PARAMETRIC STUDY OF SEMI SUBMERSIBLE RESPONSES

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by

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved:

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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.

Zareina Bt Maidin

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ABSTRACT

Semi submersibles are being increasingly used for deep water oil and natural gas development as they have better motion characteristics as compared to drill ships and jacket structure due to their configuration and economical value. The knowledge of motion response of the semi submersible under wave excitation force is of importance in view of the workability and safety. This paper presents parametric studies to find out the effect of various parameters on the motions of the semi submersible model and to identify the crucial parameter in designing a semi submersible with a favorable motion behavior. To begin with, structural properties of Ocean America rig with 4 columns had been chosen. However, a few alterations in dimensions were made such as column diameter and pontoon size. A wave spectrum analysis was done by using the application of Pierson-Moskowitz (1964) method and a wave profile was generated based on the wave spectrum produced. Then, an analysis of wave excitation forces acting on the structure designed was computed by applying the Morison equation. Subsequently, its motion response in surge and heave due to regular and random wave was analyzed based on the linear diffraction theory and Morison equation. An analysis of surge and heave responses towards varying water depth and draft were performed. It was found that the water depth in deep water has insignificant effect on the surge and heave responses. Apparently, when draft increases, surge and heave motion decrease. In addition, by varying the draft, it affects more on heave motion than it did for surge.

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ABBREVIATIONS

ISSC	International Ship Structures Congress
ITTC	International Towing Tank Conference
P-M	Pierson-Moskowitz
RAO	Response-Amplitude Operator

NOMENCLATURES

C	Damping coefficient
C_D	Drag coefficient
C_M	Inertia coefficient
d	Water depth
D	Diameter of column
f	Force per unit length
F	Total force on structure
g	Gravitational acceleration
H	Wave height
I	Inertia of structure
k	Wave number
K_s	Stiffness
L	Wave length
m	Mass of structure
M	Added mass of structure
MN	Mega-Newton
p	Dynamic pressure
s	Elevation from ocean floor
$S(\omega)$	Energy Density
t	Time
T	Wave period
u	Horizontal water particle velocity
V	Volume of structure
x	Horizontal coordinate

y	Vertical coordinate
α	Phase angle of force
η	Wave profile or vertical coordinate
ω	Wave frequency ($=2\pi/T$)
ω_o	Peak frequency
ω_N	Natural frequency
ρ	Density of water
Θ	$kx - \omega t$
ξ	Horizontal coordinate

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND STUDY

Fixed and floating platforms are very different not only in their appearance but also their structural members. They are distinctive in how they are constructed, transported and installed, what kind of excitation forces they are subjected to, how they respond to these excitation forces and how they are decommissioned and reused at the end of their design lives. The common characteristic of each type of structure is that they provide deck space and payload capacity to support equipment and variable weights used to support drilling and production operations.

While fixed structures in shallow and moderate water may be designed by applying the laws of static equilibrium to the structure, most fixed structures in deep water and all floating structures require the application of the laws of dynamics.

Mooring and station-keeping are unique requirements of floating structures. "Mooring" refers to the means for providing a connection between the structure and the seafloor for the purposes of securing the structure against environmental loads. "Station-keeping" is a term used to define a system for keeping the facility within a specified distance from a desired location. This is typically a requirement of drilling or riser connections to the seafloor, or for running equipment to the seafloor.

Other special characteristic of the floating structure is that typically it can be decommissioned readily and moved to another site for reuse. As for fixed structures decommissioned, it has to be removed in whole or in part, requiring the use of heavy lift equipment and the reverse of the installation procedure. Usually, such a structure has to be taken to shore for use of scrap steel or possibly modified and given second life. Therefore, the capital expenditure (CAPEX) for fixed platform structures needs to allocate extensive sums to cover the future decommissioning costs.

The main differences between bottom-founded and floating structure are summarized in Table 1.1.

Table 1.1: Bottom-founded vs. floating structures

Function	**Floating**	**Bottom-Supported**
Payload support	Buoyancy	Foundation-bearing capacity
Well access	"dynamic" risers subsea wellheads or surface controls	"rigid" conduits (conductors) surface wellheads and controls
Environmental loads	Resisted by vessel inertia and stability, mooring strength	Resisted by strength of structure and foundation, compliant structure inertia
Construction	Plate and frame displacement hull: ship yards	Tubular space frame: fabrication yards
Installation	Wet or dry transport, towing to site and attachment to pre-installed moorings	Barge (dry) transport and launch, upend, piled foundations
Regulatory and design practices	Oil industry practices, government petroleum regulations and Coast Guard & International Maritime regulations	Oil industry practices and government petroleum regulations

A semi submersible platform or rig is a structure used for production or drilling for oil and natural gas in offshore environments. Usually drilling semi submersibles are mobile and shift to site by tugs or under self power. On the other hand, production semi submersibles are moored permanently at the field location.

The platform payload deck is supported by columns resting on hulls or pontoons which are ballasted below water surface. Due to their deep submerged structure semi submersibles provide excellent stability in rough seas. The mobile drilling semi submersibles are kept in place by mooring systems, dynamic positioning or a combination of the two.

Leg of sufficient buoyancy of semi submersibles is to cause the structure to float, but of weight sufficient to keep the structure upright. Altering the amount of flooding in buoyancy tanks make semi submersible rigs possible to be moved from place to place and can be ballasted up or down by. During drilling operations, they are generally anchored by cable anchors while they can also be kept in place by dynamic positioning. Semi submersibles are feasible in depths from 600 to 35000 ft (180 to more than 10600 m).

At present, deep water is typically defined to cover the water depth greater than 1000 ft (305 m). For water depths exceeding 5000 ft (1525 m), general term "ultra-deep water" is often used. From a technical and economic point of view, bottom supported steel jackets and concrete platforms are impractical in deep water, thus, semi submersible structures are preferred. In deep and especially ultra-deep water, risers and mooring system provide considerable challenge. These water depths demand new materials and innovative concepts.

1.2 PROBLEM STATEMENT

Oil exploration and production companies are drilling further out into the sea and deeper under the ocean floor, at depths greater than 1000 ft to tap into remaining pockets of oil and natural gas in the world (U.S. Dept. of the Interior, 2004). Oil and natural gas production from shallow water are decreasing. Though deep water was once prohibitively expensive, high oil prices during 2007 and the first half of 2008 made the economics of deep water drilling practical. Oil's fall down during the 2008 financial crisis has killed the margins of many in the industry, but demand for deep water rigs is still high.

Offshore operations of floating systems like the semi submersibles in this paper illustrated in Figure 1.1 usually cope with severe and hostile seas. Economic advantages in avoiding restrained operation or weather induced downtime are yield when such systems are design with favorable motion behavior. Thus, during initial design stages, a detailed performance analysis and optimization is essential (Adjami M. and Shafieefar M., 2007). Semi submersibles behavior is complex, with their responses being dependent on a number of environmental variables, including the directions of the wind, wave and current (Bowers J. et al, 1997).

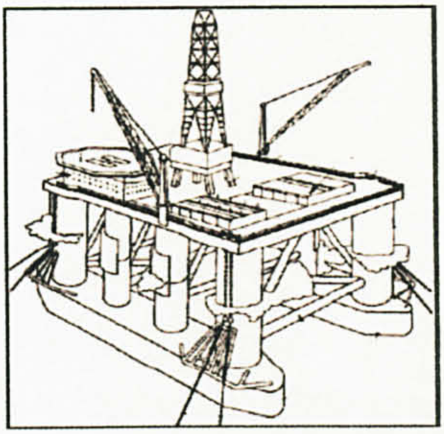

Figure 1.1: Semi submersible based floating production system (Adjami M. and Shafieefar M., 2007)

1.3 OBJECTIVE

Below are the objectives of this study:

- Gather and finalize the dimensions and all required data of a semi submersible platform for this research
- Complete a dynamic analysis of this platform due to random wave and determine the motion responses
- Complete a parametric study on the platform by varying the water depth and the draft
- Complete an experimental study of a scale model in the offshore laboratory and observe the responses

1.4 SCOPE OF STUDY

This study is based on truss pontoon semi submersible chosen with a few modifications. Herein, a numerical procedure will be carried out and described, which achieves the platform responses towards distinct parameters such as water depth, wave frequency, wave height and mooring length stiffness. The structure variable approach is also based on existing metocean criteria available regardless of the existing platform chosen.

CHAPTER 2
LITERATURE REVIEW

2.1 HISTORY OF THE SEMI SUBMERSIBLE

From a drilling vessel type called a "submersible", which is operated at the bottom of fairly shallow water and provided a working deck well above the highest expected waves, semi submersibles were evolved (Lim and Ronalds, 2000). Pontoons transited these units afloat and stability columns are required to safely submerge to a bottom founded mode of operation. To operate in deeper water, the marine riser was developed and spread moorings were perfected allowing drilling afloat. This first application was with barges, however to overcome the undesirable motions of the barges, the basic submersible design of the time was adapted to the floating drilling function. This was a Shell Oil sponsored development with Bruce Collip as the inventor of record.

These semi submersibles remain fundamentally the same as they originated, although highly evolved in size and configuration; a deck supported well above the sea by submerged pontoons, with a spread of large columns providing floatation stability. Its parent, the submersible and the semi submersible are officially designated as "column stabilized units" (USCG, ABS, etc). The columns are stability columns which primarily provide floatation stability.

2.2 SEMI SUBMERSIBLE DESIGN

Semi submersibles consist of a deck, multiple columns and pontoons. They are column stabilized, meaning that the center of gravity is above the center of buoyancy, and the stability is determined by the restoring moment of the columns. This contrasts with the spar platform, which achieves stability by placing the center of gravity below the center of buoyancy, and the TLP, whose stability is derived from the tendons (Chakrabarti, 2005).

The design of semi submersibles depends on these principle considerations which are somewhat generic to floater concepts:

- Weights and CG's (cycle of steadily improving estimates)
- Hydrostatics; tank capacities
- Intact and Damaged Stability
- Wind Forces (stability and mooring loads)
- Current forces (mooring loads)
- Ballast System Performance
- Motions (seakeeping; drift and low frequency mooring loads)
- Global Strength
- Fatigue

In the design of semi submersible and its configurations, in particular, a clear idea of its functions should be in hand. These will strongly influence configurational choices. Besides drilling, these functions include production, heavy lift, accommodations, operational support (surface, subsea), and even space launch.

Apart from the mission and support functions, there are two essential functions of a semi submersible:

- To steadily sustain a payload above the highest waves
- To minimize respond to waves

These are the principal factors that set up size of the semi submersible. The four main configurational components are:

- Pontoons
- Stability columns
- Deck
- Space frame bracing

Figure 2.1 shows sectional views of four semi submersible arrangements, identifying the above four components. Waterlines are shown at their typical operating state, semi-submerged. While each semi submersible has the noted components, each is distinctive. Case A is a typical of first generation semi submersibles, whereas Case B is quite typical of the second generation. Similarly Cases C and D are typical of the third and fourth generations respectively.

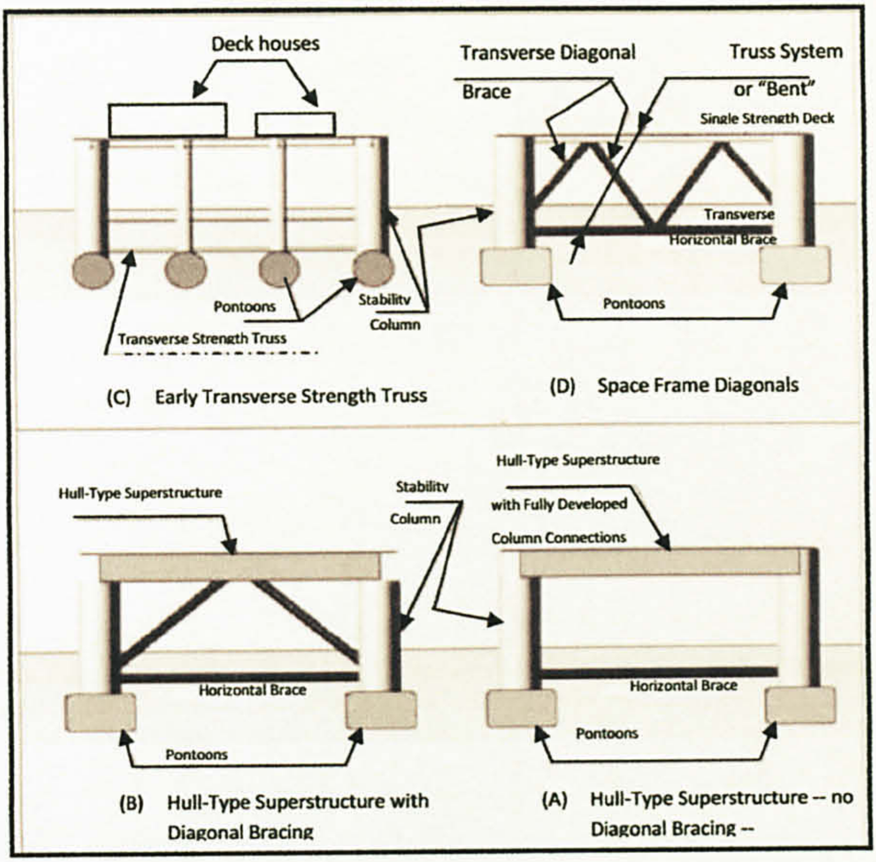

Figure 2.1: Semi submersible sectional arrangements (Chakrabarti, 2005)

2.3 SEMI SUBMERSIBLE RESPONSES

The responses of a semi submersible platform are driven by its mass properties and geometric parameters, other than environmental effects, e.g. column size, spacing, draft and pontoon size. The mooring system controls the platform responses. To enhance stability of semi submersible platforms, particularly in the lower payload range, it has been proposed to add heave plates to the base of each column. Optimization of a platform typically engages conciliation among a large number of factors including the structural weight, vertical, horizontal motion and rotations in operating and extreme sea-states, air-gap, mooring size, etc (Alexia A. et al, 2007).

A simplified hydrodynamic model or scale model is developed based on current existing platform, to capture the parametric sensitivity of the platform responses to primary design parameters. Parametric studies will be carried out to find out the effect of various parameters on the motions of the semi submersible model and to identify the crucial ones.

From the results of various parametric studies, carried out theoretically (K. Ganesh and G.L.V. Raja, 1987), on the twin circular hull model are discussed as below:

2.3.1 Draft of the Semi Submersible

It was observed that the heave response is increased when the draft is reduced, only beyond the natural frequency of the heave. The peaks of the R.A.O (in the range of 0.6 – 1.0 Hz) are observed to occur around the same frequency i.e. 0.64 – 0.68 Hz.

The motion response of the semi submersible in surge and sway also increases as the draft decreases. In the case of surge motion, the difference is less, both before and after the cancellation frequency, when compared to that of heave for various drafts. But, in the case of sway motion, the difference is about the same order before the cancellation frequency, but it is much higher after the cancellation frequency.

2.3.2 Ratio of Volume of Submerged Columns to Total Displacement Volume (Vc/Vt) or Volume Ratio

In head-sea condition, as the volume ratio increases, the R.A.O. of heave reduces since the exciting force on the hull, which dominated the total heave exciting force, reduces.
As the volume ratio increases, the surge motion increases, but the difference is very less. Similar results have been observed in beam-sea condition for beam-sea condition for heave and sway motion.

2.3.3 Number of Columns per Hull

The number of columns considered per hull has been three and four. The study of heave response in head-sea position indicates that the difference between the two case very less (a maximum of 5%). In the case of beam-sea, no difference has been observed between the two as the total area of cross-section of columns is the same and only pressure forces have been considered on the columns.

The eight columns semi submersible model has greater surge response before the first cancellation frequency but it has less surge response beyond this frequency. It is interesting to note the shift in the cancellation frequencies. It indicates that the cancellation of surge exciting force depends not only on the ratio of length of the hull to wave length and spacing between the columns, but also upon the number of columns per hull. In the beam-sea, the sway response of the eight columns model is relatively greater than the six columns model.

2.3.4 Center to Center of Hulls (B)

The variation of this parameter does not affect the motion characteristics of the semi submersible in head-sea orientation. The comparison of heave response for different values of B show that up to a frequency of about 1.17 Hz, lesser values of B gives relatively higher values of R.A.O. and the reverse is true beyond this. The variation in the sway response for different cases is less. But the shift in the cancellation frequencies can be noticed. The motion response of a semi submersible is greatly affected by the draft and the volume ration. The parameters such as number of columns per hull and center to center of hulls do not have much influence on the motion response, but they significantly influence the stability and structural behavior of the vessel.

CHAPTER 3
METHODOLOGY

3.1 PROJECT FLOW

There were some procedures developed in order to carry out this project. This is to ensure that the project flow is smooth and accomplished within the period given. Figure 3.1 shows workflow and subsequently the details of each point.

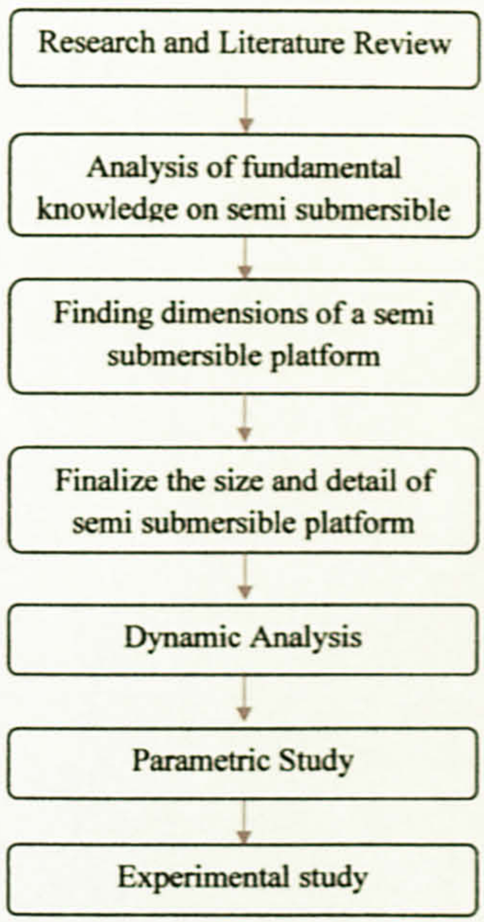

Figure 3.1: Project flow

3.2 RESEARCH AND LITERATURE REVIEW

First of all, a thorough research through the internet and from Information Resource Centre is done. Explore on this study to enable to grab as many information and records available so that better comprehension is obtained before carrying out further study and analysis. The records were online journals, handbook and literature review. As of fundamental knowledge, historical background of semi submersible platform, the development of this type of platform and deep water oil and natural gas expansion are beneficial information to enhance understanding on this study.

3.3 FINDING DIMENSIONS OF TYPICAL SEMI SUBMERSIBLE PLATFORM

Number of platform designs have been observed and study. The semi submersible design basis was based on truss pontoon semi submersible study, 4 columns. This task is required to make a simplified model or scale model so that experimental study can be carried out to study the effect of various parameters on the motions of semi submersible model.

3.4 FINALIZE SIZE AND DETAILS

The semi submersible design, size, details and properties were chosen to make a scale model. Also, the metocean or environmental conditions were selected to perform an analysis for semi submersible model platform. Nevertheless, a few data such as water depth was assumed. The finalize dimensions are seen on the next page.

Table 3.1 shows the structural properties of chosen semi submersible platform. Figure 3.2 to 3.4 show the semi submersible outlook prototype. All dimensions are in meters.

Table 3.1: Structural properties of semi submersible platform

Description	Value	Unit
Deck size	91 × 91	m^2
Number of columns	4	
Column center to center distance	61	m
Column outer diameter	16	m
Column height	54	m
Column draft	30	m

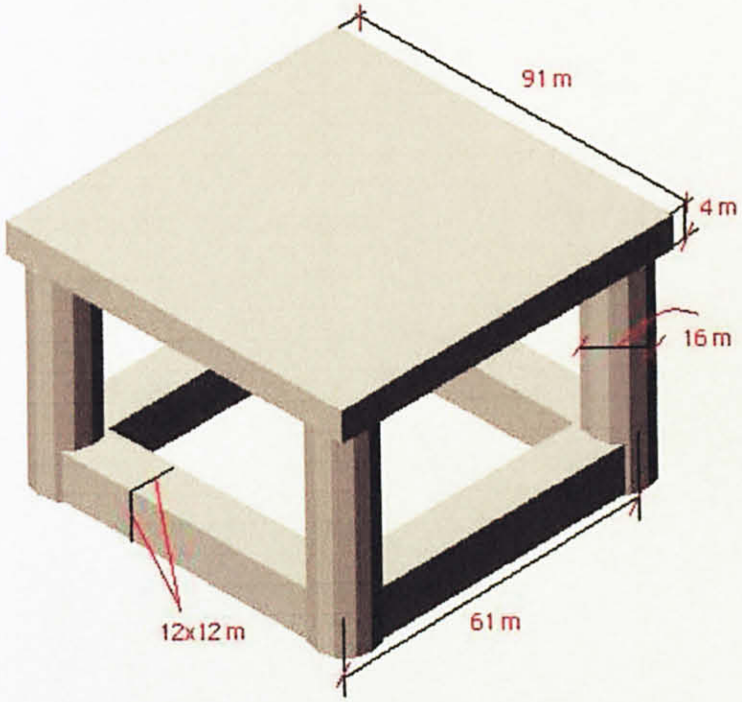

Figure 3.2: Semi submersible platform – prototype

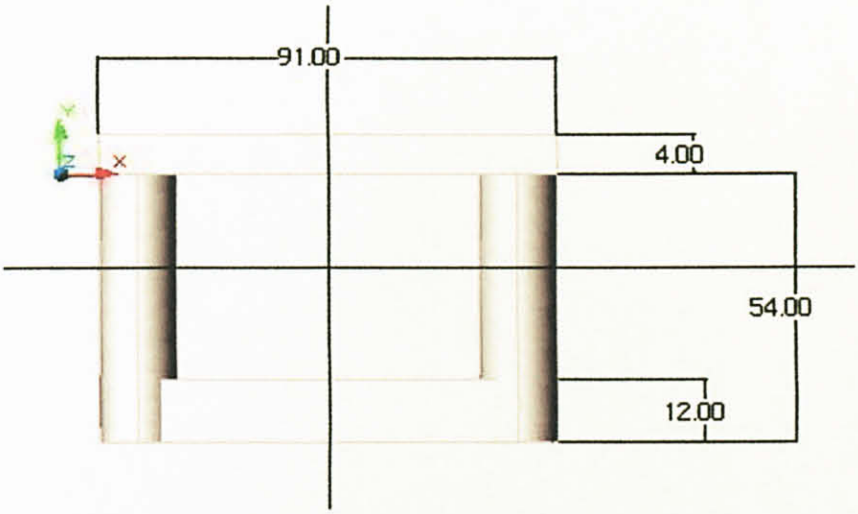

Figure 3.3: Semi submersible front dimension

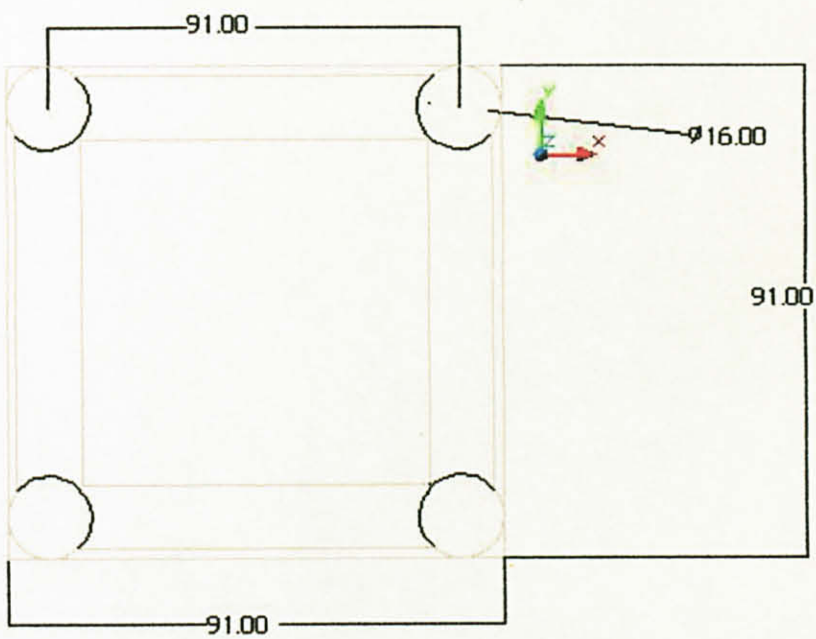

Figure 3.4: Semi submersible bottom view

3.5 DYNAMIC ANALYSIS

Dynamic analysis such as wave forces is analyzed. Parametric studies, e.g. draft of the semi submersible will be carried out by varying the parameters (C_M, C_D, Wave height, Wave frequency, etc).

Below are essential calculations used in this study:

- Morison's Equation

$$F = C_M \frac{\rho \pi D^2}{4} \dot{v} + C_D \frac{\rho D}{2} v|v| \qquad \text{(Eqn.1)}$$

Where;

F = wave force per unit length on a circular cylinder (N)

v, |v| = water particle velocity normal to the cylinder (m/s)

$\dot{v}$ = water particle acceleration normal to the cylinder (m/s^2)

ρ = water density (kg/m^3)

D = member diameter, including marine growth (m)

C_D, C_M = drag and inertia coefficients, respectively

- Linear Airy Wave Theory

The simplest and very practical of all wave theories is the small amplitude wave theory. This wave theory is also known as airy theory or sinusoidal wave theory. It is based on the assumption that the wave height is small compared to the wave length or water depth. This assumption allows the free surface boundary conditions to be linearized by dropping wave height terms which are beyond the first order. This assumption also allows the free surface conditions to be satisfied at the mean water level, rather than oscillating free surface.

- Response-Amplitude Operators (RAO)

Response amplitude is generally normalized with respect to the amplitude of the wave. The normalized response is invariant with the wave amplitude at a wave frequency for a linear system. Response-Amplitude Operator (RAO) or Transfer Function is where the normalized response function is constructed for a range of wave frequencies of interest for a given offshore structure. It is so called the Transfer Function because it allows the transfer of the exciting waves into the responses of the structure. RAO is unique because of the invariance of the normalized response for a liner system.

RAO in practice is often defined as response amplitude per unit wave height. However, RAO is more convenient to define as the amplitude of response per unit wave amplitude. In RAO computation, the waves are considered regular and a adequate number of frequencies are selected to cover the entire range of frequencies covered by the wave spectrum.

The RAO could be theoretical or measured. The theoretical RAO's are obtained with the help of simplified mathematical formulas below;

$$RAO = \frac{{}^{Fmax}/_{H/2}}{\sqrt{(K - M\omega^2)^2 + (C\omega)^2}} \qquad \text{(Eqn.2)}$$

Where;

F	= Maximum force, N
H	= Wave height, m
K_s	= Stiffness, N/m
C	= Damping
M	= Actual Mass + Added Mass, N

When the analytical computation is complicated or when the mathematical assumptions need verification, tests on a model of the prototype structure is performed with regular waves in the controlled environment of the laboratory.

- Pierson-Moskowitz Spectrum (P-M)

A new formula for an energy spectrum distribution of a wind generated sea state based on the similarity theory of Kitaigorodskii and more accurate recorded data had proposed by Pierson and Moskowitz in 1964. It is commonly recognized as P-M model has since been used broadly by ocean engineers as one of the most delegates for waters all over the world. It also has been widely applied in the design of offshore structures.

The following would be the formulations adopted in P-M spectrum:

$$S(f) = \frac{\propto g^2}{2\pi^4} f^{-5} \exp[-1.25\left(\frac{f}{f_o}\right)^{-4}] \qquad \text{(Eqn.3)}$$

Where;

$\alpha = 0.0081$

$$\omega_o^2 = \frac{0.161\ g}{H_s} \qquad \text{(Eqn.4)}$$

3.6 EXPERIMENTAL STUDY

This part is done after the completion of scale model to have a complete understanding of the semi submersibles behavior. First of all, wave kinematics, wave spectrum, wave forces and also dynamic analysis are to be carried out theoretically. Once the scale model has been completed and built, the semi submersible model is prepared for practical testing. The experiment on the semi submersible model will be carried out in the Offshore Laboratory, University Technology PETRONAS. After experimental study was completed, a clear observation on the semi submersible responses can be seen.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 ANALYSIS ON WAVE SPECTRUM

The wave spectrum is the term that describes mathematically the distribution of wave energy with frequency and direction. The wave spectrum consists of a range of frequencies. There are several mathematical spectrum models available such Pierson-Moskowitz, Bretschneider, ISSC, Scott, ITTC, JONSWAP and etc. The most common single-parameter spectrum is Pierson-Moskowitz model based on the significant wave height or wind speed. In this study, Pierson-Moskowitz model is selected since it gives more accurate data and applicable in the design of offshore structures.

Pierson-Moskowitz Spectrum (P-M)

By substituting the values into Equation (3), wave spectral density S(f) value can be obtained by means of varying the frequency, f ranging from 0.01 Hz to 0.40 Hz with an interval of 0.01. The PM wave spectrum for $H_s = 6.3$ m and $T_p = 13.1$ s represents a 100-year storm is shown in Figure 4.1. By inserting the value of gravitational acceleration, g and the significant wave height, H_s in the Equation (4), the peak frequency, f_o can be obtained:

$\omega_o = 0.5006$ rad/s

Peak angular frequency, $\omega_o = 2\pi f_o$ (Eqn.5)

Peak frequency, $f = 0.079 \approx 0.08$ Hz

Based on Figure 4.1, it can be seen that the maximum value of wave energy density is located at peak frequency, $f_o = 0.08$ Hz with energy density of 44.6 m^3s. The spectrum generally rises abruptly at low frequency end until reach maximum value and decreases gradually as the frequency increases.

From the wave energy density graph, the surface water elevation or wave profile can be generated. Figure 4.2 illustrates the time series of wave elevation with t ranges from 0 to 200 s.

It can be seen that the value of evaluation were randomly phased from t = 0 s to t = 200 s and produced wavy shape. The highest elevation is 4.14 m when t = 85 s while the lowest elevation is 4.74 m when t = 44 s.

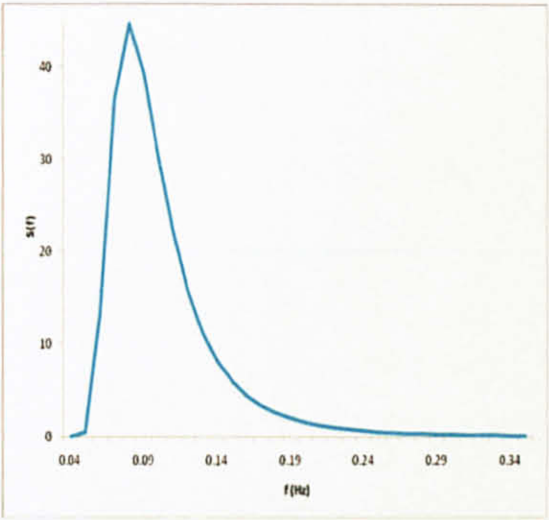

Figure 4.1: P-M wave spectrum

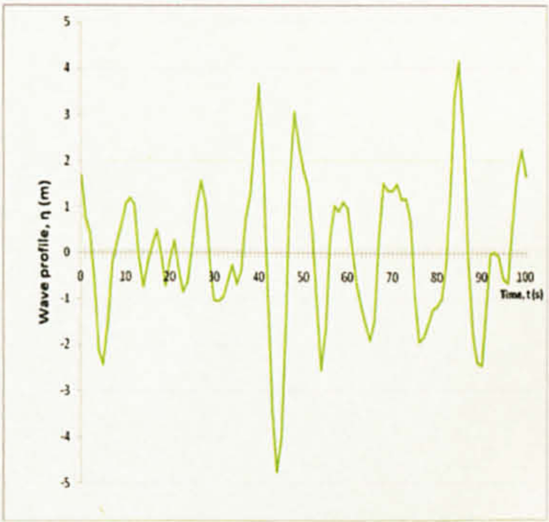

Figure 4.2: Wave elevation versus time

4.2 EQUILIBRIUM OF SEMI SUBMERSIBLE WEIGHT AND BUOYANCY FORCE

The total weight of the rig is equal to the buoyant force acting on the structure in order to keep the structure upright. Different value of draft resulted in different buoyancy force, hence, different mass of the platform. In this study, drafts selected are 30 m, 40 m and 45 m. Table 4.1 is the result of platform weight with draft variations.

Platform weight = Total Buoyancy Force

$$= (V_{Hulls} + V_{Pontoons}) \times 1030 \text{ kg/m}^3 \times 9.807 \text{ m/s}^2 \qquad \text{(Eqn.6)}$$

$$= \left[\left(4 \times \frac{\pi}{4} \times 16^2 \times 30\right) + (4 \times 12 \times 12 \times 45)\right] \times 1030 \times 9.807$$

$= \underline{505.5 \text{ MN}}$

Table 4.1: Variations of draft and platform mass

Draft (m)	Mass (MN)
30	505.5
40	586.8
45	627.4

4.3 ANALYSIS OF FORCES

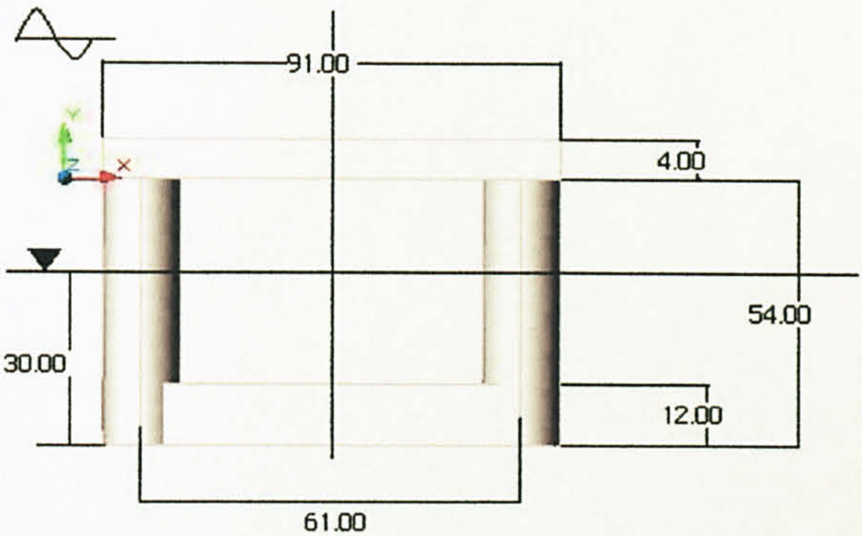

Figure 4.3: Semi submersible front dimension with origin at the center

Figure 4.3 illustrates the semi submersible (all dimensions are in meters) in two dimensional with wave propagation towards the x direction. Draft was set to 30 m. Therefore, the column is divided into 30 units of 1 m heights. The value of x is equal to 30.5 m or -30.5 m based on the distance from the origin. The total forces (F_T) acting on the structure, based on Equation (1) are tabulated in Table 4.2 for F_x and F_y.

Table 4.2: Total forces for F_x and F_y

t	Fx (MN)	Fy (MN)
0	8.80	842.1
1.7	-22.5	514.4
2.7	-31.9	100.9
3.7	-31.4	-341.1
4.7	-20.6	-687.1
5.7	-2.4	-839.4
6.7	17.8	-755.5
7.7	34.7	-458.9
8.7	43.3	-332.4
9.7	40.7	401.9
10.7	27.9	723.9
11.7	8.8	842.1

From the above results, it can be seen that the maximum force for F_x is 43.3 MN when the value of t = 8.7 s. As for F_y, the maximum force is equal to 842 MN when t = 11.7 s.

The inertia term and drag term of Morison equation were used to calculate the wave exciting force on the structure, as both were significant. The hydrodynamic coefficients for the Morison equation calculations were assumed to be $C_M = 1.6$ and $C_D = 0.65$.

4.4 ANALYSIS OF RESPONSE AMPLITUDE OPERATOR FOR REGULAR WAVE

The analysis of regular wave was done theoretically, based on metocean criteria shown in Table 4.3 and 4.4. Water depth (d) of 650 m is taken.

Table 4.3: Wave criteria

Parameters	Units	100-years Storm Event
H_s	m	6.3
H_{max}	m	12
T_p	s	13.1
T_{ass}	s	11.7

Table 4.4: Ocean current criteria

Ocean Current		Units	100-years Storm Event
At Surface		m/s	1.7
At Mid-depth	0.5*d	m/s	1.6
At Near Seabed	0.01*d	m/s	0.8

Parameters for Surge Analysis

The draft is 30 m.

Equivalent diameter of pontoon $= (Height \times Wide \times 4/\pi)^{½}$ (Eqn.7)

$= (12 \times 12 \times 4/\pi)^{½}$

$= 13.54$ m

$\omega = 2\pi/T = 0.537$

Surge Added Mass

4 columns: $4 \times (\pi/4) \times 16^2 \times 30 \times 1030 \times 9.807$ = 243.7MN

2 pontoons: $2 \times (\pi/4) \times 13.54^2 \times 45 \times 1030 \times 9.807$ = 13.0 MN

2 pontoons: $2 \times (\pi/12) \times 13.54^3 \times 1030 \times 9.807$ = 13.1 MN

Total: = 387.7 MN

Actual Mass: = 505.5 MN

Σ Surge Mass: = 893.3 MN

Natural Period, $T_n = 100$ s,

Natural frequency, $\omega_n = 0.0628 = \sqrt{(KM)}$

$K_s = 0.0628^2 \times 893285810$ N = 3.5 MN/m

$C = 2 \times \xi \times \sqrt{(KM)} = 2 \times 0.05 \times \sqrt{(3526551 \times 893285810)} = 5612680$

F_x Max = 43.3 MN

Substituting the F_x Max, H_{max}, K_s, C and ω in the Equation (2), RAO_x for surge on regular wave is obtained:

RAO_x Surge = 0.028406

Parameters for Heave Analysis

Heave Added Mass

4 columns: $4 \times (\pi/12) \times 16^3 \times 1030 \times 9.807$ = 43.3 MN

4 pontoons: $4 \times (\pi/4) \times 13.54^2 \times 45 \times 1030 \times 9.807$ = 261.8 MN

Total: = 305.1 MN

Actual Mass: = 505.5 MN

Σ Heave Mass: = 810.7 MN

$T_n = 0.58$ s,

$\omega_n = 10.833 = \sqrt{(KM)}$

$K_s = 10.833^2 \times 810669044$ N = 95136.5 MN/m

$C = 2 \times \xi \times \sqrt{(KM)} = 2 \times 0.05 \times \sqrt{(95136537009 \times 810669044)} = 878204108$

F_y Max = 842 MN

Substituting the F_y Max, H_{max}, K_s, C and ω in the Equation (2), RAO_y for surge on regular wave is obtained:

RAO_y Heave = 0.001479

4.5 ANALYSIS OF SURGE RESPONSE FOR RANDOM WAVE

Surge is the movement of the semi submersible along the horizontal x axis, left or right due to the ocean waves. Analysis of surge response of semi submersible was carried out based on the same calculation for surge analysis on regular wave, except for random wave the frequency varies and therefore a range of periods obtained.

$$\text{Surge response (t)} = RAO_{Surge} \times \eta\,(t) \qquad \text{(Eqn.8)}$$

Where;

η (t) is the wave profile as mentioned earlier in section 4.1.

RAO_{Surge} relates surge motion of the semi submersible to the wave-forcing function on the structure. Surge response spectrum $S(f)_x$ is obtained based on the P-M spectrum generated previously.

$$S(f)_x = [RAO_{Surge}]^2 \times S(f) \tag{Eqn.9}$$

Graph of RAO_{Surge} and $S(f)_x$ over a range of frequency are shown in Figure 4.4 and 4.5 respectively. From Figure 4.4, it is observed that surge response is highest at lowest frequency, which is 0.05 Hz. $S(f)_x$ as plotted in Figure 4.5 has a maximum peak value corresponding to the wave-spectral peaks. The peaks are subjected to the square of RAO for each frequency multiplied by $S(f)$ as in Equation (9).

Based on Figure 4.6, positive surge response indicates that the surge is moving on x axis to the right induced by horizontal force. Conversely, negative surge response indicates that the surge is moving to the left. Maximum positive surge response is 0.90 m at t = 86 s and t = 186 s while maximum negative surge response is 1.01 m at t = 45 s and t = 145 s.

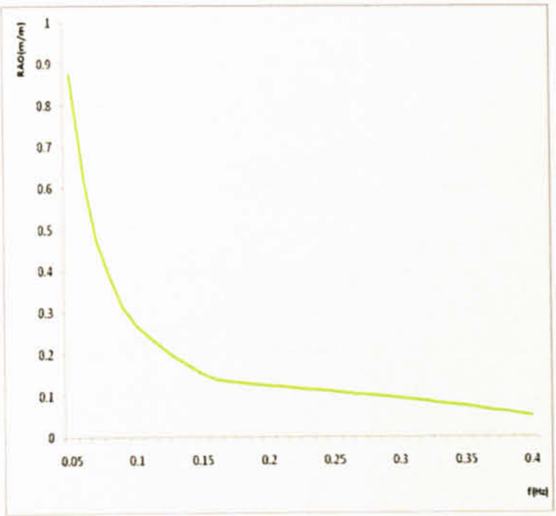

Figure 4.4: Graph of RAO_{Surge} versus frequency

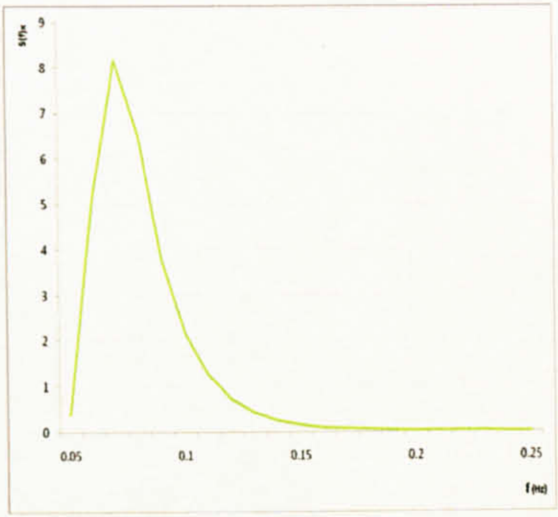

Figure 4.5: Graph of surge response spectrum, $S(f)_x$ versus frequency

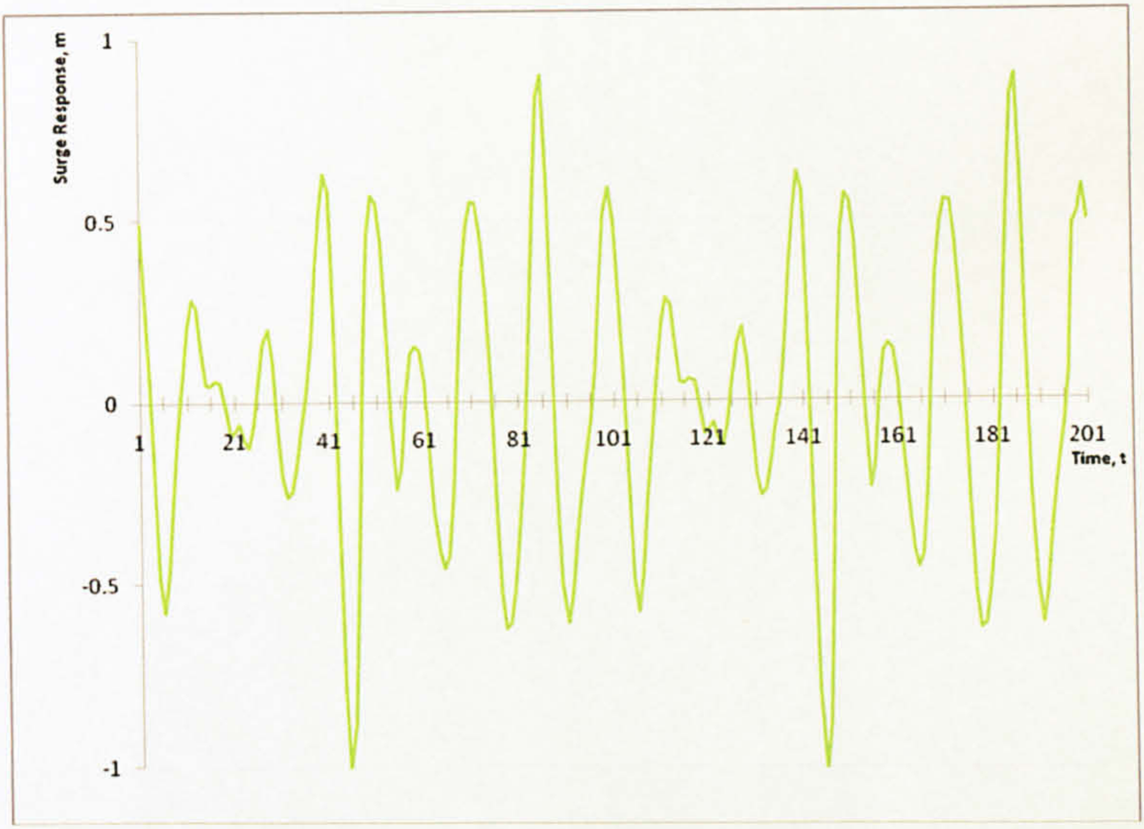

Figure 4.6: Graph of surge response versus time

4.6 ANALYSIS OF HEAVE RESPONSE FOR RANDOM WAVE

Movement of semi submersible along the y axis is called heave. The movement is vertical due to vertical forces and dynamic bottom pressure acting upon the hulls and pontoons.

The bottom dynamic pressure is obtained by using the following equation:

$$p = pg\,\frac{H}{2}\,\frac{\cosh ks}{\cosh kd}\cos\theta \qquad \text{(Eqn.10)}$$

Semi submersible will produce responses when subjected to a random wave of a range of frequency. The amplitude of the response is basically correlates with the amplitude of the wave. Graph of RAO_{Heave} and $S(f)_y$ over a range of frequency are shown in Figure 4.7 and 4.8 respectively.

From Figure 4.7, it can be seen that the heave response is highest at highest frequency which is 0.04 Hz. Heave spectrum in Figure 4.8 has a maximum peak of 0.019 m^2s. The peaks are subjected to the square of RAO_{Heave} multiplied by $S(f)$, as in Equation (9.0).

The heave responses at varying time series range from 0 s to 200 s is shown in Figure 4.9. Positive heave response indicates that the heave is moving on y axis to upward induce by vertical force. Conversely, negative heave response indicates that the heave is moving downward. Maximum positive heave response is 0.15 m at t = 40 s and t = 140 s while maximum negative heave response is 0.11 m at t = 54 s and t = 154 s.

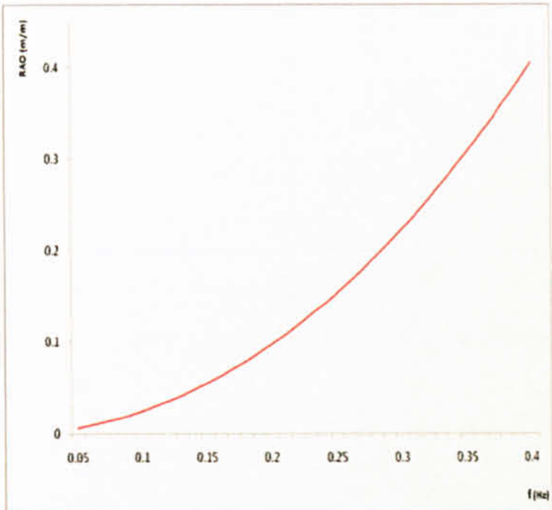

Figure 4.7: Graph of RAO_{Heave} versus frequency

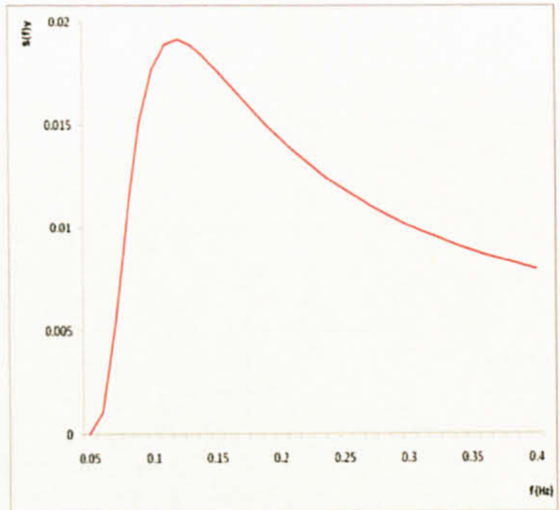

Figure 4.8: Graph of heave response spectrum, $S(f)_y$ versus frequency

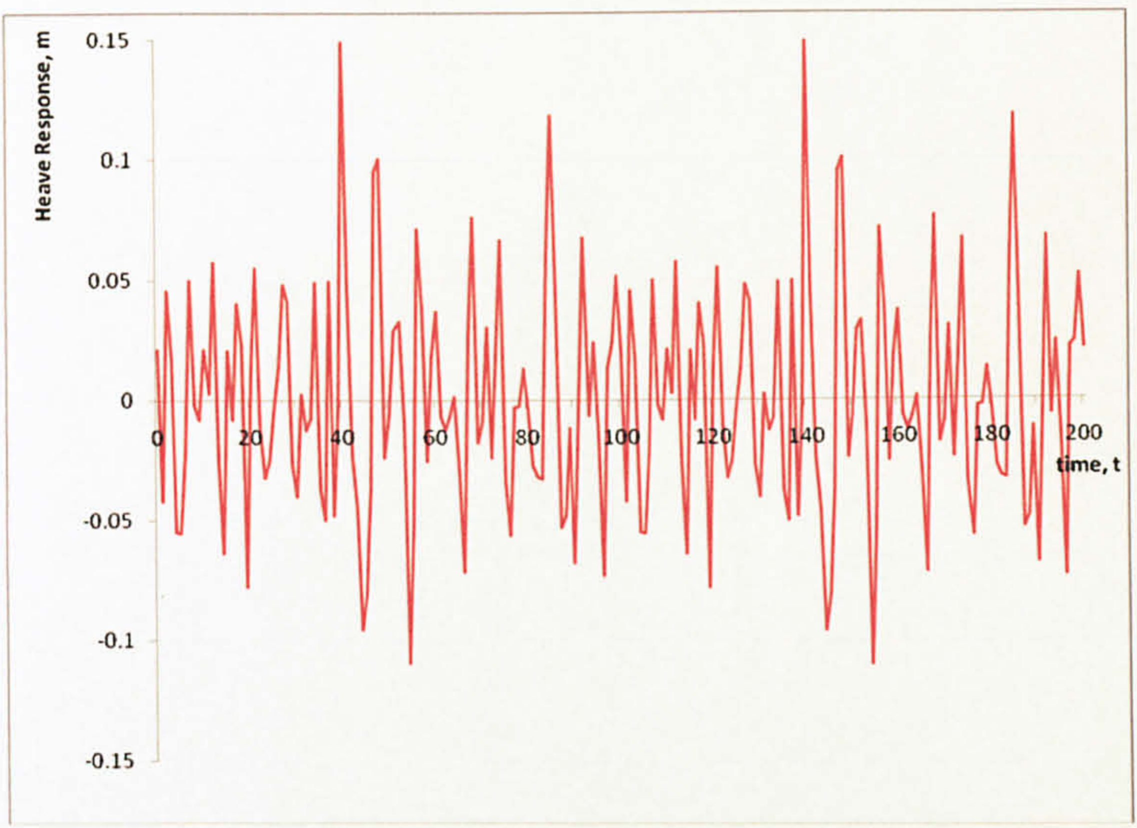

Figure 4.9: Graph of heave response versus time

4.7 EFFECT OF WATER DEPTH

Study was resumed by varying the water depth to see the effect on the response of the structure. Previously, the water depth was 650 m. For the purpose of comparison for varying water depths, a depth of 1000 m is chosen. The surge and heave responses were recalculated by changing only the water depth. Results are presented in Figure 4.10 and 4.11.

From both Figure 4.10 and 4.11, it can be observed obviously that the effect of varying the water depth is very small. Therefore, the same graph for wave spectrum and wave elevation will be produced with the depth of 650 m. The reason for this matter is that as the water depth goes deeper, above the range for deep water (>305 m), the responses will have very little effect. Thus, effect of water depth in deep water is insignificant.

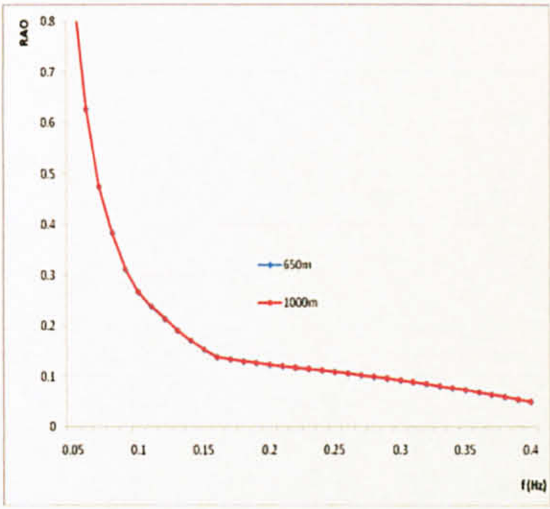

Figure 4.10: Graph of RAO_{Surge} subjected to different water depths

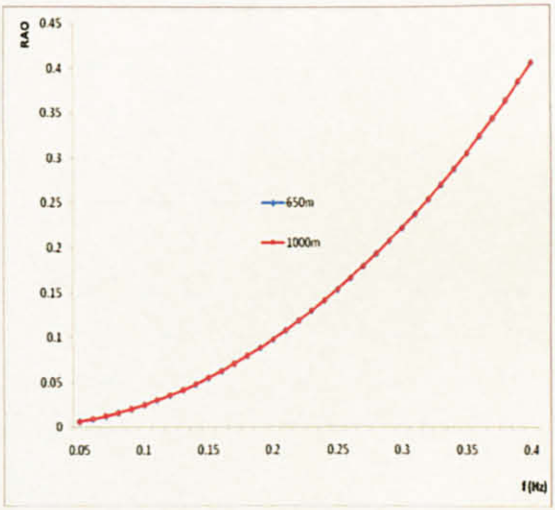

Figure 4.11: Graph of RAO_{Heave} subjected to different water depths

4.8 EFFECT OF DRAFT

When the draft changes the platform mass will differ due to the effect of buoyancy force, based on the Archimedes's Principle. A variation of 30 m (original draft), 35 m, 40 m and 45 m were selected for the purpose of examine the structure responses.

Surge Response

The surge response was recalculated by changing only the draft and the platform mass, hence total surge mass. Figures 4.12, 4.13 and 4.14 represented the results of varying the draft.

From Figure 4.12, it can be seen that the higher the draft, the lower the surge responses. For draft of 30 m, the maximum surge value is 0.87 m/m while for draft of 45 m, the maximum surge is 0.82 m/m. The surge response decreases by 5.75% as the draft change from 30 m to 45 m. The surge response for draft of 35 m decreases by 1.15%.

Based on the Figure 4.13, it can be seen that the higher the draft, the lower the wave energy density. However, it is observed that for all set of different drafts, the wave energy density value is highest at the same frequency. The wave energy density for draft of 45 m is 6.6 m^2s. It decreases by 19.22% from draft of 30 m.

Figure 4.14 shows the surge responses subjected to varying drafts. The maximum surge response is 0.9 m at draft of 30 m and the maximum surge response is 0.77 m for draft of 45 m, a decrease of 14.44%. Therefore, it can be concluded that the higher the draft the lower the surge response.

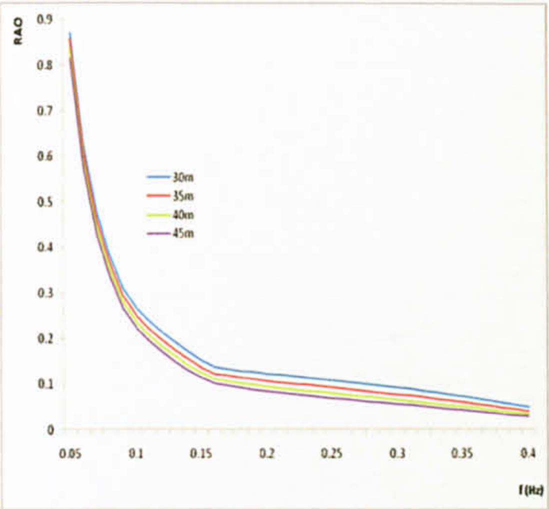

Figure 4.12: Graph of RAO_{Surge} subjected to different drafts

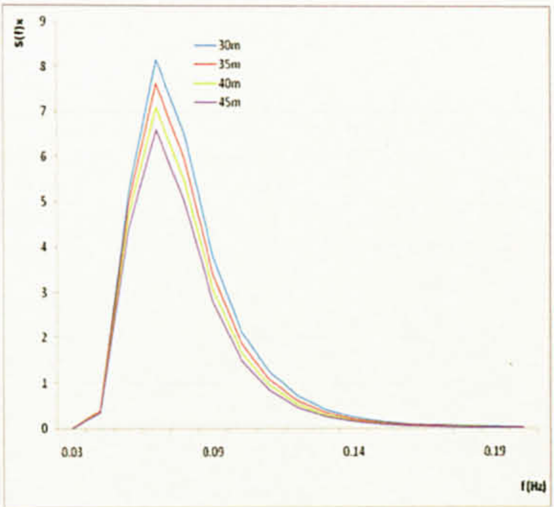

Figure 4.13: Graph of surge spectrum subjected to different drafts

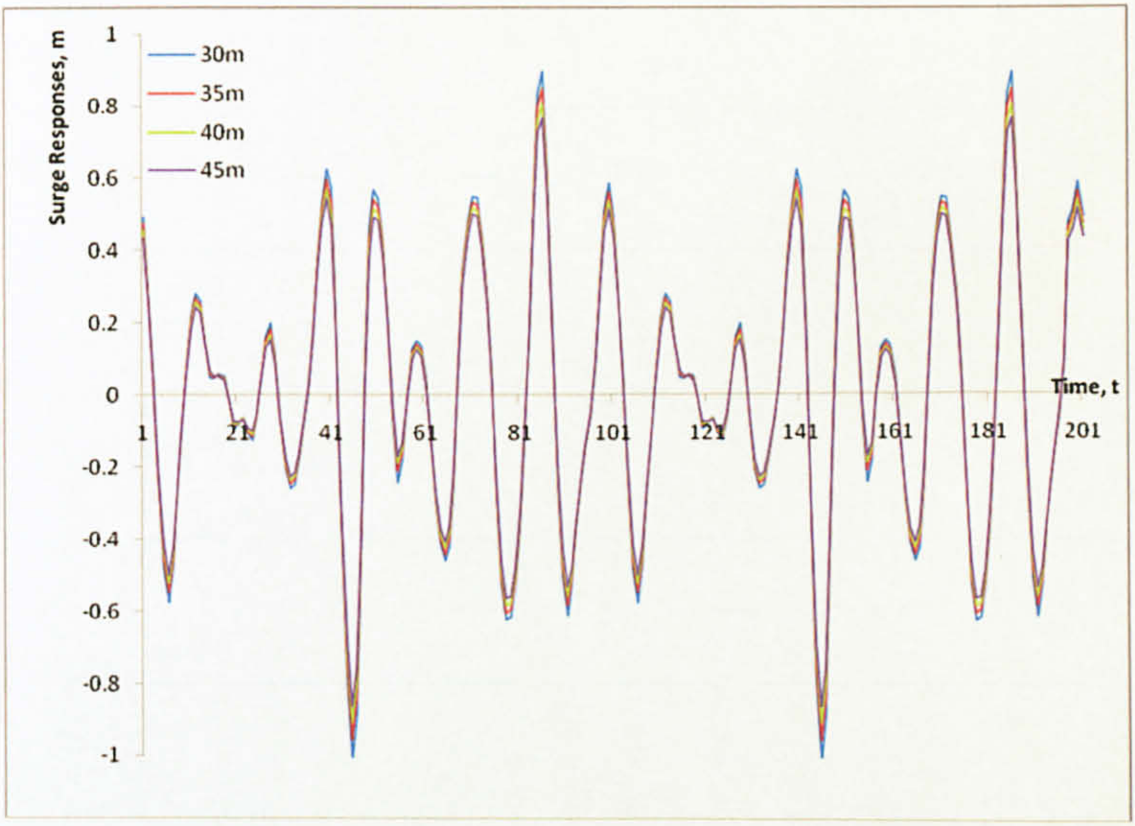

Figure 4.14: Graph of surge response subjected to different drafts

Heave Response

The heave response was recalculated by changing only the draft and the platform mass, hence total heave mass. Figures 4.15, 4.16 and 4.17 represented the results of varying the draft.

From Figure 4.15, it can be seen that the higher the draft, the lower the heave responses. For draft of 30 m, the maximum heave value is 0.41 m/m while for draft of 45 m; the maximum heave is 0.23 m/m. The heave response decreases by 43.9% as the draft change from 30 m to 45 m. The heave response for draft of 35 m decreases by 19.5%.

Based on the Figure 4.16, it can be seen that the higher the draft, the lower the wave energy density. However, it is observed that for all set of different drafts, the wave energy density value is highest at the same frequency. The highest wave energy density is 0.019 m^2s at draft of 30 m. The maximum wave energy density for draft of 45 m is 0.006 m^2s. It decreases by 68.4%.

Figure 4.17 shows the heave responses subjected to varying drafts. The maximum heave response is 0.15 m at draft of 30 m. The maximum heave response is 0.08 m for draft of 45 m. It decreases by 46.67%. Therefore, it can be concluded that the higher the draft the lower the heave response.

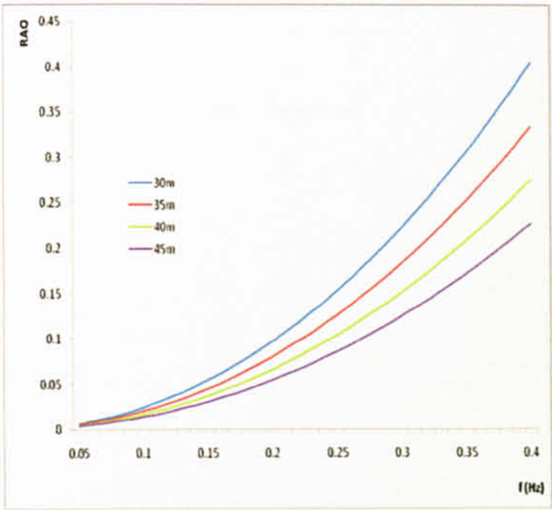

Figure 4.15: Graph of RAO_{Heave} subjected to different drafts

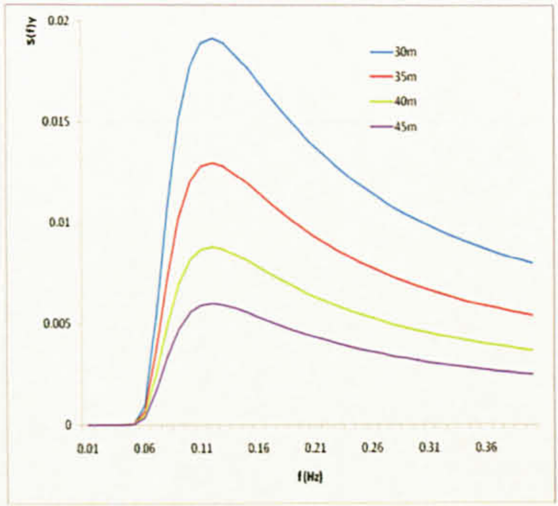

Figure 4.16: Graph of heave spectrum subjected to different drafts

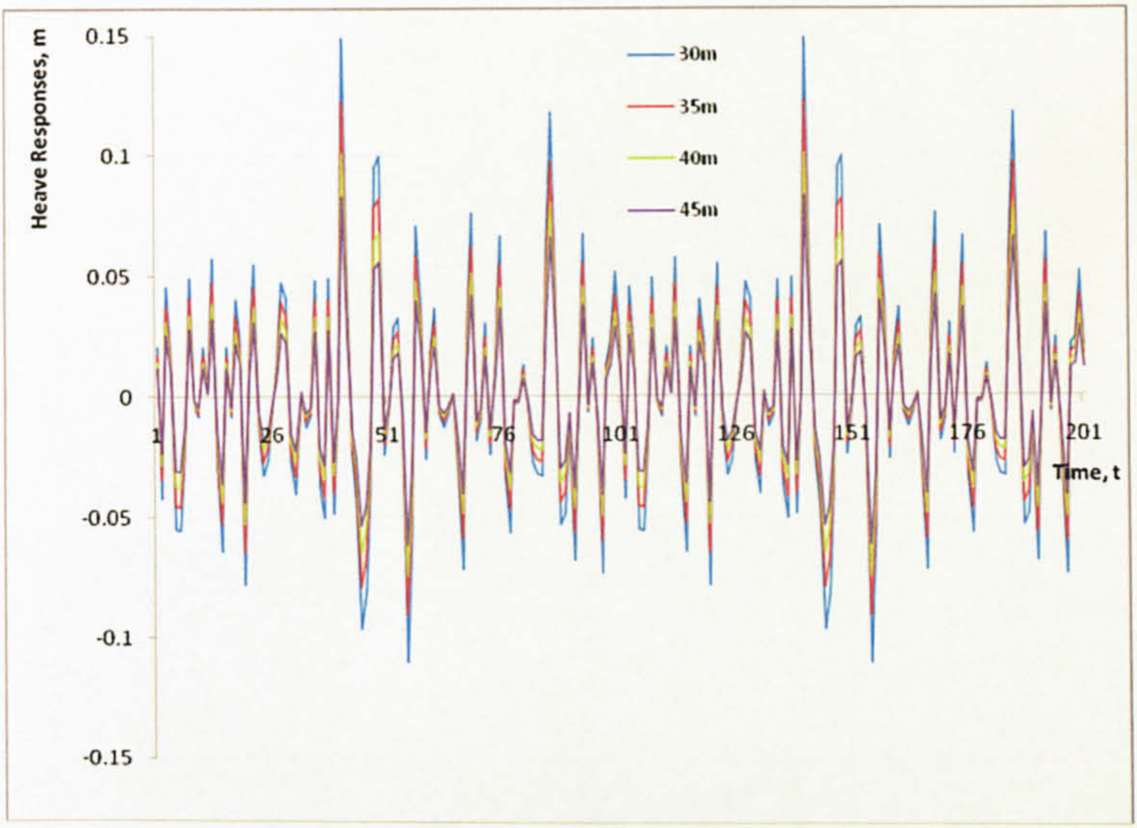

Figure 4.17: Graph of heave response subjected to different drafts

Table 4.5 shows the RAO for a regular wave in varying drafts. .

Table 4.5: RAO for a regular wave subjected to different drafts

Draft (m)	RAO Surge	RAO Heave
30	0.02841	0.00148
35	0.02707	0.00122
40	0.02583	0.00100
45	0.02468	0.00083

These values of RAO are particularly for a regular wave computation.

4.9 EXPERIMENTAL OBSERVATION

To have a complete understanding of the semi submersible behavior, model observations are carried out. The experiments have been carried out in 12 m × 22.86 m wave flume with a water depth of 1 m. Small amplitude, regular waves in the frequency range of 0.6 – 1.5 Hz were generated. As for random waves, P-M spectrum was selected with a wave height of 0.06 m and frequency of 0.81 Hz. From the experimental testing, it can be seen clearly that the trend of the responses were relatively similar to the theoretical results for surge and heave motions. Figure 4.18 and 4.19 show the surge response and heave response respectively, based on the experimental observation. The time ranges from 0 s to 50 s are selected.

Based on Figure 4.18, positive surge response indicates that the surge is moving on x axis to the right induced by horizontal force. On the other hand, negative surge response indicates that the surge motion is moving to the left. Maximum positive surge response is 0.20 cm at t = 1 s, 7 s, 13 s, 21 s, 24s, 31 s, 34 s and 46 s. Conversely, maximum negative surge response is 0.5 cm at t = 18 s, 28 s, 38 s and 44 s.

Based on Figure 4.19, positive heave response indicates that the heave is moving on y axis to upward induce by vertical force. Conversely, negative heave response indicates that the heave is moving downward. Maximum positive heave response is

2.00 cm at t = 21 s and 50 s. Maximum negative heave response is 2.00 cm at t = 18 s and 42 s.

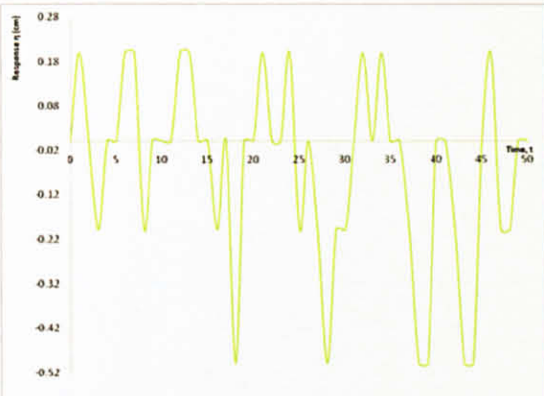

Figure 4.18: Surge responses based on experimental observation

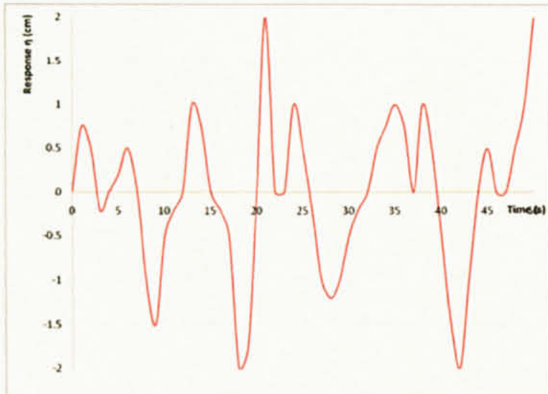

Figure 4.19: Heave responses based on experimental observation

CHAPTER 5
CONCLUSION

Semi submersibles are widely applied in the offshore industry, especially in deep water development. In this study, a research was done to get a sufficient understanding on semi submersible technology in the industry. Historical background of semi submersible and development of this structure for deep water oil and gas were known. Semi submersible design in this study is obtained based on the truss pontoon semi submersible study with a few alterations in dimension of columns, pontoons and etc. Before further analysis on the semi submersible responses, an analysis of the wave spectrum and wave elevation were done. This paper uses the Morison equation to compute the exciting forces on the structure. Its surge and heave motion responses for regular and random were analyzed by linear diffraction theory and Morison equation. A model test was done; however, in present study the results obtained are not for comparison. The model test was performed to get a clear view of the surge and heave responses of the semi submersible. Overall, from the analysis, it can be concluded that:

- For deep water, an increasing water depth has insignificant effect to the motion responses of the semi submersible.
- When draft was increased from 30 m to 45 m, the surge responses decreased by 14.44% and the heave responses were also reduced by 46.67%.
- The draft effect most significant in heave responses compared to surge responses due to combination of vertical forces of the wave and the increasing bottom dynamic pressure.
- Optimization of the semi submersible can be made by altering the draft; hence, a desirable motion response of a semi submersible to the exciting wave forces can be obtained.

CHAPTER 6

ECONOMIC BENEFITS

Offshore operations have been performed productively during the last decades, in which time period it was established that semisubmersibles are superior to conventional ship-shaped barges in view of minimum down-time requirements. To meet these requirements it is necessary to reduce the motions, which can be attained by optimization of the dimensions or the shape of the underwater hulls. For optimization purposes there is a need for theoretical methods in order to reduce costly and time-consuming model experiments. Overall, the cost that had been spent for this project, especially the scale model developed is more than RM 500. The scale model was developed to capture the parametric sensitivity of the platform responses to primary design parameters. In this case, the experimental study was performed to obtain a clear observation of the semi submersible motion responses. Semi submersible is designed to support drilling, production and workover capabilities in a range of water depths/environments including deep water. It is envisaged for operation in marginal field developments where exploitation of hydrocarbon reserves by alternative methods may prove uneconomic due to harsh environments, water depth or limited field capacity. The design offers an alternative to fixed platforms for such marginal fields with the advantage of mobility resulting in cost saving from early production and without cost penalties associated with field abandonment.

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APPENDICES

Appendix I Surge Responses Data Sheet

f (Hz)	T (s)	ω (rad/s)	$S(f)$ (m^2s)	$H(f)$ (m)	$H(f)_{Surge}$ (m)	RAO_{Surge}	$S(f)_{Surge}$ (m^2s)
0.05	20.000	0.3142	0.5059	0.2012	0.0897	0.8711	0.3839
0.06	16.667	0.3770	13.1896	1.0272	0.2027	0.6251	5.1544
0.07	14.286	0.4398	36.499t	1.7088	0.2614	0.4732	8.1724
0.08	12.500	0.5027	44.6008	1.8889	0.2749	0.3822	6.5167
0.09	11.111	0.5655	39.2847	1.7728	0.2663	0.3099	3.7737
0.1	10.000	0.6283	30.2059	1.5545	0.2494	0.2663	2.1418
0.11	9.091	0.6912	22.0023	1.3267	0.2304	0.2371	1.2372
0.12	8.333	0.7540	15.7558	1.1227	0.2119	0.2121	0.7088
0.13	7.692	0.8168	11.2858	0.9502	0.1950	0.1900	0.4072
0.14	7.143	0.8796	8.1518	0.8076	0.1797	0.1698	0.2351
0.15	6.667	0.9425	5.9589	0.6904	0.1662	0.1515	0.1368
0.16	6.250	1.0053	4.4142	0.5943	0.1542	0.1367	0.0825
0.17	5.882	1.0681	3.3143	0.5149	0.1435	0.1326	0.0583
0.18	5.556	1.1310	2.5213	0.4491	0.1340	0.1285	0.0416
0.19	5.263	1.1938	1.9421	0.3942	0.1256	0.1254	0.0305
0.2	5.000	1.2566	1.5136	0.3480	0.1180	0.1221	0.0226
0.21	4.762	1.3195	1.1925	0.3089	0.1112	0.1192	0.0169
0.22	4.545	1.3823	0.9492	0.2756	0.1050	0.1161	0.0128
0.23	4.348	1.4451	0.7627	0.2470	0.0994	0.1133	0.0098
0.24	4.167	1.5080	0.6182	0.2224	0.0943	0.1105	0.0075
0.25	4.000	1.5708	0.5052	0.2011	0.0897	0.1075	0.0058
0.26	3.846	1.6336	0.4160	0.1824	0.0854	0.1046	0.0046
0.27	3.704	1.6965	0.3450	0.1661	0.0815	0.1013	0.0035
0.28	3.571	1.7593	0.2880	0.1518	0.0779	0.0982	0.0028
0.29	3.448	1.8221	0.2419	0.1391	0.0746	0.0950	0.0022
0.3	3.333	1.8850	0.2044	0.1279	0.0715	0.0912	0.0017
0.31	3.226	1.9478	0.1736	0.1179	0.0687	0.0881	0.0013
0.32	3.125	2.0106	0.1482	0.1089	0.0660	0.0845	0.0011
0.33	3.030	2.0735	0.1271	0.1009	0.0635	0.0801	0.0008
0.34	2.941	2.1363	0.1095	0.0936	0.0612	0.0760	0.0006
0.35	2.857	2.1991	0.0948	0.0871	0.0590	0.0722	0.0005
0.36	2.778	2.2619	0.0824	0.0812	0.0570	0.0679	0.0004
0.37	2.703	2.3248	0.0718	0.0758	0.0551	0.0627	0.0003
0.38	2.632	2.3876	0.0629	0.0710	0.0533	0.0583	0.0002
0.39	2.564	2.4504	0.0552	0.0665	0.0516	0.0531	0.0002
0.4	2.500	2.5133	0.0487	0.0624	0.0500	0.0490	0.0001

Appendix II Heave Responses Data Sheet

f (Hz)	T (s)	ω (rad/s)	S(f) (m^2s)	H(f) (m)	$H(f)_{Heave}$ (m)	RAO_{Heave}	$S(f)_{Heave}$ (m^2s)
0.05	20.000	0.3142	0.5059	0.2012	0.0009	0.0062	0.0000
0.06	16.667	0.3770	13.1897	1.0272	0.0064	0.0088	0.0010
0.07	14.286	0.4398	36.4997	1.7088	0.0145	0.0120	0.0052
0.08	12.500	0.5027	44.6008	1.8889	0.0208	0.0156	0.0108
0.09	11.111	0.5655	39.2847	1.7728	0.0246	0.0197	0.0152
0.1	10.000	0.6283	30.2060	1.5545	0.0266	0.0242	0.0177
0.11	9.091	0.6912	22.0023	1.3267	0.0275	0.0293	0.0189
0.12	8.333	0.7540	15.7558	1.1227	0.0277	0.0349	0.0191
0.13	7.692	0.8168	11.2858	0.9502	0.0275	0.0409	0.0189
0.14	7.143	0.8796	8.1519	0.8076	0.0271	0.0475	0.0184
0.15	6.667	0.9425	5.9590	0.6904	0.0266	0.0545	0.0177
0.16	6.250	1.0053	4.4143	0.5943	0.0261	0.0620	0.0170
0.17	5.882	1.0681	3.3144	0.5149	0.0255	0.0701	0.0163
0.18	5.556	1.1310	2.5214	0.4491	0.0250	0.0786	0.0156
0.19	5.263	1.1938	1.9422	0.3942	0.0244	0.0877	0.0149
0.2	5.000	1.2566	1.5136	0.3480	0.0239	0.0973	0.0143
0.21	4.762	1.3195	1.1926	0.3089	0.0235	0.1074	0.0138
0.22	4.545	1.3823	0.9493	0.2756	0.0230	0.1180	0.0132
0.23	4.348	1.4451	0.7627	0.2470	0.0226	0.1292	0.0127
0.24	4.167	1.5080	0.6183	0.2224	0.0222	0.1409	0.0123
0.25	4.000	1.5708	0.5053	0.2011	0.0218	0.1531	0.0118
0.26	3.846	1.6336	0.4161	0.1824	0.0214	0.1658	0.0114
0.27	3.704	1.6965	0.3451	0.1661	0.0210	0.1792	0.0111
0.28	3.571	1.7593	0.2881	0.1518	0.0207	0.1930	0.0107
0.29	3.448	1.8221	0.2420	0.1391	0.0204	0.2074	0.0104
0.3	3.333	1.8850	0.2044	0.1279	0.0201	0.2224	0.0101
0.31	3.226	1.9478	0.1736	0.1179	0.0198	0.2380	0.0098
0.32	3.125	2.0106	0.1483	0.1089	0.0196	0.2541	0.0096
0.33	3.030	2.0735	0.1272	0.1009	0.0193	0.2709	0.0093
0.34	2.941	2.1363	0.1096	0.0936	0.0191	0.2882	0.0091
0.35	2.857	2.1991	0.0949	0.0871	0.0189	0.3061	0.0089
0.36	2.778	2.2619	0.0824	0.0812	0.0186	0.3246	0.0087
0.37	2.703	2.3248	0.0719	0.0758	0.0184	0.3438	0.0085
0.38	2.632	2.3876	0.0629	0.0710	0.0182	0.3636	0.0083
0.39	2.564	2.4504	0.0553	0.0665	0.0181	0.3840	0.0082
0.4	2.500	2.5133	0.0487	0.0624	0.0179	0.4050	0.0080