Experimental Study On The Hydrodynamic Interaction Between Two Floating Offshore Structures Moored Together And Subjected To Regular Wave

By

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15192

Dissertation submitted in partial fulfilment of

the requirements for the

BACHELOR OF ENGINEERING (Hons)

(CIVIL ENGINEERING)

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Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

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

(**FARIS SYAHIN BIN HAMZAH**)

12th August 2014.

ABSTRACT

The use floating production systems in the offshore oil and gas has been predicted to grow at a significant rate. The hydrodynamic interaction between waves and two floating offshore structures is studied experimentally. One practical example for such case is the Kikeh Project. The Kikeh field is located 120km northwest of the island of Labuan, offshore Sabah, East Malaysia in water depth of around 1300m.

This study is mainly focus on experimental studies on the dynamic motions of the connected truss spar and Semi-submersible subjected to regular waves. First and foremost, two models, basically one for truss spar and another one is for Semi-submersible were designed. Related to the models, to design the models need to use Froude modelling law to scale down the platform prototypes and the environmental conditions. The model tests were performed in the wave tank located in the Offshore Laboratory of Universiti Teknologi PETRONAS. In the experiment the models were subjected to regular waves and limited to long crested waves. In addition, static offset and free decay tests will be conducted to measure the stiffness of system and coefficient value respectively. The dynamic motions of the two floating platforms in the six degree of freedom and the tension in mooring line are measured.

ACKNOWLEDGEMENT

بِسۡمِ ٱللَّهِ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ

In the name of Allah, The Beneficent, The Merciful.

I would like to take this opportunity to thank various people who have helped me throughout the period of completing my Final Year Project I and II. First of all, my utmost appreciation and heartfelt thanks to Dr.Montasir Osman Ahmed Ali, my FYP supervisor, also thank you for the support and the time he managed to spend in answering my question and feed my curiosity. Secondly, my deepest gratitude to Mr. Anurag, Ms. Nur Zaidah, Mr. Meor, Mr. Zaid, Mr. Syahmi and members of offshore laboratory that stayed with me until midnight to finish my experiment. I also would like to deliver my special gratitude to my fellow colleagues for sharing their invaluable knowledge and expertise to help in this project.A token of appreciation to my parents who have been fully supportive during my FYP.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

In the 21stcentury, technology has developed into the whole new level. Same goes to technology and engineering in the oil and gas sector. In oil and gas sector, the extraction of hydrocarbon is now trending worldwide in the deepwater and ultra-deepwater. The first offshore platform was built in Louisiana in 1947 at Gulf of Mexico (GoM) about 6m depth(Chakrabarti S. K., 1994). Until now, about 10 000 offshore structures of various types and sizes was constructed globally.

Due to limitation of depth for hydrocarbon exploration for shallow water, fixed platform structures is not suitable to construct. This is because the cost of fabrication, technical and installation constraint. The move in exploitation of offshore oil and gas resources into deeper waters has triggered the alternative platforms such as Tension Leg Platform (TLP), Tethered Buoy Tower (TBT) and Articulated Leg Platform (ALP).

According to (Chakrabarti S. K., 2005), the production of Spars has only been installed in the GoM. Currently, in 2007 the first spar was built outside of GoM was in Sabah, Malaysia under project name KIKEH. It is national pride. As shown in **Figure 1.1**, there are generations of spar which are classic spar, truss spar and cell spar. The classic spar consists of large cylindrical hull moored together in a vertical position. The difference between classic spar and truss spar is the lower portion of truss spar is replaced with truss structure that reduces the cost and size. In addition, truss section is transparent to the surrounding current, resulting in significantly less surge offset and mooring requirements. The soft tank provides stability while the hard tank provides buoyancy. Cell spar is a scaled-down version of the original design. The cell spar includes six pressure vessels gathered around a seventh vessel. With these pressure vessels, they are more easily and cost-effectively generated through mass production. Providing the buoyancy for the facility, the vessels are held together by structural steel, which extends below the vessels and keeps with the deep-draft design by providing stability.

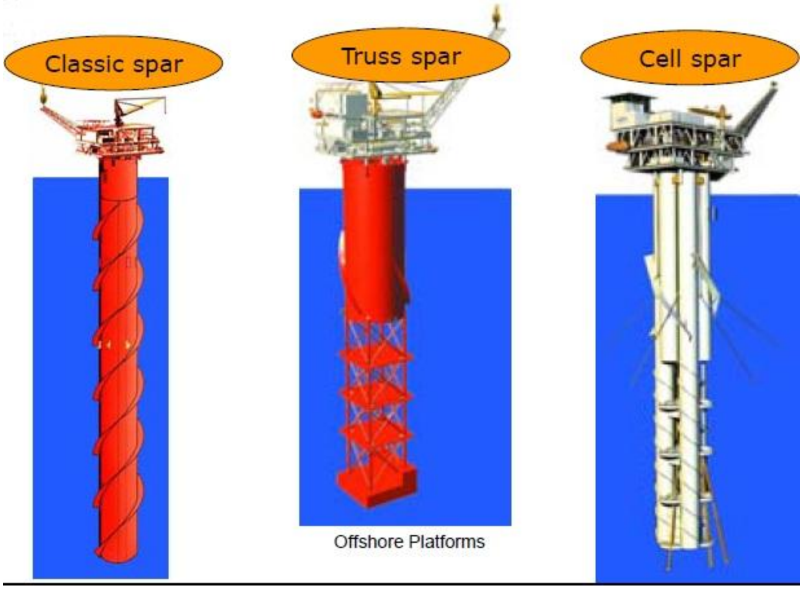


Figure 1.1 : Spar platforms

Spar platform has six degree of freedom translational and rotational. On the other hand, the dominant motions for spar are only three which are surge, heave and pitch. Thus, it is often modelled as two dimensional structures with three degree of freedom. The spar has natural frequencies of motions far lower than the dominant ocean exciting wave forces frequencies. This is due to its large mass and relatively small restoring stiffness. So, the dynamic responses of spar due to the linear ocean wave forces are insignificant. Nonlinear wave structure interactions may result in second order difference frequency forces, which have frequencies near to the natural frequencies of the spar. These forces should be considered in the design because of its substantial contribution to the motions and mooring line tensions.

There are two main approaches to evaluate the dynamic responses of any floating offshore structure. An approximate approach is to carry out the analysis in the frequency domain which results the steady state responses. Hence, this approach is adopted only in the preliminary design. An accurate approach is to analyze the structure in the time domain when the structure responses can be evaluated numerically at each time step.

Exciting wave forces can be predicted by the Morison equation, which assumes the force to be composed of inertia and drag forces linearly added together. These components involve inertia and drag coefficients, which can be determined experimentally. Morison equation is applicable when the structure is small in dimension compared to the wave length$\left(\frac{Structural\ Diameter}{Wave\ Length} \leq 0.2\right)$. When the size of the structure is comparable to the wave length, the presence of the structure is expected to change the wave field in the vicinity of the structure. In this case, diffraction of the waves from the surface of the structure should be taken into account in the evaluation of the wave forces. It is generally known as diffraction theory.

Another one type of floating platform that normally used in offshore platform is Semi-submersibles. Semi-submersible s are multi-legged floating structures with a large deck. These legs are interconnected at the bottom underneath water with horizontal buoyant members called pontoons. Some of the earlier Semi-submersibles resemble the ship form with twin pontoons having bow and a stern. This configuration was considered desirable for relocating the unit from drilling one well to another either under its own power or being towed by tugs. Early semi submersibles also included significant diagonal cross bracing to resist the prying and racking loads induced by waves.

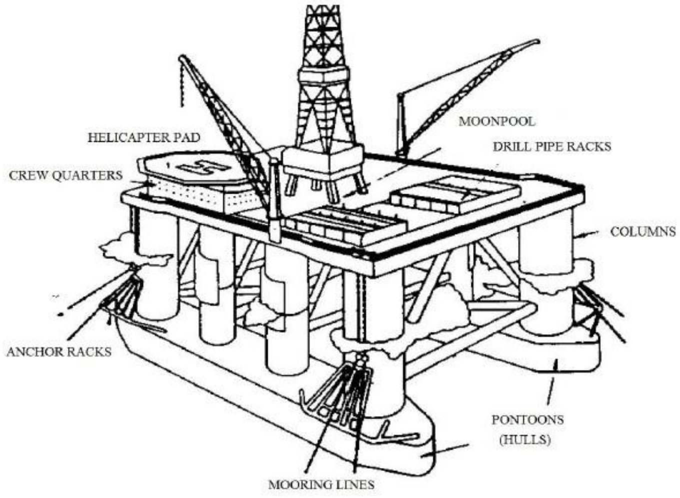
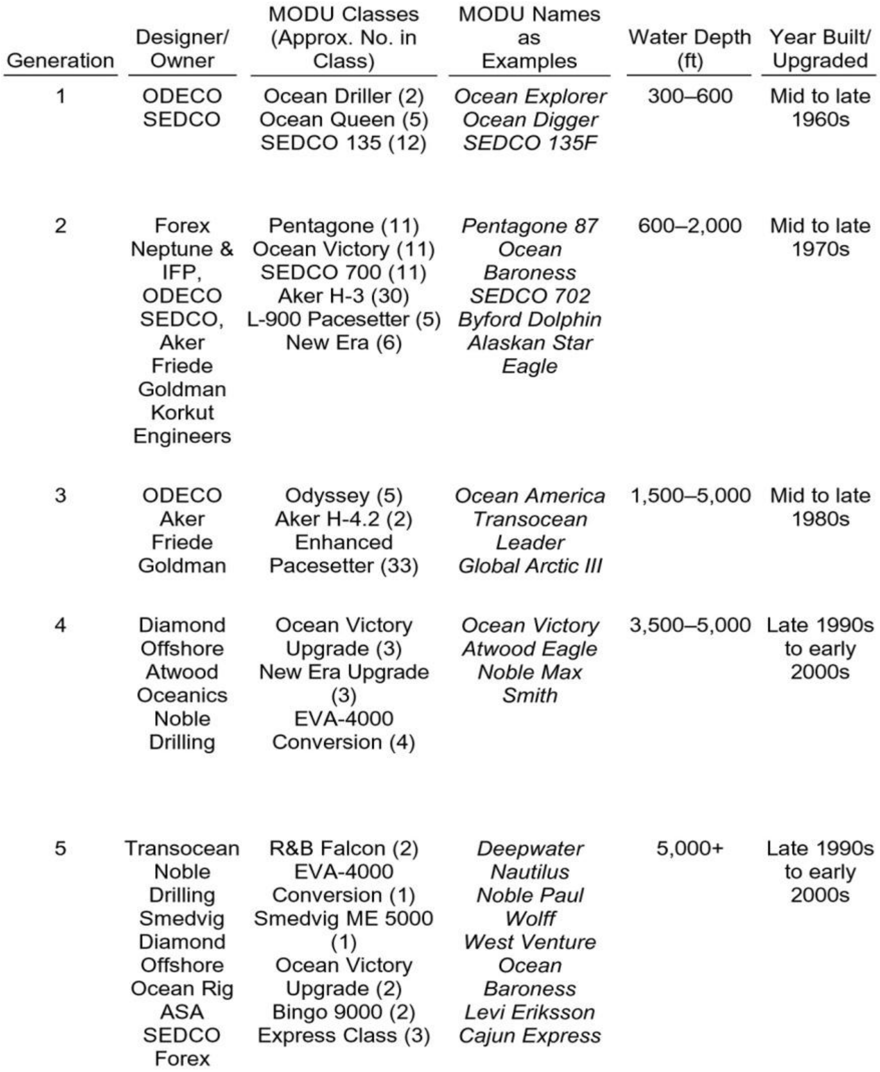


Figure 1.2 : Typical type of Semi-submersible

It is common to refer to semis as belonging to a "generation". This designation is somewhat inexact, but **Figure 1.3** gives some guidance for semis. Recently, the newer ultra deep drill ships have also adopted this type of designation. Many semis may start out as one generation, but an upgrade may graduate them into another one. This is particularly true of many second-generation units that are upgraded to fourth-generation units.



Generation	Designer/ Owner	MODU Classes (Approx. No. in Class)	MODU Names as Examples	Water Depth (ft)	Year Built/ Upgraded
1	ODECO SEDCO	Ocean Driller (2) Ocean Queen (5) SEDCO 135 (12)	*Ocean Explorer* *Ocean Digger* *SEDCO 135F*	300–600	Mid to late 1960s
2	Forex Neptune & IFP, ODECO SEDCO, Aker Friede Goldman Korkut Engineers	Pentagone (11) Ocean Victory (11) SEDCO 700 (11) Aker H-3 (30) L-900 Pacesetter (5) New Era (6)	*Pentagone 87* *Ocean Baroness* *SEDCO 702* *Byford Dolphin* *Alaskan Star* *Eagle*	600–2,000	Mid to late 1970s
3	ODECO Aker Friede Goldman	Odyssey (5) Aker H-4.2 (2) Enhanced Pacesetter (33)	*Ocean America* *Transocean Leader* *Global Arctic III*	1,500–5,000	Mid to late 1980s
4	Diamond Offshore Atwood Oceanics Noble Drilling	Ocean Victory Upgrade (3) New Era Upgrade (3) EVA-4000 Conversion (4)	*Ocean Victory* *Atwood Eagle* *Noble Max Smith*	3,500–5,000	Late 1990s to early 2000s
5	Transocean Noble Drilling Smedvig Diamond Offshore Ocean Rig ASA SEDCO Forex	R&B Falcon (2) EVA-4000 Conversion (1) Smedvig ME 5000 (1) Ocean Victory Upgrade (2) Bingo 9000 (2) Express Class (3)	*Deepwater Nautilus* *Noble Paul Wolff* *West Venture* *Ocean Baroness* *Levi Eriksson* *Cajun Express*	5,000+	Late 1990s to early 2000s

Figure 1.3 : Definition of Semi-submersible ‘generation’ designation

One of the most unusual conversions and upgrades is Noble Drilling’s EVA-4000 design, which, originally, was a shallow-water submersible. This triangular submersible was a complete redesign and turned into fourth- and fifth-generation semis. Variable deck load (VDL) and age are poor definition parameters for generation designation because some second-generation units have larger VDLs than some fourth-generation units and because age variations within a generation, especially fourth generation after upgrade, can vary widely. Fifth-generation units usually have very large VDLs, high marine-riser tension, hook load ratings of 1.5 million lbm, large deck space, high-pressure [7,500-psi working pressure (WP)] mud pumps, and extensive mud-solids control systems.

Floating platforms generally have too much motion during extreme storms. A group of engineers in California invented a floating system in the early 1970s, which could be tethered to the sea floor, effectively making it a tethered compliant platform. This gave rise to what is called the Tension Leg Platform (TLP). The first commercial application of this technology, and the first dry tree completion from a floating platform, was the Conoco Hutton TLP installed in the UK sector of the North Sea in 1984. Dry trees are possible on a TLP because the platform is heave-restrained by vertical tendons, or tethers. This restraint limits the relative motion between the risers and the hull, which allows flow lines to remain connected in extreme weather conditions. The deep draft Spar platform is not heave-restrained, but its motions are sufficiently benign that risers can be supported by independent buoyancy cans, which are guided in the center well of the spar.

One of the real-situation example for this study is Kikeh Project. Kikeh is the first deepwater oil discovery in Malaysia, Kikeh is located in 4,400 feet (1,341 meters) of water offshore Sabah, northwest of the island of Labuan, in the southern part of Block K. Considered a fast-paced project, field development was completed in five years following the initial discovery in July 2002, and production started in August 2007. The Kikeh Dry Tree Unit (DTU) consists of a Truss Spar and a tender assist drilling semi-submersible(TAD). The TAD will be operating in close proximity to the Spar over the first several years of operation as the wells are drilled and completed. Water depth for the DTU is 4364 ft. The spar ultimately will support 24 top tensioned risers. When the TAD is in place, it is connected to the spar by nylon hawsers. These are sometimes referred to as “lashings”. Four mooring lines are connected to the stern of the TAD which keeps the lashings in tension Spar and TAD were designed for two different relative positions employed during operating and extreme conditions. One and ten year storm events were defined as the operating environmental condition while 100 year event was as extreme condition.

1.2 Problem Statement

Literature is reach with the info related to the dynamic analysis of a single floating offshore structure. However, a few information related to the interaction between wave and two floating platform are available. In this study, when two floating structures are in close proximity to each other and moored together, the motion of one structure influences that of the other. This interaction comes from the fact that incident waves, upon scattering from one structure are incident on the second structure. Also, the radiated waves from one structure are experienced by the other structure. In addition to this hydrodynamic interaction, the elastic coupling between the two structures through mooring system also influences the responses of the two. Ships or barges breast-moored or in tandem experience this type of interaction problem. The smaller of the two structures is influenced more by the presence of the larger one.

1.3 Objectives

The objectives of this project are listed as follows:

- To measure the dynamic motions of the connected truss spar and Semi-submersible subjected to regular waves

- To examine the effect of the motion of one floating platform on other floating platform.

1.4 Scope of the Project

The scope of the research is confined within the following constraints:

1. Two floating offshore structures (model) which are truss spar and Semi-submersible are used in the experiment.
2. Only experimental studies will be used to achieve the objectives.
3. Only regular waves will use throughout the experiment and is limited to long crested waves.
4. Truncated mooring lines will be used in the experiment to represent the mooring line restoring forces.

CHAPTER 2

LITERATURE REVIEW

In this chapter, the related research on the aspects of the dynamic analysis of floating offshore structures spar and Semi-submersible are discussed.

A study by (Chitrapu, Saha and Salpekar, 1999) discussed the motion response of a large diameter spar platform in long crested and random directional waves and current using a time domain simulation model. Several nonlinearities such as the free surface force calculation, displaced position force computation, nonlinearities in the equation of motion and the effect of wave current interaction were considered for determining the motion response. The effect of wave directionality on the predicted surge and pitch response of the spar platform was studied. It was seen that both wave-current interaction and directional spread of wave energy had a significant effect on the predicted response.

Different analytical and numerical methods to evaluate the dynamic response of Spar platforms due to unidirectional and multidirectional waves, current and wind was presented by (Anam, 2000). Focus on the second order difference frequency forces and structural responses were done. Some numerical predictions in the time domain using Morison equation and the second order diffraction theory were compared to the measured laboratory and field data. The statistical nature of the response was also studied. Good agreement between results was achieved for the numerical result susing the HWM.

(Yilmaz and Incecik, 1996) analyzed the extreme motion response of moored Semi-submersible . They developed and employed two different time domain techniques since there are strong nonlinearities in the system due to mooring line stiffness and damping and viscous drag forces. First one is for simulation of wave frequency motions in which the first-order wave forces are the only excitation forces. First-order wave forces acting on Semi-submersible s are evaluate according Morison equation, current effect is taken into account by altering the drag term in Morison equation. Second one is to simulate the slowly varying and steady motions under the excitation of slowly varying wave, current and dynamic wind forces. Slowly varying wave forces are calculated using the mean drift forces in regular waves and applying an exponential distribution of the wave force record in irregular waves.

A case study from (Kurian, Ng and Liew, 2013), in numerical simulation, linear airy wave theory was adopted to obtain the wave properties. In this case, the wave height is assumed to be small enough with respect to the wave length or the water depth. By considering the real sea conditions, assumption was made where the water run-up and pressure distribution were taken around the bottom seated cylinder. The concept was implemented by considering surge diffraction force as a product obtained from intergrating the total length of the vertical columns. In addition, the added mass was computed by integrating it from mean sea level to the keel of the structure. In this study, two components were considered for the semisubmersible platform model, such as the column and the pontoon.

A study by (Chwang, 2003), for the oblique motion of non-circular bodies in two dimension or non-spherical bodies in three dimension, the moment acting on each body is no longer zero. Thus, the effect of rotation becomes important and the translational motion is coupled with the rotational one. Hence, the translational energy of a moving body can be transformed into the rotational energy and vice versa. Due to this coupling, the moving properties of these bodies have large differences from those in the particle dynamics.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This section explains the methods or procedure taken for the project. **Figure 3.1** below would be the flow chart of the whole project that has been planned.

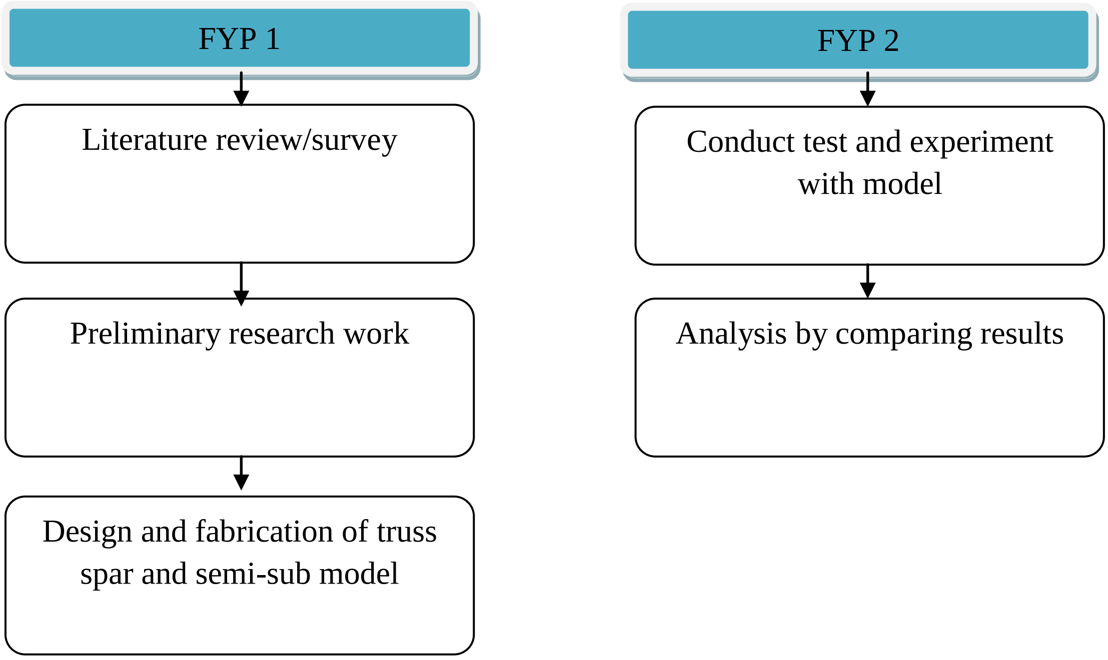


Figure 3.1 : Project flow chart

3.2 Froude's Law

In case of water flow with a free surface, the gravitational effects predominate. The effect of other factors, such as viscosity, surface tension, roughness …etc is generally small and can be neglected. In this case, Froude's model law is most applicable. The Froude number, Fr , for the model and the prototype in waves is expressed by Eq3.1, where the subscripts p, m stand for prototype and model respectively. Assuming geometric similarity $D_p = \lambda D_m$, where λ is the scale factor for the model and D stands for any characteristic dimension of the object. Thus, the prototype velocity is given by $u_p = \lambda u_m$. In this study, a general assumption was made that the model follows the Froude's law of similitude, the common variables are listed in **Table 3.1**.

$$Fr = \frac{u^2{}_p}{gD_p} = \frac{u^2{}_m}{gD_m} \qquad (3.1)$$

3.3 Scaling of Froude Model

A general assumption is made that the model follows the Froude's law. The common variables found in the study of fluid mechanics are grouped under appropriate subheadings and are listed in Table 3. The units of these quantities are listed in the M-L-T (mass-length-time) system. If the variable is dimensionless, the 'units' column includes the entry 'NONE'. Using Froude's law and the scale as λ, the suitable multiplier to be used to obtain the prototype value from the model data is shown. Nevertheless, it should be clear that Froude models do not scale all of the parameters, they satisfy the most important and predominant factor in scaling a system in wave mechanics, namely inertia.

Variable	Unit	Scale Factor
Geometry		
Length	L	λ
Area	L^2	λ^2
Volume	L^3	λ^3
Angle	None	1
Radius of gyration	L	λ
Area moment of inertia	L^4	λ^4
Mass moment of inertia	ML^2	λ^5
CG	L	λ
Kinematics and Dynamics		
Time	T	$\lambda^{1/2}$
Acceleration	LT^{-2}	1
Velocity	LT^{-1}	$\lambda^{-1/2}$
Displacement	L	λ
Angular acceleration	T^{-2}	λ^{-1}
Angular velocity	T^{-1}	$\lambda^{1/2}$
Angular Displacement	None	1
Spring constant (Linear)	MT^{-2}	λ^2
Damping coefficient	MT^{-1}	$\lambda^{5/2}$
Damping factor	None	1
Natural period	T	$\lambda^{1/2}$
Wave mechanics		
Wave height	L	λ
Wave period	T	$\sqrt{\lambda}$
Wave length	L	λ
Celerity	LT^{-1}	$\sqrt{\lambda}$
Particle velocity	LT^{-1}	$\sqrt{\lambda}$
Particle acceleration	LT^{-2}	1
Water depth	L	λ
Water pressure	$ML^{-1}T^{-2}$	λ

Table 3.1 :Model of prototype multipliers(*Source : Offshore Structure Modeling, Chakrabarti, 1994*)

3.4 Test Facilities

The offshore lab wave basin measures approximately 22 m long, 10 m wide and 1.5 m deep. The wave maker system in this tank comprises of wave maker,remote control unit, signal generation computer and dynamic wave absorption beach. The wave-maker comprises of a number of modules, each having eight individual paddles, which can move independently of one another. These paddles move backward and forward horizontally to generate waves in the basin.

The wave maker is capable of generating up to 0.3 m wave height and period as short as 0.5 s (model scale). Major random sea spectra, such as JONSWAP, ISSC, PM, Bretschneider, and Ochi-Hubble, can be simulated. Also, custom spectra can be added to the software and calibrated. The progressive mesh beach systems minimize interference from reflected waves during tests. UTP basin also includes a current making system capable of providing a current speed of 0.2 m/s at a water depth of 1 m (the speed varies with water depth).

3.5 Model Description

A truss spar and Semi-submersible models were made to the scale of 1:100 according to the dimension shown in **Figure 3.4-3.5**. The calculation and result will explain in the next chapter for further explanation. Froude scaling was applied for conversion between full scale and model scale units. Froude scaling laws assume the conservation of the ratio between inertial and gravitational forces by maintaining a constant Froude number:

$Fr = U/(g*L2)$

g = Acceleration of gravity

U = Velocity

L = Length

If length scales by a factor, λ, Froude scaling implies the following relationships.

Length	$U_m = L_f/\lambda^{.5}$
Time	$t_m = t_f/\lambda^{.5}$
Acceleration	$dU/dt_m = dU/dt_f$

Force $F_m = F_f/(\lambda^3 * \rho_f/\rho_m)$

Stiffness $K_m = K_f/(\lambda^2 * \rho_f/\rho_m)$

Pressure $P_m = P_f/\lambda$

Where, subscripts “m” and “f” are model and full (prototype) scale, respectively

t = time ,F = force , ρ = density of fluid

The platform models were tested for regular waves. The setup of the model test and the models used for the test are illustrated in **Figure 3.2**

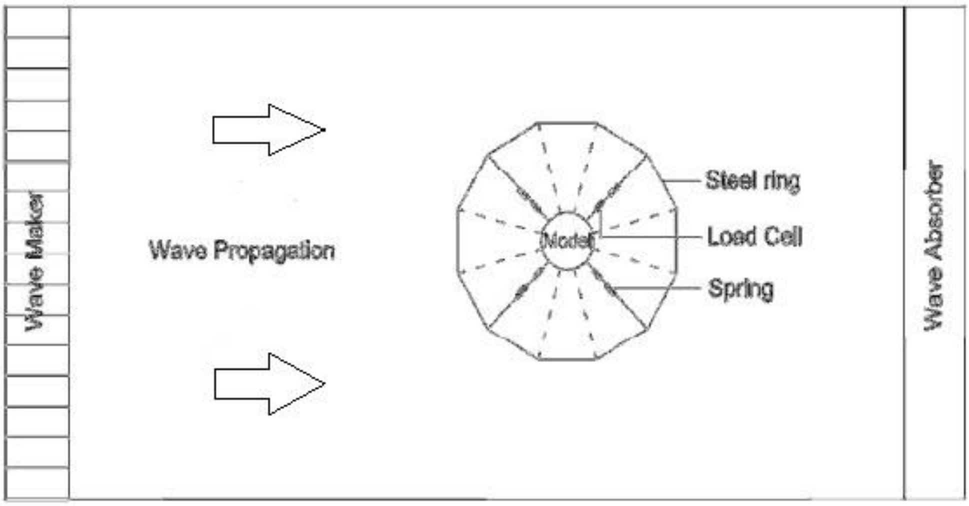


Figure 3.2 : Setup of the model

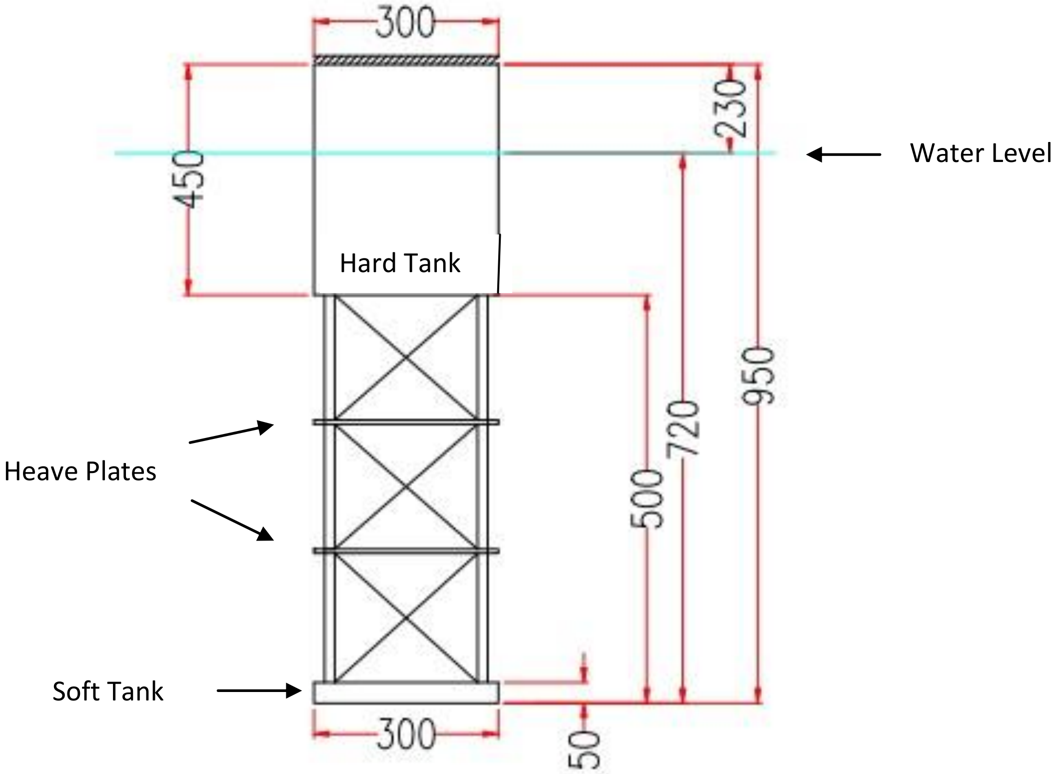


Figure 3.3 : Truss Spar dimension (in mm)

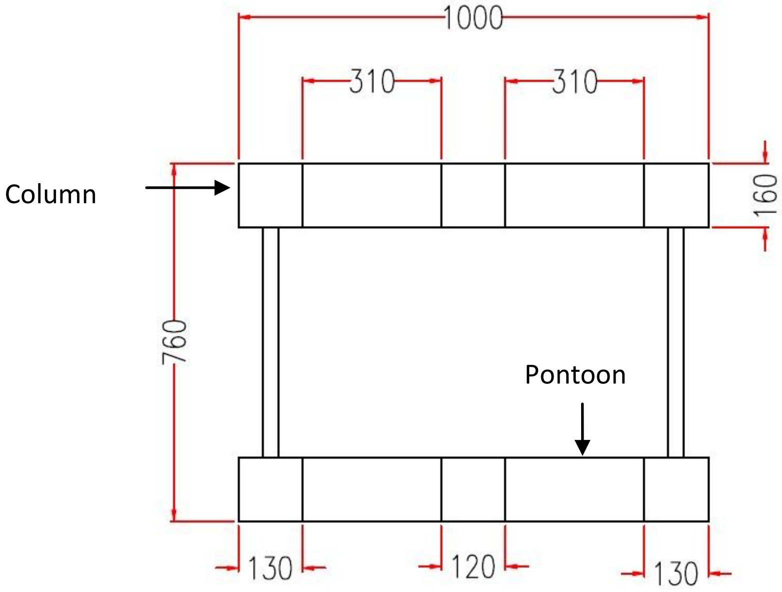


Figure 3.4 :Semi-submersible dimension (plan view)

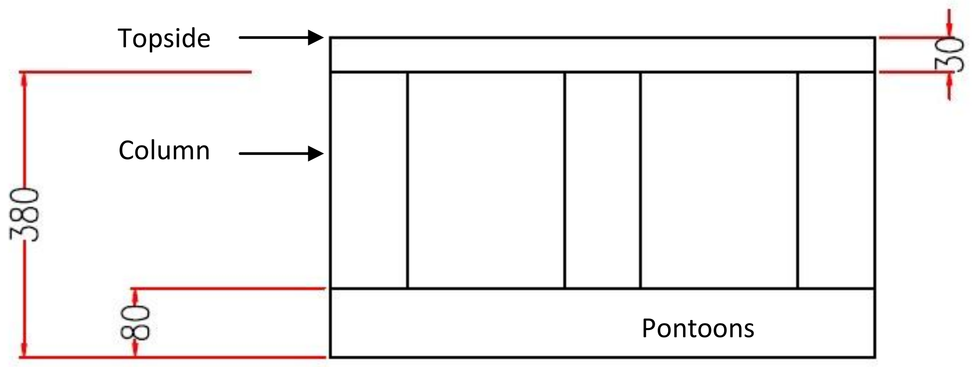


Figure 3.5 :Semi-submersible dimension (side view)

3.6 Experiment Studies

Static offset Test

Static offset tests were carried out to determine the mooring system stiffness. Load cells were attached to the downstream mooring lines.

Free Decay Test

The purpose of this test was to calculate the damping ratio and the natural periods of the system in surge, heave and sway.

Station Keeping Test : Waves

The objective of this test was to measure the platform motions subjected to regular waves.

3.7 Project Milestone

- Selection of the Project
- Literature Review
- Extended Proposal
- Proposal Defence
- Design and Fabrication of the Physical Models
- Experimental Studies
- Analysis of the Results
- Final Report

3.8 Experimental Configuration

3.8.1 Lashing Lines

The spar and semi-submersible were designed to be connected through four lashing lines. The lashings are symmetrical relative to longitudinal axis of the spar and semi-submersible, two on each side. One end of the lashings is connected to the spar through hooks located near the outer hull edge, while on the other end through hooks of semi-submersible. **Figure 4.1** and **Figure 4.2** below show the top and side views of connected lashing lines between spar and semi-submersible.

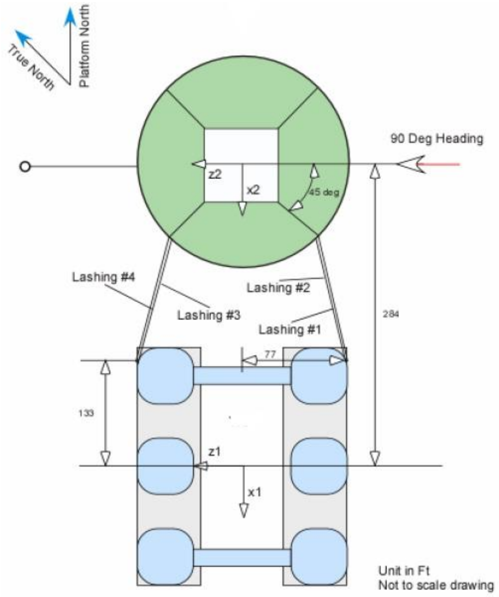


Figure 3.6 : Top view of lashing lines

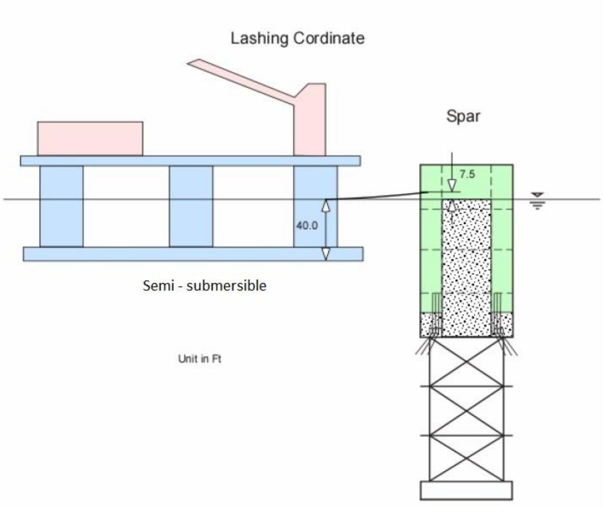


Figure 3.7 : Side view of lashing lines

3.8.2 Experimental Setup

In the experiment the models were subjected to regular waves and limited to long crested waves. The dynamic motions of the two floating platforms in the six degree of freedom and the tension in mooring line are measured. The mooring system is formed by 6 truncated mooring lines due to limitation of depth in the wave basin. Each tied to an anchor was fixed at the keel of the model to stabilize the spar from moving. The experiment was conducted in varies wave periods and wave heights according to the **Table 3.2** below. The behaviour of the truss spar and semi-submersible was recorded using video recorder in order to establish wave profiles of surge, heave and pitch obtained from the experiment.A wave probe is placed in the wave basin to record the wave profile. The videos are obtained from both cameras and the all the data is extracted from the videos. The readings from the wave probe are obtained from the technician and included in the result.Finally, a measurement of truss spar with semi-submersible that moored together is analysed and measured.

Table 3.2 : Regular Waves

Drive Signal	Wave Height (m)		Wave Period (s)	
	Target	Measured	Target	Measured
RG 1	0.1		1.0	
RG 2	0.1		1.2	
RG 3	0.1		1.4	
RG 4	0.1		1.6	
RG 5	0.1		1.8	
RG 6	0.1		2.0	

3.8.3 Configuration of lashing lines and mooring lines

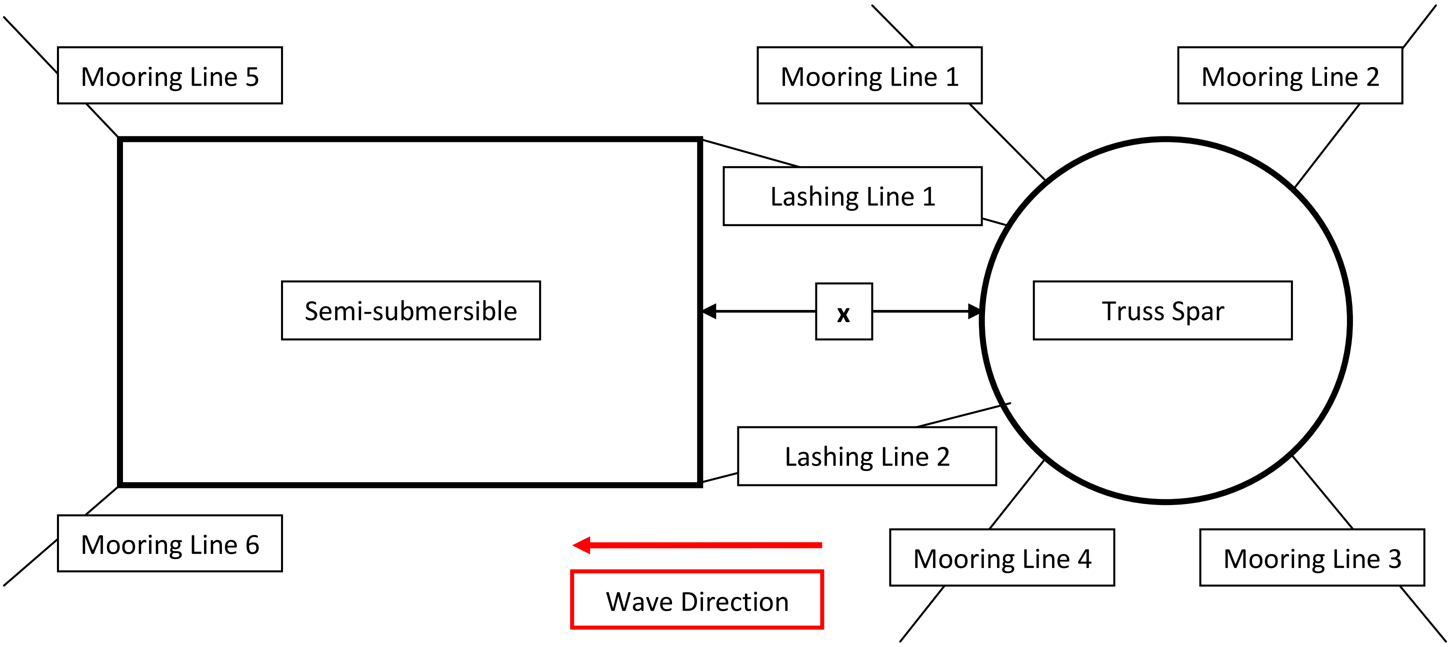


Figure 3.8 : Arrangement of mooring lines and lashing lines of truss spar and semi-submersible

Table 3.3 : Degree of mooring lines

Line	Angle (°)
1	120
2	60
3	300
4	240
5	150
6	210

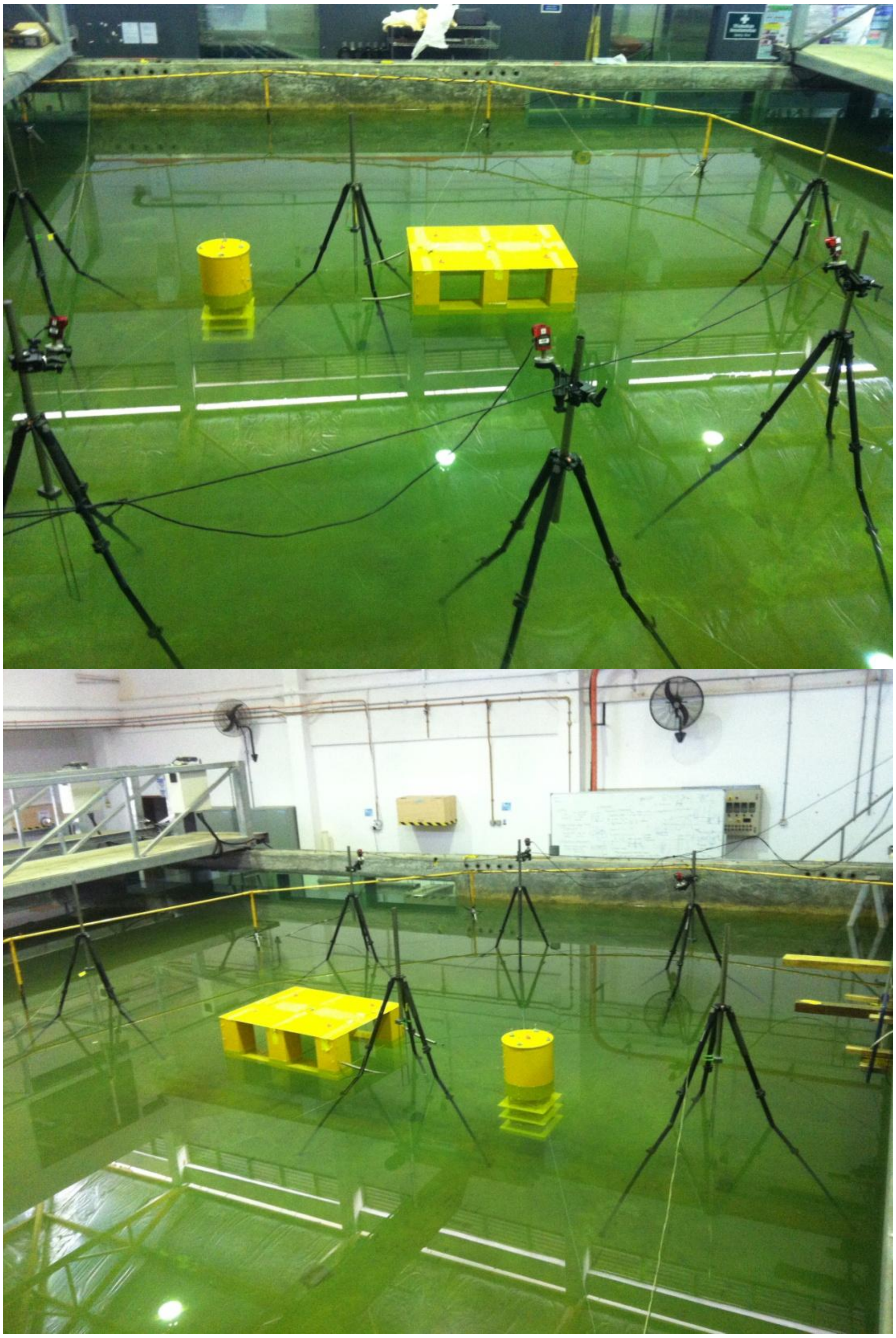


Figure 3.9 : Experimental setup in the offshore laboratory

3.8.4 Parametric studies

As throughout the experiment, there are two parametric studies need to be done which are the distance between truss spar and semi-submersible during consolidated mode and the height of lashing lines from mean water level. Both this studies need to undergo varies numbers to complete the parametric studies.

i) **Table 3.4,** Distance between truss spar and semi-submersible, **x** as in **Figure3.8**

Distance, x (m)
0.4
0.6
0.8
1.0

ii) **Table 3.5,** Height of lashing lines from mean water level.

Height of lashing lines from mean water level, H (cm)
14
21
28

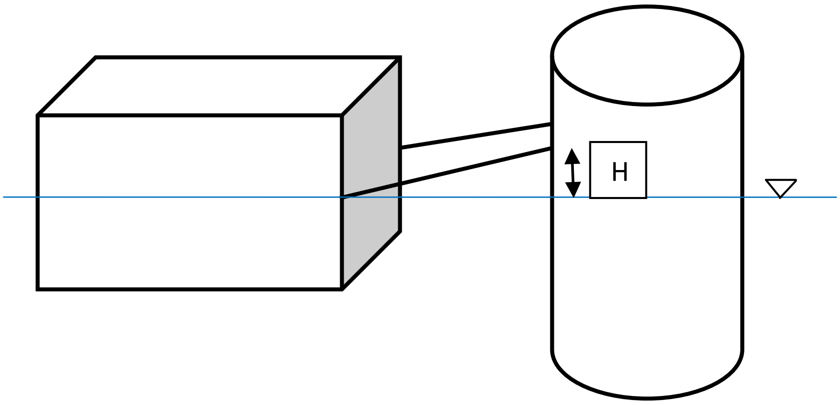


Figure 3.10 : Location of Lashing lines

3.9 Gantt Chart (FYP I)

Activities	**Week No/ Date**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Selection of Project Topic	■	■												
Literature Review/Survey		■	■	■	■									
Preparation of Extended Proposal			■	■	■	■								
Familiarize with existing techniques or framework				■	■	■								
Submission of extended proposal						■								
Project Work Continues							■	■	■	■				
Proposal Defence											■	■		
Design and Fabrication of the Physical Models													■	■
Submission of Interim Report														■
Experimental Studies	**FYP 2**													
Analysis of the Results														

3.10 Gantt Chart (FYP II)

Activities	**Week No/ Date**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**		**13**	**14**
Design of the Physical Models	■	■	■	■								**Raya Break**		
Fabrication of the Physical Models					■	■	■	■	■	■				
Submission of Progress Report							■							
Experimental Test													■	
Pre SEDEX											■			
Submission of Draft Final Report (Dissertation)													■	
Submission of Technical Report													■	
VIVA Presentation														■

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this chapter, the modeling of the structure, conversion from full scale to model scale, calculations are explained.

Based on Kikeh metaocean data for 100-year wave criteria by direction select the maximum reading of following below:

Dimension	Actual	Model Scale
Hs (m)	6.3	0.063
Tz (s)	8.1	0.81
Tp (s)	16.0	1.6
Hmax (s)	18.0	1.8

Table 4.1 : 100-year wave criteria by direction

To carry on with experimental study, must know the limitation of the offshore laboratory where;

Wave Height = up to 0.3m, Wave Period = as low as 0.5s

Thus, in the model scale, the result is wave height = 0.063 m wave period = 1.8 s. It satisfied the requirement in the lab.

4.2 Conversion from Full Scale to Model Scale

From Kikeh data for truss spar and Semi-submersible, need to follow the scaling of Froude model to scale down to model scale by using 1:100 ratio as mentioned before. Some modifications and assumptions were made to satisfy the model dimension.

Description	Prototype (ft)	Model (m)
Diameter	98	0.30
Draft	214	0.65
Freeboard	60	0.30
Total Length	330	0.95
Hard Tank Height	148	0.45
Soft Tank Height	26	0.05
Soft Tank Length	115	0.30
Truss Length	180	0.45
Heave Plates	115 x 115	0.30 x 0.30
Heave Plates Thickness	3.3	0.01
Truss height (each section)	51.17	0.156
Truss diameter	1.64	0.005

Table 4.2: Spar Dimension

4.2.1 Calculation for the design of the experimental model, Table 4.3

Symbols Used	
dr	Draft

Input Data			
S.No.	**Legend**	**Unit**	**Value**
1	Diameter of the hull	cm	30.00
2	Height of the hull	cm	45.00
3	No. of heave plates	no.	2
4	Size of heave plates and soft tank	cm	30.00
5	Diameter of vertical member in truss	cm	1.00
6	Diameter of inclined member in truss	cm	1.00
7	Length of vertical member in truss	cm	180.00
8	Spacing of heave plates	cm	15.00
9	Depth of heave plates	cm	0.30
10	Depth of soft tank	cm	5.00
11	Thickness of the hull	cm	0.15
12	Thickness of the soft tank wall	cm	0.20
13	Density of the material	g/cc	7.85
14	Density of the fluid	g/cc	1.00
Calculations			
S.No.	**Legend**	**Unit**	**Value**
1	Initial calculations		
	Total length of the spar	cm	95.00
	Length of inclined truss member	cm	21.21
2	Weight of the model		
	Hull	g	5000
	Truss members	g	2000
	Heave plate	g	4300
	Soft tank	g	3800
	Additional Weight	g	2500
	Total	g	17800
3	Weight of the fluid displaced	g	707.14
4	Draft(dr)	cm	15

*dr

Take 15 cm

Descriptions	Prototype	Model
Pontoon Length	100m	1000mm
Pontoon Width	16m	160mm
Pontoon Height	8m	80mm
Centre Column Length	12m	120mm
Centre Column Width	16m	160mm
Centre Column Height	30m	300mm
Side Column Length	13m	130mm
Side Column Width	16m	160mm
Side Column Height	30m	300mm
Topside Column Length	100m	1000mm
Topside Column Width	76m	760mm
Topside Column Height	3m	30mm

Table 4.4 :Semi-submersible Dimension

4.2.2 Calculation of centre of gravity and buoyancy, for Truss Spar

Centre of Gravity (COG)

Take 15.3 kg as the total weight of the truss spar

Hull, 5 kg * 0.225 m = 1.125 kg.m

Truss, $\left[\frac{2.2}{3}\ kg * 0.525\ m + \frac{2.2}{3}\ kg * 0.675\ m + \frac{2.2}{3}\ kg * 0.825\ m = 1.4843\ kg.m\right]$

Heave, $\left[\frac{4.3}{2}\ kg * 0.600\ m + \frac{4.3}{2}\ kg * 0.750\ m = 2.9025\ kg.m\right]$

Soft, 3.8 kg * 0.925 m = 3.515 kg.m

Thus COG = $\frac{1.125 + 1.4843 + 2.9025 + 3.515\ kg.m}{15.3\ kg} = 0.5899\ m \approx 590\ mm$

Centre of Buoyancy (COB)

Draft = 0.15 m

$W = \pi r^2 * 1000 * 0.15\ \text{m} = 15.55\text{kg}$

Hull, $15.55\ kg * \frac{0.15}{2}\ m = 1.7105\ kg.m$

Truss,
$\left[\frac{0.276}{3}\ kg * 0.295\ m + \frac{0.276}{3}\ kg * 0.445\ m + \frac{0.276}{3}\ kg * 0.595\ m = 0.1228\ kg.m\right]$

Heave, $\left[\frac{0.54}{2}\ kg * 0.370\ m + \frac{0.54}{2}\ kg * 0.520\ m = 0.2403\ kg.m\right]$

Soft, 0.48 kg * 0.695 m = 0.3336 kg.m

Thus COB = $\frac{1.7105 + 0.1228 + 0.2403 + 0.3336\ kg.m}{16.85\ kg} = 0.143\ m \approx 143\ mm$

COG – COB = 447 mm

4.3 Motion Responses of Wave Profile

4.3.1 Parametric Study on Distance of Truss Spar and Semi-Submersible

From here onwards, laboratory result shows the Response Amplitude Operator (RAO) against Frequency graphs on six degree of motions consist of Surge, Heave, Sway, Yaw, Pitch and Roll. Response spectra were obtained in terms of RAO which is given as

$$RAO = S_R(f)\ /\ S(f) \qquad \text{Equation (4.1)}$$

Where S_R (f) is motion response spectrum, S (f) = wave spectrum, f = wave frequency

At first, distance 0.8 m is included in the parameter but unfortunately all the results were very poor due to configuration or setup of the experiment. From the author’s observation, the motion of responses is decreased when the frequency is increased.

For translation motions, surge in 1.0 m distance gives the highest effect of motion other than 0.4 m and 0.6 m. For heave, all distance give almost the same effect. While sway, the effect of the motions varies from each distance and the highest most likely is distance 0.4 m.

Moving on to rotation motions, yaw and roll give bad result due to opti-track did not record the motions of platforms because does not in the range of cameras view. For pitch, the effect of the motions almost the same but distance 0.4 m gives the highest effect of motions than 0.6 m and 1.0 m

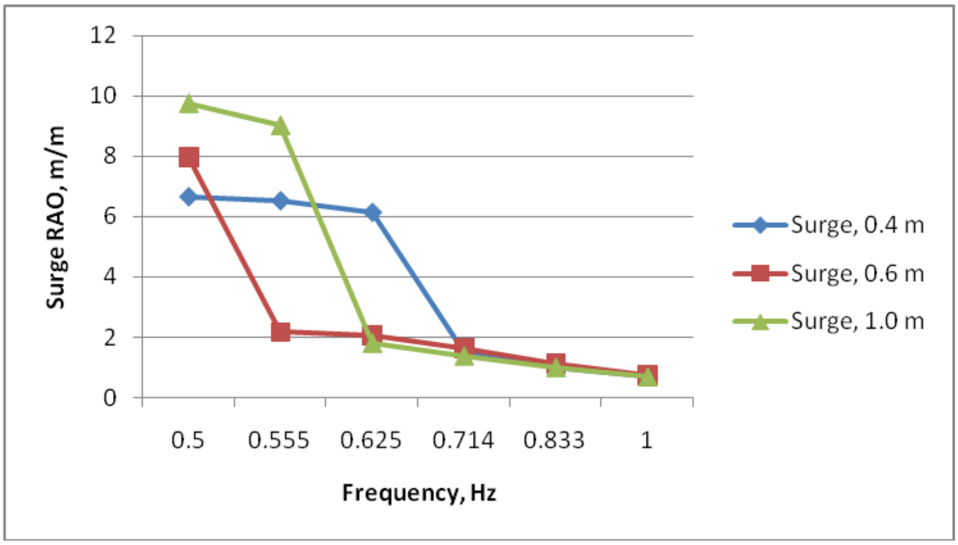


Figure 4.1 : Surge Motion RAO

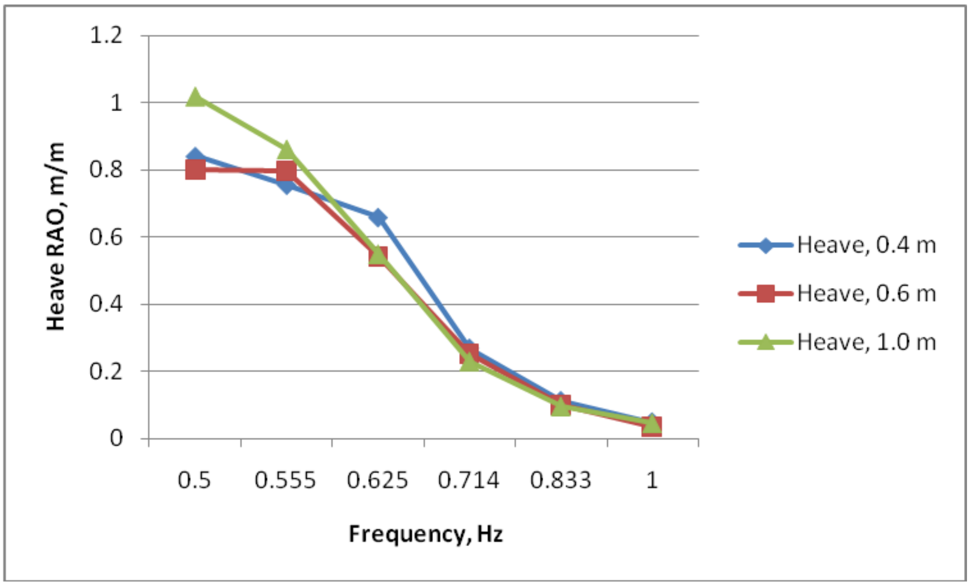


Figure 4.2 : Heave Motion RAO

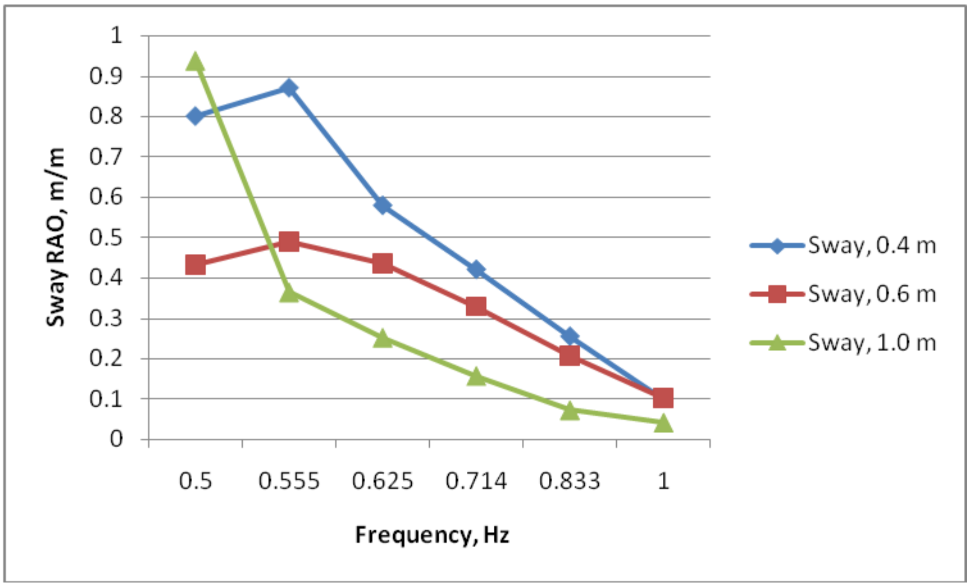


Figure 4.3 : Sway Motion RAO

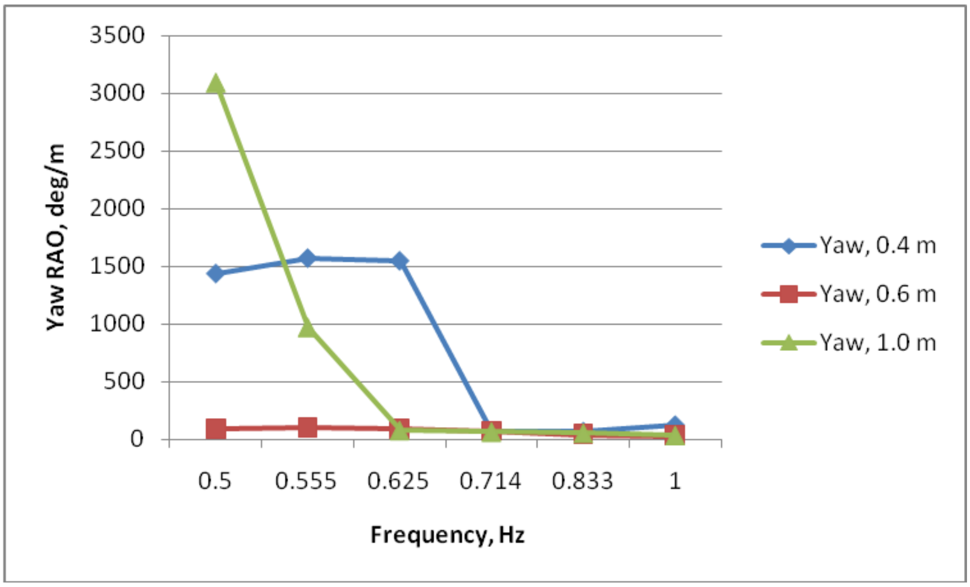


Figure 4.4 : Yaw Motion RAO

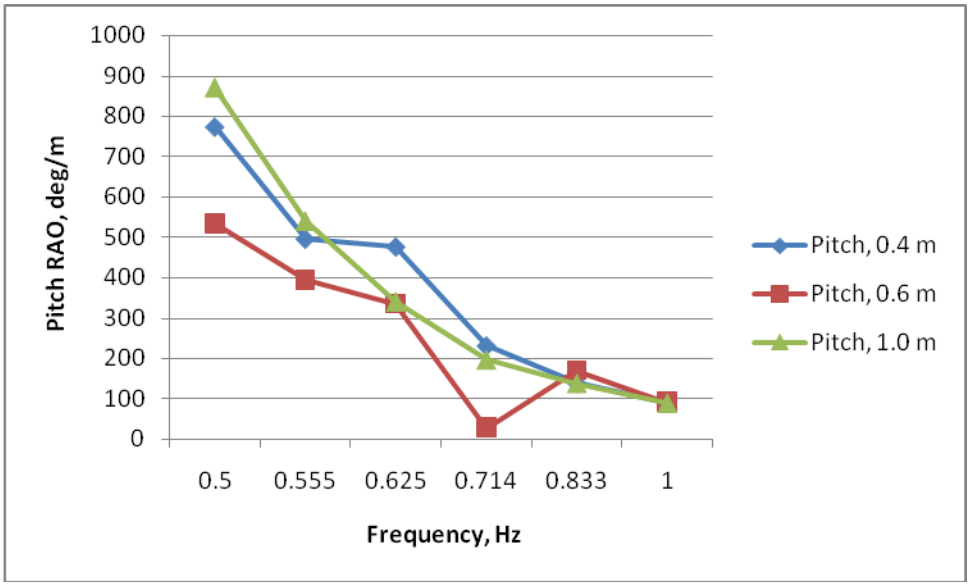


Figure 4.5 : Pitch Motion RAO

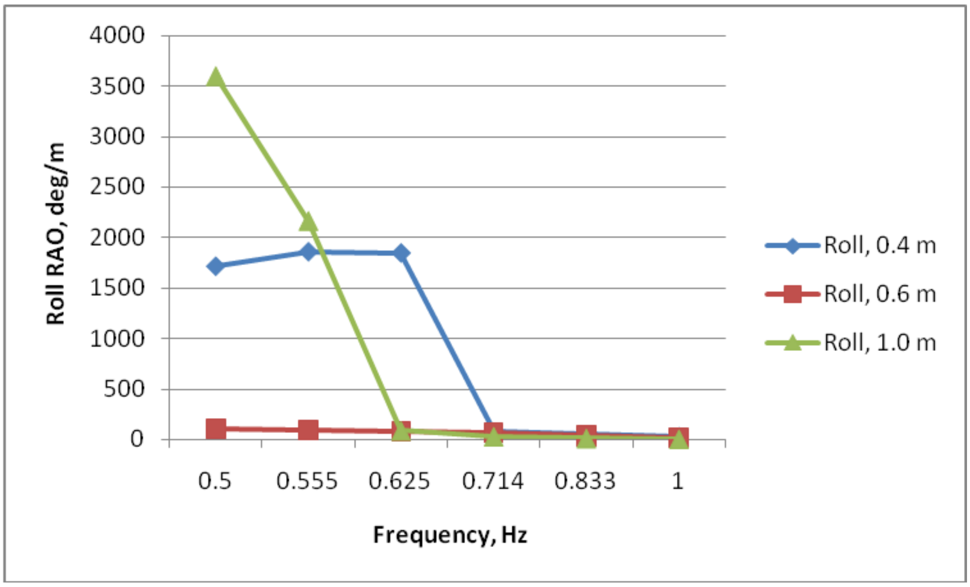


Figure 4.6 : Roll Motion RAO

4.3.2 Parametric study on Height of Lashing Lines

As figures below shows the motion responses of parametric study on the height of lashing lines. Same as first parametric study, the motion of responses is decreased when the frequency is increased. As the position of lashing lines is increased, the effect of translation motions such as surge, heave and sway do not make any difference but it does affect the motion of rotational (yaw, pitch and roll). From the result, as the height of lashing lines increased, the effect of motion of yaw, pitch and roll are also increased. In addition all the Lashing Line 3 in yaw, pitch and roll motions give the highest reading as wave is generated.

For translation motions, author concluded that, surge give the highest responses than heave and sway motions. As for surge motion, when the wave is generated and hit the structures, the responses do not make any difference when the height of lashing lines is increased. While heave and sway make responses after being hit by waves while increasing the height of lashing lines. For heave, the Lashing Line 2 gives the highest response while in sway, Lashing Line 3 gives the highest response. Some of the results are not well measured due to circumstances such as when the opti-track did not record the motions of platforms because not in the range of cameras view.

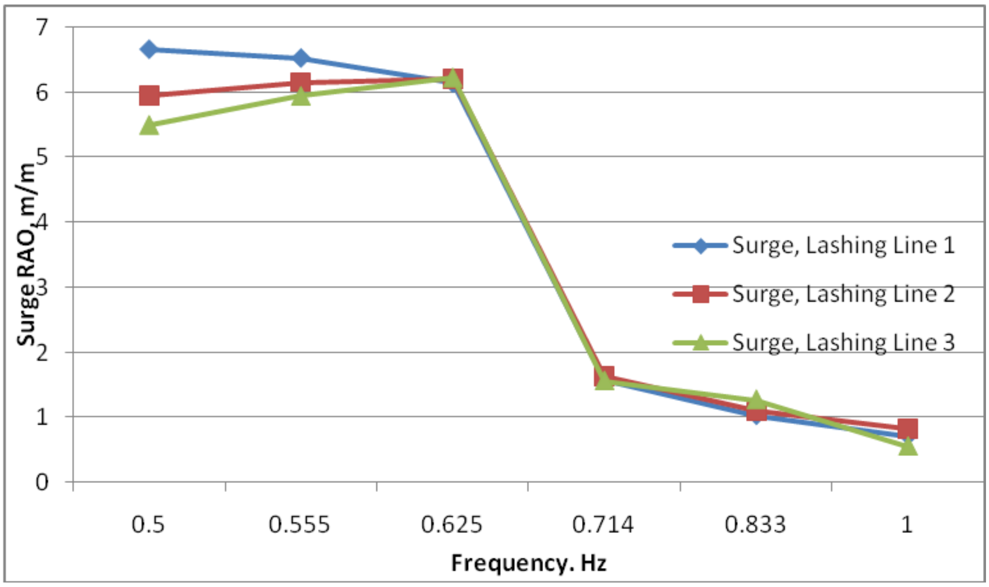


Figure 4.7 : Surge Motion RAO

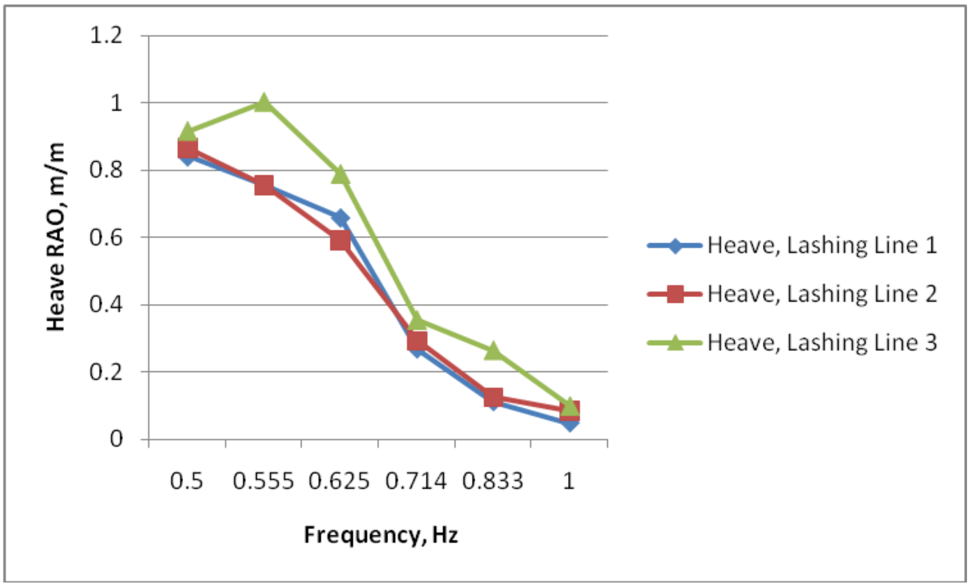


Figure 4.8 : Heave Motion RAO

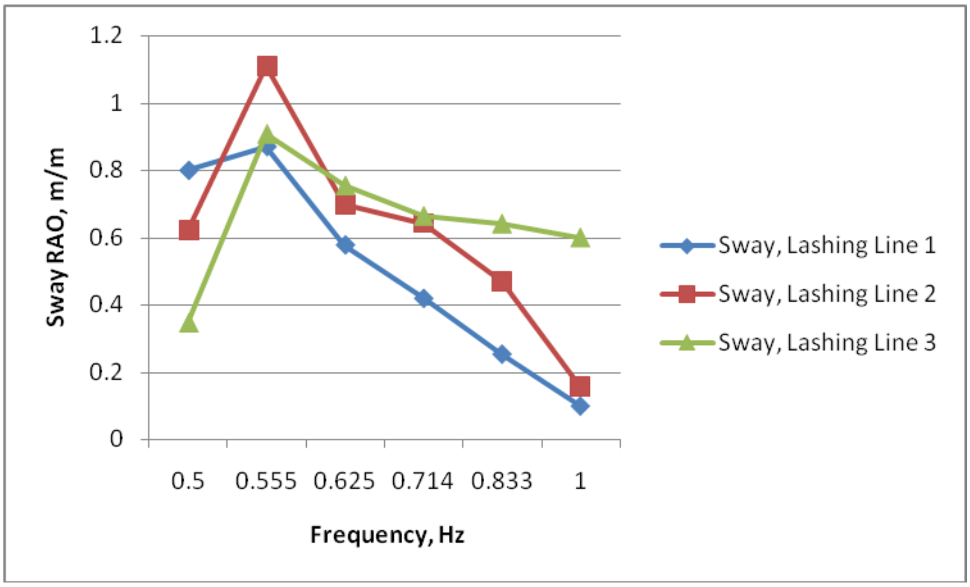


Figure 4.9 : Sway Motion RAO

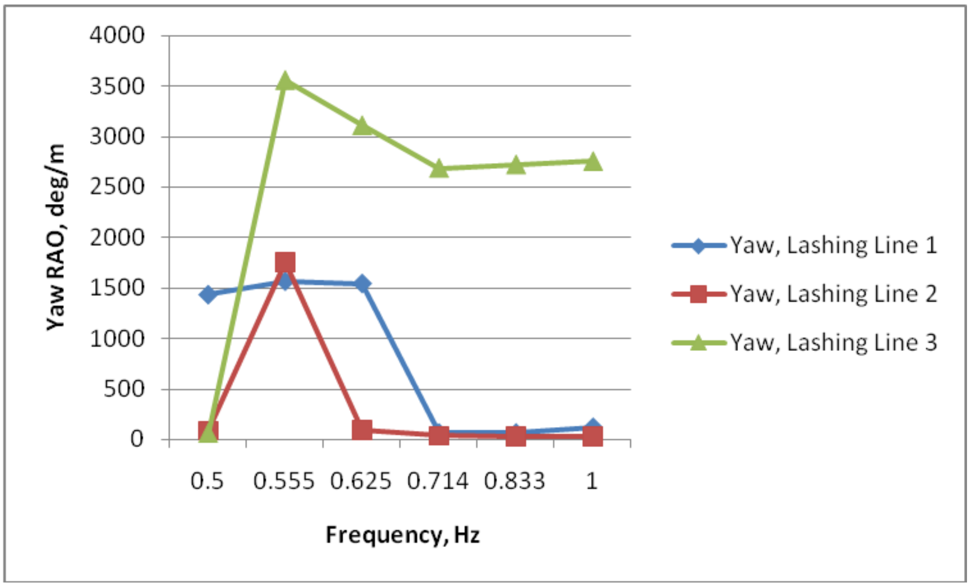


Figure 4.10 : Yaw Motion RAO

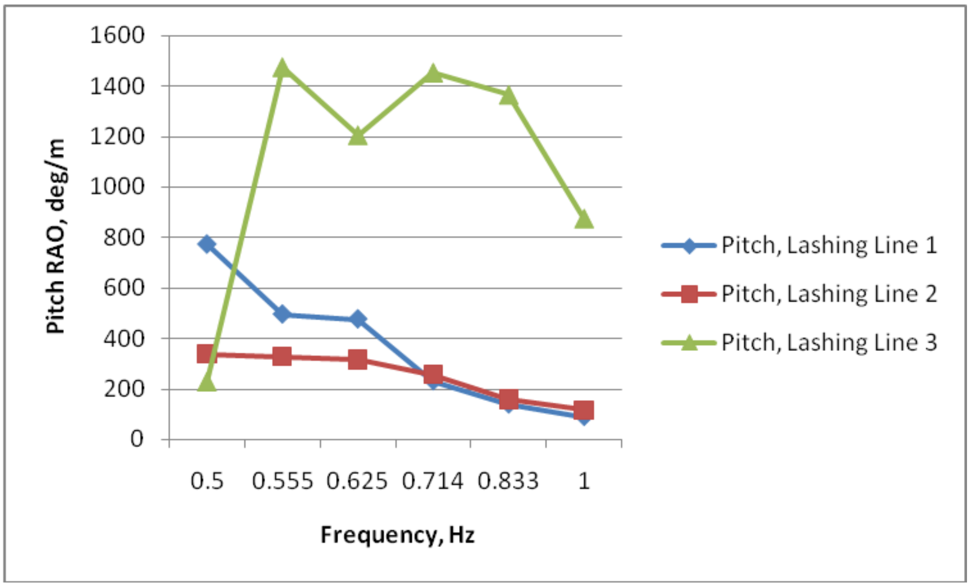


Figure 4.11 : Pitch Motion RAO

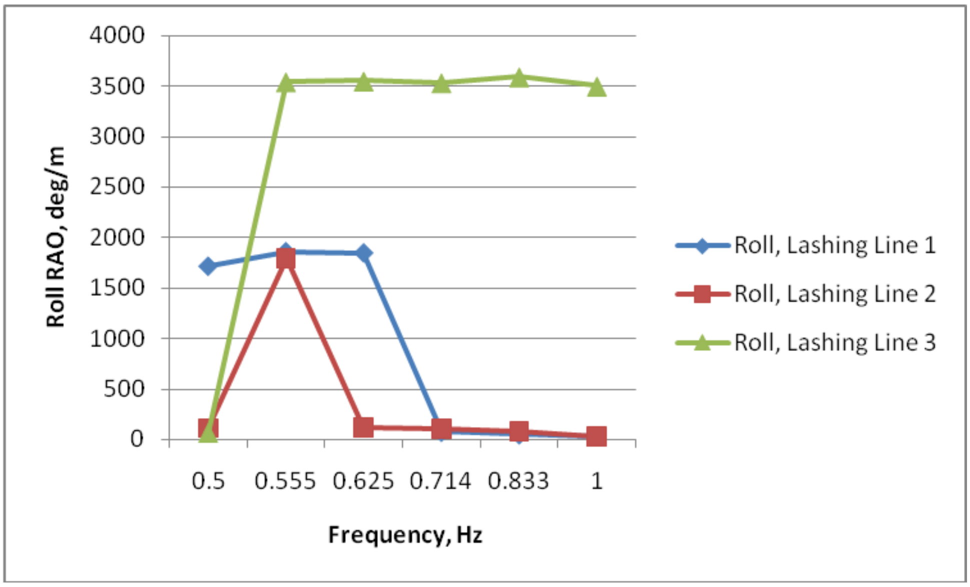


Figure 4.12 : Roll Motion RAO

4.4 Wave Test Results

Table 4.5 summarizes the target and measured regular waves which were used for the sea-keeping experiments. Six waves were selected in a way that the differences frequency of the wave component approaches the considered natural frequency of the system.

Table 4.5 : Regular Waves Result

Drive Signal	Wave Height (m)		Wave Period (Hz)	
	Target	Measured	Target	Measured
RG 1	0.1	0.11	1	1
RG 2	0.1	0.12	1.2	1.2
RG 3	0.1	0.07	1.4	1.4
RG 4	0.1	0.11	1.6	1.6
RG 5	0.1	0.12	1.8	1.8
RG 6	0.1	0.13	2	2

Table 4.6 : Comparison wave height at the between of truss spar and semi-submersible and away from platforms

Wave Frequency , Hz	Wave Height between TS & SS (mm)	Wave Height away from platforms (mm)
0.5	5.93715	5.11746
0.555	5.9619	5.9347
0.625	6.0274	5.8259
0.714	5.54785	4.9252
0.833	5.30631	4.5983
1	5.46225	4.5976

As **Table 4.6** above, the author can concluded that the wave height at the between two platforms is higher than the further from platforms. This is due to the effect of one platform to another platform subjected to regular waves. In addition, the area between truss spar and semi-submersible increase the wave acceleration that caused the incremental of the wave height.

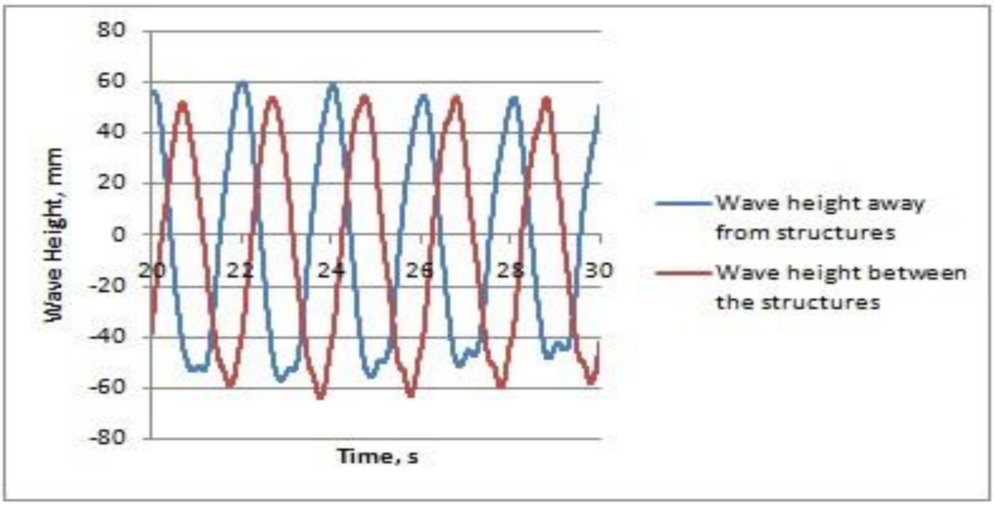


Figure 4.13: Comparison of wave heights at the between of truss spar and semi-submersible and away from platforms

4.5 Static Offset Result

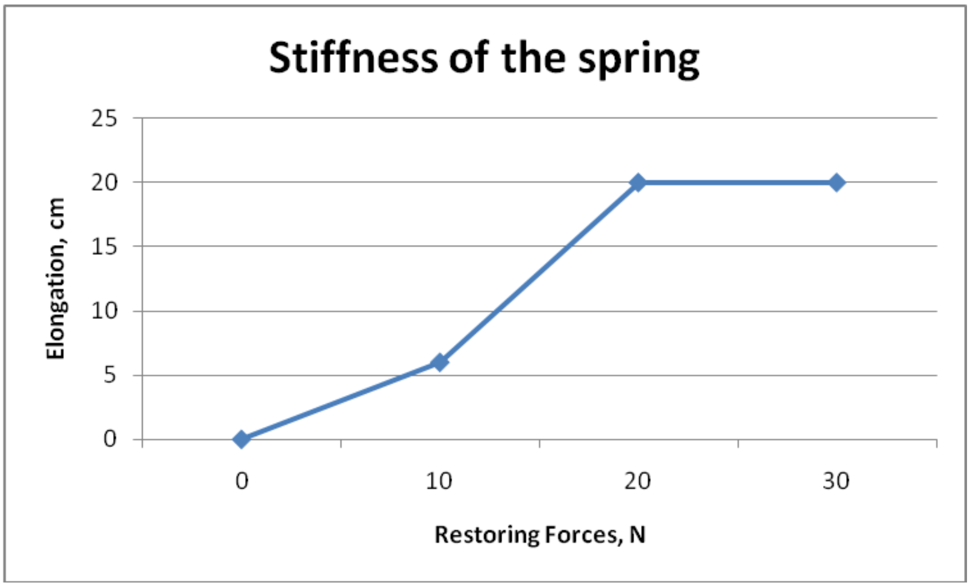


Figure 4.14 : Stiffness of the spring

Soft springs were used to represent mooring lines system.. From the static offset test, it can be concluded that the stiffness of the spring can sustain the weight up to 2 kg.

4.6 Free Decay Result

From the free decay tests, it can be concluded that the natural period of the truss spar is about 60 seconds.

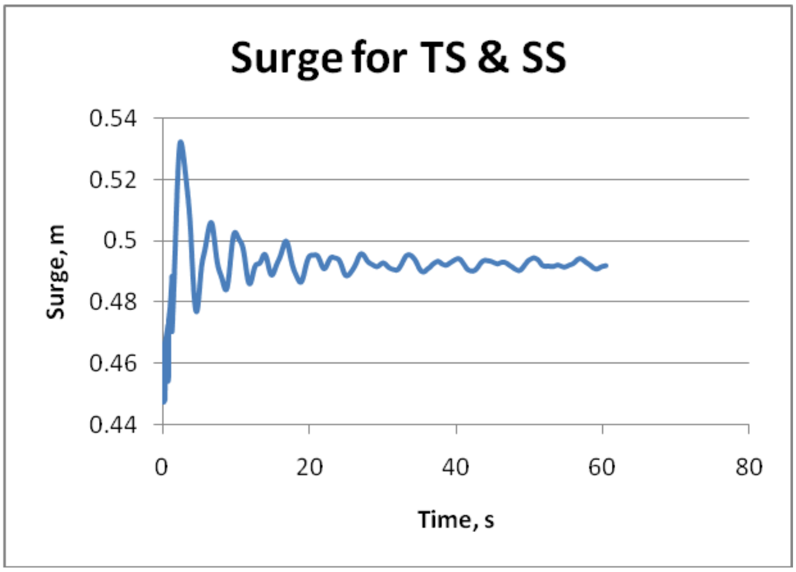


Figure 4.15 : Surge free decay results for TS & SS

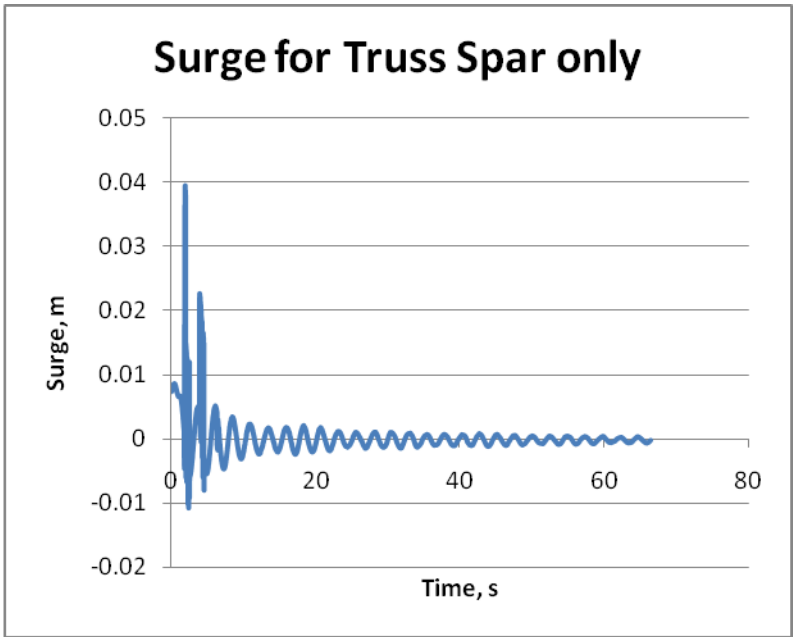


Figure 4.16 : Surge free decay results for truss spar only

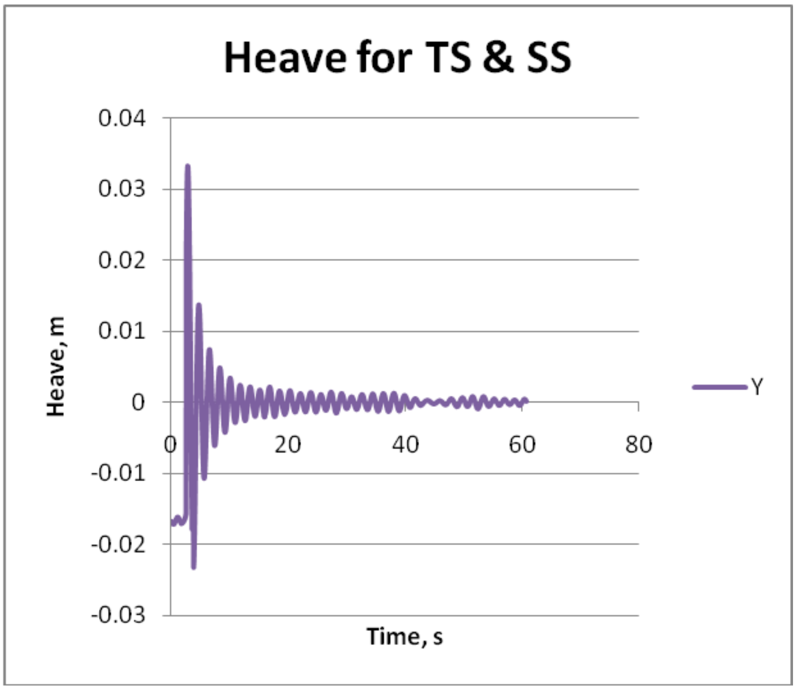


Figure 4.17 : Heave free decay results for TS & SS

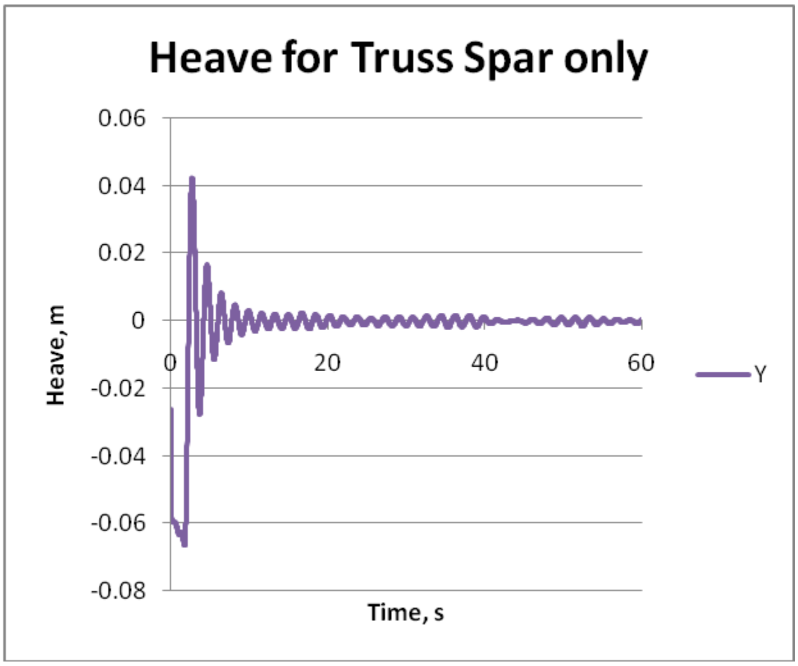


Figure 4.18 : Heave free decay results for truss spar only

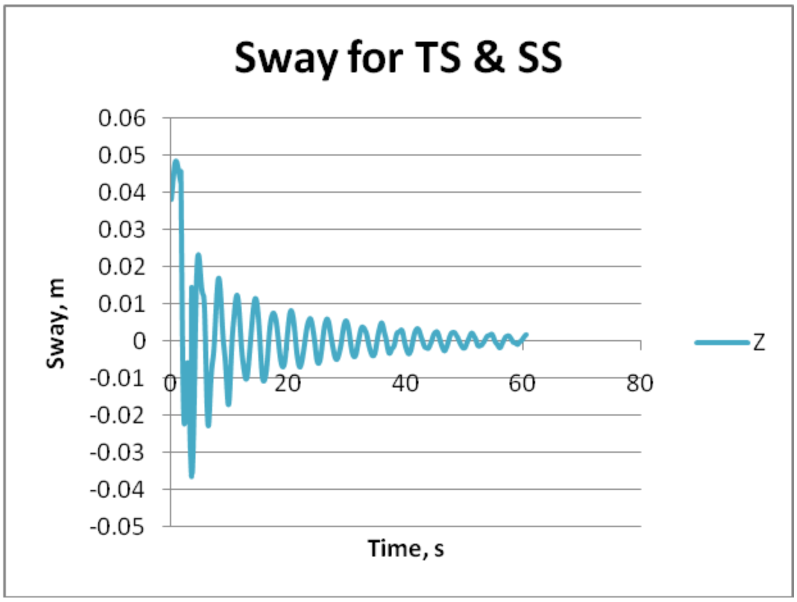


Figure 4.19 : Sway free decay results for TS & SS

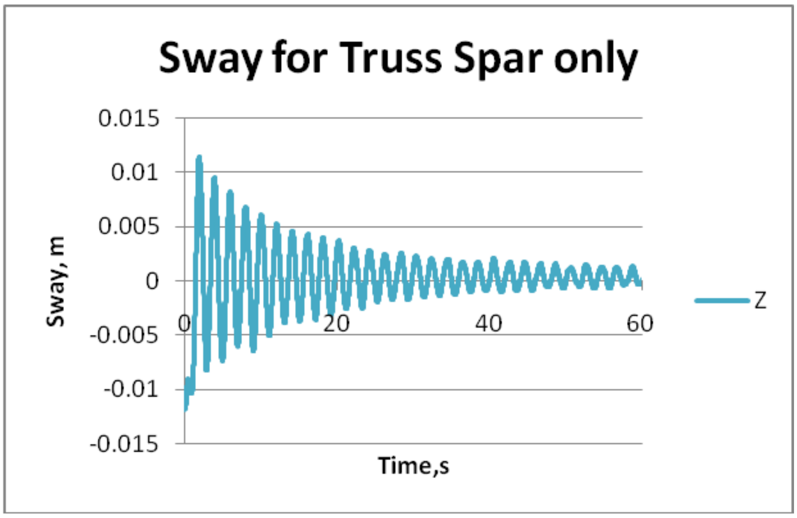


Figure 4.20 : Sway free decay results for truss spar only

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

As conclusion, throughout FYP I and II, all the project flow from literature survey to result and discussion is shown. All the calculation for design of fabrication of models (truss spar and semi-submersible) are calculated in previous chapter.In case of water flow with a free surface, the gravitational effects predominate. The effect of other factors, such as viscosity, surface tension, roughness is generally small and can be neglected. In this case, Froude's model law is most applicable. A scale factor 1:100 is used to scale down the prototype to model scale..During the experiment, three tests will be conducted which are static offset, free decay and station keeping tests. The value of centre of gravity and centre of buoyancy of truss spar are 590 mm and 143 mm respectively, and the calculation is shown in the previous chapter. Two parametric studies is conducted during the experiment which are first, the distance between truss spar and semi-submersible and second, height of lashing lines from mean water level. The mooring lines configuration and experimental setup is presented in the previous chapter. The spar and semi-submersible is moored by 6 mooring lines and attached with 2 lashing lines connected to each other. The data for wave period, wave height is presented and extracted from Kikeh's metaocean data and used in the experiment. The objectives of this study are achieved that is to measure the dynamic motions of the connected truss spar and semi-submersible subjected to regular waves and to examine the effect of the motion of one floating platform on other floating platform.

Due to many limitations and inaccuracy of the results obtain in this research, the author manage to come out with few recommendation for further improvement in the dynamic analysis and future work, as stated below. For further improvements:

- The long-crested (unidirectional) waves should be replaced with short-crested (multidirectional) waves direction in order to provide a better analysis for the spar. Consideration of all part of the spar is important since it will have a global impact for the spar responses at the end of the study.
- Focus more on the lashing lines that connected truss spar and semi-submersible. Gain more data about the lashing lines from KIKEH or any other project.
- For further research, it is recommended to compare the obtained responses to other type of spar in order to get a clear picture of the advantages and disadvantages of all three types of spar.
- Due to time constraint, for further research, can make a comparison between the responses of truss spar and semi-submersible that moored together with truss spar only.
- The steel ring in the laboratory is need to be fixed or replaced with the new one since the current steel ring is not in fixed position when the test is run. Thus will affect the result of the experiment.

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APPENDICES

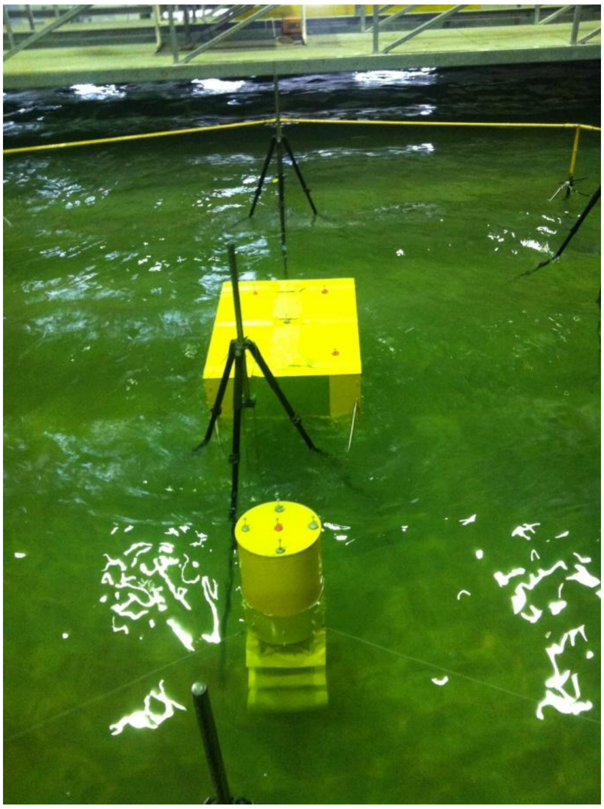

Figure 6.1 : Models are subjected to regular waves

Figure 6.2 : The author is setting up the models