EFFECT OF HYDRODYNAMIC COEFFICIENT ON CLASSIC SPARS RESPONSES

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CERTIFICATION OF APPROVAL

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Approved by,

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JULY 2009

CERTIFICATE OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecifiend sources or persons.

(______________________________)

AISHAH RADHIAH BINTI ADANAN

ABSTRACT

This report attempts to discuss the preliminary research done and basic understanding of the chosen topic, which is **Effect of Hydrodynamic Coefficient on the Classic Spars Responses**.

Objectives: To study the performance of Spars Responses with variation hydrodynamic coefficients.

As a floating structure, the motion of spar platform which connected to the sea bottom by anchoring is taken into account. The motions are affected by the environmental load such as wind, current and wave. The different type of the dynamic responses such as heave, surge, pitch, sway, roll and yaw of the classic spar platform are being analyzed.

The research is about to determine how the different values of hydrodynamic coefficients affect the platform response which are surge, heave and pitch. Surge is the motion of the platform horizontally, heave is vertically and pitch is about the rotation of the platform. In this research, three member's conditions are being considered. They are the clean member, semi-fouled member and fouled member which have different hydrodynamic coefficients values. One of factors that affect the member's condition is the marine growth. Marine growth is known to give adverse effects on the performance of offshore structure. It presents will roughened the surfaces of the structure hence increase its drag coefficients. Structures with the best protection scheme from marine organisms would after few years start to be covered by various types of growth. Generally, it was also recognized that the most important source of loading exerted on offshore structure comes from hydrodynamic action which are influenced by CD and CM values.

From the research done, it is concluded that the motion of clean member is larger compared to semi fouled and fouled member. It is because, for the fouled member, the forces are dissipated to the fouled parts.

ACKNOWLEDGMENT

First and foremost, praise upon Allah Almighty in giving me enough strength and courage to complete my Final Year Project entitles "Effect of Hydrodynamic Coefficients On Classic Spars Responses". Sincerely, I would like to give my appreciation to my FYP supervisor, Prof. Dr. Kurian V. John for his guidance, suggestions and comments towards this research project. Personally I felt that without his excellent supervision and patience, I would never be able to finish this project.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

As oil and gas offshore Exploration and Production (E&P) operations in deep water, many innovative floating offshore structures are being proposed for cost savings. Offshore structure may be defined as one which has no fixed access to dry land and which is required to stay in position in all weather conditions. One such type of floating platforms is Classic Spar platform. It is one of a compliant structure which has high stability and excellent motion performance in optimum construction and maintenance cost. To date, in conjunction with the development of oil and gas exploration into deeper and deeper water, spar platform become the most chosen platform by many companies. It is modeled as a rigid cylinder with six degrees of freedom at its center of gravity. (Jun B. Rho and Hang S. Choi, 2003). Classic Spar platform is always connected to the sea floor by multi-component catenaries mooring lines emanating from the spar's hull to keep it stationary at desired locations. Such a spread mooring is possible because unlike ships, the environmental force on a spar platform is relatively insensitive to direction.

Examples of environmental forces are wind force, wave force and current force. All of these forces are directly affect the response of the platform. There are factors that influenced the amplitude of force acting towards the platform. One of them is the hydrodynamic coefficient. The hydrodynamic coefficients consist of drag coefficient (Cd) for the drag force (Fd) and initial coefficient (Cm) for inertia force (Fi). There are several reasons why the hydrodynamic coefficient values changed. The main reason is because of the surface roughness. The platform's surface roughness plays a big role in determining the effect of the force towards the platform response. This is because, if the platform members are rough which is mostly because of the marine growth, then the flow of water will be different. Thus, effect the amount of wave and force hit the platform.

1.2 PROBLEM STATEMENT

Offshore structures are complex type of installations placed in the sea for several purposes. They usually intended for oil exploration, production, processing or accommodation. During their lifetime, they will usually experience several types of loadings. These loading among others are operational loading, gravity loading, environmental loading as well as accidental loading. Environmental loading are wind load, wave load and current load. All off these loads will affect the platform responses.

On any structure installed offshore, numerous type of marine fouling organism may be found on its submerged member after a certain time. Their distributions on structural members vary according to several factors; among others are geographical location, water depth, water temperature and season, ocean current, platform design and operation. This marine growth will affect the platform's surface roughness which then directly affects the hydrodynamic coefficient. Hydrodynamic coefficients consist of drag coefficient, Cd and initial coefficient, Cm.

Different hydrodynamic coefficient will caused different amplitude of horizontal wave and therefore caused different displacement of platform motion which is subjected to the wave. Therefore, it is important to study on the relation of surface roughness with the hydrodynamic coefficient and their effect towards the platform responses.

1.3 OBJECTIVES AND SCOPE OF STUDY

The objectives of this research are:

- To determine the water particle motion in order to get the horizontal force that effect the platform
- To determine the wave profile
- To study on how different values of hydrodynamic coefficients effect the platform responses
- To determine what condition of the platform member caused more responses.

For this project, the scope of study would be on deepwater technology in oil and gas industry. The project will be more focusing on classic spar platform which consists of:

- Study about the wave properties such as wave speed, wave frequency, wave particle and more. Besides that, sketch for particle orbit and kinematics by linear theory also being done.

- Study on the behavior of the classic spars platform under the environmental effect influent (such as wind, wave and current) and load applied.

- Analyze and determine the dynamic responses of spar platform such as heave, surge, pitch, sway, roll and yaw which are subjected to wave loads. Manual calculation using the hydrodynamics equations being done and compared with the data gained from the observation of the movement of the scaled-platform model.

CHAPTER 2

LITERATURE REVIEW

2.1 CLASSIC SPAR PLATFORM

As the development of oil and gas companies become highly competitive nowadays, the innovation of the platform becomes famous and high demand. Spar platform has been operated for offshore structures in oil and gas industry especially in deep water production. Spar platform can be installed at 500m until 3000m water depth. The shape of spar platform is usually consists of long hollow vertical cylinder with large diameter which is normally moored by means of conventional spread chain (Jun B. Rho and Hang S. Choi). Up to now, there are three types of spar which are classic spar, truss spar and cell spar. The classic spar is a large, cylindrical hull moored in a vertical position. The pioneering spar production system offers a stable platform that can accommodate dry trees and support work over and drilling operations. The truss spar replaces the lower portion of cylindrical hull with an open truss structure to reduce the size and cost. The latest and current spar which now becomes as the third generation of spar technology is called as cell spar. The spar is improved as the structure which is easy to fabricate and flexible in the water besides makes it more cost-efficient design, providing another option to reduce the reserve threshold for economic development of deepwater field. Besides that, it can be removed easily to other offshore platforms.

The characteristic of Classic Spar platform are as below:

a) It can be operated up to 3000 meters of depth.
b) It is stable since the center of buoyancy is always above the center of gravity of structure.
c) It has a favorable motion compares to the other floating structures.
d) It has a minimum hull/deck which can be configures for significant liquid storage if this is advantageous.
e) Oil can be stored at low marginal cost. (Agarwal and Jain, 2001)

In 1996, Kerr-McGee pioneered the use of spar technology in deepwater field development at its Neptune field, in the Gulf of Mexico. It was the world first spar floating production facility which has been installed in the water depth of 588 m. The spar, NEPTUNE is a classic spar with 198-m long vertical cylinder with diameter of 22 m (Günther F. Clauss, 2007). It consists of an upper buoyancy tank (hard tank) which will be withstanding the full hydrostatic pressure. The hard tank also provides buoyancy for the structure to support deck, hull, ballast and vertical tensions. The soft tank at the bottom of the hull will provide floatation during the installation stages when it is floating horizontally as well as for the placement of fixed ballast.

As the offshore industry is moving into deeper waters and more hostile environment, the oil industries with the help of contractors and consulting films has developed several alternate platform concepts for deep water production. This is to ensure that the offshore industries can achieve the target.

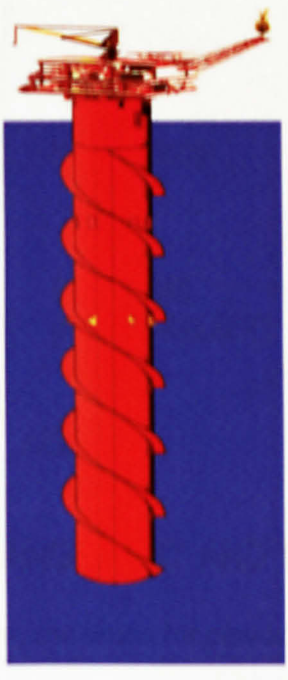


Figure 2.1: Classic Spar Platform

Classic spar platform can support the rigid and flexible risers. The required air gap must be accurately determined in order to keep the platform stable. The air gap is the region between the mean water level and the freeboard. Classic spar platform has high stability which can withstand the environmental disturbance such as wind, wave and current. Besides that, it is excellent in motion performance and the cost for construction and maintenance is low.

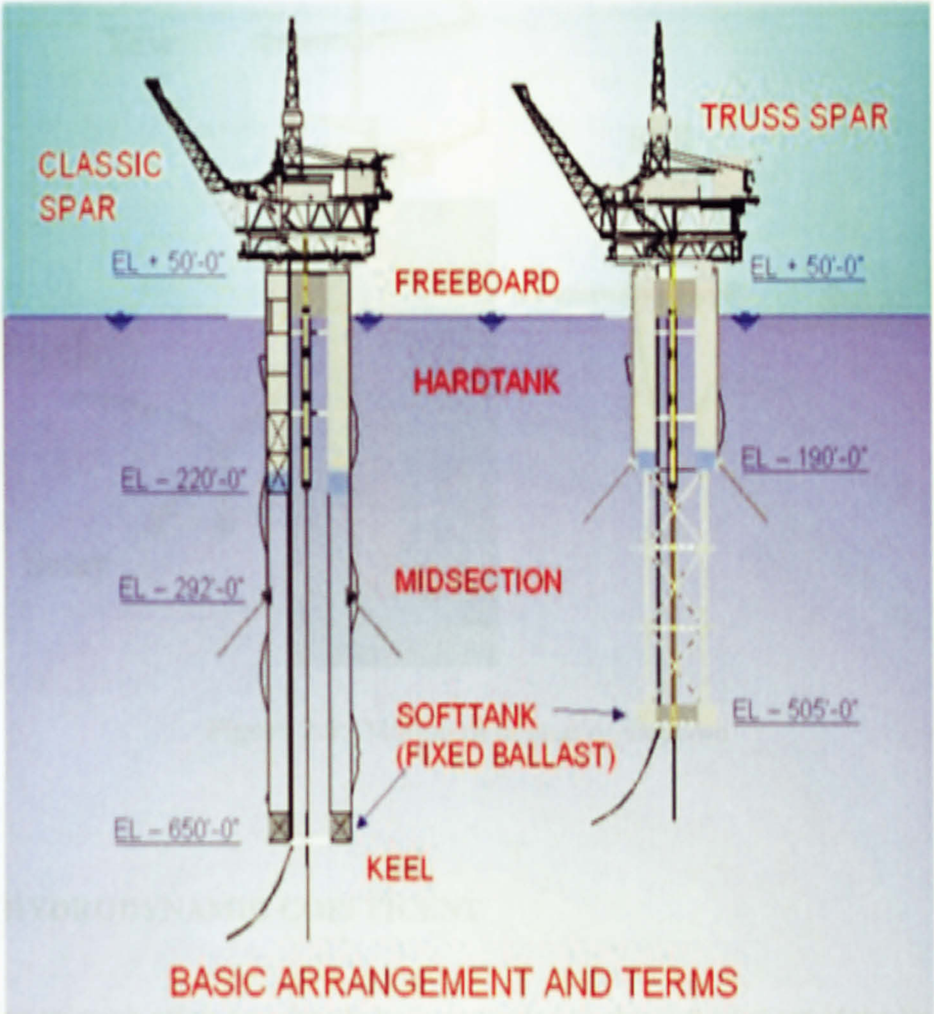


Figure 2.2: Basic arrangement and terms for classic and truss spar platform.

2.2 DYNAMIC BEHAVIOUR OF SPAR PLATFORM

The spar platform is modeled as six degree-of-freedom structure. There are three displacements consist of surge, sway and heave along X, Y and Z axis respectively and also three rotational motions which is roll, pitch and yaw about those three axis.

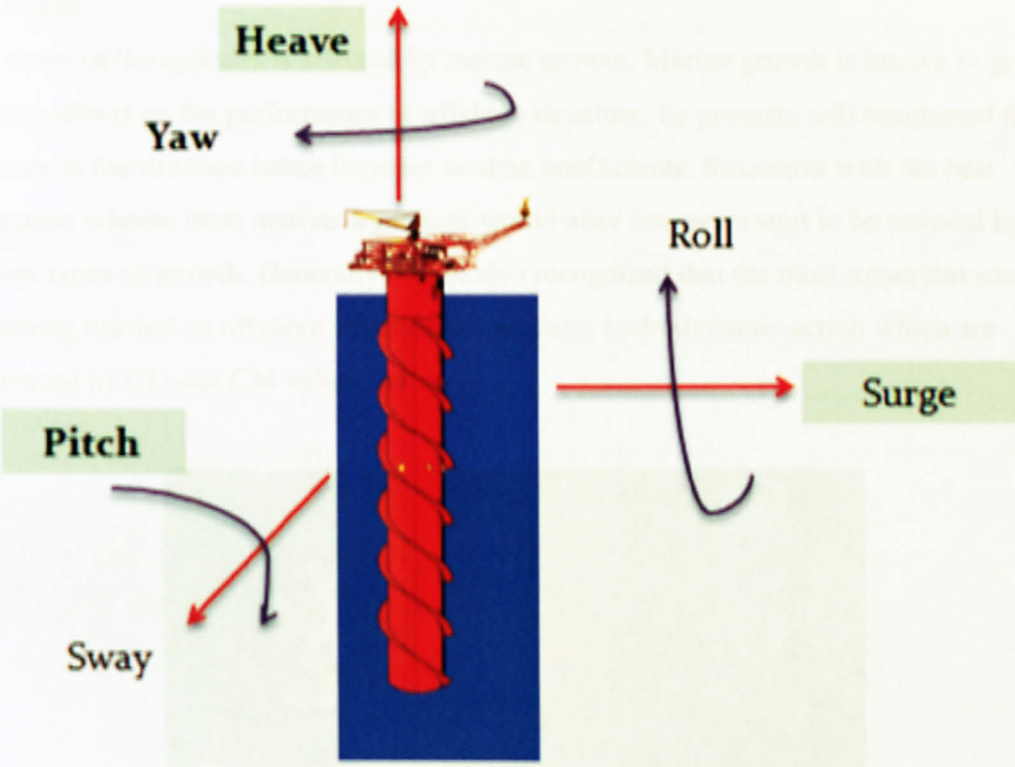


Figure 2.3: Motion of degree-of-freedom

2.3 HYDRODYNAMIC COEFFICENT

Extensive research effort has already been expended to obtain the values of the force coefficients, C_M, drag coefficient, C_D, and lift coefficient, C_L both in laboratory and in the field. Based on the research, it has successfully demonstrated the dependence of these coefficients on appropriate nondimensional quantities. However, before applying the values of any coefficients available in the literature to a design case, it is important to know how they were determined.

There are several factors that affect the hydrodynamics coefficient such as the Reynold's number, the shape of the cylinder, the forces, Keulegan-Carpenter number etc. All of these factors will give the effect to the platform because it affects the hydrodynamic coefficient.

The shape of the cylinder is affected by marine growth. Marine growth is known to give adverse effects on the performance of offshore structure. Its presents will roughened the surfaces of the structure hence increase its drag coefficients. Structures with the best protection scheme from marine organisms would after few years start to be covered by various types of growth. Generally, it was also recognized that the most important source of loading exerted on offshore structure comes from hydrodynamic action which are influenced by CD and CM values.

Figure 2.4: Example of marine growth at the platform

CHAPTER 3

METHODOLOGY

3.1 PROCEDURE

Research about the classic spars platform is very important in order to give the better understanding on the topic chosen. The information gained from the books, journals and also from the related websites. All of the information then being discussed with the supervisor and additional information is given by the supervisor. The weekly meeting with the supervisor helps a lot in getting clear view on how the project should be done.

3.1.1 Literature Survey

The journals and books available which related to the topic of project are chose to be summarized. This is a sequence of the research done by the author. The author needs to go through the journals and books and find the important information and data related to the project. Those information and data will be then highlighted and abridge into a short summary. This information soon will be used as a guideline and reference in order to complete the project. Besides that, information are also gained from the website which are related to hydrodynamic coefficient and classic spars platform.

3.1.2 Form Objectives

It is needed for the author to have an aim to make sure the project will carry on very well. Therefore, the objectives are formed so that the author clears on what to be achieved in this project. The step by step tasks have to be arranged in order to make the progress of the project going smoothly. The description of the target project is required to point out the main idea and planning of the undergoing project.

3.1.3 Manual Calculation using the hydrodynamic equations

The author has done the manual calculation using the equation gained from the literature survey. The calculation of the particle movements and hydrodynamic effect towards the platform are done using Microsoft Excel.

3.1.4 Offshore Lab

The model of the platform was build based on the data and dimension which had been finalized. The model then is tested with varies test and condition to determine the properties of the platform and to determine the hydrodynamic coefficient effect to the platform. The data gained are noted and compared with manual calculation.

3.1.5 Tools

The author needs to use some software in order to complete this project. The very basic software used for calculation is Microsoft Excel. This software helps to calculate the needed values faster and reduce the error compared to if it is done manually. Matlab software is also used in this project. Structural Analysis Computer System (SACS) software will be the main software used in this project. Finally, the tools are used while the author does the offshore laboratory.

3.2 WORK PROGRESS

There are some activities related to the project which has been completed after the mid-semester break.

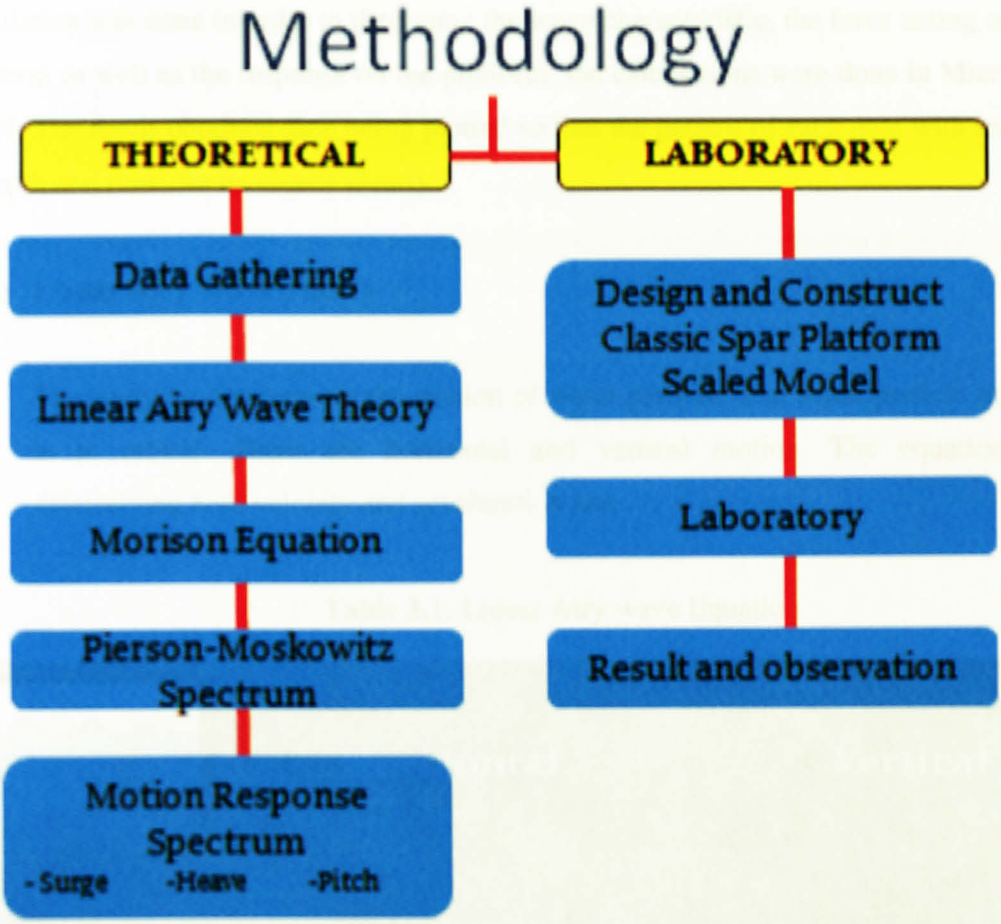


Figure 3.1: Flow of work progress

3.2.1 Research And Literature Review

A lot of research has been done for the first few weeks in order to enhance the familiarization on the chosen topic. The scopes of research are about the classic spar platform and the dynamic coefficient behavior towards the platform. The research obtained from the related journals and websites. The information gained are summarized and will be used for the further research and activities in this project.

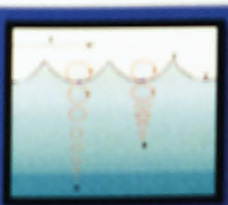
3.2.2 Manual calculation using hydrodynamic equations

The author had done manual calculation based on the chart of the methodology. The calculation was done in order to determine the wave characteristic, the force acting on the platform as well as the response on the platform. the calculations were done in Microsoft Excel. The result obtained then being plotted so that the pattern of each data with respect to depth and time can be shown clearly.

a) Linear Airy Wave Theory

The study on determining the motion of water particle. The water particle motion is in orbital. There are horizontal and vertical motion. The equations of determining both velocity and acceleration are:

Table 3.1: Linear Airy wave Equation

	Horizontal	Vertical
Water Particle Velocity	$u = \frac{\pi H}{T} \frac{\cosh ks}{\sinh kd} \cos \Theta$	$v = \frac{\pi H}{T} \frac{\sinh ks}{\sinh kd} \sin \Theta$
Water Particle Acceleration	$\dot{u} = \frac{\partial u}{\partial t} = \frac{2\pi^2 H}{T^2} \frac{\cosh ks}{\sinh kd} \sin \Theta$	$\dot{v} = \frac{\partial v}{\partial t} = \frac{2\pi^2 H}{T^2} \frac{\sinh ks}{\sinh kd} \cos \Theta$

Where:

H = Wave height , d = water depth , T = wave period

$k = \frac{2\pi}{L}$ $\theta = kx - \omega t$

b) Morison Equation

Morison equation used to determine the horizontal force acting towards the platform. Total horizontal force is the summation of initial force and drag force as the equation below:

Table 3.2: Morison Equation

Total Horizontal force =	$f = \rho C_M \frac{\pi D^2}{4} \dot{u} + \frac{1}{2} \rho C_D D \mid u \mid u$
Inertial Force	**Drag Force**
$f_I = \rho C_M \frac{\pi D^2}{4} \dot{u}$	$f_D = \rho C_D \frac{D}{2} \lvert u \rvert u$

Where:

ρ = water density, D = Hull diameter

Cm = Initial coefficient, Cd = Drag Coefficient

u = water particle velocity, $\dot{U}$ = water particle acceleration

c) Pierson-Moskowitz Spectrum

1. Wave spectrum

$$S(f) = \frac{ag^2}{(2\pi)^4} f^{-5} e^{\left[-1.25 \frac{f}{f_0}^{-4}\right]}$$

where:

α = constant value (0.0081) , $f_0 = \frac{\omega_0}{2\pi}$

2. From the above equation, the wave height for each frequency can be obtain from the equation:

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

3. Based on previous equation, wave profile can be computed from the equation:

$$\eta(x,t) = \sum_{n=1}^{N} \frac{H(n)}{2} cos[k(n)x - 2\pi f(n)t + \varepsilon(n)]$$

where:

Hn = wave height at frequency n = $H(f_n)$

$\varepsilon(n) = 2\pi R(n)$, where R(n) is random number in range $(0,2\pi)$

d) Motion Response Spectrum

Motion Response Spectrum is the phase where the responses of the platform are determined based on the force acting towards the platform.

Table 3.3: Motion Response Spectrum

Response Amplitude Operators (RAO)
$RAO = \frac{F/(H/2)}{\sqrt{(k - m\omega^2)^2 + (C\omega)^2}}$
Responses when subjected to wave
$Response(t) = RAO \; x \; \eta(t)$

Table 3.4: Computation of Response

	Force (f_i)	Wav
		$\eta(x,t) = \sum_{n=1}^{N} \frac{H(n)}{2}$ [illegible]
Surge	$f = \rho C_M \frac{\pi D^2}{4} \dot{u} + \frac{1}{2} \rho C_D D \lvert u \rvert u$	H_{surge} = RA
Heave	f = Pressure x Area $P = \rho g \frac{H}{2} \frac{\cosh ks}{\cosh kd} \cos\theta$	H_{Heave} = R
Pitch	f = moment of force f = f x distance to center of gravity	H_{pitch} = R

3.2.3 Design the Classic Spars platform mo

To get clearer about the project, the author ha
scale and dimension for the model of the
conclusion with the dimension as stated in th
based on the real platform (Neptune platform)
author had decided to use Perspex as the m
mooring line and concrete block to attached
floor)

Table 3.4: Computation of Response Spectrum and wave profile

	Force (f_i)	Wave profile $\eta(x,t) = \sum_{n=1}^{N} \frac{H(n)}{2} \cos[k(n)x - 2\pi f(n)t + \varepsilon(n)]$	Wave Spectrum
Surge	$f = \rho C_M \frac{\pi D^2}{4}\dot{u} + \frac{1}{2}\rho C_D D\lvert u\rvert u$	$H_{surge} = RAO^2_{surge} \times H(n)$	$S(f)_{surge} = RAO^2_{surge} \times S(fn)$
Heave	f = Pressure x Area $P = \rho g \frac{H}{2} \frac{\cosh ks}{\cosh kd} \cos\theta$	$H_{Heave} = RAO^2_{Heave} \times H(n)$	$S(f)_{heave} = RAO^2_{heave} \times S(fn)$
Pitch	f = moment of force f = f x distance to center of gravity	$H_{pitch} = RAO^2_{pitch} \times H(n)$	$S(f)_{pitch} = RAO^2_{pitch} \times S(fn)$

3.2.3 Design the Classic Spars platform model

To get clearer about the project, the author had discussed with the supervisor about the scale and dimension for the model of the platform. The discussion had come to conclusion with the dimension as stated in the figure below. The model is constructed based on the real platform (Neptune platform) with the scale of 1:317 centimeters. The author had decided to use Perspex as the material for the model, iron chain for the mooring line and concrete block to attached mooring line to the seabed (wave tank's floor)

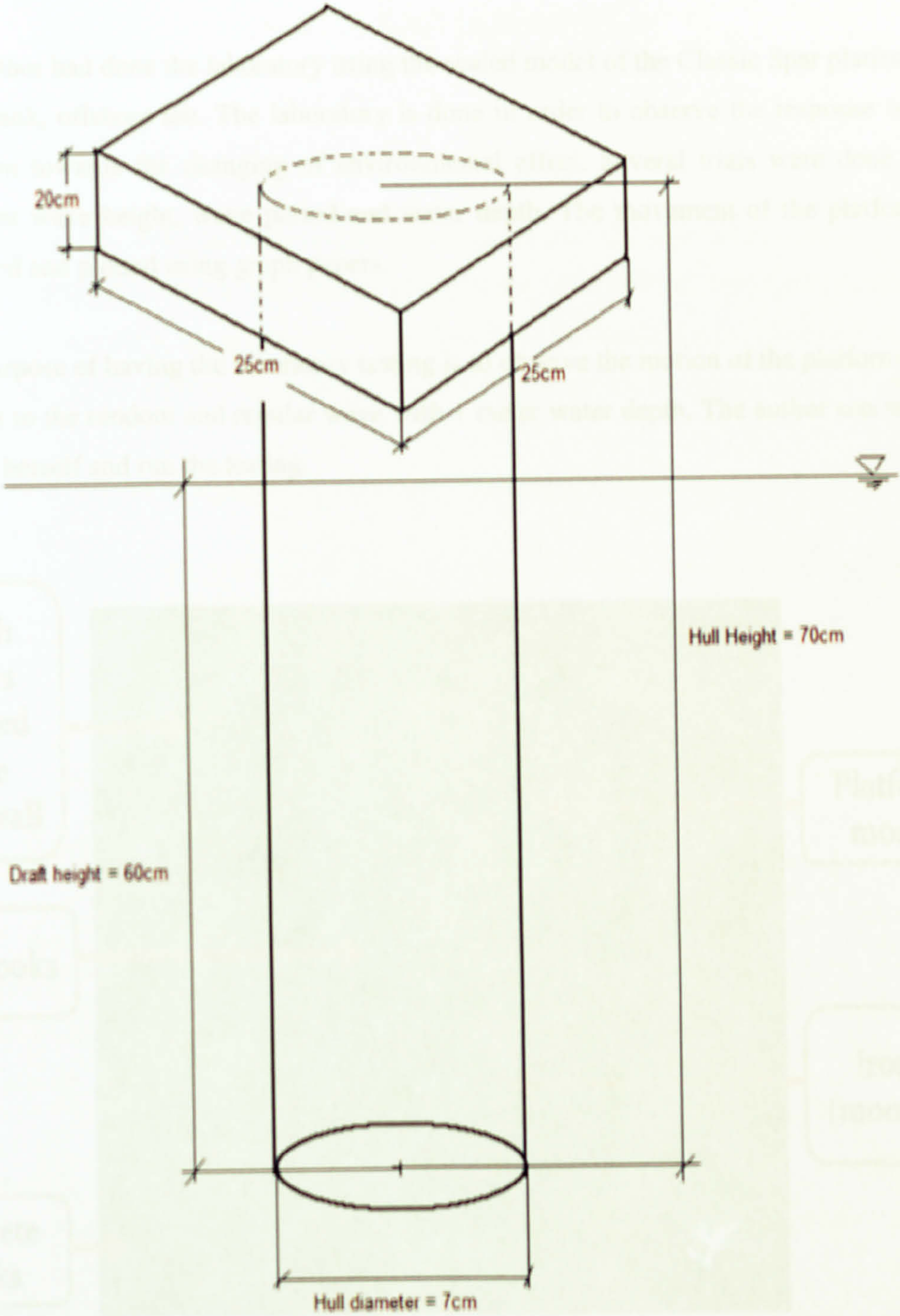


Figure 3.2: Dimension of the Classic Spar platform model with scale of 1: 317cm

3.2.4 Laboratory

The author had done the laboratory using the scaled model of the Classic Spar platform at wave tank, offshore lab. The laboratory is done in order to observe the response of the platform towards the changing of environmental effect. Several trials were done with different wave height, wave period and water depth. The movement of the platform is recorded and plotted using graph papers.

The purpose of having the laboratory testing is to observe the motion of the platform with respect to the random and regular wave with 1 meter water depth. The author sets up the model herself and run the testing.

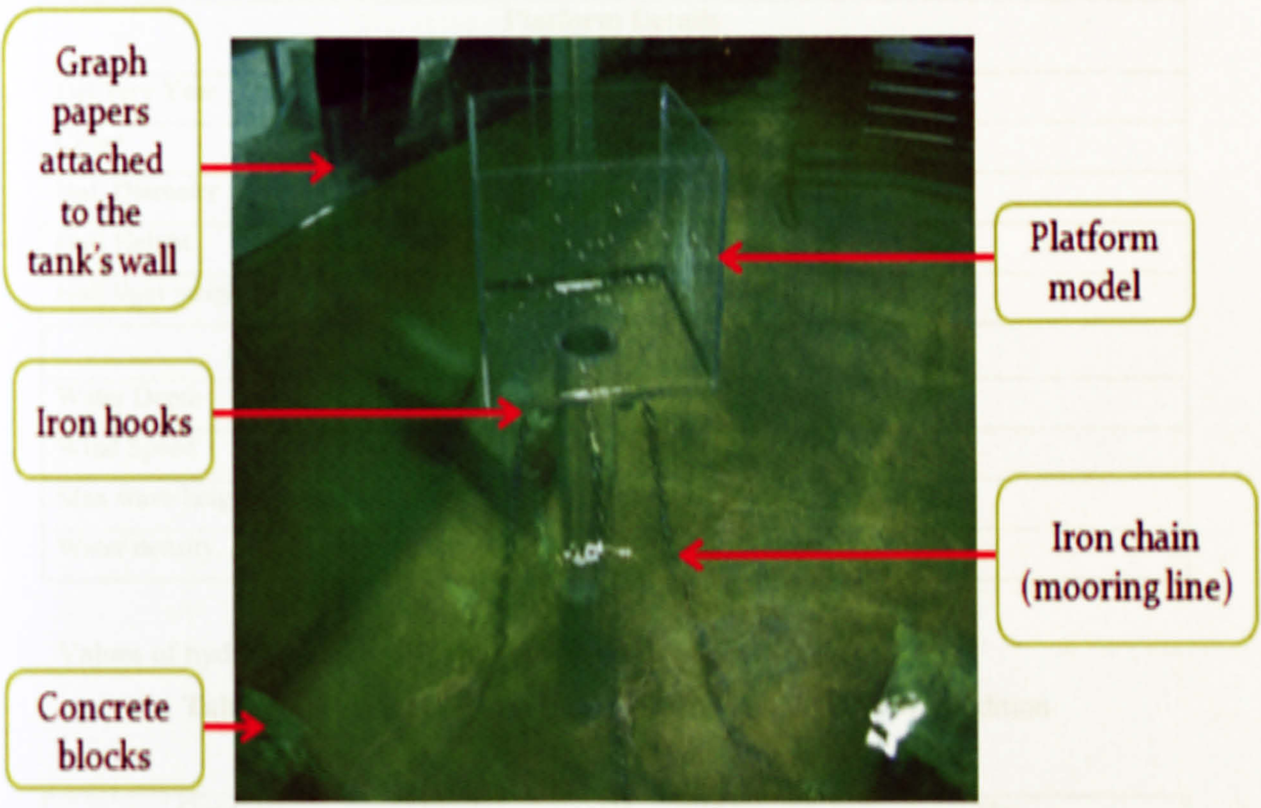


Figure 3.3: Model Setup at the Offshore Lab

CHAPTER 4
RESULTS AND DISCUSSION

4.1 RESEARCH

The author needs to do literature review and finalized the data required in order to calculate the effect of the hydrodynamic coefficient to the platform. Based on research which had been done, the author chose **Neptune Spar Platform** simply because it is the first classic spars platform developed in the world. The details for the platform are as below:

Table 4.1 : Detail of Neptune Spar Platform and environment details

Platform Details (Technip Coflexip Finland)	
Delivery Year	1996
Client	Oryx
Hull Diameter	21.95m
Hull Height	214.88m
Hull light weight	11 699tons
Environment Details	
Water Depth	1,935ft / 589.8m
Wind Speed	7m/sec
Max wave height (storm condition)	8m
Water density, ρ	1025kg/m³

Values of hydrodynamic coefficients used in this project are:

Table 4.2 : Values of hydrodynamic coefficient in different condition

Condition	Cd	Cm
Clean	0.65	1.6
Semi Fouled	0.86	1.4
Fouled	1.05	1.2

4.2 ANALYSIS

Based on the data of Neptune Spar Platform gained, the author does some analysis on the theories calculation. The results of the analysis are as shown:

4.2.1 Wave Particle Motions

Based on Linear Airy Wave Theory, the wave particle is calculated. Wave theories describe the kinematics of waves of water on the basis of potential theory. In particular, the author calculates the particle displacement, velocities and accelerations and the dynamic pressure as functions of the surface elevation of the waves.

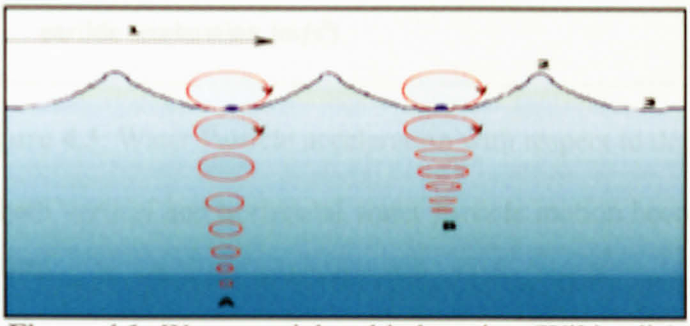


Figure 4.1: Water particle orbital motion (Wikipedia)

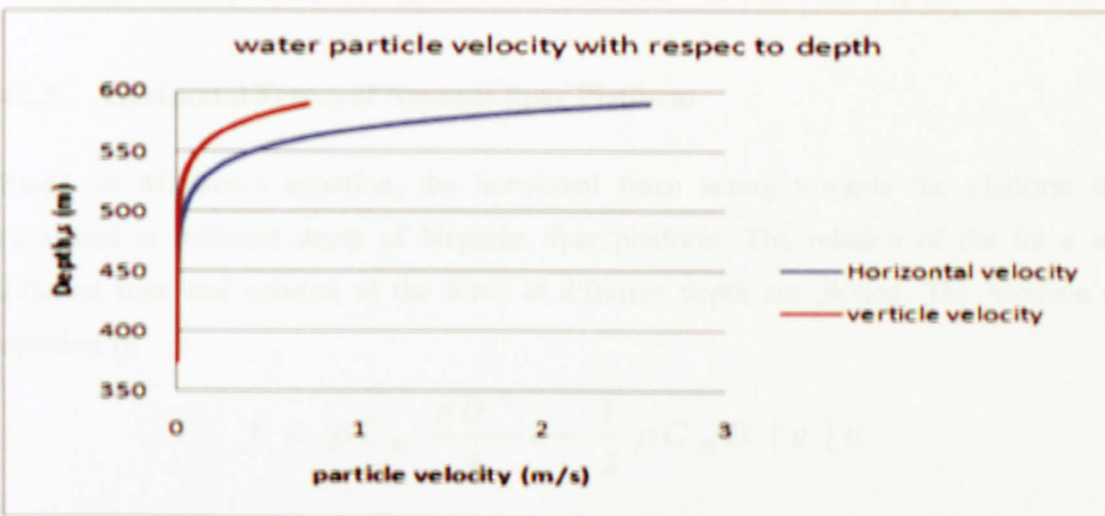


Figure 4.2: Water particle displacement with respect to depth

From the graph, velocity for both vertical and horizontal water particle motion become zero at depth = 475m

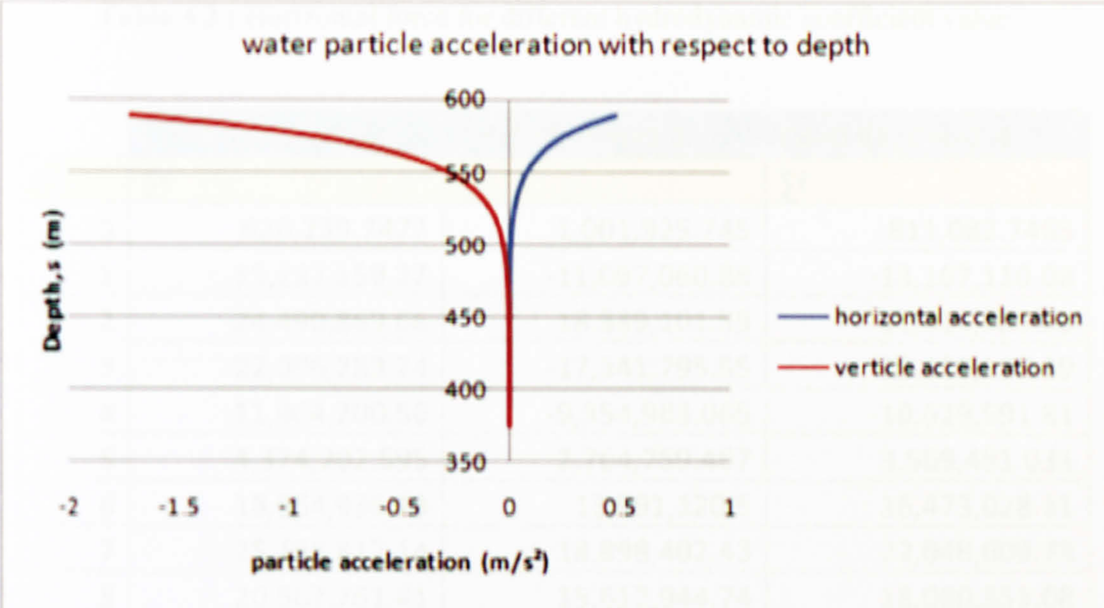


Figure 4.3: Water Particle acceleration with respect to depth

Acceleration for both vertical and horizontal water particle motion become zero at depth approximately 485m

From both of water particle motion's graph, it is said that the motion of the water particle decreasing with depth and become almost zero at almost half of water depth.

4.2.2 Horizontal Forces of Neptune Spar Platform

Based on Morison's equation, the horizontal force acting towards the platform is calculated at different depth of Neptune Spar platform. The relation of the force at different time and relation of the force at different depth are plotted. The Morison's equation is:

$$f = \rho C_M \frac{\pi D^2}{4} \dot{u} + \frac{1}{2} \rho C_D D \mid u \mid u$$

where:

$\dot{U}$ = water particle acceleration, U = water particle velocity

Table 4.3 : Horizontal force for different hydrodynamic coefficient value

	Cd=0.65, Cm=1.6	Cd=1.05, Cm=1.2	Cd=0.85, Cm=1.4
t	∑f	∑f	∑f
0	620,239.7472	1,001,925.745	811,082.7463
1	-15,237,159.27	-11,097,060.88	-13,167,110.08
2	-24,490,869.66	-18,339,101.59	-21,414,985.63
3	-22,996,283.24	-17,341,795.55	-20,169,039.39
4	-11,904,200.56	-9,354,983.065	-10,629,591.81
5	4,374,202.595	2,764,759.467	3,569,481.031
6	18,954,936.13	13,991,120.5	16,473,028.31
7	25,198,817.14	18,898,402.43	22,048,609.78
8	20,567,761.41	15,612,944.74	18,090,353.08
9	7,330,523.477	5,996,123.655	6,663,323.566
9.4	720,724.4568	1,077,280.753	899,002.6048

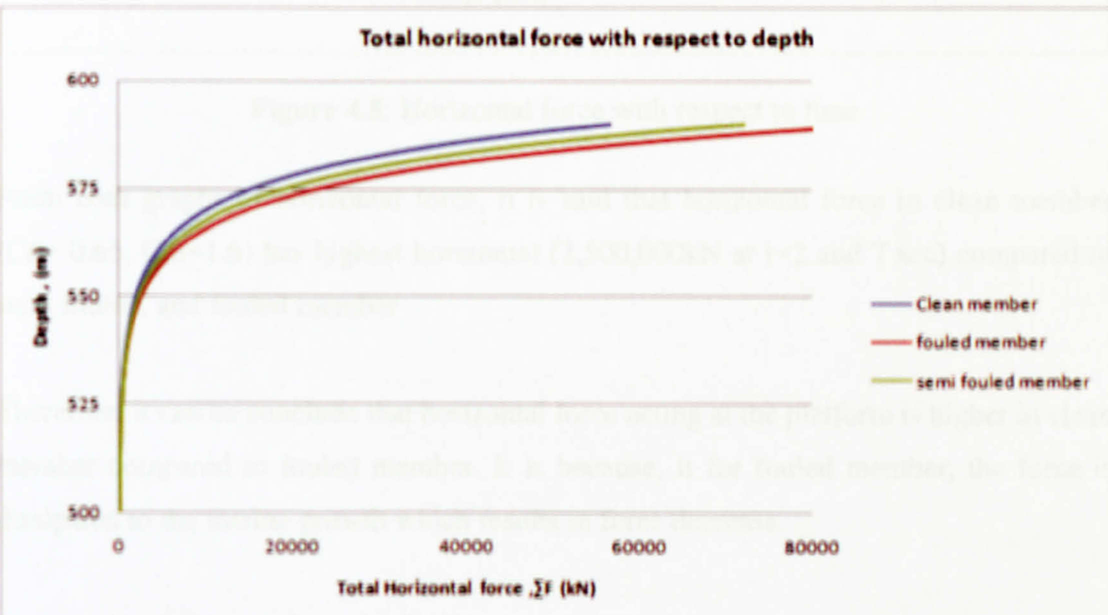


Figure 4.4: Horizontal force with respect to depth

Based on the graph above, it is shown that the horizontal force increase with respect to water depth. The force acting towards the platform is greater as it goes deeper and this is because of the pressure at deeper water is higher.

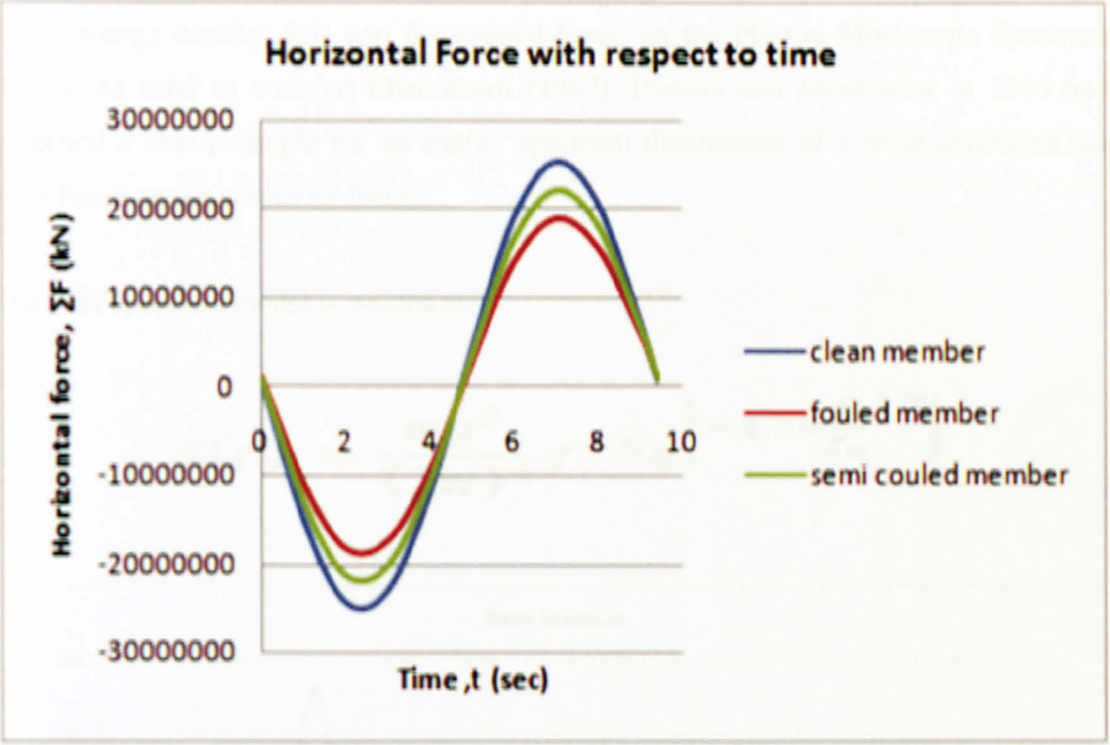


Figure 4.5: Horizontal force with respect to time

From both graphs of horizontal force, it is said that horizontal force in clean member (Cd= 0.65, Cm=1.6) has highest horizontal (2,500,000kN at t=2 and 7 sec) compared to semi fouled, and fouled member

Therefore, it can be conclude that horizontal force acting at the platform is higher in clean member compared to fouled member. It is because; it for fouled member, the force is dissipated to the marine growth which results in force decrease.

4.2.3 Wave Spectrum

Wave energy density, S(f) was determined based on the Pierson Moskowitz Spectrum theory. As refer to book of Chakrabarti (1987), Pierson and Moskowitz in 1964 had proposed a new principle for an energy spectrum distribution of a wind generated sea state based on the similarity theory.

The P-M spectrum model is written as:

$$S(f) = \frac{\alpha g^2}{(2\pi)^4} f^{-5} e^{\left[-1.25 \frac{f}{f_0}^{-4}\right]}$$

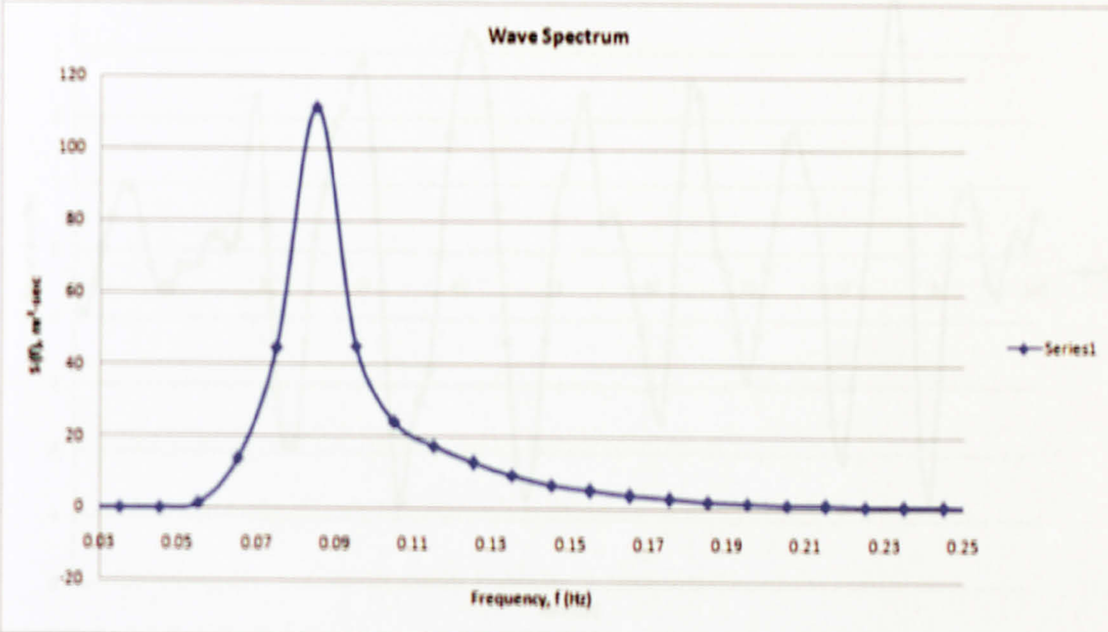


Figure 4.6: Wave Spectrum

Based on the graph obtained, it is shown that the wave spectrum behavior as parabolic towards increasing of frequency. From the graph above, the highest spectrum is 110m²s at frequency 0.09Hz

4.2.4 Wave profile

From the calculated wave height, the time series of the wave profile (t=0 – t=100sec) around the platform was computed using a random phase in range of 0 - 2π. At a frequency, f_1 , the energy density is $S(f_1)$. The wave height at this frequency is obtained using the equation:

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

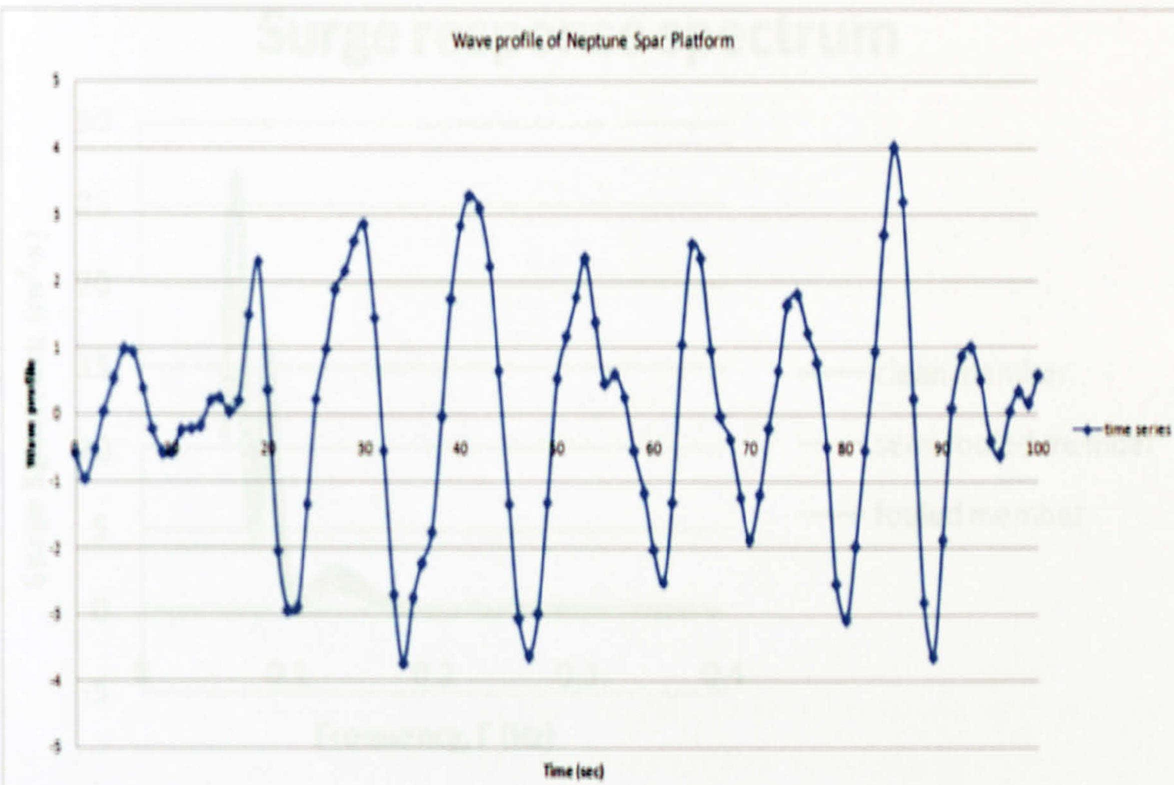


Figure 4.7: Wave profile of Neptune Spar platform.

From the graph above, it is shows that the highest wave elevation is at t=85 sec with the high of 4m.

4.2.5 Motion Response Analysis

Neptune Spar Platform is a structure that is free to move in wave's motion and it is may be critical near the resonance of the structure. Therefore, it is important for the author to study about the overall response of the structure due to a design-wave spectrum.

a) Surge Response Analysis

Surge is the horizontal platform motion. The results of surge analysis are plotted as below:

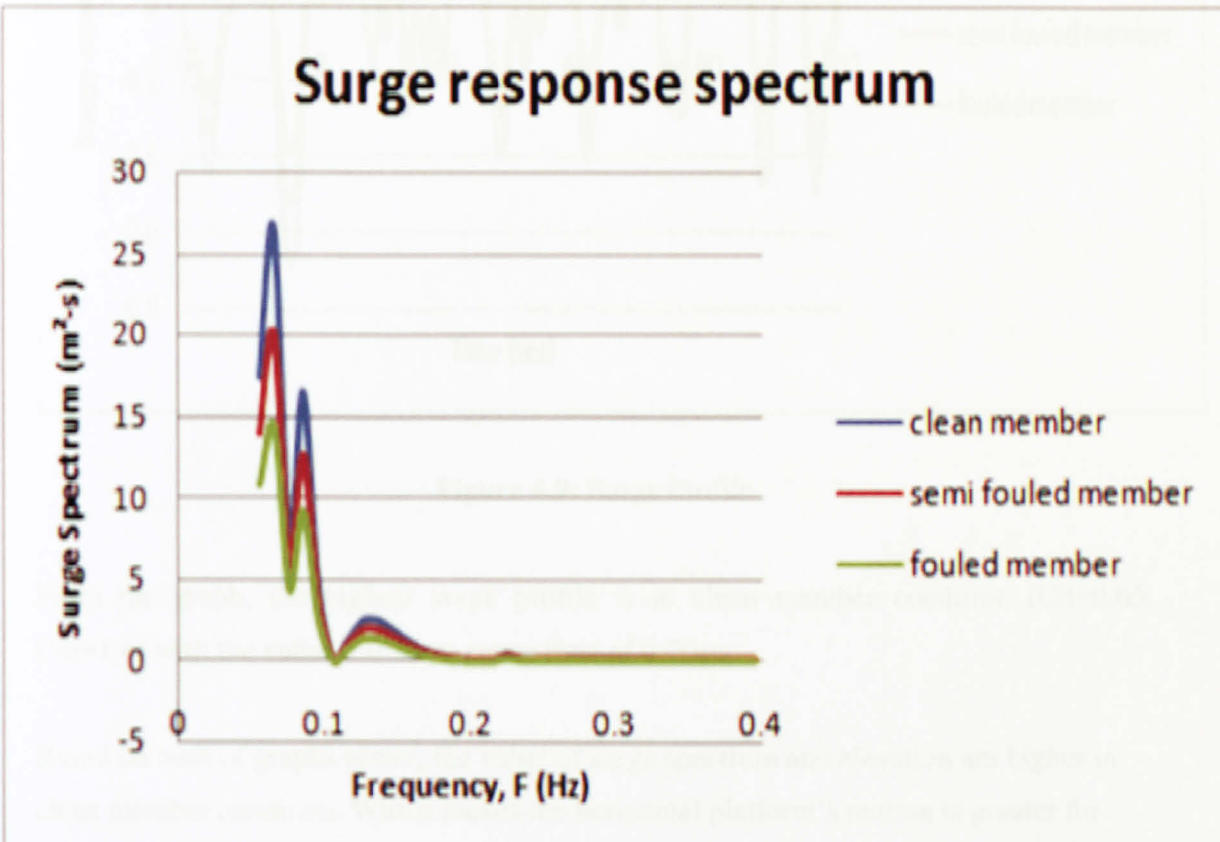


Figure 4.8: Surge Response Spectrum

From the graph, the highest surge response is at clean member condition (Cd=0.65, Cm=1.6) with the value is 27.5m²s at frequency range of 0.05-0.1Hz

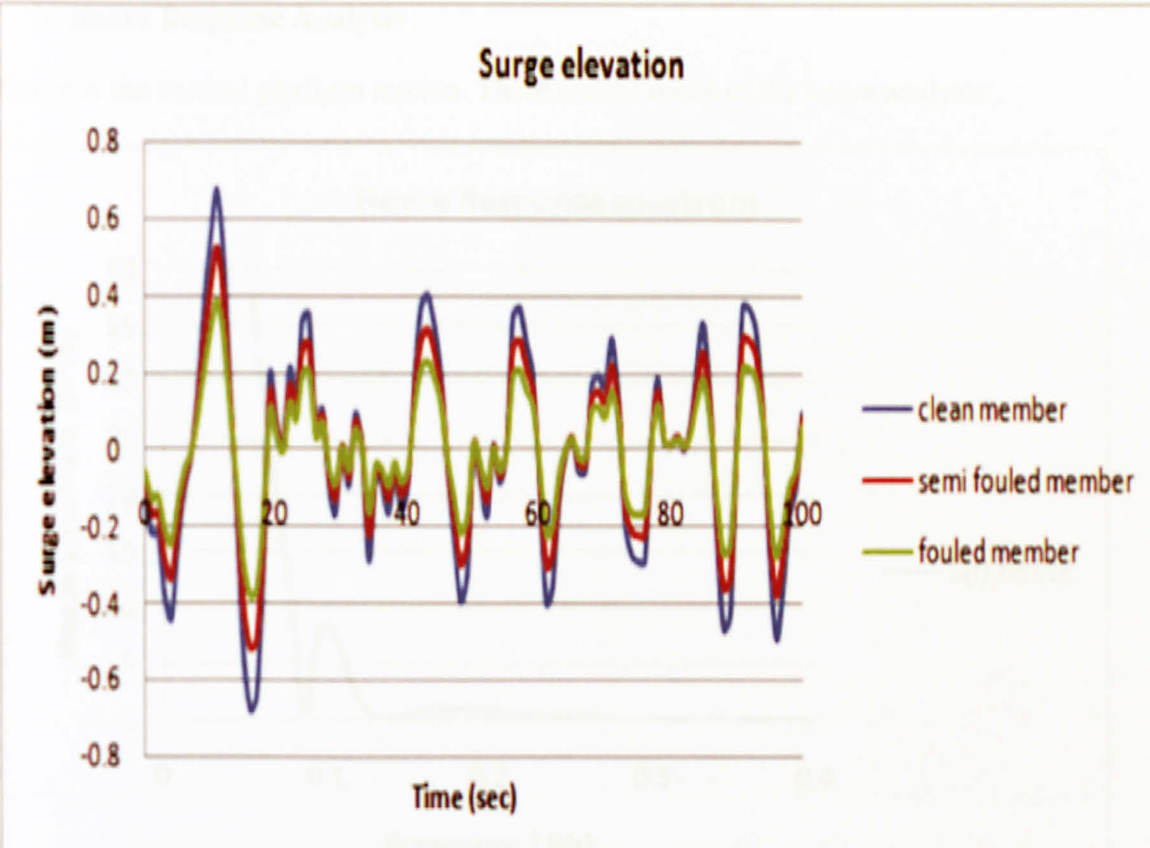


Figure 4.9: Surge Profile

From the graph, the highest surge profile is at clean member condition (Cd=0.65, Cm=1.6) with the value is 0.7m at range time of 0-20sec

Based on both of graphs above, the value of surge spectrum and elevation are higher in clean member condition. Which means the horizontal platform's motion is greater for clean member condition with the value of Cd and Cm is 0.65 and 1.6 respectively. This is because, clean member is has less weight thus caused it is easily to move.

Force for surge analysis is calculated using the Morison's equation which considers the horizontal force acting towards the platform.

b) Heave Response Analysis

Heave is the vertical platform motion. These are the result of the heave analysis:

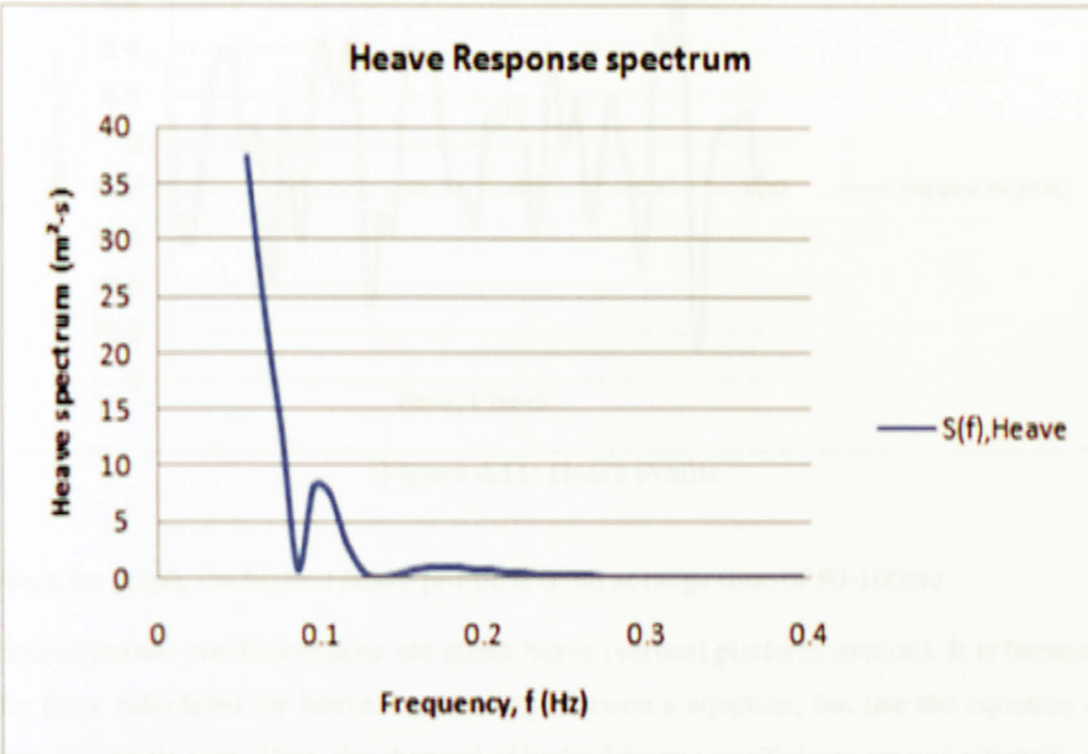


Figure 4.10: Heave Response Spectrum

From the graph, the highest heave response is within the range of 35-40m²s at frequency range of 0.05-0.08 Hz

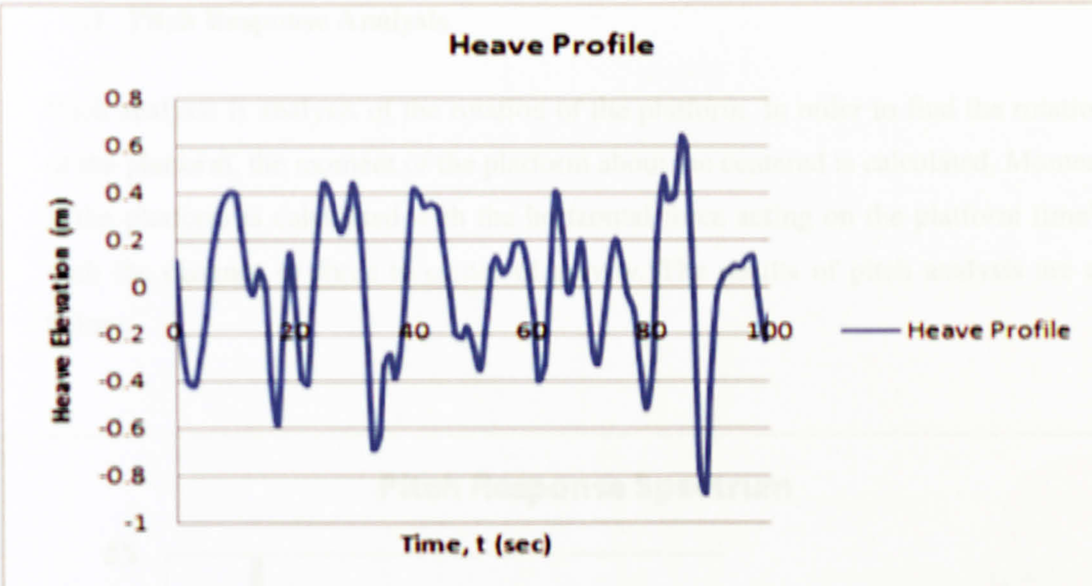


Figure 4.11: Heave Profile

From the graph, the highest heave profile is 0.9m at range time of 80-100sec

Hydrodynamic coefficient does not affect heave (vertical platform motion). It is because, the force calculated for heave is not using Morison's equation, but use the equation of pressure time's area. Thus, the changed of hydrodynamic coefficients are not affected.

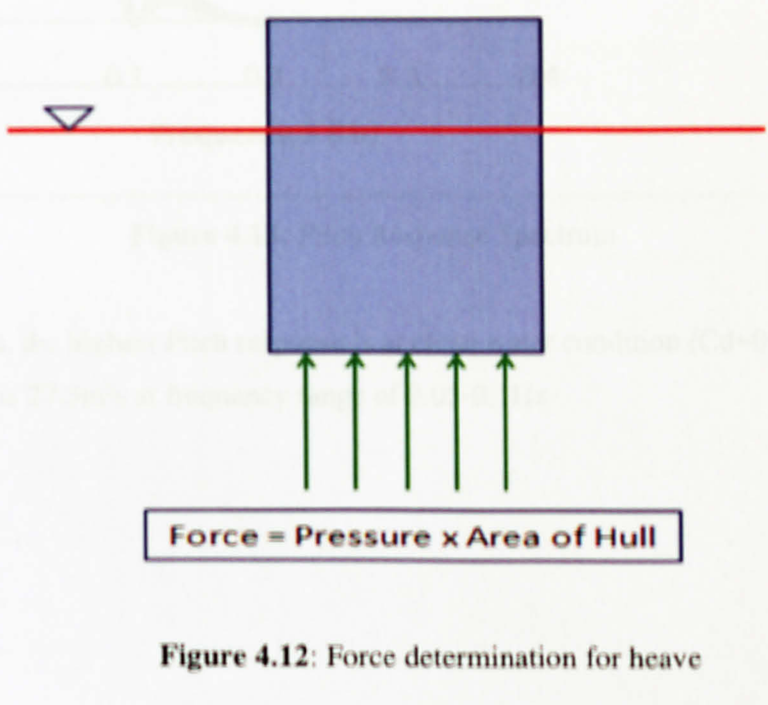


Figure 4.12: Force determination for heave

c) Pitch Response Analysis

Pitch analysis is analysis of the rotation of the platform. In order to find the rotation of the platform, the moment of the platform about the centered is calculated. Moment if the platform is calculated with the horizontal force acting on the platform time's with the distance of force to center of gravity. The results of pitch analysis are as below:

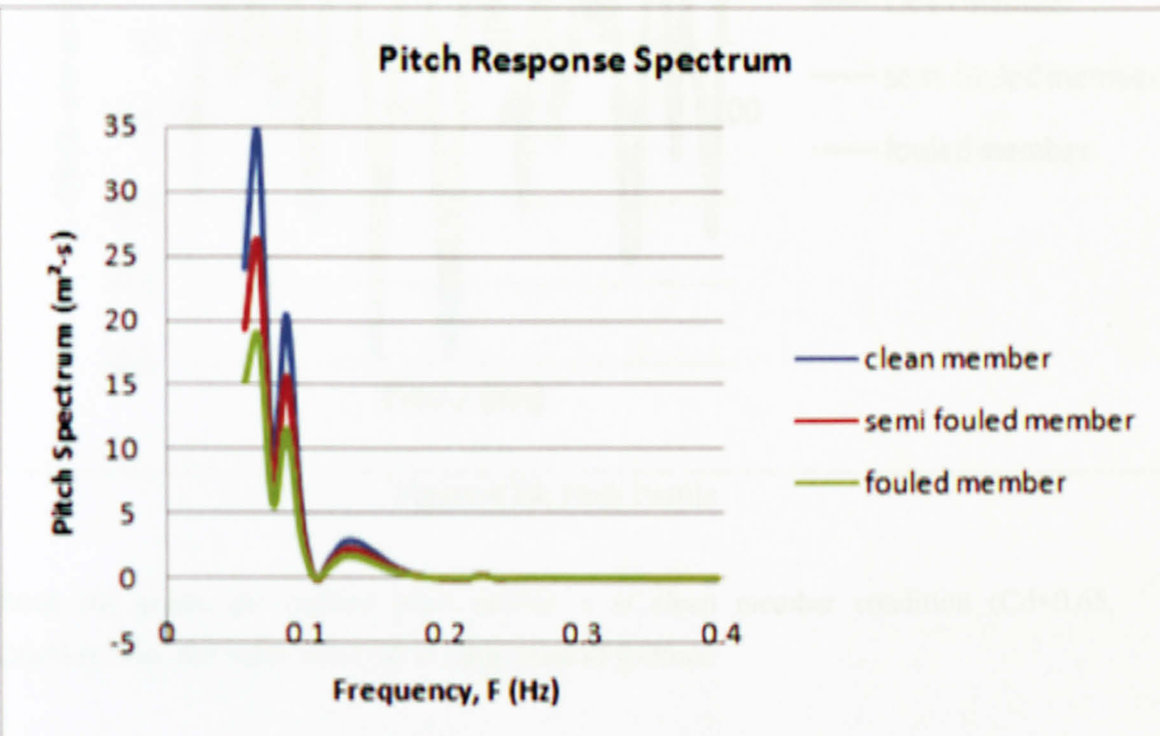


Figure 4.13: Pitch Response Spectrum

From the graph, the highest Pitch response is at clean water condition (Cd=0.65, Cm=1.6) with the value is 27.5m²s at frequency range of 0.05-0.1Hz

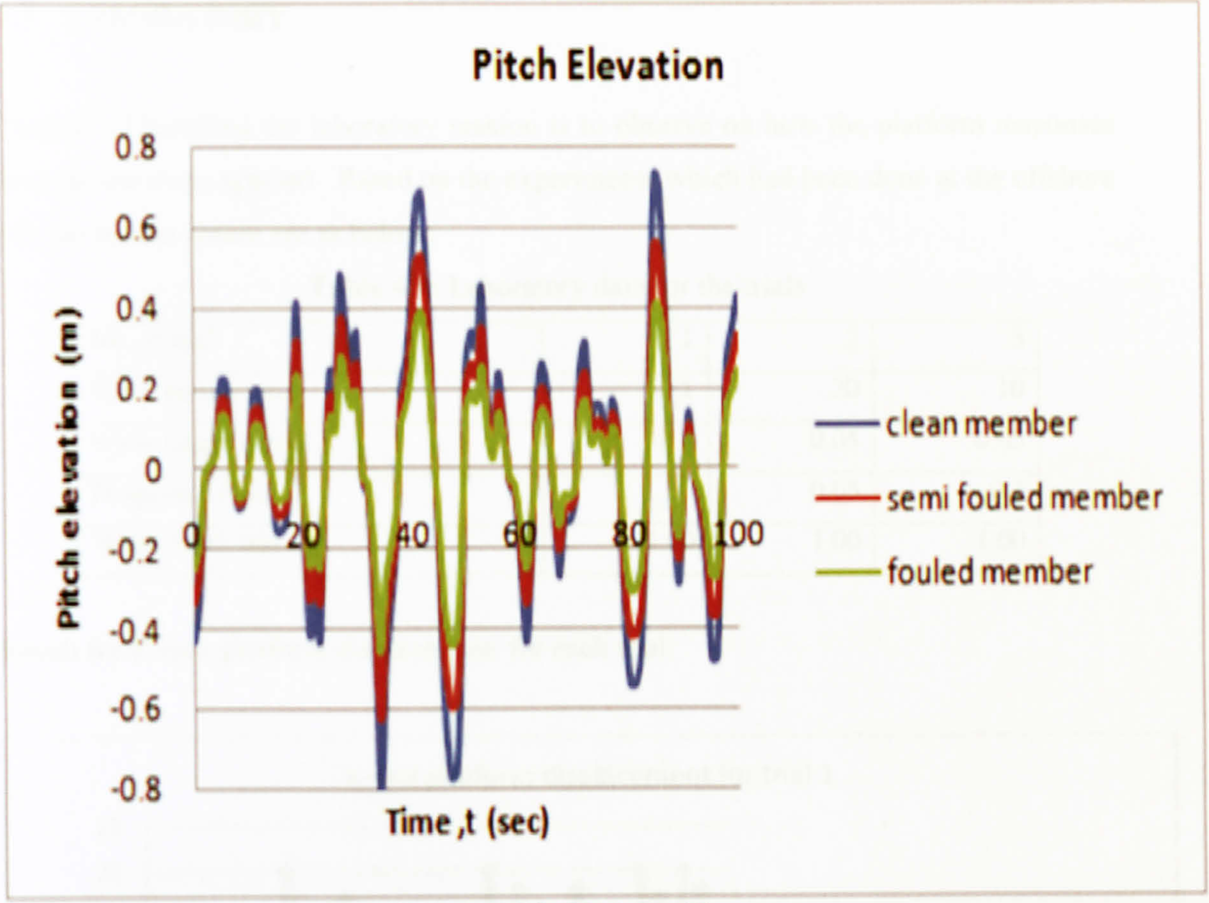


Figure 4.14: Pitch Profile

From the graph, the highest pitch profile is at clean member condition (Cd=0.65, Cm=1.6) with the value is 0.7rad at range time of 0-20sec

Based on both of graph above, the value of surge spectrum and elevation are higher in clean member condition. Which means the platform's rotation is greater for clean member condition with the value of Cd and Cm is 0.65 and 1.6 respectively. Clean member has less weight, thus the overturning is easier to occur.

4.3 LABORATORY

Purpose of handling the laboratory session is to observe on how the platform responses towards the wave applied. Based on the experiments which had been done at the offshore lab, the results obtain are as below:

Table 4.4: Laboratory data for the trials

No. of trial	1	2	3
Wave period (sec)	1	20	10
Wave height (m)	0.1	0.05	0.05
Frequency (Hz)	1	0.05	0.1
Water depth (m)	1.00	1.00	1.00

Result for X-axis platform displacement for each trial:

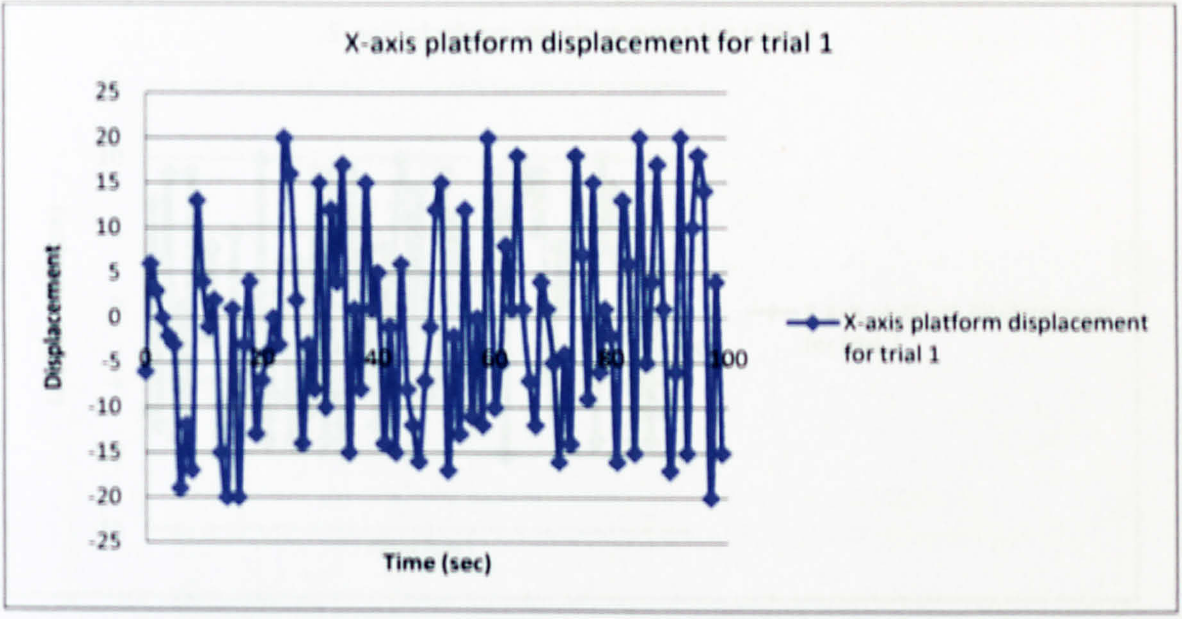


Figure 4.15: X-axis platform displacement for trial-1

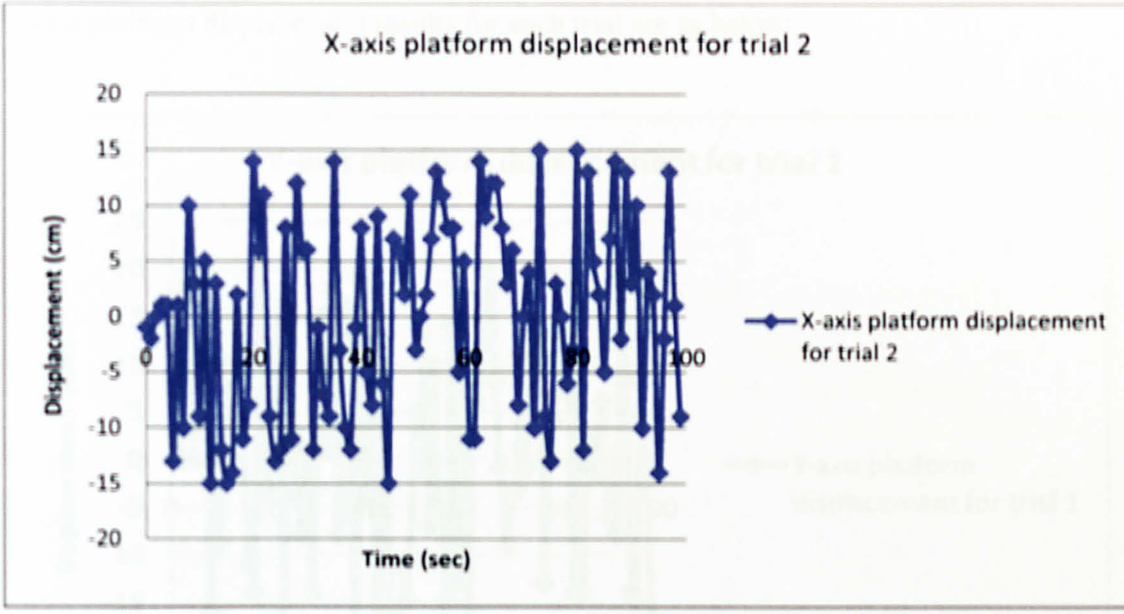


Figure 4.16: X-axis platform displacement for trial-2

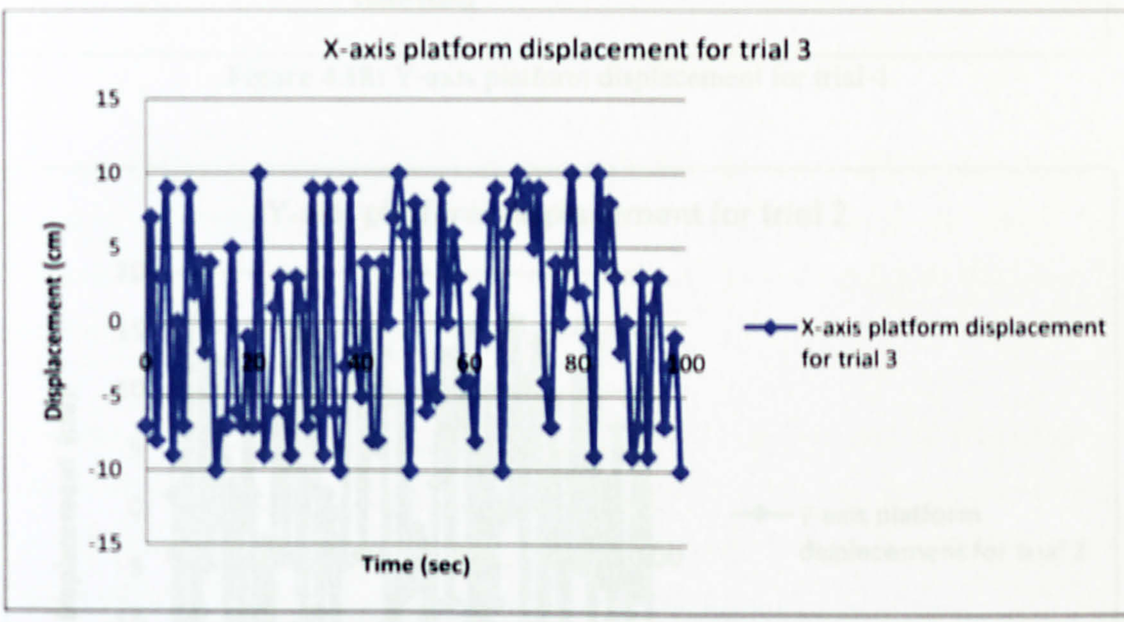


Figure 4.17: X-axis platform displacement for trial-3

From the graphs above, it is shown that the higher the wave high, the greater the displacement. The platform displacements for trial-1 are in range of -20cm to 20cm with the wave height of 0.1meter. The displacement is decreasing as the wave height and frequency is decreasing.

Y-axis platform displacement results for each trial are as below:

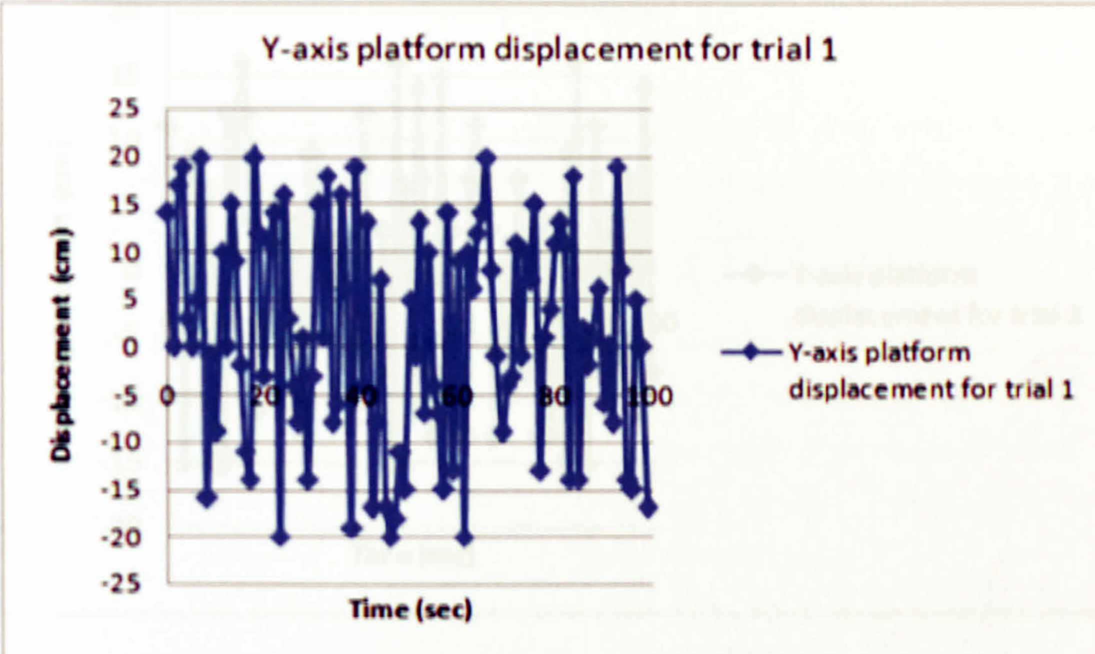


Figure 4.18: Y-axis platform displacement for trial-1

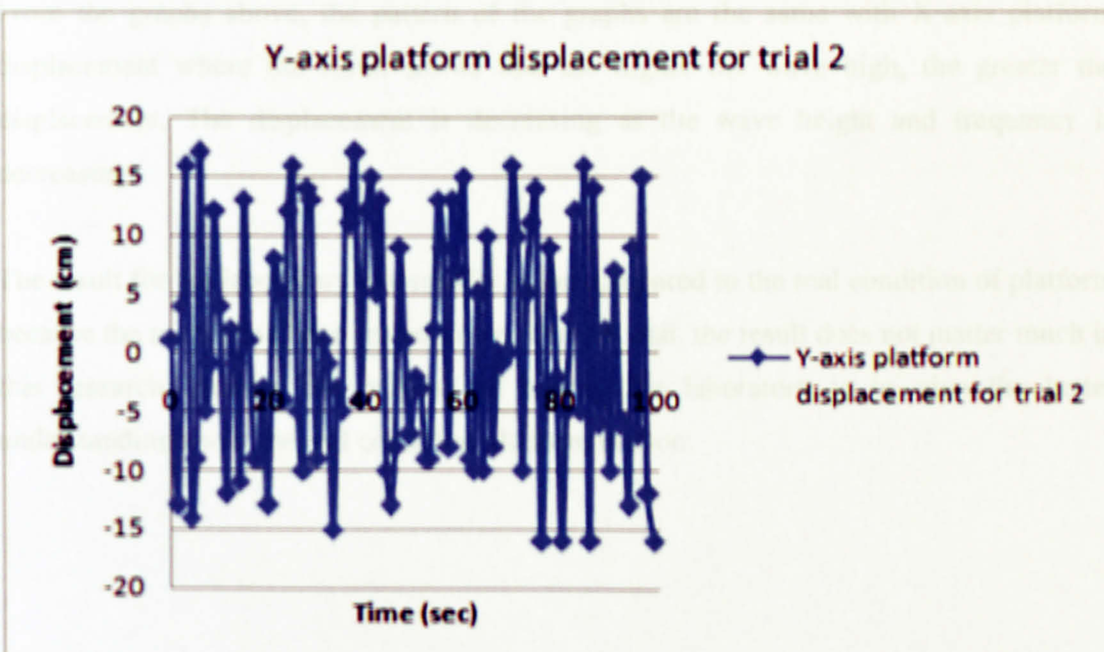


Figure 4.19: Y-axis platform displacement for trial-2

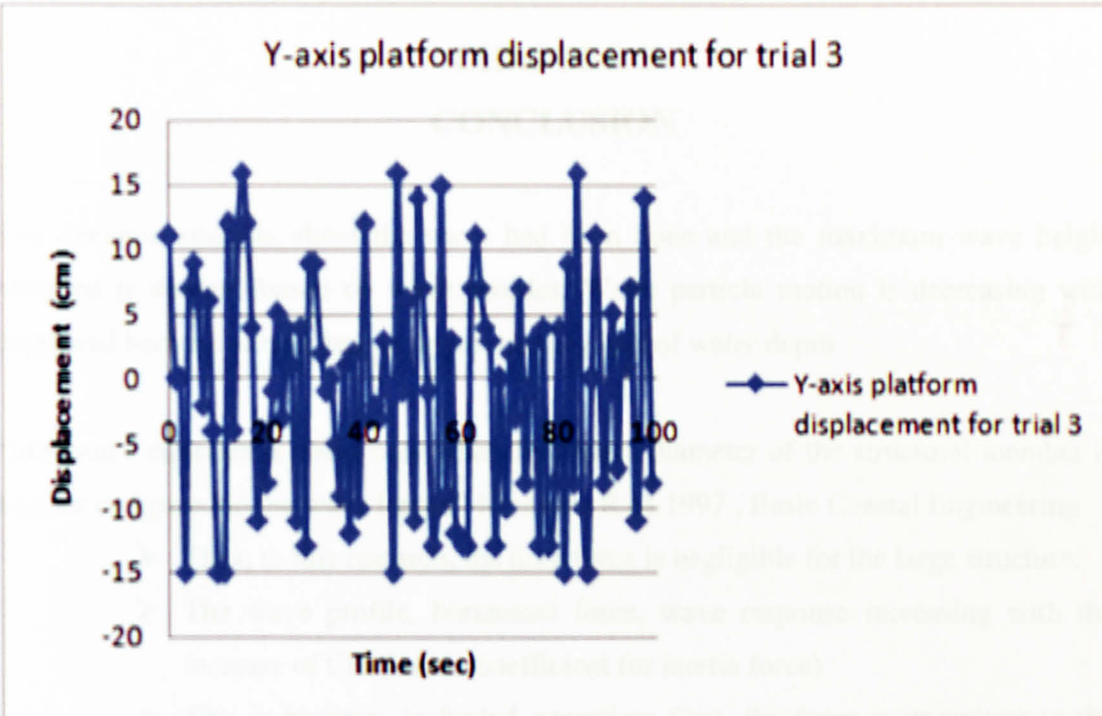


Figure 4.20: Y-axis platform displacement for trial-3

From the graphs above, the pattern of the graphs are the same with X-axis platform displacement where the result shows that the higher the wave high, the greater the displacement. The displacement is decreasing as the wave height and frequency is decreasing.

The result for the laboratory has smaller value compared to the real condition of platform because the model had been scaled down. Besides that, the result does not matter much in this research because the purpose of having the laboratory is to give the better understanding about the real condition platform motion.

CHAPTER 5

CONCLUSION

The dynamic analysis about the wave had been done and the maximum wave height obtained is 4meter (based on wave profile). Water particle motion is decreasing with depth and become almost zero at approximately half of water depth

"Morison's equation is valid only when five times diameter of the structural member is smaller compared to the wave length"-Sorensen R.M.1997 , Basic Coastal Engineering

- Thus, in this research, the drag force is negligible for the large structure.
- The wave profile, horizontal force, wave response increasing with the increase of Cm (inertia coefficient for inertia force)
- This is because, in fouled water(less Cm), the force is decapitate to the water particle and caused the force acting to the platform decrease.

Hydrodynamic coefficient does not affect the heave responses because the way force acting towards the platform is calculated for using the equation of

Force = Pressure x Area

Thus, this caused no changed of hydrodynamic coefficient seems Morison's Euation is not used.

From the model testing, the motion of the platform subjected to the wave can be seen.

RECOMMENDATION

For the further research to be done there are some recommendations so that improvement can be made. The recommendations are:

1. The laboratory should be completed with proper device such as the water particle motion and object motion's automatic recorder.

2. The study should focus more on the marine growth properties such as the thickness and the roughness so that more accurate values for hydrodynamic coefficient can be gained thus accurate response can be obtained.

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4. Subrata K.Chakrabarti .2005, *Handbook of Offshore Engineering*, (Volume I) Offshore Structure Analysis, Inc, Plainfied, Illinois, USA

5. Sorensen R.M.1997 , Basic Coastal Engineering

Appendix

Surge Response spectrum

Lo (m)	Mass (kg)	period, T (sec)	depth, d (m)	Diameter,D (m)	wave length, L (m)	k	ω	Θ	Hmax (m)	Cd	Cm	Hs (m)	Tp (s)	Tz (sec)	ωo	α	Tn
137.915	154340575.3	9.4	590	21.95	137.915	0.046	0.668	0- 0.668t	8	0.65	1.6	5.7	11	8.1	0.251327	0.0081	25

	f	0.005	0.015	0.025	0.035	0.045	0.055	0.065	0.075	0.085	0.095	0.105	0.115	0.125	0.135	0.145
Cd=0.65, Cm=1.6	S(f)surge	3492445	4712.425	2259.299	25.73333	125.1473	17.33822	26.53306	7.169053	16.44763	4.690851	0.020727	1.112576	2.336413	2.446817	1.916428
Cd=0.1, Cm=1.2	S(f)surge	1965257	2439.176	1270.876	11.02391	72.6018	10.85711	14.43409	4.375832	9.251806	2.519452	0.002681	0.686222	1.34631	1.380716	1.077308
Cd=0.85, Cm=1.4	S(f)surge	2674345	3483.072	1729.788	17.61074	97.09731	13.90892	20.02673	5.686693	12.59273	3.521469	0.009579	0.886585	1.807464	1.875899	1.466867

	f	0.155	0.165	0.175	0.185	0.195	0.205	0.215	0.225	0.235	0.245	0.255	0.265	0.275	0.285
Cd=0.65, Cm=1.6	S(f)surge	1.246443	0.700265	0.34035	0.136907	0.039315	0.004143	0.001404	0.309664	0.028238	0.042711	0.054168	0.062112	0.066795	0.059564
Cd=0.1, Cm=1.2	S(f)surge	0.694468	0.383066	0.180758	0.069182	0.017852	0.001132	0.001728	0.175091	0.018587	0.026795	0.033034	0.037167	0.039423	0.032286
Cd=0.85, Cm=1.4	S(f)surge	0.95042	0.529796	0.254294	0.100183	0.027538	0.002402	0.001562	0.237614	0.023161	0.034291	0.042951	0.048843	0.052212	0.044889

	f	0.295	0.305	0.315	0.325	0.335	0.345	0.355	0.365	0.375	0.385	0.395
Cd=0.65, Cm=1.6	S(f)surge	0.068633	0.066966	0.064241	0.060839	0.05705	0.053092	0.049117	0.045233	0.04151	0.03799	0.0347
Cd=0.1, Cm=1.2	S(f)surge	0.039764	0.038549	0.03679	0.034697	0.032427	0.030096	0.027782	0.025542	0.023408	0.021403	0.019535
Cd=0.85, Cm=1.4	S(f)surge	0.05322	0.051783	0.049565	0.046856	0.043875	0.040783	0.037695	0.034689	0.031815	0.029106	0.026576

Surge profile

Lo (m)	Mass (kg)	period, T (sec)	depth, d (m)	Diameter,D (m)	wave length, L (m)	k	ω	Θ	Hmax (m)	Cd	Cm	Hs (m)	Tp (s)	Tz (sec)	ωo	α	Tn
137.915	154340575.3	9.4	590	21.95	137.915	0.046	0.668	0- 0.668t	8	0.65	1.6	5.7	11	8.1	0.251327	0.0081	25

	Cd=0.65, Cm=1.6	Cd=1.05, Cm=1.2	Cd=0.85, Cm=1.4
t	Ση	Ση	Ση
0	-0.095340943	-0.059326127	-0.076313975
1	-0.218521439	-0.128616788	-0.170576168
2	-0.218543954	-0.122392665	-0.166938984
3	-0.38422747	-0.211652243	-0.291509727
4	-0.440993554	-0.244277904	-0.335395618
5	-0.259712425	-0.142393388	-0.196669082
6	-0.104394245	-0.055360133	-0.077973441
7	-0.018429853	-0.009988479	-0.013929118
8	0.144251108	0.079012653	0.109136834
9	0.367649292	0.204864764	0.280277736
10	0.551350372	0.30996482	0.421960146
11	0.67929515	0.384154868	0.521233891
12	0.517440822	0.294313135	0.39804481
13	0.156336308	0.090457724	0.121164068
14	-0.181479648	-0.100045263	-0.13775725
15	-0.544800337	-0.303286838	-0.415256481
16	-0.682062086	-0.381883138	-0.521117188
17	-0.647380419	-0.36781665	-0.49770943
18	-0.319699409	-0.186970914	-0.248870333
19	0.191090066	0.100129126	0.14204788
20	0.073243828	0.03360149	0.051681991
21	-0.000570276	-0.005273973	-0.003280762
22	0.212860606	0.120589817	0.163498838
23	0.125839485	0.074413477	0.098452281
24	0.338548719	0.19273262	0.260492982
25	0.352032553	0.199849877	0.270516657
26	0.047320758	0.032258473	0.039437091
27	0.104923807	0.068221081	0.085633367
28	-0.105109896	-0.052824335	-0.076843635
29	-0.167038987	-0.093065589	-0.127404044
30	0.011954184	0.00522766	0.008247562
31	-0.094593316	-0.055294404	-0.073637081
32	0.094036262	0.05054643	0.070689559
33	0.007132093	0.001571762	0.004132744
34	-0.290551839	-0.165201342	-0.223415542
35	-0.070806653	-0.041071959	-0.054907802
36	-0.08474309	-0.050717781	-0.066629777
37	-0.165015362	-0.096602339	-0.128500571

	Cd=0.65, Cm=1.6	Cd=1.05, Cm=1.2	Cd=0.85, Cm=1.4
t	Ση	Ση	Ση
38	-0.060463112	-0.03521185	-0.04697637
39	-0.155610411	-0.087568548	-0.119194796
40	-0.083706511	-0.048197094	-0.06478279
41	0.176851889	0.098113093	0.134582527
42	0.367848968	0.205924835	0.281045837
43	0.403777541	0.227128435	0.309119394
44	0.328238972	0.186315537	0.252252864
45	0.196808732	0.1129671	0.151976586
46	-0.057113924	-0.029547027	-0.042231301
47	-0.240381994	-0.130989113	-0.181586212
48	-0.396703711	-0.217278117	-0.300324695
49	-0.324801308	-0.176206304	-0.244904525
50	0.015408343	0.013622293	0.014702092
51	-0.076199767	-0.041940783	-0.057762762
52	-0.171825796	-0.09895214	-0.132865726
53	0.013450877	0.002753467	0.007502257
54	-0.085258893	-0.056268538	-0.070107215
55	0.00569353	-0.005194609	-0.000512191
56	0.347373068	0.190268842	0.26298358
57	0.370532665	0.203870336	0.281038249
58	0.278772697	0.152225543	0.210767044
59	0.195098726	0.108643635	0.148739727
60	-0.085066924	-0.045693565	-0.063857018
61	-0.39807492	-0.221164539	-0.303149555
62	-0.357370877	-0.198140781	-0.2719288
63	-0.120941104	-0.064184179	-0.09039767
64	-0.007445751	0.002426331	-0.001925221
65	0.033714556	0.029020418	0.031601358
66	-0.055159659	-0.02036722	-0.036063275
67	-0.055098569	-0.022197738	-0.037088558
68	0.167750484	0.099541234	0.131439477
69	0.19603525	0.107898011	0.148732531
70	0.165769916	0.082970966	0.121001374
71	0.291201361	0.150662515	0.215382928
72	0.155336852	0.07386394	0.111121902
73	-0.182755073	-0.116003647	-0.147588422
74	-0.272031517	-0.162663809	-0.213896082
75	-0.291003586	-0.167770341	-0.225187717

	Cd=0.65, Cm=1.6	Cd=1.05, Cm=1.2	Cd=0.85, Cm=1.4
t	Ση	Ση	Ση
76	-0.292854588	-0.162786658	-0.223098337
77	0.019168508	0.019309097	0.019625605
78	0.185418786	0.115904583	0.148717719
79	0.019065122	0.020088053	0.020068128
80	0.010099268	0.012677472	0.011814985
81	0.03731673	0.028364284	0.032830463
82	-0.000258841	0.007473492	0.004180156
83	0.068174663	0.043149037	0.054946549
84	0.219074564	0.122592498	0.167324622
85	0.328408066	0.179322077	0.248246451
86	0.131800229	0.066473647	0.096413784
87	-0.226597579	-0.136472653	-0.178715043
88	-0.469079811	-0.273040995	-0.364405443
89	-0.431774522	-0.248251053	-0.33361615
90	0.024170033	0.012819876	0.018109043
91	0.3734567	0.209101313	0.285376654
92	0.369037619	0.206495908	0.281900594
93	0.31395342	0.180913047	0.242865927
94	0.099508573	0.062934653	0.080224795
95	-0.273624092	-0.15222589	-0.20852243
96	-0.492551274	-0.278778363	-0.378121813
97	-0.375265539	-0.210207224	-0.286804685
98	-0.178317891	-0.098156914	-0.135256239
99	-0.099100264	-0.053350159	-0.074449899
100	0.095321821	0.059315097	0.07629918

Heave Response spectrum

Lo (m)	Mass (kg)	period, T (sec)	depth, d (m)	Diameter,D (m)	wave length, L (m)	k	ω	Θ	Hmax (m)	Cd	Cm	Hs (m)	Tp (s)	Tz (sec)	ωo	α	Tn
137.915	154340575.3	9.4	590	21.95	137.915	0.046	0.668	0- 0.668t	8	0.65	1.6	5.7	11	8.1	0.251327	0.0081	25

f	0.005	0.015	0.025	0.035	0.045	0.055	0.065	0.075	0.085	0.095	0.105	0.115	0.125	0.135	0.145	0.155	0.165
ω	0.03141593	0.094248	0.15708	0.219911	0.282743	0.345575	0.408407	0.471239	0.534071	0.596902	0.659734	0.722566	0.785398	0.848229	0.911061	0.973893	1.036725
ωo	0.25132741	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327
α	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081
S(ω)	0	3.7E-23	2.255838	179.5957	197.595	111.4451	57.32283	30.30536	16.86672	9.887079	6.072513	3.884305	2.573992	1.757501	1.232437	0.884468	0.647819
S(f)	0	2.33E-22	14.17384	1128.441	1241.525	700.2296	360.1697	190.414	105.9767	62.1223	38.1547	24.40579	16.16909	11.04269	7.743621	5.557273	4.070364
H(f)	0	4.31E-12	1.064851	9.501329	9.966042	7.484542	5.367828	3.902963	2.911723	2.229301	1.747105	1.397306	1.137333	0.939902	0.787077	0.66677	0.570639
R(n)	0.645	0.453	0.867	0.233	0.547	0.467	0.648	0.125	0.435	0.954	0.867	0.657	0.467	0.567	0.376	0.986	0.128
F(n)	40129033.668	28573849	59780026	30256911	-1.4E+07	24342384	-2.4E+07	-2.2E+07	6322364	26064142	29981649	23344597	12238158	6190040.2	-9542722	-1.8E+07	-2.3E+07
H(f)/2	0	2.16E-12	0.532425	4.750664	4.983021	3.742271	2.683914	1.951482	1.455862	1.114651	0.873552	0.698653	0.568667	0.469951	0.393538	0.333385	0.28532
m(kg)	154340575.3	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08
k	97488978.227	97488978	97488978	97488978	97488978	97488978	97488978	97488978	97488978	97488978	97488978	97488978	97488978	97488978	97488978	97488978	97488978
$(k-m\omega^2)^2$	9.209557E+13	7.02E+13	3.53E+13	5.22E+12	6.71E+12	7.54E+13	2.56E+14	6.01E+14	1.17E+15	2.05E+15	3.3E+15	5.02E+15	7.3E+15	1.03E+16	1.4E+16	1.87E+16	2.44E+16
c	775799969.27	775799969	775799969	775799969	775799969	775799969	775799969	775799969	775799969	775799969	775799969	775799969	775799969	775799969	775799969	775799969	775799969
$(c\omega)^2$	5.940016E+12	5.35E+13	1.49E+14	2.91E+14	4.81E+14	7.19E+14	1E+15	1.34E+15	1.72E+15	2.14E+15	2.62E+15	3.14E+15	3.71E+15	4.33E+15	5E+15	5.71E+15	6.47E+15
RAO	#DIV/0!	1.19E+12	0.82819	0.370009	-0.12989	0.230822	-0.25542	-0.2617	0.080762	0.361191	0.446166	0.369906	0.20505	0.010905	-0.1759	-0.33687	-0.46516
RAO^2	#DIV/0!	1.42E+24	0.685899	0.136907	0.01687	0.053279	0.065241	0.068487	0.006522	0.130459	0.199064	0.13683	0.042046	0.000119	0.03094	0.113481	0.216373
S(f)heave	5267.467	5876.567	6347.98	154.4913	20.94468	37.30736	23.49772	13.04089	0.691228	8.104398	7.595214	3.339451	0.679838	0.001313	0.239585	0.630646	0.880716
H(f)heave	#DIV/0!	########	########	1.300798	0.168128	0.398767	0.350201	0.267302	0.018992	0.290832	0.347785	0.191194	0.04782	0.000112	0.024352	0.075666	0.123471

f	0.175	0.185	0.195	0.205	0.215	0.225	0.235	0.245	0.255	0.265	0.275	0.285	0.295	0.305	0.315	0.325	0.335	0.345	0.355
ω	1.099557	1.162388	1.22522	1.288052	1.350884	1.413716	1.476547	1.539379	1.602211	1.665043	1.727875	1.790706	1.853538	1.91637	1.979202	2.042034	2.104865	2.167697	2.230529
ωo	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327	0.251327
α	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081
S(ω)	0.483144	0.366187	0.281588	0.219378	0.172944	0.137814	0.110906	0.09006	0.073743	0.060847	0.050564	0.042297	0.0356	0.030136	0.025648	0.021939	0.018854	0.016276	0.01411
S(f)	3.035679	2.300821	1.769268	1.378389	1.086639	0.865911	0.69684	0.565864	0.463338	0.382311	0.317703	0.265762	0.223684	0.189351	0.161151	0.137844	0.118466	0.102267	0.088654
H(f)	0.492803	0.429029	0.37622	0.332071	0.294841	0.263197	0.236108	0.212765	0.192528	0.174885	0.159425	0.145811	0.133771	0.123078	0.113543	0.105012	0.097351	0.090451	0.084216
R(n)	0.187	0.748	0.786	0.987	0.565	0.311	0.265	0.786	0.874	0.936	0.632	0.186	0.675	0.745	0.675	0.322	0.897	0.438	0.694
F(n)	-2.7E+07	-2.9E+07	-3E+07	-3E+07	-2.9E+07	-2.8E+07	-2.6E+07	-2.4E+07	-2.2E+07	-2E+07	-1.8E+07	-1.6E+07	-1.4E+07	-1.2E+07	-9936437	-8051385	-6247466	-4526495	-2888516
H(f)/2	0.246401	0.214514	0.18811	0.166035	0.14742	0.131599	0.118054	0.106383	0.096264	0.087443	0.079712	0.072906	0.066886	0.061539	0.056772	0.052506	0.048676	0.045225	0.042108
m(kg)	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08	1.54E+08
k	97488978	97488978	97488978	97488978	97488978	97488978	97488978	97488978	97488978	97488978	97488978	97488978	97488978	97488978	97488978	97488978	97488978	97488978	97488978
$(k-m\omega^2)^2$	3.13E+16	3.95E+16	4.93E+16	6.07E+16	7.39E+16	8.92E+16	1.07E+17	1.27E+17	1.49E+17	1.75E+17	2.03E+17	2.35E+17	2.71E+17	3.1E+17	3.54E+17	4.02E+17	4.54E+17	5.12E+17	5.75E+17
c	775799969	775799969	775799969	775799969	775799969	775799969	775799969	775799969	775799969	775799969	775799969	775799969	775799969	775799969	775799969	775799969	775799969	775799969	775799969
$(c\omega)^2$	7.28E+15	8.13E+15	9.03E+15	9.99E+15	1.1E+16	1.2E+16	1.31E+16	1.43E+16	1.55E+16	1.67E+16	1.8E+16	1.93E+16	2.07E+16	2.21E+16	2.36E+16	2.51E+16	2.67E+16	2.83E+16	2.99E+16
RAO	-0.56043	-0.62558	-0.66477	-0.6824	-0.68259	-0.66897	-0.64459	-0.61202	-0.5733	-0.53012	-0.48379	-0.43536	-0.38567	-0.33535	-0.2849	-0.23471	-0.18506	-0.13618	-0.08821
RAO^2	0.314086	0.391353	0.44192	0.465671	0.465931	0.447515	0.415501	0.374563	0.328675	0.281023	0.234048	0.189538	0.148738	0.112457	0.081168	0.055088	0.034248	0.018544	0.007782
S(f)heave	0.953464	0.900432	0.781875	0.641875	0.506299	0.387508	0.289537	0.211952	0.152288	0.107438	0.074358	0.050372	0.03327	0.021294	0.01308	0.007593	0.004057	0.001896	0.00069
H(f)heave	0.154782	0.167902	0.166259	0.154636	0.137376	0.117785	0.098103	0.079694	0.063279	0.049147	0.037313	0.027637	0.019897	0.013841	0.009216	0.005785	0.003334	0.001677	0.000655

Heave profile

Lo (m)	Mass (kg)	period, T (sec)	depth, d (m)	Diameter, D (m)	wave length, L (m)	k	ω	Θ	Hmax (m)	Cd	Cm	Hs (m)	Tp (s)	Tz (sec)	ωo	α	Tn
137.915	154340575.3	9.4	590	21.95	137.915	0.046	0.668	0- 0.668t	8	0.65	1.6	5.7	11	8.1	0.251327	0.0081	25

t	Σn
0	0.111426
1	-0.20552
2	-0.40655
3	-0.42103
4	-0.31928
5	-0.12185
6	0.11124
7	0.275419
8	0.354205
9	0.400925
10	0.393847
11	0.251863
12	0.033146
13	-0.03514
14	0.069571
15	-0.01285
16	-0.40179
17	-0.58171
18	-0.22846
19	0.139703
20	-0.01047
21	-0.38215
22	-0.41752
23	-0.08837
24	0.275673
25	0.444048
26	0.398921
27	0.270503
28	0.230183
29	0.341184
30	0.438688
31	0.244972
32	-0.26537
33	-0.68603
34	-0.63241
35	-0.33746
36	-0.28723
37	-0.3862
38	-0.20577
39	0.19322
40	0.412042
41	0.385399
42	0.339732
43	0.354232
44	0.326877
45	0.183649
46	-0.03704
47	-0.20591
48	-0.21897
49	-0.1722
50	-0.25512
51	-0.35408
52	-0.19168
53	0.081044
54	0.127923
55	0.056887
56	0.101806
57	0.181406
58	0.192084
59	0.122449
60	-0.11531
61	-0.40045
62	-0.32976
63	0.120689
64	0.40989
65	0.232283
66	-0.02367
67	0.048341
68	0.198715
69	0.029486
70	-0.28065
71	-0.3324
72	-0.11258
73	0.131041
74	0.205053
75	0.093569
76	-0.03037
77	-0.10408
78	-0.30275
79	-0.51874
80	-0.32399
81	0.202443
82	0.468834
83	0.367783
84	0.385976
85	0.639289
86	0.593636
87	-0.05231
88	-0.77536
89	-0.88011
90	-0.43079
91	-0.04253
92	0.048244
93	0.063628
94	0.091234
95	0.086352
96	0.116864
97	0.129788
98	-0.03967
99	-0.22577
100	-0.11145

Pitch Response Spectrum

Lo (m)	Mass (kg)	period, T (sec)	depth, d (m)	Diameter,D (m)	wave length, L (m)	k	ω	Θ	Hmax (m)	Cd	Cm	Hs (m)	Tp (s)	Tz (sec)	ωo	α	Tn
137.915	154340575.3	9.4	590	21.95	137.915	0.046	0.668	0- 0.668t	8	0.65	1.6	5.7	11	8.1	0.251327	0.0081	25

	f	0.005	0.015	0.025	0.035	0.045	0.055	0.065	0.075	0.085	0.095	0.105	0.115	0.125
Cd=0.65, Cm=1.6	S(f)pitch	22199.25	1855299	6637.849	44.0398	186.5993	24.04462	34.50846	9.200633	20.49978	5.737623	0.022008	1.362926	2.821499
Cd=0.85, Cm=1.4	S(f)pitch	16999.52	1363816	5082.142	29.56152	145.0548	19.4134	25.99048	7.334538	15.69516	4.294433	0.008874	1.09215	2.186027
Cd=1.05, Cm=1.2	S(f)pitch	12492.6	947812.4	3733.856	17.9594	108.7348	15.27712	18.6778	5.679717	11.53115	3.059942	0.001604	0.85133	1.631525

	f	0.135	0.145	0.155	0.165	0.175	0.185	0.195	0.205	0.215	0.225	0.235	0.245	0.255
Cd=0.65, Cm=1.6	S(f)pitch	2.934482	2.289547	1.483372	0.829569	0.40095	0.160043	0.045315	0.004524	0.001867	0.357811	0.033986	0.051038	0.064448
Cd=0.85, Cm=1.4	S(f)pitch	2.250229	1.752389	1.130394	0.626501	0.298455	0.116282	0.031272	0.002473	0.002135	0.274737	0.028133	0.041246	0.051354
Cd=1.05, Cm=1.2	S(f)pitch	1.656676	1.286935	0.825303	0.451893	0.211061	0.079494	0.019826	0.001037	0.00242	0.202621	0.022832	0.032495	0.039746

	f	0.265	0.275	0.285	0.295	0.305	0.315	0.325	0.335	0.345	0.355	0.365	0.375	0.385	0.39
Cd=0.65, Cm=1.6	S(f)pitch	0.073676	0.079051	0.065885	0.080967	0.078907	0.075623	0.07156	0.067058	0.062369	0.057671	0.053088	0.048701	0.04456	0.0406
Cd=0.85, Cm=1.4	S(f)pitch	0.058157	0.061977	0.049507	0.0629	0.061106	0.058413	0.055161	0.051605	0.047933	0.044275	0.040723	0.037333	0.034142	0.03116
Cd=1.05, Cm=1.2	S(f)pitch	0.044471	0.046977	0.035466	0.047111	0.045576	0.043422	0.040893	0.038174	0.035394	0.032648	0.029995	0.027474	0.025109	0.0229

Pitch Profile

Lo (m)	Mass (kg)	period, T (sec)	depth, d (m)	Diameter, D (m)	wave length, L (m)	k	ω	Θ	Hmax (m)	Cd	Cm	Hs (m)	Tp (s)	Tz (sec)	ωo	α	Tn
137.915	154340575.3	9.4	590	21.95	137.915	0.046	0.668	0- 0.668t	8	0.65	1.6	5.7	11	8.1	0.251327	0.0081	25

	Cd=0.65, Cm=1.6	Cd=0.85, Cm=1.4	Cd=1.05, Cm=1.2
t	∑η	∑η	∑η
0	-0.429919343	-0.330137612	-0.243415165
1	-0.326033076	-0.249459868	-0.183138593
2	-0.041175548	-0.025995534	-0.013743959
3	-0.001440539	0.007129082	0.013262957
4	0.045323894	0.041108147	0.036452117
5	0.219248331	0.172156341	0.13065448
6	0.21538433	0.166424737	0.123734957
7	0.0271126	0.017396849	0.009489865
8	-0.095446957	-0.080492361	-0.066381102
9	-0.086418838	-0.074630546	-0.063102567
10	0.002602228	-0.005128375	-0.010733163
11	0.189660666	0.140967634	0.099397855
12	0.194242265	0.14754123	0.107204002
13	0.069380546	0.054154431	0.040779384
14	-0.001461727	0.002536961	0.005498178
15	-0.15243508	-0.109501622	-0.073301322
16	-0.157218213	-0.112397755	-0.074735305
17	-0.123745935	-0.090287409	-0.061992092
18	0.093347127	0.072755162	0.054720581
19	0.412812347	0.315632091	0.231518509
20	-0.045488962	-0.037773176	-0.030649515
21	-0.409469218	-0.317051525	-0.236517846
22	-0.31903101	-0.245850999	-0.182311218
23	-0.423938865	-0.32612069	-0.241188628
24	-0.027161557	-0.024698765	-0.021980086
25	0.241661711	0.180435023	0.128121016
26	0.172319347	0.131008025	0.095424886
27	0.479761137	0.370652722	0.275649873
28	0.358764261	0.277635031	0.206922704
29	0.270913739	0.208057916	0.15356342
30	0.334551438	0.256564436	0.189021382
31	-0.029272892	-0.021230226	-0.014388267
32	-0.069888955	-0.051899062	-0.036643598
33	-0.375844167	-0.286251146	-0.209003999
34	-0.812994728	-0.620999468	-0.454928436
35	-0.505666436	-0.386149568	-0.282732422
36	-0.347414954	-0.267284274	-0.197673049
37	-0.187907905	-0.146466233	-0.110239905
38	0.194505625	0.147867608	0.107586259
39	0.273497471	0.209070915	0.153387354
40	0.427409685	0.326109514	0.238618332
41	0.661239966	0.505076434	0.369977221
42	0.687784037	0.525792156	0.385498441
43	0.460364823	0.35222763	0.258589284
44	0.101388686	0.078250845	0.058157838
45	-0.255530699	-0.195203091	-0.142980541
46	-0.63197413	-0.483896836	-0.355614472
47	-0.775927348	-0.593477095	-0.435512597
48	-0.761642881	-0.581594505	-0.425824198
49	-0.411540139	-0.312862374	-0.227716122
50	0.251623666	0.194443554	0.144523003
51	0.3388334	0.259331714	0.190327089
52	0.300477291	0.229093538	0.167334682
53	0.455697697	0.347769222	0.25446503
54	0.16936544	0.127420523	0.091501544
55	0.052037483	0.038600481	0.027232396
56	0.237682483	0.183559838	0.136526291
57	0.1153261	0.089633886	0.067283915
58	-0.038234038	-0.029559182	-0.021925999
59	-0.072836392	-0.055582097	-0.040658965
60	-0.253103679	-0.193628454	-0.142197783
61	-0.433281988	-0.333586859	-0.247077095
62	-0.220956265	-0.172818562	-0.130720384
63	0.143677213	0.106187821	0.074206672
64	0.262208249	0.199330918	0.145090166
65	0.199459058	0.155313917	0.116714751
66	-0.082291682	-0.057717445	-0.037183046
67	-0.269078622	-0.199503736	-0.140125508
68	-0.137177922	-0.098702204	-0.066221052
69	-0.132148325	-0.098604625	-0.069879296
70	-0.083008682	-0.065790386	-0.050572626
71	0.244444745	0.183086781	0.130452477
72	0.314117946	0.235534195	0.168154667
73	0.129518481	0.0929855	0.062305283
74	0.158863884	0.116250059	0.080208161
75	0.151604317	0.112901661	0.079884621
76	0.03217955	0.024249191	0.017438124
77	0.172159377	0.135146512	0.102535922
78	0.089824494	0.073746196	0.058969765
79	-0.361771551	-0.273832415	-0.198254499
80	-0.540932437	-0.412254112	-0.301147244
81	-0.540247897	-0.410352187	-0.298259596
82	-0.461989637	-0.348989955	-0.251659325
83	-0.138069018	-0.10204842	-0.071276855
84	0.334222678	0.256144586	0.18853527
85	0.731684514	0.557167762	0.406511228
86	0.676045782	0.512869112	0.37228068
87	0.289313891	0.215547877	0.152490771
88	-0.108840891	-0.089664888	-0.072278273
89	-0.28742998	-0.223592664	-0.167949514
90	-0.021839289	-0.016662755	-0.012294063
91	0.140533066	0.107697747	0.079233291
92	-0.022266949	-0.016652612	-0.011773034
93	-0.111245313	-0.08007974	-0.053736436
94	-0.253072656	-0.18625136	-0.12937433
95	-0.478075603	-0.362654419	-0.263060479
96	-0.472294935	-0.361366443	-0.265217481
97	-0.099183547	-0.074574102	-0.053448976
98	0.263808837	0.203092914	0.150216136
99	0.347536377	0.265935756	0.195085811
100	0.429914239	0.330133604	0.243412113