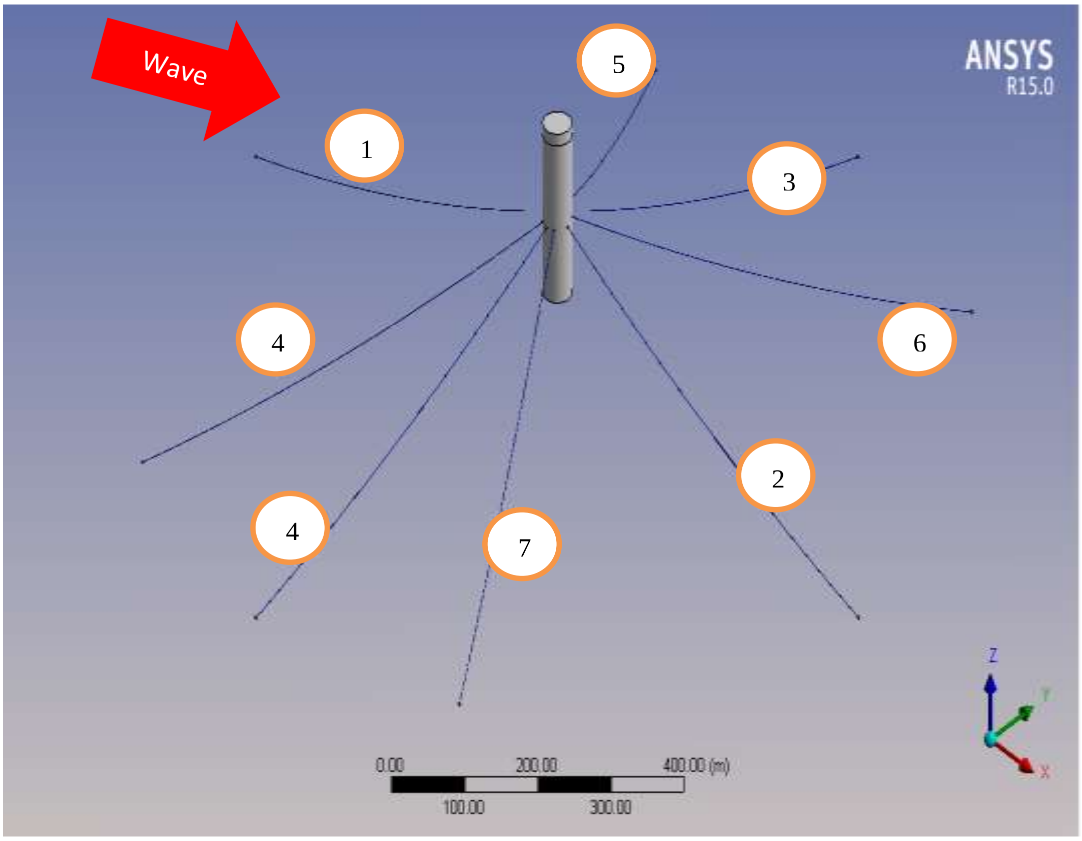


**Figure 4-18: Spar with eight mooring lines model**

**Table 4-4: Results for spar with eight mooring lines**

| Response | Surge (m) | | Heave (m) | Pitch (deg) |
|---|---|---|---|---|
| | 2.402 | | 0.470 | 3.54 |
| Mooring lines | Tension (N) | | | |
| | Maximum | | Minimum | |
| 1 | 4861849.5 | | 1695630 | |
| 2 | 2861548.25 | | 1211221.625 | |
| 3 | 2166860.5 | | 2062017 | |
| 4 | 2167254.25 | | 2061831.625 | |

The surge response in the three models shows that with increasing number of mooring lines the surge decreases. This also applies to the heave response but not as significant as the surge. Heave reduces by a few millimeters whereas compared to the surge; it reduces by a few centimeters. The pitch on the other hand remains the same in all three cases at 3.54˚. When the number of mooring lines has been increased they act as springs which are arranged in a parallel configuration and thus restrict the motion of the spar. This is also the case for the tension in each mooring lines. When more number of mooring lines is added to the system, the tension is shared among them depending on the direction of loadings. When selection is performed on the number of mooring lines to be used for a mooring system, it is not necessary to use many mooring lines. It all comes down to the purpose of the mooring line which is to hold the structure in position and prevent it from drifting away. Therefore, based on this criterion the number of mooring lines should be the least possible to withstand the loading from waves and current without snapping as the tension in the mooring line will build up. For the classic JIP spar used in this project and at a water depth of 318.5m, the four mooring line system is sufficient enough to serve its purpose. There is no need to implement an eight mooring line system even though the motion response as well as the tension in the mooring lines can be reduced. It will only be more expensive to include additional four mooring lines when just four mooring lines will suffice.

# 4. CONCLUSION AND RECOMMENDATION

The spar platform has been successfully modeled using ANSYS AQWA complete with the mooring systems and the dynamic response under regular waves and current has been determined using a time domain simulation method. The model can consider several non-linear effects and the complete non-linear rigid body equations of motion have been solved in the time domain. Hydrodynamic forces and moments were computed to predict the wave particle kinematics. The program has been able to obtain results having trends comparable with benchmark case results.

As cross-sectional area of the mooring lines is increased, the tension within the mooring lines decreases. However this trend is only visible for a certain range before the buoyancy effect takes place. Further simulation is needed to take into account the mass of the mooring lines when cross-sectional area is increased.

Dynamic analysis proves important to determine the number of mooring lines needed in a mooring system. As for the classic JIP spar at the water depth of 318.5m, four mooring lines are sufficient. For deeper water and region with high current, the analysis needs to be performed to check the tension loadings in mooring cables and determine to appropriate number of mooring lines in the system.

# 5. REFERENCES

Chakrabarti, S.K., (1987) *Hydrodynamics of Offshore Structures.* UK, WIT Press

Garrett, D. L. (2005). Coupled analysis of floating production systems. *Ocean Engineering, 32*(7), 802-816. doi: 10.1016/j.oceaneng.2004.10.010

Heurtier, J., Le Buhan, P., Fontaine, E., Le Cunff, C., Biolley, F., Berhault, C., & others,. (2001). Coupled dynamic response of moored FPSO with risers, *1*, 17--21.

Islam, A. B. M. S. (2011). Spar platform at deep water region in Malaysian sea. *International Journal of the Physical Sciences, 6*(30). doi: 10.5897/ijps11.571

Jameel M (2008). Non-linear dynamic analysis and reliability assessment of deepwater floating structure. PhD thesis. Depart. Appl. Mechanics, Indian Instit. Technol. Delhi.

Kim, M. H., Koo, B. J., Mercier, R. M., & Ward, E. G. (2005). Vessel/mooring/riser coupled dynamic analysis of a turret-moored FPSO compared with OTRC experiment. *Ocean Engineering, 32*(14-15), 1780-1802. doi: 10.1016/j.oceaneng.2004.12.013

Koo, B. J., & Kim, M. H. (2005). Hydrodynamic interactions and relative motions of two floating platforms with mooring lines in side-by-side offloading operation. *Applied Ocean Research, 27*(6), 292-310. doi: 10.1016/j.apor.2006.02.001

Low, Y. M., & Langley, R. S. (2006). Time and frequency domain coupled analysis of deepwater floating production systems. *Applied Ocean Research, 28*(6), 371-385. doi: 10.1016/j.apor.2007.05.002

Low, Y. M., & Langley, R. S. (2008). A hybrid time/frequency domain approach for efficient coupled analysis of vessel/mooring/riser dynamics. *Ocean Engineering, 35*(5-6), 433-446. doi: 10.1016/j.oceaneng.2008.01.001

Tahar, A., & Kim, M. H. (2008). Coupled-dynamic analysis of floating structures with polyester mooring lines. *Ocean Engineering, 35*(17-18), 1676-1685. doi: 10.1016/j.oceaneng.2008.09.004

Teng, B. and M. D. Yang (2011). "Nonlinear Coupled Dynamic Analysis for Waves and a Moored Platform in Time Domain." International Workshop on Water Waves and Floating Bodies: 4.

Yang, M., Teng, B., Ning, D., & Shi, Z. (2012). Coupled dynamic analysis for wave interaction with a truss spar and its mooring line/riser system in time domain. *Ocean Engineering, 39*, 72-87. doi: 10.1016/j.oceaneng.2011.11.002

Offshore Drilling Platform [Photograph]. (2008). Retrieved October 3, 2014, from http://science.howstuffworks.com/environmental/energy/offshore-drilling6.htm

Introduction and Environmental Loads, [Photograph]. (n.d.). Retrieved April 11, 2015, from http://www.fgg.uni-lj.si/~/pmoze/ESDEP/master/wg15a/l0200.htm

# Appendix A

## Gantt Chart & Key Milestones

| No | Activities | Weeks | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | FYP 1 | | | | | | | | | | | | | | FYP 2 | | | | | | | | | | | | | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| **1** | Literature review<br>- Reading about fundamentals of mooring systems dynamic modeling<br>- Basic of ANSYS AQWA | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **2** | Acquisition of the benchmark and case study problems<br>- Dimension of the spar platform<br>- Environmental loads | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **3** | Modeling and simulation of the benchmark problem<br>- Reworking Teng's work | | | | | | | | | | | | | | | | | | | | | | Δ | | | | | | |
| **4** | Modeling and simulation of the case study problem.<br>- Verification of the parameter settings<br>- Evaluation of the simulation result | | | | | | | | | | | | | | | | | | | | | | | Δ | | | | | |
| **5** | Parametric Study<br>- Simulating the effect of mooring lines thickness<br>- The effect of number of mooring lines | | | | | | | | | | | | | | | | | | | | | | | | | | | Δ | |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | Further analysis<br>- Make small modification on model<br>- Solve any arising problem that may occur | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7 | Results preparation<br>- Ensure all results are extracted<br>- Well tabulated and presented | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 8 | Report documentation | | | | | | | | | | | | | | | | | | | | | | | | | | | | Δ |

**Legend:** Δ = Key milestones

## Milestones:

1. Completion of Benchmark mooring system modeling and simulation: Date – 5/3/2015
2. Completion of modeling and simulation of the case problem: Date – 9/3/2015
3. Completion of the parametric study for the case problem: Date – 10/4/2015
4. Completion of the further analysis and report writing: Date – 17/4/2015