DYNAMIC RESPONSES OF FLOATING PRODUCTION STORAGE AND OFFLOADING (FPSO) VESSEL SUBJECTED TO RANDOM WAVES

By

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16972

Dissertation submitted in partial fulfilment of

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CERTIFICATION OF APPROVAL

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Approved by,

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FYP Supervisor

Universiti Teknologi PETRONAS

Tronoh, Perak

May 2015

CERTIFICATION OF ORIGINALITY

This is 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 that the original work contained herein not been undertaken or done by unspecified sources or persons.

NISHANTI A/P PACHIYAPPAN

ABSTRACT

Floating, Production, Storage and Offloading (FPSO) unit is ship shaped vessel which is currently used for the production and storage of hydrocarbon in deep water region. FPSO is more efficient and economical as compared to fixed structure such as topside and jacket. This is because the installation of pipeline for fixed structure is expensive and therefore FPSO is more preferred than fixed structure. FPSO is a floating structure which allows six degrees of motion in surge, heave, sway, pitch, yaw and roll. It is crucial to possess a study on dynamic responses of FPSO due to environmental load for excellent station-keeping characteristics. As wave cause the dominant environmental loads, the evaluation of responses due to random waves is necessary for the analysis and preliminary design of FPSOs. The model testing of the FPSO model is performed in UTP Offshore Laboratory to investigate the three degrees of freedom under action of waves at Malaysian deep water. The same is validated using finite element analysis of moored FPSO using frequency domain method. The metocean data is obtained from the Petronas Technical Standards (PTS) for operating condition which consist of wave height and peak period. The uncoupled analysis of the FPSO is performed using SESAM suites of programs. Diffraction potential theory is used to calculate the dynamic responses of FPSO. Hydrodynamic analysis is conducted to determine the motion of FPSO in surge, heave and pitch motion in random waves. Wave spectrum is generated using Jonswap spectrum. The motion responses of the ship is studied by using transfer functions or Response Amplitude Operator (RAO) and both numerical and experimental results were compared. Since there are no study has been reported on dynamic responses of FPSO in Malaysian waters by using SESAM, therefore this study is very useful for the future design of FPSO and also to ensure the excellent station keeping characteristics in deep water.

ACKNOWLEDGEMENT

First and foremost, my praise and gratitude goes to God Almighty for granting me strength and courage to endure challenging 28 weeks of FYP I and FYP II. I would like to take this wonderful opportunity to thanks all those people who have helped me throughout this period. My highest gratitude goes to my supervisor, Prof. Dr. Kurian V. John for all his guidance and support in the completion of the project.

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In a nutshell, I feel blessed to have completed my final year project successfully. I would like to thanks again all the people that has helped me throughout this study period.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

As the demand for oil and gas increasing gradually over the past few years, the oil and gas exploration has been extended to deep water in which the water depth is greater than 300 m. Floating structures such as Tension Leg Platform (TLP), SPAR Platform, Semi-Submersible and Floating, Production, Storage and Offloading (FPSO) have been used in deeper water. In this study, only FPSO will be focused mainly.

Floating, Production, Storage and Offloading (FPSO) unit is a ship-shaped floating structure which is widely used in deep water for the processing of hydrocarbons and storage for oil. It has been proved that FPSO vessels are a competitive solution for the development of oil and gas field in offshore. In the economic point of view, FPSOs are believed to be more effective as compared to fixed offshore platforms because excessive capital investment are required for the installation of oil pipelines for the fixed platforms. Besides that, the demand of oil and gas which has been increasing gradually every year causes the oil and gas industry to extend their production in deep water and ultra-deep water.

FPSOs have been successfully installed and operated in many places globally for oil and gas production. According to the Offshore Magazine (2014), a total of 151 FPSO vessels are operating all over the world. There are 3 FPSOs from Malaysia offshore, 10 are in Western Australia offshore, 14 in China offshore, 7 in Vietnam offshore and many more. It is expected that more FPSOs will be installed in the future. Figure 1.1 shows the distribution of FPSO vessels worldwide.

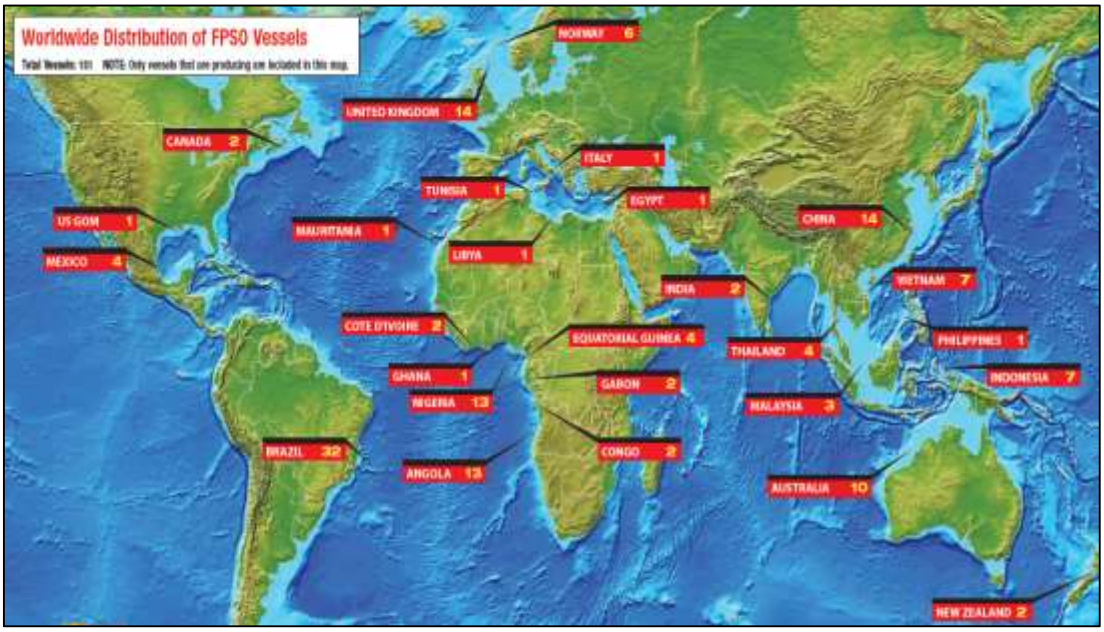

Figure 1.1: Distribution of FPSO vessels worldwide (Retrieve from: Offshore Magazine, 2014)

The first FPSO was built in Spain in 1977 which is a tanker-based single-point moored FPSO facility for oil. In 2002, Malaysia's first deep water FPSO was constructed for the development of Kikeh field. This FPSO can accommodate oil production at a rate of 120,000 barrels per day (bpd).

The ship-type floating structures are used for the production and storage of oil even in the harsh environment. Therefore, FPSO vessels have become a major floating production unit for both shallow and deep water because they are believed to survive even in the most critical environmental conditions at any location of the sea. Most of the FPSO exist nowadays are basically ship-shaped structure, even though there are variety of shapes like cylindrical FPSO are being developed by oil and gas industry.

1.2 Structure and Parts of FPSO

Since FPSO vessels are mainly used for the production, storage and offloading of hydrocarbons, thus the structure of FPSO is equipped with all the parts that can carry out these processes. An FPSO basically consists of hull structure, mooring system, process area, storage and offloading system, dynamic positioning system and many more. Mooring system can be divided into two types which are spread mooring system and single point mooring system (SPM). These systems are used to retain the FPSO unit at a definite location of designated service area permanently for a long period of time. The process equipment or production equipment consists of gas treatment, oil processing, gas compression, water injection, metering system and others. Storage system is located at the center tanks of the FPSO. Crude oil that is stored in the FPSO will be transferred directly to a shuttle tanker by a hose or exported via a pipeline.

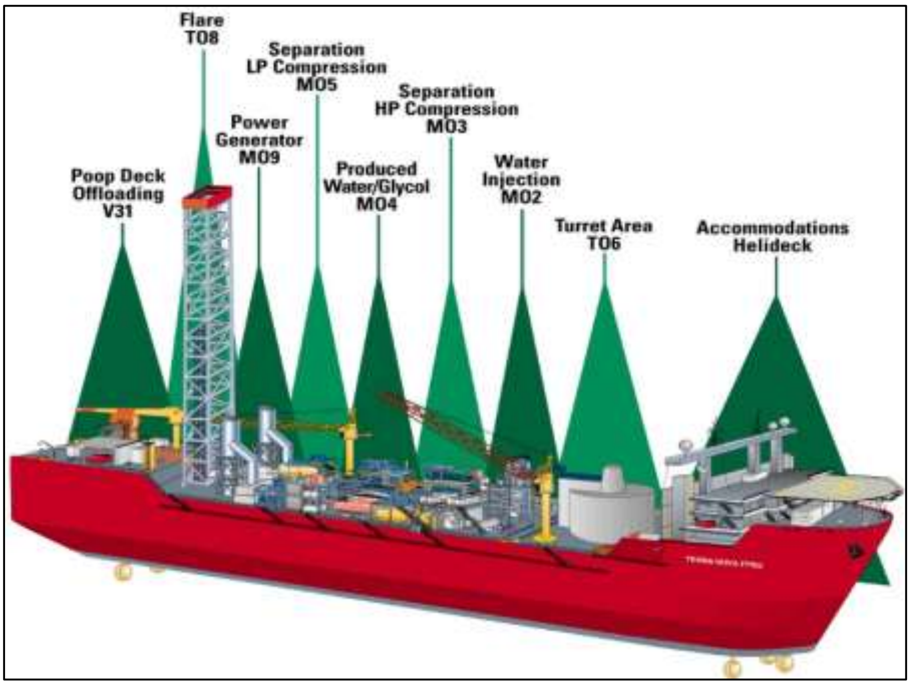

Figure 1.2: Structure Parts and of an FPSO (Retrieve from: Marine Insight)

1.3 Advantages of FPSO

There are several advantages of using FPSO vessels for oil and gas exploration in offshore field. FPSO are more economical as compared to fixed platforms because they have huge storage capacity and they do not require costly long distance pipelines to an onshore terminal. In addition, this floating structure can be decommissioned once it is used and can be reused again by relocating it to other fields. Another advantage of FPSO is that they can be used in any water depth and the ample deck space of the FPSO can reduce the risk of oil spilling. Besides, the FPSO vessels can rotate freely at any direction in respond to critical environmental condition or bad weather situation and can release mooring for safety purposes.

1.4 Dynamic Response and Wave Loads acting on FPSO

FPSO is usually designed for a specific location by considering its dynamic responses due to wind, wave and current. This is because in the design of floating structure like FPSO, the dynamic response and environmental loads acting on FPSO plays a very crucial part in the design. Among all the environmental loads, only wave load will be focused in this study. Chakrabarti (2001) stated that structures are able to move due to motion waves.

The structure is assumed to be rigid and experiences a total of six independent degrees of motion – three translational and three rotational. The six degrees of motion of a floating structure includes surge, heave, sway, roll, yaw and pitch. All six degrees of freedom will be measured for this study. There are different types of wave conditions such as regular wave, irregular wave and random wave. Only random wave will be discussed in this study.

1.5 Problem Statement

Due to the growing demand for oil and gas, floating structures such as FPSO vessels have been installed worldwide to explore oil resources in deep water instead of shallow water. FPSO is becoming more popular as a means of developing marginal fields. However, a lots of factors such as wave actions and loads on FPSO need to be taken into account to ensure that the design of FPSO is acceptable. One of the challenging engineering problem is to design a moored FPSO that is effective and with minimum environmental impacts. Moreover, extreme environmental condition may also bring effect to the floating structures that is going to be designed. The effect of wave loads on FPSO has become one of the issues to be solved. This is because waves cause the dominant environmental loads and the evaluation of responses due to real random waves is necessary for the analysis and preliminary design of FPSO.

Besides, there are no studies have been reported on dynamic responses of FPSOs in Malaysian waters based on the literature review. Therefore, it is very crucial to investigate the dynamic response of FPSO due to environmental load condition. The motion of the structure should be identified in addition to the wave forces in order to determine the stress distribution on the structure. The design of the structure is acceptable when it is able to withstand extreme condition with a longer period of serviceability. In a nutshell, a study on dynamic response of FPSO due to environmental loads is necessary for the operation of the structure in deep water.

1.6 Objectives of the Study

The purpose of doing this project is basically to investigate the dynamic response of Floating, Production, Storage and Offloading (FPSO) unit subjected to random waves. There are a few objectives that needs to be achieved at the end of this project. The objectives are as such:

1) To evaluate the dynamic responses in six degrees of freedom for FPSO in Malaysian metocean conditions using SESAM software.
2) To measure the dynamic responses of FPSO in surge, heave and pitch using wave tank model tests for few selected metocean data and to compare with numerical results.

1.7 Scope of Study

There are a few parameters that needs to be taken into account in order to analyze the dynamic responses of Floating, Production, Storage and Offloading (FPSO) subjected to random waves. For the experimental study, FPSO model is selected and fabricated with the scale of 1:100. The mooring lines connected to the FPSO is considered as nonlinear spring with insignificant mass and damping in the uncoupled analysis. Spread mooring system will be used to anchor the FPSO to the sea bed and only horizontal excursion of the mooring line will be considered.

In this study, the type of wave condition measured is random wave and the structure experiences a total of six independent degrees of motion – three translational and three rotational. The FPSO is considered free to move in six degrees of freedom which are in surge, heave, sway, pitch, yaw and roll.

The wave force on FPSO is calculated using diffraction theory. Besides that, the Linear Airy Wave Theory is used to calculate fluid particle velocity and acceleration. Response Amplitude Operator (RAO) is used as amplitude factor to identify the responses at surge, heave, pitch, yaw, sway and roll motion direction.

Hydrodynamic analysis is conducted to determine the motion of FPSO in surge heave and pitch motion in random wave by using frequency domain analysis method. The wave profile is generated using Jonswap wave spectrum in random wave. The research is conducted on dynamic response characteristics of FPSO in Malaysian deep water and the research parameters are water depth, metocean data and structure data.

1.8 Relevancy of Project

This research is more focus on the understanding of environmental condition from the metocean data obtained for the dynamic response of the FPSO under random wave. From this research there is clear correlation between the knowledge gained from offshore structure course with actual analysis that has been done. The basic knowledge that already in hand help to ease work throughout the duration of 8 months.

1.9 Feasibility Study

The availability of resources have given a positive outcome for this entire project. The data, facilities and resources are provided either by UTP and parties interested.

a) Metocean Data - Provided by PETRONAS (PETRONAS Technical Standards)

b) Facilities - 1.0 m depth wave tank in offshore laboratory for the actual observation of the responses of the barge.

c) Support and Technical Expertise - From supervisor which have many years of experience in offshore structure.

d) Referencing material - The availability of resources from Information Resource Centre (IRC) for books, journal and research paper.

CHAPTER 2

LITERATURE REVIEW

2.1 Theoretical Background

Nowadays, Floating, Production, Storage and Offloading (FPSO) unit have been widely utilized as the search for oil resources moves into deeper water. It is believed that many FPSOs will be designed and installed in the future for deep water exploration. Therefore, it is crucial to study about the dynamic response of FPSO subjected to environmental loads. Numerous studies have been carried out by the researchers regarding the dynamic behavior of FPSO and single point mooring system. For example, Pinkster and Remery (1975) had conducted model test of single point mooring system. Besides that, numerical studies and experimental investigation on dynamic response of FPSO subjected to wave loads has also been conveyed. Luo and Baudic (2003) had done investigation on FPSO responses through model testing and experimental study.

2.2 Wave Induced Loads and Motions on Floating Structures

The basic knowledge in understanding the wave induced loads and motions is very crucial for both design and model testing in the laboratory. According to Chakrabarti (2001), the motion of the structure should be known in addition to the wave forces on it in order to determine the stress distribution on such a structure. He said there are two approaches to be considered in the dynamic problem. The two approaches are frequency domain analysis and time domain analysis.

Frequency domain analysis is an analysis that is conducted to problems of floating platform dynamics and is useful for long term forecast. Frequency-domain analysis is very helpful in measuring the motion responses due to random waves input through spectral formulations (Chakrabarti, 2001). This analysis is much simpler to interpret if compared to time domain analysis. On the other hand, time domain analysis develops the numerical integration of equations of motion which includes all system nonlinearities such as fluid drag force, mooring line force, viscous damping and others.

There will be a series of motion that act on the floating body. According to Chakrabarti (2001), floating structures is assumed rigid and experiences six independent degree of freedom, in which three are translational and the other three are rotational. The FPSO is subjected to three-dimensional plane of hydrodynamic motion which results in six degrees of motion. All these motions are acting at the center of the structure. The translational motion comprises of surge heave and sway. These motions acts along the x, y and z axis. On the other hand, the rotational motion comprises of roll, pitch and yaw (Chakrabarti, 2001). Figure 2.1 shows the degrees of motion acting on the FPSO.

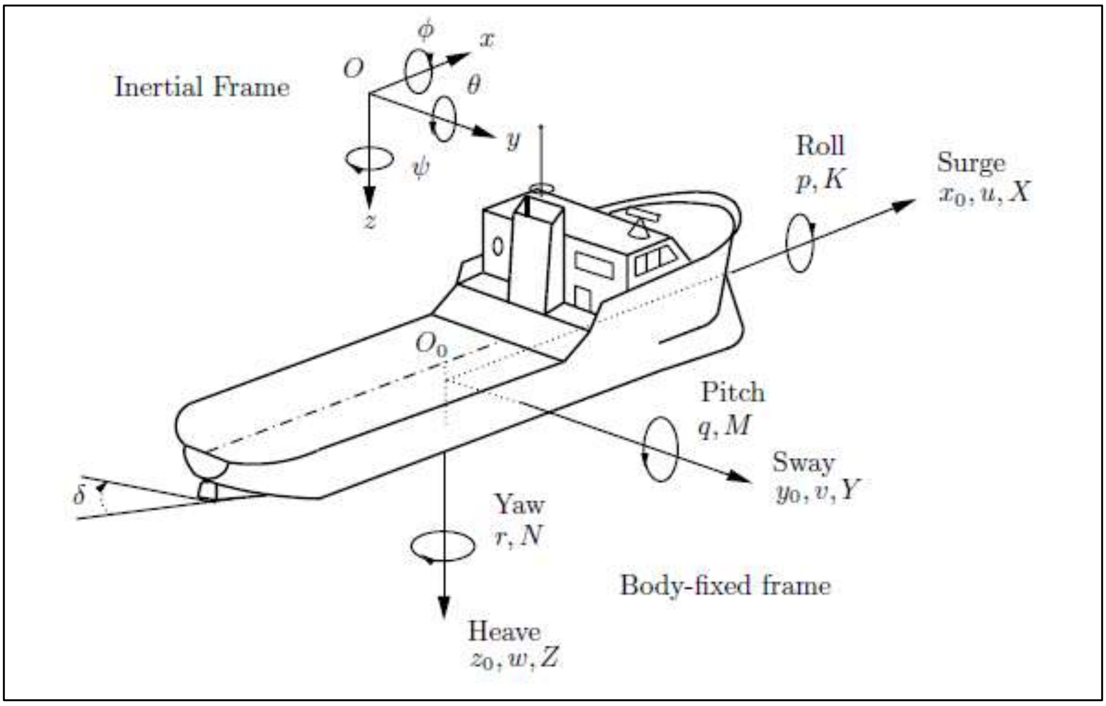

Figure 2.1: Six Degrees of Freedom of Floting Structure. (Retrieve from: Perez, 2002)

2.3 Wave Theory

Chakrabarti (2001) mentioned that different environments will have different water wave theories which depends on the environmental parameters like water depth (d), wave height (H) and wave period (T). The design of offshore structures are based on these three parameters. Common wave theories that are being used assumes that waves are two dimensional in XY plane (Chakrabarti, 2001). Therefore, wave theories are very important for the purpose of this study.

2.3.1 Linear Wave Theory

According to Chakrabarti (2001), linear wave theory or small amplitude wave theory is the simplest and most commonly used wave theory. It is also well-known as Airy Theory. In this theory, the assumption made is the wave height is smaller compared to the wave length or water depth. Therefore, it will permit the assumption of free surface boundary conditions. Moreover, this assumption also ensure that the free surface to be fulfilled at mean water level (MWL). Equation 2.1 presents the surface wave profile as shown:

$$\eta = \propto \cos(kx - \omega t) \tag{2.1}$$

$$= \frac{H}{2}\cos(kx - \omega t)$$

Type	Formula
Horizontal force	$u = \frac{\pi H \cosh ks}{T \sinh kd} \cos\theta$
Vertical Force	$v = \frac{\pi H \sinh ks}{T \sinh kd} \sin\theta$
Horizontal Acceleration	$\dot{u} = \frac{2\pi^2 H \cosh ks}{T^2 \sinh kd} \sin\theta$
Vertical Acceleration	$\dot{v} = -\frac{2\pi^2 H \sinh ks}{T^2 \sinh kd} \cos\theta$
Horizontal Particle Displacement	$\xi = -\frac{H \cosh ks}{2 \sinh kd} \sin\theta$
Vertical Particle Displacement	$\eta = \frac{H \sinh ks}{2 \sinh kd} \cos\theta$
Dynamic Pressure	$\rho = \rho g \frac{H \cosh ks}{2 \cosh kd} \cos\theta$

Table 2.1: Equations for kinematics and dynamics

2.3.2 Random Wave

Random waves are generated by winds blowing the sea surface which are not of the same height or period (Holmes, 2001). By referring to the linear wave theory, Holmes (2001) also point out that the waves with longer period travels at higher speed as compared to the waves with shorter period. Thus, the waves with longer periods have a tendency to travel faster than the waves with shorter period. The wave characteristics can be predicted by using the linear wave theory. Figure 2.2 shows the random wave profile.

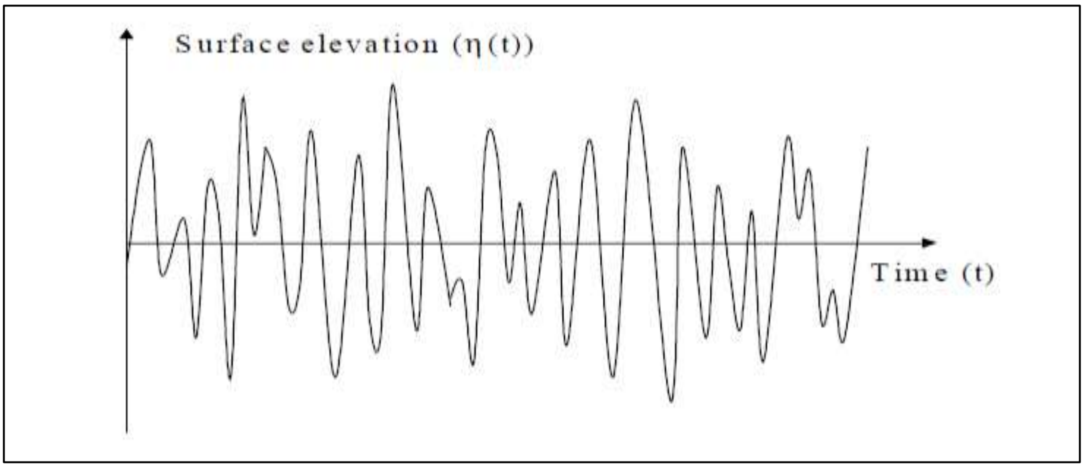

Figure 2.2: Random Wave Profile. (Retrieve from: Holmes 2001)

There are different types of ocean waves such as regular wave, irregular wave and random wave. The difference between the wave profile of these waves are presented in Figure 2.3.

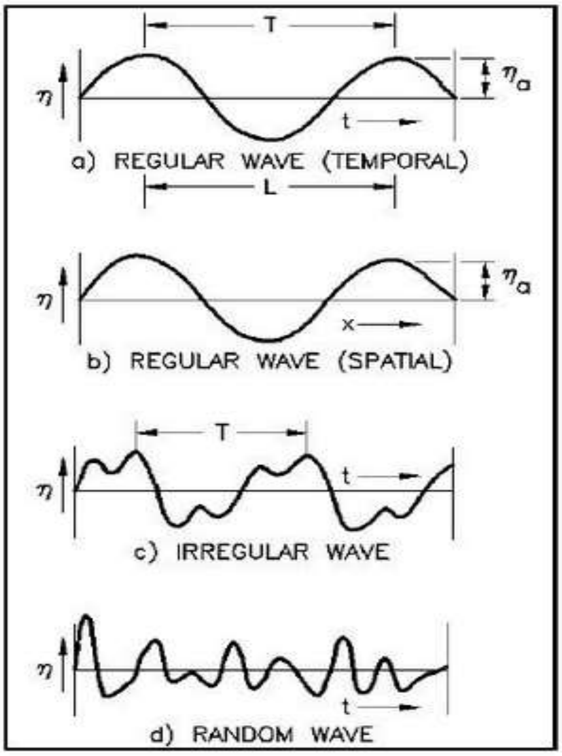

Figure 2.3: Representation of various types of wave profiles (Retrieve from: Chakrabarti,2001)

2.4 Wave Spectrum

There are basically two approaches which are considered for selecting the design wave environment (Chakrabarti, 2001). The two approaches are single wave method and wave spectrum. Single wave method represents the design wave by a wave period and a wave height while the wave spectrum represents the concept of wave energy density spectrum.

2.4.1 JONSWAP Wave Spectrum

JONSWAP wave spectrum were considered in this study. According to Chakrabarti (2001), this wave spectrum was developed during a joint North Sea wave. The formula can be written as:

$$S(\omega) = \alpha g^2 \omega^{-5} exp\left[-1.25\left(\frac{\omega}{\omega_0}\right)^{-4}\right]\gamma^{exp\left[-\frac{(\omega-\omega_0)^2}{2\tau^2{\omega_0}^2}\right]} \tag{2.2}$$

Where γ = peakness parameter

τ = shape parameter $\tau_a \; for \; \omega \; \leq \; \omega_0 \; and \; \tau_b \; for \; \omega \; > \omega_0$

Considering a prevailing wind field with a velocity of Uw and a fetch of X, the average values of these quantities are given by

γ = 3.30	may vary 1 to 7
τ_a= 0.07	considered fixed
τ_b= 0.09	considered fixed
$\alpha = 0.076(X_0)^{-0.22}$	α =0.0081 (when X is unknown)

2.4.2 Simulation of Wave Profile from Spectra

Chakrabarti (2001) stated that for particular frequency and energy density, the height of the wave is calculated using the formula below:

$$H(f_1) = 2\sqrt{2S(f_1)\Delta f} \qquad (2.3)$$

This relationship was transformed to calculate the motion spectrum in terms of wave spectrum and RAO. The following equation is obtained by multiplying the equation 2.4 with square of RAO from surge, heave and pitch direction. The equation is as shown:

$$S(f) = \frac{Fi/[(Hmax)/2]}{[(K - m\omega^2)^2 + (C\omega)^2]^{1/2}} \qquad (2.4)$$

2.5 Transfer Function or Response Amplitude Operator (RAO)

RAO is basically used as wave amplitude factor to determine the responses at all motion direction (i.e heave, pitch, sway, surge, yaw, and roll). The dynamic response of FPSO subjected to random wave is presented in terms of RAO. According to Kurian et al. (2012), the RAO can be expressed by using the equation 2.6:

$$RAO = \sqrt{\frac{S_R(f)}{S(f)}} \qquad (2.6)$$

S_R = the motion response spectrum of six degree of motion,

S = the wave spectrum

f = the wave frequency (Chakrabarti, 2001)

2.6 Dynamic response of floating structures due to waves

Wave is one of the most important load to be considered as it can cause great impact on the floating structure like FPSO. Froude-Krylov force and diffraction theory were proposed in order to calculate the wave forces on large structure (Chakrabarti, 2001). He explained that Froude-Krylov force is only applicable when the drag force is small and the inertia force dominates but the structure is still quite small while diffraction theory is used when the structure is large as compared to the wave length.

Chakrabarti (2001) specified that dynamic responses of FPSO subjected to wave motions can be also identified as transfer functions or Response-Amplitude Operator (RAO) in which it allows the transfer of the exciting waves into the response of the structure. He also defined RAO as the amplitude of response per unit wave amplitude.

Furthermore, Kurian et al. (2012) has conducted a study based on dynamic response on floating structure due to random waves in order to compare the experimental results and theoretical analysis which uses computer programs. The results of the model test which is subjected to random waves in surge, heave and pitch motion were expressed in terms of Response Amplitude Operators (RAO) as shown in Figure 2.4 until Figure 2.6. (Kurian et al., 2012).

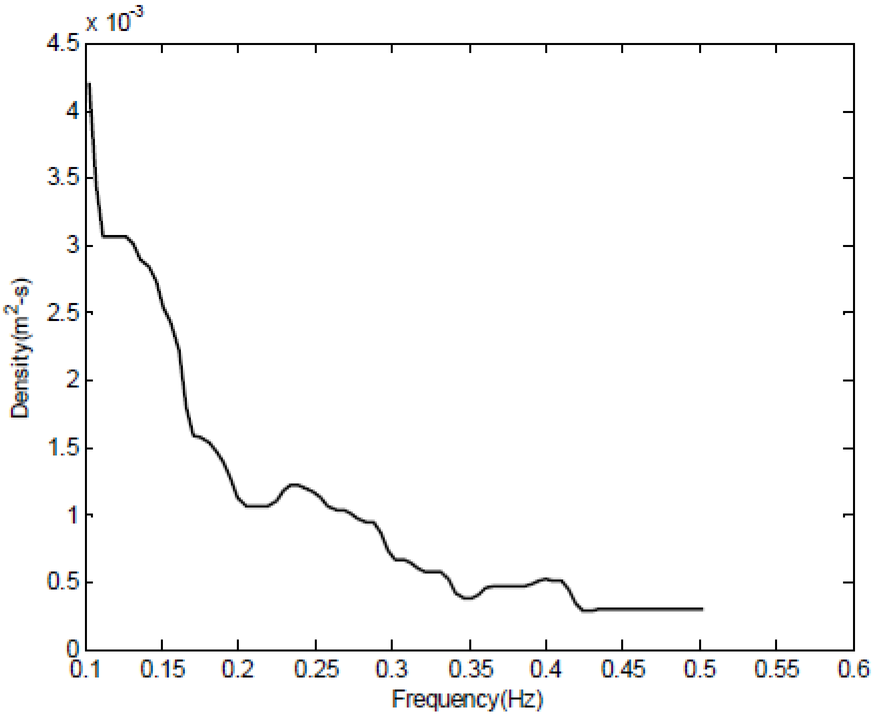

Figure 2.4: The measured surge response spectrum (Retrieve from: Kurian et al., 2012)

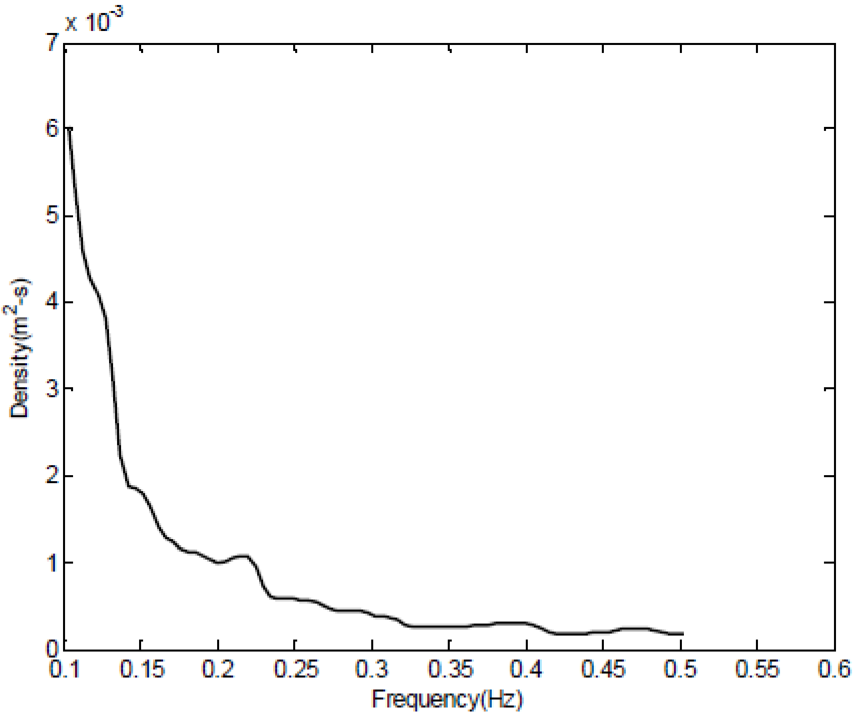

Figure 2.5: The measured heave response spectrum (Retrieve from: Kurian et al., 2012)

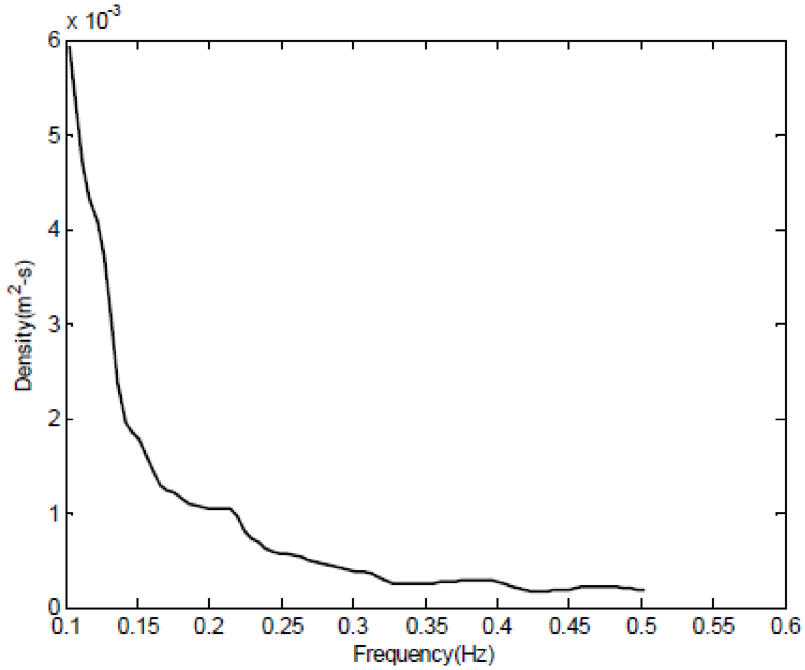

Figure 2.6: The measured pitch response spectrum (Retrieve from: Kurian et al., 2012)

Dynamic responses of the structure in surge, heave and pitch degrees of freedom were also investigated and the results from the model tests were compared with the numerical results which is based on both linear diffraction and Froude-Krylov theory as shown in Figure 2.7 until Figure 2.9 (Kurian et al., 2012).

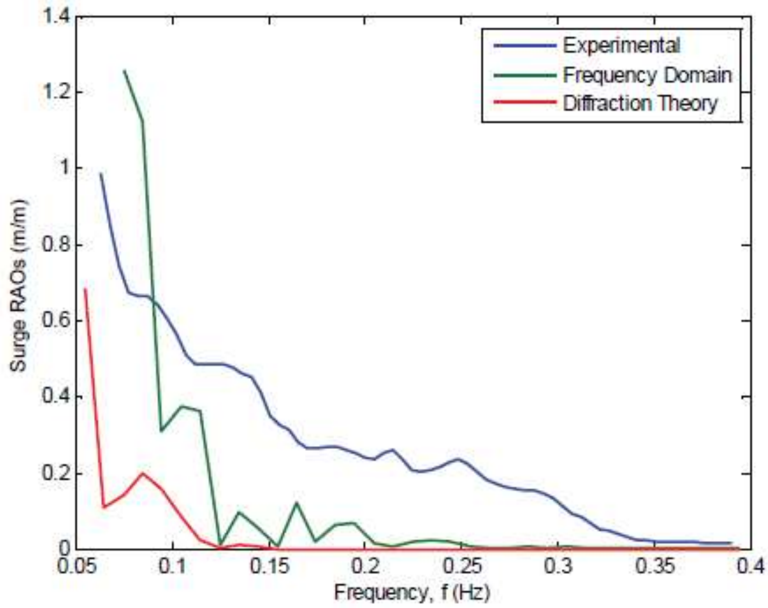

Figure 2.7: Comparison of surge motion RAOs (Retrieve from: Kurian et al., 2012)

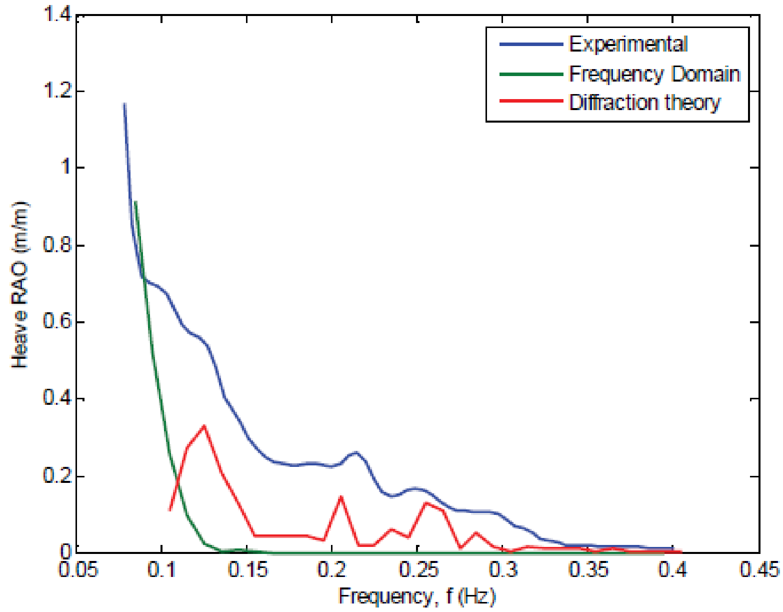

Figure 2.8: Comparison of heave motion RAOs (Retrieve from: Kurian et al., 2012)

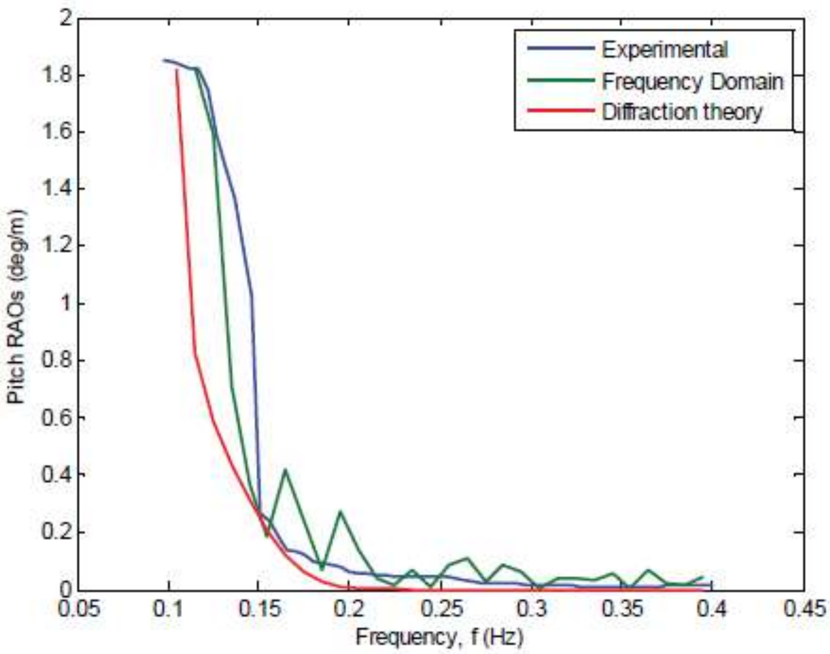

Figure 2.9: Comparison of pitch motion RAOs (Retrieve from: Kurian et al., 2012)

Further researches has been conducted on dynamic responses of FPSO due to environmental loads. Liu and Sakai (1996) had developed a numerical method to analyze the dynamic responses of large-scale floating structures to waves. They mentioned that the dynamic responses of structures due to waves are the most important factor to be studied. They used boundary element method (BEM) to evaluate the fluid motion and finite element method (FEM) to analyze the response of the structure.

Ma et al. (2012) has developed a mathematical model of a moored ship to examine the motion behavior of moored ships under common random waves and wave groups. They concluded that the surge motion of moored ship under random wave action is lower than the surge motion induced by wave groups. They also clarified that the roll motion is less sensitive while surge motion is greater when the spectrum peak frequency induced by wave group is close to natural frequency.

2.7 Dynamic Response of Single Point Mooring Systems and Ships

A few researches had been conducted to study the dynamic analysis and model testing of ship shaped vessel. Since FPSO is a ship-shaped vessel, therefore it is important to discuss the dynamic behavior of ships. Besides that, the wave motion on FPSO can be large due to extreme environmental load or bad weather condition. Therefore, the study on the model testing of single point mooring system of FPSO has to be discussed.

A comparisons between two linearization theories used for ship motion problem which are Neumann – Kelvin and Double – Body linearization has been made (Kim et al., 2010). The purpose for the comparison is to identify the hydrodynamic coefficients, motion responses and load. They concluded that double body linearization is suggested for low Froude number and wide displacement ships while Neumann – Kelvin is better for high Froude number and for slender bodies.

Hassen et al. (2013) prepared some computation by using linear potential-theory to study the effect of bow shape, the pitch radius of gyration and water depth on mean surge drift force. It has been found that the drift forces are sensitive towards changes of gyration and the mean surge drift forces are highly sensitive towards the bow shape. Figure 2.10 shows the mean surge drift force transfer function in head seas for wave direction of 180 degrees.

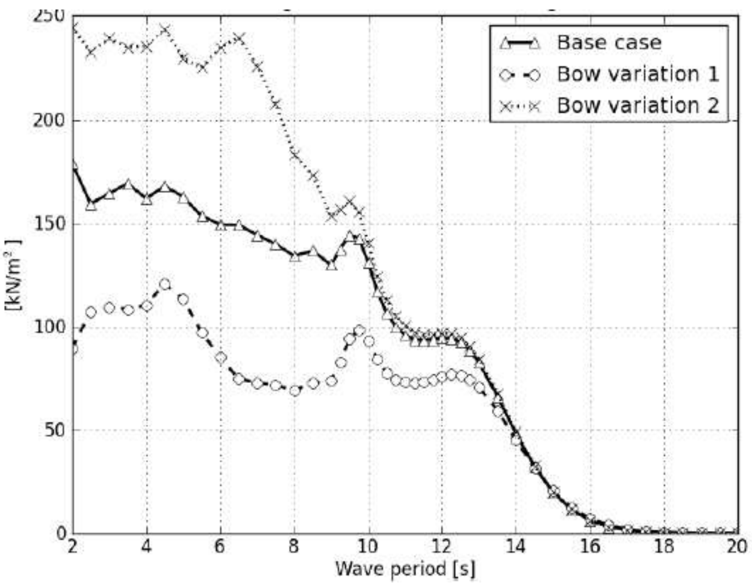

Figure 2.10: Mean surge drift force transfer function in head seas for three models (Retrieve from: Hanssen et al., 2013)

A computational fluid dynamics simulation method was established by Wu et al. (2012) to predict the heave and pitch motions of ship in head waves. The flow around the ships were solved by using the kinematics equations of rigid body and the Reynolds Averaged Navier – Stokes (RAN) equations to predict the motion of ship in waves. They concluded that the simulation method can appropriately predicted the heave and pitch transfer functions which illustrate the ability of the present method to assess seakeeping characteristics.

Momoki et al (2012) proposed a method for analyzing the ship structural response in waves. They presented a calculation method for the pressure acting on a hull and confirmed the method by simulation of forced oscillation test in waves. Nonlinear strip method is used to calculate the ship motion and the wave load while the pressure distribution acting on the hull is directly calculated by computational fluid dynamics (CFD).

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2.8 Dynamic Response of FPSO

A few studies has been done by the researchers to investigate the dynamic behavior of ship-shaped vessels due to wave loads. Researches were conducted to study the dynamic response and model testing of FPSO.

Heurtier et al. (2001) conducted a numerical study regarding dynamic responses of moored FPSO subjected to environmental sea loads. A comparison case study was made between uncoupled and coupled analysis of the moored FPSO in harsh environment condition. He concluded that it is effective to use uncoupled analysis for early design phase of mooring system and there was a good agreement between both uncoupled and coupled analysis even though the maximum values are different.

This study was further justified by Luo and Baudic (2003), where investigation on FPSO responses in deep water was done by conducting model test and numerical analysis. They applied both coupled and non-coupled time domain analysis method to study the motion responses of FPSO. They summarizes that the non-coupled analysis is more efficient and preliminary design of FPSO mooring systems can be done using this analysis.

An experimental study has been conducted to investigate the motion responses of FPSO vessel moored in irregular wave (Ha, 2011). He carried out the investigation based on both frequency and time-domain approaches by using three-dimensional panel method, fast time-domain technique and by solving six coupled equations of motion. He concluded that a comparison with simulation results by using software will be valuable for a further study.

On the other hand, a dynamic analysis program in time domain was developed to simulate the global motion of a turret moored FPSO (Kim et al., 2005). They carried out a physical model testing to study the vessel global motion and mooring tension for non-parallel wind, wave current and 100 year hurricane condition in Gulf of Mexico. They also compared the numerical results with the model-testing results and the results were in good agreement.

Choi and Lee (2000) carried out a study on the dynamic behavior of a FPSO-Shuttle tanker system in current, wind and waves. They used a three dimensional singularity distribution method to describe the fluid motion based on potential theory. Nonlinear responses of the system are simulated numerically while the static and dynamic stability are analyzed based on the linearization equation of motion in surge, sway and yaw modes.

2.9 Critical Analysis of Literature

Based on the research done, there are several studies that have been conducted on dynamic analysis of FPSO using numerical methods and model testing. But this is the first attempt of obtaining the dynamic responses of FPSO subjected to random waves in Malaysian water by using SESAM software.

Moreover, there are very few experimental study by using wave tank test to study the dynamic responses of FPSO due to random waves with six degrees of freedom. Therefore, more experiments have to be conducted to investigate the dynamic response of FPSO subjected to random wave under six degrees of motion. Furthermore, there are no research has been conducted on dynamic response characteristics of FPSO in Malaysian water. According to all the information gathered, this proves that the present study are essential. Thus, the studies on dynamic responses of FPSO subjected to random wave by wave tank experiments and simulation model have to be investigated and compared.

CHAPTER 3

THEORETICAL CALCULATION

3.1 Wave Forces on FPSO

According to Chakrabarti (2001), when wave hits the floating offshore platform, it generates forces which is based on the following condition:

1. Morison Equation
    - The force composes of drag force and inertia force in which the drag force is very big in value. This usually happens when the offshore structure is small compared to the wavelength.
2. Diffraction Theory
    - When the waves smashes the offshore structure, waves tend to scattered from the surface of the platform in the form of reflected waves.
3. Froude-Krylov Theory
    - If neither separation (structure not too small compared to wave length), or (structure not too large compared to wavelength), then this theory is applicable.

3.2 Diffraction Theory

As the structure of FPSO is very big and have larger surface area compared to the incident wave, the wave experiences scattering from the surface of the structure in the form of reflected wave. Deo (2013) stated that the diffraction of waves involves energy transfer laterally along the crest line. The height of the incident wave and the patterns of its direction changes following the diffraction.

In diffraction theory, the flow is assumed to be irrotational, incompressible and inviscid. In potential theory, the total velocity potential is equal to the sum of the incident and scattered potential.

$$\phi = \phi_0 + \phi_s \tag{3.1}$$

It has to satisfy the Laplace Equation:

Laplace Equation:

$$\nabla^2\phi = \frac{\partial^2\phi}{\partial x^2} + \frac{\partial^2\phi}{\partial y^2} + \frac{\partial^2\phi}{\partial z^2} = 0 \qquad (3.2)$$

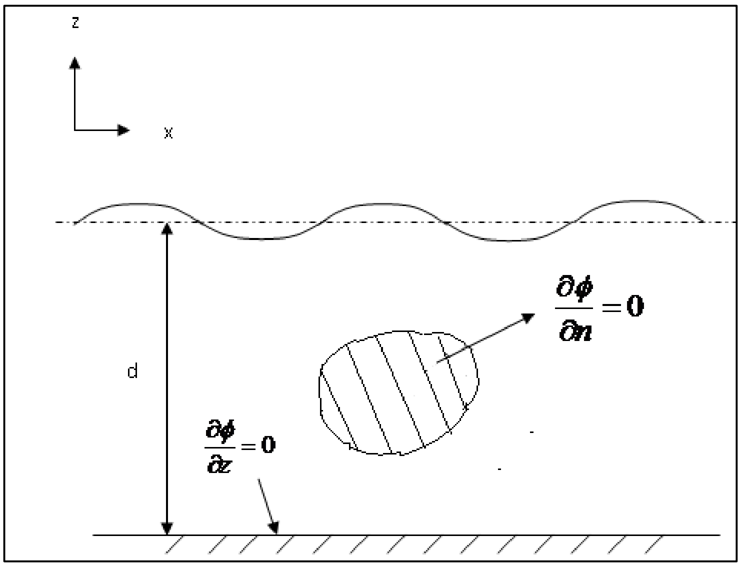

Figure 3.1: Boundary Condition

The free surface boundary condition:

1. Dynamic Boundary Condition

$$\frac{\partial\phi}{\partial t} = g\eta + \frac{1}{2}\left[\left(\frac{\partial\phi}{\partial x}\right)^2 + \left(\frac{\partial\phi}{\partial y}\right)^2 + \left(\frac{\partial\phi}{\partial z}\right)^2\right] = 0 \text{ on } y = \eta \qquad (3.3)$$

2. Kinematic Boundary Condition

$$\frac{\partial\eta}{\partial t} + \frac{\partial\phi}{\partial x}\frac{\partial\eta}{\partial x} + \frac{\partial\phi}{\partial z}\frac{\partial\eta}{\partial z} - \frac{\partial\phi}{\partial y} = 0 \text{ on } y = \eta \qquad (3.4)$$

3. Bottom Boundary Condition

$$\frac{\partial\phi}{\partial y} = 0 \text{ on } y = -d \qquad (3.5)$$

4. Body surface Boundary Condition

$$\frac{\partial\phi}{\partial\eta} = 0 \text{ on } -d \le y \le \eta \qquad (3.6)$$

Radiation Condition:

$$\phi_s \rightarrow 0, at\ very\ large\ radial\ distance\ from\ the\ object \tag{3.7}$$

Sommerfield R.C. (at large radial distance R the scattering effect is zero)

$$\lim_{R \to \propto} \sqrt{R} \left(\frac{\partial}{\partial R} \pm i\lambda \right) \phi_s = 0 \tag{3.8}$$

CHAPTER 4

METHODOLOGY

4.1 Introduction

As referred to the objective, the purpose of doing this project is to study the dynamic responses of FPSO subjected to random waves. This research involves physical model testing of Berantai FPSO and simulation of the model by using software.

4.2 Research Methodology

The research flow of this project is as shown in Figure 4.0. The research starts with the project selection until the conclusion and recommendation. Once the topic is decided, extensive research on previous paper that is related to my topic was done in Literature Review section. Certain parameters have been looked for identifying the research gap before conducting the experiment in order to improve the previous research. By relating to this topic, the parameters considering this study are metocean data, structure data and water depth.

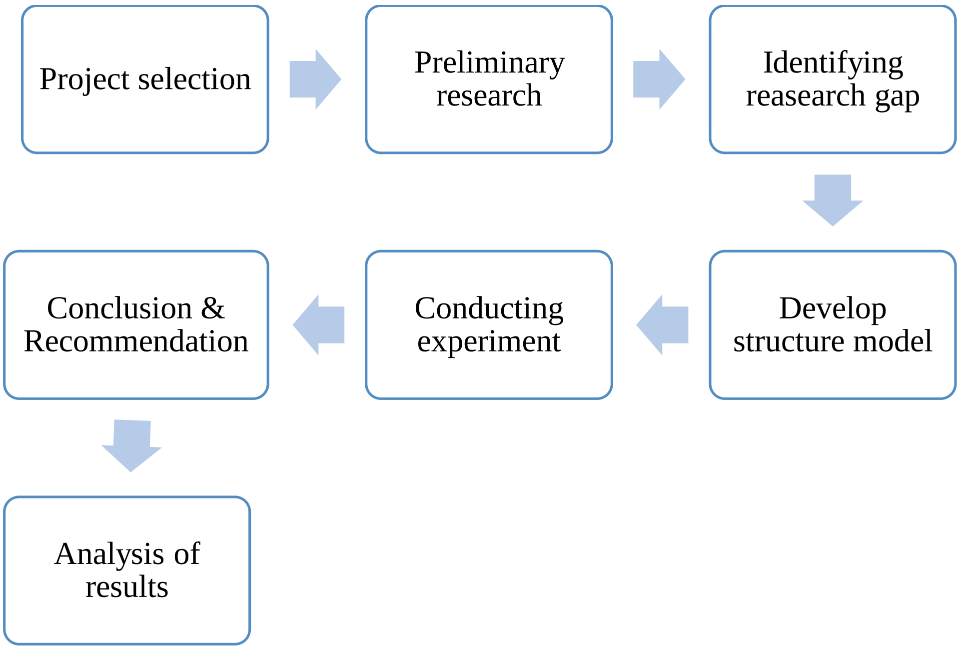

Figure 4.1: Research Flow of Project

4.3 Project Activities

i. **Investigate the dynamic response of FPSO using SESAM suite of programs.**

The hull model of FPSO is developed by using Rhino-3D and exported in SESAM GENIE V5.3-10 software. Finite element model is created by meshing after the full model of FPSO is developed by using SESAM GENIE V5.3-10.

Next, SESAM HYDRO D V4.5-08 software is used to investigate the dynamic response of the FPSO. Uncoupled analysis is performed in frequency domain method to obtain the response transfer functions using WADAM program. Strutural finite element analysis is performed using SESTRA and the results are presented using XTRACT V3.0-00. The inertia effects and hydrodynamic loading on mooring lines are neglected. Figure 4.1 shows the work flow by using SESAM MANAGER.

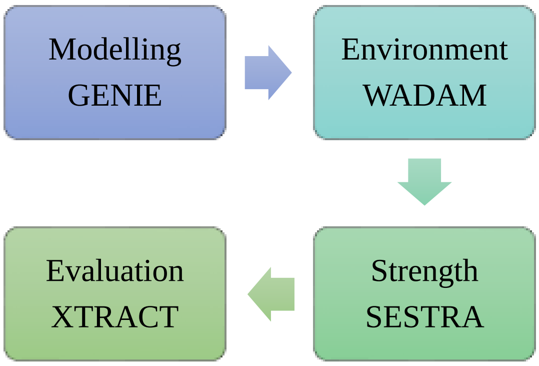

Figure 4.2: Work Flow in SESAM

SESAM software is a powerful tool in which it is used for designing and analyzing offshore structures made of beams and plates. Therefore, dynamic linear analysis for FPSO subjected to random wave is performed using this software.

The model will be developed based on the specification of the Berantai FPSO model as shown in Table 4.1.

Table 4.1: Specification of Berantai FPSO model

Specification	Design Scale
Length Overall, LOA (m)	207.43
Length Between Perpendicular, LBP (m)	198.68
Depth of ship, D (m)	16.75
Width of Ship, B (m)	32.25
Draft to Baseline (m)	12.603

ii. Wave tank experiments in Laboratory

This experiments are carried out in the wave tank of University Technology Petronas (UTP) offshore laboratory. A well-prepared experimental set-up is essential in ensuring the quality of the experimental results obtained. The laboratory experiment is conducted in a controlled environment whereby currents and wind will not be taken into consideration.

Detail step of the experiment:

1. The experiments are conducted on Berantai FPSO model using a spread mooring system. The dynamic responses of FPSO are measured for random waves.
2. The wave tank is equipped with multiple paddle maker which is able to generate random waves. Instruments required for the model tests are wave probe, load cells, accelerometers, wave generator, qualisys track manager and others. The wave probe are used to record the wave profile while the load cells are used to measure tension in mooring lines. Accelerometers are used to measure the acceleration of the model and the wave generator are used to generate random waves. The qualysis track manager is used to capture motion to get the exact position of FPSO.
3. All the equipment required for conducting the model tests are calibrated to ensure the results obtained are accurate.

4. The model is positioned in the wave tank and the motion is restrained by mooring system attached to linear spring. Random wave will be generated.
5. The data measurement will be obtained which includes the motion of FPSO in three degree of freedom and tensions in the mooring line. The Response Amplitude Operators (RAO) is obtained for surge, heave and pitch direction. All the necessary results and data are recorded.
6. After the experiments conducted in the laboratory, the simulation model of Berantai FPSO in SESAM will be validated with the model tests result obtained from laboratory.

4.4 Wave Tank Dimension

The dimension and specification wave tank are shown in the Table 4.2 and Figure 4.2.

Table 4.2: Dimension of Wave Tank in UTP Offshore Laboratory

Wave Tank	Dimension (m)
Length	20 m
Width	10 m
Depth	1.5 m

Figure 4.3: Wave Tank in UTP Offshore Laboratory

4.5 Model Description

The dynamic analysis is performed on the Berantai FPSO Model. The model scale adopted is 1:100. The details of Berantai FPSO model are given Table 4.3.

Table 4.3 shows the dimension of prototype modeled in GENIE V5.3-10.

Measurement	Full Scale	Model (1:100)	Unit
Displacement	68305.76	0.068	tone
Volume	66639.77	0.067	m^3
Draft to Baseline	12.6	0.126	m
LWL	198.68	1.987	m
LOA	207.43	2.07	m
LBP	198.68	1.99	m
B_{ext}	32.286	0.33	m
B	32.25	0.32	m
Depth of Ship	16.75	0.17	m
GT(ITC 69)	31308	0.031	tone
NT (ITC 69)	15612	0.016	tone
DWT	55337	0.055	tone
FB	4.15	0.04	m

WSA	9856.852	0.986	m^2
Max Cross Sect Area	404.786	0.04	m^2
Water plane Area	5748.848	0.575	m^2
C_p	0.829	0.829	
C_b	0.825	0.825	
C_m	0.996	0.996	
C_{wp}	0.897	0.897	
LCB from zero point	106.231	1.062	m
LCF from zero point	101.761	1.018	m
KB	6.53	0.065	m
KG	0	0	m
BMt	6.829	0.068	m
BMl	235.366	2.354	m
GMt	13.36	0.134	m
GMl	241.896	2.419	m
KMt	13.36	0.134	m
KMl	241.896	2.419	m
Immersion	58.926	0.006	tonne/cm
MTCM	831.625	0.001	tonne/cm

Figure 4.4: FPSO Model

4.6 Research Activities

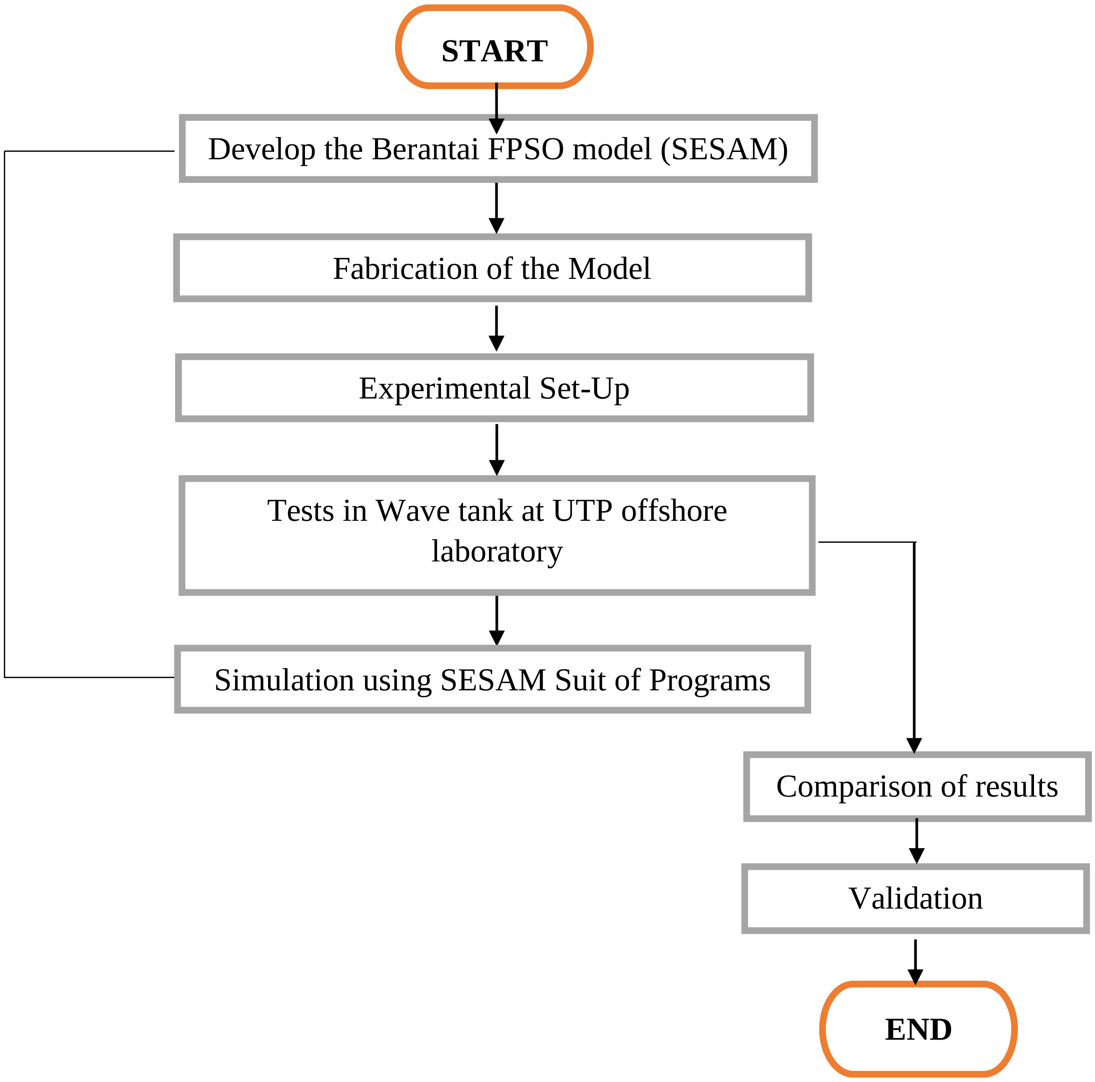

Figure 4.5: Flow chart of Research Activities

4.7 Environmental Design Conditions

The research is conducted on dynamic response characteristics of FPSO in Malaysian deep water. The environmental data is obtained from the Petronas Technical Standards (PTS). The location which is studied for conducting the model test is Erb West location under operating condition. The dynamic response for other location can be generated using SESAM software. The details are as shown in the Table 4.4.

Table 4.4: Environmental Data at 1 Year Operating Condition for Erb West

Environmental Condition	Erb (Operating)
Significant Wave Height (Hs)	3.60 m
Significant Peak Wave Period (Tp)	8.5 s
Associated Zero Wave Period (Tass)	7.9 s

4.8 Model Setup

The FPSO model is tested for random waves. The setup of the model test and the models used for the test are illustrated in Figure 4.6.

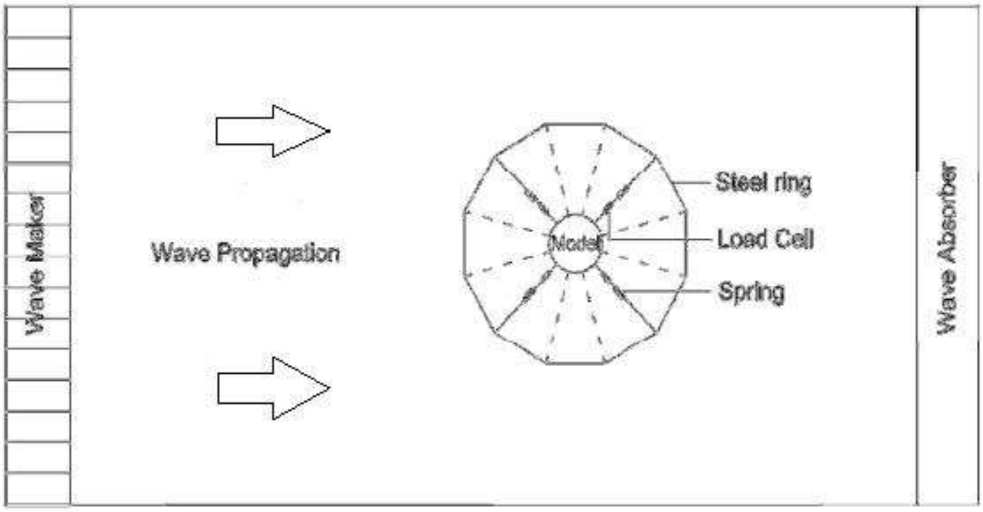

Figure 4.6: Model Set-Up in Offshore Laboratory

4.9 Calibration Tests

i. Static Offset Test
   - Static offset tests are carried out to determine the mooring system stiffness in surge, heave, pitch, yaw, sway and roll direction. Load cells are attached to the downstream mooring lines.

ii. Free Decay Test
   - The aim of this test is to calculate the damping ratio and the natural periods of the system in surge, heave and sway direction.

iii. Station Keeping Test: Waves
   - The purpose of this test is to measure the motion of Berantai FPSO subjected to random waves.

4.10 Project Timeline:

week 1-2

- Selection of project title.
- Finalize the project title after discussion supervisor.

week 3-4

- Preliminary research work
- Collect reference document
- Study on related topic - determine the objective and problem statement

week 5-6

- Prepare the literature review and do the extended proposal.
- Submission of extended proposal.

week 7-8

- Develop the hull model of FPSO using Rhino 3D software.
- Preparation of slide for proposal defense.

week 9-10

- Develop model of FPSO using SESAM software.
- Preparation of slide for proposal defense.

week 11-12

- Proposal defense
- Simulation of FPSO model using Genie V5.3-10.
- Preparing the interim report.

week 13-14

- Continue to develop the model using Genie V5.3-10.
- Submission of interim draft report.
- Submission of interim report.

week 15-16

- Continue with the modelling of FPSO using SESAM software.

week 17-18

- Set up wave tank test
- Develop panel model, structural model and composite model in SESAM.

week 19-20

- Conduct wave tank experiment.
- Hydrodynamic analysis of the model using Hydro D.
- Prepare progress report.

week 21-22

- Submission of progress report.
- Preparation for Pre-SEDEX.

week 23-24

- Continue with wave tank experiments in offshore laboratory.
- Pre-SEDEX.

week 25-26

- Record both results obtained from simulation model and model tests and made comparison.
- Submission of dissertation (soft bound) and technical paper.

week 27-28

- Viva.
- Submission of dissertation (hard bound).

4.10 Project Key Milestone:

Task (FYP 1)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of Project Topic	■	■												
Preliminary Research Work		■	■	■	■									
Submission of Extended Proposal						●								
Proposal Defense								■	■					
Project work continues										■	■	■		
Submission of Interim Draft Report													●	
Submission of Interim Report														●

Task (FYP 2)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project work continues	■	■	■	■	■	■	■							
Submission of progress report							●							
Project work continues								■	■	■	■	■		
Pre-SEDEX										●				
Submission of Draft Final Report											●			
Submission of Dissertation (soft bound)												●		
Submission of Technical Paper												●		
Viva													●	
Submission of Project Dissertation (hard bound)														●

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Numerical Studies

5.1.1 Modelling in Sesam Genie

The lines of the FPSO is generated in Rhinoceros 3d by using the dimension of the Berantai FPSO. The ship hull is then imported to Sesam Genie V5.3-10 and the model of the FPSO is developed using this software. Sesam is a tool used for designing and analyzing offshore and maritime structures made of plates and shells. First, the concept model of the Berantai FPSO is modelled using Genie V5.3-10. The final finite element model is created with redefined meshing. Figure 5.1 shows the concept model of Berantai FPSO.

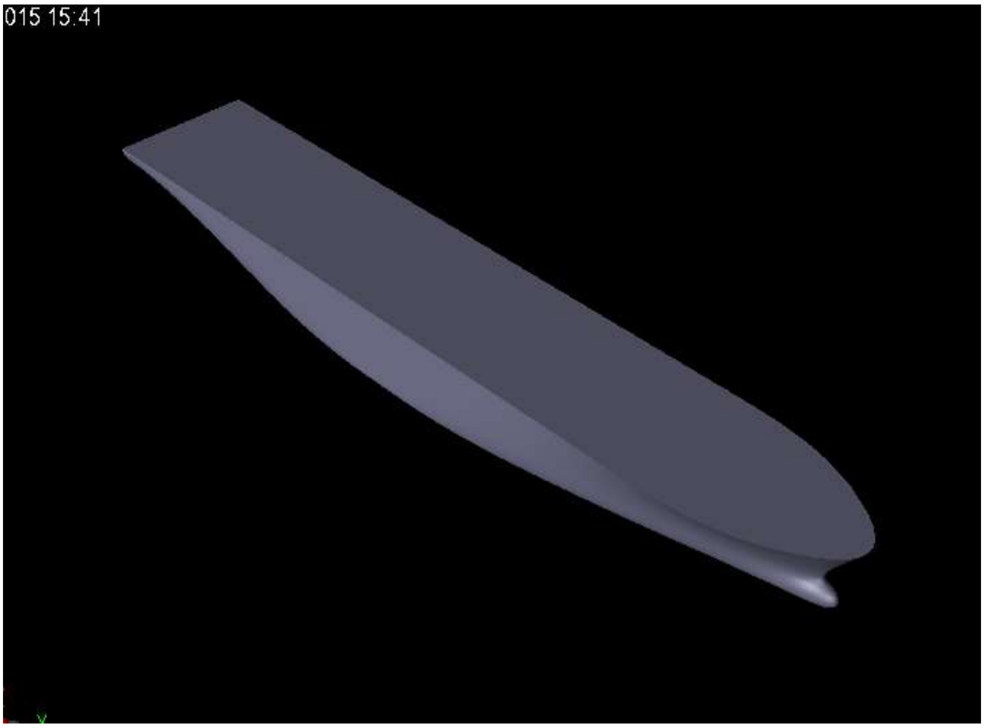

Figure 5.1: FPSO Concept Model

The outline of the ship-shaped FPSO structure is created by using guiding geometry tool and cover plates are assigned to the outline structure. After creating the model, the compartments for the Berantai FPSO model are generated. Figure 5.2 shows the side view of FPSO along with the compartments.

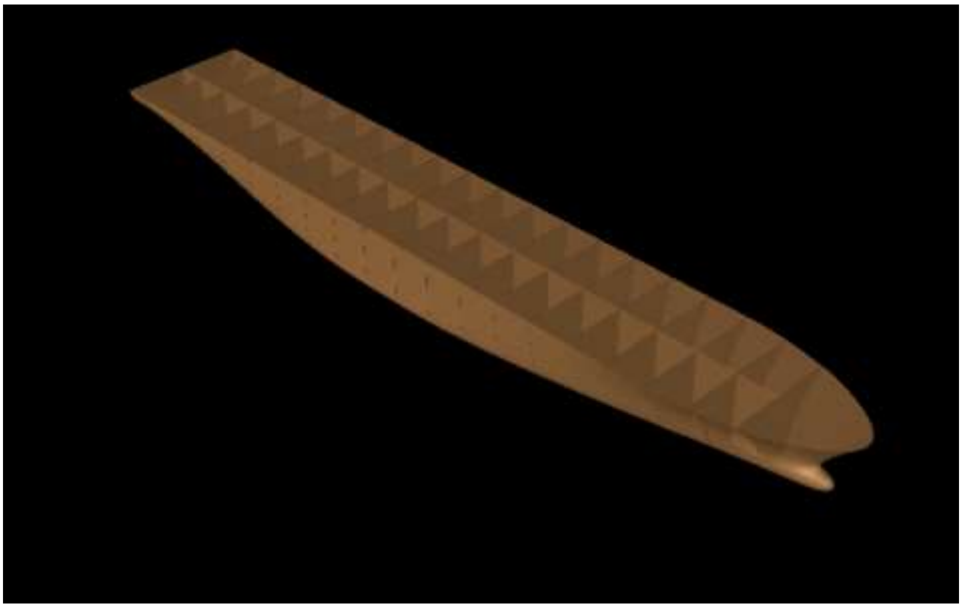

Figure 5.2: Side view of the FPSO model with compartments

Load cases are assigned for the hydro pressure acting on FPSO hull and the compartments. After creating the concept model, the panel model is also created by using Genie V5.3-10. This panel model is used for hydrodynamic analysis in HYDRO D. Panel model is developed by creating the portside half of the panel model. Figure 5.3 shows the half portside of the Berantai FPSO model.

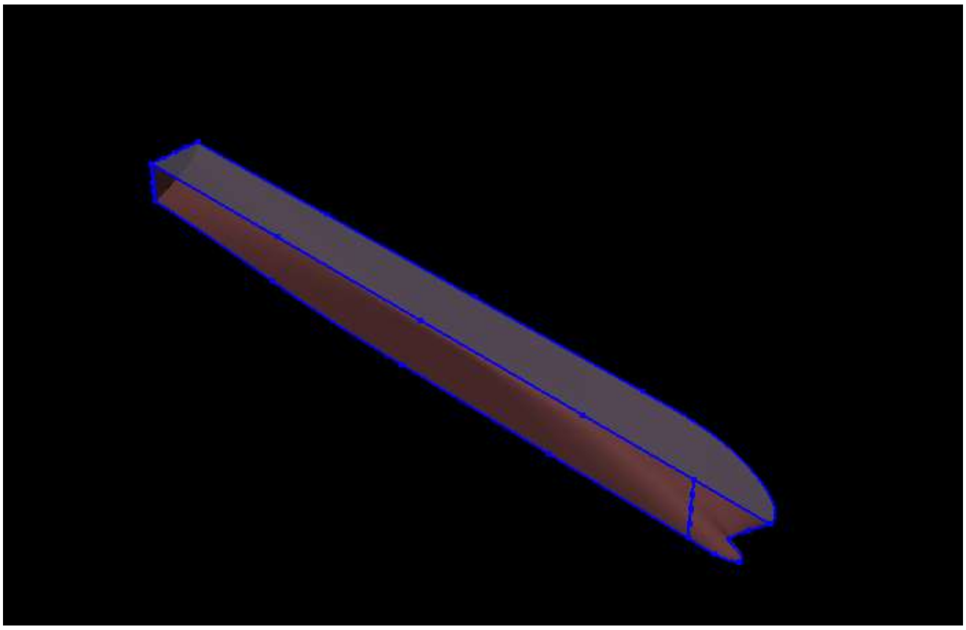

Figure 5.3: Half portside of the Berantai FPSO model

The following requirements is satisfied to develop the panel model:

- The hull form geometry from the global structural model is used
- The half model of the ship is adjusted to positive y-coordinates.
- Mesh line at maximum draught of 12.603 m.
- The bilge shape is kept as in the global model

The panel model mesh can be generated by using different ways of mesh controls in Genie. The panel model is divided into a regular rectangular panels by maintaining an element line at the maximum draught still water level. The division of the plates of the structure is carried out by using the actual plate element as a guideline. Figure 5.4 shows the panel model mesh created by using Genie V5.3-10.

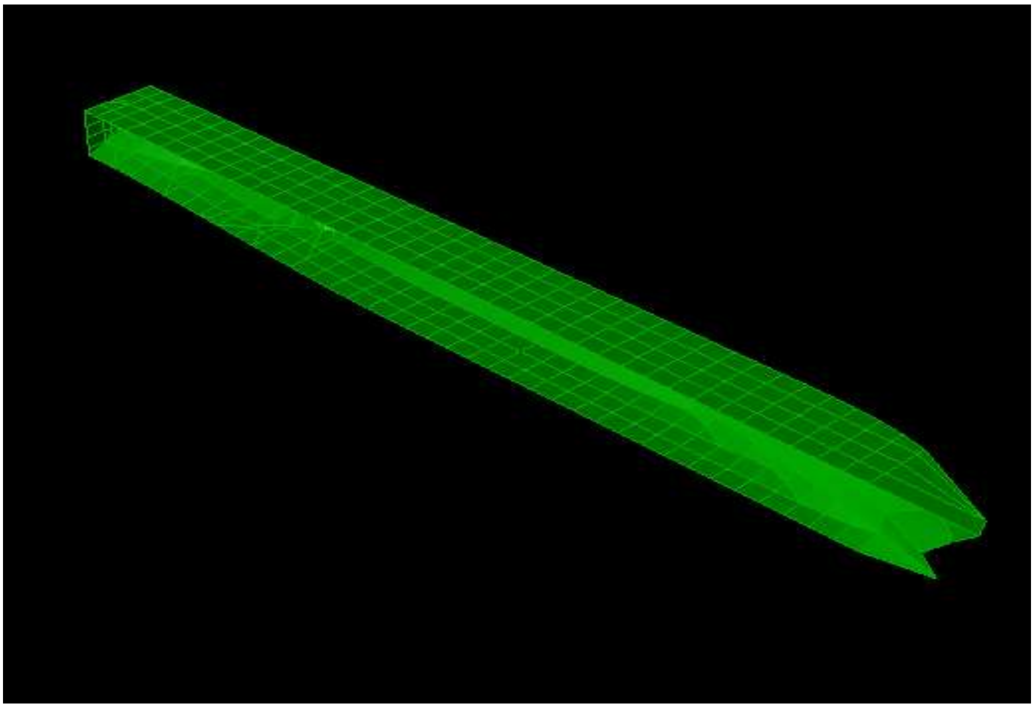

Figure 5.4: Meshing of the panel model

Finally, the plates of the whole model are divided accordingly at the maximum draft to create an accurate meshing The Morison and structural model are joined and the finite element mesh is generated for further analysis in Hydro D V4.5-08. The finite element mesh are as shown in Figure 5.5.

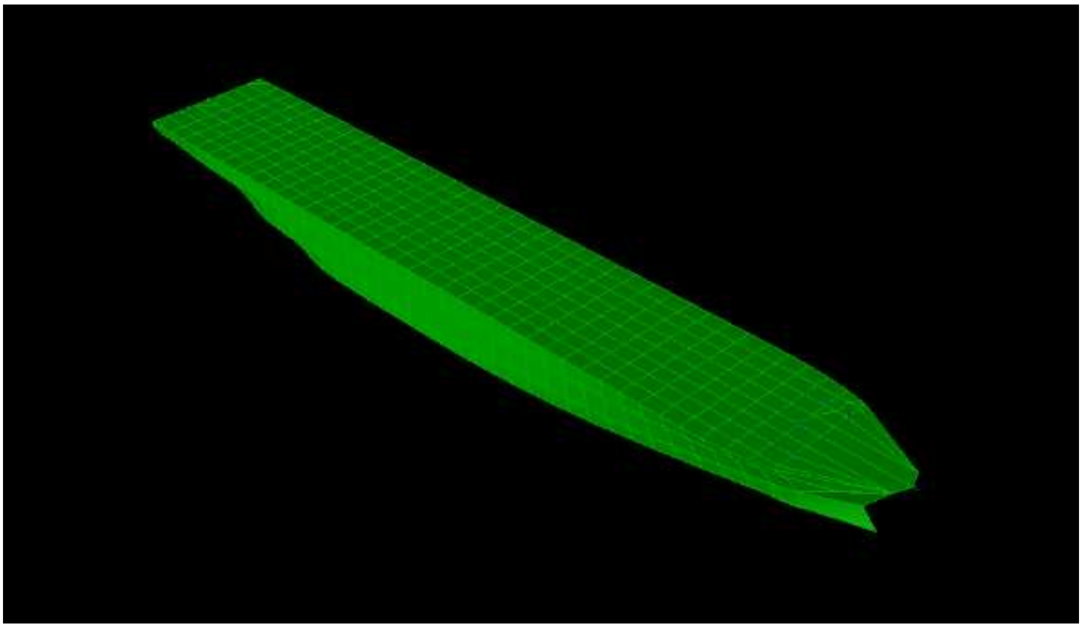

Figure 5.5: Finite Element Mesh for Composite model

5.1.2 Hydrodynamic Analysis of FPSO

The hydrodynamic analysis of Berantai FPSO is performed using HydroD V4.5-08. The finite element model which is generated in Sesam Genie V5.3-10 is used as an input to the HydroD. The structural model which consists of panel model and structural model is chosen as composite model in the wadam wizard settings. Johnswap spectrum is used to represent the design wave and there are total of two wave directions are considered for computing the responses which are 180 degree (head sea) and 90 degree (beam sea). The water depth of is given as 62 m according to the metocean data for Erb West location. The significant wave height is 3.6 m and the peak period is 8.5 s. Table 5.1 shows the input data which is used in HydroD for Erb West location.

Table 5.1: Input Data in HyroD (Erb West-Operating Condition)

Erb West – Operating condition			
Parameter	**Unit**	**Prototype Scale**	**Model Scale**
Hs	m	3.6	0.036
Tp	sec	8.5	0.85

The six degrees of freedom of the Berantai FPSO is calculated by using the input data or metocean data for Erb West location in HydroD. All the necessary details are given and the FPSO compartments generated are fully loaded. The results for all six degrees of freedom (6 DOF) are obtained. The response amplitude operators (RAO) for surge, heave, sway, roll, pitch and yaw for both head sea and beam sea condition are plotted against time. The Figure 5.6 and Figure 5.7 shows the graph of RAO for 6 DOF in head sea and beam sea condition.

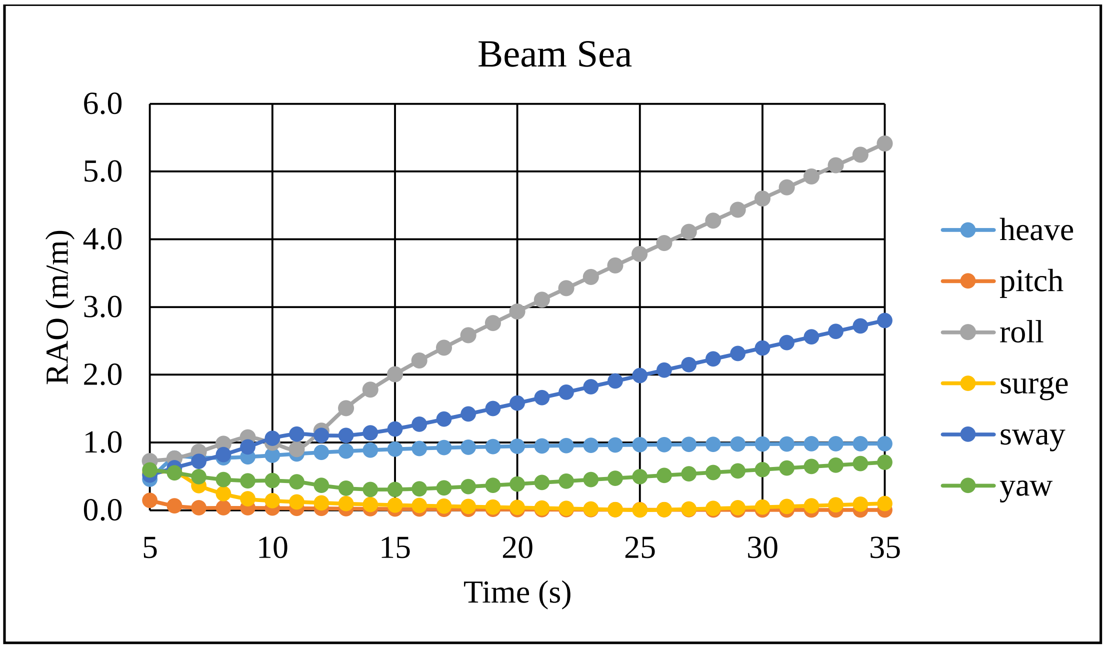

Figure 5.6: RAOs in Six Degrees of Freedom (Beam Sea Condition)

From Figure 5.6, it can be observed that the maximum response occurs for the beam sea condition at an angular frequency of 0.1795 rad/s and the RAO is 5.415 in roll. The roll response of the FPSO is found to be significant in the beam sea condition. This is because as wave hitting the roll of the FPSO, the higher RAO value for roll is obtained and this can be overcome by appropriate designing of the bilge keel. For sway motion, the RAO is 2.8025 at an angular frequency of 0.1795 rad/s. The RAO for the pitch, heave, surge and yaw motion of the FPSO is very small. Table 5.2 shows the maximum responses for all the motions in beam sea condition.

Table 5.2: Maximum RAOs for 6 DOF in Beam Sea Condition

Direction	RAO
Surge	0.5605
Sway	2.8025
Heave	0.9831
Roll	5.415
Pitch	0.1426
Yaw	0.7074

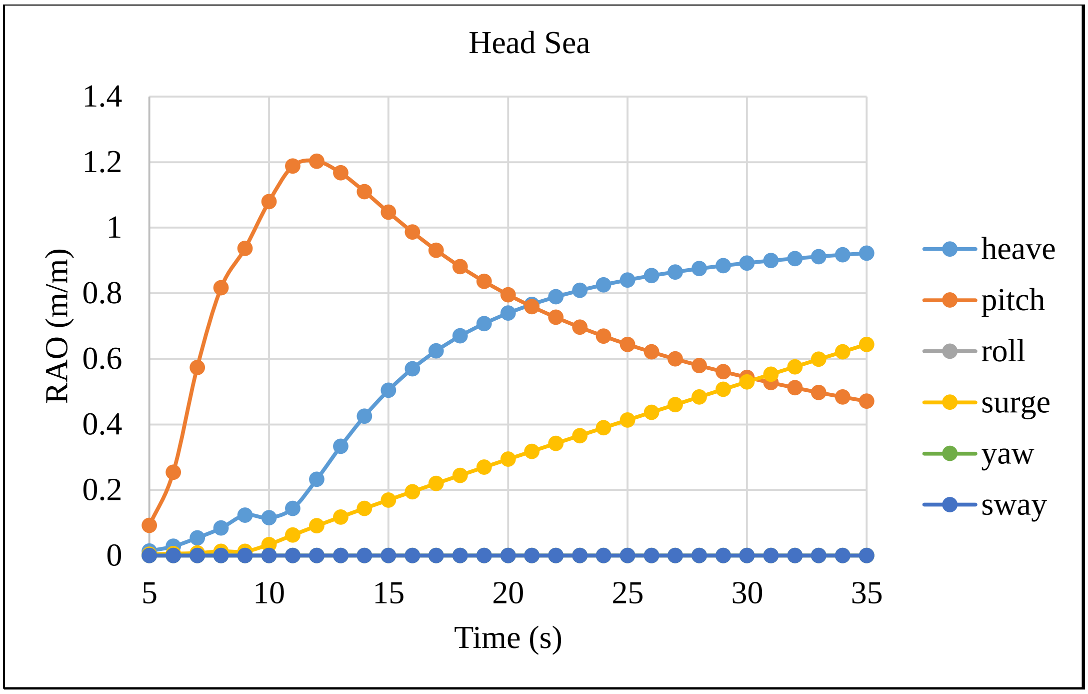

Figure 5.7: RAOs in Six Degrees of Freedom (Head Sea Condition)

From Figure 5.7, it is found that the pitch RAO is 1.203 at an angular frequency of 0.5236 rad/s and the heave RAO is 0.9222 at an angular frequency of 0.1795 rad/s when the FPSO is in the head sea conditions. The RAO for pitch and heave RAO are well within safe limits whereas the surge RAO is 0.6442 which is also within the safe limits. As we can see from the Figure 5.7, pitch motion has higher RAO value as compared to heave and surge. As wave hitting the pitch of the FPSO, the higher RAO value for pitch is obtained. The RAO for sway, yaw and roll are very small and therefore it is negligible. Table 5.3 shows the maximum responses for all the motions in head sea condition.

Table 5.3: Maximum RAOs for 6 DOF in Head Sea Condition

Direction	RAO
Surge	0.6442
Sway	0.0002
Heave	0.9222
Roll	0.0015
Pitch	1.203
Yaw	0.0001

5.2 Experimental studies

5.2.1 Measured and Targeted Spectrum

During the experimental studies, the wave probe calibration is carried out. The wave spectrum is obtained as shown in Figure 5.8. The wave spectrum used for this study is Jonswap spectrum. The energy wave spectrum is generated using Jonswap spectrum with the significant wave height of 3.6 m and peak period of 8.5 s. The range of frequency that was used varies with 0 Hz to 0.5 Hz. The maximum wave energy for the targeted spectrum is at 0.12 Hz with density energy spectrum of 21.2 m^2/s whereas the maximum wave energy for the measured spectrum is at 0.12 Hz with density energy spectrum of 21.0 m^2/s. This shows that the wave generated in the wave tank is same with the targeted wave.

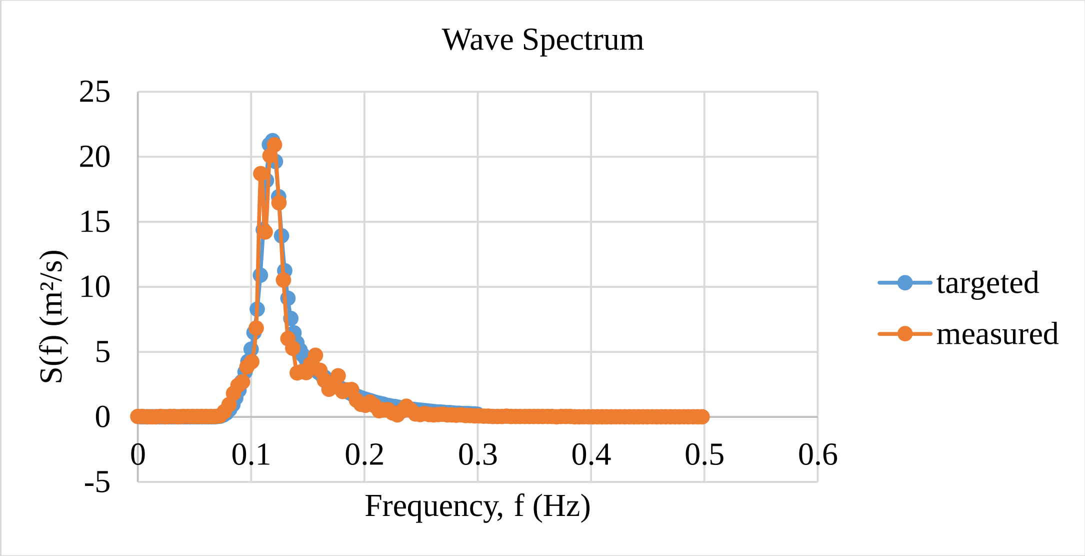

Figure 5.8: Jonswap Wave Spectrum for Hs=3.6m

5.2.2 Time Series Analysis

According to Chakrabarti (2001), time series is collection of observations of well-defined data obtained through repeated measurement over time. The data are obtained and presented in model scale as shown in Figure 5.9.

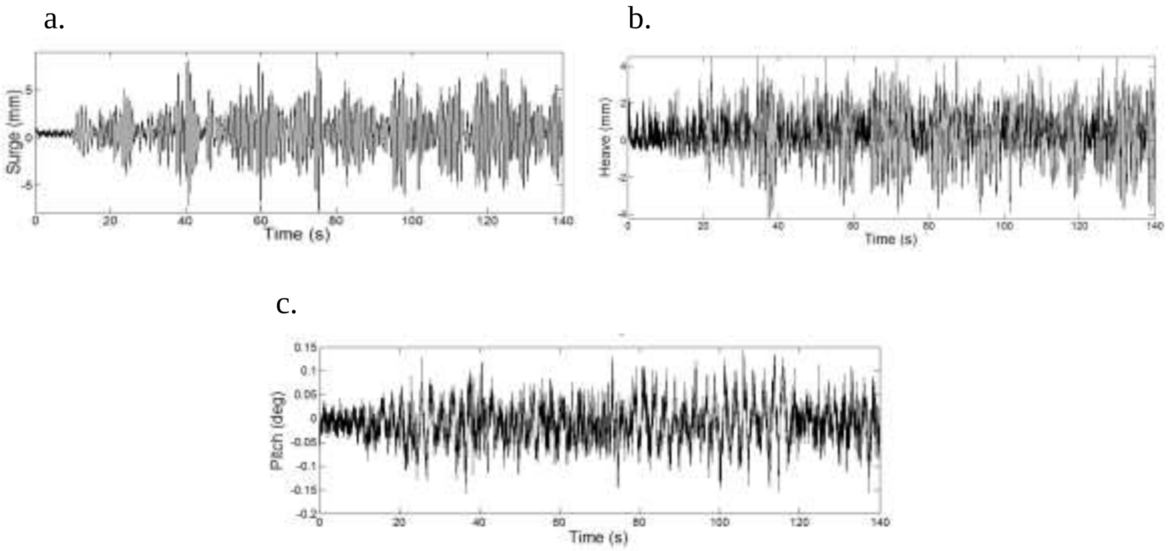

Figure 5.9: Motions of Random Waves

Based on the random waves graph for three degrees of freedom shown in Figure 5.9 a, b and c (surge, heave and pitch), we can observe the motions of the FPSO during the experiment is conducted. From the Figure 5.9 a. and Figure 5.9 b., we can see that the surge motion is about 20 mm and heave motion is about 8.5 mm. On the other hand, the pitch angular motion is about 0.3 degree as shown in Figure 5.9 c.

5.2.3 Wave Spectrum Analysis

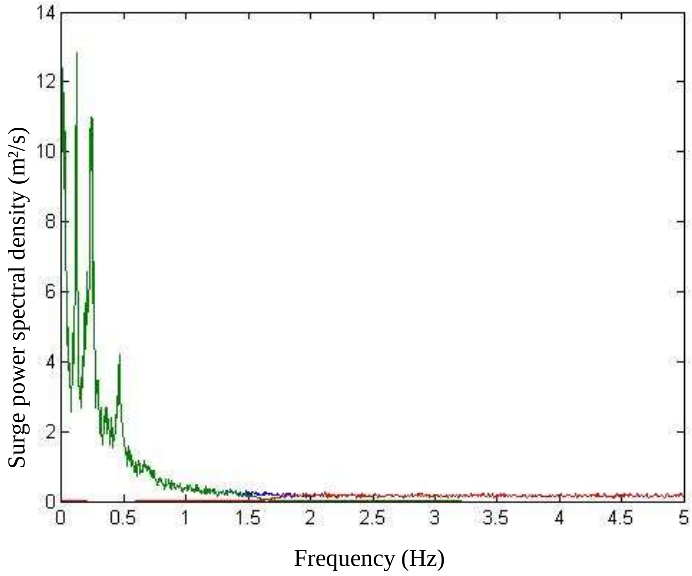

Figure 5.10: Wave spectrum of Surge Motion

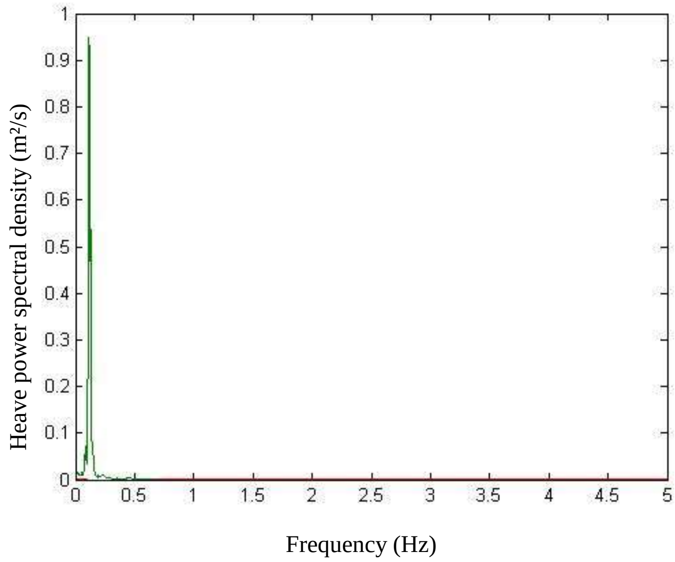

Figure 5.11: Wave spectrum of Heave Motion

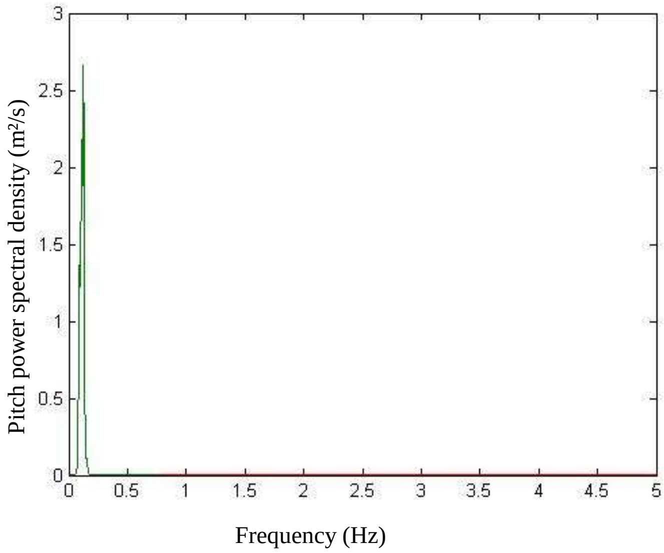

Figure 5.12: Wave spectrum of Pitch Motion

Based on Figure 5.10 to 5.12, the wave spectral density graphs are obtained for surge, heave and pitch motion. In Figure 5.10, the peak power spectral density of surge motion is 12.9 m^2/s at 0.12 Hz. For heave, the peak power spectral density is 0.95 m^2/s at 0.12 Hz and the peak power spectral density for pitch is 2.62 m^2/s at 0.12 Hz.

5.2.4 Static offset test results

The stiffness value for both surge and heave motion are obtained by doing static offset test in offshore laboratory. This values are needed in order to identify the stiffness of the mooring line which is attached to the FPSO model. The mooring line can control the movement of the FPSO model in wave tank. Therefore, it is necessary to find the stiffness of the mooring line. The larger the stiffness of the mooring line, the lesser the motion of the FPSO model in the wave tank. The mooring line stiffness value is presented in model scale as shown in Table 5.4.

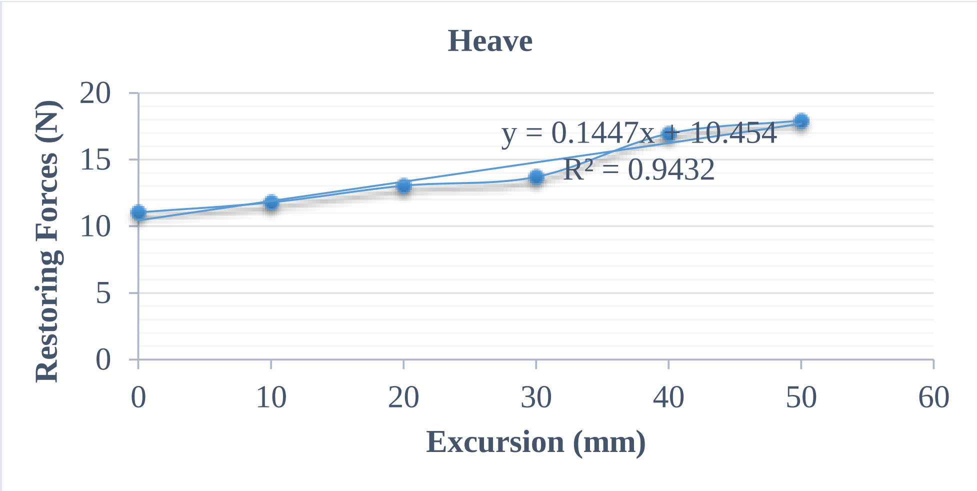

Figure 5.13: Static Offset Test Result - Heave

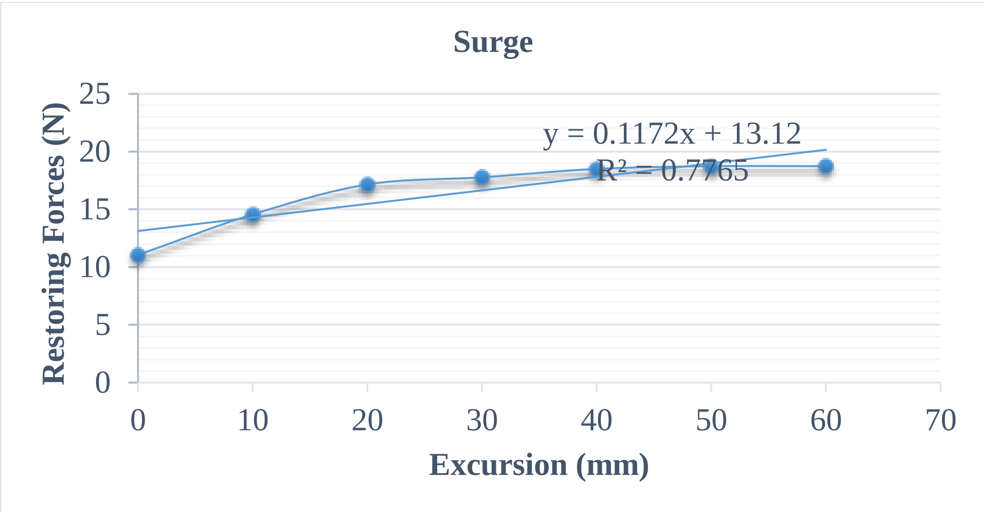

Figure 5.14: Static Offset Test Result - Surge

Table 5.4: Mooring line stiffness at Heave and Surge Motion

Motion	Stiffness Value (N/mm)
Heave	0.1447
Surge	0.1172

5.2.5 Free Decay Test Results

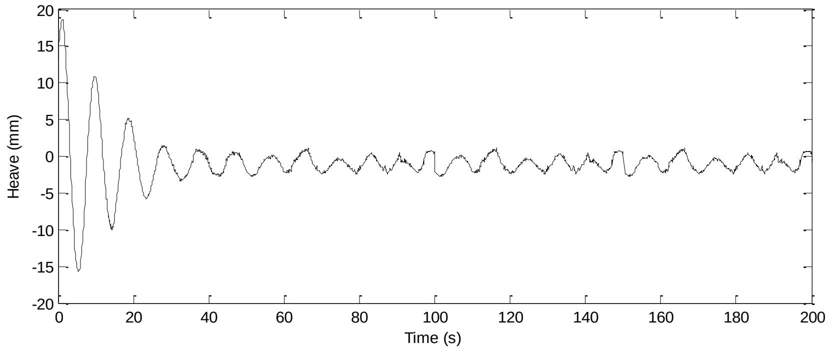

Figure 5.15: Free Decay Test Result - Heave

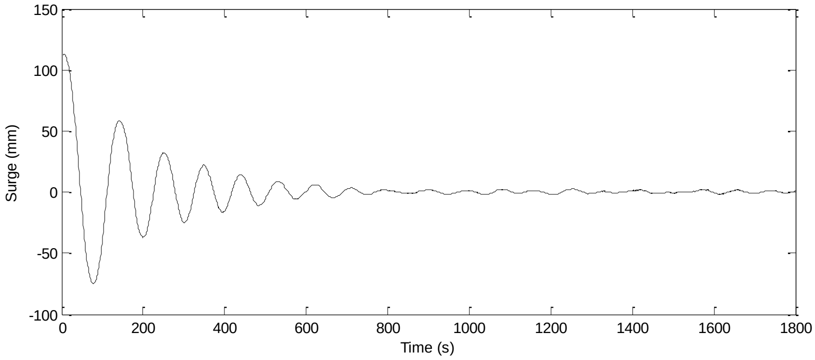

Figure 5.16: Free Decay Test Result - Surge

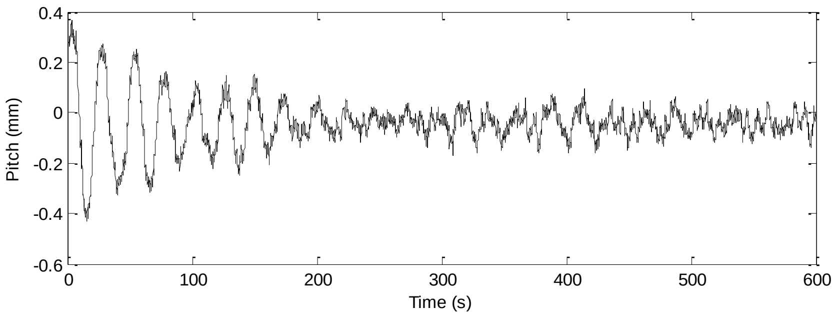

Figure 5.17: Free Decay Test Result - Pitch

From the free decay result obtained for surge, heave and pitch motion as in Figure 5.15 to Figure 5.17, the natural period of the FPSO has been tabulated in Table 5.5.

Table 5.5: Natural Period for Surge, Heave and Pitch motions of FPSO

Motions	Natural Period (sec)
Surge	102.4
Heave	10.7
Pitch	10.5

5.2.6 Response Amplitude Operators (RAO)

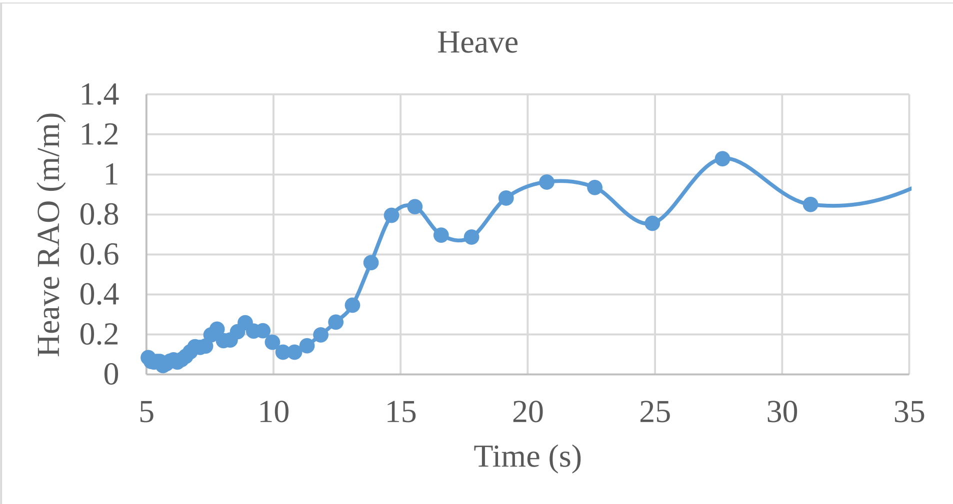

Figure 5.18: RAO for Heave

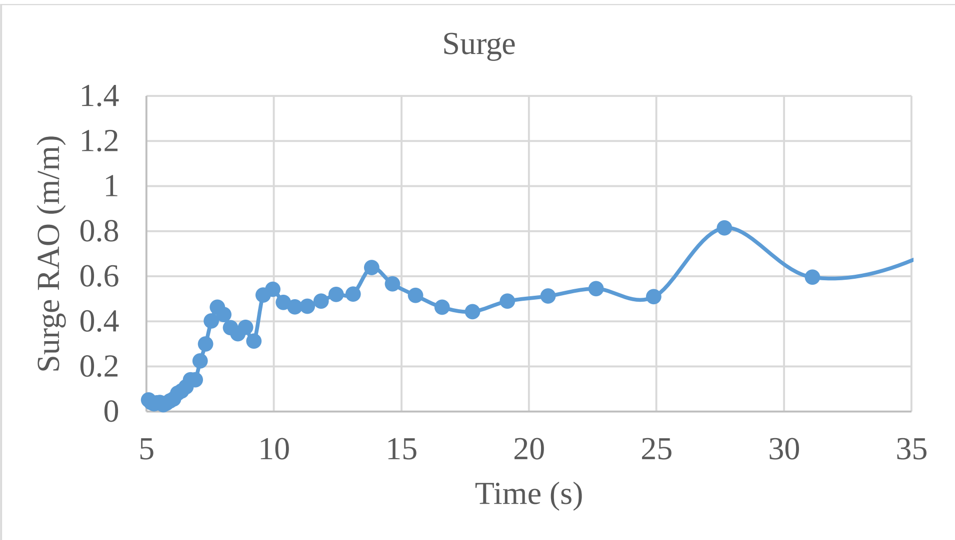

Figure 5.19: RAO for Surge

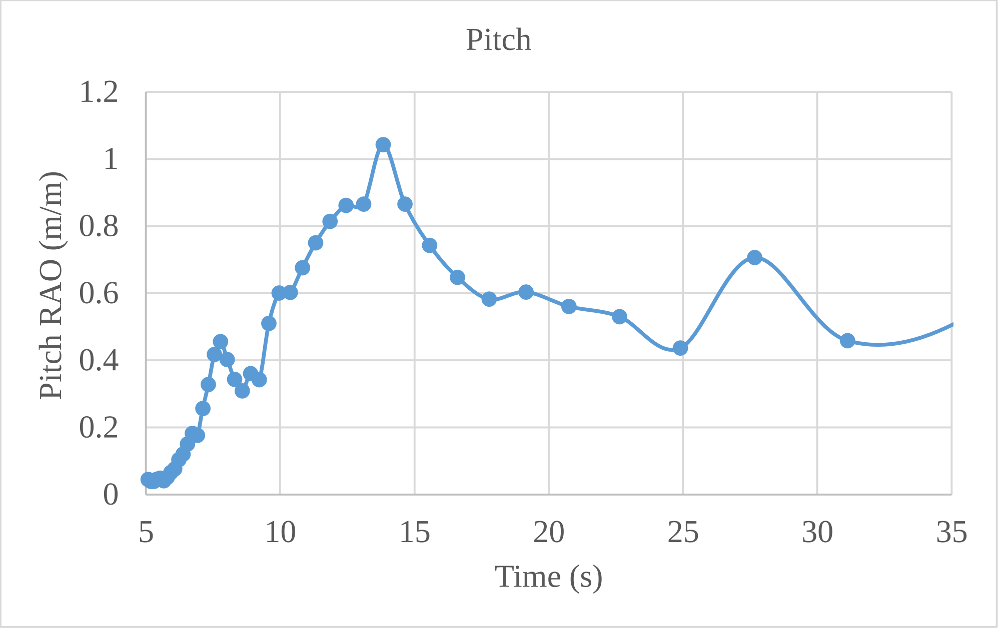

Figure 5.20: RAO for Pitch

From Figure 5.18, the maximum RAO for heave is 1.08. Figure 5.19 shows the maximum RAO for surge is 0.81. Lastly, the maximum RAO for pitch is 1.04. Based on the results, we can observe that the response for pitch, heave and surge motion are within the safe limits. The RAO for heave motion is higher than that of pitch motion and surge motion. This shows that the heave motion is high in head sea conditions. There are some fluctuation or sudden pear occurs in the results of responses. This is due to resonance effect when angular frequency of the wave is almost matching with the heave, pitch and surge natural frequency of the body

5.3 Comparison of numerical and experimental results

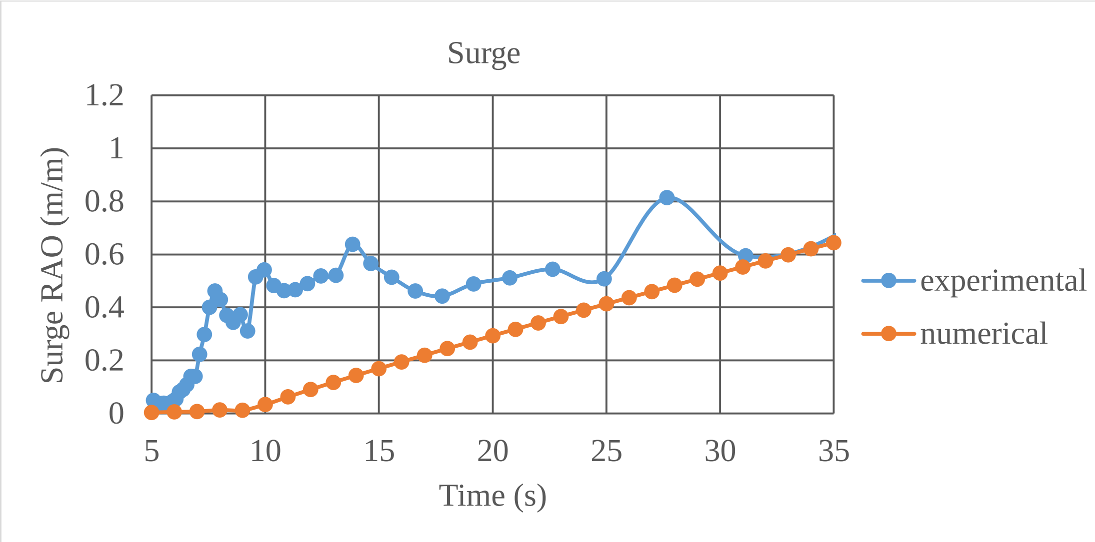

Figure 5.21: Comparison between numerical and experimental result for Surge RAO

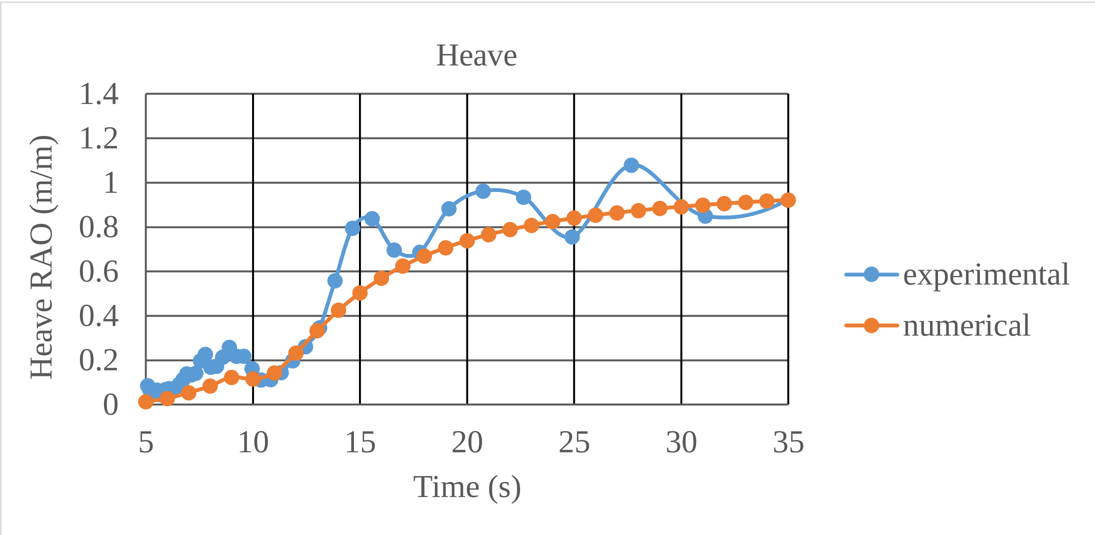

Figure 5.22: Comparison between numerical and experimental result for Heave RAO

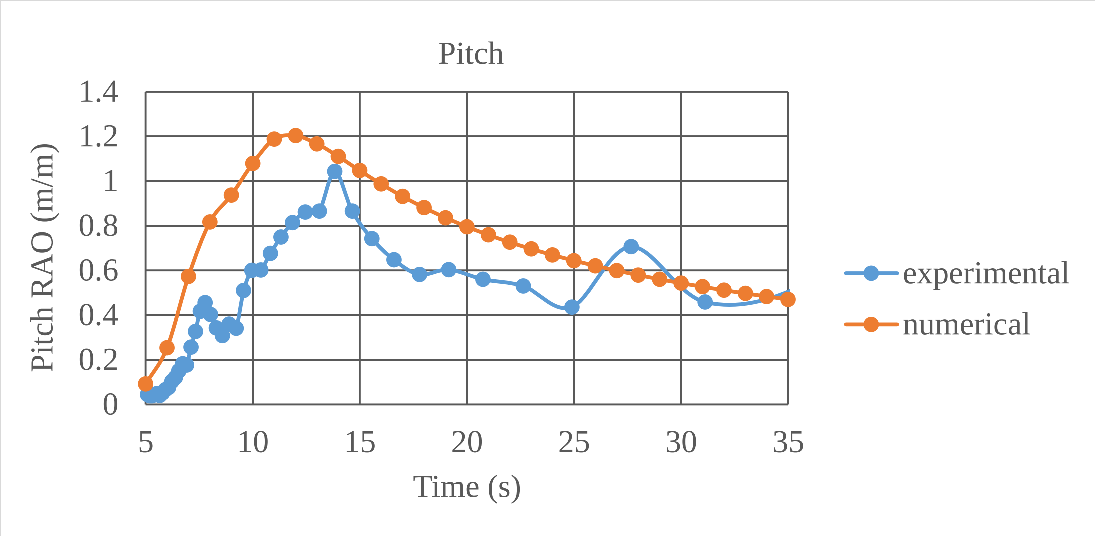

Figure 5.23: Comparison between numerical and experimental result for Pitch RAO

The results for both numerical and experimental studies are obtained successfully. Motion responses obtained from the model test are compared with the numerical analysis. Figure 5.21 shows the comparison between numerical and experimental results for surge motion. The surge responses predicted by these two methods show satisfactory agreement in terms of trend. However, there are large variations in the magnitudes for wave period of 13.83s or angular frequency of 0.4542 rad/s. The experimental responses are much greater than those due to numerical responses. This might be due to the circumstances that during the model testing, the waves that were produced from the wave generator or wave paddles were not aligned exactly in the specified surge direction and hit the FPSO sides also resulting in increasing surge responses. After wave period of 31.13s or angular frequency of 0.2018 rad/s, the responses of the experimental studies agreed with the numerical studies.

Figure 5.22 shows the comparison between numerical and experimental results for heave motion. The heave responses predicted by these two methods are comparatively the same in terms of trend and it shows better comparisons than surge and pitch responses. The model tests and numerical analysis agree well for the low wave period region up to 13.11s but thereafter there are some fluctuation in the experimental results for heave responses. This might be due to the angular frequency of the wave is almost matching with the heave natural frequency of the body and therefore resonance occurs. In other words, there is a resonance whenever two frequency is matched. Above wave period of 30s or angular frequency of 0.2094 rad/s, the RAO values for heave agrees very well.

Figure 5.23 shows the comparison between numerical and experimental results for pitch motion. The pitch responses obtained by the two methods show satisfactory agreement in terms of trend. The RAO values agree well in the wave period range of 5s until 7.78s. After that, the experimental responses are much lower than those due to numerical responses but responses are within the safe limits. Besides that, there is a sudden peak at wave period of 27.67s and this might be due to the resonance effect. Above wave period of 30s or angular frequency of 0.2094 rad/s, the RAO values for pitch agrees very well. In conclusion, the responses for heave, surge and pitch are in safe limits. Therefore, the RAO values obtained from this study would be helpful in the modelling and design of FPSO in the future.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

The experimental study and numerical study on the dynamic responses of Floating, Production, Storage and Offloading (FPSO) vessel subjected to random waves was performed. Many literature reviews have been studied on the dynamic responses of FPSO due to random wave in surge, heave and pitch motion. Based on the Gantt chart for FYP I and FYP II, the work planned and actual work has been carried out successfully.

As according to the problem statement and literature review, this study is very crucial to ensure the excellent station keeping characteristics of the FPSO in deep water. The dynamic responses of FPSO in surge, heave and pitch motion were obtained using the Response Amplitude Operator (RAO) for both numerical and experimental studies. The simulated FPSO model were validated using the laboratory test data by establishing correlation between the results obtained from software and model tests. The results for both experimental and numerical studies are obtained for surge, heave and pitch directions. RAO values obtained for both experimental and numerical studies are comparatively safe. The RAO values obtained will be useful for the future design of FPSO especially for Malaysian region.

Finally, it is recommended that more detailed dynamic analysis is to be conducted in future work by considering wind and current condition instead of taking consideration on the wave effects only.

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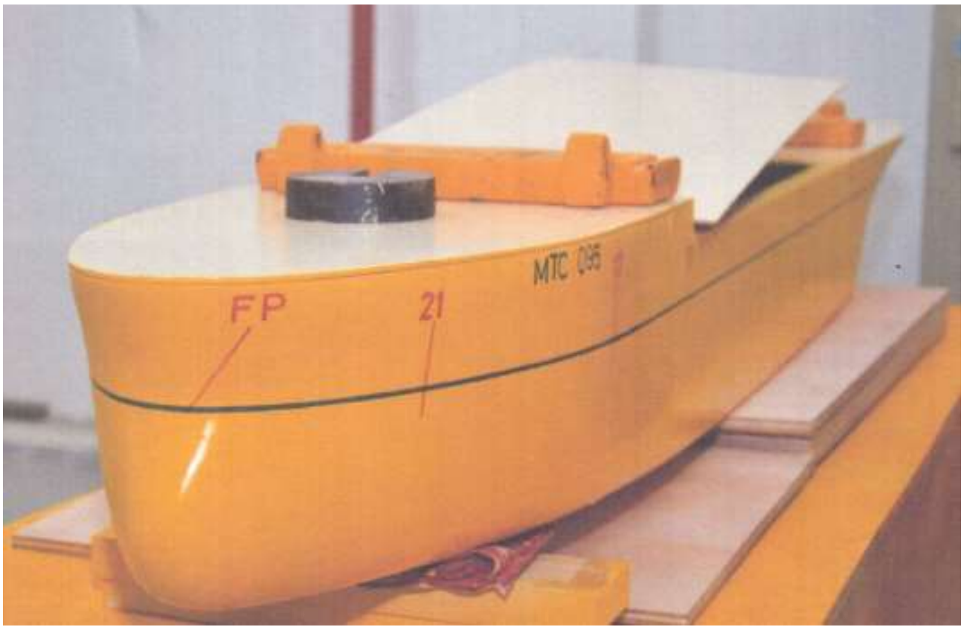
APPENDIX I

Berantai FPSO Model

Berantai Floating, Production, Storage and Offloading (FPSO) unit.



Berantai FPSO model which is ready to be tested.

APPENDIX II

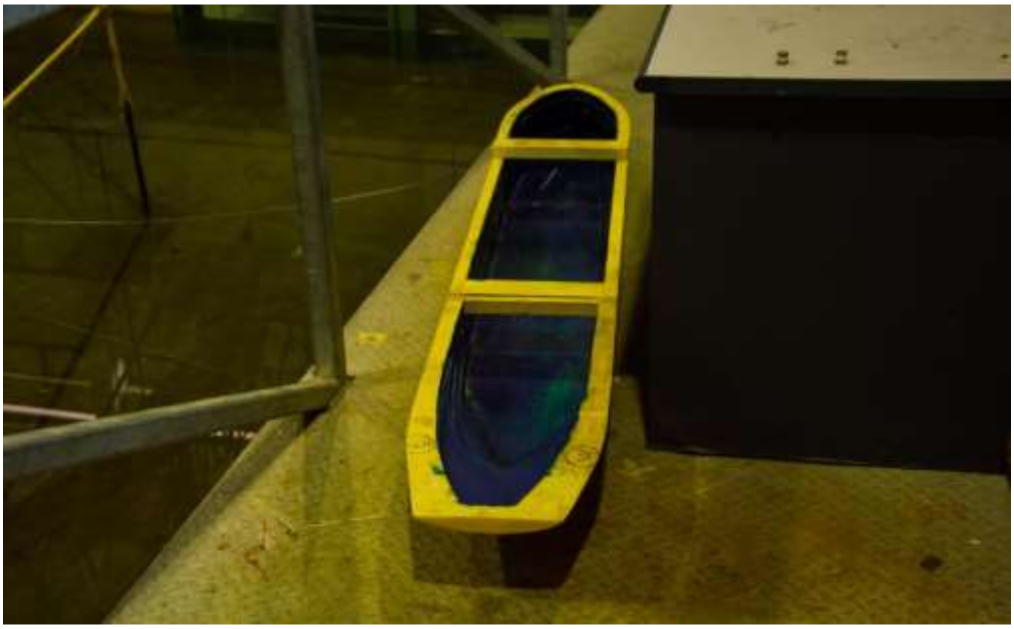
Wave Probe Calibration in Wave Tank

Wave generator in Offshore Laboratory

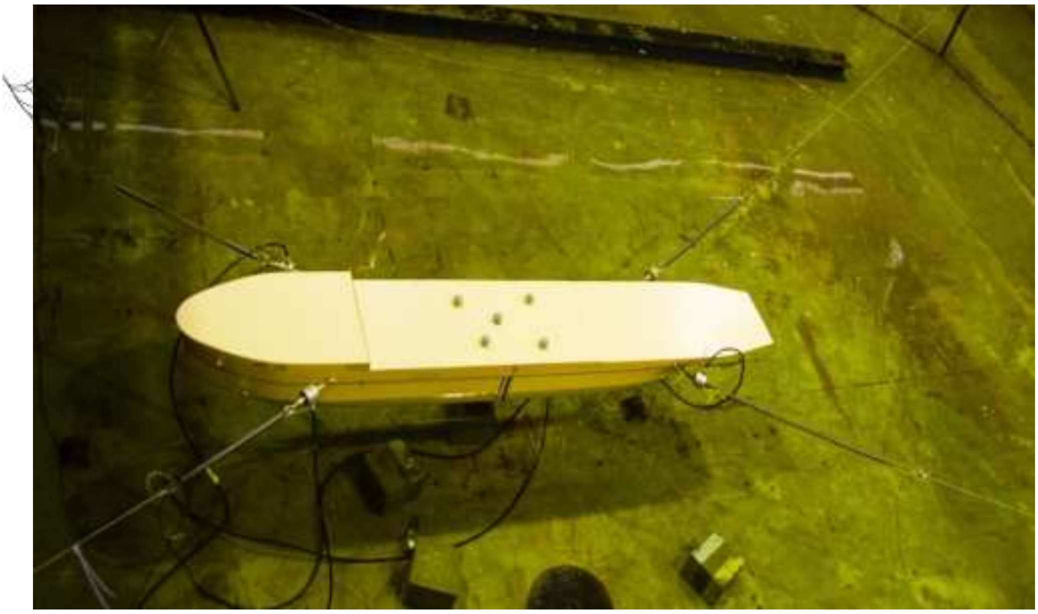
Wave Probe Calibration

APPENDIX III

FPSO Model Position in the Wave Tank



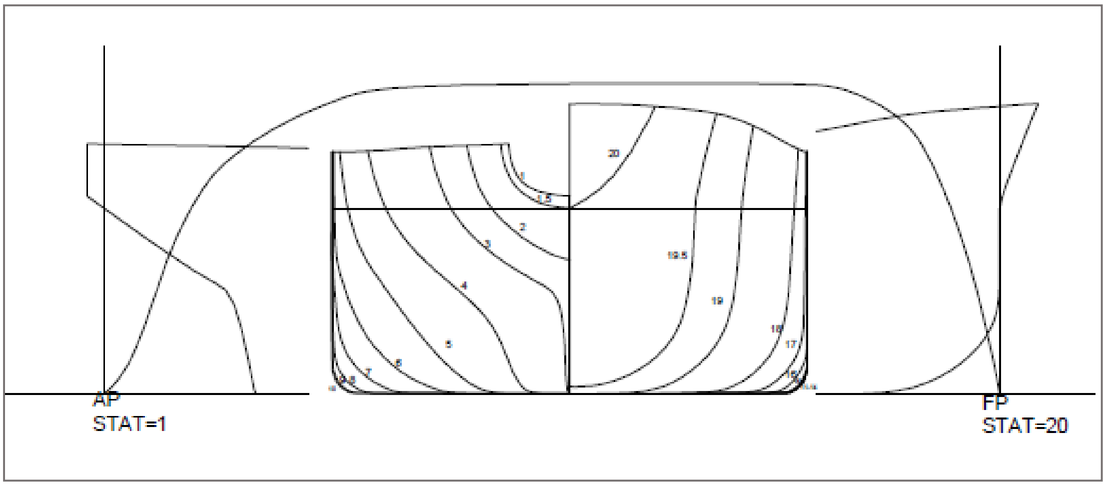
FPSO Model (1:100)



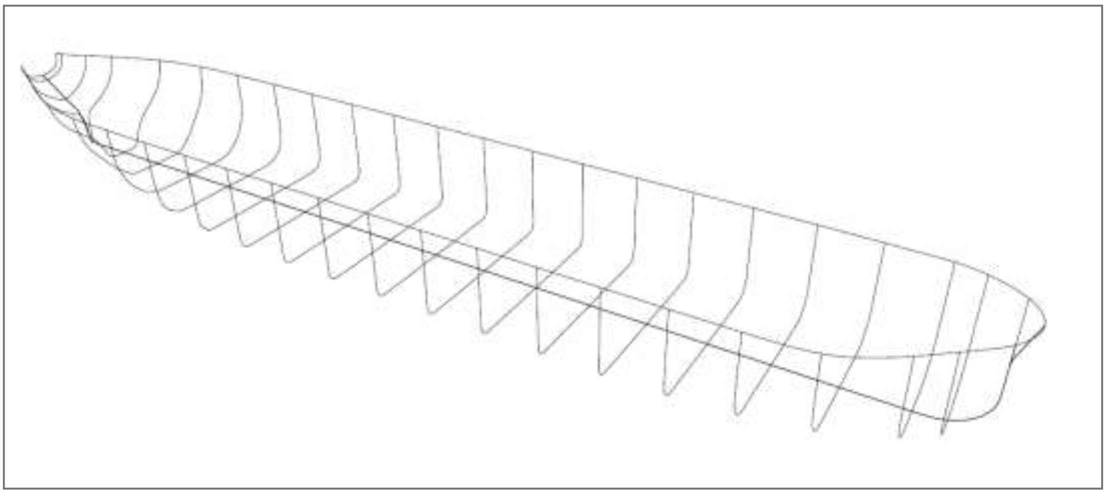
FPSO attached to mooring lines

APPENDIX IV

Body plan, Profile View, Cross Section Area Curve and Perspective View of Berantai FPSO



Body plan, Profile View and Cross Section Area Curve



Perspective View

APPENDIX V

Model to Prototype Multiplier

Variable	Unit	Scale factor
Wave Height	L	λ
Wave Period	T	$\sqrt{\lambda}$
Wave Frequency	T^{-1}	$1/\ \sqrt{\lambda}$
Wave Length	L	λ
Celerity	$L\ T^{-1}$	$\sqrt{\lambda}$
Particle Velocity	$L\ T^{-1}$	$\sqrt{\lambda}$
Particle Acceleration	$L\ T^{-2}$	1
Wave Pressure	$ML^{-1}T^{-2}$	λ
Weight	$ML\ T^{-2}$	$\propto \lambda^3$
Force	$ML\ T^{-2}$	$\propto \lambda^3$

Model to Prototype Multiplier