PARAMETRIC STUDY OF FPSO RESPONSES

By

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FINAL YEAR RESEARCH PROJECT REPORT

Submitted to the Civil Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Civil Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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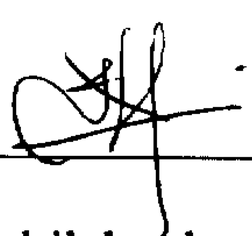
Approved by.



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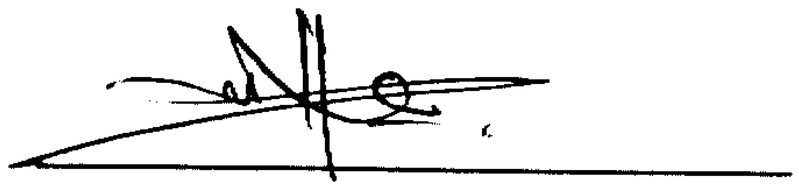
June 2010

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



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ABSTRACT

The demand for oil increases with the development of oil production in deeper water area. Due to its economic, flexibility and ability to adapt with variety of water depth, FPSO has been recently used as an attractive alternative of offshore oil production. This study present concern in the operations of FPSO systems by investigating the effects of different parameters toward the FPSO. The selection of structural configuration and other parameters is very important as it become the basis for design an efficient structure. Data has been obtained from Ruby FPSO and has been adjusted to perform dynamic analysis such as wave forces, wave spectrum and time series with subject to three degree of motions namely surge, heave and pitch. Parametric studies by varying the water depth and the wave spectra have been made for each motion. From the study, it is observed that there is significantly small changes in wave frequency motion as water depth increase from shallow water to deepwater and ultra deepwater. As for the changes in wave spectra, the wave frequency motion for PM spectrum is doubled the wave frequency motion for Jonswap spectrum. This finding may help the ocean engineers determine the condition of the sea at Ruby field when designing any offshore structure in the future.

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CHAPTER1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Nowadays, offshore industry requires more exploration of oil and gas in deepwater and ultra deepwater to ensure continuous production in oil and gas industry. Since the production in shallow water is decreasing, a new concept of design that promise efficient and economical floating, production, storage and offloading (FPSO) was created. The development of structure that can ensure continuous production from the deepwater and ultra deepwater oil region has become a major challenge since the operation and design of the new structures is not the same as in shallow water.

This has initiated the development of new structures and concepts. These structures are unique in many aspects and their efficient and economic design and installation are a challenge to the offshore community (Chakrabarti, 2005).

Since 1947, more than 10,000 offshore platforms of various types and sizes have been constructed and installed worldwide. As of 1995, 30% of the world's production of crude came from offshore. Recently, new discoveries have been made in deeper waters. In 2003, 3% of the world's oil and gas supply came from deepwater (>1000 ft or 305 m) offshore production (Westwood, 2003). This is projected to grow to 10% in the next fifteen years. The bulk of the new oil will come from deep and ultra deepwater production from three offshore areas, known as the "Golden Triangle": The Gulf of Mexico, West Africa and Brazil.

The first floating production system, a converted semi-submersible, was installed on the Argyle field by Hamilton in the UK North Sea in 1975. The first ship-shaped floating

production and storage system was installed in 1977 by Shell International for the Castellon field, offshore Spain. There were 40 semi-submersible floating production systems (FPSs) and 91 ship-shaped FPSOs in operation or under construction for deep waters as of 2002 (Offxshore, 2002). Petrobras is the pioneer in pushing floating production to increasingly deeper waters in their Campos Basin fields, offshore Brazil.

1.1.1 FPSO

Floating structures have been used since the 1950s for drilling and they have become increasingly popular for production, particularly in deep water. FPSOs are an important and increasingly common form of offshore oil production system. In addition, the movement of oil and gas development into ever deeper waters is expected to result in a significant increase in the use of FPSOs (HR Wallingford, 2003).

The selection of structural configuration and other parameters including the environmental information and data is very important as it become the basis for design of an efficient structure. An additional requirement is the ability and efficiency for FPSO to remain on station for the duration of field life, without problems due to change in sea condition, and without dry-docking for inspection, maintenance or repair.

FPSO may show different responses towards different parameters such as water depth, wave height and centre of gravity. All these parameters need to be considered in order to build an efficient yet economical FPSO since FPSO has been recently established as attractive alternative for the exploitation of offshore oil field. This is due to its flexibility, reliability, the low cost and adapting for the variety of water depth. It is important to study on the different selected parameters on FPSO responses for future increasing quality of petroleum exploration and production in oil and gas industry.

1.1.2 FPSO Hull Design

There are four principal requirements that drive the size of a typical FPSO;

1. Provision of oil storage capacity compatible with the production rate and offloading arrangements, i.e. shuttle tanker turnaround time.

2. Provision of topsides space for a safe layout of the process plant, accommodation and utilities.

3. Provision of displacement and ballast capacity to reduce the effects of motions on process plant and riser systems.

4. Provision of space for the production turret (bow, stern or internal), and the amount of hull storage capacity lost as a consequence (new build or conversion)

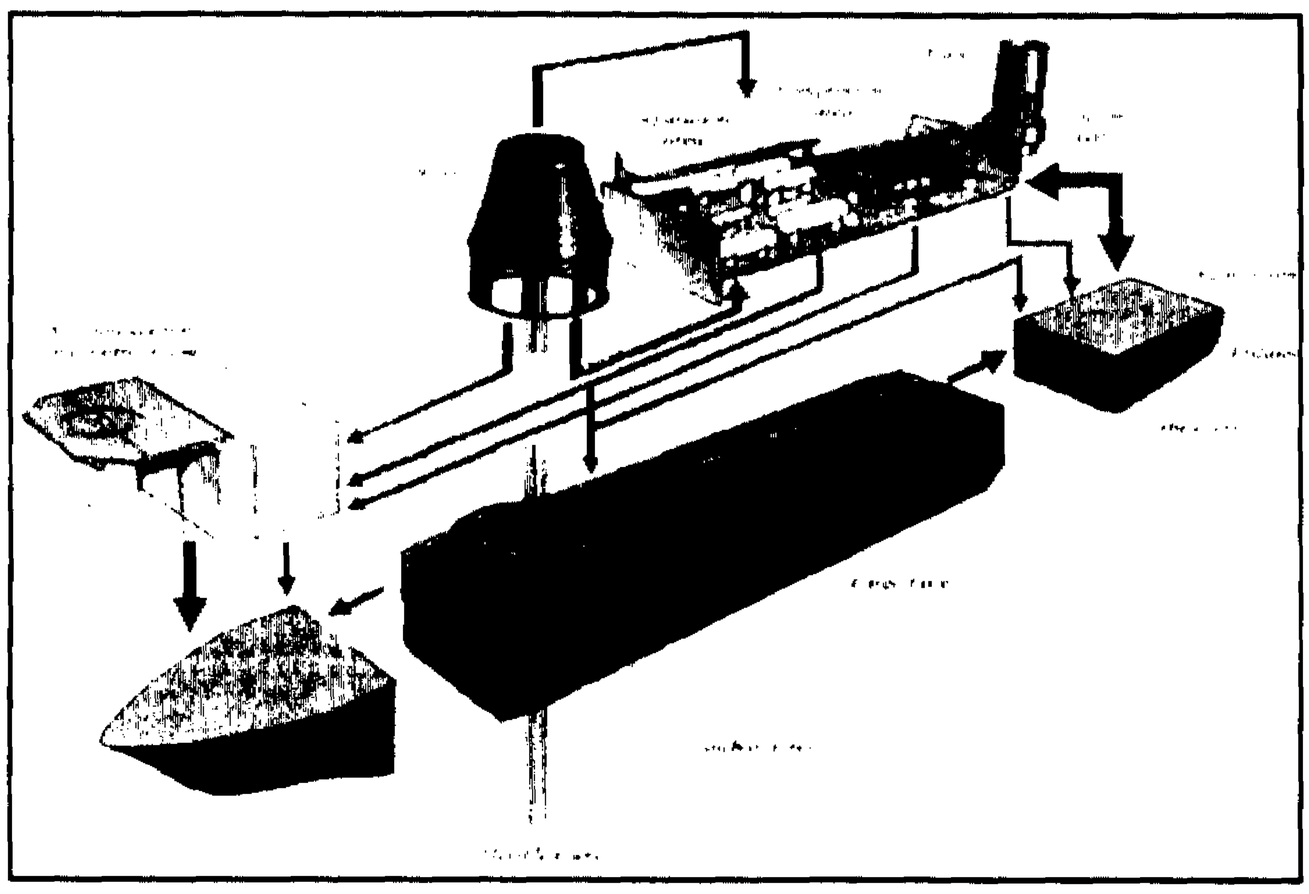

Figure 1.1: Typical new-build FPSO configuration (J. Ray McDermott, Inc.)

Figure 2.2 shows a typical new-build FPSO configuration. As water depths increase, the sensitivity of the FPSO mooring and riser systems to wave frequency motions increases rapidly. The FPSO hull form can be optimized to counter this by varying primarily the length, width, depth, draft and mass distribution. The hull length can be adjusted with respect to the expected wave lengths to ensure that the extreme environmental conditions do not generate wave lengths located in the range of the peak heave and/or pitching responses, thus reducing the turret vertical motions and associated dynamic loads. The hull form can also be adjusted in order to control rolling and pitching

behavior thus reducing riser bend-stiffener design requirements, particularly for transverse conditions. This optimization also reduces the need for special topsides process equipment design requirements such as baffles for separators. The hull form can also be optimized to reduce the wave and current actions by varying the length, width, draft and shape of bow and stern. This reduces the vessel loading with respect to incoming waves under transverse conditions, reducing mooring loads and vessel roll. The aforementioned hull form optimization can have a beneficial contribution to the long term operational performance of the FPSO, but this should be carefully assessed against the fabrication cost and Life of Field (LOF) costs. In the more recent FPSO developments, there have been cases where the cargo carrying capacity of the FPSO is not sized against the initial production flow rate, but one further into the production life where a reduced and more economical storage can be achieved. The initial storage requirements are met by supplementing the FPSO with a Floating Storage Unit (FSU) based on a cheap second hand tanker. The above highlights that a full LOF approach should be taken in deciding both the vessel design and the field configuration.

1.1.3 FPSO of Ruby Project

The study of response of FPSO subjected to regular and random waves is focuses on FPSO of Ruby Project. The Ruby field is located in Block 01 and 01 PSC, 160km east of offshore Vung Tau Port of Vietnam in a water depth of 49m. The Ruby Field comprised of existing facilities Ruby-A wellhead platform (RBDP-A), Ruby-B Wellhead Platform (RBDP-B) and FPSO Ruby Princess.

The PCVL selected option for the extended field development is to provide a replacement FPSO (herein after refer as the FPSO) for Ruby Princess with minimum down time. As such the first oil date of the FPSO was scheduled in August 2008 to enable disconnection of Ruby Princess in October 2008. The development concept will consist of 5 risers connected to 2 PLEMS. 1 PLEM tie to Topaz field and the other PLEM tie to Pearl and Rubys. Subsea pipe line connecting Ruby-A&B shall be retained. New pipe line shall be laid to tie to Ruby-A. The only down time is during connection

of the new pipe line at the Ruby-A field. The construction from the PLEMs to the field will be dealt with by the PCVL. The scope for the FPSO project includes all components of the FPSO system from the first flange off the Pipe Line End Manifold (PLEM) (excluding PLEM), the FPSO turret mooring system, FPSO hull, production facilities, floating hoses and export tanker mooring system.

1.2 PROBLEM STATEMENT

Nowadays, oil and gas industry requires continuous development of new technologies in order to explore potential oil region. Plus, petroleum exploration in deepwater has become the main activity for most of oil and gas company since the rate of petroleum exploration in shallow water decreased. For that reason, Floating Production Storage and Offloading (FPSO) has become one of the structures that stand out that has high potential in increasing petroleum production. Efficient and economical designs are part of the reason why FPSO has become important structure in deepwater petroleum exploration. A lot of aspects need to be considered in developing a FPSO including environmental aspect and response towards the variety of parameter. Hence, this is considered as one of contribution towards PETRONAS in overcome one of the major problems in oil and gas industry.

1.3 OBJECTIVES OF STUDY

The objectives of this study are:

1. Carry out a detailed literature survey about the FPSO technology, existing FPSO and dynamic analysis.

2. Perform a simple dynamic rigid body analysis in frequency domain for the Ruby FPSO subjected to random waves for determining the FPSO response motions.

3. Perform parametric studies of above responses changing parameters of FPSO.

1.4 SCOPE OF STUDY

Various theories need to be applied in order to complete the project. It includes the understanding of the basic operation of the FPSO and the wave theories. Froude-Krylov theory was used as the basis for force calculation due to the geometry and floating behavior of FPSO. The model is designed based on an existing Ruby Project and therefore, will be used as reference model to get all the calculated data.

The calculation is done on three motions of the FPSO, namely surge, heave and pitch. The scope of this project will take into account the parameters that give the highest effects to the FPSO responses, which are the water depth and wave spectrum. This will provide some general information of the FPSO responses toward different parameters.

CHAPTER 2

THEORY AND LITERATURE REVIEW

2.1 THEORY

2.1.1 Wave Theories

In calculating the various environments which mostly depends on the specific environmental parameters such as water depth, wave height and wave period, many water wave theories have been developed and can be applicable in most of the design of an offshore structure. However, the theories built here will be limited to a flat bottom having a constant uniform water depth.

Unlike the ocean waves, all water wave theories assume that the waves are periodic and uniform, having a period T and height H. Note that the period of the wave is defined as the time required for a crest to travel a distance of one wave length, and the adjacent trough of the wave. The wave length is the horizontal distance between similar points on two successive waves measured in the direction of propagation of the wave (Chakrabarti, 1986)

2.1.2 Design Wave Environment

In choosing the design wave environment for an offshore structure, two basic approaches are available to be use. Single wave method, which one of the approaches will be use in the design analysis and easy determination of the response duet to extreme wave conditions (as opposed to the design sea state). Single wave method use a wave period and a wave height, where several possible single design waves of varying period and worst loads experienced should be analyzed.

Second basic approaches will be the wave spectrum where an appropriate wave spectrum that describes a short term wave condition which will represent a suitable density distribution of the sea waves at the site under consideration. As an alternative, one chooses one of the theoretical spectrum models available based on the fetch, wind and other meteorological conditions of the site.

In an open ocean, area in which waves that usually generated by wind traveling are called swells and area in which waves been generated are known as sea. The ultimate growth of a sea depends primarily on wind speed, duration and fetch.

2.1.3 Wave Force Formulations

With understanding of the interaction phenomenon through analytical studies, laboratory experiments and at sea measurement and together with some theories available, wave loads on most of offshore structures can be predicted. In order to design an offshore structure, wave forces determination become the primary stage which it involves the complexity of the interaction of waves with the designated structure. Its effect on the offshore structure is obviously being more difficult as the random nature of the ocean and the inadequacy of the highly nonlinear wave theories been examined.

Basically, wave forces on offshore structures are calculated in three different ways:

1. Morison equation
2. Froude-Krylov theory
3. Diffraction theory

The Morison equation assumes the force to be composed of inertia and drag forces linearly added together. The components involve an inertia (or mass) coefficient which must be determined experimentally. The Morison equation is applicable when the drag force is significant. This is usually the case when a structure is small compared to the water wave length. When the drag force is small and the inertia force predominates, but the structure is still relatively small the Froude-Krylov theory can be applied. It utilizes

the incident wave pressures and the pressure-area method on the surface of the structure to compute the force. The advantage of this method is that for certain symmetric objects the force may be obtained in a closed form and the force coefficient are, generally, easy to determine (Chakrabarti, 1986).

2.1.4 Froude-Krylov Force on Structure

The forces on a submerged structure in waves appear from the pressure distribution on its surface. For a small structure these pressure distributions are difficult to compute because of the complex flow around the structure and formation of vortices in its vicinity. This is the reason for the use of the Morison empirical equation described above. However, if the flow remains essentially attached to the surface, then it is easier to compute this pressure field. When the structural dimension is large relative to the wavelength, then the flow around the surface of the structure remains attached. In this case, the incident wave experiences scattering from the surface of the structure, which should be taken into account in computing this pressure field. If the computation of the scattered wave potential is waived and its effect is incorporated by a force coefficient, then it is possible to compute a force simply by the incident wave potential. Thus, the calculation of the force is performed assuming the structure is not there to distort the wave field in its vicinity. The force is computed by a pressure-area method using the incident wave pressure acting on the submerged surface of the structure. This force is called the Froude-Krylov force.

While limited in its application to offshore structure design, the simplicity of the Froude- Krylov theory allows computation of forces in terms of a simple expression for a variety of shapes. The limiting criterion may be circumvented through the application of a force coefficient to account for the wave diffraction. For moderate-sized structures of simple contour shapes, this method provides a reasonable estimate of the forces. Its application is generally limited to estimating only approximate forces on structures. A few applications of this method may be cited as follows: concept design and rough

estimate of structure sizes, sizing mooring lines, design of towing and transportation schemes, and model test planning such as scale selection and choosing load cells.

2.1.5 Floating Structure Dynamics

Consider an offshore structure in Figure 2.1, the structure is assumed rigid and move in waves. The structure undergoes six independent degrees of motion which consist of three translational and three rotational. From Figure 2.1, assuming O is the center and X, Y and Z are the axes, the longitudinal motion along X is termed as surge, the transverse motion along Z is sway, and the vertical motion along Y is heave. The angular motions are defined as motions about the three axes X, Y, and Z. The angular motion about Z is called pitch, about X is roll and about the vertical axis, Y, it is yaw.

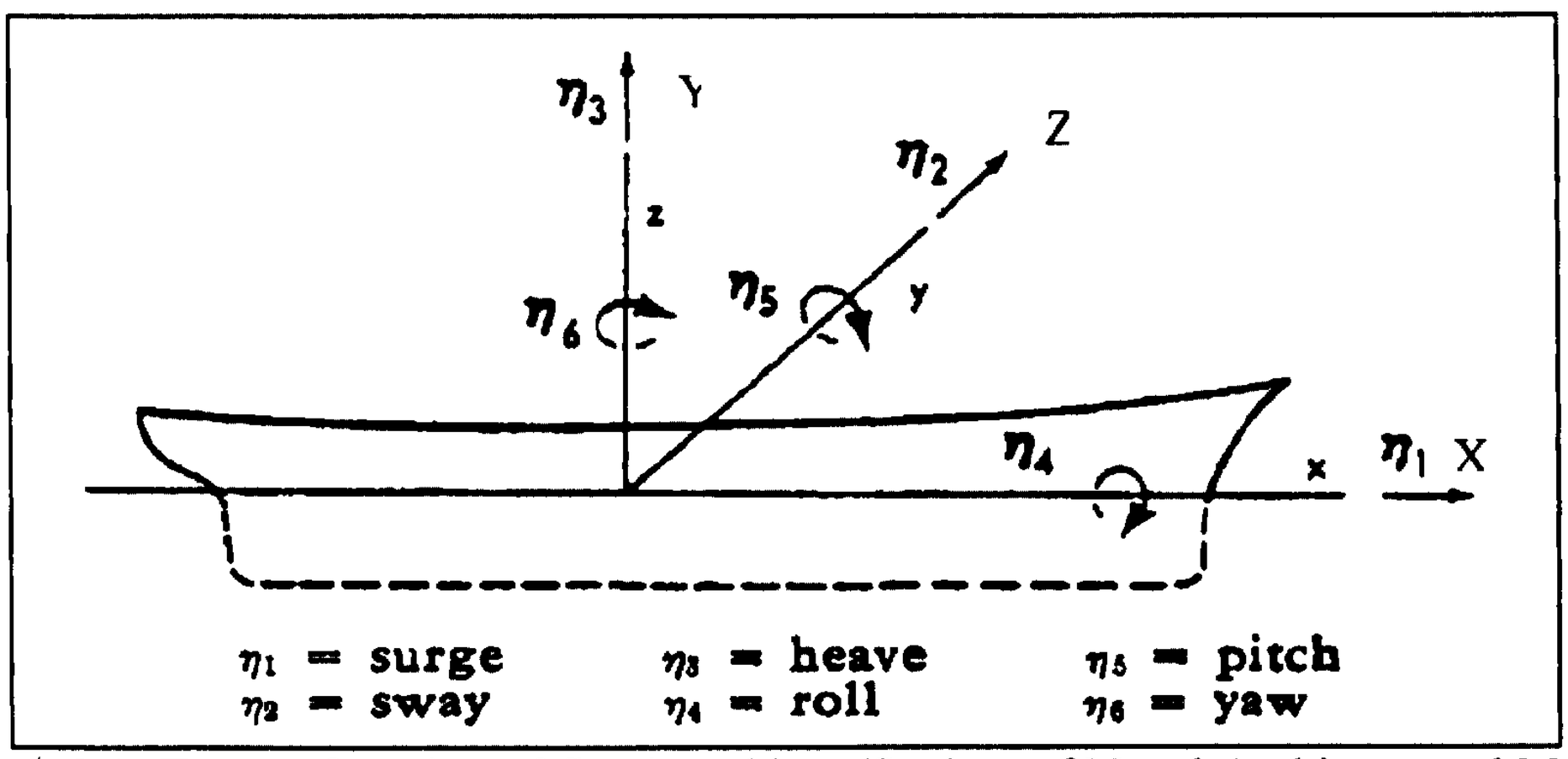

Figure 2.1: Types of motion of floating object (Society of Naval Architects and Marine Engineers, 1998)

2.1.6 Archimedes's Principle

It is named after Archimedes of Syracuse, who first discovered this law. According to Archimedes' principle, "Any object, wholly or partly immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object."

Archimedes' principle does not consider the surface tension (capillarity) acting on the body. The weight of the displaced fluid is directly proportional to the volume of the displaced fluid (if the surrounding fluid is of uniform density). Thus, among completely submerged objects with equal masses, objects with greater volume have greater buoyancy.

2.2 LITERATURE REVIEW

There were many literatures has been found about the investigation on FPSO responses towards various experiments. For this study, the existing FPSO for Ruby Field that has operated by PETRONAS Carigali Vietnam Limited (PCVL) which is located at Vietnam had been selected as a reference existing FPSO to the scale model. This study should also be referred to the PETRONAS Technical Standard - Supplementary PTS 20.073 "Design of Fixed Offshore Structure" for some design code and other references.

Based on the Supplementary PTS, phase 2.2.1, Operational (Normal) Condition, the operational condition should consider the effects of all dead loads and functional loads in combination with the simultaneous and collinear occurrence of 1 year return period environmental loads. Thus, all data and information are taken from Limiting Offloading Condition (1 year operating condition) from FPSO Design Basis of Ruby Project as a reference for further study.

Review for the study was taken abundantly from journals and the internet and had been using as reference for this study.

2.2.1 General

In liquefied natural gas (LNG) production and offloading, sloshing partially filled tanks. It becomes an important research subject for the offshore industry as it may induce significant impact pressures on the containment system of the LNG FPSO or carrier. It mist be studied carefully to ensure that the tank walls can withstand possible impact loads. This problem which has been investigated by Kyoung *et al* (2005) obtain a numerical results by imposing the exact non linear free surface conditions and comparing with those predicted by Morison's formula.

Graczyk *et al* (2005) conclude that further work required establishing an accurate method in solving the problem of determining characteristic extreme values of sloshing pressures for structural design. In the analysis, they suggest that the method should account for variation in significant wave height, mean wave period, ship sheep and tank filling ratio.

For details of interaction characteristics of side-by-side moored vessels, the respective literature should be consulted (see Hong *et al* 2005, and Kashiwagi *et al* 2005 for examples) where the problem been investigated using numerical and experimental methods. A higher-order boundary element method combined with generalized mode approach was applies for analyzing the motion and drift force of side-by-side moored multiple vessels (LNG FPSO, and shuttle tankers). Specific attention was given to the wave drift forces and moments. For solving the first-order radiation and diffraction problems the authors applied a higher-order boundary-element method directly to the whole wetted surface of the two vessels. The second-order wave drift forces were computed by the near-field method based on pressure integration.

Publications addressing the response of FPSOs have been presented by Morishita *et al* (2005) where the author formulate a control strategy for the shuttle vessel by perform a systematic study on the dynamics of a turret moored FPSO in single and tandem configuration. His second paper established the accurate prediction of the extreme excursions and the corresponding forces applied on the mooring in multi-directional environmental conditions. A response-based method was used with calculations for a 200,000 dwt FPSO.

A parametric study to compare the AQWA software with the model test has been conducted to evaluate the effect of the yaw stability in various Floating, Production, Storag and Offloading (FPSO) systems operating around the world. Yadav *et al* (2007) have studied that hydrodynamic analyses verified by the reliability of the result from the model test are economical means of analyzing the dynamics of a turret based system when subjected to different sea states.

For investigation in effect of water depth to FPSO, Li *et al* (2003) have discovered that with the decrease of the water depth, the wave frequency motions of the FPSO decrease obviously. This investigation had been done to single point moored 320 kDWT FPSO in 100- year environment conditions with different water depth. The research result was to be used in optimizing design of the FPSO in the oil fields with shallow water. While Miao *et al* (2006) highlighted that the water-depth has a substantial effect on

hydrodynamic force where the hydrodynamic force increases with the decrease of water-depth in shallow especially in the shallow water.

Further study on effect of waves towards FPSO proves that many the wave environment in which FPSOs operates are usually more benign than those wave environments that classification Rules have historically considered in design. Johnson et al. (1997) highlighted once the strength for the specific operating is known, the current state of the vessel can then be assessed to determine what areas of the structure will need to reinforced to ensure adequate performance for the desired time on site upwards to twenty years on site for example. With an extended period of time on station, careful planning needs to take place before the actual shipyard conversion. Pinkster *et al* (1997) summarized that the behavior in waves of large structures partly or wholly supported by multiple air cushions can be predicted by means of 3-D linear potential theory computations. Results of computations have shown that air cushions can influence significantly the behavior of floating structures.

Britani *et al* (1997) have studied the wave drifts damping and the interaction between waves and current that plays an important role in the ship motion in surge. It was also shown that the effect of mooring line damping may be important in determining the ship response. However, for large ships, at least in small water depth, its effect is of second order.

2.2.2 Structural design

Corrosion damage is a big issue in designing a FPSO. Corrosion protection by MacMillan *et al* (2004) suggested some overview of corrosion related issues and it is recommended for a newbuilding FPSOs to have a combination of coating, cathodic protection and corrosion allowance to decrease this sort of problem.

Apart of corrosion damage, fatigue damage also becomes a big issue in designing FPSOs. In this critical issue, Fricke *et al* (2004) investigated the problem of fatigue crack initiation at fillet-welds around stiffener and bracket toes. They revealed the

importance of residual welding stress at the end of the attachment. Bergan *et al* (2004) presented work on general overview of the FPSO fatigue capacity JIP, which also provided numerous interesting papers including Kang *et al* (2004).

Lotsberg *et al* (2004) indicated that fatigue damage of the side longitudinal in a typical FPSO structure, was significantly more severe in the ballast than the loaded condition. With regard to fatigue analysis methodology, Dong (2004) presented a "new structural stress method", based on element nodal stresses, opening possibilities to cover welds of various type classifications into one master S-N curve. This Battelle structural stress method, using a computed equivalent structural stress parameter instead of the so-called hot-spot stress derived by extrapolation of surface stresses towards the weld toe, is being studied in the continuing Batelle Structural Stress JIP.

The paper presented by Hodgson *et al* (2004) and Fyfe *et al* (2004) discussed the phenomenon of green water and bow wave impact while Semdley *et al* (2004) provided information about penetration depths for collisions at typical energy levels. Extensive studies are presented into the ultimate strength reduction characteristics of ship panels that wasted due to pit corrosion, fatigue cracking or local denting damage. Wang *et al* (2003) studied corrosion rates of structural members in oil tankers. The paper compared observations of tanker corrosion rates with databases published by Tanker Structure Cooperative Forum (TSCF) in 1992.

2.2.3 Operational experience

FPSO existed since 1950s, therefore a lot of problems occur not only during designing, also during constructing and operational stage of FPSO and a lot have been overcome due to the existence of deep study and experimental results.

FPSO projects tend to experience significant interface problems due to reasons such as:

· Lack of understanding of scope at the interface areas

· Failure to identify gaps in work scopes or contract scopes

· Lack of experience in project teams

· Inadequate interface management systems

In several North Sea FPSO projects during the 1990s, the following issues have been highlighted as the most important (note that a number of these are appropriate because of the severe weather conditions):

- Green water - damage to equipment and windows at the accommodation block
- Hull strength - cracks in-between tanks
- Turret location - free turret recommended
- Turret design - wear in bearings
- General layout - more effort in design required
- Capex over-run - better interaction between contractor and company
- Compression problems - due to undersized gas-scrubbers
- Accommodation - too few beds for e.g. maintenance crew
- Uptime performance - excellent but often due to significant unscheduled modification/repair
- Safety - no evidence that FPSOs are less safe than other offshore installations
- In situ repair and modifications - marine standards assume periodic visits to port & dry docking.

In UK continental shelf, incident information was collected and compiled with objective to improve safety, drive down operating and maintenance costs and disseminates the lesson learned. Lloyds Register (2003) undertakes the study into maintenance, repair and inspection of the FPSO.

For details of discussing problems associated with ROV access to the risers in deep water, the respective literature should be consulted (see Chapin (2005) and Thethi *et al* (2005) as examples).

Assessment of FPSO fatigue by Hoogeland *et al* (2003) highlighted the necessity of improved models for prediction of loading at structural details and Sigurdsson et al (2004) gave associated inspection planning examples. Marshall *et al* (2005) described experience gained through inspection management for a fleet of spars.

CHAPTER 3

METHODOLOGY

3.1 PROJECT METHOD

The project methodology is according to Table 3.1.

Table 3.1: Methodology of project

Literature	Literature Studies	Literature studies is conducted on written materials subjected to the offshore structures especially FPSO and other relevant topic. The review provides background information, theories, facts, and data that are relevant to the research project.
Data Collection	Data collection and analysis	Data collection is obtained from the existing FPSO of Ruby Project at Vietnam. Among the kind of data needed are: i) Dimension of FPSO ii) Environmental data of Ruby Field
Results	Dynamic analysis	Perform dynamic analysis such as wave force calculation, Response Amplitude Operator (RAO) calculation, Wave Spectrum and Time Series calculation subjected to regular and random waves.
	Parametric study	Perform parametric study by vary the selected parameters such as water depth and wave spectrum and investigate the responses of each parameter towards the FPSO.
Presentation of Works	Report writing	Report writing will be prepared to accomplish the objective of the project. Report writing is the requirement upon completing the project.

3.2 DATA COLLECTION

Table 3.2 shows all the environmental design conditions. The FPSO was designed to withstand the following limiting environmental conditions prevailing in the Ruby field. Based on the FPSO Design Basis of Ruby Project (Supplementary to PTS 20.073, 2005), the limiting environmental criteria set is based on the data provided and stipulated by the Petronas Carigali Vietnam Limited (PCVL) extracted from Metocean Criteria, Pearl Development Project, Block 01 & 02 Offshore Vietnam.

Table 3.2: Environmental data for Ruby Project

Parameters	Operating Criteria	100-year Storm Event
Maximum wave height(H_{max})	9.6 m	14.7 m
Significant wave height (H_{sig})	4.9 m	7.5 m
Significant peak wave period (T_p)	9.6 sec	11.1 sec
Significant zero crossing period (T_z)	6.8 sec	7.9 sec
Associated wave period (T_{ass})	8.9 sec	10.3 sec
Wave spectrum	P-M	P-M
Wind (Hourly mean; 10 m above MSL)	21 m/s	39 m/s
Wind (1 Minute mean; 10 m above MSL)	25 m/s	50 m/s
3 Second gust	30 m/s	57 m/s
Most probable wind direction	NE and SW	NE and SW
Surface current	0.80 m/s	1.75 m/s
Most probable current direction	NE and SW	NE and SW

The dimensions of FPSO vessel were taken from Ruby Project as shown in Table 3.3.

Table 3.3: Dimensions of FPSO for Ruby Project

Specifications	Full Scale
Length overall (m)	270
Length between perpendiculars (m)	260
Breadth(m)	43.4
Depth (m)	22.45
Design draft (m)	17.1
Tonnage (DWT)	140,000

3.2 DATA ANALYSIS

A thorough search was made through the internet and from libraries to collect all available information on the use of FPSO in offshore context. The collections of technical details regarding various FPSO in the world are essential to compare their performances in the form of hydrodynamic motions when subjected to environmental loads. Simple hydrodynamic analysis has been carried out for a typical FPSO.

3.2.1 Tools Required

This study has used various types of software in order to help the calculation method (e.g. hydrodynamic analysis) such as:

1. AutoCad
2. Microsoft Excel

3.2.2 Volume and Weight of Displaced Water

The FPSO was divided into two parts due to the different shape; the volume and weight of the displaced water were calculated separately. The weight of the displaced water was calculated using equation (3.1)

$$Weight = density\ of\ sea\ water\ x\ volume \qquad (3.1)$$

3.2.3 Linear Airy Wave Theories

A wave creates a free surface motion at the mean water level acted upon by gravity. The elevation of the free surface varies with space x and time t. The simplest and most applied wave theory is the linear wave theory. It is also called small amplitude wave theory or Airy theory. For the linear wave theory, the wave has the form of a sine curve and the free surface profile is written in Equation (3.2)

$$\eta = a \sin(kx - \omega t) \qquad (3.2)$$

Where: a is called the amplitude of the wave

ω is the frequency of oscillation of the wave

$$\omega = \frac{2\pi}{T} \qquad (3.3)$$

k is called the wave number.

$$k = \frac{2\pi}{L} \qquad (3.4)$$

To calculate celerity or speed of propagation of the progressive wave

$$c = \frac{\omega}{k} = \frac{L}{T} \qquad (3.5)$$

3.2.4 Wave Force Calculation

From the divided part of the FPSO from the displaced water calculation due to the different dimension and cross section for each part, the force acting on the body surface of the FPSO can be calculated. With reference to Figure 3.1, there were two forces that have been calculated which are F_H, force in x direction and F_V, force in y direction. These forces were calculated by assuming pressure acting on a surface area in certain angle. The force, F can be obtained by multiplying the pressure with the surface area. Since each part of the FPSO gives the different cross section and shapes, separate calculations of the surface area were done.

In this study, there were three area of forces considered which were at the back, tendem and bow part of the FPSO. The side parts of the FPSO were not considered as they cancelled out with each other. In force calculation, negative sign indicates that the force is acting on opposite direction.

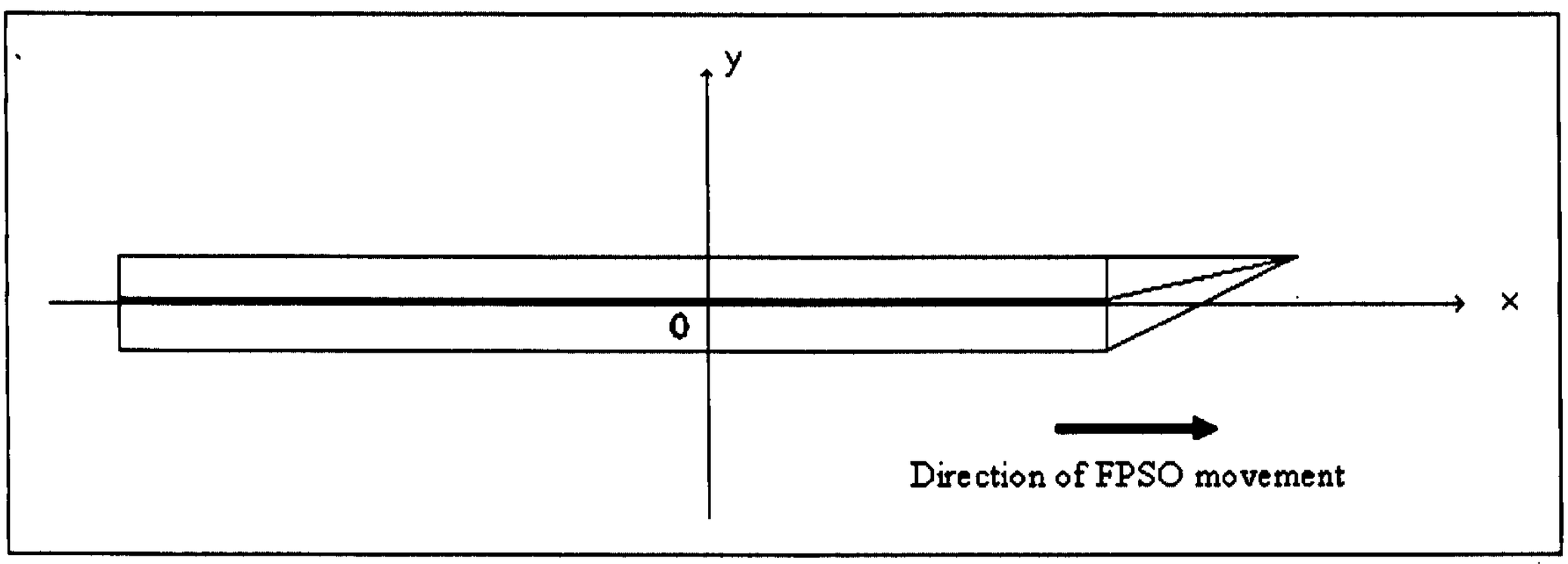

Figure 3.1: x and y axes of the FPSO and the direction of FPSO movement.

3.2.5 Froude-Krylov Theory

According to the Froude-Krylov theory forces on the structure are calculated by a pressure-area method in which the expression of the pressure due to the incident waves is used in performed assuming that the structure is not there as far as the waves are concerned. Because of the above assumption, this approach has limited practical applications. However, it is simple but good exercise in understanding the problem of wave forces on a submerged structure.

It is recognized that the forces derived by the Froude-Krylov theory are not directly applicable without making further correction due to the change of the oscillatory fluid flow around the structure by its presence. The bodies considered for the derivation of the Froude-Krylov forces are (1) a horizontal cylinder, (2) a horizontal halfcylinder, (3) a vertical cylinder, (4) a rectangular block, (5) a hemisphere and (6) a sphere.

The general formulas for the Froude-Krylov method of wave force calculation are outlined below. A closed-form expression for forces may be obtained only in a few cases. Linear wave theory is the simplest of the mathematical theories describing ocean waves. Based on this theory, the expression of dynamic wave pressure is given by equation 3.6

$$p=\rho g\alpha \frac{\cosh (k(z+h))}{\cosh (kh)} \cos \theta \qquad (3.6)$$

The expression for ρ (equation 3.6) represents the pressure above the static head at a point on the surface of a submerged structure acting normal to the surface at that point. The total force on the structure in a particular direction is then obtained by integrating the component of this pressure in that direction over the submerged portion of the structure. The expressions for the horizontal and vertical force components in the x and y direction are written as in equation 3.6 and 3.7

$$F_x = C_H \iint p n_x \, dS \qquad (3.7)$$

$$F_y = C_V \iint p n_y \, dS \qquad (3.8)$$

In which C_H and C_V = horizontal and vertical force coefficients, n_x, n_y = direction normal in the x and y directions, respectively, and dS = an element surface area of the submerged structure. The integration is carried out on the entire submerged surface of the structure. Note that the coefficient C_H and C_V are not determined by the Froude-Krylov theory, but rather are assigned values to obtain the total force accounting for the fluid flow around the structure.

3.2.6 Archimedes's Buoyancy Principle

A body completely or partially submerged in a fluid (gas or liquid) at rest is acted upon by an upward, or buoyant, force the magnitude of which is equal to the weight of the fluid displaced by the body. The volume of displaced fluid is equivalent to the volume of an object fully immersed in a fluid or to that fraction of the volume below the surface for an object partially submerged in a liquid. The weight of the displaced portion of the fluid is equivalent to the magnitude of the buoyant force. This principle was used to calculate the weight of the FPSO.

3.2.7 Wave Spectrum

The other approach in selecting the design wave environment considers the wave spectrum. In this case a suitable wave spectrum model was chosen to represent an appropriate density distribution of the sea waves at the site under consideration. The most suitable spectrum is seldom available. As an alternative, one chooses one of the theoretical spectrums at the site, although such spectrum model is available based on the fetch, wind and other meteorological conditions of the site. The chosen wave spectrum describes a short term wave conditions.

3.2.7.1 Pierson-Moskowitz (PM) Spectrum

The PM spectral model describes a fully-developed sea determined by one parameter, namely, the wind speed. The fetch and duration are considered infinite. For the applicability of such a model, the wind has to blow over a large area at a nearly constant speed for many hours prior to the time when the wave record is obtained and the wind should not change its direction more than a certain specified small amount. In spite of these assumptions, the P-M model has been found to be useful in representing a severe storm wave in offshore structure design.

The PM spectrum model is written as equation (3.8)

$$S(\omega) = \frac{\alpha g^2}{(2\pi)^4} f^5 \exp \left[-1.25\left(\frac{f}{f_o}\right)^{-4}\right] \qquad (3.9)$$

Where $\alpha = 0.0081$, and peak frequency, $f_o(\omega_o/2\pi)$.

For this spectrum, the relationship between the peak frequency and the significant height for the wave was as follows:

$$\omega_o = 0.161 g/H_s \qquad (3.10)$$

At frequency f_1, energy density was $S(f_1)$. The weight height at this frequency as follows:

$$H(f_1) = 2\sqrt{2}(f_1)\Delta f \qquad (3.11)$$

The time history of the wave profile was determined from:

$$\eta(x,t) = \sum \frac{H(n)}{2} \cos\left[k(n)x - 2\pi f(n)t + \varepsilon(n)\right] \qquad (3.12)$$

Where, x was location of evaluation of wave profile from the origin in the horizontal direction; t was the time instant at which wave profile was evaluated and was incremented; wave number k(n); wave length L(n) corresponded to the wave length for nth frequency; wave height H(n) was computed from equation (3.11) for the nth

frequency; and the n was the total number of frequency band of width Δf, dividing the total energy density.

3.2.7.2 Motion Response Spectrum

The responses of the FPSO towards the motion of surge, heave and pitch were calculated by multiplication of the wave energy spectrum with the square of RAO function to evaluate the response spectrum value at particular frequency. The expression may be written as follow:

$$S_x(f) = [RAO(\omega)]^2 S(f) \qquad (3.13)$$

$$S_x(f) = \left[\frac{F_1/(H/2)}{[K-m\omega^2)^2+(C\omega)^2]^{1/2}} \right]^2 S(f) \qquad (3.14)$$

Where, RAO was amplitude of responses per unit wave amplitude; F1, was inertia force; K was stiffness of the structure associated with different type of motion; m was summation of mass and added mass of the structure associated with different type of motion; C was structural damping ratio; H was wave height corresponding to particular frequency; and ω was natural frequency corresponding to particular frequency.

3.2.8 PARAMETRIC STUDIES

Parametric studies will be made by varying parameters to study the variation in platform responses caused by changing the water depth and wave spectrum. RAO and time series of responses subjected to the variation of parameters were plotted using Equations (3.12) and (3.14).

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 DIMENSIONS

For further investigation on the FPSO responses, final shape and dimensions were determined. The final dimensions that were used for this study are summarized in Table 4.1

Table 4.1: Final dimensions of FPSO

Specification	Full Scale from Ruby Project	Final Dimension
Length overall (m)	270	270
Length between perpendiculars (m)	260	260
Breadth(m)	43.4	42.1
Depth (m)	22.45	22.1
Design draft (m)	17.1	17
Tonnage (DWT)	140,000	

The final shape of the FPSO in 3-D view is shown in Figure 4.1, while for figure of FPSO complete with dimension is shown in Figure 4.2.

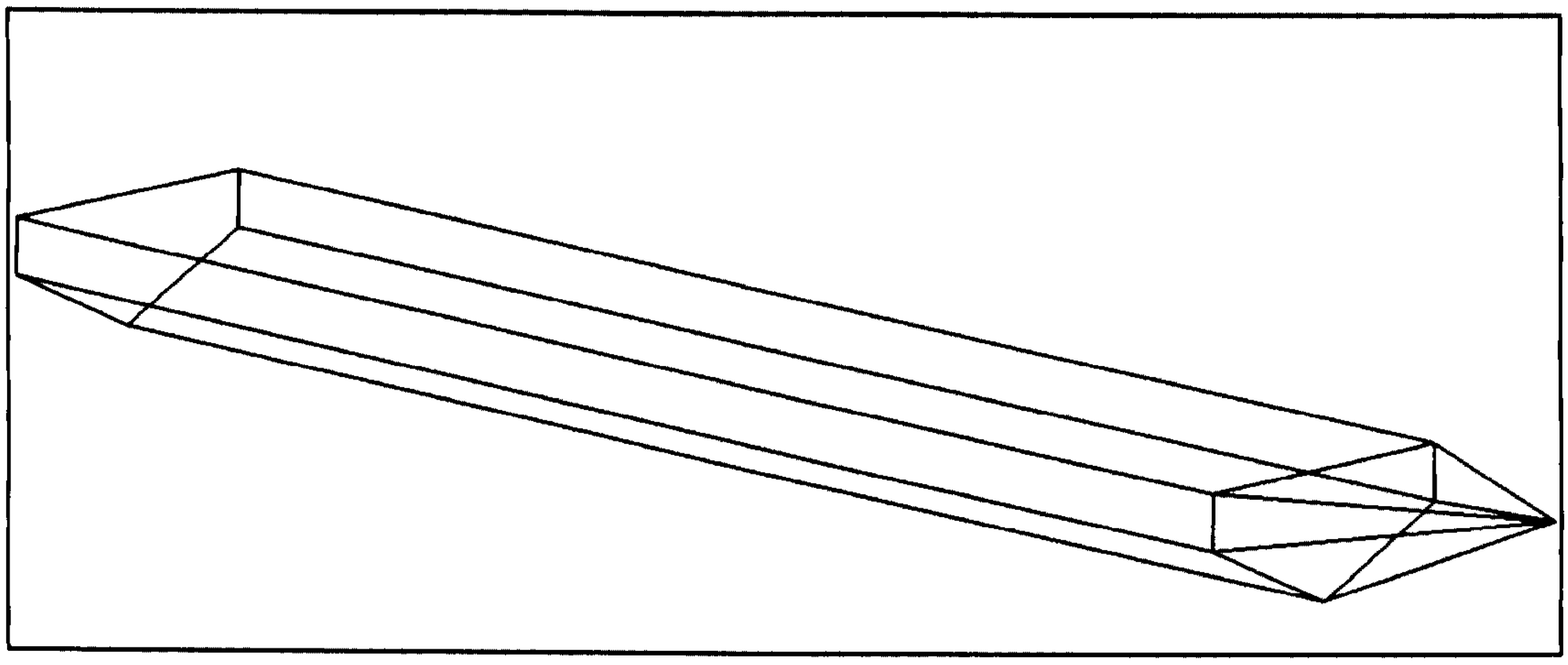

Figure 4.1: Full view of the FPSO

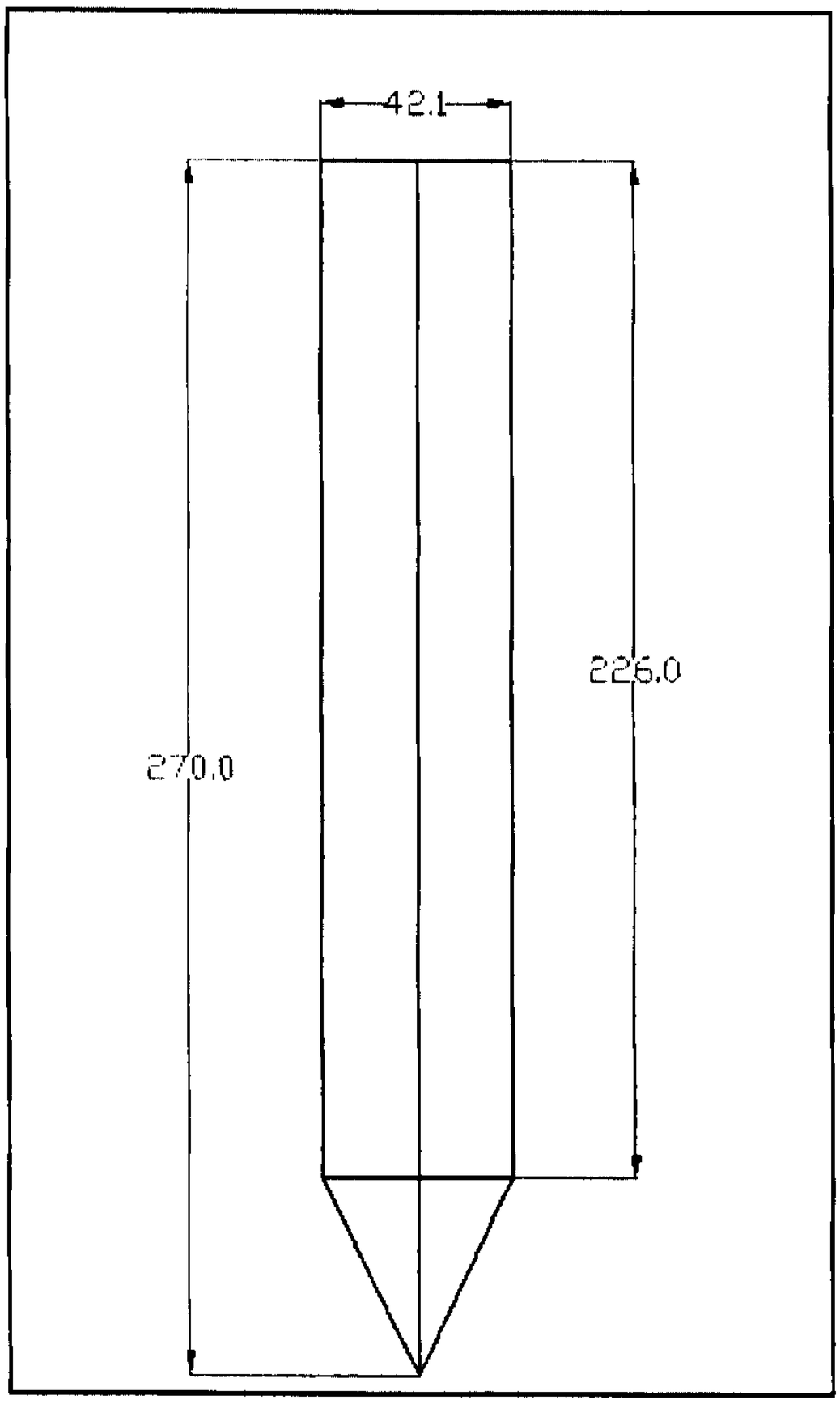

Figure 4.2: Plan view of the FPSO (all units are in meter)

4.2 VOLUME AND WEIGHT OF DISPLACED WATER

In order to get the volume of displaced water for the FPSO, the FPSO need to be divided into two parts due to the different dimension of cross section. The divided part will make it easy to calculate the volume.

For the first part, which cover the tandem and the back of FPSO, the volume of displaced water is **$102.6x10^3$ m^3** and volume of displaced water for second part which covers the bow of the FPSO is **$6.4x10^3$ m^3**. In calculating volume, for cross sections above the Sea Water Level, it is neglected since it does not displace any water. Hence, the total volume for the FPSO is **$109.0x10^3$ m^3** and the weight is **111.7 Mg**.

4.3 WAVE FORCES AND MOMENTS

Table 4.2 summarize the maximum force and moment acting at center (0m), back (-135m) and front point (+135m) of the FPSO.

Table 4.2: Wave force and moment distribution on the FPSO

x	Max $\sum F_H$ (M-N)	Max $\sum F_V$ (M-N)	Moment (M-Nm)
0m	160	453	933.3
+135m	160	450	776.4
135m	160	453	776.4

From Table 4.2, value for maximum and maximum for all three x coordinate (x=0m, x=135m and x=-135m) are approximately the same. As for value of moment, at x=0m experience bigger moment compare to other coordinate. This is due to the weight distribution at the center of the structure. These forces increase because of the longer moment arm, which results in increased added inertia for pitch and shifts the natural period away from the wave excitation (Nico *et al*, 2008). Refer to Appendix A for

example of detail calculation on wave forces calculation and Appendix B for example of detail calculation on moment calculation.

4.4 WAVE SPECTRUM

Table 4.3 summarizes the RAO for surge, heave and pitch of the FPSO. Refer to Appendix C for example of detail calculation on RAO calculation.

Table 4.3: RAO surge and heave for FPSO

x	RAO		
	surge	heave	pitch
0m	0.06772	0.30068	0.00007
+135m	0.06726	0.29860	0.00006
135m	0.06765	0.30036	0.00006

The wave energy spectrum, S(f) was determined based on the Equation 3.9 and the significant height was obtained from a wave record of 4.9m. The PM spectrum was drawn range from the frequencies of 0.01Hz to 0.40Hz with a frequency increment of 0.01Hz and the corresponding wave height from each frequency in the range was obtained.

From the calculated wave height, the time history of the wave profile (t=0sec to t=200sec) in front of the FPSO at x=0m (initial position) was computed and a random phase in the range of $(0,2\pi)$ was assigned to a random number generator, RN to retain randomness of the time history. The stimulated wave profile for x=0m, x=+135m and x=-135m are shown in Figures 4.3 and 4.4.

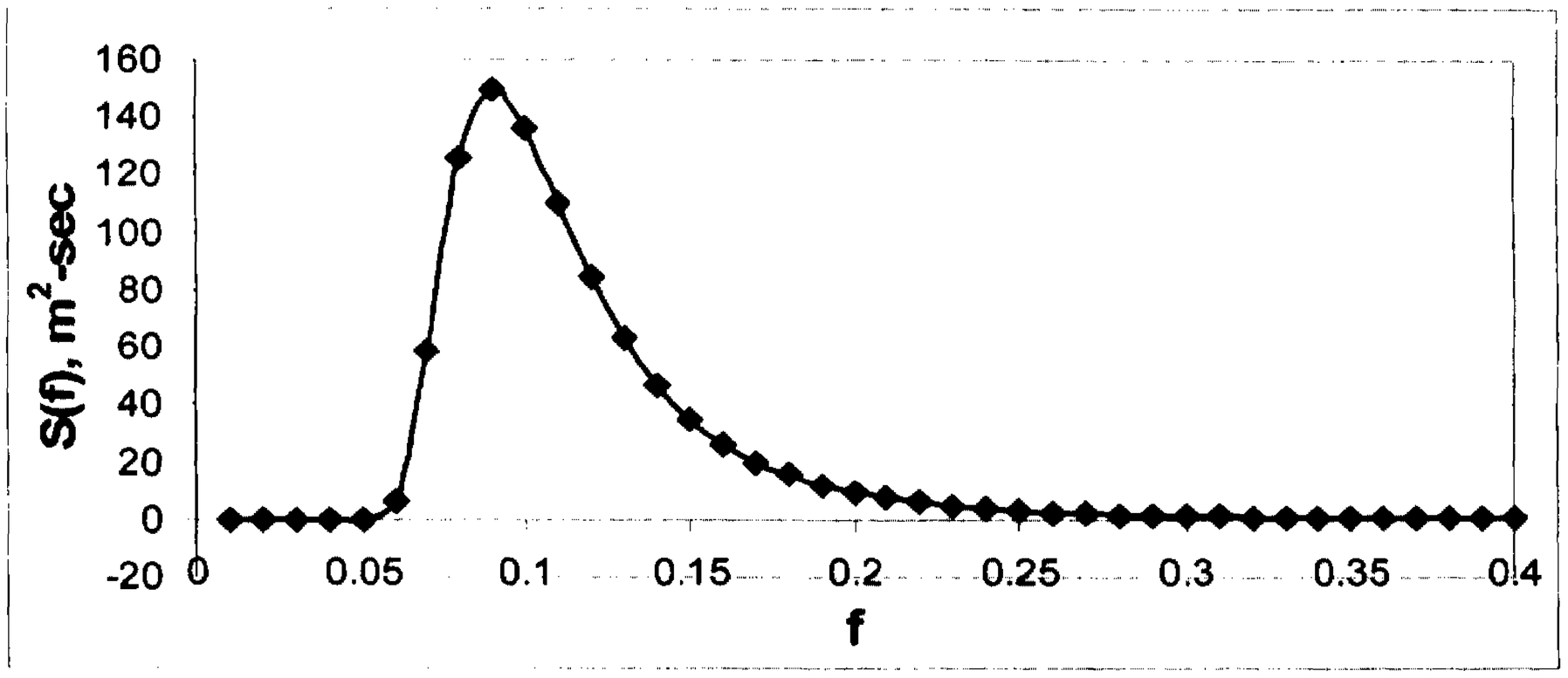

Figure 4.3: Energy density spectrum (PM spectrum) for H_s= 4.9m

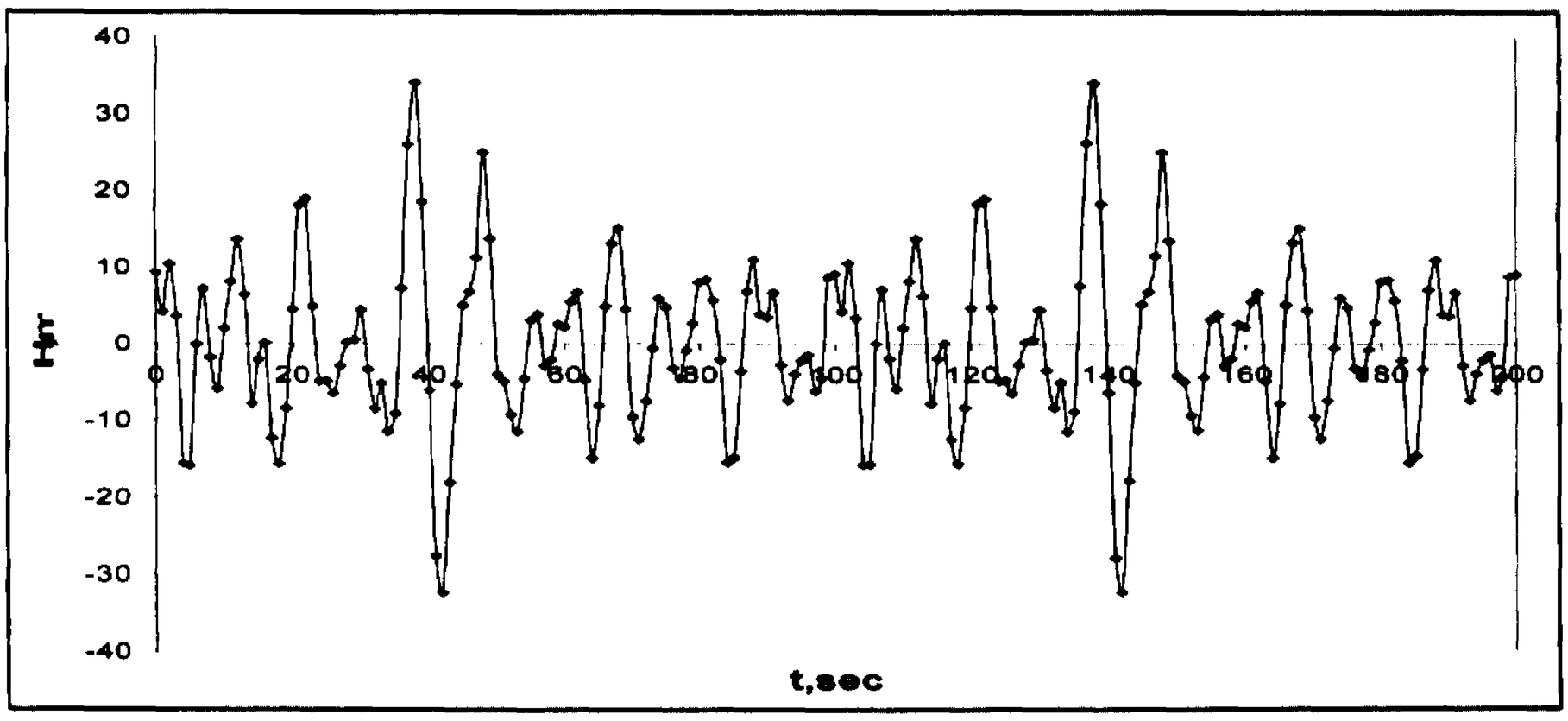

Figure 4.4: Simulated wave profile at x=0m (t=0sec to 200sec)

4.5 MOTION-RESPONSE SPECTRUM

In determining the motion-response spectrum, three types of motions; surge, heave and pitch were chosen to analysis the response of FPSO towards three motions. As stated in section 3.2.7.2, the motion-response spectrum of surge, heave and pitch were determined based on Equation (3.14), structure damping ratio 0.05%, and the PM model of H_s= 4.9m. For the computation of RAO, the wave train was considered as random and frequencies (0.01Hz to 0.40Hz) in the wave train were chosen to cover the entire range of frequencies of the wave spectrum. RAOs for all the motions were multiplied with PM spectrum to finally obtain the response spectrum as shown in Figure 4.5,

Figure 4.6 and Figure 4.7. Refer to Appendix D for example of detail calculation on wave spectrum calculation.

Based on Figures 4.5, 4.6 and 4.7, the maximum energy distribution is at x=0m for all three motions. This is due to the maximum value of forces acting on that coordinate which result to higher energy distribution. However, all responses are approximately the same with respect to the degree of motion.

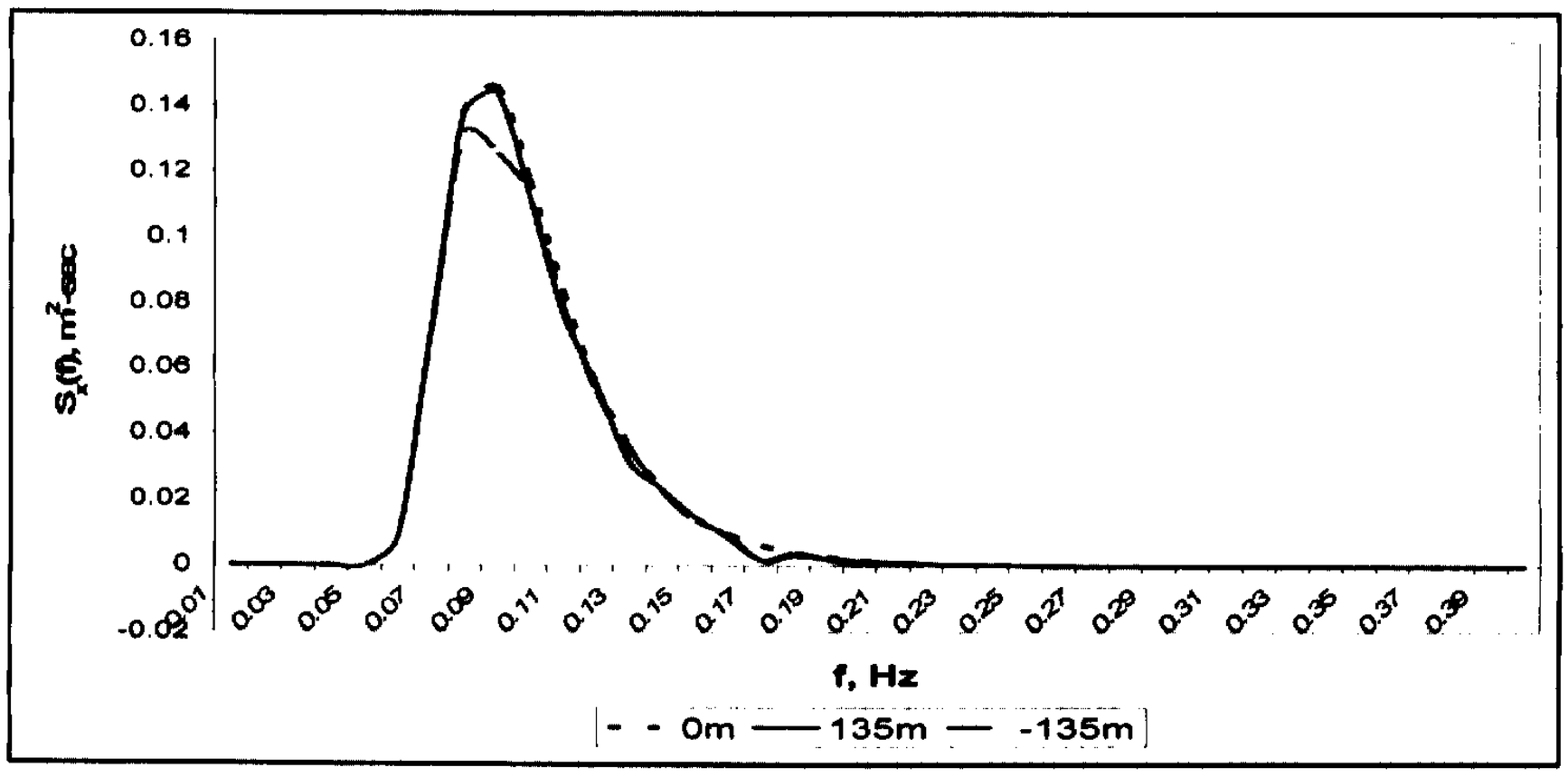

Figure 4.5: Combine surge response spectrum

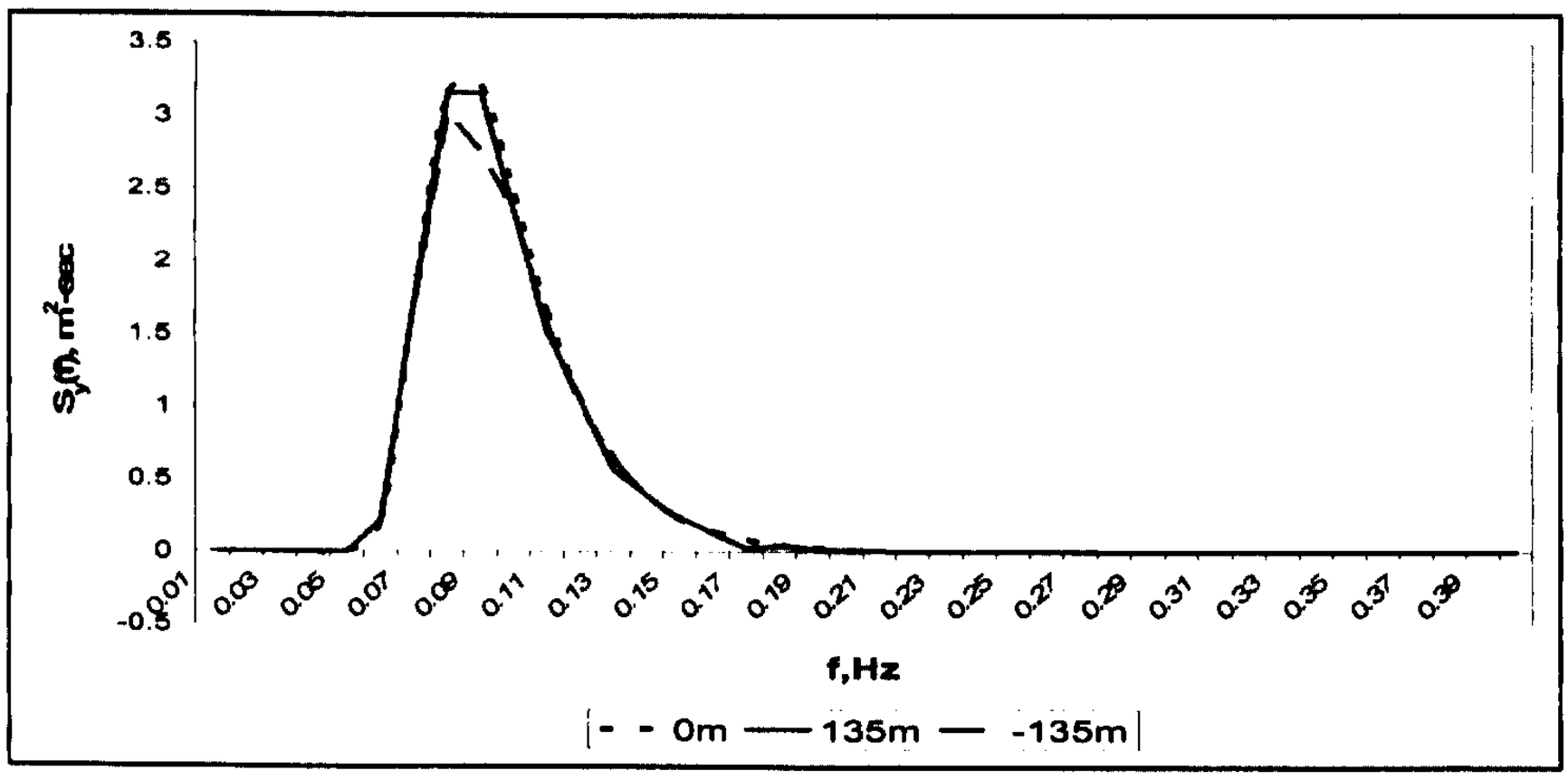

Figure 4.6: Combine heave response spectrum

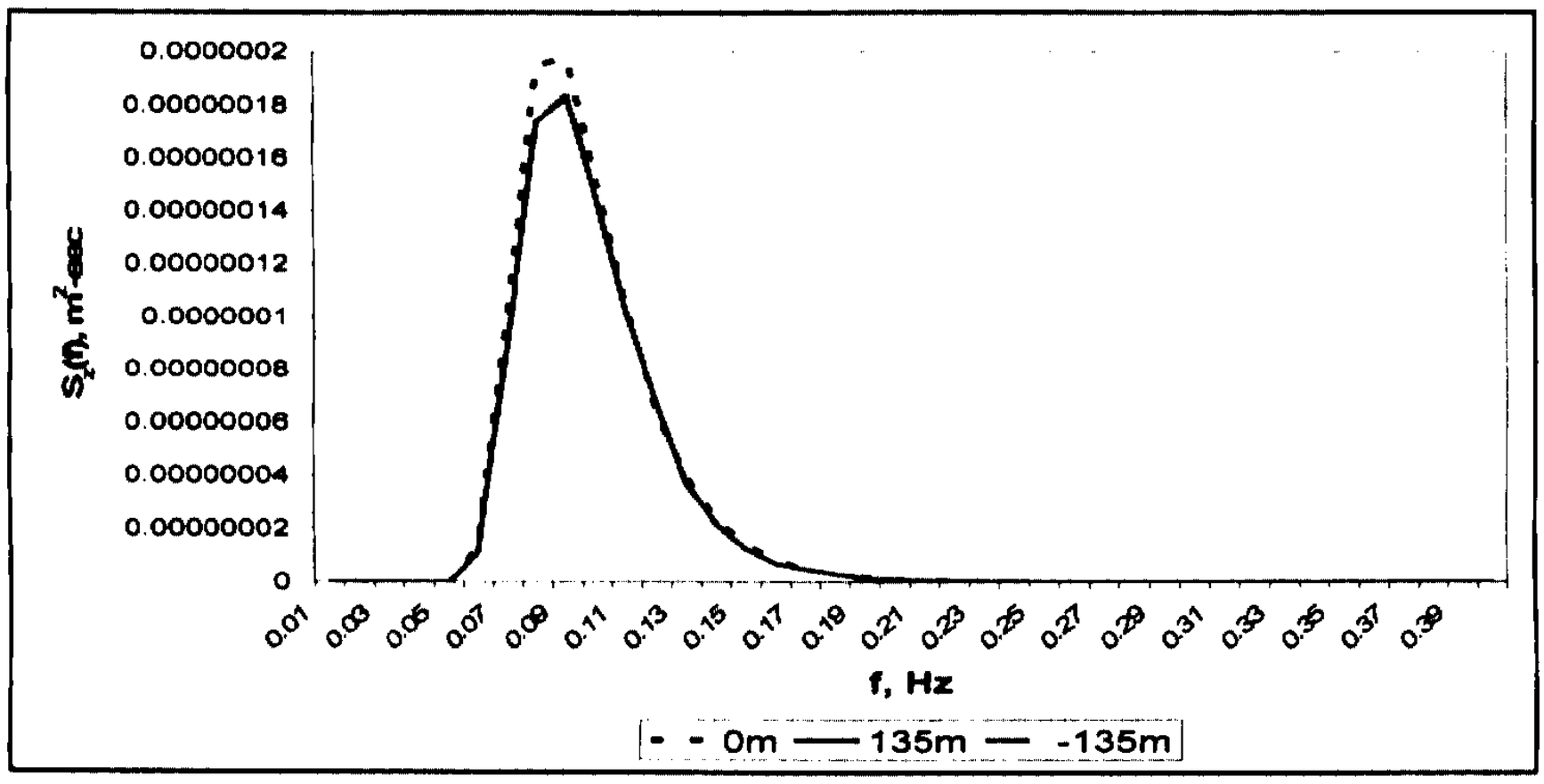

Figure 4.7: Combine pitch response spectrum

4.6 RESPONSE OF FPSO ON SURGE, HEAVE AND PITCH MOTIONS.

The time history responses of the FPSO are illustrated as in Figures 4.8, 4.9 and 4.10 for x=0m, x=135m and x=-135m respectively. The three motions for all three coordinates experience approximately the same maximum amplitudes. Based on Equation 3.11, the responses of the motions depend on the response spectrum.

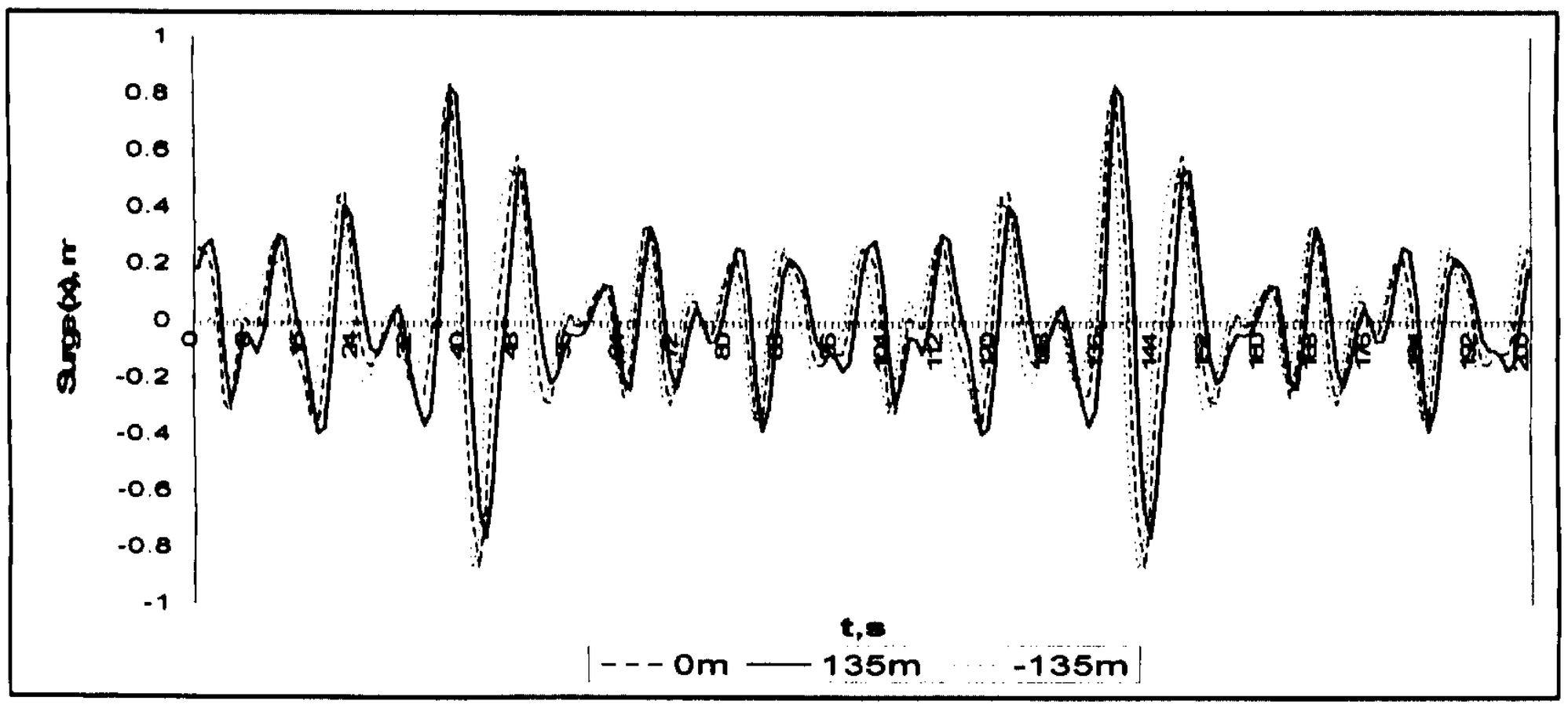

Figure 4.8: Combine stimulated surge

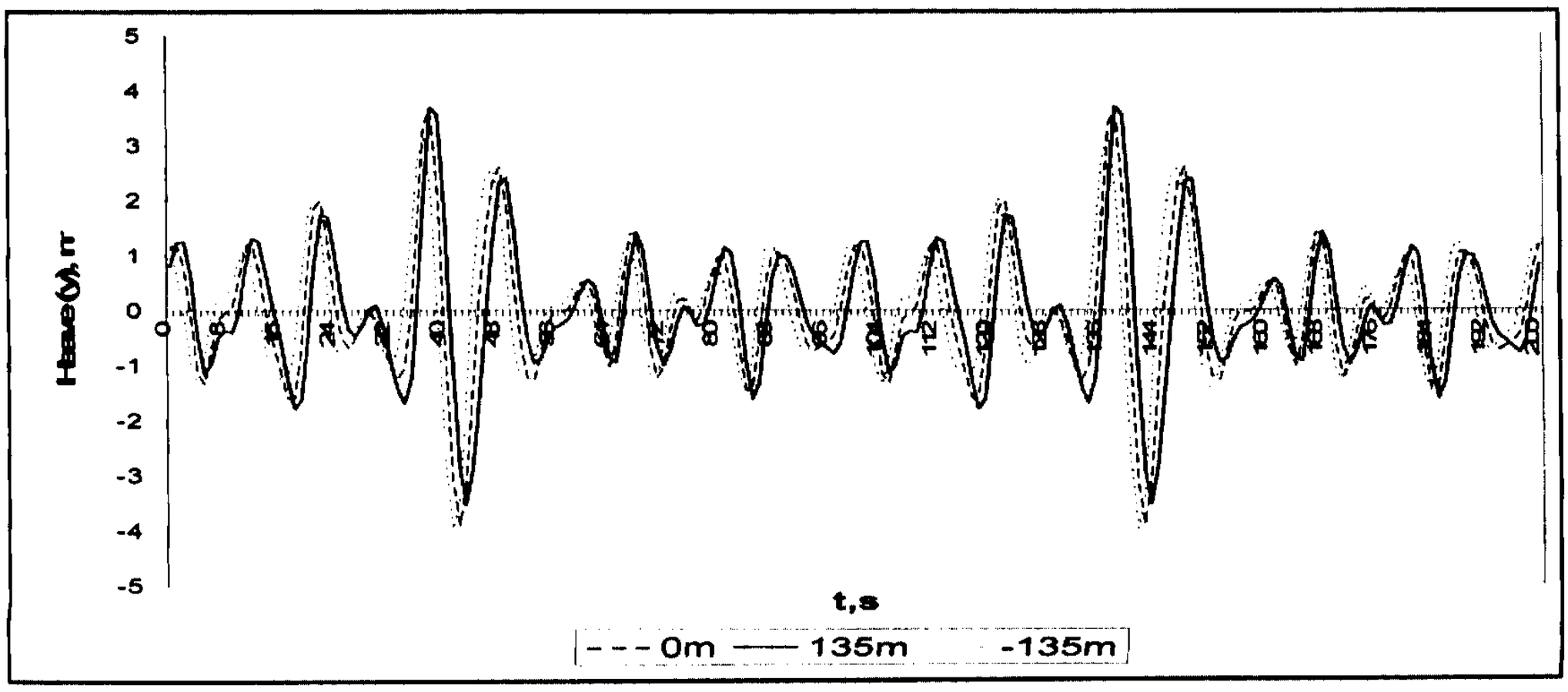

Figure 4.9: Combine stimulated heave

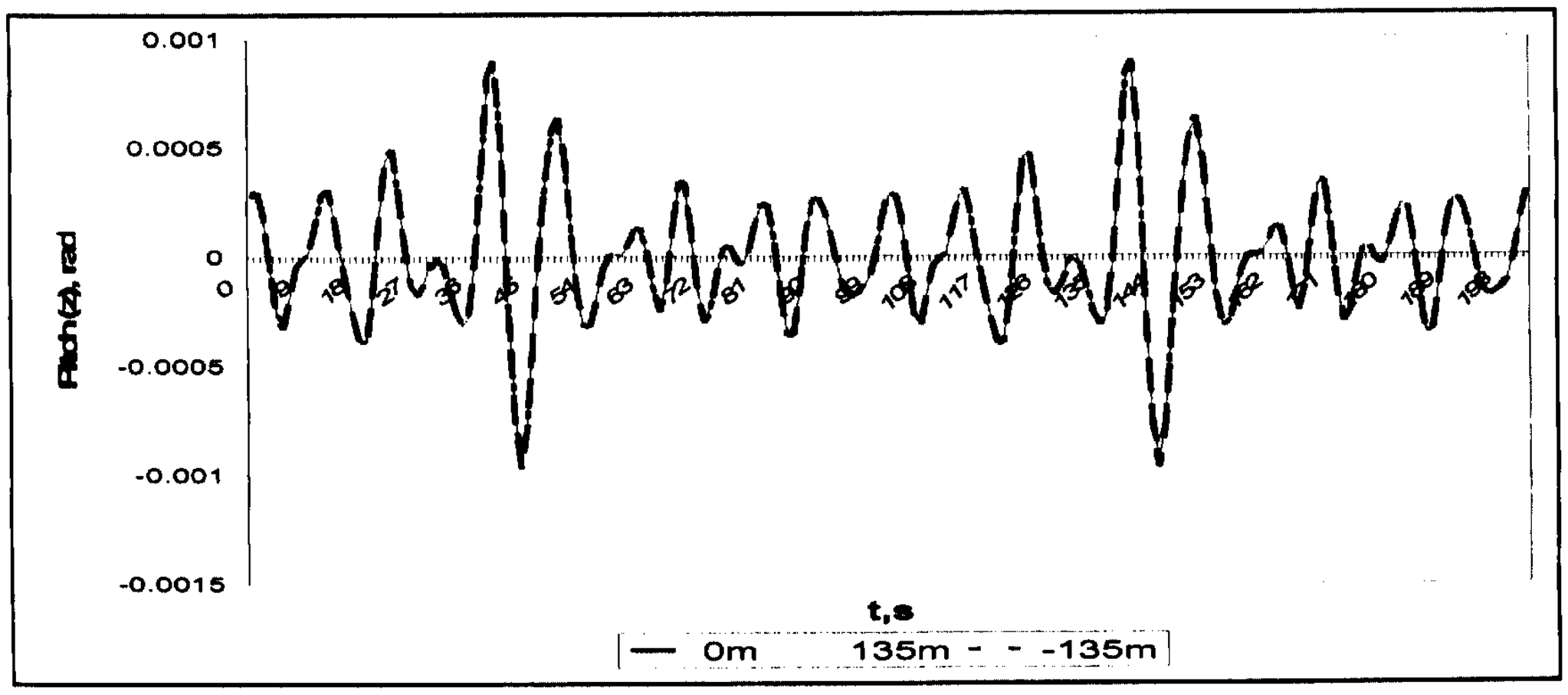

Figure 4.10: Combine stimulated pitch

4.7 PARAMETRIC STUDIES

Two parameters were chosen to study the effects of these parameters on the responses of the FPSO: (1) water depth and (2) wave spectrum. The comparison between surge, heave and pitch responses on all parameters were represented by two approaches; the wave spectrum curve and time series curve.

4.7.1 Water Depth

Three water depths; D=50m, D=500m and D=1500m were taken to investigate the effects of different water depth on the responses of FPSO. Water depth, D=50m represent the response of FPSO in shallow water area, water depth, D=500m represent the response of FPSO in deepwater area, and water depth, D=1500m represent the response of FPSO in ultra deepwater area.

Figures 4.12, 4.14 and 4.16 show the wave spectrum of surge, heave and pitch for x=0m respectively. These figures also represent the wave spectrum for x=135m and x=-135m since the responses were also same even though at different x coordinate. From these figures, the maximum energy distribution for surge motion decreases about 8% as water depth increases to deepwater and ultra deepwater. As for heave and pitch motion, the maximum energy distribution decrease about 11% as water depth increase.

The decreasing trend of the energy distribution is due to:

1) The water depth has a substantial effect on hydrodynamic force. The hydrodynamic force will increase with the decrease of water depth (Miao *et al*, 2006). Based on Equation 3.14, as the hydrodynamic force increase, the motion responses will increase as well. Therefore, as water depth increase into deepwater and ultra deepwater, it will decrease the hydrodynamic force experienced by the structure. With the decrease in force, the motion responses decrease as shown in Figures 4.12, 4.14, and 4.16.

2) G. Clauss *et al* (2009) stated that the influence of limited water depth is induced by the presence of the bottom boundary condition. In shallow water, waves do interact with the seafloor while in deepwater, waves do not interact with the

seafloor and orbits of the water is in circular motion. If the water depth exceeds one half of the wavelength, the wave kinematics decays down to less than 5 percent. Therefore, the water depth can be neglected. The water particle experience the strongest effect as it close to the sea bottom and least affected as it at the water surface. Figure 4.11 shows the relation of the deformation of orbital velocities and the water depth.

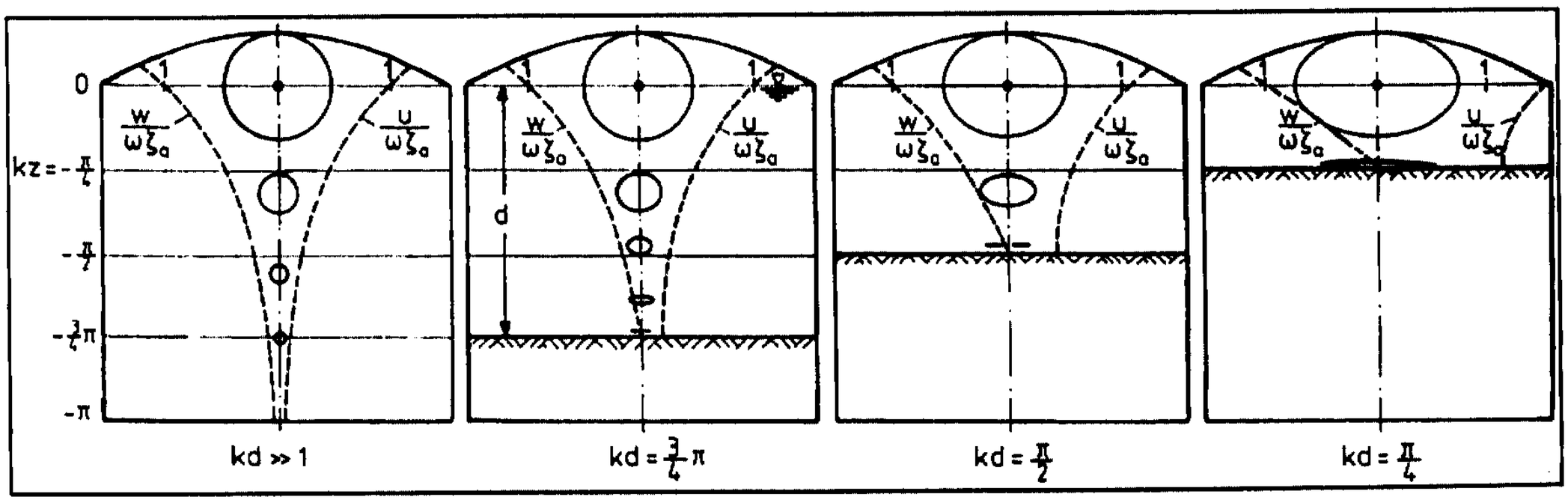

Figure 4.11: Relationship between water depth and the orbital velocities.

(G. Clauss *et al*, 2009)

Figures 4.13, 4.15 and 4.17 illustrate the comparison between the time histories of different water depth of surge, heave and pitch for x=0m respectively. Similar to the figures for wave spectrum, these figures also represent the time series for x=135m and x=-135m since the responses were also the same even at different x coordinate. From the figures, it is observed that there are no differences with the time series even though water depth increases from 50m to 500m and 1500m.

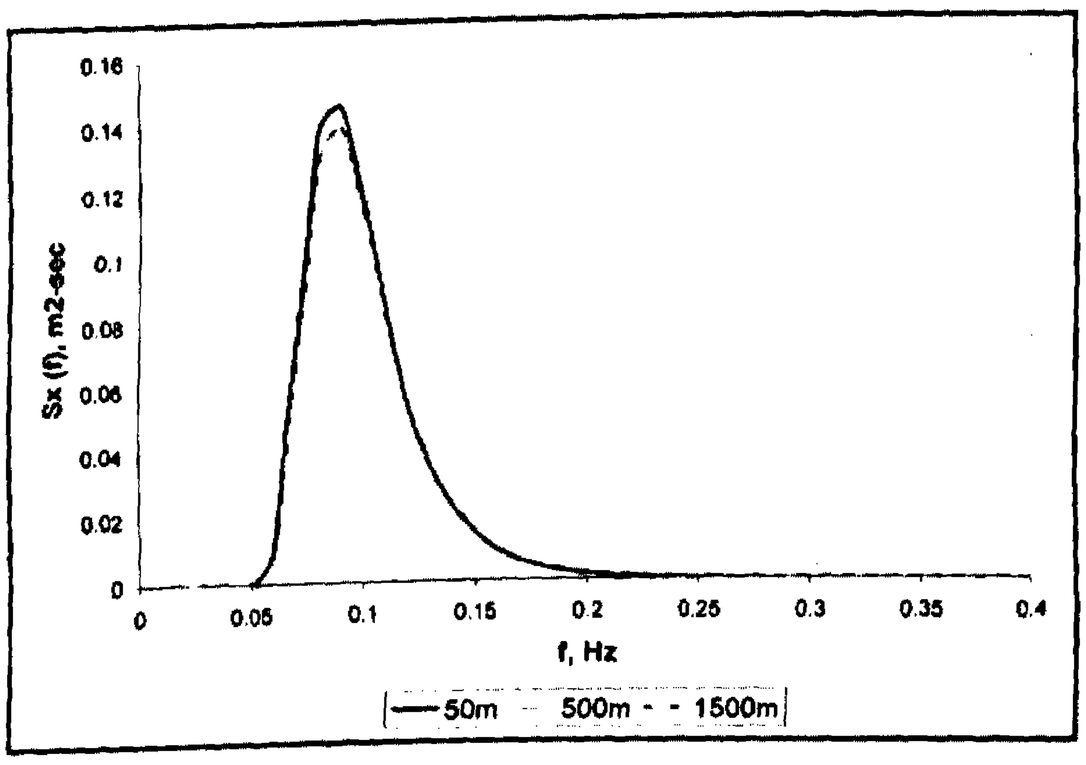

Figure 4.12: RAO surge with different water depth

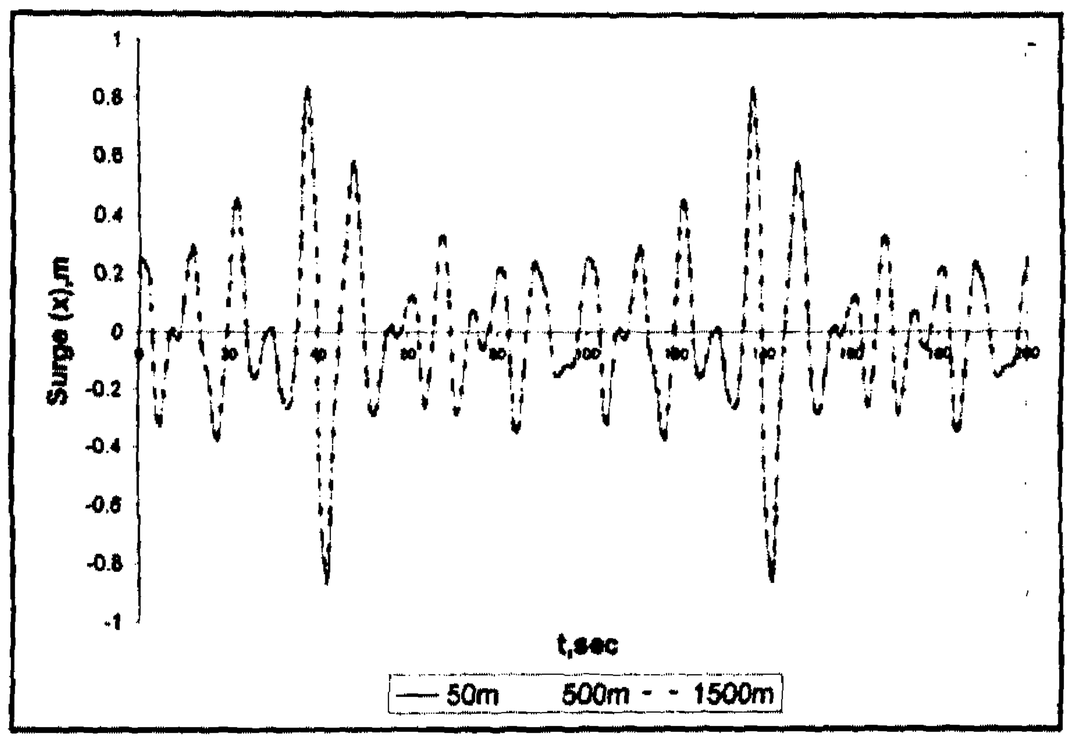

Figure 4.13: Time series of surge

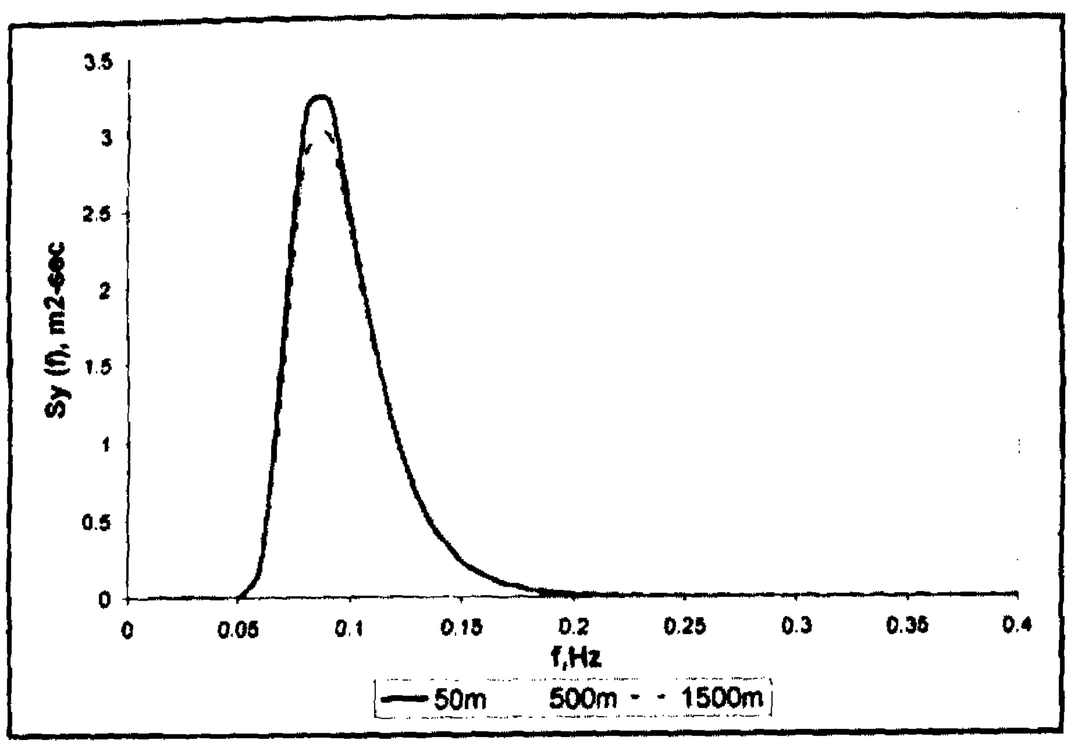

Figure 4.14: RAO heave with different water depth

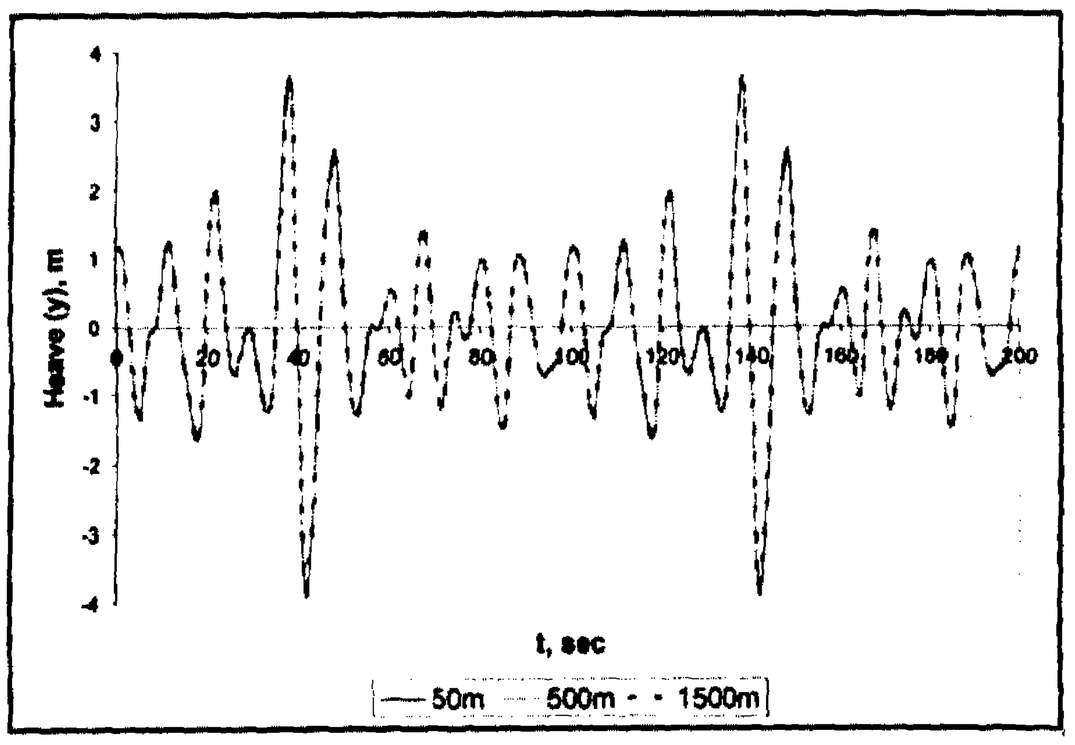

Figure 4.15: Time series of heave

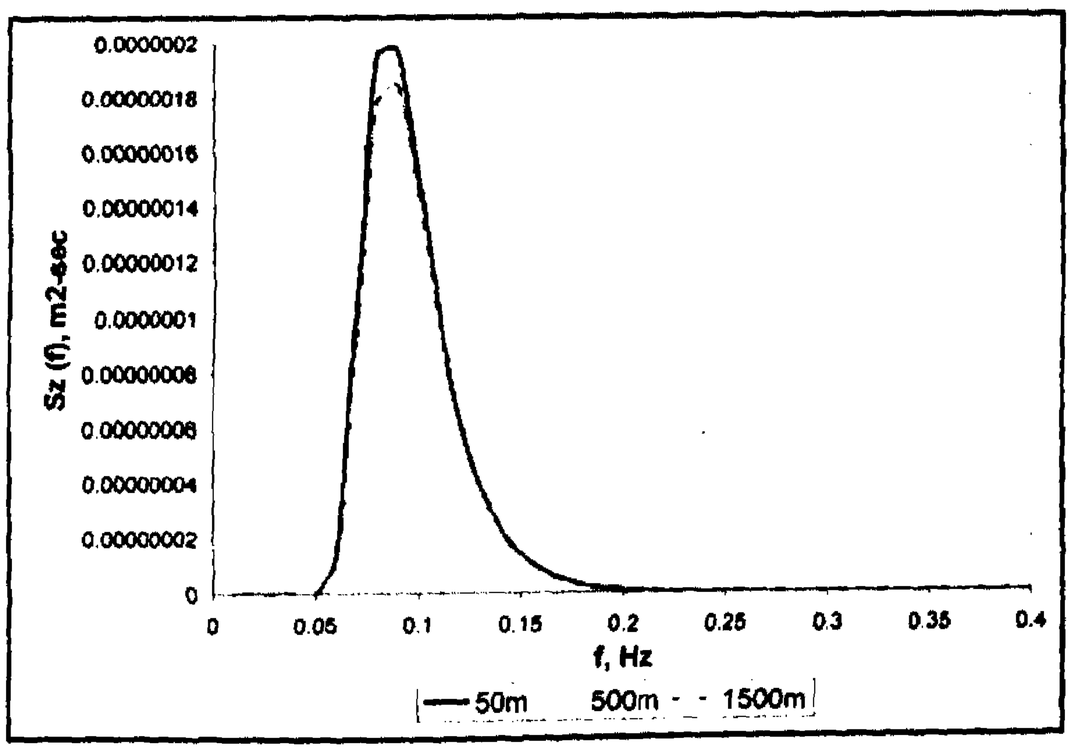

Figure 4.16: RAO pitch with different water depth

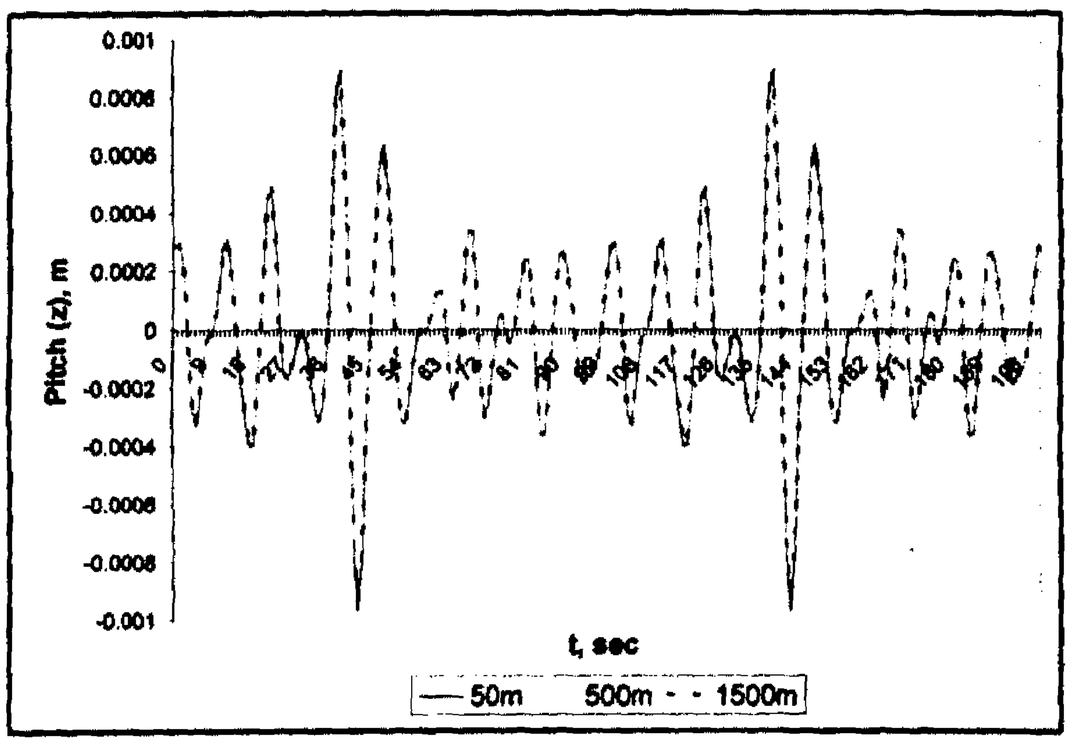

Figure 4.17: Time series of pitch

4.7.2 WAVE SPECTRUM

The change of wave spectrum from PM spectrum to Jonswap spectrum had effect all three degrees of freedom which are surge, heave and pitch motion. Figure 4.18 illustrates the change in energy distribution by both spectrum of x=0m. The figure not only represent the changes at coordinate x=0m for surge, heave and pitch motion, it also represent the change in RAO of x=135m and x=-135m for all three motions as they also undergone the same changes as well. Based on the figure, the difference of the maximum energy distribution between both spectrums decrease more than 50% as the spectrum change from PM to Jonswap.

The comparison between the spectrums was made in order to understand the condition of the sea at Ruby field at different wave spectrum. Based on explanation of PM spectrum at Section 3.2.7.1, PM spectrum has been extensively used by ocean engineers as one of the most representative for waters all over the world. It is derived from very stable sea condition. Jonswap spectrum was chosen to compare with PM spectrum as Jonswap wave spectra usually had been used in the design of an offshore structure in a fetch limited area. Fetch along with wind speed determines the size of waves produce. Therefore, with the limitation of fetch, the wave will not be large and the power and energy of the wave may also decrease. This can be seen in the figure where Jonswap has less maximum energy distribution compared to PM spectrum. The comparison also been made to understand the condition of the Ruby field at a rough sea state. This may be useful to ocean engineers to determine the condition of the sea at Ruby field when designing any offshore structure in the future.

Figure 4.19 shows the comparison of time series between both spectrum of x=0m for all three motions. The changes were can also be seen in the time series of x=135m and x=-135m and therefore also represented by this Figure 4.19 as well.

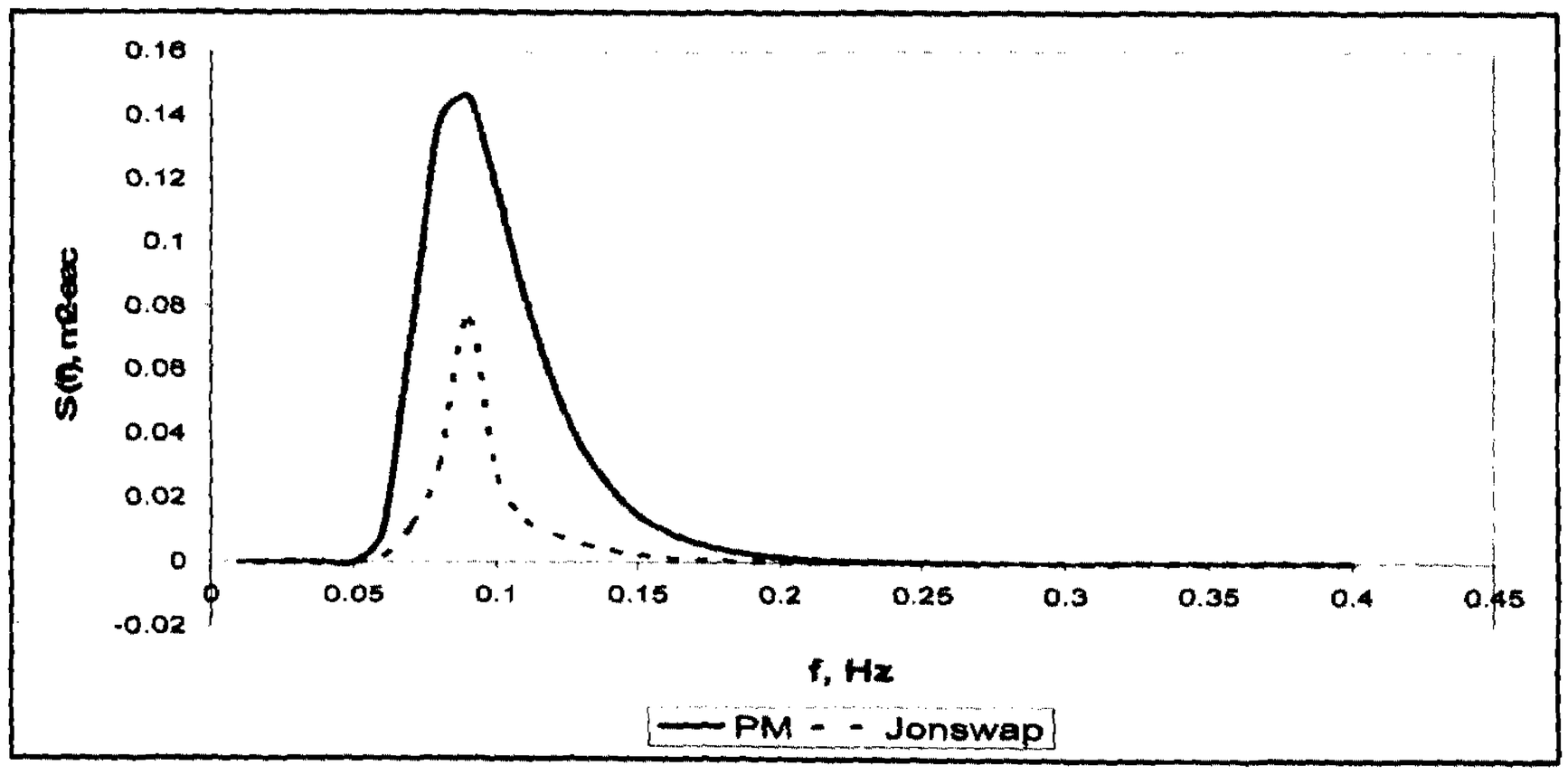

Figure 4.18: RAO surge of x=0m for different wave

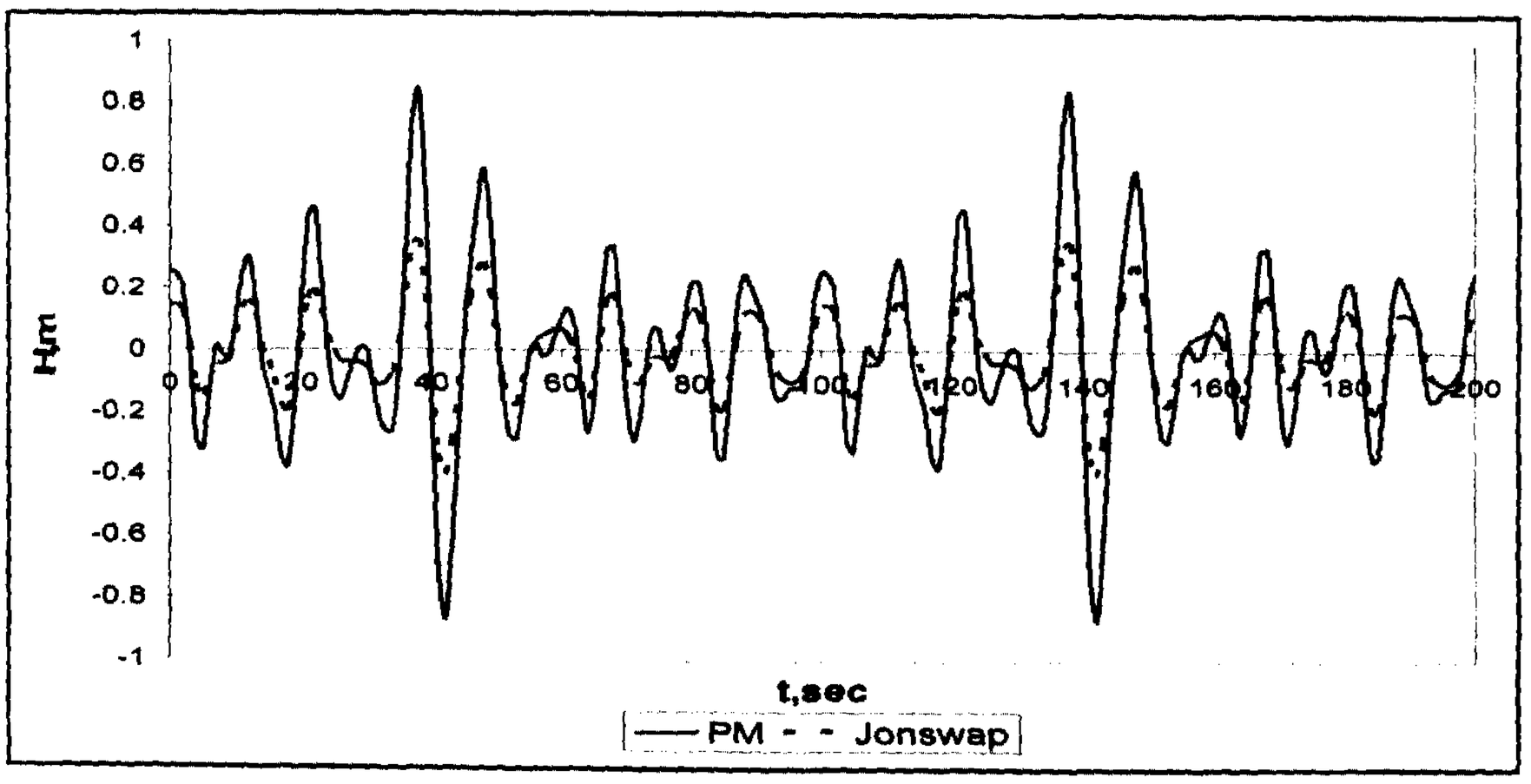

Figure 4.19: Time series for x=0m of surge

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

In this study, all detailed literature review related with FPSO including the environment, loading and response of FPSO, structural design of FPSO and construction of FPSO already presented. Appropriate references have been included in many cases.

In completing the dynamic analysis of FPSO, most of the wave theories that are normally used in the design of an offshore structure have been practically used appropriate with all related parameters and the structure itself. The procedure and solutions were using simple estimation and some mathematical forms as well. It is expected that this study will give more understanding in predicting the responses of the FPSO towards the selected parameters; water depth and wave spectrum. On the other hand, this study enables more understanding of hydrodynamic principles for FPSO for further research work. The results of parametric studies highlighted the variation in platform responses caused by changing parameters.

Based on the discussion in the previous section, the conclusions from this study are summarized as follows:

- Dynamic analysis and parametric study of the FPSO with wave height of 4.9m, and using Ruby FPSO as reference were successfully completed.

- Froude-Krylov theory was used as it as the basis for force calculation due to the geometry and floating behavior of FPSO.

- The developed frequency domain analysis of typical FPSO has been able to predict the responses in surge, heave and pitch degrees of freedom when the

FPSO was subjected to random waves developed from Pierson-Moskowitz spectrum.

- Change of water depth from shallow water to deepwater and ultra deepwater have slightly difference effect on the responses of FPSO in term of its surge, heave and pitch motion for all three x coordinate.

- Increase in water depth will not have much affect between deepwater and ultra deepwater in all terms.

- The maximum energy distribution decrease as water depth increase from shallow to deep and ultra deepwater.

- Compared to the PM spectrum, the maximum energy distribution and time series for Jonswap spectrum decrease in all terms of its surge, heave and pitch motions.

5.2 RECOMMENDATIONS

Based on the present study, the following recommendations are made to further improve the dynamics analysis and the future research work:

- Further study to investigate on a specific water depth where all terms of motions will no longer be affected by the dynamic analysis.

- Other parameters should be included in the parametric studies such as draft, center of gravity and the shape of FPSO.

- More specific calculations on determining the wave forces and the weight of FPSO should be perform since a lot of considerations need to be made in order to get more accurate data on the forces acting on the structure and the additional weight applied in designing FPSO.

CHAPTER 6

ECONOMIC BENEFITS

Parametric study of FPSO responses looks at the bottom line economic benefits of introducing an economical and beneficial FPSO by reducing problems due to change in sea condition and the offshore structure itself. The FPSO could experience the most dramatic and positive impacts according to their specification and behavior when operates in oil field. The study is designed to verify the benefit of the FPSO with respect to the reference field which is Ruby Field at Vietnam.

The result of this study can be very useful to ocean engineers to determine the condition of the sea at Ruby field when designing any offshore structure in the future. From the chosen parametric, the ocean engineers can predict the responses of the offshore structure in different sea state and different water depth at the Ruby field.

By using the findings from this study, ocean engineers and other engineers can build FPSO depending on their selection of environmental data and predict the responses of the offshore structure. Let say they pick a water depth to place the FPSO, they can determine weather the water depth is categorized as shallow, deep or ultra deepwater first and hence, can predict the responses of the structure at that particular water depth. This may save in cost and time of their project especially in planning stage.

As per discussed before, different parametric will give different responses. Different shape of the FPSO will determine different responses as well, as they will affect the volume of the displaced water, the wave forces until the RAO calculation. In this study, triangular shape has been selected as the shape at the bottom of the FPSO. Triangular shape will give an easier way to carry calculation for volume of displaced water compared with other shapes.

FPSO vessels are particularly effective in remote or deepwater locations where seabed pipelines are not cost effective. FPSOs eliminate the need to lay expensive long-distance pipelines from the oil well to an onshore terminal. They can also be used economically in smaller oil fields which can be exhausted in a few years and do not justify the expense of installing a fixed oil platform. Once the field is depleted, the FPSO can be moved to a new location.

This study promised greater economic benefits if a model can be build to compare the results from the numerical computation with the results from the experimental lab. The cost for a new build FPSO model is estimated to be more than RM 700.00 due to quality of material been used and specific design given to contractor that may be difficult to be build. This model may be beneficial to continue to predict responses of another parametric towards the offshore structure.

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APPENDICES

WAVE FORCE CALCULATION - SURGE AND HEAVE for x=0m, t =0s

Regular Wave-Froude Krylov Force
Parametric Data for Surge, Heave and Pitch

PI (π)	=	3.1416	
Gravity Accleration (g)	=	9.807	m/s^2
Sea Water Density (ρ)	=	1030	kg/m^3
Water Depth , (d)	=	1200	m
Distance from origin (x)	=	**0**	m
Time at x distance (t)	=	**0.0**	s
		(varies from t=0s to t=9s)	

Wave Data

Wave Height (H)	=	9.6	m
Wave Period (T)	=	8.9	s
Wave Length (L)	=	123.45679	m
Wave Frequency (ω)	=	0.7060674	rad/s
Wave Number (k)	=	0.0509004	
C_H	=	2.00	
C_V	=	1.10	

Calculated Data

kx-ωt (Θ)	=	**-6.2122**	
cos Θ	=	**0.9975**	
cosh kd	=	3.97E+25	
H/2	=	4.8	m

Final Year Project Calculation Sheet	Project **Parametric Study of FPSO Responses**	Sheet No 1
Title **Wave Forces Calculation**	Design **Aiza Amelia Yazid@Majid**	Check/Review **Ms Nabilah Abu Bakar, Dr Kurian V John**

D	50
H_s	4.9
T_s	6.8
T_p	9.6
H_{max}	9.6
T_{max}	8.9
g	9.807
π	3.142
L_o	123.6175
d/L_o	0.404473
L	123.4568
k	0.0509
ω	0.706067
ρ	1030
kd	2.54502
cosh kd	6.410977
C_x	2
C_y	1.1
x	0

t 0
θ 0
cos θ 1

layer	y	z	kz	cosh kz	p	back A	back F_x	side A	side F_y	front (bow) A	front (bow)	front (bow) F_x	front (bow) F_y	$\sum F_x$	$\sum F_y$	$\sum F$
1	-0.5	49.5	2.5196	6.251873	47282.51	42	3971731	0	0	157.2	0	6748992	0	10720722.9	0	10720723
2	-1.5	48.5	2.4687	5.945712	44967.04	42	3777231	0	0	150.4	0	6140842	0	9918073.47	0	9918073.5
3	-2.5	47.5	2.4178	5.654959	42768.09	42	3592520	0	0	145.8	0	5661914	0	9254433.22	0	9254433.2
4	-3.5	46.5	2.3669	5.37886	40679.97	42	3417118	0	0	137.2	0	5067814	0	8484931.52	0	8484931.5
5	-4.5	45.5	2.3160	5.116701	38697.28	41.72	3228901	889.536	32457778	89.32	50.32	3138448	1908497	6367349.08	34366274.8	34951166
6	-5.5	44.5	2.2651	4.8678	36814.86	38.95	2867878	963.664	33452120	514.52	514.52	17199320	18565037	20067197.2	52017156	55753717
7	-6.5	43.5	2.2142	4.631514	35027.85	35.6	2493983	963.664	31828334	510.72	510.72	16243595	17533422	18737577.2	49361756.2	52798483
8	-7.5	42.5	2.1633	4.407231	33331.6	32.2	2146555	963.664	30287029	464.36	464.36	14053900	15169854	16200454.8	45456882.9	48257465
9	-8.5	41.5	2.1124	4.194368	31721.74	28.8	1827172	963.664	28824211	422.56	422.56	12171138	13137590	13998309.5	41961800.8	44235115
10	-9.5	40.5	2.0615	3.992375	30194.07	25.4	1533859	963.664	27436087	372.4	372.4	10209799	11020511	11743658.3	38456598.6	40209744
11	-10.5	39.5	2.0106	3.800727	28744.65	22	1264765	963.664	26119062	323.76	323.76	8450183	9121173	9714948.09	35240234.3	36554813
12	-11.5	38.5	1.9597	3.618929	27369.73	18.6	1018154	963.664	24869722	277.4	277.4	6893865	7441274	7912018.35	32310995.5	33265605
13	-12.5	37.5	1.9088	3.446509	26065.72	15.2	792398	963.664	23684829	230.28	230.28	5450193	5882967	6242590.5	29567795.8	30219604
14	-13.5	36.5	1.8579	3.28302	24829.27	11.85	588453.6	963.664	22561314	183.16	183.16	4129338	4457229	4717791.2	27018542.6	27427344
15	-14.5	35.5	1.8070	3.128039	23657.15	8.5	402171.6	963.664	21496264	136.8	136.8	2938559	3171896	3340730.88	24668160.5	24893345
16	-15.5	34.5	1.7561	2.981163	22546.35	5.1	229972.7	963.664	20486920	87.4	87.4	1789260	1931337	2019232.81	22418256.7	22509010
17	-16.5	33.5	1.7052	2.842014	21493.97	1.7	73079.49	963.664	19530666	28.88	28.88	563637.1	608392.9	636716.629	20139058.8	20149121
														160076736	452983514	509602692

d/L 0.405
L 123.4568

t 1
θ -0.70607
cos θ 0.760919

layer	y	z	kz	cosh kz	p	back A	back F_x	side A	side F_y	front (bow) A	front (bow)	front (bow) F_x	front (bow) F_y	$\sum F_x$	$\sum F_y$	$\sum F$
1	-0.5	49.5	2.5196	6.251873	35978.18	42	3022167	0	0	157.2	0	5135439	0	8157605.99	0	8157606
2	-1.5	48.5	2.4687	5.945712	34216.29	42	2874168	0	0	150.4	0	4672686	0	7546854.48	0	7546854.5
3	-2.5	47.5	2.4178	5.654959	32543.07	42	2733618	0	0	145.8	0	4308260	0	7041877.74	0	7041877.7
4	-3.5	46.5	2.3669	5.37886	30954.18	42	2600151	0	0	137.2	0	3856198	0	6456348.97	0	6456349
5	-4.5	45.5	2.3160	5.116701	29445.51	41.72	2456933	889.536	24697753	89.32	50.32	2388106	1452212	4845039.42	26149965.1	26595020
6	-5.5	44.5	2.2651	4.8678	28013.14	38.95	2182224	963.664	25454367	514.52	514.52	13087296	14126496	15269519.6	39580863	42424084
7	-6.5	43.5	2.2142	4.631514	26653.37	35.6	1897720	963.664	24218797	510.72	510.72	12360066	13341521	14257786	37560317.8	40175390
8	-7.5	42.5	2.1633	4.407231	25362.66	32.2	1633355	963.664	23045988	464.36	464.36	10693885	11543036	12327240.3	34589023.9	36720041
9	-8.5	41.5	2.1124	4.194368	24137.68	28.8	1390331	963.664	21932901	422.56	422.56	9261255	9996647	10651585.2	31929548.1	33659357
10	-9.5	40.5	2.0615	3.992375	22975.26	25.4	1167143	963.664	20876651	372.4	372.4	7768834	8385721	8935977.39	29262371.8	30596374
11	-10.5	39.5	2.0106	3.800727	21872.36	22	962384.1	963.664	19874501	323.76	323.76	6429908	6940477	7392292.44	26814977.8	27815266
12	-11.5	38.5	1.9597	3.618929	20826.16	18.6	774733	963.664	18923854	277.4	277.4	5245675	5662210	6020408.23	24586063.2	25312444

13	-12.5	37.5	1.9088	3.446509	19833.91	15.2	602951	963.664	18022246	230.28	230.28	4147157	4476463	4750108.19	22498709.3	22994683
14	-13.5	36.5	1.8579	3.28302	18893.07	11.85	447765.8	963.664	17167341	183.16	183.16	3142093	3391592	3589858.83	20558933.1	20869998
15	-14.5	35.5	1.8070	3.128039	18001.19	8.5	306020.2	963.664	16356924	136.8	136.8	2236007	2413557	2542026.92	18770481.8	18941829
16	-15.5	34.5	1.7561	2.981163	17155.95	5.1	174990.7	963.664	15588895	87.4	87.4	1361483	1469592	1536473.41	17058486.4	17127542
17	-16.5	33.5	1.7052	2.842014	16355.18	1.7	55607.6	963.664	14861262	28.88	28.88	428882.4	462938	484490.033	15324200.5	15331857
														121805493	344683942	387766573

t 2
θ -1.41213
cos θ 0.157997

						back		side		front (bow)						
layer	y	z	kz	cosh kz	p	A	F_x	A	F_y	A		F_x	F_y	$\sum F_x$	$\sum F_y$	$\sum F$
1	-0.5	49.5	2.5196	6.251873	7470.479	42	627520.2	0	0	157.2	0	1066318	0	1693838.37	0	1693838.4
2	-1.5	48.5	2.4687	5.945712	7104.641	42	596789.9	0	0	150.4	0	970232.6	0	1567022.44	0	1567022.4
3	-2.5	47.5	2.4178	5.654959	6757.215	42	567606.1	0	0	145.8	0	894563.4	0	1462169.5	0	1462169.5
4	-3.5	46.5	2.3669	5.37886	6427.3	42	539893.2	0	0	137.2	0	800697.6	0	1340590.81	0	1340590.8
5	-4.5	45.5	2.3160	5.116701	6114.04	41.72	510155.5	889.536	5128220	89.32	50.32	495864.3	301536.1	1006019.86	5429756.5	5522167.3
6	-5.5	44.5	2.2651	4.8678	5816.625	38.95	453115.1	963.664	5285323	514.52	514.52	2717435	2933214	3170550.06	8218536.71	8808900.8
7	-6.5	43.5	2.2142	4.631514	5534.282	35.6	394040.9	963.664	5028770	510.72	510.72	2566434	2770222	2960474.54	7798992.42	8341983.7
8	-7.5	42.5	2.1633	4.407231	5266.282	32.2	339148.5	963.664	4785249	464.36	464.36	2220469	2396786	2559617.69	7182035.49	7624518.1
9	-8.5	41.5	2.1124	4.194368	5011.928	28.8	288687.1	963.664	4554129	422.56	422.56	1922999	2075695	2211686.1	6629824.2	6989000.2
10	-9.5	40.5	2.0615	3.992375	4770.562	25.4	242344.6	963.664	4334810	372.4	372.4	1613114	1741204	1855458.74	6076013.97	6353005
11	-10.5	39.5	2.0106	3.800727	4541.559	22	199828.6	963.664	4126724	323.76	323.76	1335101	1441115	1534929.31	5567839.17	5775538.2
12	-11.5	38.5	1.9597	3.618929	4324.325	18.6	160864.9	963.664	3929333	277.4	277.4	1089208	1175696	1250072.44	5105029.24	5255854.3
13	-12.5	37.5	1.9088	3.446509	4118.297	15.2	125196.2	963.664	3742124	230.28	230.28	861112.2	929489.1	986308.423	4671612.86	4774596.4
14	-13.5	36.5	1.8579	3.28302	3922.941	11.85	92973.71	963.664	3564612	183.16	183.16	652421.5	704227.2	745395.233	4268839.38	4333428.6
15	-14.5	35.5	1.8070	3.128039	3737.751	8.5	63541.77	963.664	3396338	136.8	136.8	464282.5	501149	527824.307	3897486.86	3933065.3
16	-15.5	34.5	1.7561	2.981163	3562.247	5.1	36334.92	963.664	3236865	87.4	87.4	282697.1	305144.8	319032.031	3542009.6	3556348.3
17	-16.5	33.5	1.7052	2.842014	3395.975	1.7	11546.31	963.664	3085780	28.88	28.88	89052.78	96124.05	100599.098	3181903.94	3183493.8
														25291588.9	71569880.4	80515521

t 3
θ -2.1182
cos θ -0.52047

						back		side		front (bow)						
layer	y	z	kz	cosh kz	p	A	F_x	A	F_y	A		F_x	F_y	$\sum F_x$	$\sum F_y$	$\sum F$
1	-0.5	49.5	2.5196	6.251873	-23641.3	42	-1985865	0	0	157.2	0	-3374496	0	-5360361.4	0	5360361.4
2	-1.5	48.5	2.4687	5.945712	-22483.5	42	-1888616	0	0	150.4	0	-3070421	0	-4959036.7	0	4959036.7
3	-2.5	47.5	2.4178	5.654959	-21384	42	-1796260	0	0	145.8	0	-2830957	0	-4627216.6	0	4627216.6

θ -3.53034
cos θ -0.92539

layer	y	s	kz	cosh kz	p	back A	back F_x	side A	side F_y	front (bow) A	front (bow)	front (bow) F_x	front (bow) F_y	$\sum F_x$	$\sum F_y$	$\sum F$
1	-0.5	49.5	2.5196	6.251873	-43754.6	42	-3675383	0	0	157.2	0	-6245421	0	-9920803.5	0	9920803.5
2	-1.5	48.5	2.4687	5.945712	-41611.9	42	-3495396	0	0	150.4	0	-5682648	0	-9178043.2	0	9178043.2
3	-2.5	47.5	2.4178	5.654959	-39577	42	-3324466	0	0	145.8	0	-5239454	0	-8563920	0	8563920
4	-3.5	46.5	2.3669	5.37886	-37644.7	42	-3162152	0	0	137.2	0	-4689682	0	-7851834.2	0	7851834.2
5	-4.5	45.5	2.3160	5.116701	-35809.9	41.72	-2987979	889.536	-3E+07	89.32	50.32	-2904275	-1766096	-5892253.7	-31802059	32343308
6	-5.5	44.5	2.2651	4.8678	-34067.9	38.95	-2653893	963.664	-3.1E+07	514.52	514.52	-1.6E+07	-1.7E+07	-18569897	-48135932	51593691
7	-6.5	43.5	2.2142	4.631514	-32414.3	35.6	-2307896	963.664	-2.9E+07	510.72	510.72	-1.5E+07	-1.6E+07	-17339486	-45678663	48858960
8	-7.5	42.5	2.1633	4.407231	-30844.6	32.2	-1986391	963.664	-2.8E+07	464.36	464.36	-1.3E+07	-1.4E+07	-14991669	-42065149	44656767
9	-8.5	41.5	2.1124	4.194368	-29354.8	28.8	-1690839	963.664	-2.7E+07	422.56	422.56	-1.1E+07	-1.2E+07	-12953835	-38830850	40934542
10	-9.5	40.5	2.0615	3.992375	-27941.2	25.4	-1419411	963.664	-2.5E+07	372.4	372.4	-9448002	-1E+07	-10867413	-35587186	37209521
11	-10.5	39.5	2.0106	3.800727	-26599.9	22	-1170395	963.664	-2.4E+07	323.76	323.76	-7819679	-8440602	-8990073.9	-32610808	33827300
12	-11.5	38.5	1.9597	3.618929	-25327.6	18.6	-942185	963.664	-2.3E+07	277.4	277.4	-6379484	-6886048	-7321668.5	-29900133	30783515
13	-12.5	37.5	1.9088	3.446509	-24120.8	15.2	-733274	963.664	-2.2E+07	230.28	230.28	-5043530	-5444013	-5776803.9	-27361615	27964789
14	-13.5	36.5	1.8579	3.28302	-22976.6	11.85	-544547	963.664	-2.1E+07	183.16	183.16	-3821230	-4124656	-4365776.4	-25002573	25380872
15	-14.5	35.5	1.8070	3.128039	-21892	8.5	-372164	963.664	-2E+07	136.8	136.8	-2719301	-2935228	-3091464.5	-22827563	23035945
16	-15.5	34.5	1.7561	2.981163	-20864.1	5.1	-212813	963.664	-1.9E+07	87.4	87.4	-1655756	-1787231	-1868569.1	-20745534	20829516
17	-16.5	33.5	1.7052	2.842014	-19890.2	1.7	-67626.7	963.664	-1.8E+07	28.88	28.88	-521582	-562998	-589208.45	-18636397	18645709
														-148132720	-419184459	471579037

t 6
θ -4.2364
cos θ -0.45821

layer	y	s	kz	cosh kz	p	back A	back F_x	side A	side F_y	front (bow) A	front (bow)	front (bow) F_x	front (bow) F_y	$\sum F_x$	$\sum F_y$	$\sum F$
1	-0.5	49.5	2.5196	6.251873	-21665.5	42	-1819902	0	0	157.2	0	-3092481	0	-4912382.3	0	4912382.3
2	-1.5	48.5	2.4687	5.945712	-20604.5	42	-1730779	0	0	150.4	0	-2813818	0	-4544597.4	0	4544597.4
3	-2.5	47.5	2.4178	5.654959	-19596.9	42	-1646142	0	0	145.8	0	-2594366	0	-4240508.3	0	4240508.3
4	-3.5	46.5	2.3669	5.37886	-18640.1	42	-1565770	0	0	137.2	0	-2322142	0	-3887912.1	0	3887912.1
5	-4.5	45.5	2.3160	5.116701	-17731.6	41.72	-1479527	889.536	-1.5E+07	89.32	50.32	-1438080	-874499	-2917606.7	-15747099	16015104
6	-5.5	44.5	2.2651	4.8678	-16869.1	38.95	-1314101	963.664	-1.5E+07	514.52	514.52	-7880964	-8506754	-9195065.1	-23834975	25547118
7	-6.5	43.5	2.2142	4.631514	-16050.2	35.6	-1142777	963.664	-1.5E+07	510.72	510.72	-7443038	-8034055	-8585815	-22618234	24192989
8	-7.5	42.5	2.1633	4.407231	-15273	32.2	-983581	963.664	-1.4E+07	464.36	464.36	-6439690	-6951035	-7423270.7	-20828968	22112233
9	-8.5	41.5	2.1124	4.194368	-14535.3	28.8	-837235	963.664	-1.3E+07	422.56	422.56	-5576982	-6019824	-6414217.5	-19227473	20269137
10	-9.5	40.5	2.0615	3.992375	-13835.3	25.4	-702835	963.664	-1.3E+07	372.4	372.4	-4678270	-5049750	-5381105.4	-17621341	18424656
11	-10.5	39.5	2.0106	3.800727	-13171.2	22	-579533	963.664	-1.2E+07	323.76	323.76	-3871990	-4179446	-4451522.5	-16147559	16749917
12	-11.5	38.5	1.9597	3.618929	-12541.2	18.6	-466532	963.664	-1.1E+07	277.4	277.4	-3158863	-3409694	-3625395.4	-14805341	15242757

Final Year Project Calculation Sheet	Project **Parametric Study of FPSO Responses**	Sheet No 5
Title **Wave Forces Calculation**	Design **Aiza Amelia Yazid@Majid**	Check/Review **Ms Nabilah Abu Bakar, Dr Kurian V John**

13	-12.5	37.5	1.9088	3.446509	-11943.7	15.2	-363088	963.664	-1.1E+07	230.28	230.28	-2497353	-2695656	-2860440.6	-13548370	13847037
14	-13.5	36.5	1.8579	3.28302	-11377.1	11.85	-269638	963.664	-1E+07	183.16	183.16	-1892119	-2042363	-2161756.7	-12380267	12567585
15	-14.5	35.5	1.8070	3.128039	-10840	8.5	-184281	963.664	-9849883	136.8	136.8	-1346488	-1453406	-1530768.7	-11303290	11406472
16	-15.5	34.5	1.7561	2.981163	-10331	5.1	-105377	963.664	-9387388	87.4	87.4	-819864	-884965	-925240.18	-10272353	10313937
17	-16.5	33.5	1.7052	2.842014	-9848.83	1.7	-33486	963.664	-8949219	28.88	28.88	-258266	-278774	-291752.3	-9227993.1	9232603.9
														-73349357	-207563262	233506946

t 7
θ -4.94247
cos θ 0.228058

						back		side		front (bow)						
layer	y	s	kz	cosh kz	p	A	F_x	A	F_y	A		F_x	F_y	$\sum F_x$	$\sum F_y$	$\sum F$
1	-0.5	49.5	2.5196	6.251873	10783.17	42	905786.1	0	0	157.2	0	1539163	0	2444949.5	0	2444949.5
2	-1.5	48.5	2.4687	5.945712	10255.1	42	861428.8	0	0	150.4	0	1400470	0	2261898.66	0	2261898.7
3	-2.5	47.5	2.4178	5.654959	9753.617	42	819303.8	0	0	145.8	0	1291246	0	2110550.02	0	2110550
4	-3.5	46.5	2.3669	5.37886	9277.405	42	779302	0	0	137.2	0	1155757	0	1935058.79	0	1935058.8
5	-4.5	45.5	2.3160	5.116701	8825.234	41.72	736377.5	889.536	7402265	89.32	50.32	715749.1	435248.5	1452126.61	7837513.14	7970902.3
6	-5.5	44.5	2.2651	4.8678	8395.933	38.95	654043.2	963.664	7629032	514.52	514.52	3922447	4233910	4576490.26	11862942.5	12715096
7	-6.5	43.5	2.2142	4.631514	7988.39	35.6	568773.4	963.664	7258715	510.72	510.72	3704486	3998642	4273259.42	11257356.7	12041131
8	-7.5	42.5	2.1633	4.407231	7601.548	32.2	489539.7	963.664	6907207	464.36	464.36	3205108	3459611	3694647.68	10366818	11005514
9	-8.5	41.5	2.1124	4.194368	7234.404	28.8	416701.7	963.664	6573600	422.56	422.56	2775729	2996136	3192430.24	9569735.64	10088184
10	-9.5	40.5	2.0615	3.992375	6886.008	25.4	349809.2	963.664	6257027	372.4	372.4	2328429	2513319	2678238.38	8770345.29	9170164.5
11	-10.5	39.5	2.0106	3.800727	6555.456	22	288440.1	963.664	5956668	323.76	323.76	1927134	2080159	2215574.24	8036826.82	8336627.3
12	-11.5	38.5	1.9597	3.618929	6241.892	18.6	232198.4	963.664	5671746	277.4	277.4	1572203	1697044	1804401.21	7368789.69	7586496.2
13	-12.5	37.5	1.9088	3.446509	5944.504	15.2	180712.9	963.664	5401521	230.28	230.28	1242961	1341659	1423674.38	6743180.32	6891830.6
14	-13.5	36.5	1.8579	3.28302	5662.52	11.85	134201.7	963.664	5145294	183.16	183.16	941729.6	1016508	1075931.29	6161802.05	6255032.6
15	-14.5	35.5	1.8070	3.128039	5395.21	8.5	91718.56	963.664	4902401	136.8	136.8	670162.7	723377.2	761881.3	5625777.97	5677133.2
16	-15.5	34.5	1.7561	2.981163	5141.881	5.1	52447.18	963.664	4672211	87.4	87.4	408055.6	440457.3	460502.738	5112668.82	5133365.9
17	-16.5	33.5	1.7052	2.842014	4901.877	1.7	16666.38	963.664	4454130	28.88	28.88	128542.1	138749	145208.492	4592878.88	4595173.8
														36506823.2	103306636	116219108

t 8
θ -5.64854
cos θ 0.805282

						back		side		front (bow)						
layer	y	s	kz	cosh kz	p	A	F_x	A	F_y	A		F_x	F_y	$\sum F_x$	$\sum F_y$	$\sum F$
1	-0.5	49.5	2.5196	6.251873	38075.74	42	3198362	0	0	157.2	0	5434839	0	8633201.33	0	8633201.3
2	-1.5	48.5	2.4687	5.945712	36211.13	42	3041735	0	0	150.4	0	4945108	0	7986842.49	0	7986842.5
3	-2.5	47.5	2.4178	5.654959	34440.36	42	2892990	0	0	145.8	0	4559435	0	7452425.17	0	7452425.2
4	-3.5	46.5	2.3669	5.37886	32758.84	42	2751742	0	0	137.2	0	4081017	0	6832759.59	0	6832759.6
5	-4.5	45.5	2.3160	5.116701	31162.21	41.72	2600175	889.536	26137653	89.32	50.32	2527335	1536877	5127509.32	27674530.2	28145532

Final Year Project Calculation Sheet	Project **Parametric Study of FPSO Responses**	Sheet No 6
Title **Wave Forces Calculation**	Design **Aiza Amelia Yazid@Majid**	Check/Review **Ms Nabilah Abu Bakar, Dr Kurian V John**

6	-5.5	44.5	2.2651	4.8678	29646.33	38.95	2309449	963.664	26938378	514.52	514.52	13850296	14950083	16159745.5	41888460.8	44897445
7	-6.5	43.5	2.2142	4.631514	28207.28	35.6	2008358	963.664	25630773	510.72	510.72	13080669	14119343	15089027	39750116.1	42517649
8	-7.5	42.5	2.1633	4.407231	26841.33	32.2	1728582	963.664	24389589	464.36	464.36	11317347	12216005	13045928.9	36605593.3	38860851
9	-8.5	41.5	2.1124	4.194368	25544.93	28.8	1471388	963.664	23211608	422.56	422.56	9801194	10579460	11272581.7	33791067.8	35621726
10	-9.5	40.5	2.0615	3.992375	24314.73	25.4	1235188	963.664	22093777	372.4	372.4	8221764	8874616	9456952.44	30968392.8	32380168
11	-10.5	39.5	2.0106	3.800727	23147.54	22	1018492	963.664	21033201	323.76	323.76	6804777	7345113	7823269.35	28378313.7	29436920
12	-11.5	38.5	1.9597	3.618929	22040.34	18.6	819900.6	963.664	20027130	277.4	277.4	5551503	5992321	6371403.13	26019451.5	26788181
13	-12.5	37.5	1.9088	3.446509	20990.25	15.2	638103.5	963.664	19072958	230.28	230.28	4388940	4737445	5027043.53	23810403.1	24335293
14	-13.5	36.5	1.8579	3.28302	19994.55	11.85	473870.9	963.664	18168212	183.16	183.16	3325280	3589325	3799150.64	21757536.4	22086737
15	-14.5	35.5	1.8070	3.128039	19050.67	8.5	323861.4	963.664	17310547	136.8	136.8	2366368	2554270	2690229.25	19864816.8	20046154
16	-15.5	34.5	1.7561	2.981163	18156.16	5.1	185192.8	963.664	16497741	87.4	87.4	1440858	1555270	1626051.11	18053010.6	18126093
17	-16.5	33.5	1.7052	2.842014	17308.7	1.7	58849.57	963.664	15727687	28.88	28.88	453886.6	489927.6	512736.212	16217614.3	16225718
														128906857	364779308	410373693

t	9
θ	-6.35461
cos θ	0.997451

						back		side		front (bow)						
layer	y	s	ks	cosh ks	p	A	F_x	A	F_y	A		F_x	F_y	$\sum F_x$	$\sum F_y$	$\sum F$
1	-0.5	49.5	2.5196	6.251873	47161.97	42	3961605	0	0	157.2	0	6731786	0	10693391.2	0	10693391
2	-1.5	48.5	2.4687	5.945712	44852.4	42	3767601	0	0	150.4	0	6125187	0	9892788.07	0	9892788.1
3	-2.5	47.5	2.4178	5.654959	42659.06	42	3583361	0	0	145.8	0	5647479	0	9230839.72	0	9230839.7
4	-3.5	46.5	2.3669	5.37886	40576.26	42	3408406	0	0	137.2	0	5054894	0	8463299.81	0	8463299.8
5	-4.5	45.5	2.3160	5.116701	38598.62	41.72	3220669	889.536	32375029	89.32	50.32	3130447	1903631	6351115.99	34278660.6	34862060
6	-5.5	44.5	2.2651	4.8678	36721	38.95	2860566	963.664	33366836	514.52	514.52	17155471	18517706	20016037.4	51884542.1	55611577
7	-6.5	43.5	2.2142	4.631514	34938.54	35.6	2487624	963.664	31747190	510.72	510.72	16202183	17488722	18689807.2	49235912	52663877
8	-7.5	42.5	2.1633	4.407231	33246.63	32.2	2141083	963.664	30209815	464.36	464.36	14018070	15131179	16159153	45340993.9	48134436
9	-8.5	41.5	2.1124	4.194368	31640.86	28.8	1822514	963.664	28750725	422.56	422.56	12140108	13104097	13962621.9	41854822.3	44122341
10	-9.5	40.5	2.0615	3.992375	30117.09	25.4	1529948	963.664	27366141	372.4	372.4	10183770	10992415	11713718.7	38358556.3	40107232
11	-10.5	39.5	2.0106	3.800727	28671.37	22	1261540	963.664	26052473	323.76	323.76	8428640	9097919	9690180.54	35150391.9	36461619
12	-11.5	38.5	1.9597	3.618929	27299.95	18.6	1015558	963.664	24806318	277.4	277.4	6876289	7422303	7891847.24	32228621	33180797
13	-12.5	37.5	1.9088	3.446509	25999.27	15.2	790377.8	963.664	23624446	230.28	230.28	5436298	5867968	6226675.47	29492414.9	30142562
14	-13.5	36.5	1.8579	3.28302	24765.97	11.85	586953.4	963.664	22503795	183.16	183.16	4118810	4445865	4705763.54	26949660.8	27357420
15	-14.5	35.5	1.8070	3.128039	23596.84	8.5	401146.3	963.664	21441461	136.8	136.8	2931068	3163810	3332213.93	24605270.8	24829881
16	-15.5	34.5	1.7561	2.981163	22488.87	5.1	229386.4	963.664	20434690	87.4	87.4	1784698	1926413	2014084.92	22361103	22451625
17	-16.5	33.5	1.7052	2.842014	21439.17	1.7	72893.18	963.664	19480874	28.88	28.88	562200.2	606841.9	635093.367	20087715.7	20097753
														159668632	451828665	508303498

APPENDIX B

Example of Moment Calculation

Final Year Project Calculation Sheet	Project **Parametric Study of FPSO Responses**	Sheet No 1
Title **Moment Calculation**	Design **Aiza Amelia Yazid@Majid**	Check/Review **Ms Nabilah Abu Bakar, Dr Kurian V John**

t	0
θ	0
cos θ	1
D	50
H_s	4.9
T_1	6.8
T_p	9.6
$H_{s,w}$	9.6
$T_{z,w}$	8.9
g	9.807
π	3.142
L_o	123.6175
d/L_o	0.404473
L	123.4568
k	0.0509
ω	0.706067
ρ	1030
kd	2.54502
cosh kd	6.410977
C_x	2
C_y	1.1
x	0

d/L	0.405
L	123.4568

layer	y	s	ks	cosh ks	p	back A	back F_x	side A	side F_y	front (bow) A	front (bow)	front (bow) F_x	front (bow) F_y	$\sum F_x$	$\sum F_y$	$\sum F$
1	-0.5	49.5	2.5196	6.251873	47282.51	42	3971731	0	0	157.2	0	6748992	0	10720723	0	10720723
2	-1.5	48.5	2.4687	5.945712	44967.04	42	3777231	0	0	150.4	0	6140842	0	9918073.5	0	9918073.5
3	-2.5	47.5	2.4178	5.654959	42768.09	42	3592520	0	0	145.8	0	5661914	0	9254433.2	0	9254433.2
4	-3.5	46.5	2.3669	5.37886	40679.97	42	3417118	0	0	137.2	0	5067814	0	8484931.5	0	8484931.5
5	-4.5	45.5	2.3160	5.116701	38697.28	41.72	3228901	889.536	32457778	89.32	50.32	3138448	1908497	6367349.1	34366275	34951166
6	-5.5	44.5	2.2651	4.8678	36814.86	38.95	2867878	963.664	33452120	514.52	514.52	17199320	18565037	20067197	52017156	55753717
7	-6.5	43.5	2.2142	4.631514	35027.85	35.6	2493983	963.664	31828334	510.72	510.72	16243595	17533422	18737577	49361756	52798483
8	-7.5	42.5	2.1633	4.407231	33331.6	32.2	2146555	963.664	30287029	464.36	464.36	14053900	15169854	16200455	45456883	48257465
9	-8.5	41.5	2.1124	4.194368	31721.74	28.8	1827172	963.664	28824211	422.56	422.56	12171138	13137590	13998310	41961801	44235115
10	-9.5	40.5	2.0615	3.992375	30194.07	25.4	1533859	963.664	27436087	372.4	372.4	10209799	11020511	11743658	38456599	40209744
11	-10.5	39.5	2.0106	3.800727	28744.65	22	1264765	963.664	26119062	323.76	323.76	8450183	9121173	9714948.1	35240234	36554813
12	-11.5	38.5	1.9597	3.618929	27369.73	18.6	1018154	963.664	24869722	277.4	277.4	6893865	7441274	7912018.4	32310996	33265605
13	-12.5	37.5	1.9088	3.446509	26065.72	15.2	792398	963.664	23684829	230.28	230.28	5450193	5882967	6242590.5	29567796	30219604
14	-13.5	36.5	1.8579	3.28302	24829.27	11.85	588453.6	963.664	22561314	183.16	183.16	4129338	4457229	4717791.2	27018543	27427344
15	-14.5	35.5	1.8070	3.128039	23657.15	8.5	402171.6	963.664	21496264	136.8	136.8	2938559	3171896	3340730.9	24668160	24893345
16	-15.5	34.5	1.7561	2.981163	22546.35	5.1	229972.7	963.664	20486920	87.4	87.4	1789260	1931337	2019232.8	22418257	22509010
17	-16.5	33.5	1.7052	2.842014	21493.97	1.7	73079.49	963.664	19530666	28.88	28.88	563637.1	608392.9	636716.63	20139059	20149121
														160076736	452983514	509602692

F	arm distant	moment
10720722.9	2.7	28945951.81
9918073.47	1.7	16860724.9
9254433.22	-1.7	-15732536.47
8484931.52	-2.7	-22909315.1
6367349.08	-3.7	-23559191.59
20067197.2	-4.7	-94315826.96
18737577.2	-5.7	-106804190.2
16200454.8	-6.7	-108543047.4
13998309.5	-7.7	-107786983.4
11743658.3	-8.7	**-102169827.3**
9714948.09	-9.7	**-94234996.46**
7912018.35	-10.7	-84658596.4
6242590.5	-11.7	-73038308.8
4717791.2	-12.7	-59915948.2
3340730.88	-13.7	-45768013.0
2019232.81	-14.7	-29682722.3
636716.629	-15.7	-9996451.1
	total moment	-933309277.9

APPENDIX C

Example of RAO Calculation

Final Year Project Calculation Sheet	Project **Parametric Study of FPSO Responses**	Sheet No 1
Title **RAO Calculation**	Design **Aiza Amelia Yazid@Majid**	Check/Review **Ms Nabilah Abu Bakar, Dr Kurian V John**

maxFH	160076735.8 160.0767358				
RAO				PI	3.14159
Mass				Cross Sec Area-Surge, m_2	453.60000
Buoyancy Weight	1101.2 M-kg			Diameter, Dr	24.03209
Fpso Weight	1644 M-kg			Natural Period (Tn),s	206.80000
Damping Ratio (ζ)	0.05			ωn	0.03038
Inertia Coef, Cm	2			ω	0.70598
Gravity Accleration (g)	9.807 m/s^2			Stiffness,K (M-N/m)	1.02000
Sea Water Density (ρ)	1030 kg/m^3			Critical Damping, Cc	67.14274
H/2	4.3 m			Constant Damping Coef, C	3.35714
				$(K-m\omega^2)^2$	3.022E+05
	Added Mass (M-kg)	Total Mass(M-kg)	Total Mass(M-N)	$(C\omega)^2$	5.617E+00
Surge	**3.743E+00**	**1.105E+03**	**1.084E+04**	$((K-m\omega^2)^2+(C\omega)^2)^{1/2}$	5.49691E+02

maxFV	452983513.6 452.9835136				
RAO				PI	3.14159
Mass				Cross Sec Area-Surge, m_2	453.60000
Buoyancy Weight	1101.2 M-kg			Diameter, Dr	24.03209
Fpso Weight	1644 M-kg			Natural Period (Tn),s	10.70000
Damping Ratio (ζ)	0.05			ωn	0.58721
Inertia Coef, Cm	2			ω	0.70598
Gravity Accleration (g)	9.807 m/s^2			Stiffness,K (M-N/m)	759.43110
Sea Water Density (ρ)	1030 kg/m^3			Critical Damping, Cc	2586.55838
H/2	4.3 m			Constant Damping Coef, C	129.32792
				$(K-m\omega^2)^2$	1.144E+05
	Added Mass (M-kg)	Total Mass(M-kg)	Total Mass(M-N)	$(C\omega)^2$	8.336E+03
Surge	**3.743E+00**	**2.202E+03**	**2.160E+04**	$((K-m\omega^2)^2+(C\omega)^2)^{1/2}$	3.50355E+02

APPENDIX D

Example of Wave Spectrum Calculation

Final Year Project Calculation Sheet	Project **Parametric Study of FPSO Responses**	Sheet No 1
Title **Wave Spectrum Calculation**	Design **Aiza Amelia Yazid@Majid**	Check/Review **Ms Nabilah Abu Bakar, Dr Kurian V John**

Hs	π	ω_	g	RAO	RAO²
4.9	3.142	0.56765306	9.807	0.370882775	0.137554033

f	ω	ω/ω_	exp	S(ω)	S(f)	Hf	RN	ε	RAO2xS(f)	T
0.01	0.06284	0.11070142	0	0	0	0	0.79944898	5.02373736	0	100
0.02	0.12568	0.22140284	1.192E-226	2.962E-222	1.8615E-221	1.7258E-111	0.86299263	5.42304567	2.561E-222	50
0.03	0.18852	0.33210426	2.3611E-45	7.7248E-42	4.85428E-41	3.41325E-21	0.48791668	3.06606843	6.6773E-42	33.33333
0.04	0.25136	0.44280568	7.5819E-15	5.8864E-12	3.69903E-11	3.44048E-06	0.91891396	5.77445533	5.0882E-12	25
0.05	0.3142	0.5535071	1.6457E-06	0.00041868	0.002630987	0.032440637	0.8713693	5.47568469	0.0003619	20
0.06	0.37704	0.66420852	0.00162487	0.16612696	1.04394183	0.707878576	0.07092598	0.44569884	0.14359841	16.66667
0.07	0.43988	0.77490994	0.03122267	1.47691782	9.28095159	2.279765973	0.51912002	3.2621502	1.27663232	14.28571
0.08	0.50272	0.88561136	0.13106477	3.17989319	19.98244881	3.576138593	0.91875128	5.77343304	2.74866642	12.5
0.09	0.56556	0.99631278	0.281223	3.78629792	23.79309611	4.138964749	0.17550062	1.10284591	3.27283633	11.11111
0.1	0.6284	1.1070142	0.43503306	3.45858732	21.73376273	4.169773397	0.86029045	5.40606516	2.98956671	10
0.11	0.69124	1.21771562	0.5663773	2.7958824	17.56932499	3.932048574	0.20378899	1.28061002	2.41673151	9.090909
0.12	0.75408	1.32841704	0.66938541	2.13868341	13.43948654	3.591922477	0.59298589	3.72632336	1.84865557	8.333333
0.13	0.81692	1.43911846	0.74719954	1.59991283	10.05385221	3.233574848	0.8608873	5.40981581	1.38294792	7.692308
0.14	0.87976	1.54981988	0.80520113	1.19025684	7.479574001	2.89432598	0.32493587	2.04189699	1.02884557	7.142857
0.15	0.9426	1.6605213	0.84839283	0.88821311	5.581531214	2.588018056	0.15298595	0.96136369	0.76776213	6.666667
0.16	1.00544	1.77122272	0.88073017	0.66775854	4.196194638	2.317569662	0.97364728	6.11839952	0.5772035	6.25
0.17	1.06828	1.88192414	0.90514913	0.50681798	3.184844218	2.081198726	0.48384076	3.04045533	0.43808817	5.882353
0.18	1.13112	1.99262556	0.92377388	0.38866876	2.442394516	1.875379456	0.96984793	6.0945244	0.33596122	5.555556
0.19	1.19396	2.10332698	0.93812889	0.3012111	1.892810643	1.696193438	0.22391209	1.40706359	0.26036374	5.263158
0.2	1.2568	2.21402839	0.94930909	0.23584906	1.482075496	1.539909346	0.41760806	2.62424905	0.20386546	5
0.21	1.31964	2.32472981	0.95810523	0.18650618	1.172004828	1.403199241	0.29286754	1.84037962	0.16121399	4.761905
0.22	1.38248	2.43543123	0.96509289	0.14887857	0.935552955	1.283188685	0.54378257	3.41712965	0.12868908	4.545455
0.23	1.44532	2.54613265	0.97069489	0.11990024	0.753453109	1.17743523	0.80079854	5.03221801	0.10364051	4.347826
0.24	1.50816	2.65683407	0.97522496	0.09736997	0.611872903	1.083880055	0.79416667	4.99054337	0.08416559	4.166667
0.25	1.571	2.76753549	0.97891767	0.07969345	0.500793623	1.000793309	0.76926124	4.83403764	0.06888618	4
0.26	1.63384	2.87823691	0.98195093	0.06570517	0.41289128	0.926722107	0.62396616	3.92100334	0.05679486	3.846154
0.27	1.69668	2.98893833	0.98446019	0.0545451	0.342761474	0.860444527	0.86420534	5.43066637	0.04714822	3.703704
0.28	1.75952	3.09963975	0.98654982	0.04557276	0.286379239	0.800930394	0.50265467	3.15868193	0.03939262	3.571429
0.29	1.82236	3.21034117	0.9883009	0.03830678	0.240719829	0.747308506	0.8391481	5.2732069	0.03311198	3.448276
0.3	1.8852	3.32104259	0.9897769	0.03238229	0.203490295	0.698839544	0.67301576	4.22923103	0.02799091	3.333333
0.31	1.94804	3.43174401	0.99102788	0.02752035	0.172937855	0.654893794	0.98293775	6.17678084	0.0237883	3.225806
0.32	2.01088	3.54244543	0.99209367	0.02350603	0.147711889	0.614932871	0.88841762	5.58281631	0.02031837	3.125
0.33	2.07372	3.65314685	0.99300612	0.02017245	0.126763695	0.578494731	0.01319523	0.0829188	0.01743686	3.030303
0.34	2.13656	3.76384827	0.99379088	0.01738909	0.109273056	0.545181356	0.29316315	1.84223726	0.01503095	2.941176
0.35	2.1994	3.87454969	0.99446878	0.01505315	0.094594001	0.51464862	0.77711342	4.88338073	0.01301179	2.857143
0.36	2.26224	3.98525111	0.99505676	0.01308314	0.082214423	0.486597924	0.70759794	4.44654544	0.01130893	2.777778
0.37	2.32508	4.09595253	0.99556875	0.01141403	0.071725783	0.460769268	0.80957813	5.08738895	0.00986617	2.702703
0.38	2.38792	4.20665395	0.99601621	0.00999367	0.062800209	0.436935504	0.50076209	3.14678895	0.00863842	2.631579
0.39	2.45076	4.31735537	0.99640865	0.00877993	0.055173066	0.414897536	0.83212322	5.22906231	0.00758928	2.564103
0.4	2.5136	4.42805679	0.99675398	0.00773864	0.048629599	0.394480311	0.1929691	1.21274357	0.0066892	2.5

Final Year Project Calculation Sheet	Project **Parametric Study of FPSO Responses**	Sheet No 2
Title **Wave Spectrum Calculation**	Design **Aiza Amelia Yazid@Majid**	Check/Review **Ms Nabilah Abu Bakar, Dr Kurian V John**

Hs	0	1.7258E-111	3.41325E-21	3.44048E-06	0.032441	0.707879	2.279766	3.576139	4.138965	4.169773	3.932049	3.591922	3.233575	2.894326	2.588018	2.31757	2.081199	1.875379	1.696193	1.539909	1.403199	1.283189
ε	5.023737	5.423045665	3.066068426	5.774455331	5.475685	0.445699	3.26215	5.773433	1.102846	5.406065	1.28061	3.726323	5.409816	2.041897	0.961364	6.1184	3.040455	6.094524	1.407064	2.624249	1.84038	3.41713
ω	0.06284	0.12568	0.18852	0.25136	0.3142	0.37704	0.43988	0.50272	0.56556	0.6284	0.69124	0.75408	0.81692	0.87976	0.9426	1.00544	1.06828	1.13112	1.19396	1.2568	1.31964	1.38248
k	0.051151																					
x	0																					

t	η1	η2	η3	η4	η5	η6	η7	η8	η9	η10	η11	η12	η13	η14	η15	η16	η17	η18	η19	η20	η21	η22
0	0	5.6291E-112	-1.70176E-21	1.5024E-06	0.011213	0.319363	-1.131609	1.560744	0.933457	1.33301	0.56254	-1.497582	1.038378	-0.65682	0.740694	1.143087	-1.035282	0.921052	0.138242	-0.669195	-0.186857	-0.617393
1	0	4.7648E-112	-1.64748E-21	1.24679E-06	0.007042	0.353105	-1.08226	0.947257	1.777894	0.135997	1.634338	-1.770269	-0.192736	0.575073	1.293781	0.451861	-0.40655	0.232911	0.828912	0.155491	0.608604	-0.287048
2	0	3.8254E-112	-1.53482E-21	9.14815E-07	0.002181	0.337243	-0.826854	0.099373	2.068655	-1.112976	1.955832	-1.083123	-1.302221	1.389849	0.779381	-0.658948	0.643667	-0.722776	0.471806	0.765246	0.489362	0.509919
3	0	2.8257E-112	-1.36777E-21	5.21474E-07	-0.002893	0.274003	-0.41402	-0.773102	1.71519	-1.936723	1.379427	0.191289	-1.589927	1.196529	-0.377012	-1.15788	1.026571	-0.848205	-0.481681	0.31722	-0.365367	0.477967
4	0	1.7814E-112	-1.15226E-21	9.73589E-08	-0.007684	0.172271	0.077641	-1.454273	0.827576	-2.020522	0.169744	1.361985	-0.874293	0.135334	-1.223111	-0.581643	0.345193	0.000705	-0.826305	-0.569292	-0.670967	-0.330963
5	0	7.09E-113	-8.95915E-22	-3.32876E-07	-0.011722	0.046337	0.55452	-1.775585	-0.317765	-1.332357	-1.117866	1.794217	0.393072	-1.024024	-1.0606	0.534688	-0.694059	0.848805	-0.126447	-0.668885	0.031864	-0.601883
6	0	-3.7459E-113	-6.07826E-22	-7.42189E-07	-0.014613	-0.086106	0.925821	-1.657529	-1.364146	-0.135149	-1.892278	1.253631	1.412385	-1.440628	-0.023488	1.154526	-1.013756	0.721877	0.733245	0.156106	0.686805	0.105612
7	0	-1.4523E-112	-2.98199E-22	-1.10486E-06	-0.016073	-0.206453	1.120851	-1.129319	-1.985701	1.113694	-1.797968	0.033331	1.540398	-0.812305	1.032992	0.70231	-0.282456	-0.234276	0.666086	0.765315	0.309512	0.641425
8	0	-2.507E-112	2.19942E-23	-1.39808E-06	-0.01596	-0.297796	1.102478	-0.321659	-1.988864	1.937037	-0.878233	-1.205042	0.696327	0.405206	1.237639	-0.402048	0.741676	-0.921315	-0.243031	0.316648	-0.532963	0.134544
9	0	-3.5223E-112	3.41408E-22	-1.60344E-06	-0.014283	-0.347304	0.874198	0.565594	-1.372649	2.020312	0.444688	-1.790044	-0.587169	1.328809	0.421695	-1.133077	0.996886	-0.550033	-0.844948	-0.569714	-0.57442	-0.591051
10	0	-4.4819E-112	6.48725E-22	-1.70802E-06	-0.011208	-0.348022	0.479476	1.312892	-0.32896	1.331704	1.563458	-1.404491	-1.500125	1.28859	-0.74199	-0.811969	0.218589	0.453076	-0.378818	-0.668574	0.247448	-0.35584
11	0	-5.3709E-112	9.33054E-22	-1.70525E-06	-0.007036	-0.299849	-0.006535	1.735316	0.817174	0.134302	1.964464	-0.257428	-1.466413	0.313721	-1.29381	0.263107	-0.786327	0.935733	0.566152	0.15672	0.697414	0.45782
12	0	-6.1751E-112	1.18432E-21	-1.59531E-06	-0.002175	-0.209552	-0.491303	1.728336	1.708822	-1.114412	1.463608	1.029212	-0.507305	-0.888699	-0.778719	1.09387	-0.97603	0.343508	0.795484	0.765384	0.0992	0.527253
13	0	-6.882E-112	1.39362E-21	-1.3851E-06	0.002899	-0.089816	-0.882529	1.293681	2.068304	-1.937351	0.290828	1.757817	0.771942	-1.446521	0.376525	0.908903	-0.153848	-0.643308	0.019293	0.316076	-0.648107	-0.260411
14	0	-7.4802E-112	1.55354E-21	-1.08784E-06	0.00769	0.042537	-1.105726	0.538905	1.783669	-2.020102	-1.015468	1.533339	1.564048	-0.955141	1.223627	-0.120042	0.827833	-0.891151	-0.781285	-0.570136	-0.42134	-0.624753
15	0	-7.9605E-112	1.65841E-21	-7.2221E-07	0.011727	0.168914	-1.118399	-0.349223	0.943559	-1.33105	-1.855575	0.47749	1.369145	0.229029	1.059693	-1.037519	0.951271	-0.115323	-0.594289	-0.668263	0.43868	0.026497
16	0	-8.3152E-112	1.70451E-21	-3.11187E-07	0.014616	0.271562	-0.918136	-1.150935	-0.190397	-0.133454	-1.84381	-0.837252	0.310229	1.247078	0.021907	-0.991591	0.088492	0.792977	0.343912	0.157334	0.639385	0.634674
17	0	-8.5387E-112	1.69022E-21	1.19394E-07	0.016074	0.33606	-0.543064	-1.66785	-1.265059	1.115129	-0.985574	-1.698039	-0.94446	1.360587	-1.033944	-0.024905	-0.86603	0.790379	0.847394	0.765452	-0.120875	0.211131
18	0	-8.6275E-112	1.61603E-21	5.42471E-07	0.015959	0.353347	-0.064596	-1.772056	-1.945752	1.937664	0.325126	-1.638155	-1.603138	0.487224	-1.237176	0.964907	-0.922708	-0.120133	0.279738	0.315504	-0.639466	-0.555624
19	0	-8.5803E-112	1.48458E-21	9.31453E-07	0.01428	0.320995	0.426171	-1.437767	-2.020495	2.019892	1.486566	-0.690069	-1.250139	-0.739536	-0.4202	1.058739	-0.022782	-0.892647	-0.641518	-0.570557	-0.226794	-0.419163
20	0	-8.3976E-112	1.30052E-21	1.26189E-06	0.011204	0.243549	0.835797	-0.747704	-1.466009	1.330396	1.965541	0.632171	-0.108228	-1.42989	0.743285	0.169461	0.900762	-0.639772	-0.75187	-0.667951	0.586738	0.398685
21	0	-8.0826E-112	1.07038E-21	1.51303E-06	0.00703	0.131888	1.086292	0.127378	-0.454975	0.132607	1.54216	1.611649	1.101982	-1.083105	1.293837	-0.877173	0.890455	0.348014	0.088171	0.157948	0.518431	0.568435
22	0	-7.64E-112	8.02315E-22	1.66906E-06	0.002168	0.001699	1.129963	0.97094	0.697749	-1.115847	0.410793	1.717297	1.616775	0.049286	0.777456	-1.109293	-0.043019	0.936034	0.816761	0.765519	-0.329053	-0.185857
23	0	-7.0769E-112	5.05817E-22	1.72026-06	-0.002906	-0.128729	0.958495	1.574244	1.633178	-1.937978	-0.909165	0.891832	1.111285	1.145928	-0.380037	-0.311361	-0.931893	0.448825	0.512933	0.314932	-0.681987	-0.638022
24	0	-6.4021E-112	1.91395E-22	1.66322E-06	-0.007695	-0.241072	0.604535	1.788002	2.059998	-2.019682	-1.811736	-0.417181	-0.095492	1.411397	-1.22414	0.775691	-0.854641	-0.553952	-0.439262	-0.570978	-0.009927	-0.053025
25	0	-5.6264E-112	-1.29809E-22	1.50171E-06	-0.011732	-0.319549	0.135475	1.55932	1.845288	-1.329742	-1.882561	-1.5	-1.242008	0.65314	-1.058785	1.142462	0.108648	-0.920401	-0.836213	-0.667639	0.677052	0.618169
26	0	-4.7619E-112	-4.46413E-22	1.24582E-06	-0.014619	-0.353135	-0.359379	0.944785	1.055913	-0.131759	-1.089126	-1.769524	-1.604742	-0.578857	-0.020326	0.448381	0.959298	-0.229579	-0.176159	0.158562	0.346455	0.284474
27	0	-3.8223E-112	-7.47198E-22	9.11627E-07	-0.016075	-0.337111	-0.785809	0.096464	-0.062297	1.116564	0.204314	-1.079619	-0.954788	-1.390993	1.034894	-0.662051	0.815409	0.724962	0.706567	0.765586	-0.504847	-0.511659
28	0	-2.8224E-112	-1.02151E-21	5.20139E-07	-0.015957	-0.273729	-1.062625	-0.775728	-1.161106	1.938291	1.403956	0.195653	0.297696	-1.194204	1.236712	-1.157725	-0.173843	0.846734	0.696164	0.314359	-0.597388	-0.476044
29	0	-1.778E-112	-1.25962E-21	9.59596E-08	-0.014277	-0.171893	-1.137124	-1.455966	-1.898321	2.019471	1.959058	1.364842	1.362315	-0.131225	0.418704	-0.578374	-0.982866	-0.004143	-0.194217	-0.571399	0.207916	0.333423
30	0	-7.055E-113	-1.4531E-21	-3.3425E-07	-0.011199	-0.045908	-0.99512	-1.775926	-2.044355	1.329088	1.614781	1.794018	1.567232	1.026935	-0.744579	0.538036	-0.772917	-0.850261	-0.839101	-0.667326	0.700733	0.600881
31	0	3.781E-113	-1.59509E-21	-7.43453E-07	-0.007024	0.086525	-0.663651	-1.656434	-1.553731	0.130912	0.529178	1.250484	0.783131	1.44023	-1.293862	1.154844	0.238342	-0.719678	-0.423329	0.159176	0.140382	-0.108447
32	0	1.4557E-112	-1.68055E-21	-1.10593E-06	-0.002162	0.206804	-0.205827	-1.127059	-0.579239	-1.117281	-0.799364	0.028942	-0.495173	0.808886	-0.776191	0.699302	1.002504	0.237603	0.527547	0.765653	-0.630957	-0.641485
33	0	2.5104E-112	-1.70647E-21	-1.3989E-06	0.002912	0.29803	0.291186	-0.318793	0.57564	-1.938603	-1.760928	-1.208293	-1.460993	-0.409165	0.381548	-0.405588	0.727334	0.921948	0.811583	0.313786	-0.453998	-0.131732
34	0	3.5255E-112	-1.67192E-21	-1.60395E-06	0.007701	0.347387	0.732758	0.568358	1.551252	-2.019259	-1.914072	-1.790395	-1.504838	-1.330438	1.224652	-1.133862	-0.301888	0.547245	0.069746	-0.571819	0.405298	0.592163

Final Year Project Calculation Sheet	Project **Parametric Study of FPSO Responses**	Sheet No 3
Title **Wave Spectrum Calculation**	Design **Aiza Amelia Yazid@Majid**	Check/Review **Ms Nabilah Abu Bakar, Dr Kurian V John**

1.283189	1.177435	1.08388	1.000793	0.926722	0.860445	0.80093	0.747309	0.69884	0.654894	0.614933	0.578495	0.545181	0.514649	0.486598	0.460769	0.436936	0.414898	0.39448
3.41713	5.032218	4.990543	4.834038	3.921003	5.430666	3.158682	5.273207	4.229231	6.176781	5.582816	0.082919	1.842237	4.883381	4.446545	5.087389	3.146789	5.229062	1.212744
1.38248	1.44532	1.50816	1.571	1.63384	1.69668	1.75952	1.82236	1.8852	1.94804	2.01088	2.07372	2.13656	2.1994	2.26224	2.32508	2.38792	2.45076	2.5136

η_{22}	η_{23}	η_{24}	η_{25}	η_{26}	η_{27}	η_{28}	η_{29}	η_{30}	η_{31}	η_{32}	η_{33}	η_{34}	η_{35}	η_{36}	η_{37}	η_{38}	η_{39}	η_{40}	Σ
-0.617393	0.185095	0.148807	0.060723	-0.329602	0.283124	-0.400407	0.198739	-0.162333	0.325595	0.23509	0.288254	-0.073087	0.043786	-0.06392	0.084384	-0.218465	0.102478	0.069123	3.684426
-0.287048	-0.531305	-0.510773	-0.496711	-0.304266	-0.356915	0.068397	-0.355928	-0.244054	-0.152267	-0.279432	-0.117945	0.260869	-0.230848	-0.140077	-0.214011	0.158523	-0.193909	0.052599	1.675351
0.509919	-0.318078	-0.212751	-0.06052	0.36794	-0.193502	0.374744	-0.021544	0.31328	-0.213417	0.002995	-0.174557	-0.206596	0.227699	0.24256	0.208712	-0.01272	0.19642	-0.15425	4.17263
0.477967	0.451692	0.484139	0.496736	0.257904	0.405504	-0.209004	0.366654	0.050291	0.309495	0.276881	0.286214	-0.039373	-0.036933	-0.16926	-0.071827	-0.139974	-0.108859	0.197042	1.438708
-0.330963	0.431134	0.273361	0.060318	-0.400437	0.091679	-0.296323	-0.16099	-0.344384	-0.014594	-0.238906	-0.101347	0.248809	-0.184265	-0.026703	-0.110343	0.216852	-0.028622	-0.164646	-6.218012
-0.601883	-0.343781	-0.449917	-0.49676	-0.207447	-0.428525	0.320188	-0.286507	0.162711	-0.298744	-0.073326	-0.188518	-0.22738	0.253634	0.203314	0.222945	-0.176274	0.152977	0.069424	-6.319675
0.105612	-0.517181	-0.329686	-0.060116	0.426576	0.015925	0.176185	0.303624	0.243748	0.234684	0.301382	0.283074	-0.005029	-0.114017	-0.232584	-0.194988	0.04022	-0.207182	0.052289	-0.060761
0.641425	0.214334	0.408643	0.496785	0.153697	0.424526	-0.386294	0.135352	-0.313468	0.125848	-0.18346	-0.08436	0.232772	-0.119547	0.0933	0.044098	0.117619	0.16638	-0.154049	2.833537
0.134544	0.570828	0.380844	0.059913	-0.445943	-0.122525	-0.031243	-0.371007	-0.049868	-0.327398	-0.145068	-0.201753	-0.244531	0.254607	0.113599	0.134595	-0.211751	-0.049281	0.197027	-0.724313
-0.591051	-0.071459	-0.360965	-0.496809	-0.097506	-0.39376	0.398017	0.049349	0.344312	0.115353	0.307062	0.278846	0.029394	-0.17988	-0.238172	-0.22843	0.191191	-0.090416	-0.164823	-2.331206
-0.35584	-0.588713	-0.426034	-0.059711	0.458229	0.221399	-0.118097	0.346439	-0.163088	0.242416	-0.116559	-0.067048	0.213017	-0.043063	0.190142	0.178247	-0.067074	0.188652	0.069725	0.804113
0.45782	-0.075893	0.307629	0.496833	0.039768	0.338166	-0.353706	-0.22182	-0.243442	-0.293945	-0.207751	-0.214213	-0.257774	0.230523	-0.004316	-0.015686	-0.093373	-0.200377	0.051979	3.207127
0.527253	0.569718	0.464546	0.059508	-0.46324	-0.306314	0.250812	-0.236009	0.313657	-0.025861	0.293569	0.273545	0.063348	-0.22804	-0.184638	-0.156765	0.203245	0.120216	-0.153848	5.443931
-0.260411	0.21849	-0.249473	-0.496858	0.018602	-0.261249	0.259599	0.339314	0.049445	0.312997	-0.042378	-0.049478	0.189857	0.037659	0.239785	0.230381	-0.203032	0.015072	0.197012	2.55212
-0.624753	-0.515031	-0.495778	-0.059306	0.460896	0.371914	-0.348216	0.067086	-0.344239	-0.20473	-0.257461	-0.225849	-0.266898	0.183752	-0.12116	-0.158749	0.092849	-0.143449	-0.164999	-3.112867
0.026497	-0.3474	0.187406	0.496882	-0.076677	0.167861	-0.128944	-0.372712	0.163466	-0.162169	0.261743	0.267191	0.09629	-0.253757	-0.08527	-0.012968	0.067625	0.206045	0.070025	-0.848999
0.634674	0.428078	0.519239	0.059104	-0.451234	-0.414064	0.396597	0.118464	0.243135	0.324203	0.034448	-0.031718	0.163663	0.114674	0.229904	0.17651	-0.19147	-0.174155	0.051669	0.053638
0.211131	0.454546	-0.122402	-0.496906	0.133534	-0.063888	-0.019863	0.313736	-0.313845	-0.076677	-0.291094	-0.236616	-0.271757	0.118896	-0.207927	-0.228768	0.211608	0.062403	-0.153647	-4.896258
-0.555624	-0.314308	-0.534563	-0.058901	0.434408	0.430107	-0.389144	-0.274653	-0.049022	-0.267713	0.213573	0.259811	0.127693	-0.2545	0.035265	0.136795	-0.11713	0.077965	0.196996	-6.226655
-0.419163	-0.533215	0.05548	0.49693	-0.188271	-0.044113	0.165874	-0.177003	0.344165	0.273907	0.109123	-0.013836	0.134854	0.180404	0.162953	0.041422	-0.04079	-0.182581	-0.165175	-3.384895
0.398685	0.180847	0.541508	0.058699	-0.410685	-0.41903	0.326906	0.362772	-0.163843	0.065921	-0.306549	-0.246473	-0.272273	0.042339	-0.24308	-0.193524	0.176616	0.20347	0.070326	1.780115
0.568435	0.57848	0.012312	-0.496954	0.240019	0.149333	-0.288533	-0.003598	-0.242828	-0.322472	0.152066	0.251431	0.157056	-0.230196	0.147046	0.223616	-0.216781	-0.131055	0.051359	7.221326
-0.185857	-0.036057	-0.539967	-0.058496	0.380442	0.381532	-0.218646	-0.360981	0.314032	0.17165	0.176984	0.004099	0.103891	0.228379	0.055552	-0.112725	0.139528	-0.001458	-0.153445	7.583686
-0.638022	-0.587505	-0.079911	0.496978	-0.287956	-0.245137	0.370571	0.183308	0.0486	0.196014	-0.302862	-0.255382	-0.268439	-0.038384	-0.217891	-0.069235	0.013298	0.133302	0.19698	1.955927
-0.053025	-0.110993	0.529963	0.058294	-0.344159	-0.319978	0.079603	0.269723	-0.344091	-0.316057	0.081063	0.242084	0.183909	-0.183237	0.222325	0.207544	-0.158922	-0.204019	-0.16535	-1.931454
0.618169	0.559724	0.146258	-0.497001	0.331322	0.325484	-0.400439	-0.317586	0.16422	0.036831	0.233794	0.022019	0.071267	0.253877	-0.06564	-0.215004	0.218467	0.181178	0.070626	-1.909678
0.284474	0.251089	-0.511653	-0.058091	0.302411	0.238248	0.070646	-0.111617	0.242521	0.288923	-0.280262	-0.263309	-0.260315	-0.11533	-0.138615	0.086911	-0.159682	-0.075255	0.051048	-2.57167
-0.511659	-0.496878	-0.210312	0.497025	-0.369427	-0.385308	0.373932	0.373153	-0.314219	-0.249686	0.004998	0.231806	0.207823	-0.118245	0.242415	0.095976	0.014407	-0.065177	-0.153243	-1.161448
-0.476044	-0.375455	0.485324	0.057889	-0.255862	-0.141495	-0.210949	-0.074153	-0.048177	-0.104975	0.276004	0.039853	0.037504	0.25439	-0.170537	-0.218354	0.138671	0.175722	0.196963	0.103579
0.333423	0.402904	0.27107	-0.497049	0.401666	0.420838	-0.294782	-0.336237	0.344017	0.327023	-0.240162	-0.270224	-0.248032	-0.180926	-0.024929	0.203067	-0.21664	-0.205686	-0.165525	0.21632
0.600881	0.476299	-0.451388	-0.057687	0.20525	0.035822	0.321554	0.241544	-0.164597	-0.135949	-0.071378	0.220636	0.228416	-0.041616	0.202329	-0.059753	0.177268	0.141329	0.070926	1.764018
-0.108447	-0.283689	-0.327579	0.497072	-0.427528	-0.429833	0.174131	0.215987	-0.242214	-0.226866	0.300978	0.057535	0.003142	0.229867	-0.233101	-0.121233	-0.041881	-0.012163	0.050738	-1.32959
-0.641485	-0.547305	0.410378	0.057484	-0.15138	0.072111	-0.38689	-0.349071	0.314406	0.303086	-0.185064	-0.276099	-0.231784	-0.228716	0.094945	0.225786	-0.116191	-0.122581	-0.153041	-3.367423
-0.131732	0.146701	0.378955	-0.497096	0.446603	0.411726	-0.028966	-0.042207	0.047754	0.003577	-0.143298	0.208618	0.245359	0.03911	0.112018	-0.187988	0.211329	0.201112	0.196946	-2.013873
0.592163	0.584024	-0.362937	-0.057282	0.095106	-0.175496	0.397759	0.370083	-0.343942	-0.305722	0.307159	0.074995	-0.03127	0.182722	-0.237802	0.03167	-0.192003	-0.18742	-0.1657	-4.536068
0.353444	-0.000523	-0.424391	0.497119	-0.458587	-0.367659	-0.120278	-0.142034	0.164974	0.221654	-0.11841	-0.280912	-0.211834	-0.253996	0.19125	0.144615	0.068681	0.087783	0.071225	-3.626592