CHAPTER 1
INTRODUCTION

1.1. BACKGROUND OF STUDIES

Oil and gas can be considered as the most widely used source of energy in this modern life. The oil fuels cars, trucks and planes hold the modern lifestyles and economies all. Other than fueling and underpin modern lifestyles and economies, the by-products from the oil refining are being used to produce variety kind of lubricants, tars, asphalts and also waxes. All the pesticides and most of the fertilizers also fall into the oil refined products or its by-products. In the other hand, the gas also been used to produce the wide range and different kind of industrial products such as polymers, textile, paints, dyes and even plastic.

In the scope of Malaysia, the oil and gas industry been known as the second largest producer in Southeast Asia. Having with the amount of 28.35 billion barrel and 38.5 Tcf for oil and gas reserves accordingly as for 2013 [1]. Almost all the Malaysia's oilfield is located at offshore. Malay basin in the west Sarawak and Sabah basin in the east are where the continental shelves located. In Malaysia, the deepwater explorations have started with the Kikeh field, followed by Gumusut-Kakap and the coming soon Malikai. Soon or later, deepwater oil will be the major activities for this industry due to limited resources at shallow and onshore region.

In offshore field, there are many uncertainties e.g. environmental condition that affects the platform. The major contributors of the mentioned effect are the ocean waves and current. For the waves, it can be classified into two types which is long-crested and short-crested waves. Long-Crested wave is the 2D waves. It is likely to be propagates in one direction. As for Short-Crested waves, defined as 3D waves that propagates from much direction and cause the deflection and diffraction. It can be considered as more real waves that experienced by the offshore platform.

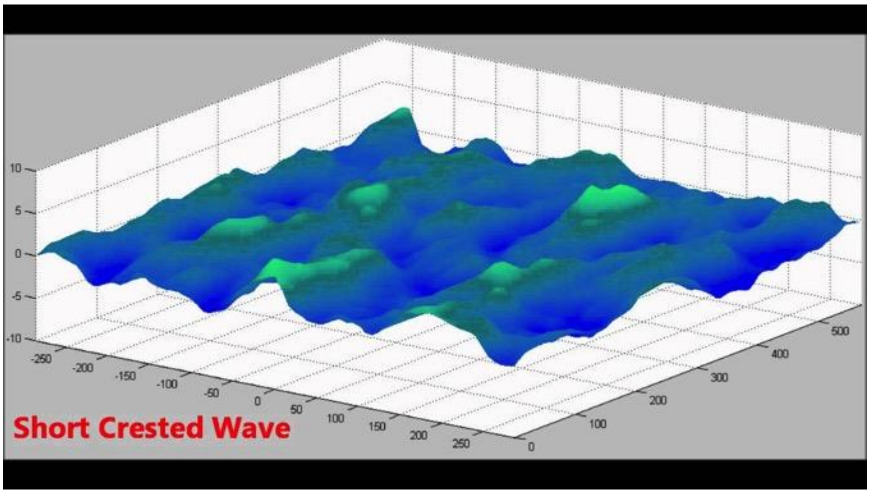


Figure 1: Visual of Short-Crested Wave

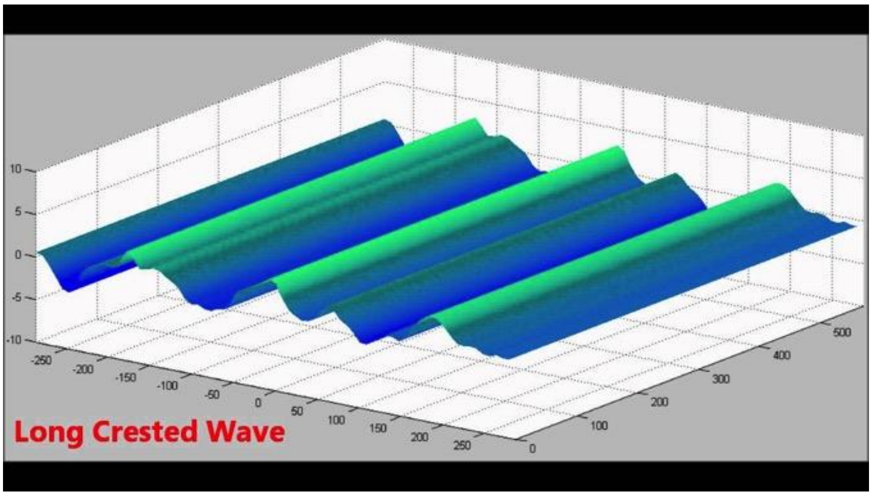


Figure 2: Visual of Long-Crested Wave

1.2. PROBLEM STATEMENT

Offshore platforms are located far away from shore. The integrity of the structure has to be taken care very carefully. The biggest threat for these platforms will be the environmental effect such as ocean waves, current, wind and even iceberg. In the real sea conditions, the short-crested waves are the waves that exerted on these platforms. Designing offshore platforms according to the long-crested waves is much more conservative. The reason is that for this design, the platform stretch is subjected to long-crested wave; the effects are assumed to be on all the stretches of the platform. This assumption indeed would overestimate the environmental effect subjected to the structure eventually overdesign the structure. Hence it is more important to determine the importance and significance of the short-crested wave with current

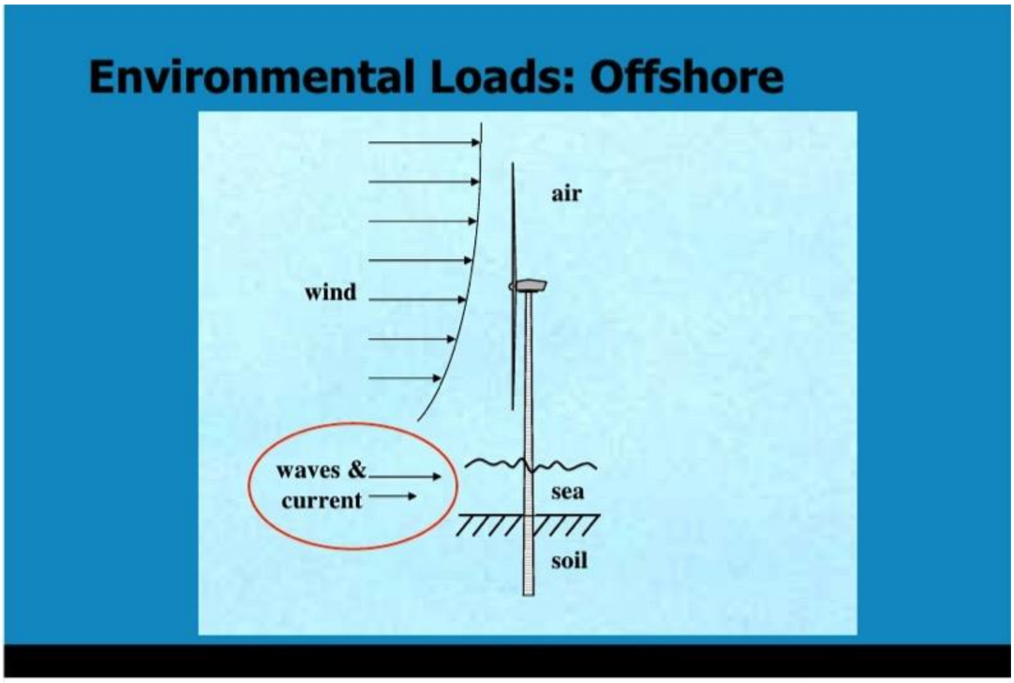


Figure 3: Environmental Loads on Offshore Structure

1.3. OBJECTIVE

There are several objectives identified in this project:

- To determine the dynamic responses of Truss Spar model from the Long-Crested wave with current induced by frequency domain analysis.
- To determine the dynamic responses of Truss Spar model from the Short-Crested waves and current induced by frequency domain analysis
- To quantify the efficiency of the short-crested waves with current exerted on a Truss Spar model as compared to the Long-Crested wave with current

1.4. SCOPE OF STUDY

The scope of study comprise of few elements:

- The study on the dynamic responses of offshore platform
    - Structure: Truss Spar
    - Environmental condition: Waves and Current
    - Motions: Surge, Pitch and Heave
    - Wave Spectrum: Pierson-Moskowitz Spectrum

- The research emphasizes the difference on dynamic response due to Long and Short-Crested wave with current

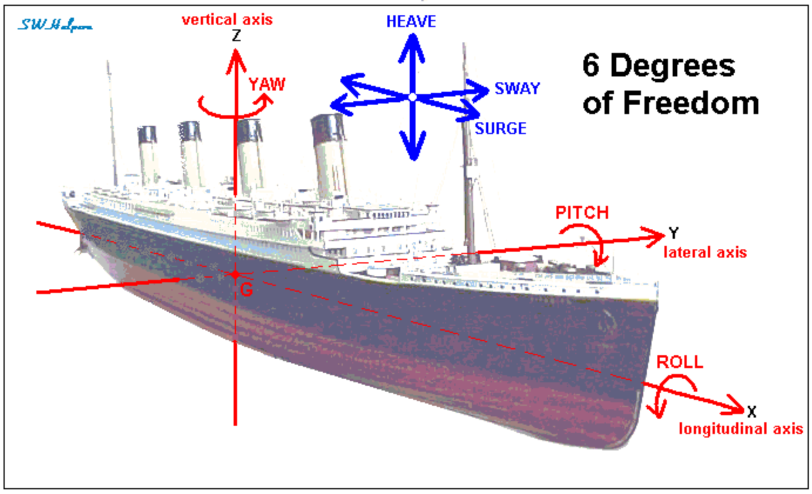


Figure 4: 6 Degrees of Freedom or Motions

CHAPTER 2
LITERATURE REVIEW

This chapter presents critical review of the literatures as the conceptual guideline for the responses of Truss Spar due to long and short-crested with current study. The main focus of the study would be emphasizing on the differences and comparison between long and short-crested wave with current induces dynamic response onto Truss Spar model.

2.1. INTRODUCTION

In the oil and gas industry, onshore and offshore explorations are available. Most of the onshore fields are located at the Middle East and offshore field are available worldwide. With the advancement of technologies and limited resources at shallow water, now deepwater oil is currently being exploited. Within the scope of Malaysia, famous with the sweet oil, rising demand from Malaysia water had been increasingly high for export. Thus, it was hoped that new oil reserves could be found in deepwater Sabah [2]. There only few deepwater field exploited in Malaysia water i.e. the Kikeh, Kakap-Gumusut and the coming soon Malikai. With the progress into exploiting deepwater oil the conventional jacket type platform can’t be used. Bullwinkle at the Gulf of Mexico held the deepest fixed platform with the depth of 412.1m [3]. Any deeper depth of water would be hard to use fixed typed platform. Thus, using floating structure would be necessary for deepwater case. Floating structure would mostly depend on the anchorage to hold into position in against environmental loads. “Every offshore facility is subjected to several type of environmental loads during its lifetime” [4]

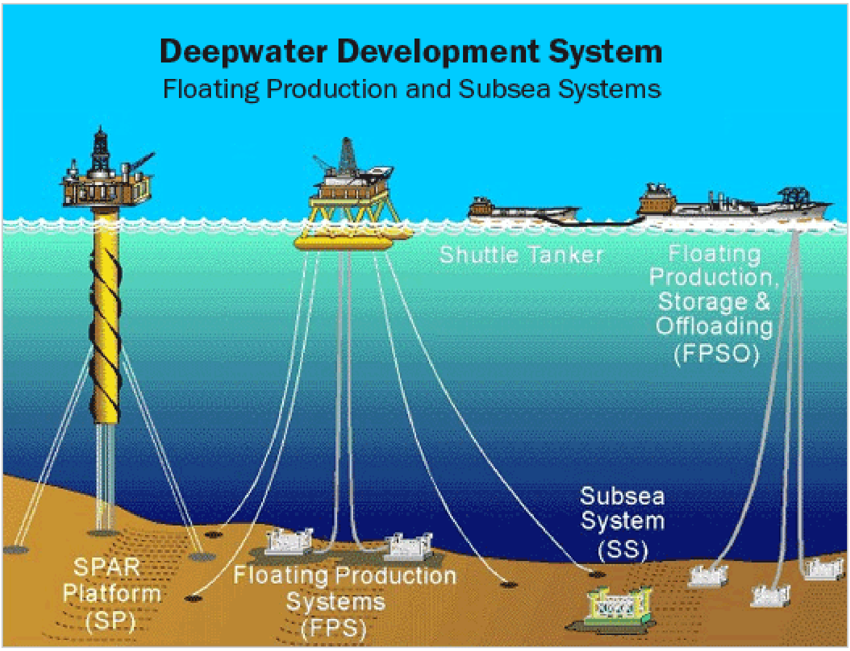


Figure 5: Variety type of floating offshore structure for deepwater

Narrowing the scope to spar, spar is an anchored buoy-like vessel that flows vertically and has on its top the production, treating and storage modules. It is a single, large-diameter cylinder that usually moored in position by traditional spread mooring. Spar said to experience a very small motion even in the 100-year hurricane event. A very low center of gravity gave spar a big advantage in standing upright and in a stable position. The mooring used is to reduce the motion of the platform the there is a hit by any environmental forces. Spar has been used for decades as a marker buoys and for gathering oceanography data where in the early days, it had been used as storage units. Till date, there are three types of production spar that had been built: Classic Spar, Cell Spar and Truss Spar. Related to this study, Truss Spar have a several horizontal plates and the lower part of it possess much lighter truss structure. The advantage of this Truss Spar, which made it more favorable to be, used that because it has the reduced current loadings on mooring. [5]

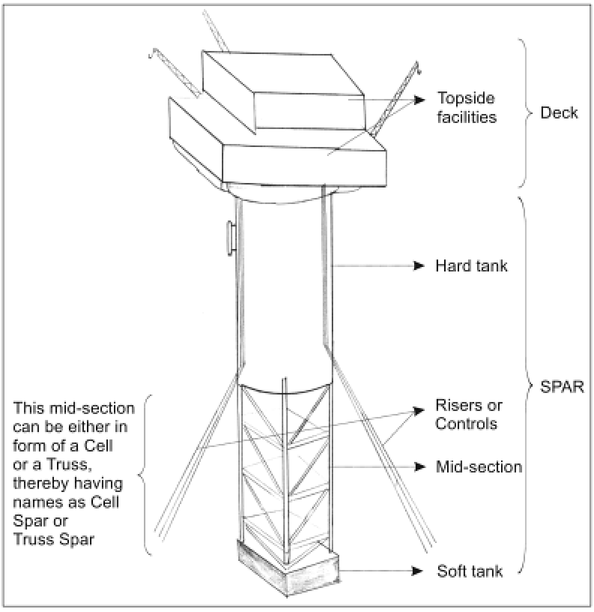


Figure 6: Schematic drawing of Truss Spar

2.2. LONG-CRESTED WAVE

Ocean wave and current is one of the biggest contributors to environmental loads. Thus, it will be a challenge for a floating structure to withstand against these forces. As for ocean waves, based on the wave propagation, it can be categorized by long-crested and short-crested wave. According to Roberts and Peregrine [6] Long-crested waves are profoundly to be a two dimensional force of short-crested waves which acts in one direction. Unidirectional or 2 dimensional wave are the other name been used for long crested wave. Current offshore structure had been designed with environmental loads that take long-crested wave into account. Hogben and Cobb [7] mentioned that the common design practice of assuming that the waves can be described by unidirectional spectra could thus often be very misleading. It is in the form of one direction wave exerted force onto the structure without any forces counter back at the other side. The forces impact by the long-crested wave is in the worst-case scenario.

2.3. SHORT-CRESTED WAVE

In the real sea condition, the waves propagate from different directions subject to diffraction, deflection or even wind blowing from different at different place. It is merely impossible for real sea state to have one directional ocean waves, which bring in the adoption of short-crested wave as the real condition of the sea. Jian et al, [8] stated that the short crested-waves generated by winds reflects the real sea condition and will be much appropriate to be adopted for analysis. It is also complexly three-dimensional waves [9]. When forces come from many directions, the net force is reduced compared to forces come from a single point.

There will be a gap between short-crested wave and long-crested wave as force exerted by three-dimensional wave are believed to be smaller than the two directional waves [10]. Since 1970s, the directional wave spectrum, and vertical circular cylinder on short-crested waves had been studied for the analytical solution derived for short-crested diffraction along positive x-axis direction on a large circular cylinder [11]. The studies are closely related to the Truss Spar model. For design purposes, many studies had been done to come out the best design guide for environmental force friendly structure. Wind-generated sea and swell wave had been included in the modeling of an offshore structure due to parametric directional spectrum were introduced by Hogben and Cobb [7].

2.4. OCEAN CURRENT

Ocean current is a movement of seawater that is continuous and directed by the variety of forces acting on it. It holds a big role in the climate of many earth region in creating the Thermohaline Circulation [12]

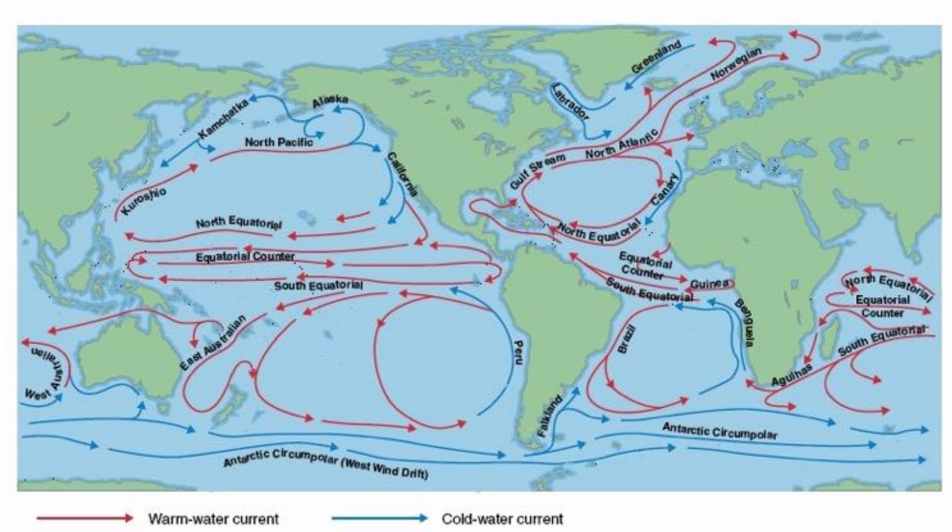


Figure 7: Global Flux of Ocean Current

Current takes place in the few forces in the environmental loads for offshore structure. According to Taniguchi and Kawano [13] current gave a significant effect on offshore structure towards their response. Inclusion of wave-current structure interaction to evaluate the dynamic response of offshore structure would be very important. Current considered as an important environmental force is analyzing any responses for offshore structure. Depending to the incident angle, current does influences [8]:

- Wave run-up
- Wave frequency
- Wave forces
- Inertia Coefficient
- Drag Coefficient

Thus, considering current into the study is vital.

2.5. PIERSON-MOSKOWITZ SPECTRUM

Based on similarity theory of Kitaigorodskii with more accurate recorded data, Pierson and Moskowitz [14] proposed new formula for an energy spectrum distribution of a wind generated sea state. According to Chakrabarti [9] the P-M spectral model describes a fully developed sea determined by one parameter, namely, the wind speed.

The P-M spectrum model is written as:

$$S(\omega) = \alpha g^2 \omega^{-5} \exp\left[-1.25 \left(\frac{\omega}{\omega_0}\right)^{-4}\right] \qquad (1)$$

Where:

$\alpha = 0.0081$; $g = 9.80665$; $\omega = 2\pi f$; $\omega_0 = \sqrt{0.161 g/H_S}$; $f =$ from 0.01 to 0.50Hz

An equivalent expression for P-M spectrum in terms of the cyclic frequency, $f = \omega/2\pi$ or $f_0 = \omega_0/2\pi$ may be written as

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

Other than P-M Spectrum, JONSWAP Spectrum is among the famous and widely used spectrum. In this study, P-M Spectrum had been chosen instead of other spectrum because P-M Spectrum has been extensively used and it can represents for waters all over the world [9]. In the other hand, JONSWAP for example, is developed during a joint North Sea wave project that may less be suitable to the Malaysian waters.

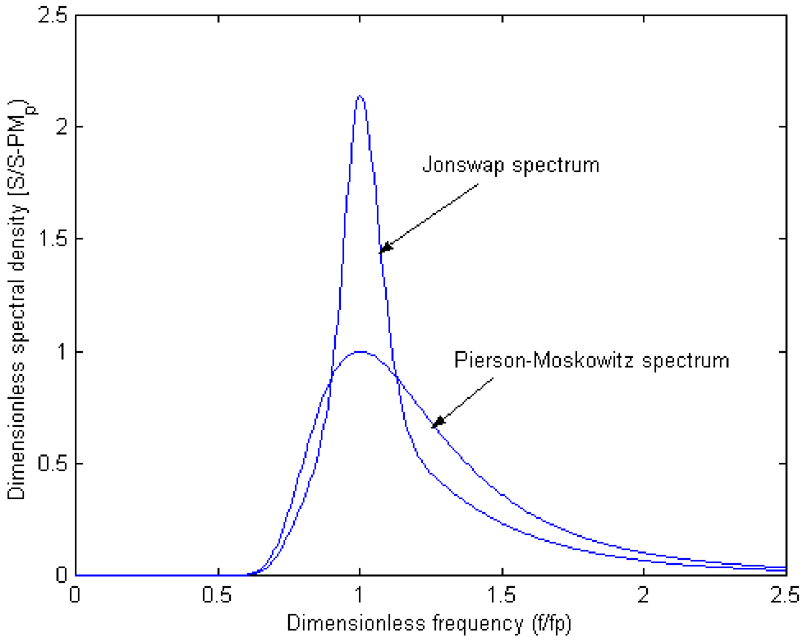


Figure 8: Differences Between P-M and JONSWAP Spectrum

2.6. MORISON EQUATION

The Morison Equation was developed by Morison, O'Brien, Johnson and Shaaf (1950) in describing the horizontal wave forces. It is composed of two components, inertia and drag forces. In this equation it there is water particle velocity that taken from Linear Airy Wave Theory where it can be included or excluded ocean current.

In situation where current is present with waves, the total water particle velocity will include steady current, U with the oscillatory component [9]:

$$F_t = \left[C_M\left(\frac{\rho\pi D^2}{4}\right)\dot{u}\right] + \left[C_D\left(\frac{\rho D}{2}\right)|u \pm U|(u \pm U)\right] \quad (3)$$

Where:

$$\dot{u} = \frac{2\pi^2 H}{T^2}\frac{\cosh ks}{\sinh kd}\sin\theta \qquad u = \frac{\pi H}{T}\frac{\cosh ks}{\sinh kd}\sin\theta \qquad U = Steady\ Ocean\ Current$$

In including the ocean current it is either the ocean current flowing parallel or against the wave propagation. The +U is when the current flowing parallel and together with the ocean wave whereby –U is the other way around. As for excluding current, the equation would be:

$$F_t = \left[C_M\left(\frac{\rho\pi D^2}{4}\right)\dot{u}\right] + \left[C_D\left(\frac{\rho D}{2}\right)\ |u|(u)\right] \qquad (4)$$

Where the $\dot{u}$ and u are the same.

Wave forces were identified using this Morison Equation and later on the forces were used to compute the Response Amplitude Operator (RAO)

2.7. DYNAMIC PRESSURE

With the involvement of dynamic pressure in water, the vertical forces can be identified,

$$Pressure, P = \frac{Force, F}{Area, A} \qquad (5)$$

Thus, in identifying the forces, the dynamic pressure of water particle is:

$$P = \rho g \frac{H}{2}\frac{\cosh ks}{\cosh kd} cos\theta \qquad (6)$$

2.8. RESPONSE AMPLITUDE OPERATOR

Transfer Function or Response Amplitude Operator (RAO) is a function of normalized response function constructed for a range of frequencies for any offshore structure. RAO can be written as:

$$RAO = \left[\frac{F/(H/2)}{\sqrt{[(K-m\omega^2)^2+(C\omega)^2]}}\right]^2 \quad (7)$$

Where:

$F = Inertia\ Forces$;

$K = Stiffness\ of\ structure$;

$m = Summation\ of\ mass$;

$C = Structural\ Damping\ Ratio$:

$H = Wave\ height$;

$\omega = natural\ frequency$

2.9. COSINE POWER LAW

The directional distributions of short-crested wave are described by a cosine power law [9]. It is the distribution of cosine-squared on the direction of Long-Crested wave within the range of $\pm 90°$.

$$S(\omega,\theta)f(x) = \begin{cases} \frac{2}{\pi}S(\omega)cos^2\theta, & -\pi/2 \leq \theta \leq \pi/2 \\ 0, & Elsewhere \end{cases} \quad (8)$$

Where $S(\omega)$ = P-M Spectrum

The function of the frequency, ω and heading angle of waves or direction, θ is the energy density.

2.10. WAVE PROFILE

The pattern and trend of a wave can be visualized by generating this wave profile by time history. It can be determined from:

$$\eta(x,t) = \sum_{n=1}^{N} \frac{H(n)}{2} \cos[k(n)x - 2\pi f(n)t + \varepsilon(n)] \quad (9)$$

Where:

$H(n) = H(f_1) = 2\sqrt{2(f_1) \vartriangle f}$

$(f_1) = S(f) = 2\pi S_{total}$

$\varepsilon(n) = 2\pi R_N$

$R_N = Randon\ Number$

$t = varies\ from\ 0\ to\ 500s$

2.11. FREQUENCY DOMAIN ANALYSIS

According to Kulkarni [15] frequency domain analysis is arguably the most far reaching among all the mathematical tools. It is widely used in many fields of engineering. Ocean wave, similar to electrical wave are either subjected to time or frequency domain in order to be analyzed. Within the scope of this study, there will be variety of ocean wave frequencies up to 0.5Hz. However, by frequency domain in the equations of motion, need to be replaced by linear approximations due to nonlinearities [16].

2.12. CRITICAL LITERATURE REVIEW

Current offshore design had been considering long-crested wave as the wave force. In improvising the efficiency of the design, most studies had been performed considering only wave (short-crested wave) without taking into consideration of ocean current

The study performed in improving the research been done in associate with short-crested wave in inducing dynamic response to the Truss Spar model with taking current into consideration since it mentioned to gave a significant impact to the offshore structure by Taniguchi and Kawano [13].

CHAPTER 3
METHODOLOGY

In order for this to success, there are few elements, steps and flow in achieving the objectives.

3.1. PROJECT WORKFLOW

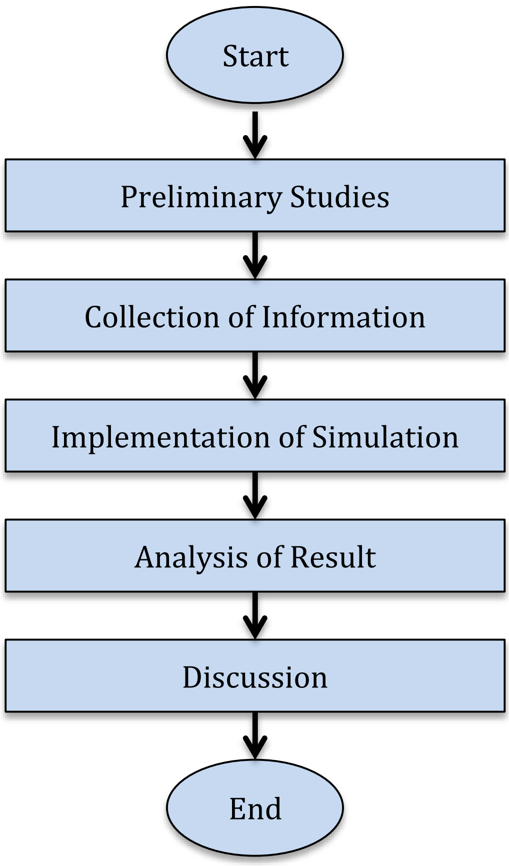


Figure 9: Final Year Project Workflow

The project workflow above presents the overview of FYP methodology. The study is developed from study had been done related to dynamic response of Truss Spar due to environmental loads.

3.1.1. Preliminary Studies

Study been done by Kurian et al, [11] proven that there is a gap between short and long-crested wave. The real sea condition of Short-Crested wave induces less force compared to Long-Crested wave. However, it is only the ocean wave were taken into consideration. The importance of ocean current had been highlighted in some other studies for the impact of offshore structure due to environmental forces. Therefore, by including the ocean current it is believed that the condition that close to real sea state giving the impact to the offshore structure can be achieved. The literature review done in the preliminary studies phase. The literature review mainly focusing on:

- Understanding Short and Long-Crested wave
- Impact of environmental loads onto offshore structure
- Research that been done related to the study
- Importance of ocean current to the impact of offshore structure
- Spectrums and equations related to the study
- Frequency domain for the numerical analysis

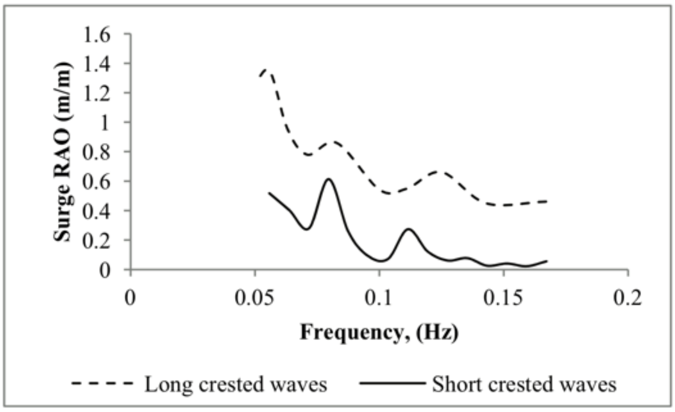


Figure 10: Surge RAO due to long and short crested wave [11]

In the Surge direction, by doing experiment and numerical analysis, short-crested wave gave a lower RAO compared to long-crested wave.

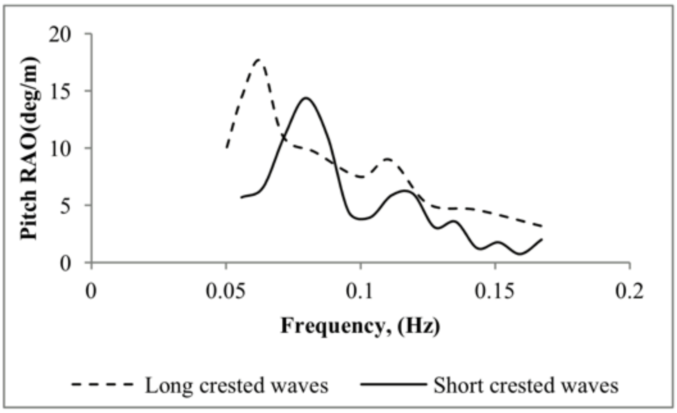


Figure 11: Pitch RAO due to long and short crested wave [11]

In pitch motion, there are slight differences between short and long-crested wave where long-crested wave have less RAO at some frequency

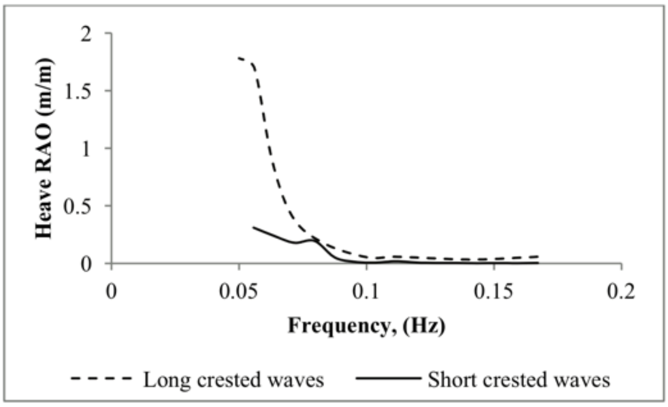


Figure 12: Heave RAO due to long and short crested wave [11]

In Heave motion, huge difference can be seen on the lower frequency and there's only small difference in a higher frequency

3.1.2. Collection of Information

Once already firm with the idea of studies, in the collection of information phase, all related data and parameters identified and analyzed. Parameters including the scaling of the Truss Spar model size, mass and other required information (e.g. Metocean data and equations) that needed for the numerical analysis. At the same time, the method of comparing short and long-crested were decided in this phase, which by comparing the time history wave profile.

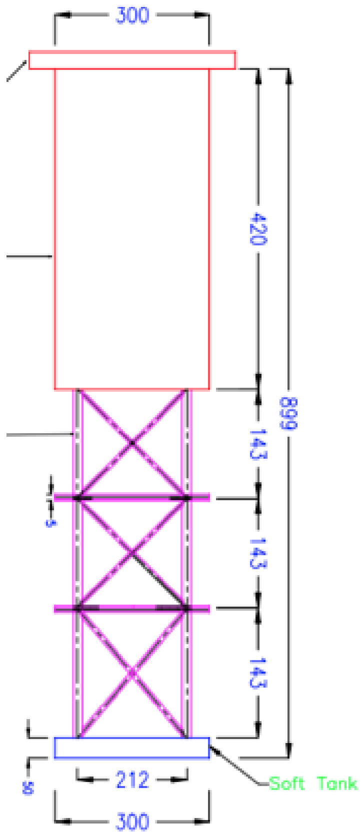


Figure 13: Truss Spar model used

3.1.3. Implementation of Simulation

The numerical analysis will be done using Microsoft Excel. Graph will plotted based on generated spectrum and the comparison will be made using the Wave Response Spectrum graphs. The variable data are; frequency, water depth (for Surge and Pitch motion); and time. Whereby the metocean and truss spar model data are constant.

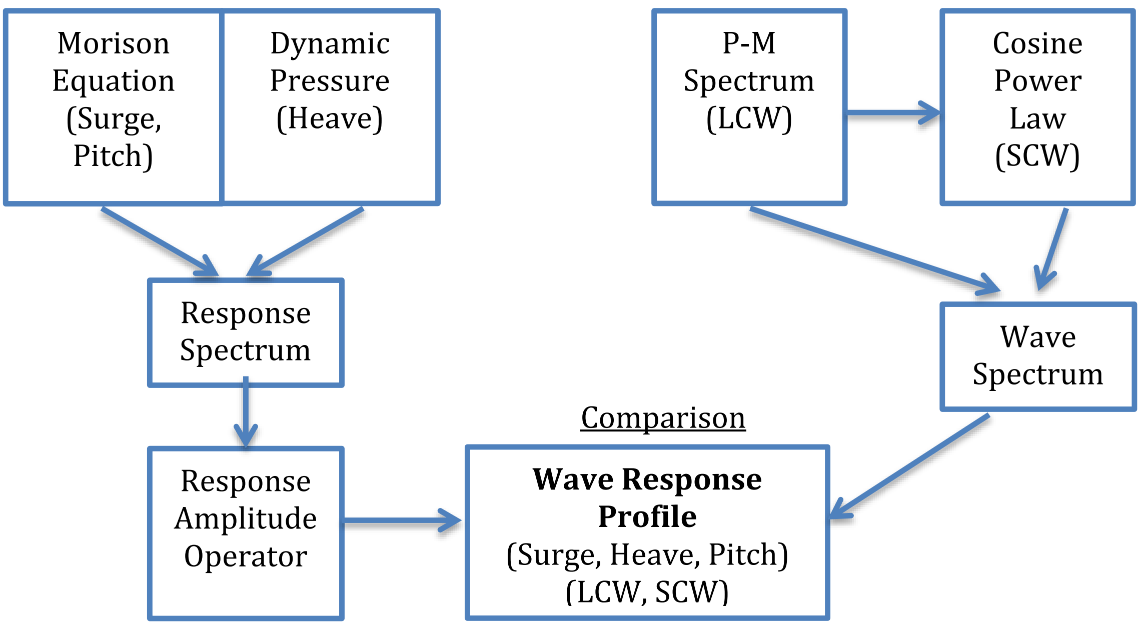


Figure 14: Flow of simulation and analysis of the study

The analysis had been divided into two parts in order to generate the wave profile, which is the Wave Spectrum and Response Spectrum. Since it is comparison between short and long-crested wave with current, thus wave spectrum will have both short and long-crested wave. As per mentioned in the scope of study, this research would only review the 3 out of 6 degree of freedom, which is Surge, Pitch and Heave.

For Response Spectrum, Morison and Dynamic Pressure had been used. Morison Equation used for both Surge and Pitch, as it will produce the horizontal force. Pitch at the other side adopted the pressure-area method to determine the vertical force. Once the forces been computed, the Response Amplitude Operator was calculated according to the frequency.

P-M Spectrum was considered in this study. The spectrum represented the long-crested wave. As for Short-Crested wave, Cosine Power Law had been used as the spreading function to have a wave propagates from many direction. The angle of wave propagates ranged from $-90°$ to $90°$ with the increment of $10°$.

With both Response and Wave Spectrum ready, the wave profile were generated and the profile of each long and short-crested wave will be displayed. The time history will require time from 0s to 500s to have a clear profile of the wave.

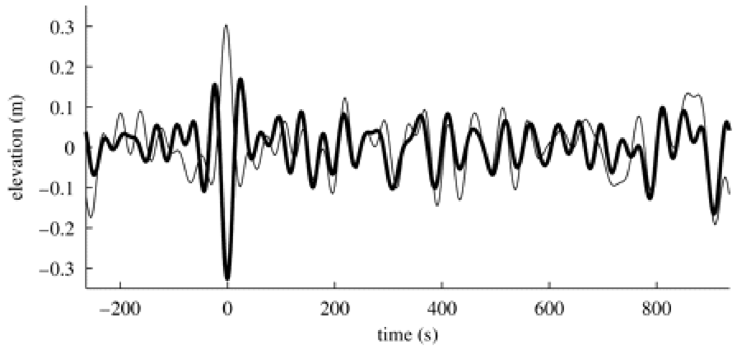


Figure 15: Example of Wave Profile

3.1.4. Analysis of Result

The comparison been made by visualizing the two lines of each wave profile. Comparing the maximum crest, minimum trough and the amplitude of the wave profile was analyzed. Percentage difference of both waves also were displayed.

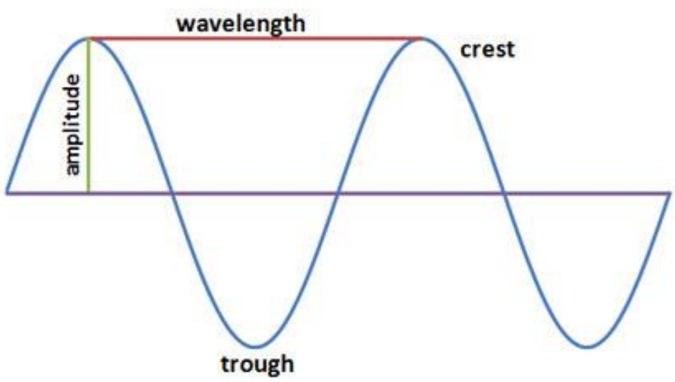


Figure 16: Visualization of Crest, Trough and Amplitude

3.1.5. Discussion

The outcome of the result will be discussed whether it is reasonable and aligned with the research done. Any further recommendation in improving the study shall be discuss also.

3.2. GANTT CHART

No.	***Activities /Month (2014-2015)***	***9***	***10***	***11***	***12***	***1***	***2***	***3***	***4***
1	*Preliminary Study & Literature Review*								
2	*Methodology Studies*								
3	*Collecting Information for Numerical Analysis*								
4	*Implementation of analysis*								
6	*Collecting and Analyze Result*								
7	*Compilation and Finishing Report*								

Figure 17: Gantt Chart

CHAPTER 4
RESULTS AND DISCUSSION

This project aims to compare dynamic responses of Truss Spar exerted by Short-Crested Wave and Long-Crested Wave with current. The gap and differences between both ocean waves and efficiency of Short-Crested wave will be discussed in this chapter.

4.1. PARAMETER USED

Below are the metocean and Truss Spar Model parameters that had been used for this numerical analysis.

Table 1: Parameters used for numerical analysis

Drag Coefficient	Cd	1.60			Ocean Current		
Inertia Coefficient	Cm	0.65			At surface	1.30	m/s
Wave Height	H	14.50	m		0.5D	1.20	m/s
Point of Depth	z	-2 to -90	m		0.01D	0.70	m/s
Centre of Gravity	X	0	m				
Water Depth	d	1300.00	m		Natural Period		
Gravitational Acceleration	g	9.81	m/s2		Surge	200.00	s
Truss Spar Diameter	D	30.00	m		Pitch	50.00	s
Truss Spar Mass	M	51.62	M Kg		Heave	30.00	s

The metocean parameters are adopted from PETRONAS Technical Standard (PTS). Since Truss Spar commonly used for deepwater thus the water depth assumed should be more than 1000m. As for the natural period it specifically designed for Spar are 150s – 350s for Surge, 40s – 80s for Pitch and 25s – 40s for Heave [17].

4.2. WAVE SPECTRUM

Waves composed of various lengths and periods. The spectrum of ocean wave is the simplification that comes close in describing the surface. It gives the distribution of wave energy among different wave frequencies of wavelength on the sea surface.

4.2.1. Long-Crested Wave

Since this study will consider P-M Spectrum, the spectrum itself will represent the wave of long-crested wave.

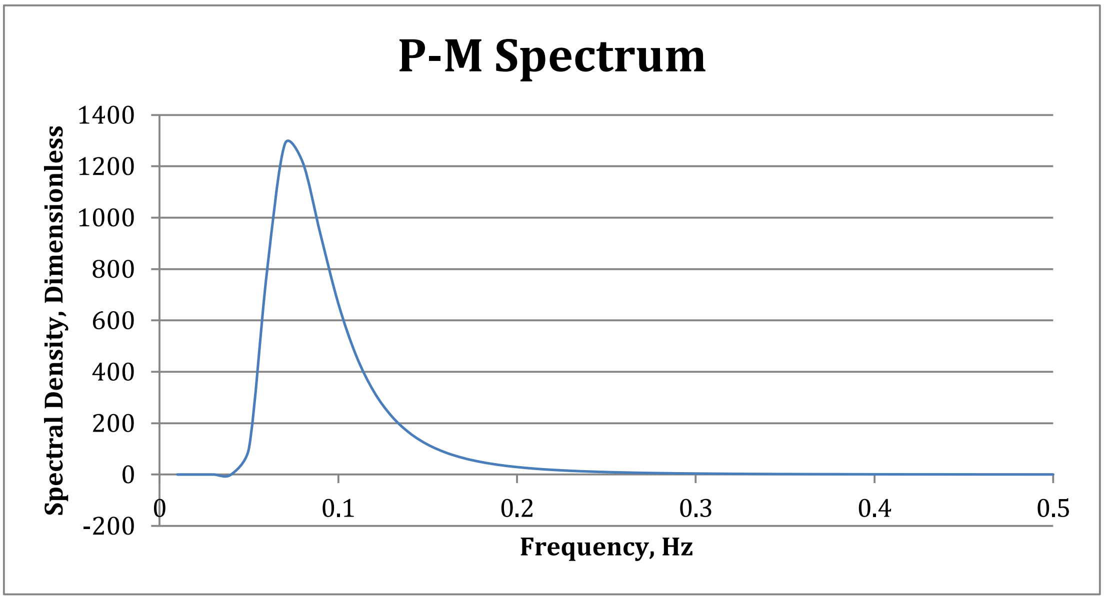


Figure 18: P-M Spectrum

Above is the P-M Spectrum represents Long-Crested wave.

4.2.2. Short-Crested Wave

Cosine Power Law been used as a spreading function to have the wave propagates from many angles. For this study, the wave propagates with an increment of 10° ranging from −90° to 90°.

f'	S(w)	S(w,-90)	S(w,-80)	S(w,-70)	S(w,-60)	S(w,-50)	S(w,-40)	S(w,-30)	S(w,-20)
0.01	0	0	0	0	0	0	0	0	0
0.02	7.12001E-93	1.7009E-125	1.36679E-94	5.3023E-94	1.13318E-93	1.87282E-93	2.65992E-93	3.39955E-93	4.00251E-93
0.03	2.78636E-16	6.65633E-49	5.34882E-18	2.07501E-17	4.43463E-17	7.32913E-17	1.04094E-16	1.33039E-16	1.56635E-16
0.04	0.000718899	1.71738E-36	1.38003E-05	5.35367E-05	0.000114416	0.000189096	0.000268569	0.000343249	0.000404129
0.05	0.860132521	2.05477E-33	0.016511478	0.064054384	0.136894342	0.226245779	0.321331591	0.410683027	0.483522986
0.06	6.580743043	1.57207E-32	0.126326806	0.490070347	1.047357785	1.730972028	2.45845911	3.142073354	3.699360791
0.07	10.76662538	2.57204E-32	0.206680824	0.80179454	1.71356165	2.832009584	4.022237016	5.14068495	6.05245206
0.08	10.19416171	2.43528E-32	0.195691563	0.75916296	1.622451227	2.681431056	3.808373851	4.86735368	5.730641946
0.09	7.839269371	1.87272E-32	0.150486025	0.583793265	1.247658471	2.062009702	2.928624181	3.742975412	4.406840618
0.1	5.57769064	1.33245E-32	0.107071776	0.415372667	0.887717036	1.467133182	2.083734964	2.663151109	3.135495479
0.11	3.876641825	9.2609E-33	0.074417703	0.288694938	0.616986709	1.019696183	1.448250653	1.850960127	2.179251898
0.12	2.694785364	6.43757E-33	0.051730272	0.200681654	0.428888411	0.70882544	1.006728205	1.286665234	1.514871991
0.13	1.892879403	4.5219E-33	0.036336536	0.140963423	0.301261114	0.497895341	0.707149114	0.903783341	1.064081031
0.14	1.349192429	3.22308E-33	0.025899685	0.100474855	0.214730644	0.354886118	0.504036459	0.644191933	0.758447722
0.15	0.977135852	2.33428E-33	0.018757525	0.072767665	0.155516001	0.257021862	0.365042142	0.466548003	0.549296339
0.16	0.719040973	1.71772E-33	0.013803023	0.053547245	0.114438925	0.189133629	0.268622072	0.343316776	0.404208456
0.17	0.537259895	1.28346E-33	0.010313475	0.040009941	0.085507568	0.141318669	0.200711603	0.256522704	0.302020331
0.18	0.407236264	9.72846E-34	0.007817484	0.030327034	0.064813664	0.107117779	0.152136878	0.194440993	0.228927624
0.19	0.3128259	7.47309E-34	0.006005142	0.02329626	0.049787788	0.082284459	0.116866694	0.149363365	0.175854894
0.2	0.24328727	5.81188E-34	0.004670248	0.018117692	0.038720372	0.063993299	0.090888187	0.116161115	0.136763794
0.21	0.191374724	4.57175E-34	0.003673712	0.014251746	0.030458233	0.050338433	0.0714945	0.0913747	0.107581187
0.22	0.152130485	3.63424E-34	0.002920363	0.011329213	0.024212319	0.040015787	0.056833488	0.072636956	0.085520062
0.23	0.122113764	2.91717E-34	0.002344149	0.009093857	0.019435009	0.03212031	0.045619726	0.058305027	0.06864618
0.24	0.098903498	2.3627E-34	0.001898595	0.00736538	0.015740981	0.026015176	0.036948746	0.047222942	0.055598543
0.25	0.080773562	1.9296E-34	0.001550564	0.006015237	0.012855512	0.021246351	0.030175696	0.038566535	0.04540681
0.26	0.06647781	1.58809E-34	0.001276137	0.004950627	0.010580272	0.017486054	0.024835034	0.031740816	0.037370461
0.27	0.05510592	1.31642E-34	0.001057837	0.004103758	0.00877038	0.014494838	0.02058668	0.026311139	0.03097776
0.28	0.045985449	1.09855E-34	0.000882757	0.003424553	0.007318812	0.012095827	0.01717942	0.021956435	0.025850693
0.29	0.038614438	9.22459E-35	0.00074126	0.002875631	0.006145679	0.010156985	0.014425729	0.018437036	0.021707083
0.3	0.032614475	7.79126E-35	0.000626082	0.002428812	0.005190755	0.00857878	0.01218424	0.015572265	0.018334208

Figure 19: Excel Spreadsheet data of Short-Crested Wave

The Short-Crested wave also considering P-M Spectrum whereby it propagates and heading to and from different angle. It made the spectrum complex and three-dimensional.

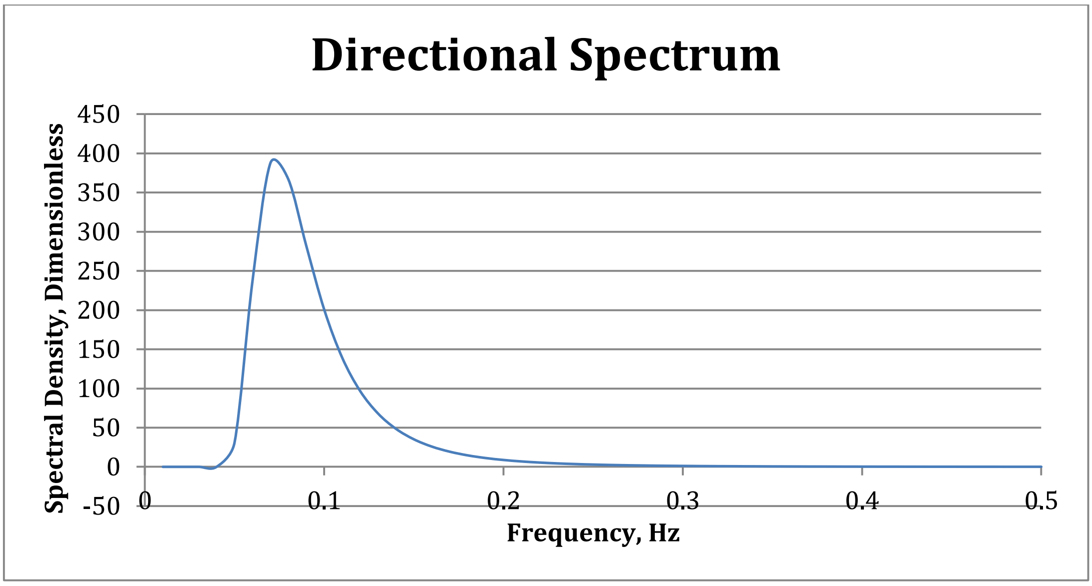


Figure 20: Directional Spectrum as Short-Crested wave

By comparing both of the wave spectrum (Directional and P-M Spectrum) it can be seen that P-M Spectrum that represents Long-Crested wave has a higher Spectral Density. This is because the wave force experienced by long-crested wave are the net force from one direction whereas the short-crested wave the force from many direction cancel each other resulted in lower net force.

4.3. RESPONSE SPECTRUM

Response spectrum can be measured by the displacement, velocity or acceleration of a varying natural frequency that forced into motion. The response of Truss Spar due to waves and current are based on the force exerted by the environmental loads.

4.2.1. Surge

In Surge direction, force is oriented in horizontal direction. Thus, the involvement of current would be necessary as current move horizontally. Comparison between with and without current will be made.

Since the numerical analysis will be in frequency domain, variety of wave frequency of wave will be analyzed. The forces identified by Morison Equation are subjected to time. So the highest force experienced will be used accordingly to the water depth. Then, by summing up all maximum forces according to depth, it will be the total forces experienced at certain wave frequency. Those total forces are used to calculate the Response Amplitude Operator (RAO) later on.

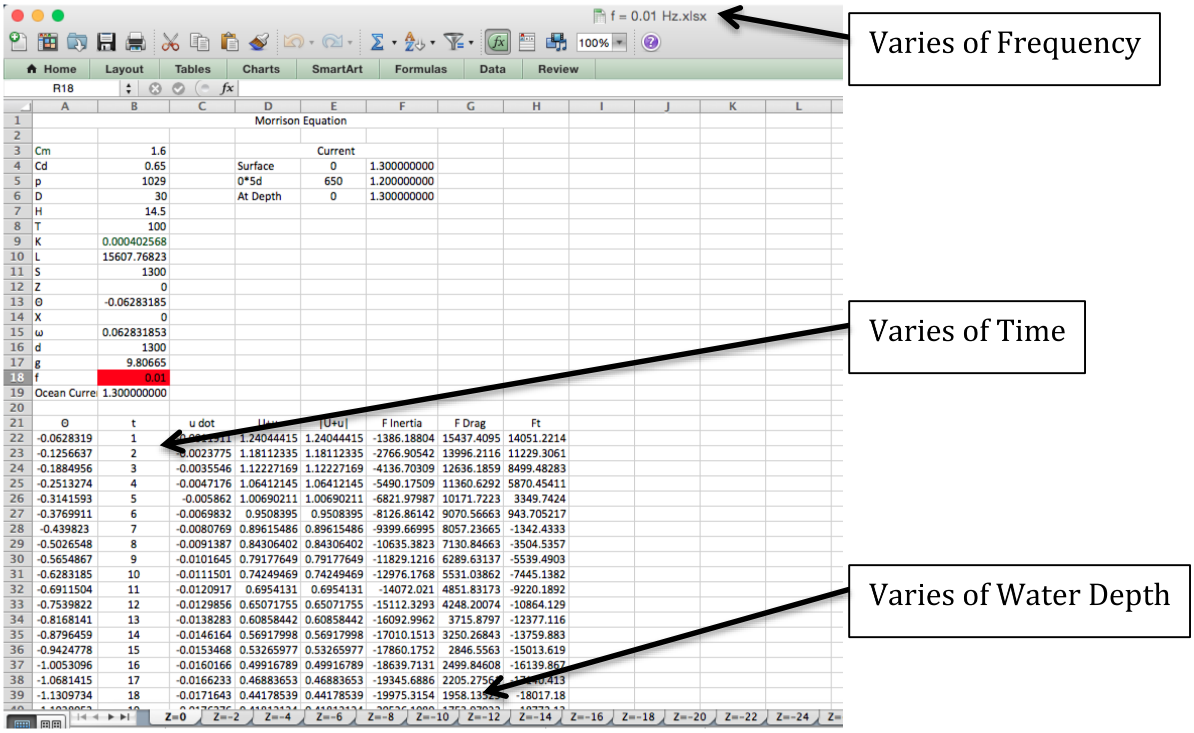


Figure 21: Spreadsheet data on Surge Horizontal Forces

The forces are identified for frequency ranging from 0.01Hz to 0.5Hz.

3.1.1 Without Current

By excluding current, the water particle velocity will be only considering the ocean waves. From the analysis done, we can see that at frequency 0.36Hz the structure will experience the highest force at the surface of the water (0m depth).

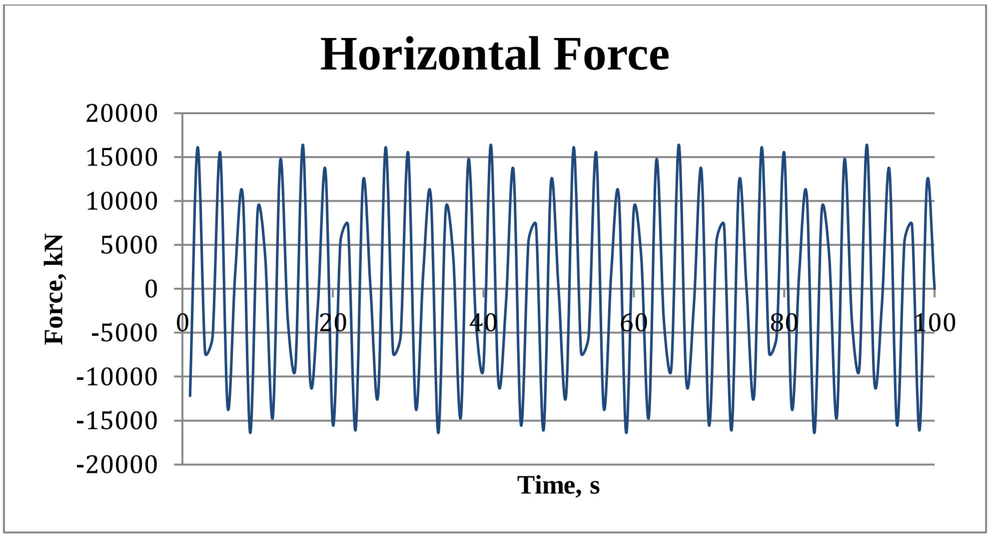


Figure 22: Horizontal Force without current at depth 0m and frequency 0.36Hz

At the frequency 0.1Hz, the structure will experience the least force within the same depth.

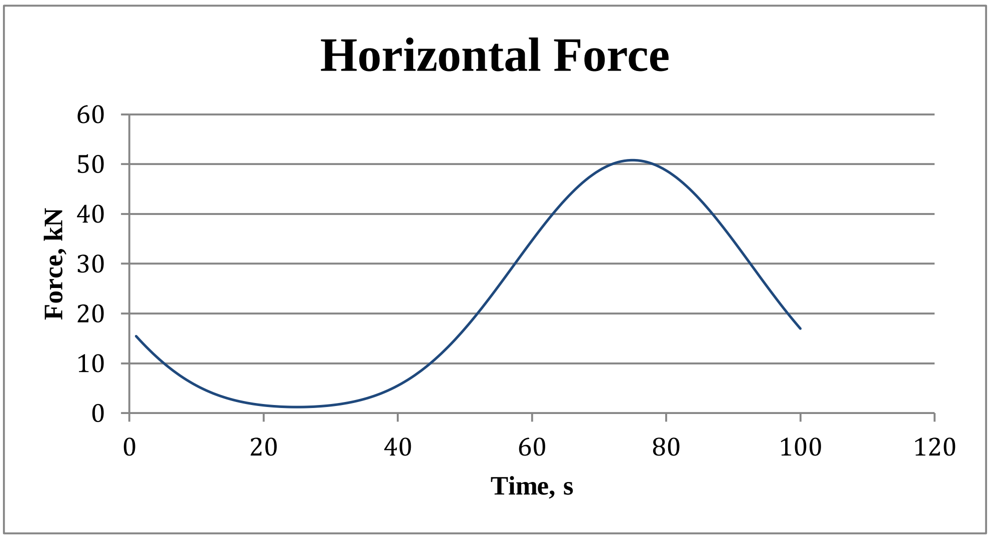


Figure 23: Horizontal Force without current at depth 0m and frequency 0.01Hz

From the plotting of the horizontal forces, the trend of the forces according to time also different subject to wave frequency where the higher the frequency, there will be more waves in 100s time.

RAO

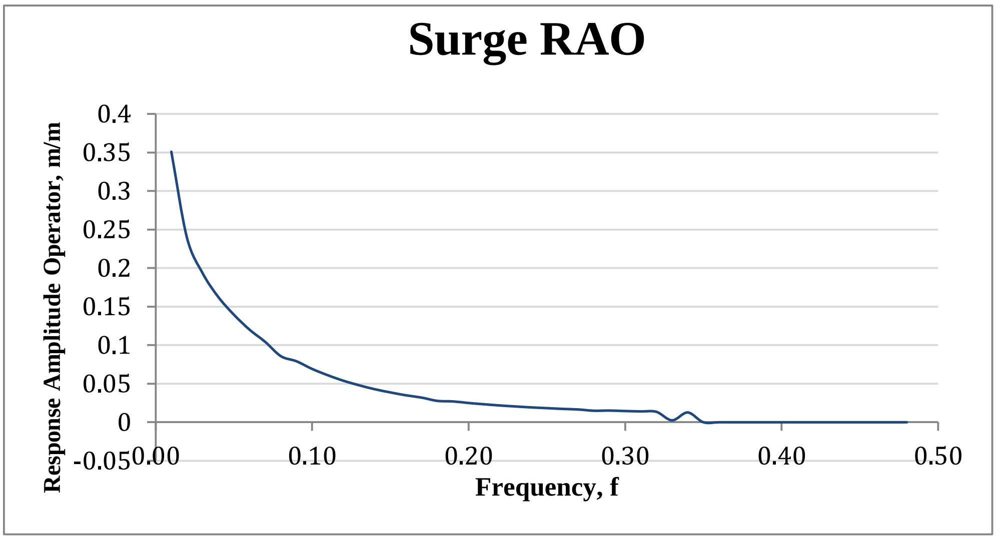


Figure 24: RAO Surge Without Current

3.1.2 With Current

The water particle velocity included the ocean current velocity. The trend of forces by including current is almost the same with without current.

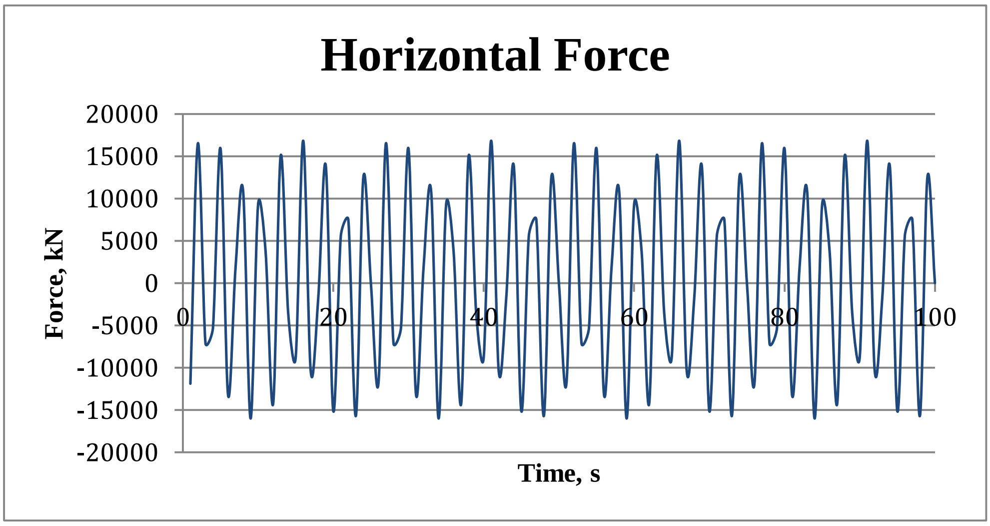


Figure 25: Horizontal Force with current at depth 0m and frequency 0.36Hz

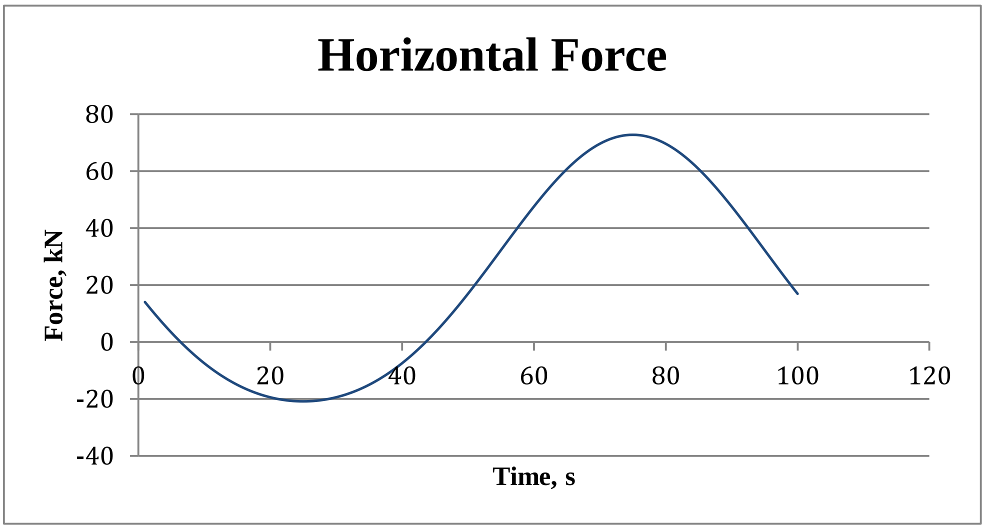


Figure 26: Horizontal Force with current at depth 0m and frequency 0.01Hz

The horizontal forces of waves with current do exerted more load compared to without current. The differences of value are significant. So by excluding the ocean current would be dangerous for offshore design that considering short-crested wave. By considering short-crested wave rather than long-crested wave, there will be reduction in the design.

<u>RAO</u>

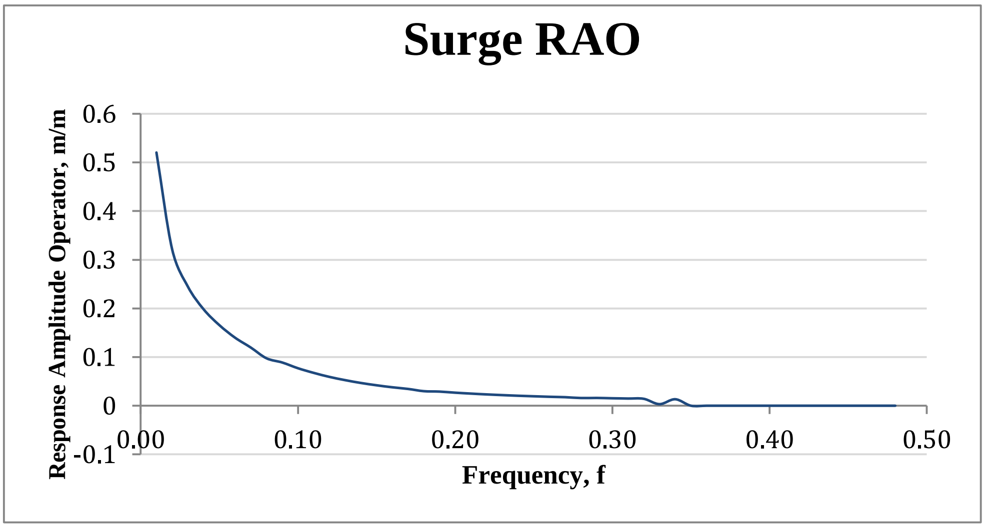


Figure 27: Surge RAO with Current

3.1.3 Difference in Considering Ocean Current

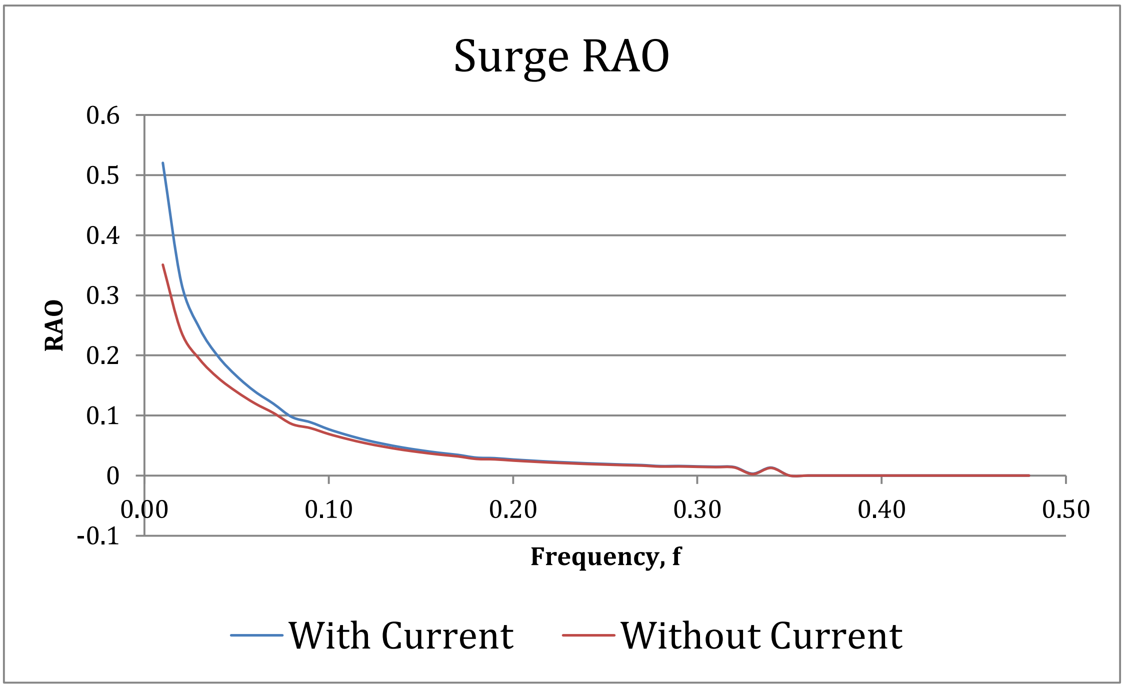


Figure 28: Comparison with and without current for Surge

From the comparison above we can see that ocean current does affect the RAO, where with ocean current, the RAO are slightly greater than without current. Thus, by excluding ocean current in the offshore structure design in considering Short-Crested wave in the design code, the design would be insufficient and may be dangerous for the integrity if the structure,

4.2.2. Pitch

For the motion of Pitch, the moment of the structure been identified according the forces obtained in the Surge motions by multiplying with the moment arm from the center of gravity. In including and excluding the ocean current also would affect motion in Pitch.

3.2.1 Without Current

By excluding current, the horizontal forces would be the same in the surge motion and multiplied with the moment arm of the Truss Spar model. The trends of the graphs are the same. At frequency 0.36Hz giving greater moment and 0.01Hz the least.

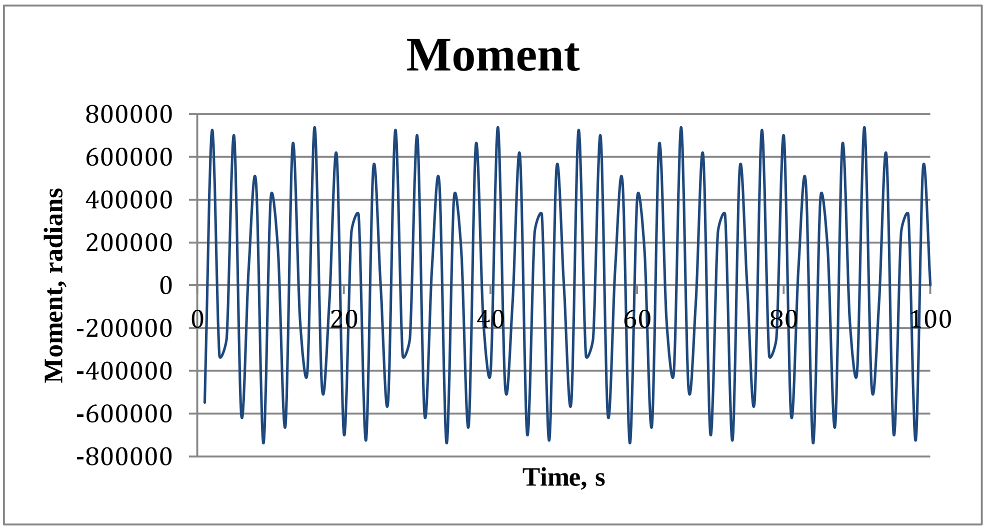


Figure 29: Moment without current at depth 0m and frequency 0.36Hz

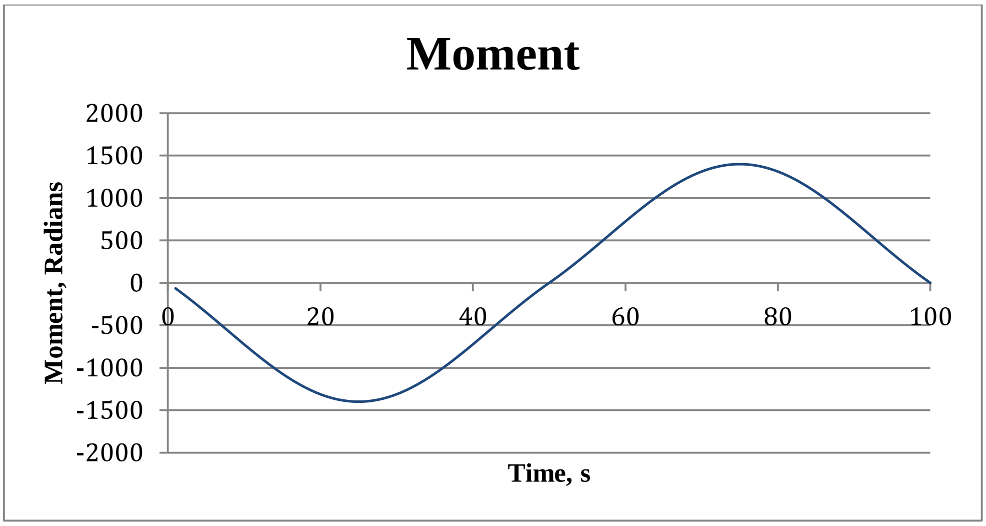


Figure 30: Moment without current at depth 0m and frequency 0.36Hz

<u>RAO</u>

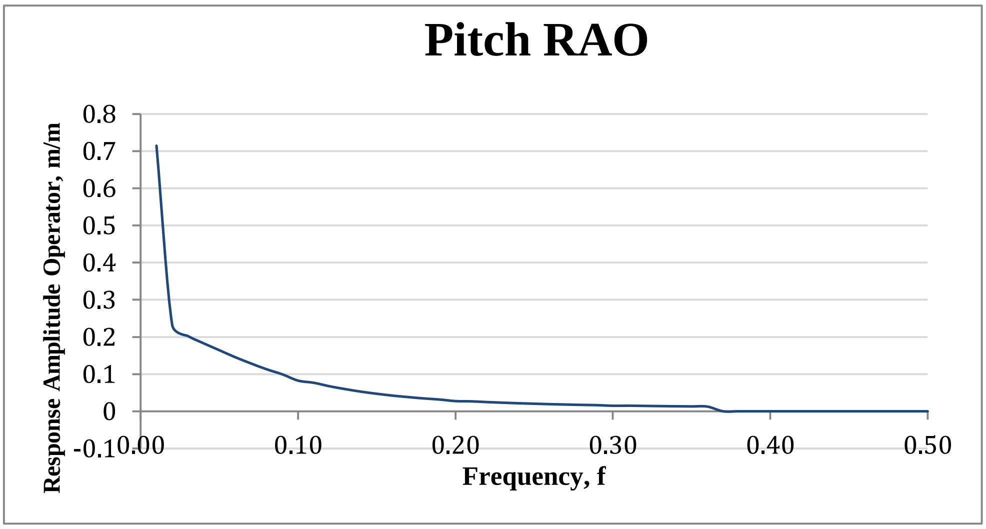


Figure 31: Pitch RAO without Current

3.2.2 With Current

The trend will be the same for Pitch with ocean current. The values of moment are bigger at 0.36Hz and lowest at 0.01Hz within the same depth

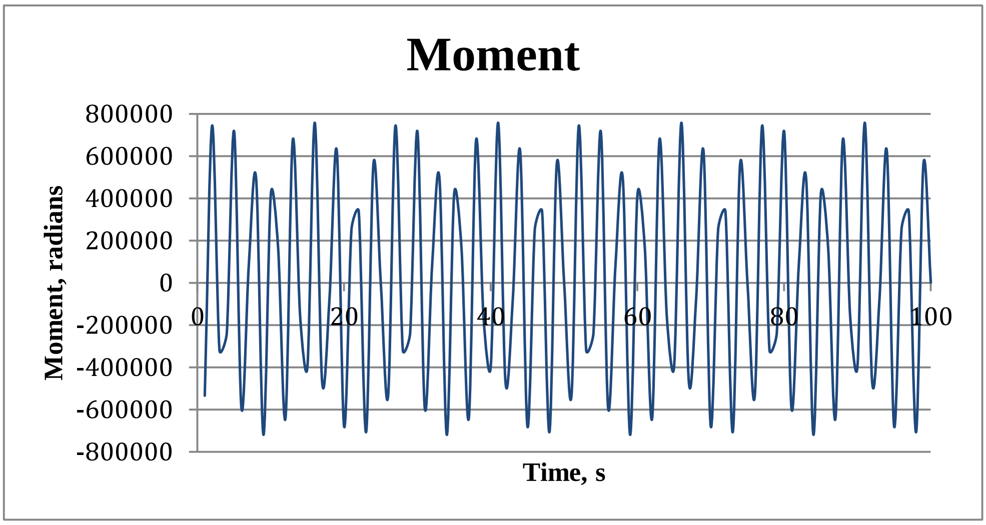


Figure 32: Moment with current at depth 0m and frequency 0.36Hz

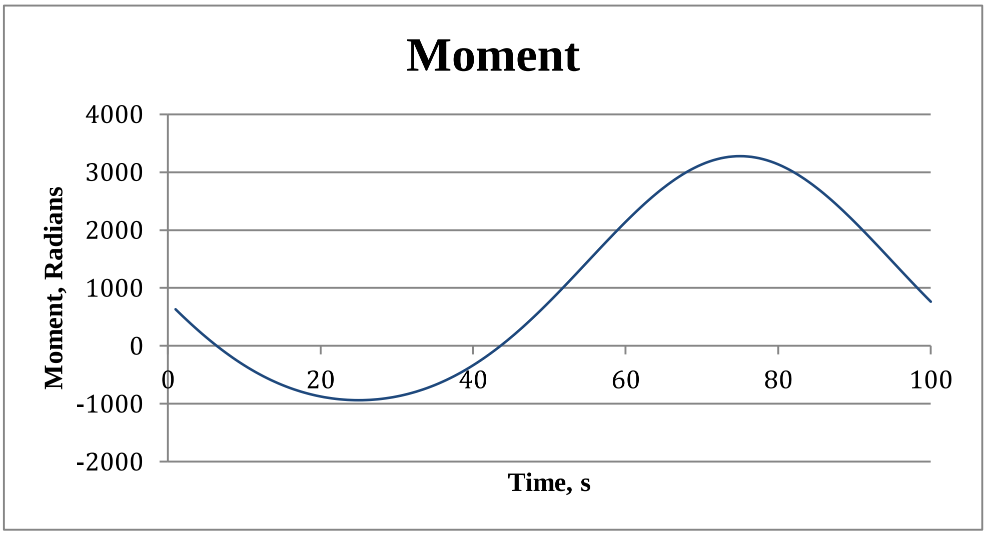


Figure 33: Moment with current at depth 0m and frequency 0.01Hz

By comparing with and without current for Pitch, the values of moment are bigger with ocean current compared to without current. The different affect by the horizontal force influences the different in moment motion of Pitch.

RAO

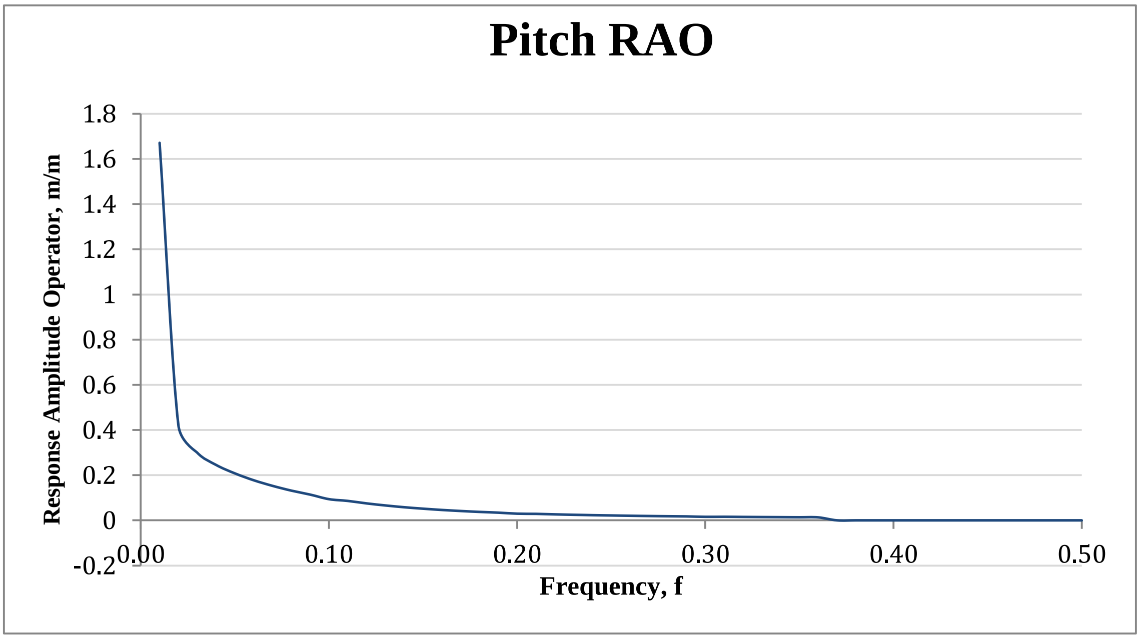


Figure 34: Pitch RAO with Current

3.2.3 Difference in Considering Ocean Current

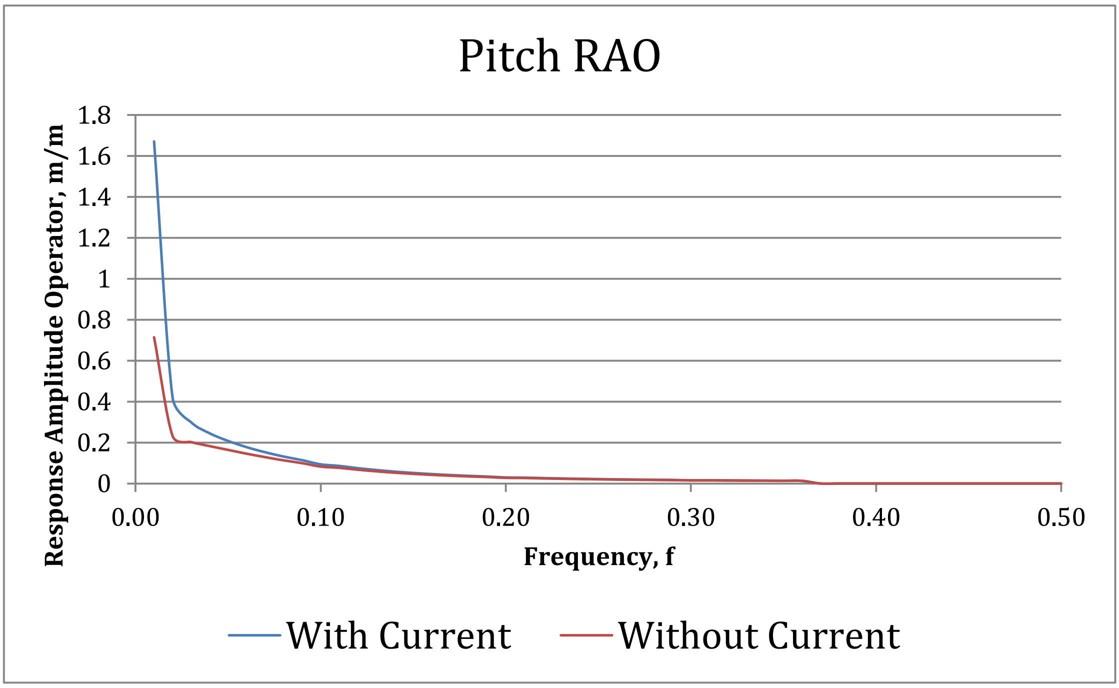
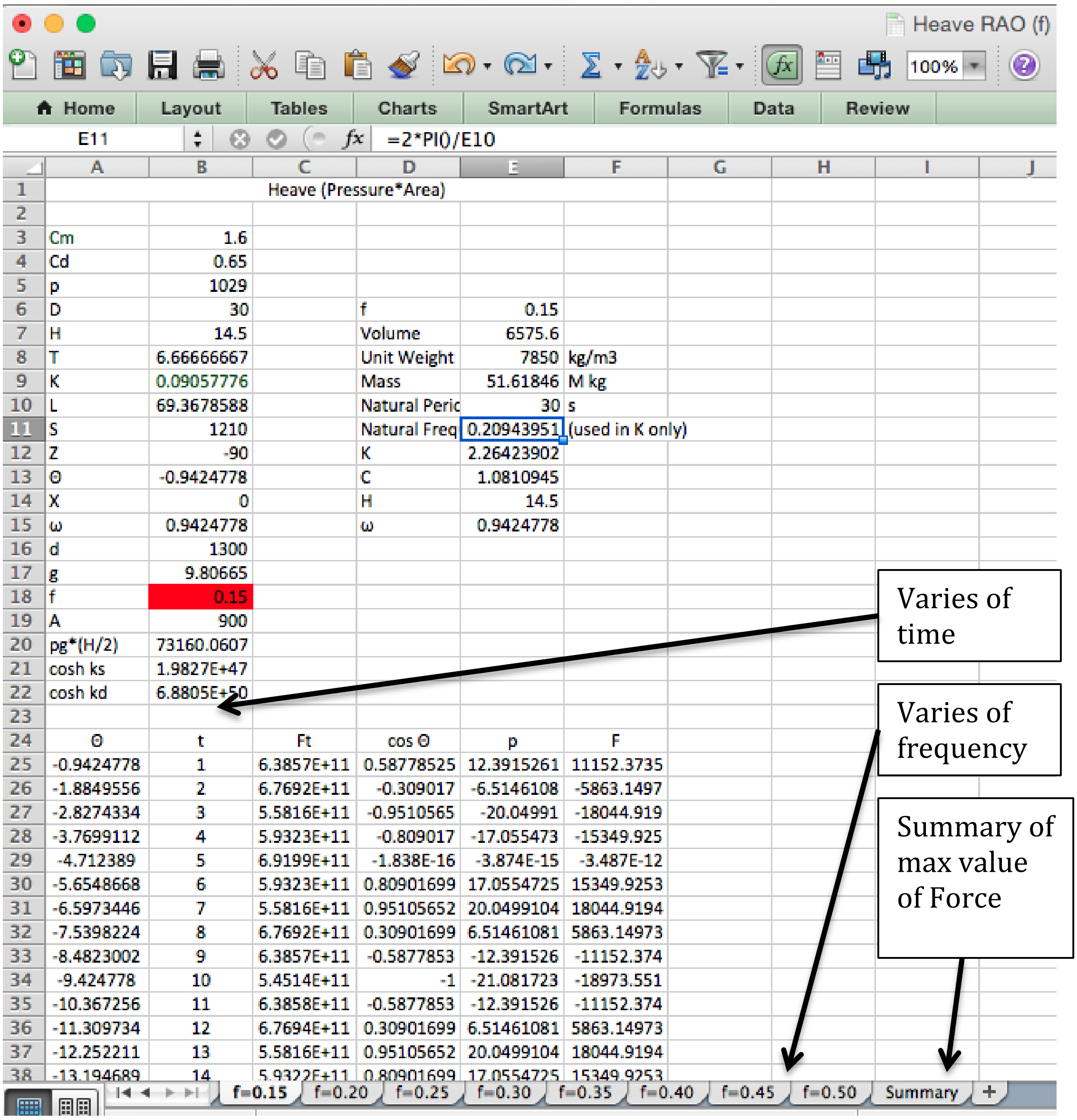


Figure 35: Comparison with and without current for Pitch

The differences for Pitch also results the same with Surge as RAO with ocean current gave a bigger RAO compared to without current.

4.2.3. Heave

Heave is influences by vertical forces. In determining the vertical force that exert onto the structure, the forces can be obtained from the Dynamic Pressure. Dynamic Pressure is the pressure acting at the bottom of the Truss Spar model. By multiplying with Area of contact at the bottom of Truss Spar model, the vertical forces can be identified.



	A	B	C	D	E	F
1			Heave (Pressure*Area)			
2						
3	Cm	1.6				
4	Cd	0.65				
5	p	1029				
6	D	30		f	0.15	
7	H	14.5		Volume	6575.6	
8	T	6.66666667		Unit Weight	7850	kg/m3
9	K	0.09057776		Mass	51.61846	M kg
10	L	69.3678588		Natural Peric	30	s
11	S	1210		Natural Freq	0.20943951	(used in K only)
12	Z	-90		K	2.26423902	
13	Θ	-0.9424778		C	1.0810945	
14	X	0		H	14.5	
15	ω	0.9424778		ω	0.9424778	
16	d	1300				
17	g	9.80665				
18	f	0.15				
19	A	900				
20	pg*(H/2)	73160.0607				
21	cosh ks	1.9827E+47				
22	cosh kd	6.8805E+50				
23						
24	Θ	t	Ft	cos Θ	p	F
25	-0.9424778	1	6.3857E+11	0.58778525	12.3915261	11152.3735
26	-1.8849556	2	6.7692E+11	-0.309017	-6.5146108	-5863.1497
27	-2.8274334	3	5.5816E+11	-0.9510565	-20.04991	-18044.919
28	-3.7699112	4	5.9323E+11	-0.809017	-17.055473	-15349.925
29	-4.712389	5	6.9199E+11	-1.838E-16	-3.874E-15	-3.487E-12
30	-5.6548668	6	5.9323E+11	0.80901699	17.0554725	15349.9253
31	-6.5973446	7	5.5816E+11	0.95105652	20.0499104	18044.9194
32	-7.5398224	8	6.7692E+11	0.30901699	6.51461081	5863.14973
33	-8.4823002	9	6.3857E+11	-0.5877853	-12.391526	-11152.374
34	-9.424778	10	5.4514E+11	-1	-21.081723	-18973.551
35	-10.367256	11	6.3858E+11	-0.5877853	-12.391526	-11152.374
36	-11.309734	12	6.7694E+11	0.30901699	6.51461081	5863.14973
37	-12.252211	13	5.5816E+11	0.95105652	20.0499104	18044.9194
38	-13.194689	14	5.9322E+11	0.80901699	17.0554725	15349.9253

Figure 36: Spreadsheet data on Heave Vertical Forces

For heave, there will be variable of frequency since this analysis is in frequency domain. The time and distance to center of gravity also varies. Since the Truss Spar is geometrical shape of cylinder, thus the distance to center of gravity are 0 because it is located at the center of the cylinder of Truss Spar.

Heave also not affected by ocean current that flowing in horizontal direction. So the comparisons between with and without ocean current will not being demonstrated for Heave motion.

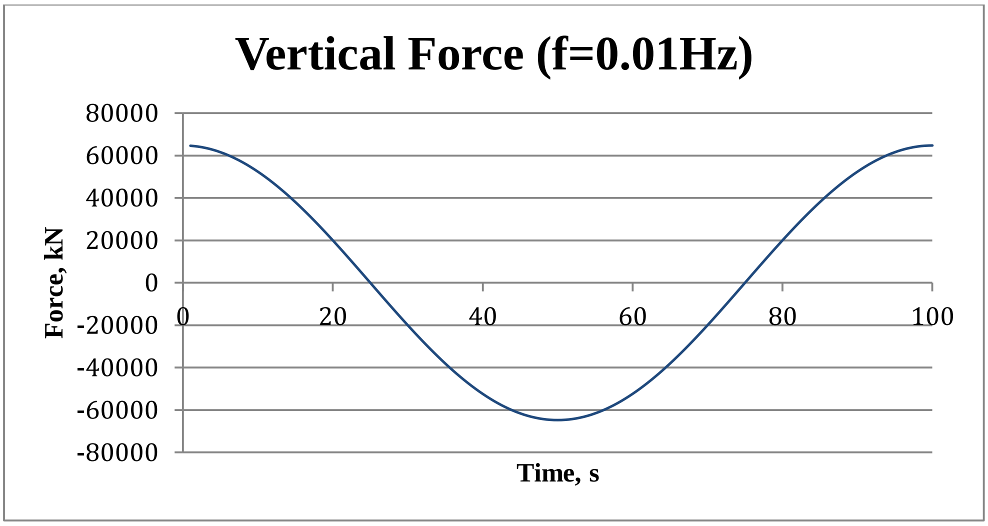


Figure 37: Vertical Force at frequency 0.01Hz

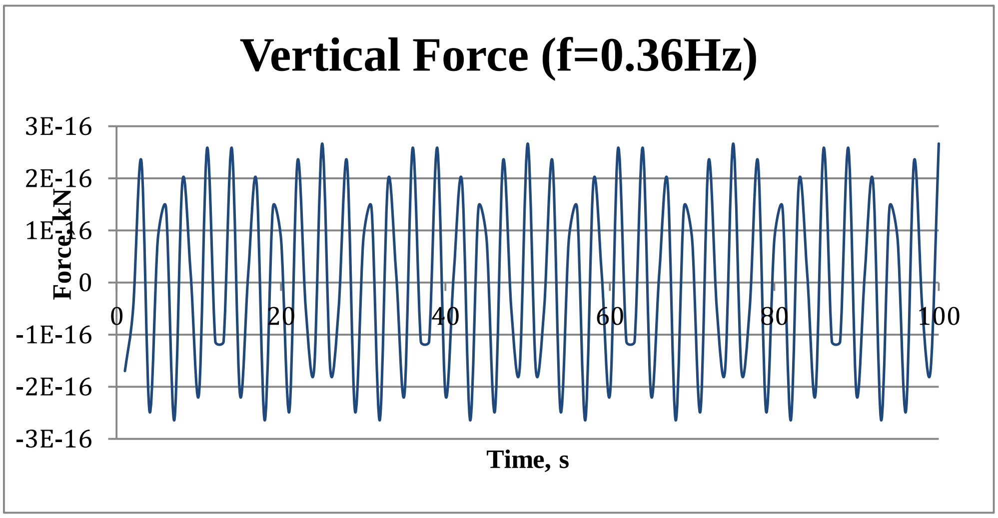


Figure 38: Vertical Force at frequency 0.36Hz

The force trend for vertical force are different with the horizontal force where it experience the highest at a low frequency of 0.01Hz and the least force at 0.36Hz. The occurrence depth for this vertical force are the same for all time and frequency which at the bottom of the Truss Spar model.

RAO

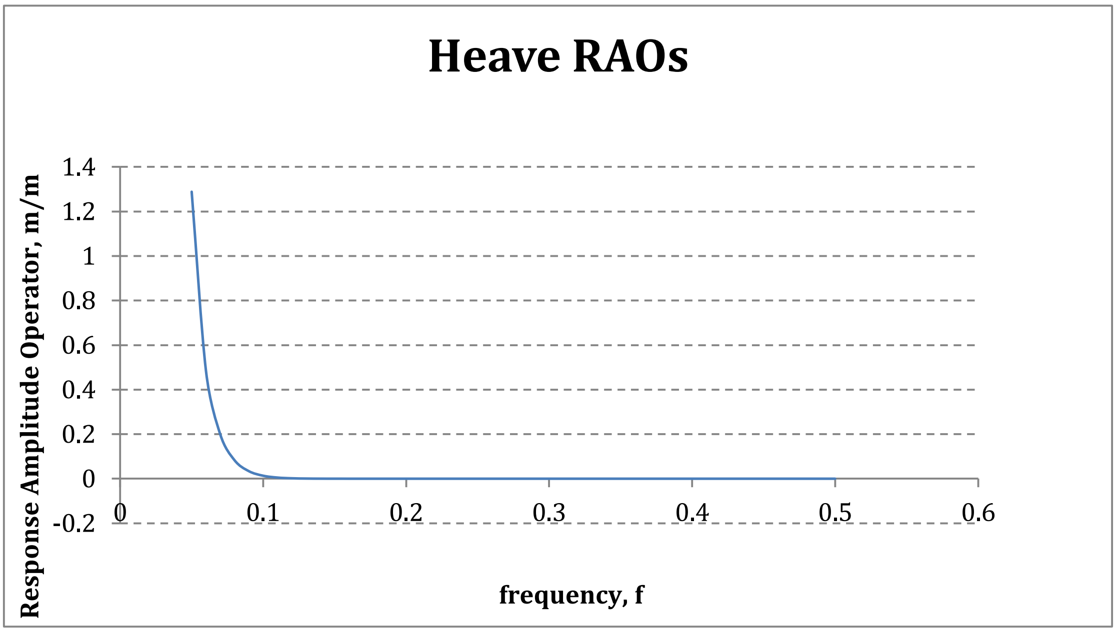


Figure 39: Heave RAO

RAO for all three motions had been obtained to be used in generating wave profile. The RAO approaching 0 value when the frequency increase until 0.5Hz. The common trend of RAO is the same with the RAO obtained for all three motions.

4.4. WAVE PROFILE

To compare between long and short-crested wave, wave profile will be plotted and the differences between two waves can be displayed. The wave profile is displayed by time history of the wave. The time is ranging from 0s to 500s.

4.2.1. Surge

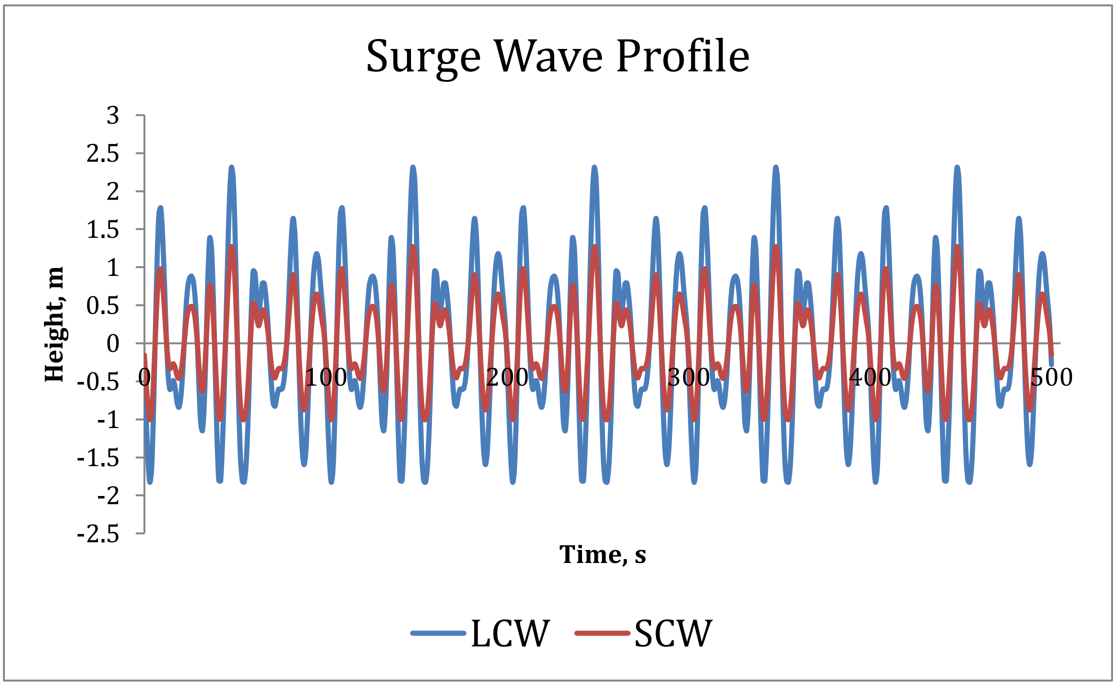


Figure 40: Surge Wave Profile due to Long and Short-Crested Wave

Long-crested wave yield greater responses compared to the responses due to short-crested wave.

4.2.2. Pitch

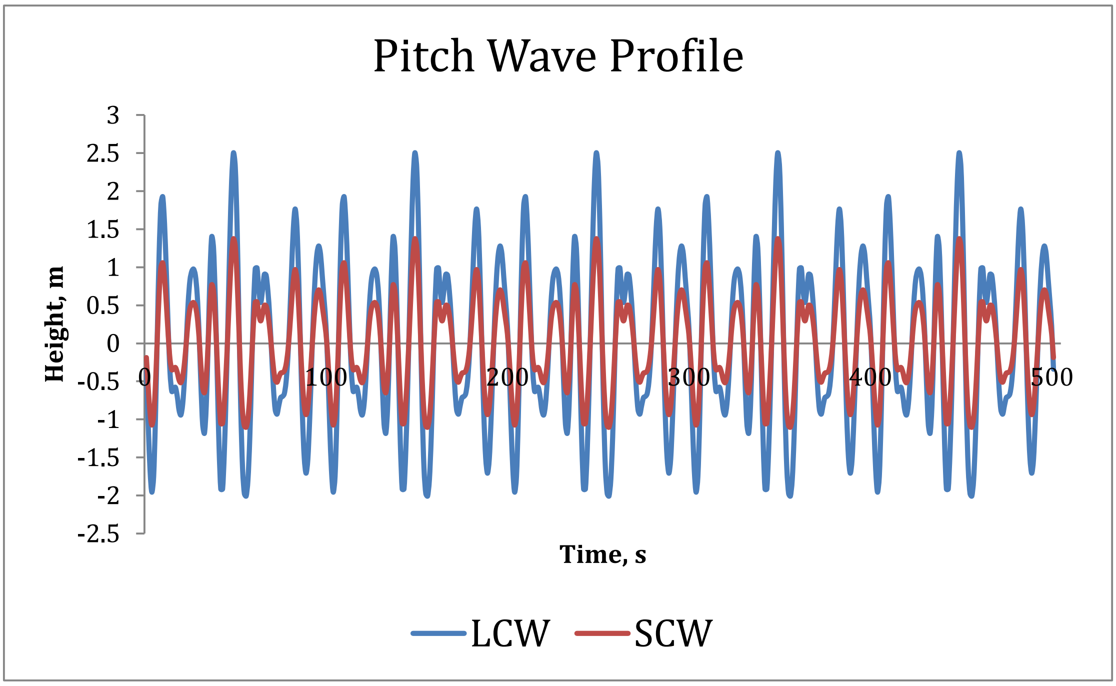


Figure 41: Pitch Wave Profile due to Long and Short-Crested Wave

In the Pitch motion, the rotation experienced by the impact of wave and current force is greater in long-crested wave with current compared to short-crested wave with current. The difference in horizontal between long and short-crested wave cause the difference in the moment in this motion.

The Truss Spar model tends to tilt more when long-crested wave with current hit the structure. Thus, the real sea condition of short-crested wave with current won't give such a big impact onto the structure where it is lower. It is because the resultant force experienced in short crested wave are lower due to force come from different direction rather than one direction of long-crested wave resulted in greater response.

4.2.3. Heave

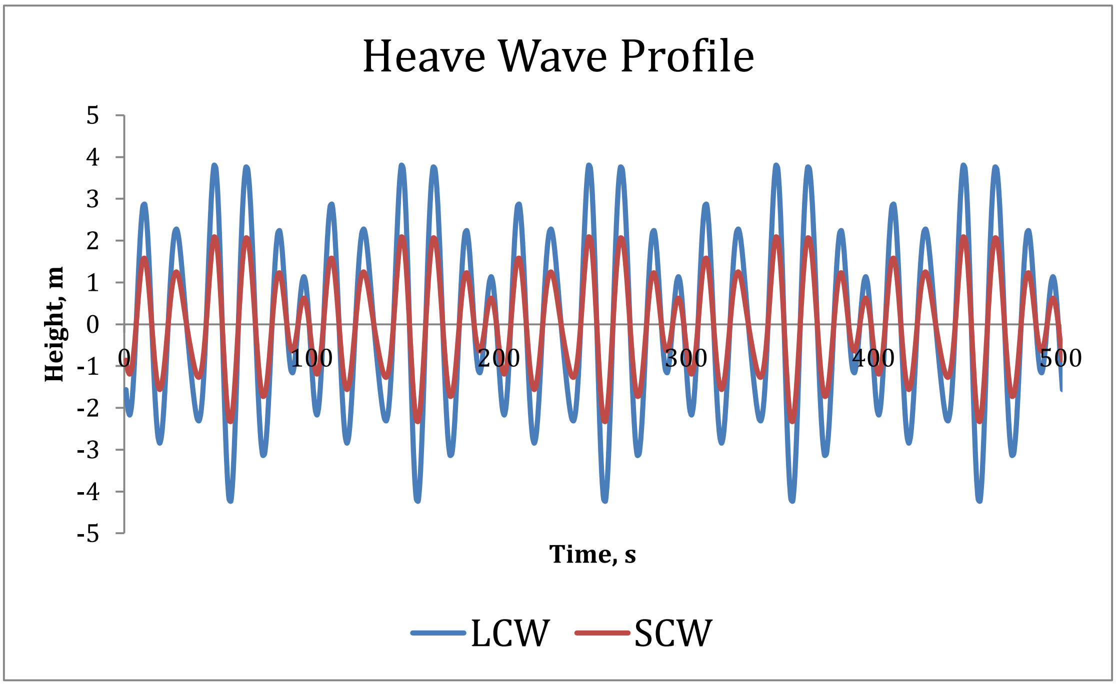


Figure 41: Heave Wave Profile due to Long and Short-Crested Wave

The heave responses give the same trend as the surge responses. Long-crested wave yield greater responses at the bottom of the structure compared to short-crested wave.

In a nutshell, all three motions of Surge, Pitch and Heave shows that long-crested wave with current does induced greater dynamic responses compared to short-crested wave with current. Whereby design using long-crested wave will be overestimate for the structure members.

Based on the result obtained, there are huge differences in considering long to short-crested wave with current. This shows that in the design of offshore structure in would be not cost-effective and overdesign if long-crested wave were considered rather than short-crested wave.

Table 2: Summary of Difference between Short and Long-Crested Wave

Comparison				
		LCW	SCW	% Diff
Surge	Max Crest (m)	2.31	1.27	45.09
	Min Trough (m)	-1.83	-1.00	45.09
	Amplitude (m)	2.07	1.14	45.09
Pitch	Max Crest (m)	2.50	1.38	45.09
	Min Trough (m)	-2.00	-1.10	45.09
	Amplitude (m)	2.26	1.24	45.09
Heave	Max Crest (m)	3.80	2.09	45.09
	Min Trough (m)	-4.23	-2.32	45.09
	Amplitude (m)	4.02	2.21	45.09

The percentage different of the short and long-crested wave is up to 45%. By reducing the member size and design by 45% could save huge cost for constructing the structure that can be spend for more important things.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

As conclusion, the aim of this study is to quantify the effect of dynamic responses induced by short-crested with the presence of ocean current. The study, proven that ocean current also plays a big role as the environmental load that would affect the dynamic response of the structure. Wave without current response yield smaller compared to waves with current, thus it will be insufficient to design and far from close to real sea condition.

Coming back to the main focus of this study, short-crested wave with current which represented the real sea condition does induces smaller response compared to long-crested wave that currently use in the design practice. A comparison on the motion response profile subjected to both long and short-crested waves was conducted. From the comparison, maximum differences about 45% were observed.

In economic perspective, designing accordingly to short-crested wave with current that suits real sea condition would save the expenditure and cost-effective. By reducing the member size, the cost can be spending to other thing that is more important.

On the other hand, it is recommended to further study on this by including the wind load as the environmental forces consist of wave, current and wind load. Future work also can include the remaining 3 motions, which is Sway, Roll and Yaw because Short-Crested wave propagated from all direction. Furthermore, other Spectrum can be considered into the study that suits the region and location to be focused on.

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APPENDICES

APPENDIX 1: COMPARISON OF LONG AND SHORT CRESTED WAVE DATA

APPENDIX 2: PITCH AND SURGE WITH AND WITHOUT CURRENT COMPARISON

APPENDIX 3: TRUSS SPAR MODEL