Experimental Studies On The Optimum Configuration of Mooring Line for Truss Spar Platform

Final Report

By

Mohd Fazran Hakin Bin Faddzal

16759

Bachelor of Engineering (Hons)

(Civil Engineering)

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Supervise by: Dr Montasir Osman Ahmed Ali

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

____

(Dr. Montasir Osman Ahmed Ali)

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

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.

Mohd Fazran Hakin Bin Faddzal

25th August 2015

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ABSTRACT

Cost optimization is can be consider as main aspect on the offshore structure project. It is crucial to find the best options of mooring configuration for a certain platform and metocean data. The main objective of this field of work is to reduce the dynamic response of the offshore structure as a whole. In this paper, optimum configuration study is based on two design parameters which are pretension load and azimuth angle. The motion response analysis of the platform is modelled on a truss spar, as a rigid body with six degree of freedom. Froude's Law is used to convert the responses of the platform model into the actual scale (prototype scale). However, notice that Froude's Law models do not scale all the parameters, it only applicable predominant factor in scaling system in wave mechanics, namely inertia.

This study presents the literature review and experimental methodology obtained from the physical model tests carried out with two different parameters of design variables. An experimental study by wave tank test has been performed in order to quantify the dynamic response of the truss spar platform subjected to regular and random waves. A model truss spar platform which is fabricated by steel plate with 1:100 ratio scales from the prototype is used in the study of optimum configuration for mooring lines. In wave tank, regular and random wave were generated by wave generator. Wave probe recorded the wave profile and the motion of the truss spar was captured by Qualisys Track Manager in six degree of freedom. There are three test were conducted which are static offset test, free decay test and sea keeping test. The results were presented in term of Response Amplitude Operator (RAO) in six degree of freedom. In summary, generally, the higher pretension has given lesser motion in term of RAO and the symmetric configuration for azimuth angle significantly can reduce the dynamic motion of truss spar platform as a whole.

CONTENTS

CERTIFICATION OF APPROVAL i
CERTIFICATION OF ORIGINALITY ii
ACKNOWLEDGEMENT iii
ABSTRACT iv
LIST OF EQUATION vii
LIST OF FIGURES viii
LIST OF TABLES x
CHAPTER 1 1
1.1 Chapter Overview 1
1.2 Background of the Research 1
1.3 Problem Statement 4
1.4 Objectives of the Research 5
CHAPTER 2 6
LITERATURE REVIEW 6
2.1 Chapter Overview 6
2.2 Spar Platform 6
2.2.1 Dynamic Responses of Truss Spar Platform 7
2.3 Mooring Line 8
2.3.1 Mooring Line Design Variables 9
CHAPTER 3 11
EXPERIMENTAL PROCEDURE / METHODOLOGY 11
Chapter Overview 11
3.1 Froude's Law 11
3.2 Scaling of a Froude Model 12
3.3 Experiment Studies 14
3.3.1 Experimental Setup 15
3.4Test Facilities 17
3.5 Wave Test 17
3.5.1 Data Analysis 19
3.5.2 Presentation of Results in Response Amplitude Operator 19
3.6 Project Timeline and Key Project Milestones 20
3.7 Parametric Studies 22

CHAPTER 4 25
RESULT AND DISCUSSION 25
4.1 Conversion from Full Scale to Model Scale 25
4.1.1 Calculation of centre of gravity and buoyancy, for Truss Spar 27
4.2 Motion Responses of Wave Profile (Regular waves) 28
4.2.1 Parametric Study on Pretension of mooring lines of Truss Spar 28
4.2.2 Parametric Study on Azimuth Angle of mooring lines of Truss Spar 32
4.3 Motion Responses of Wave Profile (Random waves) 36
4.3.1 Parametric Study on Pretension of mooring lines of Truss Spar 36
4.3.2 Parametric Study on Azimuth Angle of mooring lines of Truss Spar 40
4.3 Static Offset Result 44
4.4 Free Decay Result 46
4.4.1 For Pretension parameter 46
4.4.2 For Azimuth Angle parameter 47
4.5 Wave Test Results 48
CHAPTER 5 49
CONCLUSION & RECOMMENDATIONS 49
REFERENCES 51
APPENDICES 54

LIST OF EQUATION

Equation 3.1 Froude’s Law……………………………………………………21

Equation 4.1 Response Amplitude Operator (RAO)………………………..38

LIST OF FIGURES

Figure 1.1 Different design of the spar platform………………………………….2

Figure 1.2 Components of a truss spar platform..3

Figure 1.3 An example of mooring lines connected to a floating platform……..…3

Figure 3.1 Dimension of the truss spar model……………………………………..15

Figure 3.2 Actual model truss spar platform………………………………………15

Figure 3.3 Arrangement of ’12 side-ring’, mooring lines, load cells and
wave generator...16

Figure 3.4 Current arrangements at the UTP Offshore Laboratory………………..16

Figure 4.1 Surge Motion RAO for pretension (regular)…………………………..…29

Figure 4.2 Heave Motion RAO for pretension (regular)………………….………29

Figure 4.3 Sway Motion RAO for pretension (regular)……………….…………..30

Figure 4.4 Roll Motion RAO for pretension (regular)…………………………….30

Figure 4.5 Pitch Motion RAO for pretension (regular)…………………………....31

Figure 4.6 Yaw Motion RAO for pretension (regular)……………………..…...31

Figure 4.7 Surge Motion RAO for azimuth angle (regular)…………….………...33

Figure 4.8 Heave Motion RAO for azimuth angle (regular)………...………….......33

Figure 4.9 Sway Motion RAO for azimuth angle (regular)…………………….…34

Figure 4.10 Roll Motion RAO for azimuth angle (regular)……………………….34

Figure 4.11 Pitch Motion RAO for azimuth angle (regular)………………… …...35

Figure 4.12 Yaw Motion RAO for azimuth angle (regular)…………….……...35

Figure 4.13 Surge Motion RAO for pretension (random)…………………..…….37

Figure 4.14 Heave Motion RAO for pretension (random)……………….…….37

Figure 4.15 Sway Motion RAO for pretension (random)………………………...38

Figure 4.16 Roll Motion RAO for pretension (random)…………………………..38

Figure 4.17 Pitch Motion RAO for pretension (random)…………………………...39

Figure 4.18 Yaw Motion RAO for pretension (random)……………………………39

Figure 4.19 Surge Motion RAO for azimuth angle (random)……………………41

Figure 4.20 Heave Motion RAO for azimuth angle (random)……………………41

Figure 4.21 Sway Motion RAO for azimuth angle (random)……………………..42

Figure 4.22 Roll Motion RAO for azimuth angle (random)………………………42

Figure 4.23 Pitch Motion RAO for azimuth angle (random)……………………..43

Figure 4.24 Yaw Motion RAO for azimuth angle (random)……………………...43

Figure 4.25 Stiffness of mooring line for Surge…………………………………...44

Figure 4.26 Stiffness of mooring line for Heave…………………………………44

Figure 4.27 Stiffness of mooring line for Sway……………………………….....45

Figure 6.1 Experimental setup……………………………………………….....54

Figure 6.2 Author is setting up the models……………………………………......54

LIST OF TABLES

Table 3.1 Model of prototype multipliers (Source : Offshore Structure Modeling,(Chakrabarti, 1994)………………………………………….............12

Table 3.2 Wave Test Characteristics…………………………………………..18

Table 3.3 Project Timeline and Key Project Milestones for FYP 1……………..20

Table 3.4 Project Timeline for FYP 2…………………………………………...21

Table 3.5 Pretension of mooring lines…………………………………………...22

Table 3.6 Azimuth angle (Degree of mooring lines)…………………………….22

Table 4.1 Spar Dimension……………………………………………………..35

Table 4.2 Calculation for the design of the experimental model……………...…36

Table 4.3 Free Decay Parameter for Pretension Parameter……………………...56

Table 4.4 Free Decay Parameter for Azimuth Angle Parameter………………...57

Table 4.5 Regular Waves Result (from wave probe)……………………………...58

CHAPTER 1
INTRODUCTION

1.1 Chapter Overview

In this chapter, the background pertaining to this research study giving an overview of spar platforms and mooring line, discussed on the background of study, problem statement, and scopes of study. The problem statements are focusing on the situation of the problem and research questions, which lead to the objectives of the study.

1.2 Background of the Research

Generally, there are two categories of offshore platforms designed for oil and gas exploration and production activity which are the fixed platforms and floating platforms. Jacket platform, Gravity Based Structure (GBS) and Compliant Tower are the examples of fixed platforms. Meanwhile, floating platforms including Tension Leg Platform (TLP), Semi-Submersible, Spar Platform and Floating, Production, Storage and Offloading (FPSO).

In oil and gas industry, it is acknowledged that the application of spar platform is economical and efficient. This type of floating offshore structure is commonly used in ultra-deep water region. Spar platform is among the largest platforms in new generation of drilling platforms. It consist of large vertical that supporting the deck of the platform. The vertical cylinder is tethered by mooring lines in the mean of cables and lines to the seafloor as well as to stabilizes platform and allow movement to absorb environmental load impacts.

There are features that commonly on spar platform, named hull which is act as protection for the riser as well as provide storage for the produced oil and gas. As depicted in the Fig. 1.1, spar platform to-date is designed in three configurations: classic/conventional spar, truss spar and cell spar.

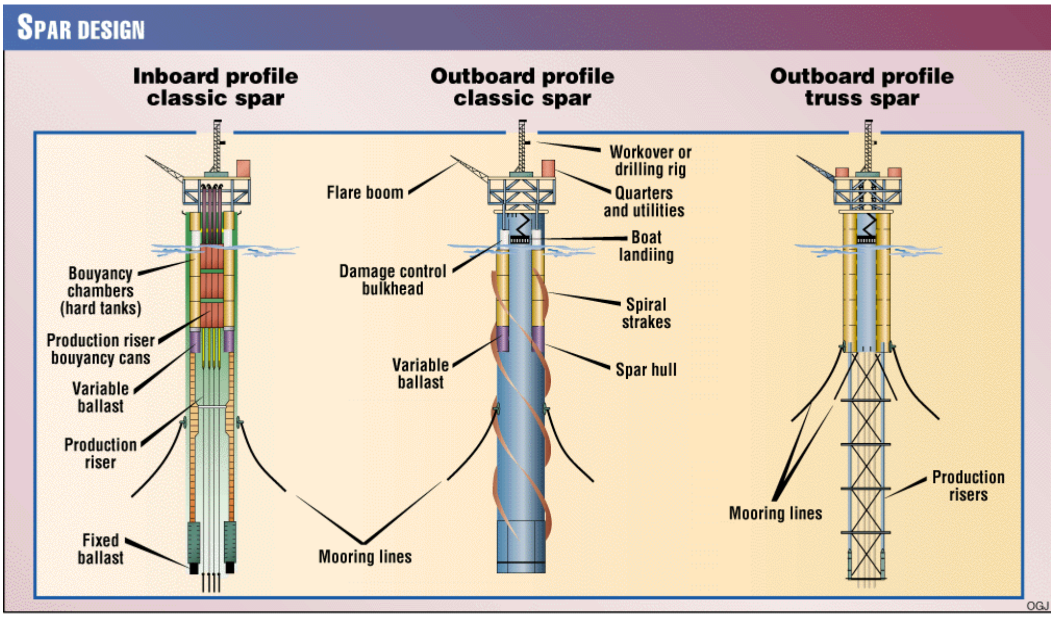


Figure 1.1: Different design of the spar platform (L.C Skaug , 1998)

Among the spar configurations mentioned in Fig. 1.1, the truss spar is considered more suitable because the cylindrical hull is shorted and thus, making the platform weigh less, the centre of buoyancy and centre of gravity integrate better stability than classic spar. These features reduce the material as well as transportation cost incurred in the project.

As shown in Fig. 1.2, A spar platform consists of a large-diameter, single vertical cylinder supporting a deck. The cylinder is weighted at the bottom by a chamber filled with a material that is denser than water to lower the center of gravity of the platform and provide stability. Additionally, the spar hull is encircled by helical strakes to mitigate the effects of vortex-induced motion. Spars are permanently anchored to the seabed by way of a spread mooring system composed of either a chain-wire-chain or chain-polyester-chain configuration.

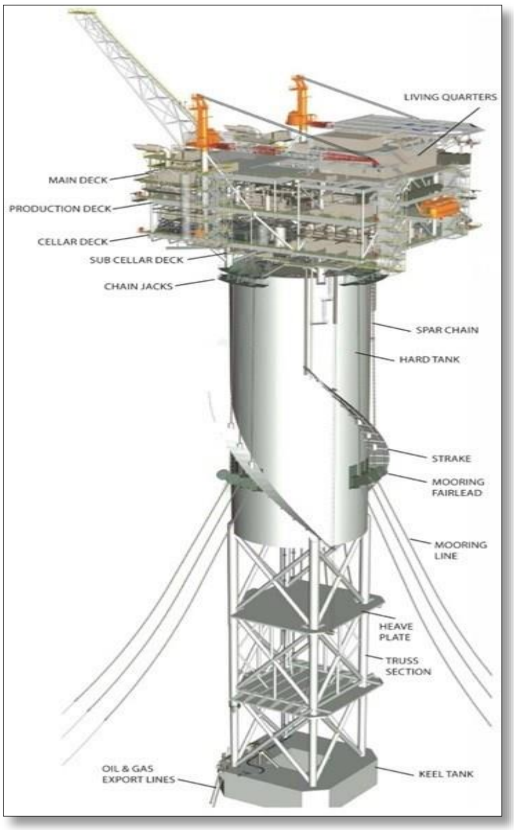


Figure 1.2: Components of a truss spar platform (Green, 2013)

The catenary system and taut leg mooring system are the most common type of mooring system employed in deep water. The catenary refers to the shape that a free hanging line assumes under the influence of gravity. The catenary system provides restoring forces through the suspended weight of the mooring lines and its change in configuration arising from vessel motion. Meanwhile, the taut leg system or taut system is characterized that the mooring lines are pre-tensioned until they are taut.

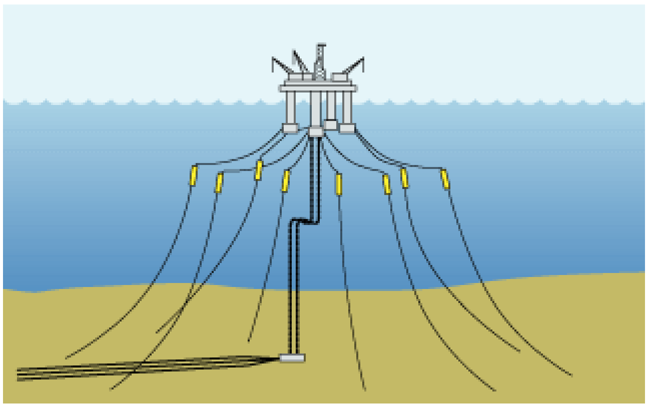


Figure 1.3: An example of mooring lines connected to a floating platform (Sefton, Firth and Hallam, 1998)

1.3 Problem Statement

In order to design a floating structure, there are a lot of consideration needs to be make. Environmental load such as wind, wave, current and geo-hazard are the main challenges that are usually resulting impact on the offshore structure. As a researcher and designer, they need to invent and improve current design to withstand these kind of environmental load. The design parameters factor including material, durability, maintenance cost and mooring line clashing (Rendon and Heredia, 2015).

It is challenging as we know offshore structure usually fabricated in large scale and much complicated than other type of structure. Therefore, it is difficult to perform or simulate the experimental studies in modelled scale. The nonlinearities that subjected to analysis of floating structure make the simulation is more challenging and difficult. This has encourages researches to come out with simulation and programming code to simulate the dynamic response of floating structure.

Generally, a mooring system refers to any permanent structure to which a platform may be secured. An anchor mooring fixes a platform's position relative to a point on the bottom of a waterway without connecting the vessel to shore. As a verb, mooring refers to the act of attaching a platform to a mooring. Related to truss spar platform, an optimize configuration of mooring lines may protect the riser which act as conductor pipe that used to transfer hydrocarbons, gas, mud and water to the deck (Cao and Zhang, 1996). Therefore, it is essential for designer to develop mooring system that capable to not only minimize the displacement of platform but also to protect the riser. To achieve that, there are several parameters that need to be considered such as mooring arrangement, material, length, size and pretension of a mooring design.

As for now, the design methodology is very reliable on numerical and the analysis is performed by simulation program. These show that engineer and expert are using trial and error method to decide the best configuration of mooring lines for given platform. As this approach are used, there are difficulties in determine the best configuration as designer need time and cost to perform different configuration.

Based on the challenges listed, this experimental study is necessary to be performed in order to quantify the optimization of the mooring lines of the truss spar platform subjected to regular and random wave.

1.4 Objectives of the Research

The specific objectives of this study are:

1. To determine the effect of mooring design variables –pretension and azimuth angle on the dynamic responses of truss spar platform.

CHAPTER 2

LITERATURE REVIEW

2.1 Chapter Overview

In this chapter, a critical review of past research studies related to mooring line analysis, mooring line parameters (material, pretension, azimuth angles, diameter, fairlead slopes), dynamic analysis of truss spar platform and optimization techniques is presented. At the end, the gaps in literature pertaining to this research study are discussed.

2.2 Spar Platform

For over 30 years, spar technology has been used in offshore environments in such application as research vessel, a huge communication relay station, and storage and offloading buoys. In 1987, Edward E. Horton has patented a special form of spar technology for deep water drilling and production platform (Skaug, 1998). The structure consists of a vessel with a circular cross-section that installed vertically in the ocean. The buoyancy is main component that make the stability of the spar secured. Commonly, the structure is supported by buoyancy chambers (“hard tank”) at the top and stabilized by a structure (“midsection”) hanging from the hard tanks.

Spar can be described as a huge rigid cylinder with six degrees of freedom. It commonly has addition on stability as anchored to the sea with vertical and catenary cables. The Spar platform has been regarded as a competitive floating structure for deep and ultra-deep water, oil and gas production (Islam, Jameel, Jumaat, Shirazi, & Salman, 2012). Besides that, the study state that spar stability may be supplemented by solid ballast placed in compartments at the keel. The vessel is held in place by a taut or catenary mooring system, providing lateral station keeping.

In the year 2007, first spar for Malaysia has successfully installed in Kikeh field with 1330 m in water depth (Islam et al.,2012). One good thing about spar, it can be installed at the various of water depth, number of wells and loading deck as its heave natural period is dependent only on the draft of the Spar. This full cylinder form can be used for drilling, production and oil storage.

Presently, most of the spar platforms are operating in the Gulf of Mexico region. The interest in this technology has led to studies for adapting the spar concept to wide range of deep water location and oceanographic conditions. Most research on spar platforms are conducted in numerical program. For example, (Jeon et al, 2013) addressed the numerical investigation of dynamic responses of a spar type hallow cylindrical floating substructure moored by three catenary cables subjected to random wave. From the numerical simulation, the time and frequency responses of a rigid spar type hallow cylindrical floating substructure and the tension of mooring cables were investigated with respect to the total length and the connection position of mooring cables.

2.2.1 Dynamic Responses of Truss Spar Platform

Morison equation, Froude Krylov theory and Diffraction theory are the reliable theories that used to evaluate the wave force for offshore structures. (Kurian et al, 2012) has support this statement by stating that this theory can be applied regards to the type and size of the member of the structure. They also started the study of dynamic response on spar platform subjected to long crested wave and short crested wave. (Kurian et al, 2012) have presented the results of numerical investigation of an offshore classic spar platform subjected to long crested waves. In this study, two numerical simulations were developed by incorporating the Morison equation and Diffraction Theory to obtain the wave forces.

(Kurian et al, 2012) pursue this study by investigating numerically on dynamic responses of classic spar platform subjected to long crested wave, subjected to regular and random waves by incorporating with Diffraction Theory. (Jha et al, 1997) has performed the study on comparison between analytical predicted motions of floating spar buoy platform and the experimental studies on wave tank by considering surge and pitch motions only. The study describes the behavior of nonlinear diffraction loads, multi degree of freedom, stiffness and damping of spar platform model. (Chitrapu et al, 1998) perform the study using a time domain simulation model on spar platform's response. They used various environmental conditions such as regular, bichromatic, random waves and current to simulate same condition on the ocean. By using Morison equation, they conclude that, combination between Morison Equation and wave particle kinematics, it may give the reliable prediction of platform response for wave-frequency and low-frequency range.

2.3 Mooring Line

(Bruno, Mauro, Carl, Beatriz et al., 2013) has supported the idea of moored floating platform is one of the important components that supporting the riser system as it is used to transfer the extracted hydrocarbon. Besides that, optimized mooring system is responsible to keep platform in safe operational zone. This concept is related to the previous study by (Faltinsen, 1990) which mention about usual floating platform that are has less motion due to anchored with spread mooring system around the platform. This feature provides resistance to horizontal displacement whenever environmental loads are applied on the floating platform. Another description of mooring system by (Agarwal and Jain, 2003) is increases mooring system weight as water depth increases is not significant factor in design of a spar. This is due to vertical loads from the mooring systems are relatively small compared to the overall loads of spar. Even, a doubling water depth causes minor increase in hull loads.

2.3.1 Mooring Line Design Variables

Material is one of the major factors in fabricated mooring lines cables. Since 1980s, oil and gas operator start to use synthetic fiber ropes as the main component of mooring line materials. This can be seen of several of floaters such as MODU, FPSO, Spar and Semi-submersible. As we know steel wire ropes is a conventional material of mooring lines. However, with the latest technology nowadays, synthetic fiber ropes seems a suitable to substitute steel wire in deep water mooring applications (Islam et al, 2012). Petrobas is one of the well-known platforms that applied fiber rope as mooring lines. In deep water operations, the mooring lines are long and diameter of the polyester rope is in hundred millimeters. This is to ensure the demand of breaking strength is satisfied which has been assumed as challenges for the installation of the vessel. Due to that circumstance, researches are trying to propose better materials than polyester. In history, there are some application of aramid and HMPE (which has higher modulus of elasticity than polyester) in mooring line materials (Francois and Davies, 2012)

In materials testing, (Fernandes et al, 1999) contributed a comprehensive set of experiment with actual scale of polyster mooring cables with diameter of 0.127 m. He discovered that minor effect of the dynamic stiffness on the frequency. In the line pretension, (Bosman and Hooker, 1999) performed experimental studies of dynamic modulus characteristics of the polyester. They discovered of breaking strength of 11.25 tons and the actual-size rope with breaking strength of 150 tons. In this literature, we can conclude that there are good predictions of the modulus based on small scale test into actual-size test. (Casey and Banfield,2002) have performed an experiment of dynamic axial stiffness of polyester ropes. They noticed that the strain amplitude does exist as a variable for the dynamic stiffness.

(Wibner et al., 2003) have used the upper and lower bound stiffness to technically calculate the dynamic stiffness of the polyster rope, in which the mean load is considered as parameter study. Besides that, (Davies et al., 2002) investigate the effects of the mean load, load range and loading frequency on stiffness by using of various type of rope including polyester, aramid and HMPE. From the experiment, they described that stiffness and bending behavior of aramid and HMPE ropes. (François and Davies, 2000) performed the experiment on the polyester subrope samples with 70-tons breaking strength (modelled scale) and full size rope with 800-ton breaking strength (actual scale). From the experiment, slow variations of mean load under the effect of changing weather conditions is depend on visco-elastic response.

CHAPTER 3

EXPERIMENTAL PROCEDURE / METHODOLOGY

Chapter Overview

Sea keeping tests of floating offshore platforms use techniques, methodology, and standards from other ITTC Loads and Response procedures. Offshore platforms are subject to wave, current, and wind in terms of environmental conditions. In addition to prediction of long term statistics, often extreme events are modelled to ascertain survivability characteristics. The offshore platform could be moored or dynamically positioned. It can be tested in an operational, survival, or transit configuration.

3.1 Froude's Law

Water tank in UTP offshore lab is considered as water flow with a free surface which mean the gravitational effects predominate and need to be granted. The effect of other factors, such as viscosity, surface tension, roughness etc. is generally insignificant and can be neglected. In this case, Froude's model law is most applicable. Eq 3.1 expressed the Froude Number, Fr, for the model and the prototype in waves.

Where the subscripts *p,m* stand for prototype and model respectively. Assuming geometric similarity *Dp* = λ*Dm*, 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 = λ*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 1.

$$\boldsymbol{Fr = \frac{u^2 p}{g D_3} = \frac{u^2 m}{g D_3}} \quad \dots\dots\dots \text{ Equation 3.1}$$

3.2 Scaling of a Froude Model

Generally, the model is made is based on the Froude's law for prototype scale conversion. The common variables found in the study of fluid mechanics are grouped under appropriate subheadings and are listed in Table 3.1. 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. However, 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.

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

Variables	**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	$\lambda^{0.5}$
Acceleration	LT^{-2}	**1**
Velocity	LT^{-1}	$\lambda^{-0.5}$
Displacement	L	λ

Angular acceleration	T^{-2}	λ^{-1}
Angular velocity	T^{-1}	$\lambda^{-0.5}$
Angular Displacement	None	1
Spring constant (Linear)	MT^{-2}	λ^{2}
Damping coefficient	MT^{-1}	$\lambda^{2.5}$
Damping factor	None	1
Natural period	T	$\lambda^{0.5}$
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

Scaling laws assume the conservation of the ratio between inertial and gravitational forces by maintaining a constant Froude number. The weights were scaled down so that the model will have the same weight distribution as the prototype. A correct weight distribution will get the model to float at the correct draft as being planned. One way to get accurate weight distribution is by choosing the right thickness for each plate use to fabricate the model.

$Fr = U/(g*L2)$, where

g = Acceleration of gravity
U = Velocity
L = Length

3.3 Experiment Studies

Three different types of test were conducted. The details are as follow:

Quasi-Static Test of Static Offset Test

Static offset tests were carried out to determine the mooring system stiffness. Load cells were attached to the up and down stream mooring lines. Static forces were applied and the load cell readings were recorded accordingly.

Free Decay Test

The purpose of these tests was to predict the natural frequencies of the system in different conditions.

Sea Keeping Test

The general objectives of these tests were to measure the platform motions to regular and random waves. For evaluating the sea-keeping characteristics of the model, it was tested for regular and random waves. Soft linear springs were attached to steel wires to form the mooring line system of the model.

The truss spar model was tested for one-model orientations (head seas) in wave basin of the UTP. The model motion and the restraining lines tension were measured by optical tracking system and load cell respectively. About 60 runs are expected to carry out including free-decay, static offset and sea keeping test.

3.3.1 Experimental Setup

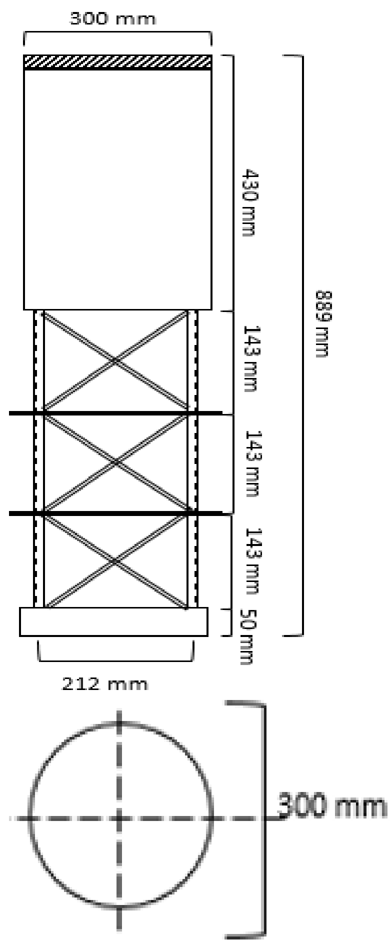


Figure 3.1 Dimension of the truss spar model truss spar platform

Figure 3.2 Actual model truss platform

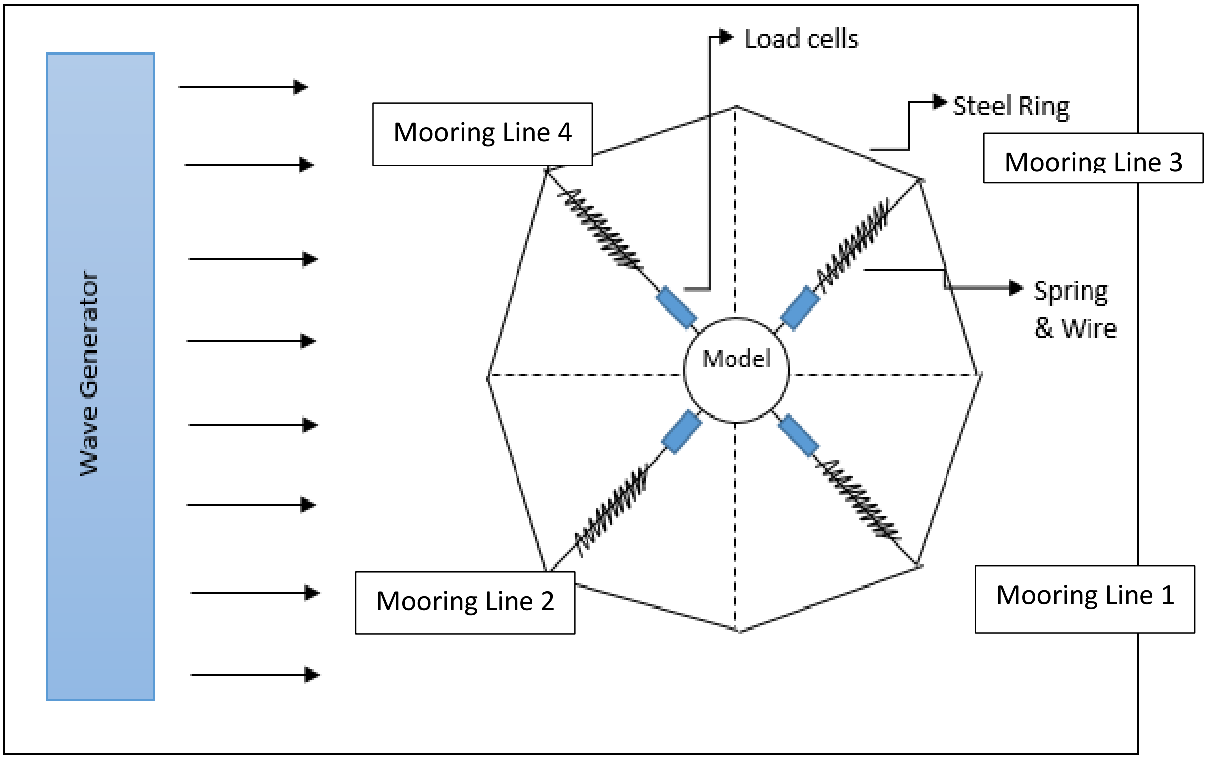


Figure 3.3 Arrangement of '12 side-ring', mooring lines, load cells and wave generator

Figure 3.4 Current arrangements at the UTP Offshore Laboratory

3.4Test Facilities

The offshore lab wave basin measures approximately 22 m long, 10 m wide and 1.5m 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. The tracking system called Qualysis Spectra is used to capture the motion of platform respose. 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 1m (the speed varies with water depth).

3.5 Wave Test

During this research, wave test is the dominant factor. Based on the experiment, the actual movement of truss spar platforms subjected to wave loads during operation hour can be shown. Major design parameters are varied systematically to cover extensive range, which include as following:

a) Wave Height, *H*
b) Wave Period, *T*
c) Wave Type (Regular or Irregular Wave)
d) Configuration of mooring line (Configuration and Pretension)

Estimated there will be around 60-wave test with variable parameters to be conducted throughout this experiment. Significance of each parameter can be seen through motion response truss platform.

Table 3.2 Wave Test Characteristics

LONG CRESTED - WITHOUT CURRENT			
REGULAR WAVE TESTS			
Test Run	H (m)	f (Hz)	T (s)
1	0.04	2.0	0.5
2	0.03	1.43	0.7
3	0.05	1.11	0.9
4	0.04	1.00	1.0
5	0.06	0.56	1.8
RANDOM WAVE TESTS - JONSWAP			
Test Run	Hs (m)	f (Hz)	T (s)
1	0.04	1.190	0.84
2	0.03	1.111	0.9
3	0.05	1.124	0.89
4	0.04	1.064	0.94
5	0.04	1.266	0.79

3.5.1 Data Analysis

In determining the motions for regular wave analysis, the average amplitude and period of at least 10 cycles should be obtained. Alternatively, a spectral analysis following the procedures outlined below for irregular waves could be followed to obtain the amplitude and period characteristics of waves and responses.

Energy spectra of waves and relevant responses should be produced through spectral analysis using either the indirect method of Fourier transformation of the autocorrelation function, or the direct method of splitting the record into suitable blocks and subjecting these to Fast Fourier Transform.

In addition to the spectral analysis, statistical analysis should be performed to calculate the mean, maximum, minimum, and the mean of the highest values. Techniques utilised to smoothen spectral shapes, such as block overlapping, should be documented in the presentation of the results. When reporting statistics of wetness the number of events and number of encounters should be reported independently, as well as the overall statistics

3.5.2 Presentation of Results in Response Amplitude Operator

The dynamic motion responses of the classic spar are presented in terms of Response Amplitude Operator (RAO). Thus, the RAO of six degree of motion for surge, heave, sway, roll, pitch and yaw.

3.6 Project Timeline and Key Project Milestones

Table 3.3: Project Timeline and Key Project Milestones for FYP 1

Legend : Process Key Milestones

Activities	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of Project Title														
- Preliminary research work - Develop objective, problem statement, general methodology						●								
-Register Laboratory Facilities and Services Unit (LFSU) -Purchase or usage of resource and services (form 03) -Submission of Extended Proposal														
- Preparing the Wave Tank Test for long crested wave (Equipment, Data, Procedure) - Wave Tank Test Set up														
- Continuing wave tank test set up - Proposal Defense														
- Submission of Interim draft report - Submission of Interim report													●	●
Experimental Studies	FYP 2													
Analysis of the results														

Table 3.4: Project Timeline for FYP 2

Activities	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
- Run Test for Long and Short crested wave plus current - Complete the test and record all the result														
-Do the analysis of Long and Short crested wave plus current														
-Report the findings of the analysis -Preparing the progress report FYP 2														
-Submission of Progress report -Pre SEDEX Preparation														
-Write Technical Paper -Pre SEDEX														
-Submission of dissertation (soft bound) and technical paper														
-Viva presentation														
-Submission of dissertation (hard bound)														

3.7 Parametric Studies

As throughout the experiment, there are two parametric studies need to be done which are the pretension of mooring line that attached to truss spar during consolidated mode and the configuration of azimuth angle. Both this studies need to undergo varies numbers to complete the parametric studies.

i) Table 3.5 Pretension of mooring lines

Pretension (N)
1
3
5
7
10

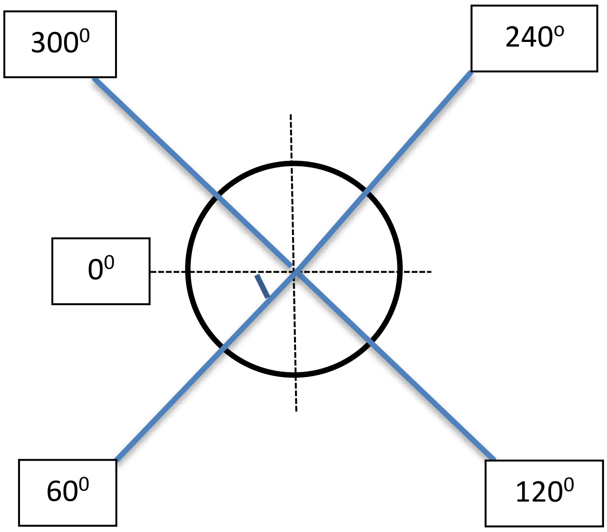
ii) Table 3.6 Azimuth angle (Degree of mooring lines)

Azimuth Angle (◦) Configuration
1. 60,120,240,300 (Symmetric)
2. 0,90,180,270 (Symmetric)
3. 30,90,180,270 (Asymmetric)

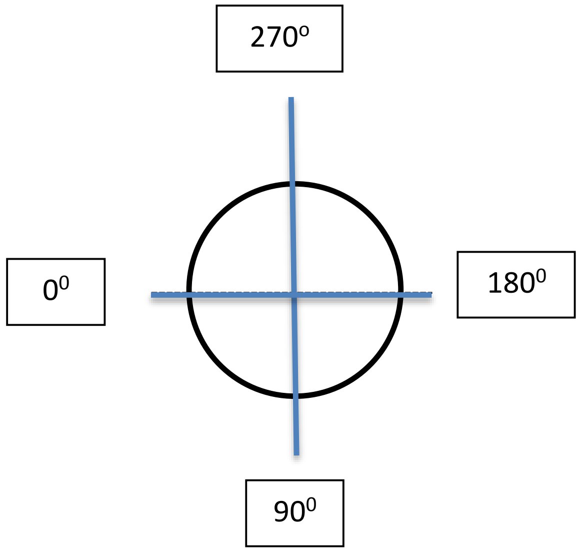
Author has done 2 symmetric and 1 asymmetric mooring configurations in terms of azimuth angles. This arrangement is chosen in regards to the present scenario where many floating platforms contain mooring lines more commonly these configurations.

Symmetric: The mooring lines are placed symmetrical to each other and various configurations are generated by changing one mooring line from 0^o to 60^o with respect to the wave heading like 1^{st} and 2^{nd} configuration.

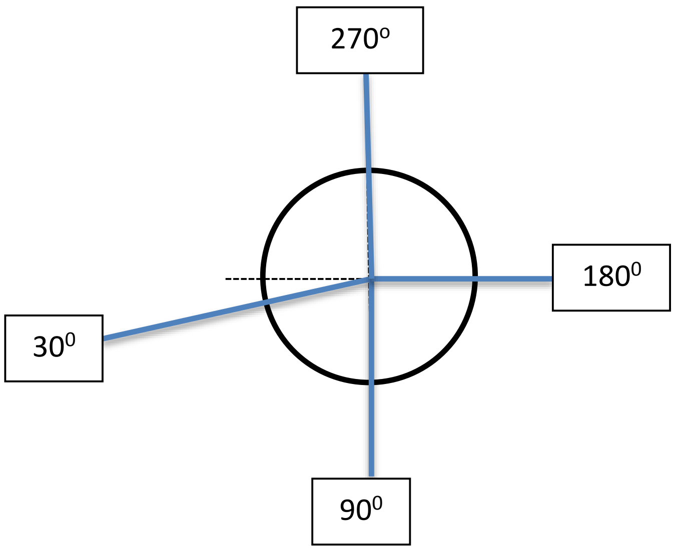
Asymmetric: These configurations are generated by changing only one mooring line (with other lines retained as in symmetric configurations) from 0^o to 60^o with respect to the wave heading like 3^{rd} configuration.



Azimuth Angle Configuration 1



Azimuth Angle Configuration 2



Azimuth Angle Configuration 3

CHAPTER 4

RESULT AND DISCUSSION

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

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.

4.1 Conversion from Full Scale to Model Scale

From Kikeh data for truss spar, 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.

Table 4.1 Spar 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 Calculation for the design of the experimental model

Input			
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
Calculation			
S.No.	**Legend**	**Unit**	**Value**
1	Initial calculations		
	Total length of the	cm	95.00
	Length of inclined truss	cm	21.21
2	Weight of the model		
	Hull	g	5000
	Truss members	g	2000
	Heave plate	g	4300
	Soft tank	g	3800
	Additional	g	2500
	Total	g	17800
3	Weight of the fluid displaced (draft)	g	707.14
4	Draft(dr)	cm	15

4.1.1 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

$W = \pi r^2 * 1000 * 0.15$ m $= 15.55$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, 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

4.2 Motion Responses of Wave Profile (Regular waves)

4.2.1 Parametric Study on Pretension of mooring lines of Truss Spar

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. RAOs are effectively transfer functions used to determine the effect that a sea state will have upon the motion of a spar through the water. Response spectra were obtained in terms of RAO which is given as

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

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

At first, pretension of 1N and 10N are 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 3N pretension gives the highest effect of motion compared to 5N and 7N. By refer to Figure 4.1, the RAO for 7N is less compare to RAO 5N and 3N. This indicate when higher pretension are applied on mooring lines, it gives less motion on truss spar platform model. By referring to Figure 4.2, RAO for 7N significantly is less compared to RAO of 5N and 3N. For sway as referred to Figure 4.3 the trend are significantly same with the surge and heave motion. The pretension of 7N give less motion in RAO compared to 5N and 3N. For roll motion, Figure 4.4 has showed that the RAO is less as higher pretension is applied. The trend is quite similar with Figure 4.5 and Figure 4.6. Higher pretension on mooring lines has given less motion on pitch and yaw motion. For pitch, the effect of the motions almost the same but 3N pretension gives the highest effect of motions than 5N and 7N pretension. Generally, as pretension increased, it provides more restoring force to minimize the motion of truss spar platform model.

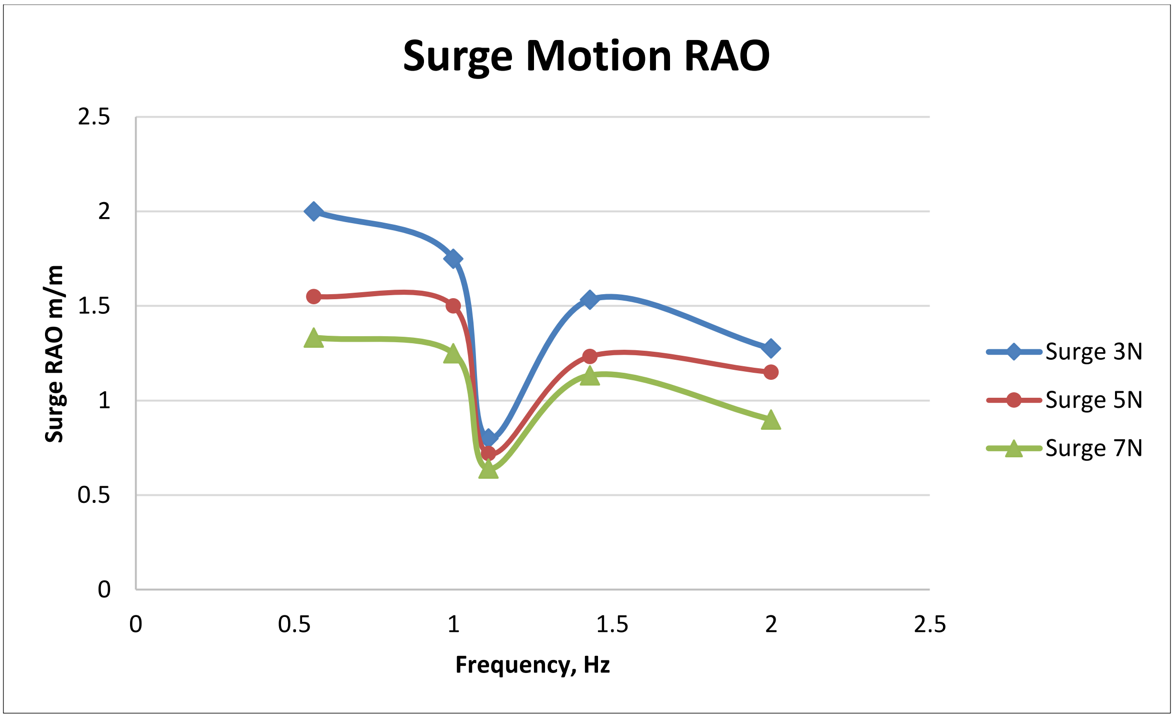


Figure 4.1. Surge Motion RAO for pretension (regular)

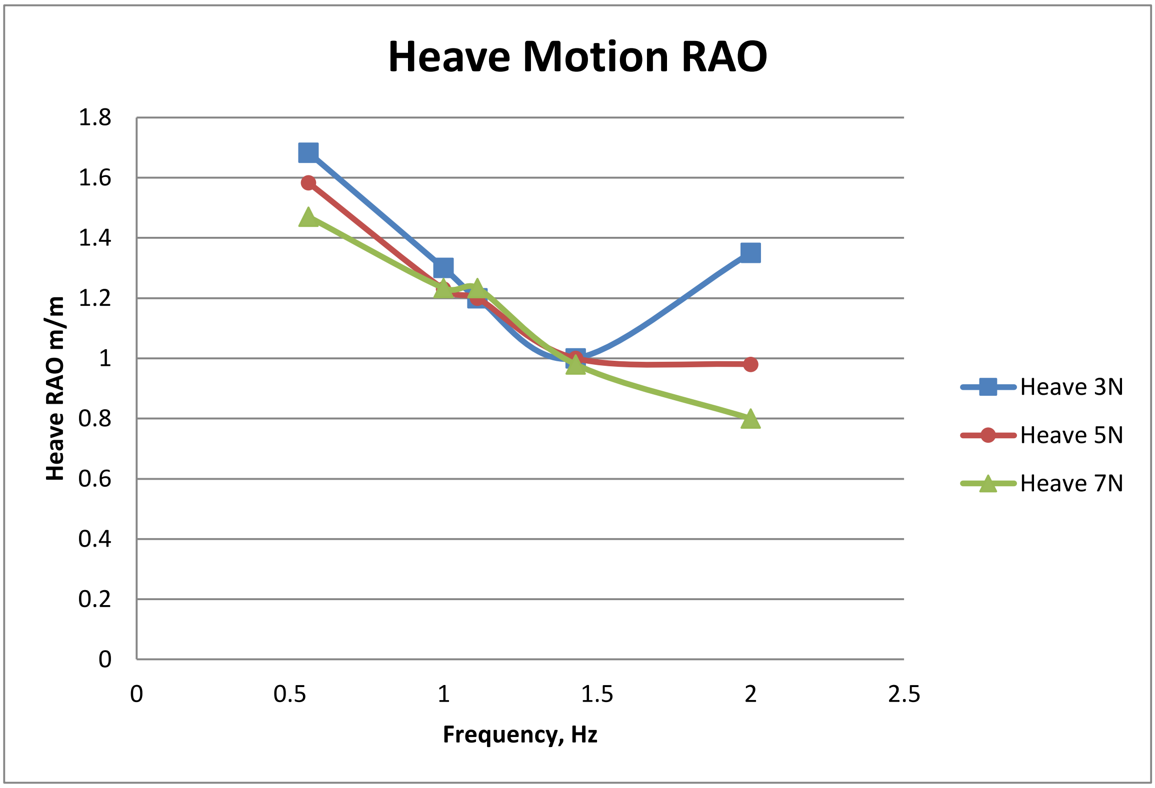


Figure 4.2 Heave Motion RAO for pretension (regular)

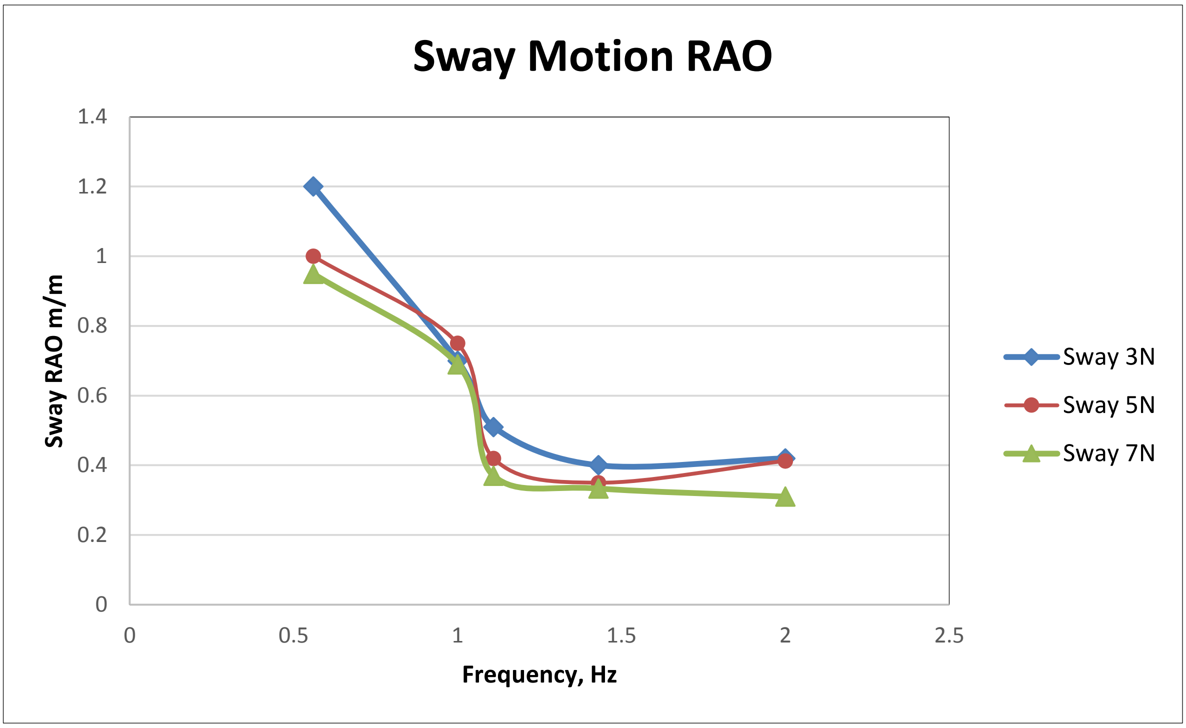


Figure 4.3 Sway Motion RAO for pretension (regular)

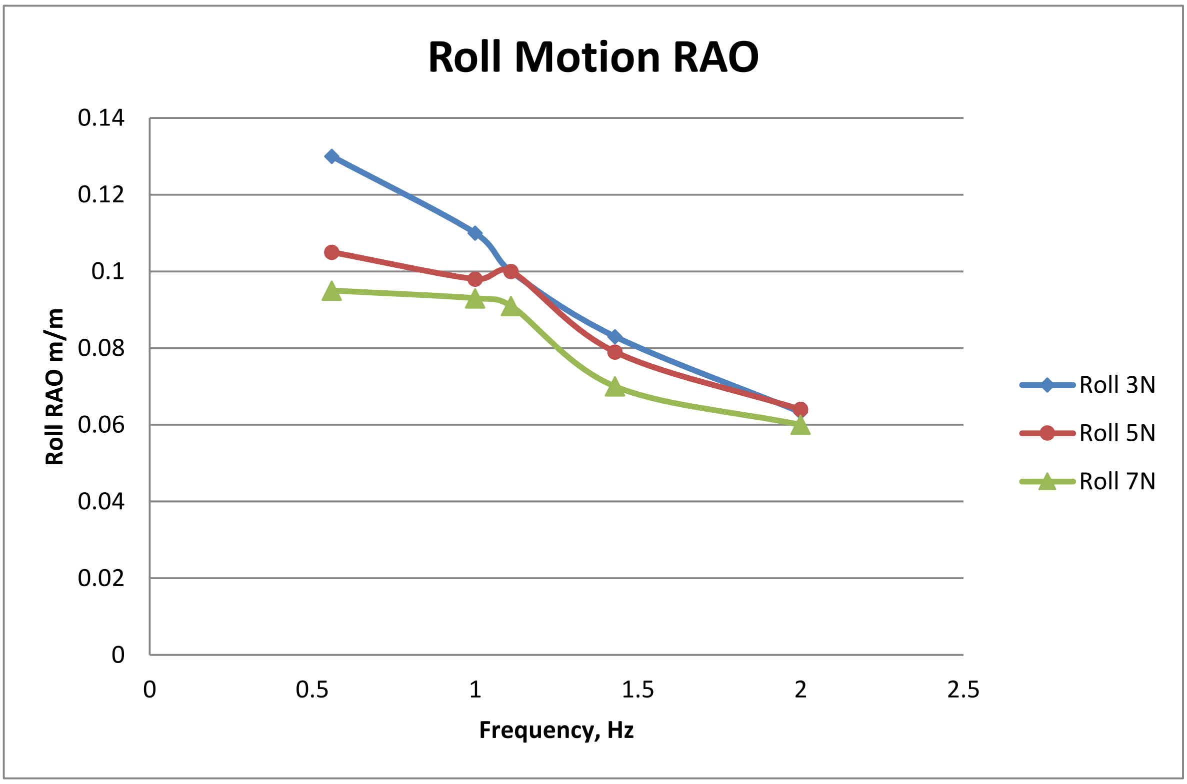


Figure 4.4 Roll Motion RAO for pretension (regular)

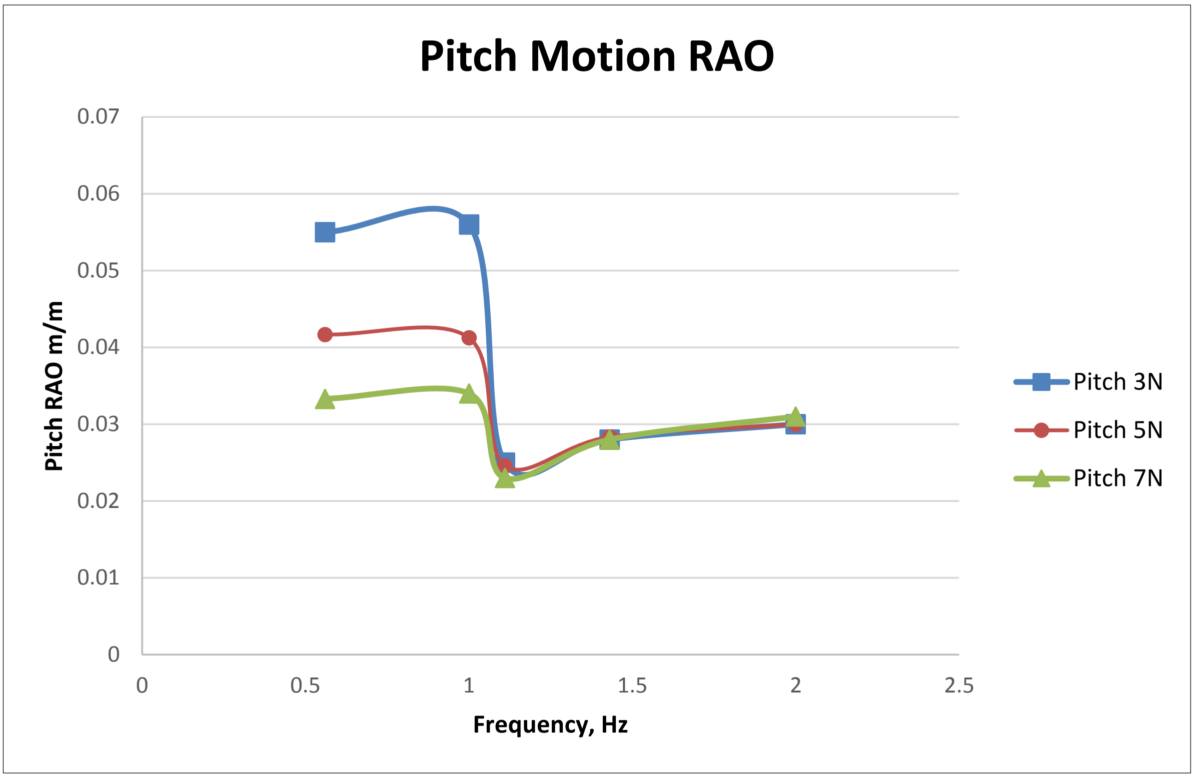


Figure 4.5 Pitch Motion RAO for pretension (regular)

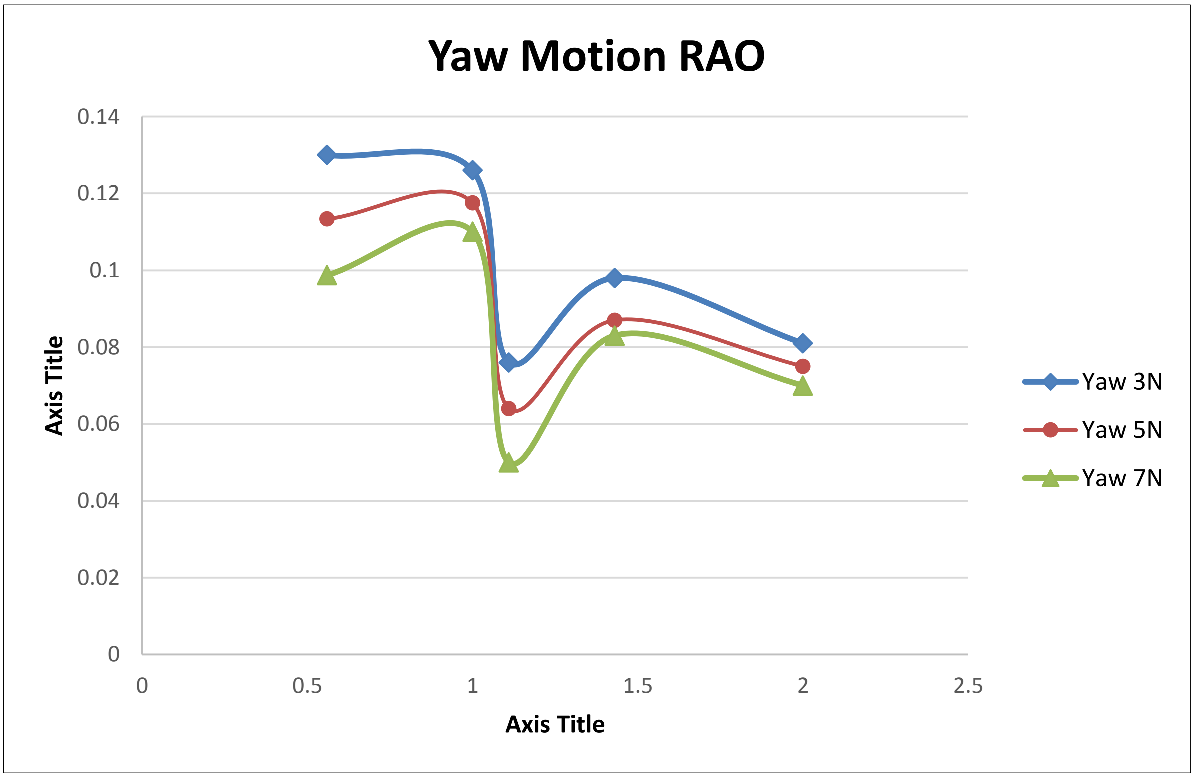


Figure 4.6 Yaw Motion RAO for pretension (regular)

4.2.2 Parametric Study on Azimuth Angle of mooring lines of Truss Spar

Figures 4.7 until Figure 4.12 show the restoring behaviour of mooring system for symmetric and asymmetric configurations defined in terms of azimuth angles. For symmetric azimuth angle it was predictable that it may significantly reduce the motion of truss spar platform model for every each of degree of freedom. As shown in Figure 4.7, 4.8 and 4.9, the first and second configurations have given less RAO compared to third configuration. For Figure 4.10, 4.11 and 4.12, the trend are predictable and author can conclude that symmetric configuration have given less motion on truss spar platform. This is applicable to all rotation motion (roll, pitch, and yaw).

For rotation motion (roll, pitch and yaw), the difference between three configuration are not much. Addition on that, wave heading are more affecting on translation motion (surge, heave and sway). This can be seen on Figure 4.10, 4.11 and 4.12, the difference of three configurations are significantly small. However, in order to make a general comparison, symmetric configuration are more optimize configuration for truss spar platform model. In others words, it can be observed that the mooring restoring performance is decreasing as the mooring line is shifted away from wave heading. It shall be noted that the symmetric configurations exhibit better mooring restoring performance compared to its corresponding asymmetric configurations.

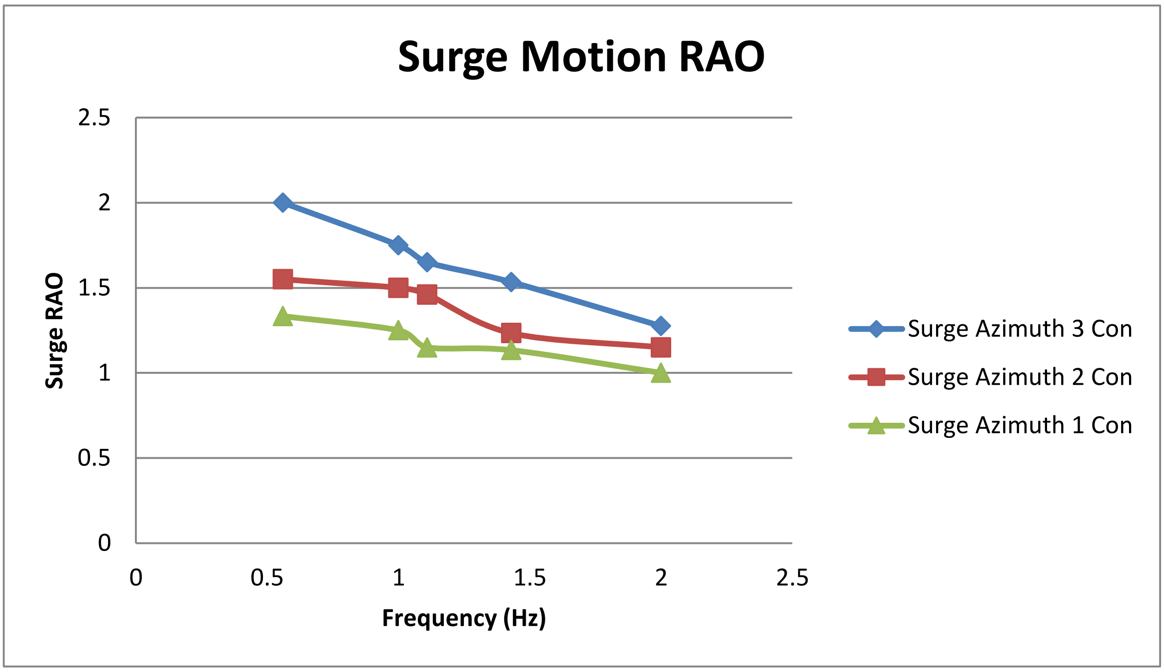


Figure 4.7 Surge Motion RAO for azimuth angle (regular)

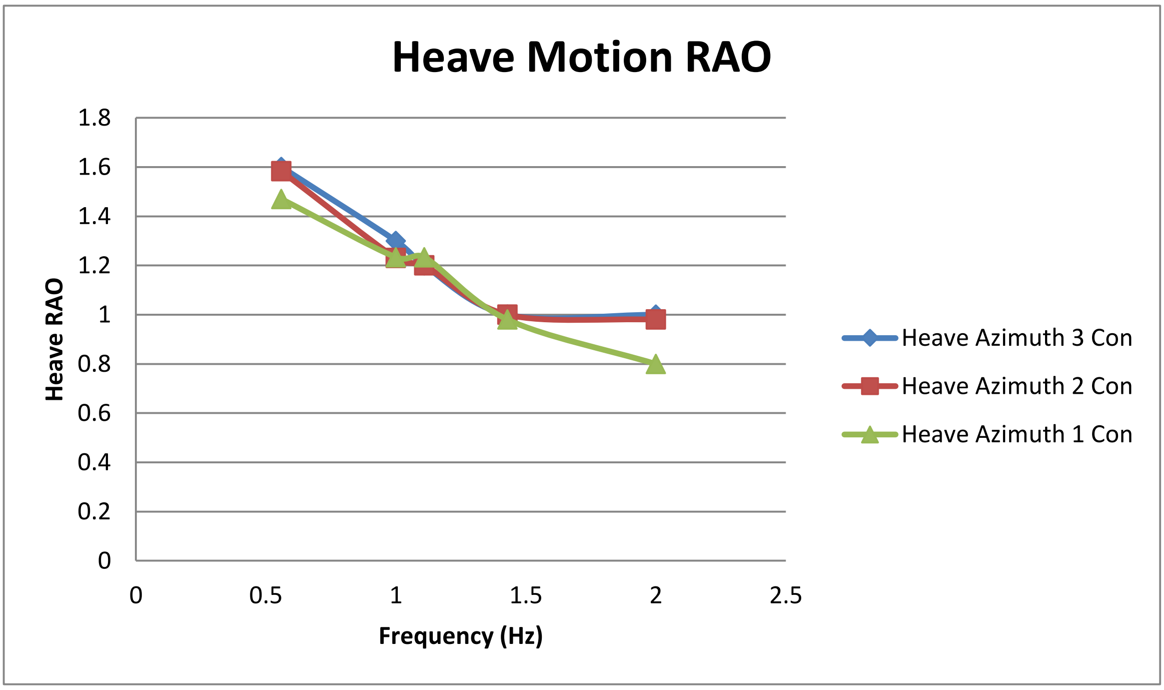


Figure 4.8 Heave Motion RAO for azimuth angle (regular)

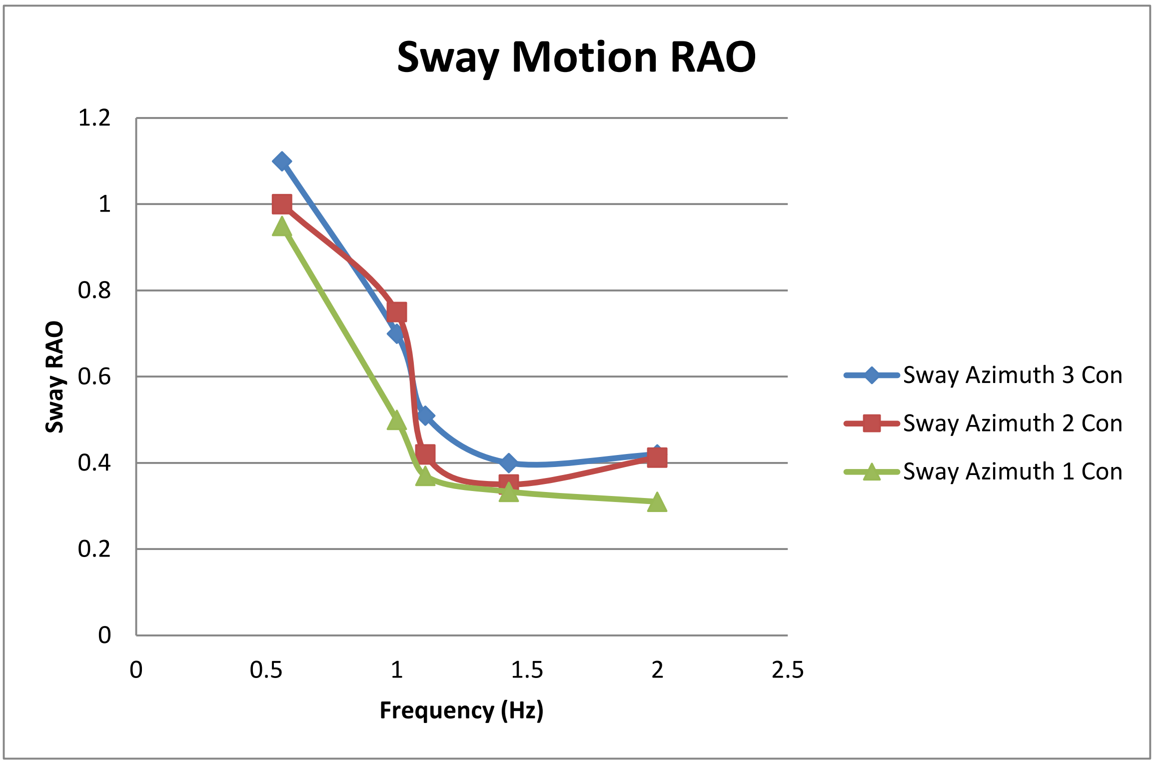


Figure 4.9 Sway Motion RAO for azimuth angle (regular)

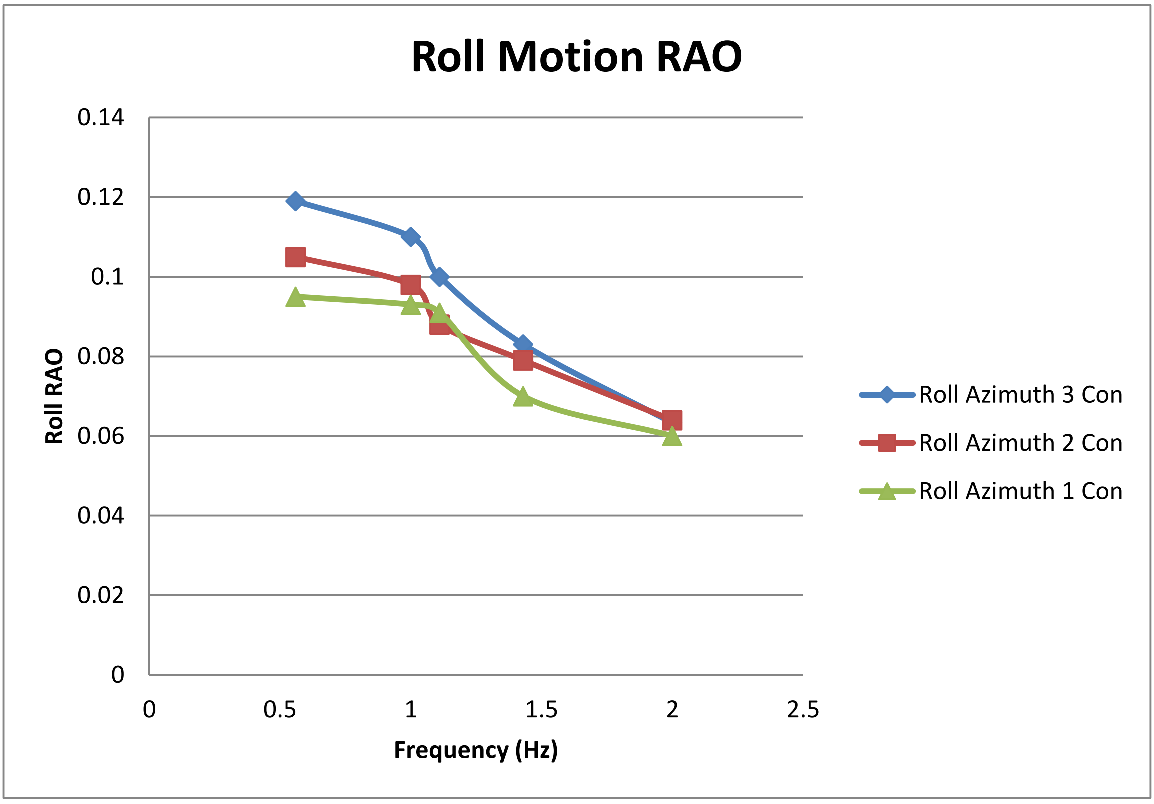


Figure 4.10 Roll Motion RAO for azimuth angle (regular)

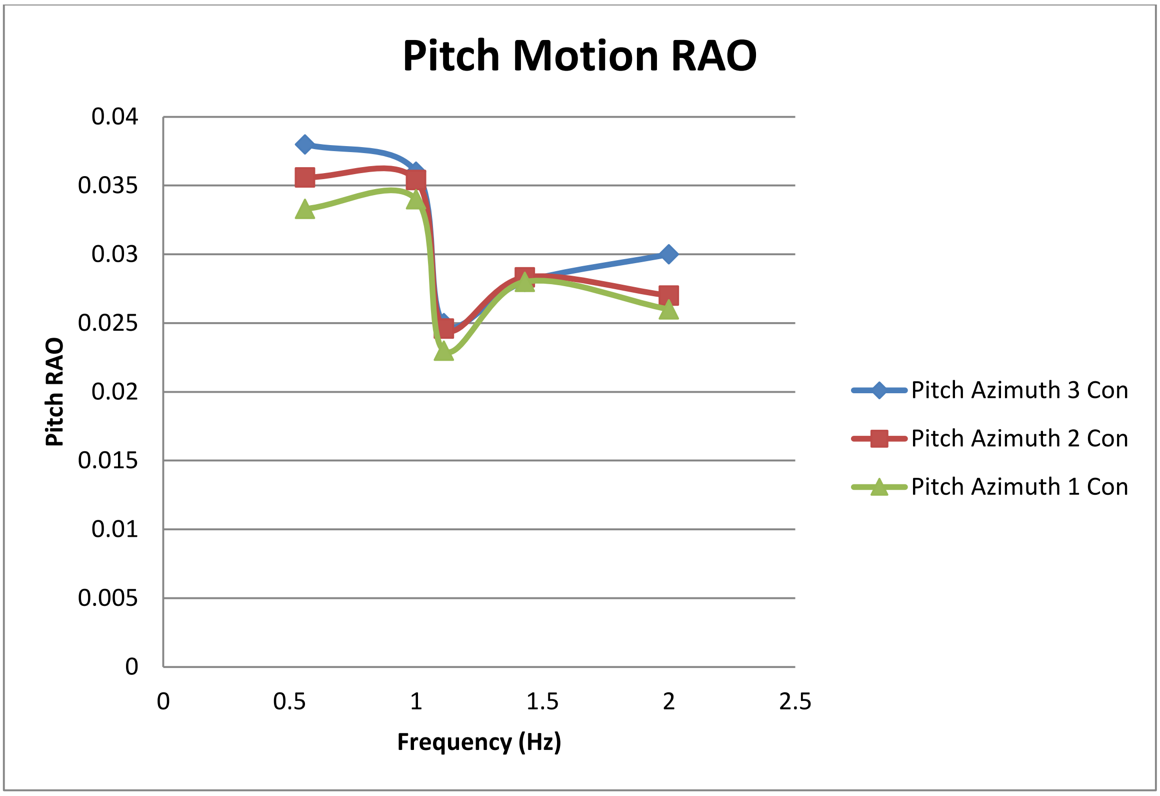


Figure 4.11 Pitch Motion RAO for azimuth angle (regular)

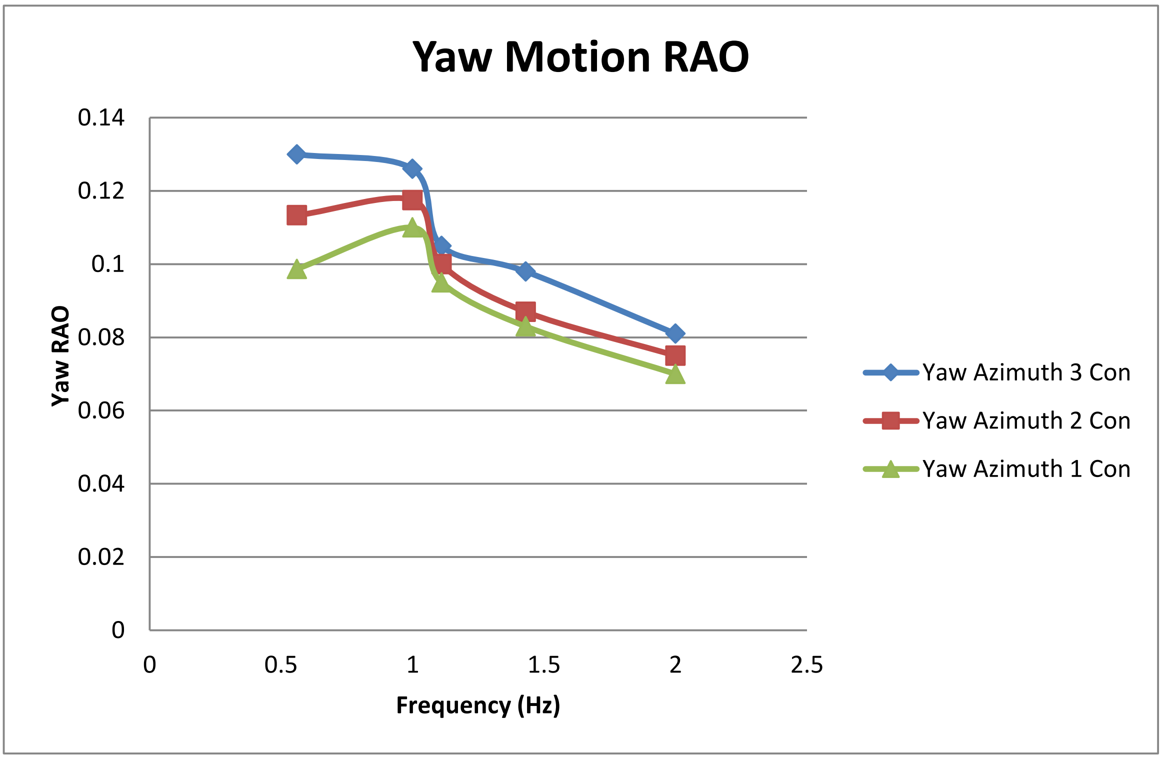


Figure 4.12 Yaw Motion RAO for azimuth angle (regular)

4.3 Motion Responses of Wave Profile (Random waves)

4.3.1 Parametric Study on Pretension of mooring lines of Truss Spar

In the model test, the generated wave field was intended to match the widely-used JONSWAP- spectrum. The waves came from a direction that is parallel to the plane of the mooring line. A test period of approximately 8 minutes in real time is examined here. During this period, the significant wave height H is found to be 1.03 meters and the spectral peaks period T is approximately 1.2 sec.

The model test provided the tension transfer function for the top of the line as shown in figure 4.13 until 4.18 below. This transfer function includes the effects of the dynamic responses of both the spar buoy and the mooring line.

From the spectrum obtain on Figure 4.13, 4.14 and 4.15, author can conclude that the maximum energy occur at the range of 0.5Hz to 1Hz , to be more specific it achieve maximum at 0.75 Hz. Surge Motion has gave maximum RAO magnitude which is 42 and the minimum is 43 as stated in Figure 4.13. This is due to wave generated is directly headed the surge motion. Meanwhile, in Figure 4.14, the highest heave RAO is 19.5 and the minimum is 15.7 which occurred on 0.75 Hz. Figure 4.15 has gave maximum value of 18 and the minimum is 17.8 in sway RAO.

In Figure 4.16, the maximum of roll RAO is 0.047 and the minimum is 0.045. Figure 4.17 has showed that the maximum of pitch RAO is 0.22 and the minimum is 0.2. Both of this motion occurred at the frequency of 0.8Hz. Meanwhile, Figure 4.18 has showed the maximum yaw RAO is 0.36 and the minimum is 0.35 that occurred at 0.75 Hz

By comparing between translation motion and rotation motion, after all, author can say that RAO on surge, heave and sway have given significant value on RAO which mean the dynamic motion is higher on that motion compared to circular Degree of freedom (roll, pitch and yaw).

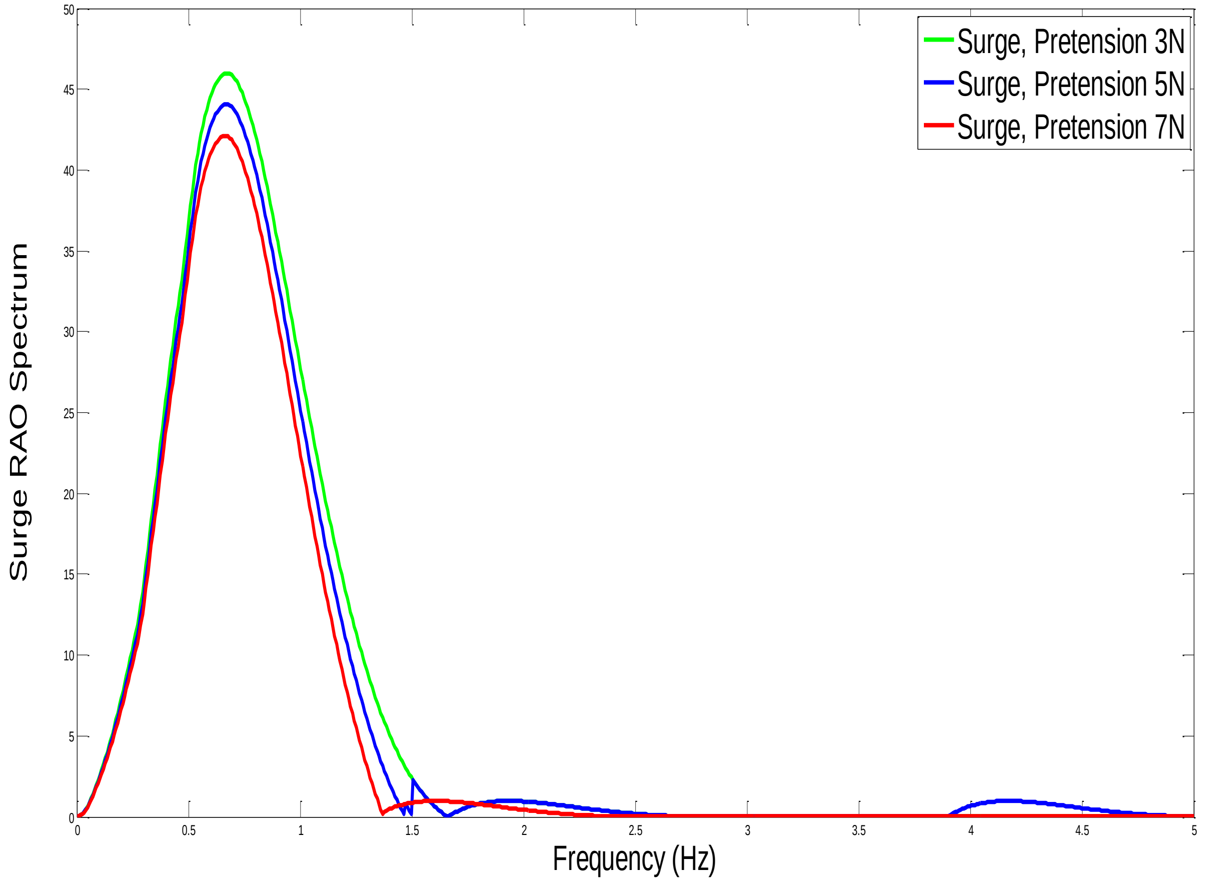


Figure 4.13 Surge Motion RAO for pretension (random)

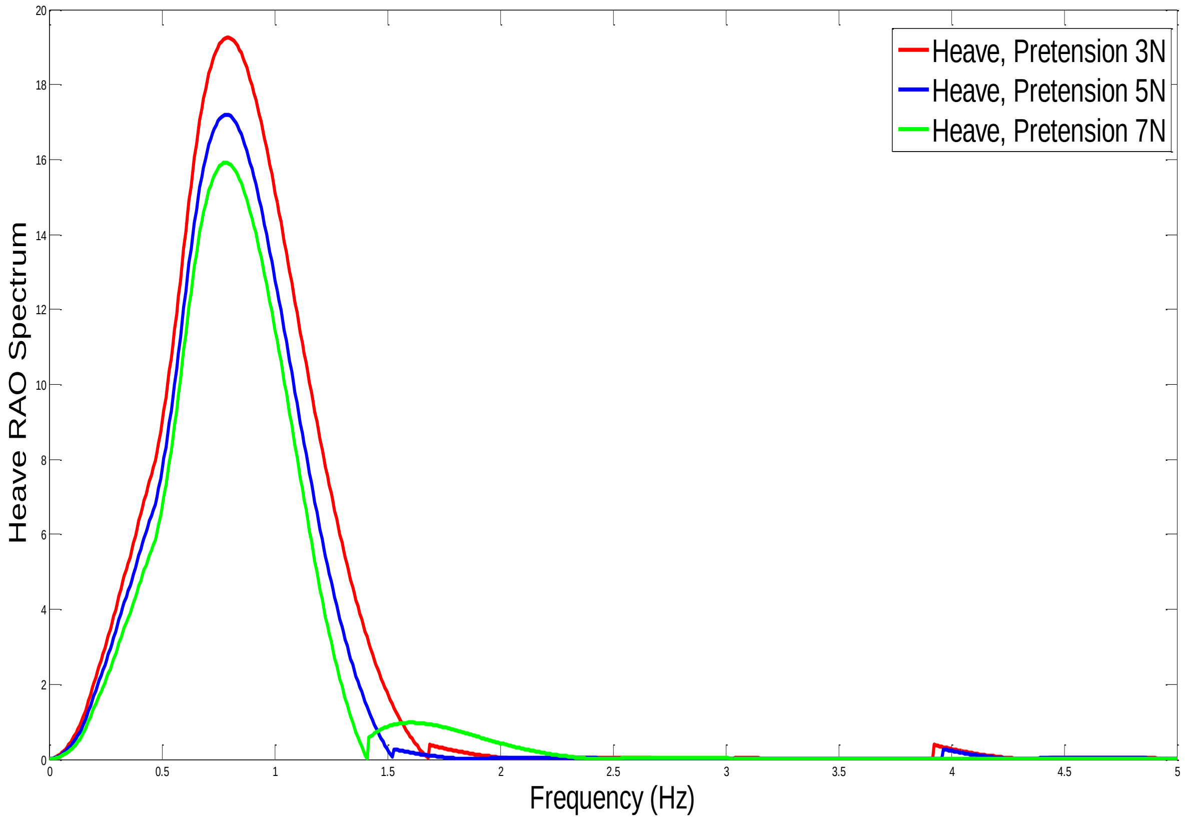


Figure 4.14 Heave Motion RAO for pretension (random)

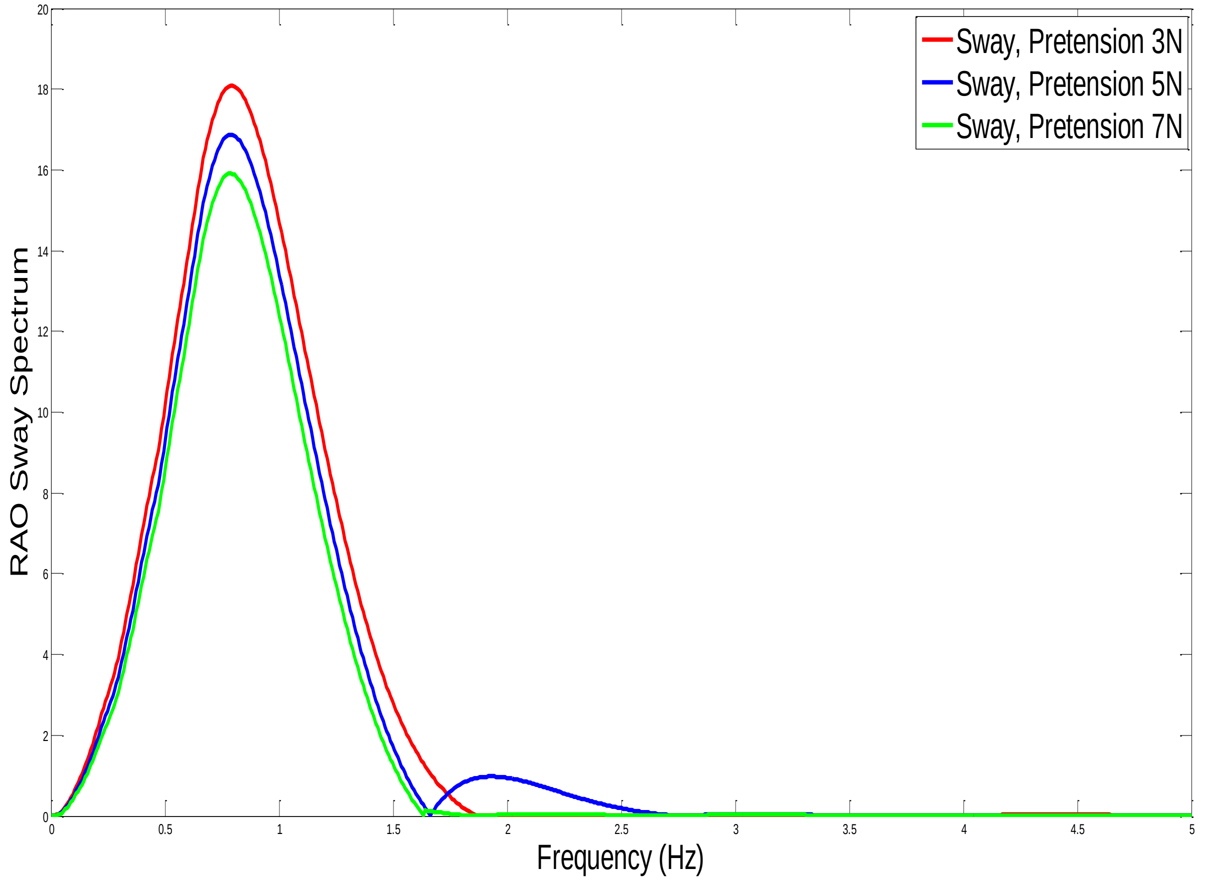


Figure 4.15 Sway Motion RAO for pretension (random)

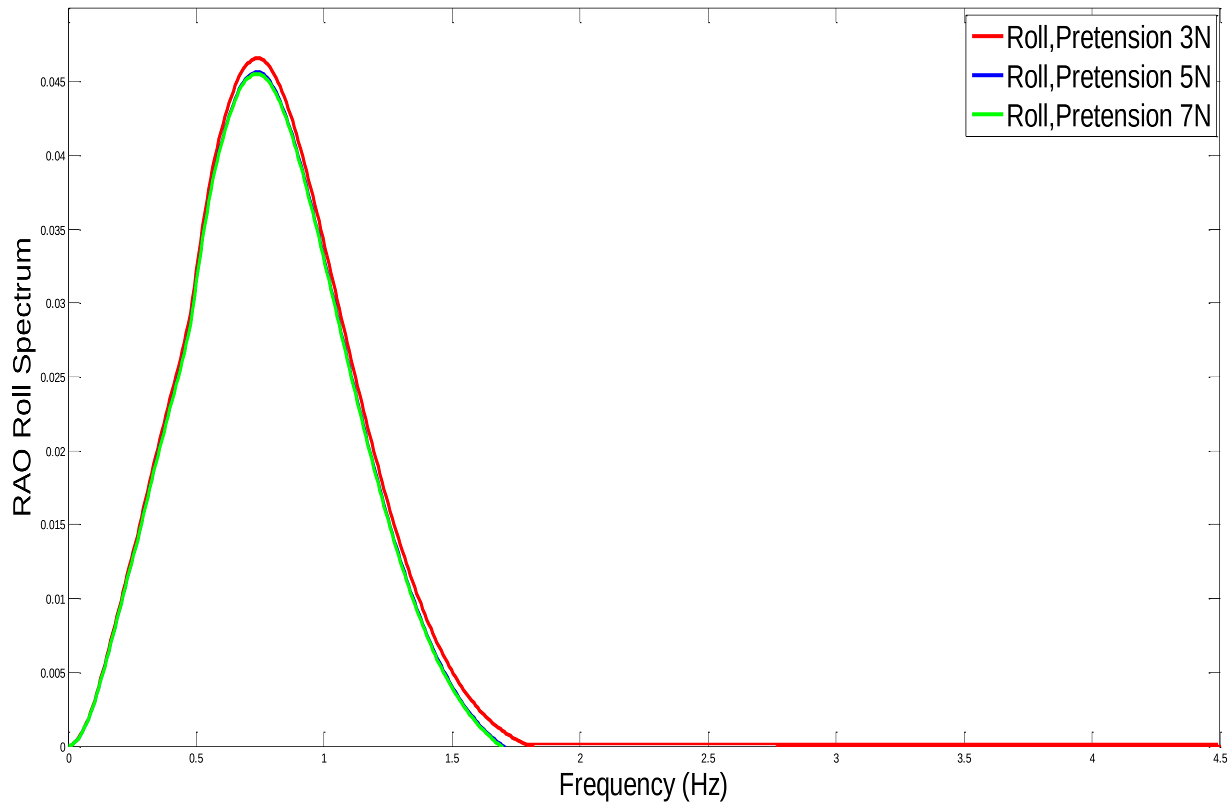


Figure 4.16 Roll Motion RAO for pretension (random)

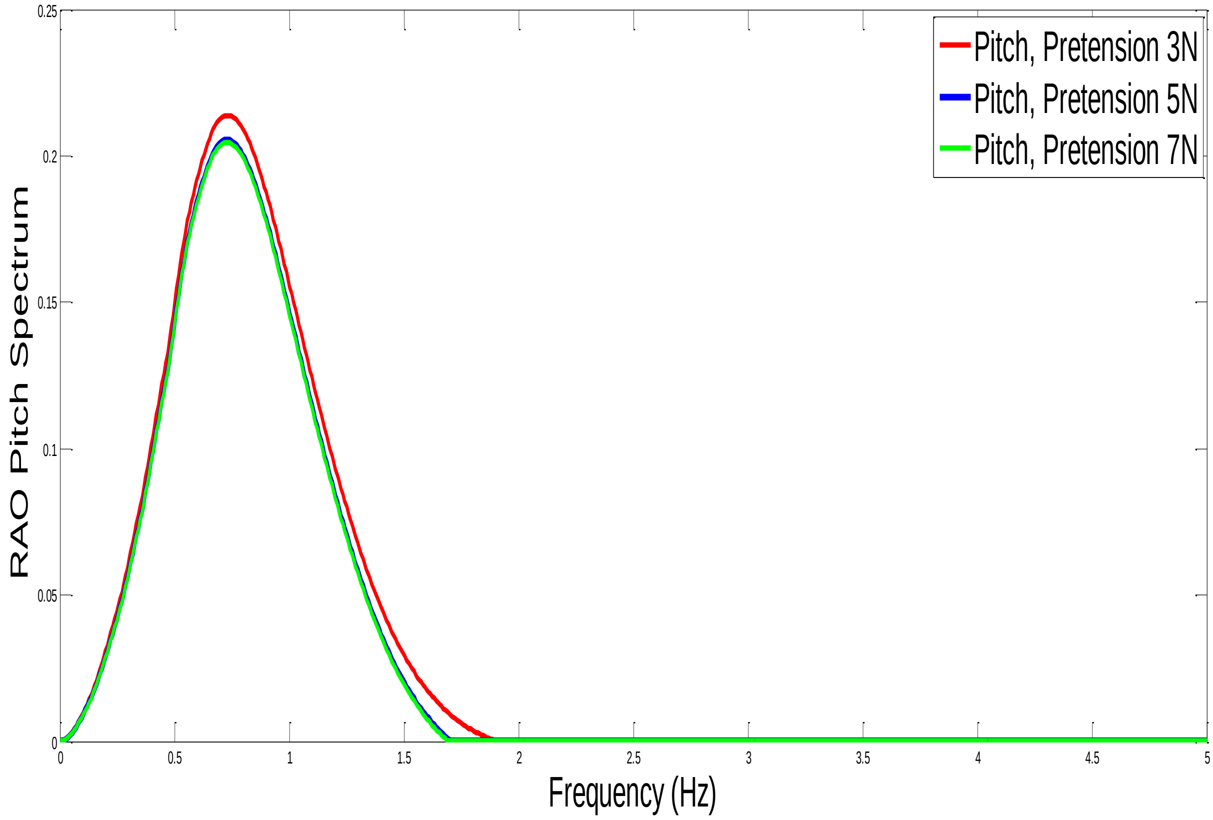


Figure 4.17 Pitch Motion RAO for pretension (random)

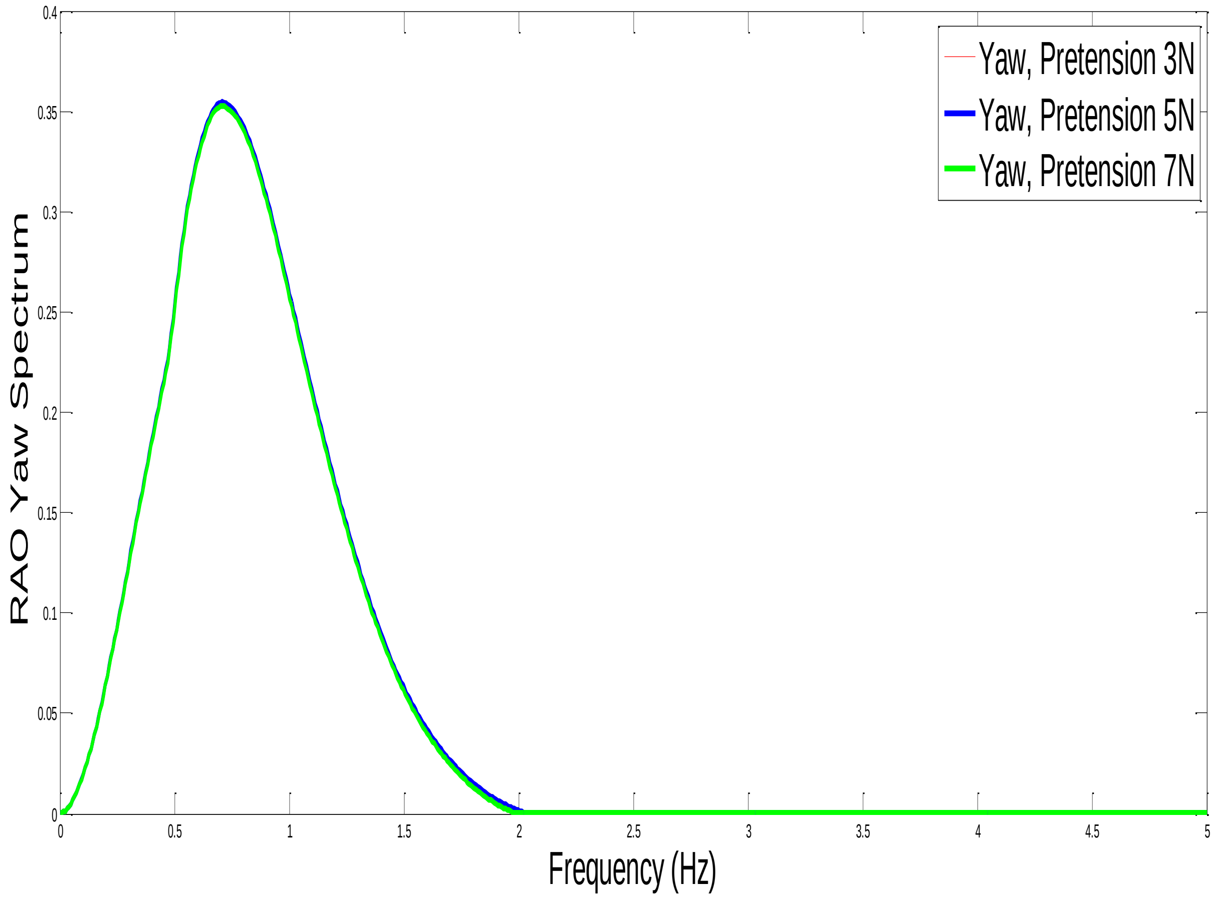


Figure 4.18 Yaw Motion RAO for pretension (random)

4.3.2 Parametric Study on Azimuth Angle of mooring lines of Truss Spar

From the spectrum obtain, author can conclude that the maximum energy occur at the range of 0.5Hz to 1Hz, to be more specific it achieve maximum at 0.75 Hz.As shown in Figure 4.19, Surge Motion has gave maximum RAO magnitude which is 47 and the minimum RAO is 43 that both occurred at 0.75Hz. Figure 4.20 has showed that maximum heave RAO is 19.5 and the minimum is 16.3 which both occurred at the 0.8Hz. Figure 4.21 has given the maximum value of sway RAO which is 18 and the minimum value is 17. Both occurred at 0.75Hz. For Figure 4.22, the maximum value of roll RAO is 0.047 and the minimum is 0.04. For pitch RAO, the maximum is 0.22 and the minimum is 0.19 as shown in Figure 4.23. Besides that, there is significant difference on yaw RAO as maximum value is 0.36, meanwhile minimum value of yaw RAO is 0.28.

For clarification, the minimum energy indicates that minimum dynamic motion of the spar. From the spectrum, author can conclude that first configuration has experienced least dynamic motion compared to second and third configuration. Hence first configuration is the optimum configuration compared to second and third configuration.

After all, author can say that RAO on surge, heave and sway have given significant value on RAO which mean the dynamic motion is higher on that motion compared to circular Degree of freedom (roll, pitch and yaw).

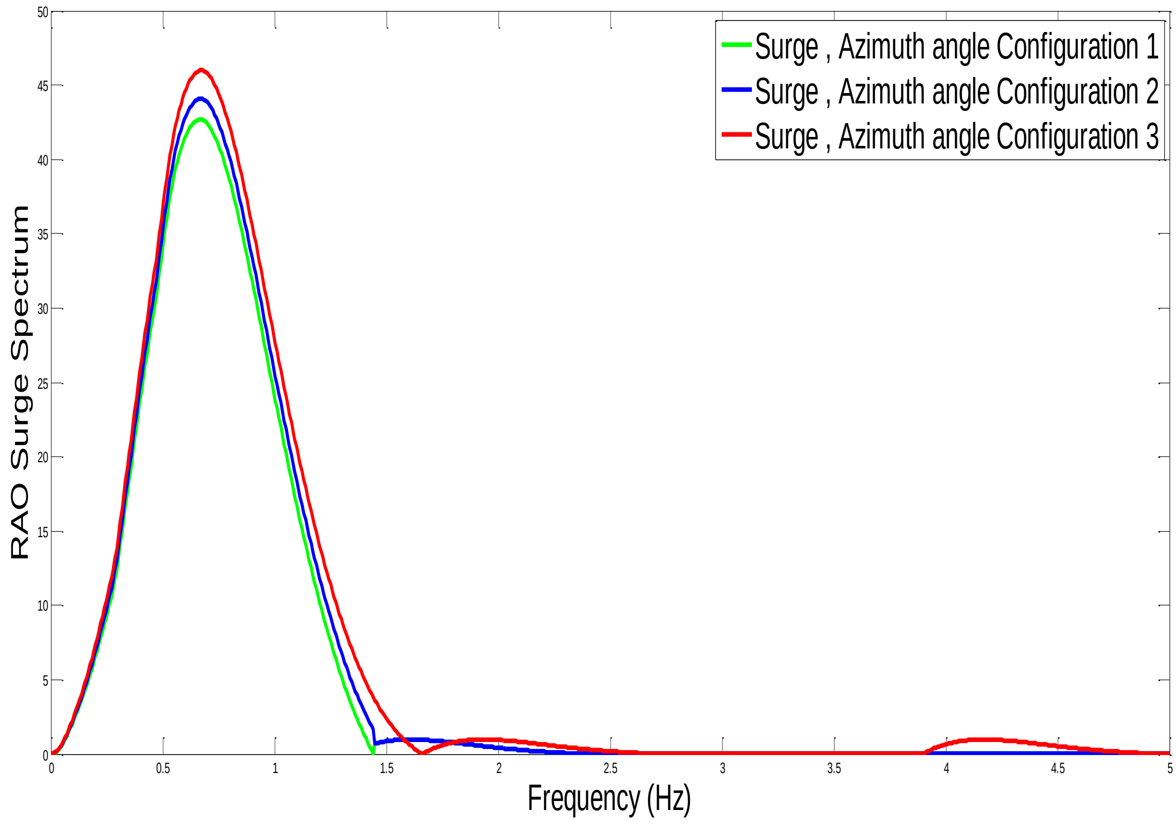


Figure 4.19 Surge Motion RAO for azimuth angle (random)

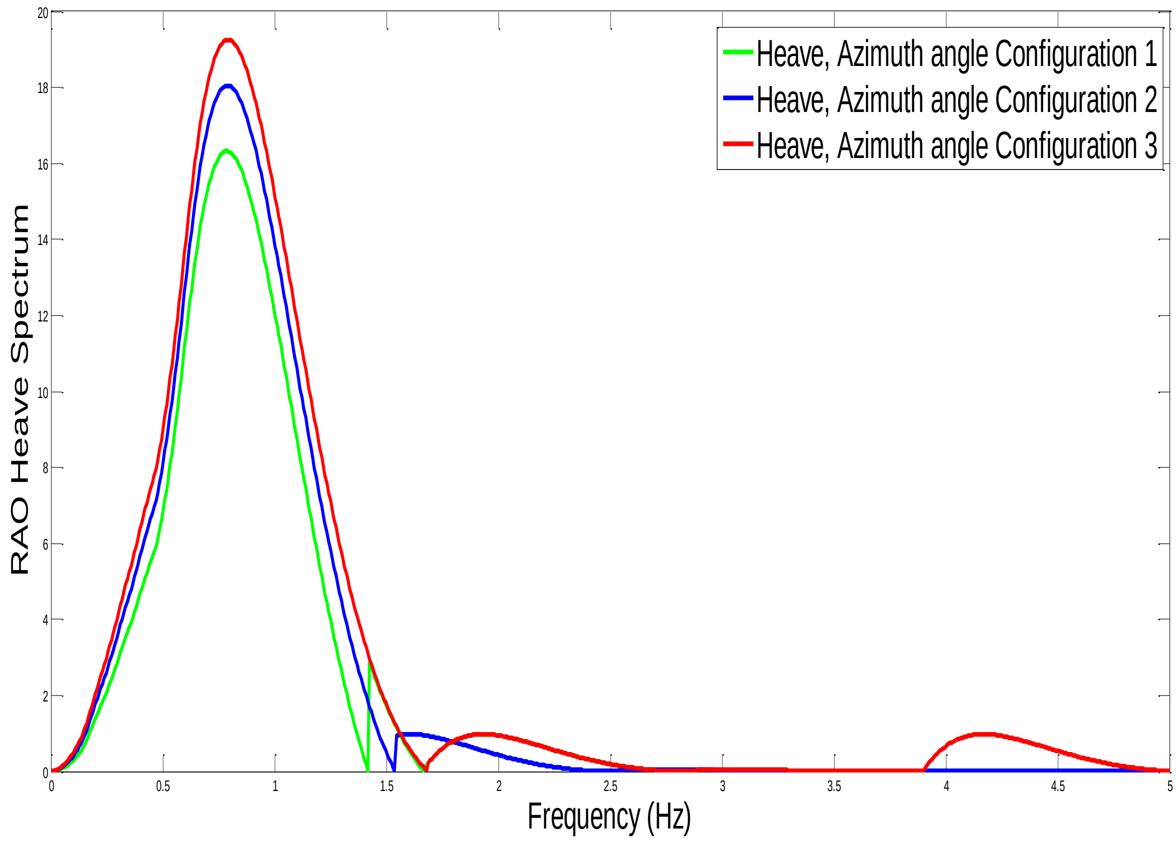


Figure 4.20 Heave Motion RAO for azimuth angle (random)

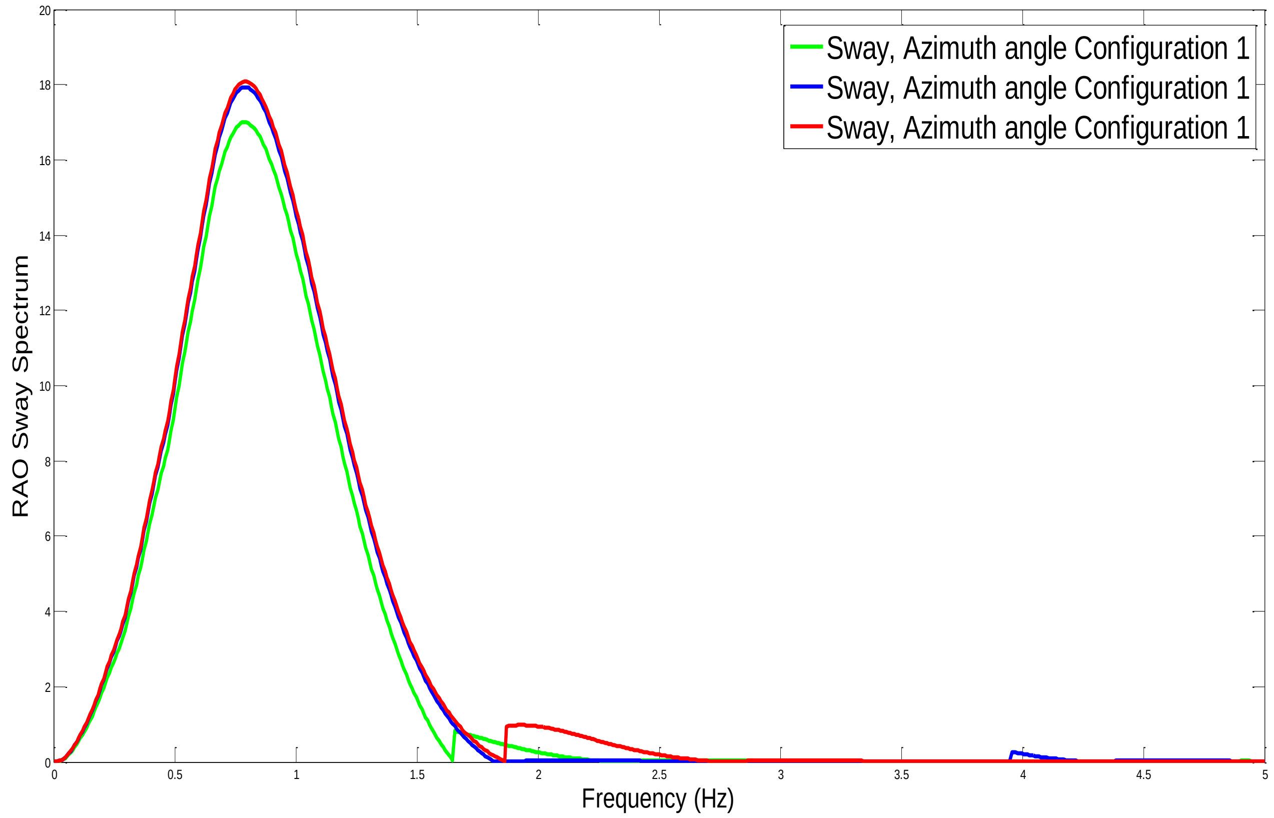


Figure 4.21 Sway Motion RAO for azimuth angle (random)

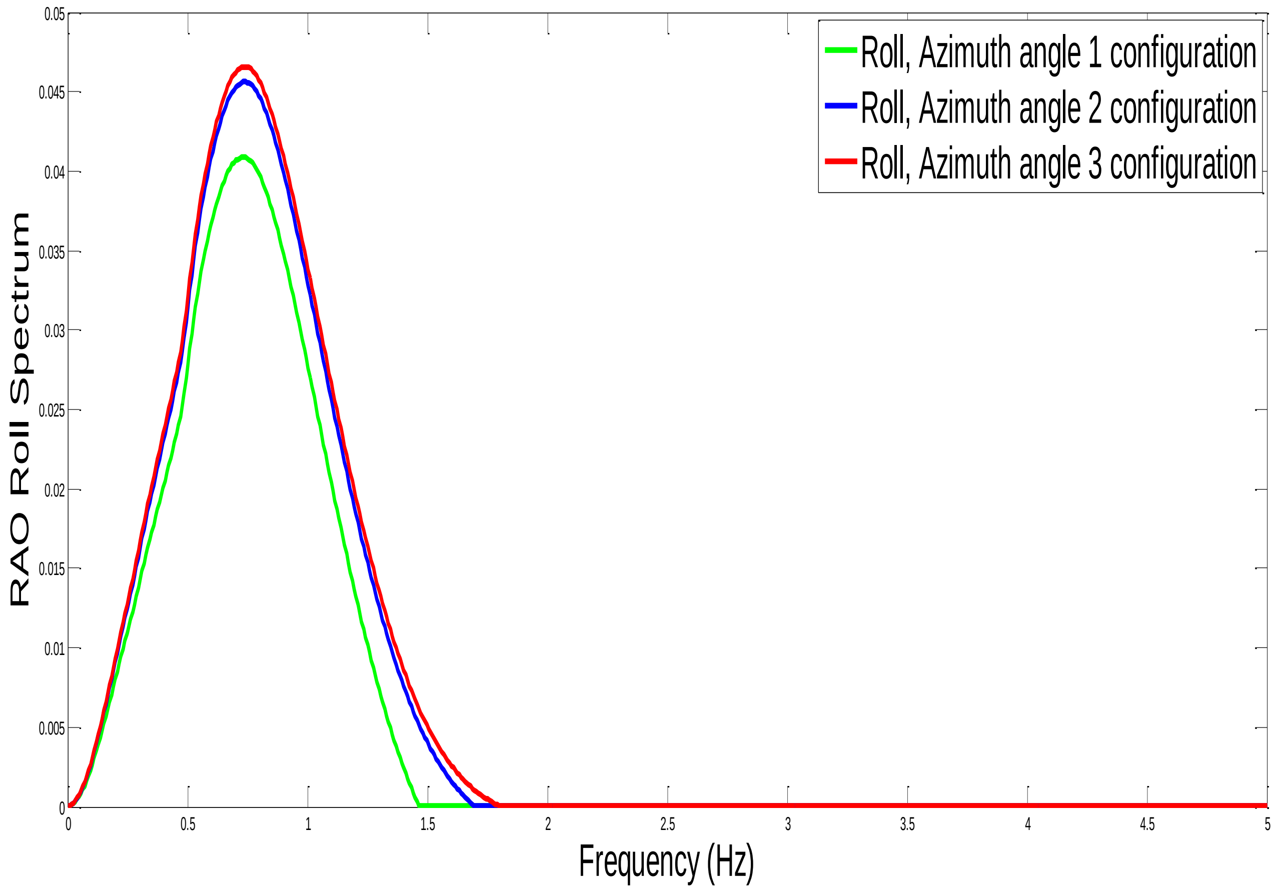


Figure 4.22 Roll Motion RAO for azimuth angle (random)

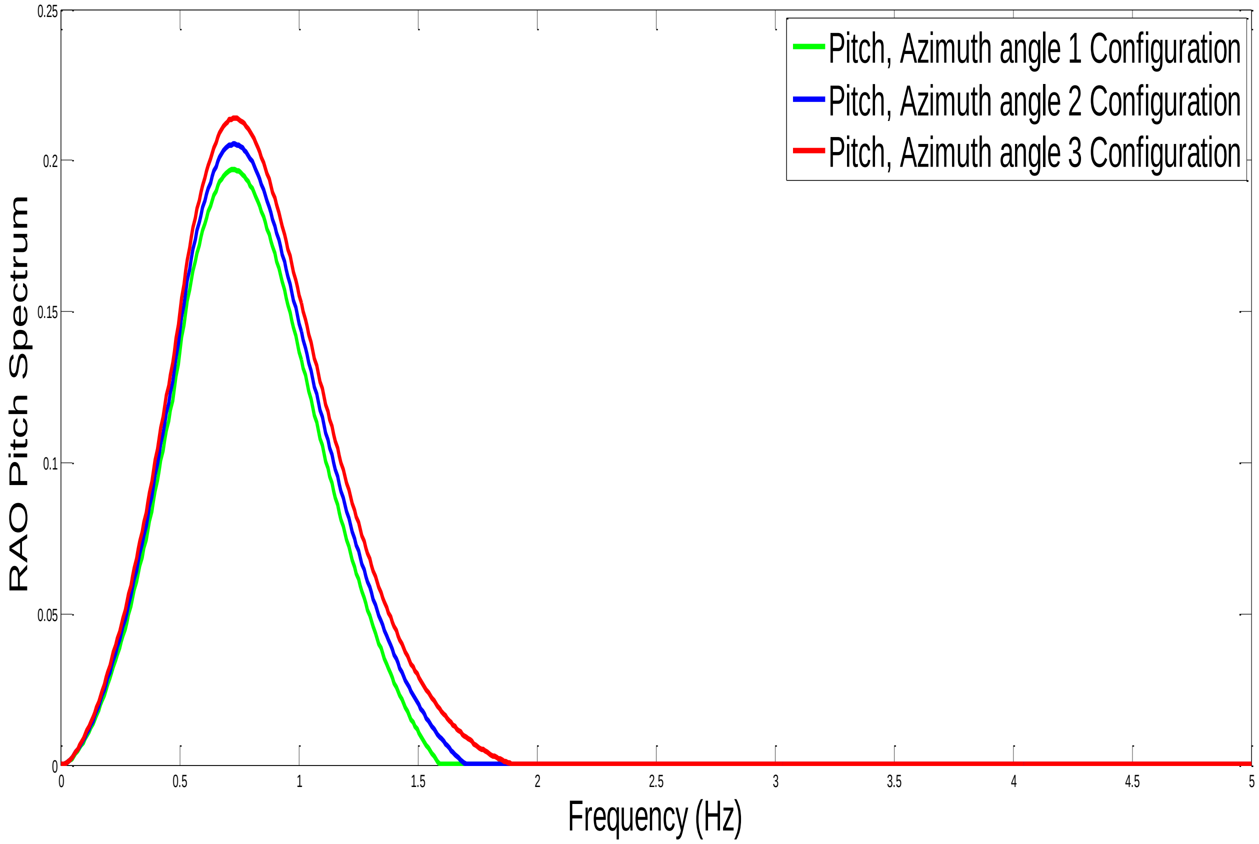


Figure 4.23 Pitch Motion RAO for azimuth angle (random)

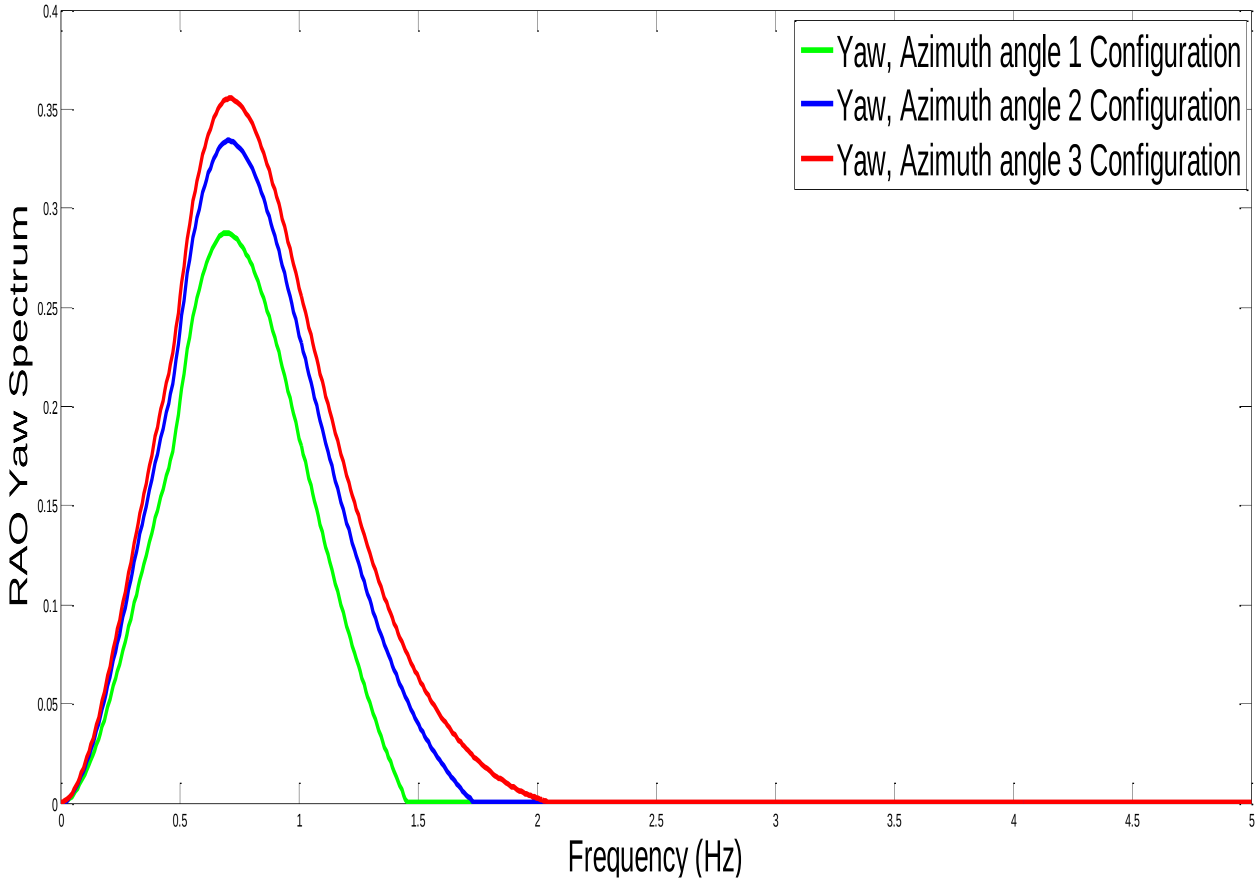


Figure 4.24 Yaw Motion RAO for azimuth angle (random)

4.3 Static Offset Result

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 almost 11 N.

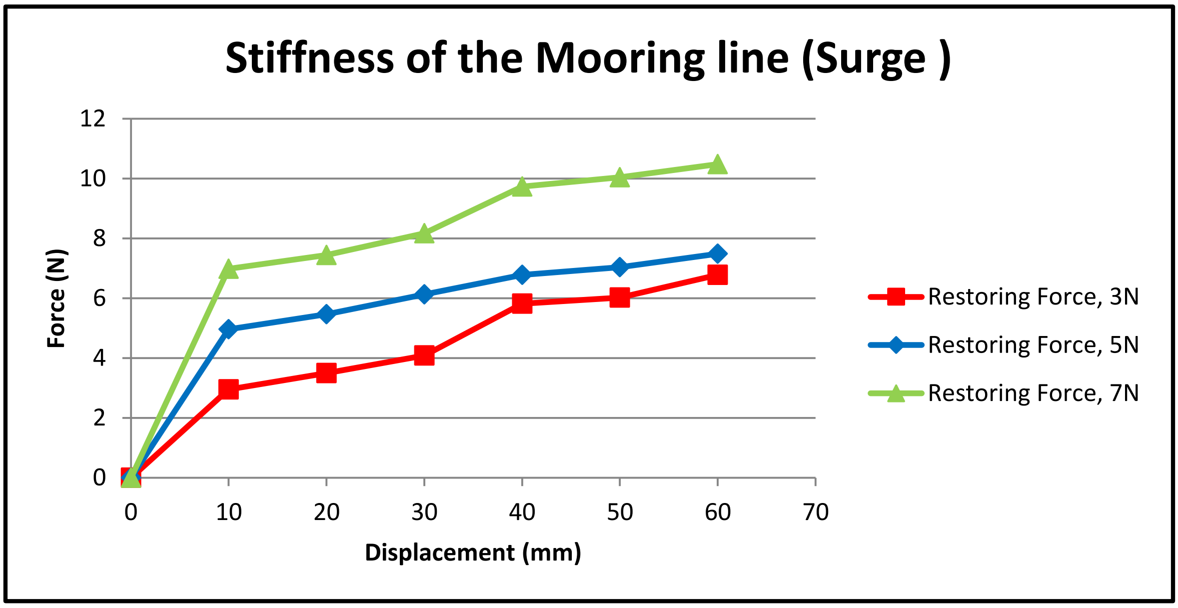


Figure 4.25 Stiffness of mooring line for Surge

As shown in Figure 4.25, generally, as the pretension is increased, the restoring force also increased. The 7N pretension has given highest value of restoring forces. This shows that the spring can uphold the tension up until 11N for surge motion.

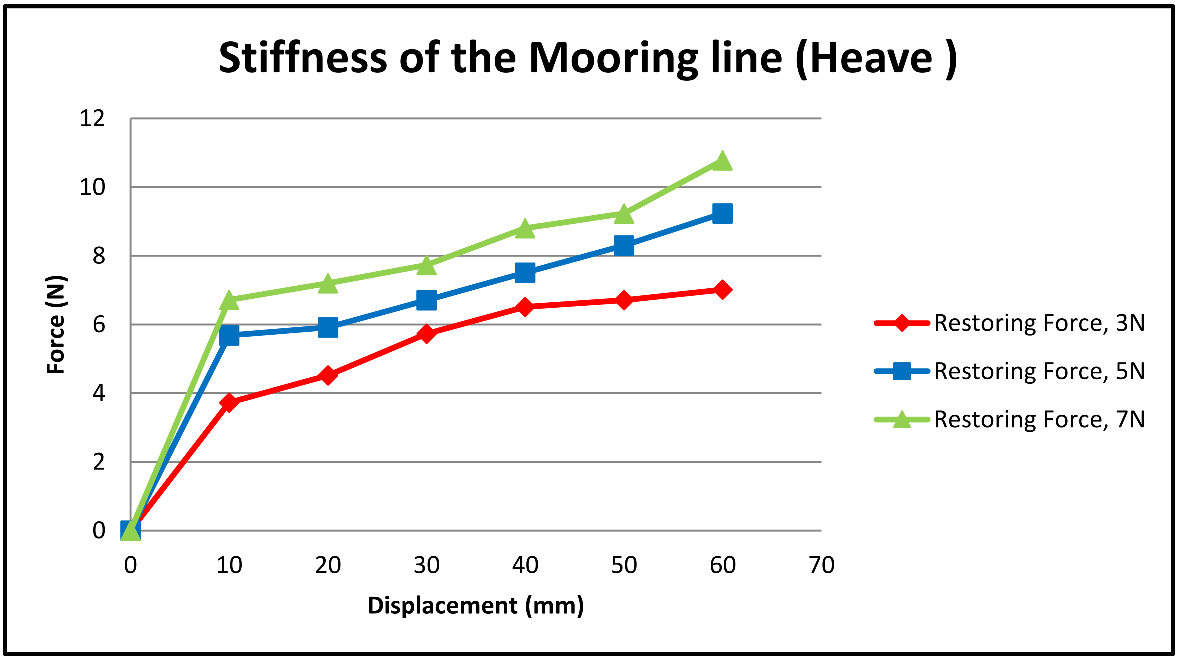


Figure 4.26 Stiffness of mooring line for Heave

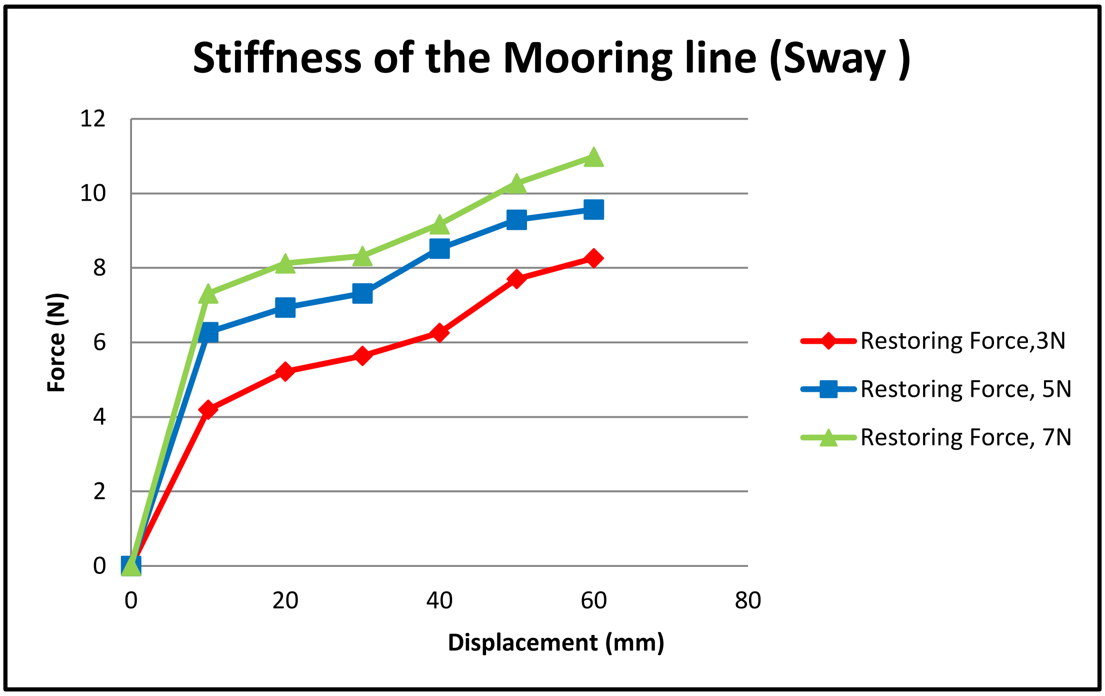


Figure 4.27 Stiffness of mooring line for Sway

As shown in Figure 4.27, the trends are quite similar with another motion such as surge and heave motion. As the pretension increased, the spring has higher restoring forces which indicated the stiffness of the spring. In general, the higher pretension is providing optimum configuration.

4.4 Free Decay Result

4.4.1 For Pretension parameter

Table 4.3 Free Decay Parameter for Pretension Parameter

Pretension Configuration	Natural Frequency,Hz (Surge)	Natural Frequency,Hz (Heave)	Natural Frequency,Hz (Sway)
3	1.0	1.0	1.1
5	0.5	0.52	0.56
7	0.35	0.34	0.35

For free decay result, author able to do three degree of freedom of motion only due to limitation on data for another three rotation- degree of freedom

The result shows that the natural frequency is lower as pretension increase. This show that the higher pretension has given more restoring force and it take few times to complete one period. It can be observed that the restoring performance in mooring line increases as the line pretension increases. It can also be observed that the difference in mooring restoring performance directly proportional to natural frequency of mooring line system.

For this result, author can conclude that the 7N pretension is optimum configuration for pretension model testing.

4.4.2 For Azimuth Angle parameter

Table 4.4 Free Decay Parameter for Azimuth Angle Parameter

Azimuth Angle (◦) Configuration	Natural Frequency,Hz (Surge)	Natural Frequency,Hz (Heave)	Natural Frequency,Hz (Sway)
1. 60,120,240,300	0.5	0.52	0.56
2. 0,90,180,270	0.75	0.76	0.75
3. 30,90,180,270	1.5	1.62	1.5

It can be observed that the restoring performance in first configuration is higher than second and third configuration. This can also be observed that the difference in mooring restoring performance is decrease as mooring lines is shifted away from wave heading. For this result, author can conclude that the first configuration is the optimum configuration compare to second and third configuration

4.5 Wave Test Results

Table 4.5 summarizes the target and measured regular waves which were used for the sea-keeping experiments. Five 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 (from wave probe)

Drive Signal	Wave Height (m)		Wave Period (s)	
	Target	Measured	Target	Measured
RG 1	0.04	0.04	0.5	0.55
RG 2	0.03	0.285	0.7	0.7
RG 3	0.05	0.05	0.9	0.9
RG 4	0.04	0.04	1	1
RG 5	0.06	0.55	1.8	1.8

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 static offset, free decay and sea- 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, pretension of mooring lines and second is configuration of azimuth angle of mooring lines attached to truss spar. The mooring lines configuration and experimental setup is presented in the previous chapter. The spar and is moored by 4 mooring lines and attached to truss spar. As for now, the dynamic response of mooring line configuration is obtained from motion of RAO that have shown is previous chapter. Result of static offset and free decay is obtained and presented in the previous chapter. After all, author can conclude that for pretension, the pretension's optimum configuration for this model testing will be 7N. Meanwhile for azimuth angle is 1 configuration. In general, the higher pretension has led to more restoring forces and minimizes the motion of spar when subjected to environmental load. Meanwhile for azimuth angle configuration for symmetric condition is more optimum compared to asymmetric condition.

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:

1. Calm Water Acquisition

Prior to running a wave test, a data acquisition should be done in calm water measuring all channels. This will provide a record of all pre-experiment transducer “zero” levels, and may be useful in identifying electronic drift later in the experiment. It will serve as an additional transducer check, and provide a record of basin standing wave conditions. Additional calm water runs can be acquired throughout the experiment.

2. Instrumentation Sign Check

Following the model and instrumentation installation, and prior to experiment commencement, the performance and sign convention of all transducers and gauges will be confirmed by applying a known load or displacement. The process will be recorded through the data acquisition and stored for quality assurance purposes. The measured result will be compared to the applied quantity. This will indicate whether the transducer/gauge is functioning according to the calibration, and conforming to the defined sign convention. Adjustments can be made to the non-conforming devices, prior to testing, or corrections can be applied during processing.

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APPENDICES

Figure 6.1 Experimental setup

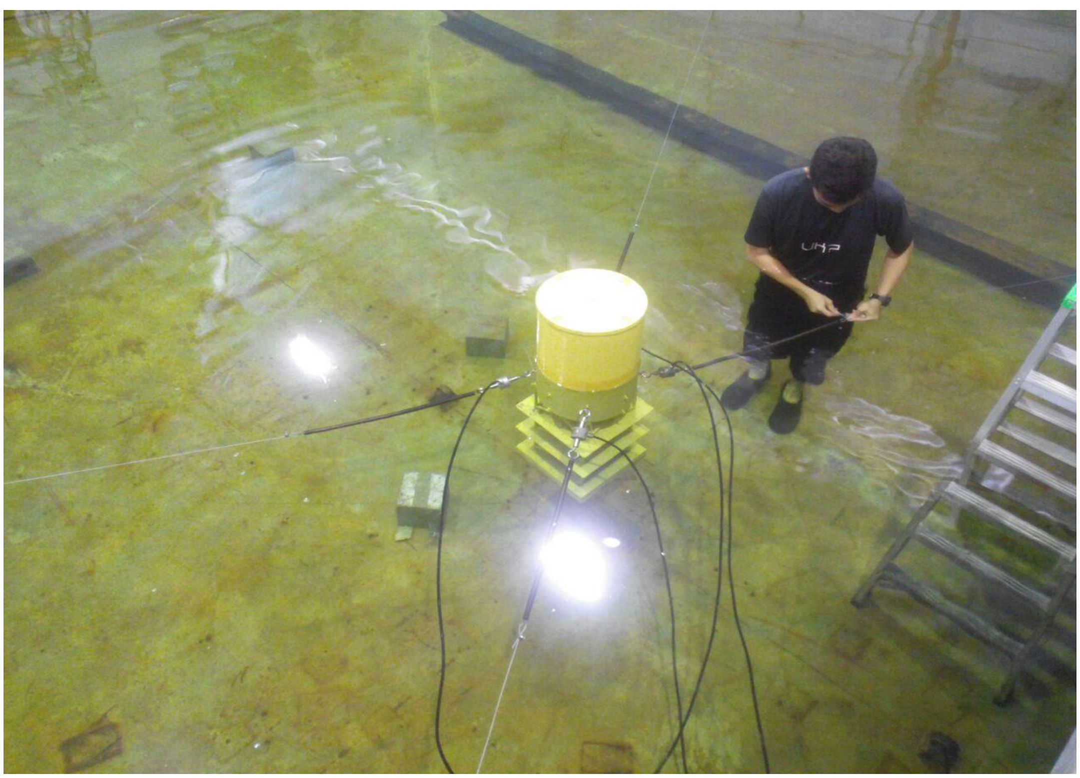

Figure 6.2 Author is setting up the models