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MOTION RESPONSES OF THE H-TYPE FLOATING BREAKWATER SUBJECTED TO REGULAR WAVE

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ABSTRACT

This study focuses on the hydrodynamics behaviour of a floating breakwater with taut-leg mooring configuration. The aim of the study is to understand the motion responses of the H-type floating breakwater on the motion responses of the floating breakwater that subjected to the regular wave. This study focuses only on the heave, surge and pitch movement, whilst the other motion responses were restricted. During the past studies of this H-float, small numbers of tests were conducted due to budget and time constraints. The tests conducted were confined to limited test ranges such as wave period, breakwater draft and also water depth. To tackle this issue, thorough study has been carried out on the related subjects and also the development of the previous floating breakwater. The model with a scale of 1:15 will be tested in the 25 meter long wave flume with a total of 132 tests each for regular. Other equipment that will be used in the test is wave paddle, wave probe, wave absorber, data logger, and OPTITRACK. The variable parameters for this study include wave period, wave height and breakwater draft. During the test, this model will be moored with taut leg mooring system, in order to avoid excessive movement experienced due the wave actions. Finally, In order to quantify the motion responses of the floating breakwater, the Response Amplitude Operator (RAO) was utilized in this study. The RAO values for heave, surge and pitch obtained in the study will provide an insight on the extent of the movement of the H-type floating breakwater subjected to various wave condition.

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Coastal areas often need protection against excessive wave action. Some of the natural protection features are island, shoal, and spits. However, the degree of protection provided by these costal features might not be adequate in suppressing the excessive energy of the waves. In such case, manmade structure like breakwater are constructed to reduce the height of the incident wave at the sheltered zone. Breakwater reduces wave energy mainly through wave breaking, wave overtopping and wave reflection. The best know and universally used method of wave energy suppression has been bottom seated (or fixed) breakwater. One of the most conventional fixed breakwaters is rubble-mould breakwater which typically constructed with core of quarry-run stone, sand or slag and protected from wave action by one or more stone under layer and a cover layer composed of stone or specially shape concrete armour units. Over the years, there are various types of fixed breakwater that have been used such as the sloping (mound) type, vertical (upright) type, composite type and the horizontally composite type (Takahashi, 1996). It is undeniable that fixed structure breakwater offer advantage in the form of excellent storm protection; however, at the same time they contribute several drawbacks to the environment. The fixed breakwater can be total barrier to close off a significant portion of a waterway or entrance channel, thereby causing a faster river flow in the vicinity as well as potentially trapping debris on the up drift side. The presence of these gigantic structures may also create unacceptable sedimentation and poor water circulation behind the structure.

Another shortcoming of a fixed breakwater is that their wave dampening power decreases rapidly as the tide level rise due to the fact that wave dissipation over the breakwater is mainly caused by wave breaking on the slope. It is often uneconomical and impractical to build a fixed breakwater in water deeper that about 20 feet as the construction cost of the breakwater is proportional to the square of water depth McCartney, 1985). Very careful thought must be given to design of fixed breakwater and its effects on the physical system in which it is to be placed because, once constructed, very few are ever removed. They became permanent part of the landscape and any environmental damage they may cause must either be accepted or the breakwater must be removed. This may be a very expensive penalty for a mistake.

Due to short-comings of the fixed breakwater, engineer came out with floating breakwater as the alternative to the fixed breakwater. Various type of floating breakwater was reported by McCartney (1985); there are four general types of floating breakwater which are pontoon type, mat type, box type and tethered float type of floating breakwater. Some of the advantages of floating breakwater are low construction cost, quick installation at site, more environmental friendly, removable and easy to be fixed. Previously, many researchers had develop and tested various floating breakwater (McCartney, 1985) and now the increase demand for the application of floating breakwater at sites has led further research on the design optimization of the breakwater.

These optimizations aimed to increase the performance of the floating breakwater in attenuating the incident waves. The design of the box-type floating breakwater (Nece and Skjelbreia, 1984; Isaacson and Brynes, 1988) had become the basis for the construction of the H-type floating breakwater (Teh and Nuzul, 2013). A lot of factors that need to be consider in the design of a floating breakwater likes, overall design and geometry, the mooring orientation and etc. As far as this study concern, the main focus of the study is to investigate the effect of mooring design in the hydrodynamic performance of floating break water.

1.2 Problem statement

In the endeavour to meet the wave protection problem with a functional cost effective engineering design, an H-shape floating breakwater was specially developed in 2005. Experimental studies showed that it was capable of attenuating the incident wave height up until 80% (Teh *et al*., 2005).

It is worth to note that the following breakwater tested using a small scale experiment which was subject to the following drawbacks:

i) <u>Scale Effects</u>

The experiment will be done by means of testing a small-scale test model of the floating breakwater. The major concern of the small scale experiment is the risk of the scale effects, in which the test model in reduce the size does not behave in the similar manner to the prototype that it is intended to emulate. The problem can only be minimizing by adopting a model in a larger or similar scale as the proposed prototype.

ii) <u>Inadequate measurement technique for wave hydrodynamic</u>

Wave hydrodynamic is a very subjective subject, in which the quantification of the wave hydrodynamic, either the motion or the forces acted on the breakwater due to the wave movement need to be studied with proper mechanism. The available measuring technique is subjected to the measuring errors due to manual observation and individual preferences. The limitation on the measuring equipment also might become a limitation in obtaining a more accurate result.

iii) <u>Limited test cases</u>

Due to the limitation of study in the field, especially in the cases of mooring configuration that are opted to be used in the study, there are limited number of reference that can be used to compare the result of the test. Thus, this may limit the validity of the testing result, as there is limited benchmark values that can be used.

iv) <u>Poor understanding of hydrodynamics and motion responses of the breakwater</u>

A study of energy dissipation and movement of the breakwater due to the respond from the wave movement upon the breakwater is a wide field of study. Thus, it is important for us to tackle the basic studies and have the main idea on how does the system works. A lack in this field of the study might affect our judgment in providing good final findings.

The present research is aimed at tackling the abovementioned limitations of the previous experiments, with the aids of physical modelling of larger scales. It is hoped that the research work carried out could provide greater insight on the hydrodynamics performance of the floating breakwater under various sea conditions.

1.3 Significant of study

Apart from suppressing waves for temporary port and marinas, breakwater also function to perform the following task:

- Provide perimeter protection
- Provide certain extent of shoreline erosion control
- Serve as floating pontoon in marinas
- Act as swim area barrier
- Function as debris boom to keep floating rubbish from entering open sea.
- Provide access from one place to another
- Function as net panel and aquaculture fish cage

This study is undertaken with the aim to develop an innovative floating breakwater that provide good hydraulic performance and is particularly suitable to be installed in Malaysia seas for protection of onshore and offshore facilities in Malaysia. It is hope for this research to expand the understanding of the hydrodynamic behaviour of the newly-designed breakwater by both physical and numerical simulations and to establish radical procedure in providing quick response in withstanding the storm waves. The result obtained in this study will provide valuable information in the process of designing the H-type floating breakwater in its real life applications, especially in the design of its mooring lines.

1.4 Objective of the study

For this project, the objectives of the study are as follows:

1. To investigate motion responses of the H-type floating breakwater subjected to regular wave.
    i. Heave
    ii. Surge
    iii. Pitch

1.5 Scope of study

In order to achieve the objective mention in section 1.4, the scopes of study are stated as follows:

1. Literature survey
    - A comprehensive desk study and patent search of the latest floating breakwater designs is to be undertaken

2. Enhancement of the breakwater design (complete with proper mooring system)
    - Additional features are introduced to the existing floating breakwater design so as to enhance the overall hydraulic performance of the breakwater. The geometrical and hydraulic properties of the breakwater are to be ascertained

3. Selection of construction materials for the proposed breakwater
    - Construction materials are proposed to stimulate both geometrical and dynamic properties of the newly proposed floating breakwater. A ballast tank is to be designed within the breakwater so as to provide arbitrary immersion depths by filling the tank with water or sand. The test model must be waterproof and has high resistance to wave impact

4. Fabrication of the breakwater model and the mooring system
    - The test models are to be fabricated according to appropriate scale. Froude similitude is to be applied as the test mostly deal with gravity, free surface water

5. Laboratory set-up for physical modelling simulation
    - All test apparatus and equipment are to be calibrated with care so to prevent systematic error during measurement. These measurement equipment's include load cell, optical tracking system, wave probe and velocimeters. The wave-structure interactions and underwater activities will be captured by a water proof still camera and video camera

6. Laboratory tests
    - Extensive laboratory test are to be carried out to quantify the hydrodynamic behaviour of the test models. Some of the dependant variables considered in this study is wave types (monochromatic and random waves), wave height breakwater drafts and water depths. Both head-on and oblique waves will be considered in physical modelling.

CHAPTER 2

LITERATURE REVIEW

2.1 General

This chapter outlines the fundamental concept on the mooring line to support the floating breakwater structure. It report on the previous studies done by other researcher on this aspect of the study. The study on the mooring line for the floating structure would provide some performance rule-of-thumbs in developing mooring system that would give best performance for this study. This information will be benchmark for the evaluation of the mooring lines for the floating breakwater that will use in this study.

2.2 Hydrodynamics Motions and Floating Body

Hydrodynamics of floating breakwater refers to the study of the dynamics or motion of a floating body. This section of study will emphasize on the hydrodynamics motion of a floating body, as well the hydrodynamics forces acted upon the mooring lines due to the dynamic behaviour. The six (6) degree of freedom concept will be further discussed in this section.

2.2.1 Six Degree of Freedom of a Floating Body

For a floating body in definite space, there is a series of motion set that will be acted on the body. The hydrodynamic motion of these bodies acted in a three-dimensional plane, acted in a way in such resulted in a six degree of freedom. These six degree of freedom are acting at the centre of its gravity and every motion is based on its own axis, as shown in Figure 2.0

In every directional axis, there will be two types of movement involved, which are the transitional movement, which moves along the axis, and the rotational movement, which moves around the axis. Each directional axis has its own transition and rotational movements, namely surge and roll for x-axis, heave and yaw for y-axis and sway and pitch for z-axis. Table 2.0 summarizes the details of a floating body.

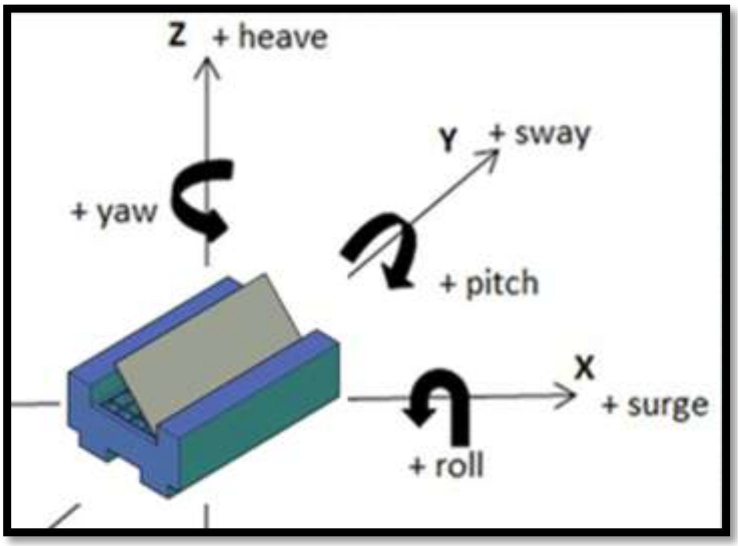


Figure 2.0 : Six degree of freedom movement

Axis	Movement	Transitions	Rotations
Horizontal axis (x)	Left-Right	Surge	Roll
Vertical axis (y)	Up-Down	Heave	Yaw
Horizontal trans-axial (z)	Forward-Back	Sway	Pitch

Table 2.0: Movement of Degree of Freedom With Respect To its Axis

In order to quantify the displacement of the movement for each degree of freedom, the Response Amplitude Operator (RAO) method can be used. RAO measure the amplitude movement of a particular degree of freedom with respect to the wave amplitude. The quantification of the RAO can be further simplified by using the following formulas, which will give the value of RAO for each degree of freedom, as according to Loukogeorgaki and Angelides (2005). In the formula, the RAO for each of the degree of freedom is represented by the constant *j*. Each *j* value represents each degree of freedom movement of the floating body, as being shown in table 2.1

$$\mathrm{RAO}_j = \frac{|\xi_j|}{A} \quad , \text{where } j = 1,2, ...,6$$

A= wave amplitude

ξ_j= Amplitude of motion in 6 DoFs

j= degree of freedom (1, 2, 3…, 6)

j	**Type of Motion**
1	Surge
2	Sway
3	Heave
4	Roll
5	Pitch
6	Yaw

Table 2.1: Value of *j* and its representation in respect to type of motion

2.3 Types of mooring

Mooring refers to the way the floating breakwater is anchored to the seabed by means of using a line restrain the movement of the floating breakwater. There are several types of mooring configuration that are commonly used for floating breakwater applications. For this study the mooring configuration used is Taut-leg mooring system.

2.3.1 Taut-leg moorings

Another conventional way of connecting mooring line to the floating breakwater is the taut-leg mooring system. The taut-leg mooring system can be defined as a straight string of line connected directly from the anchor at the sea bottom to the floating breakwater. As far as the system goes, the mooring line attached is fully suspended, with no line resting on the sea bed, as opposed to the catenary mooring system, as described in the following figure 2.1. Note that in the figure, the mooring line is completely suspended with no lines being rested on the sea bed.

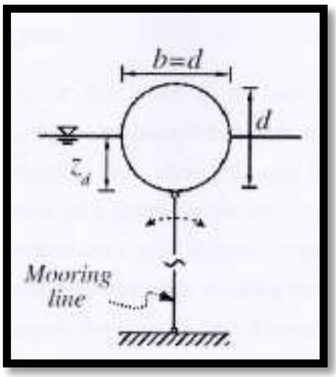


Figure 2.1: Taut Mooring system (Source: Ozeren et al, 2011)

Due to the suspended nature of the taut line system, it is subjected to both horizontal and vertical tension on the mooring line. The line can be attached either in a vertical direction or slightly inclined. Both these difference in ways of connecting the taut lines will have an effect to the instantaneous movement of the floating breakwater, as being studied by Rahman et al (2006). Based on the figure 2.2, the response of the floating breakwater towards wave action differs depending on the way the floating breakwater is moored, either in a straight vertical direction or slightly inclined.

Due to its ways of connection, taut-leg mooring system is most suitable to be used in a deep water condition. Furthermore, anchor type embedment is most suitable to be used with taut-leg system, as it provides more strength in term of withstanding capability in handling the vertical and horizontal forces acting on line. Due to this nature, the usage of synthetic lines is more advisable as compared to metal chains.

The effectiveness of the taut line is subjected to various factors that may affect the performance of the taut line and the breakwater as a hole. These factors will be discussed further in this chapter in order to understand their effects towards floating breakwater behaviour.

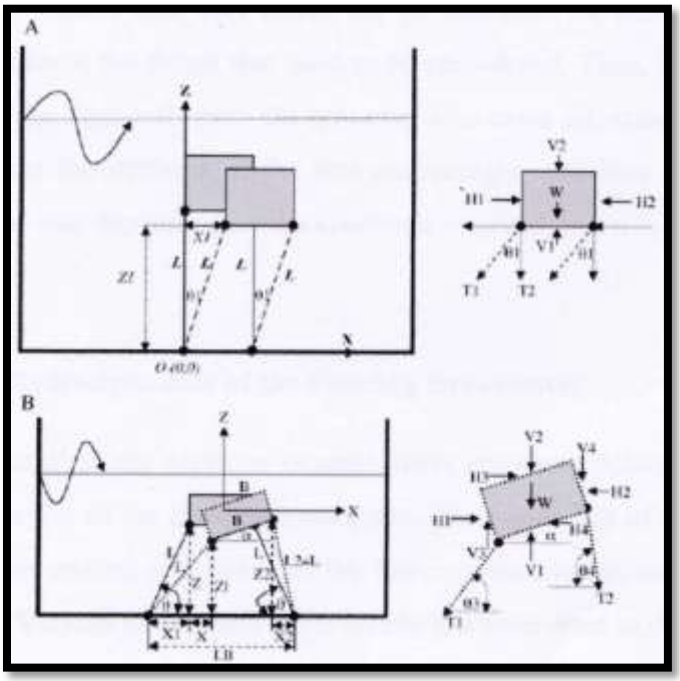


Figure 2.2: Instantaneous movement for submerge body for (A) Vertical moored body and (B) Inclined moored body (Source: Rahman et al, 2006)

2.4 Factors Affecting Hydrodynamics of the Floating Breakwater

As being mentioned in the previous chapter, there are some parameters that may affect the hydrodynamics behaviour of the floating breakwater. The variability of these parameters may affect the hydrodynamics motion and forces of the floating breakwater, such as the heave, roll, moored tension and etc. Various studies and experiments has been done to determine the effect of such parameter and what are the optimum values of these parameter in order us to get maximum efficiency of the floating breakwater.

2.4.1 Mooring Line Stiffness

The stiffness of mooring line will decide on the motion of the floating breakwater subjected to the wave movement, as well as the damping forces acted on the mooring line itself. Thus, it is important for us to find the corrected mooring line tension in order to obtain the best stiffness line to get an efficient floating breakwater performance.

The stiffness of the mooring line might go down to the configuration of the mooring line system that being used, as both taut line and catenary mooring system gives different mooring stiffness value. Besides that, alternating the mooring line stiffness also might give us an advantage depending on the type of waves that are being considered throughout the process.

Loikogeorgaki and Angelides (2005) have done a study based on the effect of the mooring line stiffness of the hydrodynamics of the floating breakwater, as being shown in Figure 2.3. In the figure, the graph C1 denotes the base case of the study, which is at pre-tension stresses and graph C2 denotes the variation in the tensile force with a pre-tensile stress applied to the mooring line. From the result, it is clear that the lines with a higher stiffness value produce a higher mooring tension. Thus, it can be said that there are considerable effects of the mooring line stiffness to the dynamic of the floating breakwater, in a sense that both the hydrodynamics motion and forces are being affected in the process. The effect of the mooring line stiffness also can be found in the studies of Diamantoulaki and Angelidis (2011), Matulea et al (2008), Rahman et al (2006) and Gobat and Grosenbaugh (2001), in which all of these studies underline the significant impact of various mooring line stiffness to the hydrodynamics of the floating breakwater.

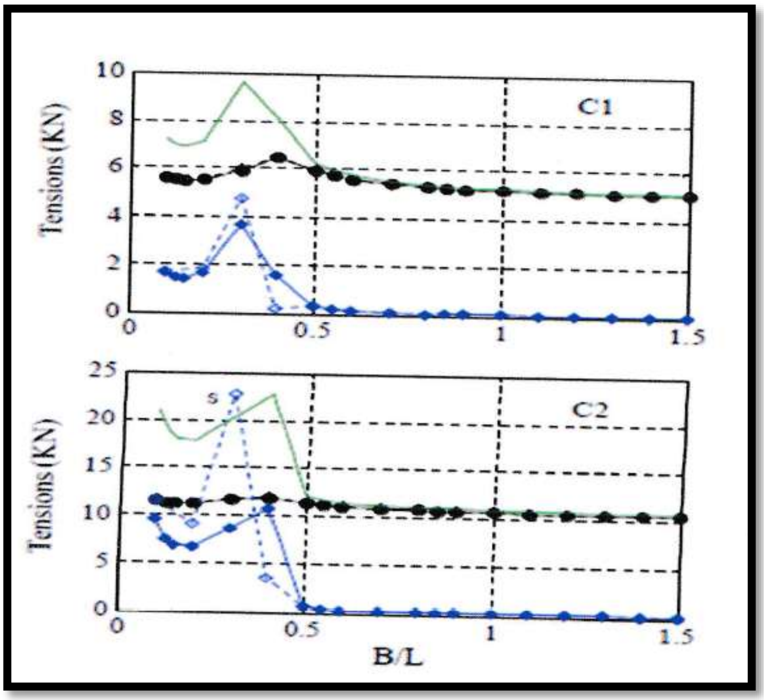


Figure 2.3: Variation of mooring line tension based on different stiffness (Source: Loukogeorgaki and Angelides, 2005)

2.4.2 Mooring line damping

The main sources for the total damping for a moored structure are viscous hull, radiation, wave drift and mooring line damping. L. Johanning et al (2007) had conducted a study about the contribution of the damping to the mooring line. The mooring line damping for a catenary mooring system will result from the line friction of the sea bed and internal friction damping within the chain and from the drag force along the line as it moves through the fluid. Most of the contribution in the literature addressing mooring line damping fall in the categories of (a) physical model test investigation, (b) fully dynamic finite element methods and (c) simple analytical model as discuss by Bauduin Naciri (2000).

Result from the study by L. Johanning et al (2007) tell us that at natural mooring line frequencies indicates the important if the transition from a slack mooring ine towards a semi-taut mooring line, where the mooring line motion became dominated by dynamics. This is support by the findings from the driven test where a steep increase in top-end loading result in large energy dissipation (damping) as a result of mooring line stretching as discussed by Papazoglou et al (1990). The result for semi-taut or high frequency oscillation modes reported that typically increase the damping properties and the accumulated cyclic loading to the mooring system. In particular fatigue damage could became major source of failure for this installation for mooring system.

2.4.3 Mooring Line Configurations

According to the study done by McCartney (1985), there are two ways to attach the breakwater and the lines of the mooring. The mooring lines can be attached either by straight configurations or by crossing the lines, as being shown in the Figure 2.4. The ways of attaching the lines to the breakwater may have an impact on the hydrodynamics of the breakwater, as it can restrict the movement of the floating breakwater. Keel clearance for boats moored alongside the breakwater can be provided by giving the breakwater a crossed line configurations. However, crossed line will also cause an increase in the heave and sway motion of the breakwater. This theory is supported by a study done by Whiteside (1994). In the study, the effect of the position of the moored on the breakwater is also being studied. According to the study, by placing the mooring attachment points at the site of the breakwater, the sway motion can be restricted as compared to placing the attachment points directly at the bottom of the breakwater.

Sannasiraj *et al* (1995) also suggested that crossed mooring produced a higher transmission coefficient values and higher mooring forces. Thus, it is not advisable to use crossed mooring, as it will significantly affect the performance of the floating breakwater. Another mooring line configuration factor that can affect the performance of the hydrodynamics of the floating breakwater is the breakwater is the number of attachment pint provide for the mooring. A more mooring attachment points on the breakwater will give the breakwater a more stable posture, in which restricted the sway motion due to wave's impact. Thus, this will directly give the floating breakwater a better wave transmission ability.

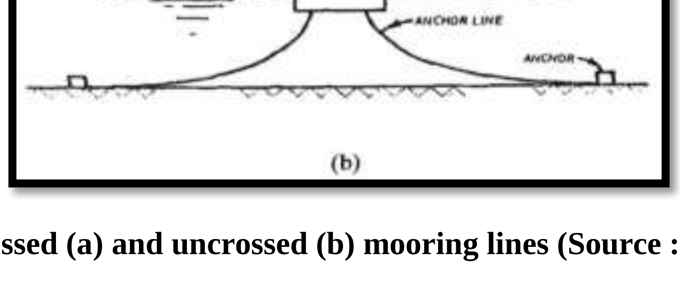


Figure 2.4: Crossed (a) and uncrossed (b) mooring lines (Source : McCartney, 1985)

Wang et al (2010) introduce us the bidirectional mooring system that he used to test the impermeable sidewall. Figure 2.5 show the concept of the bidirectional mooring system that used for the experiment.

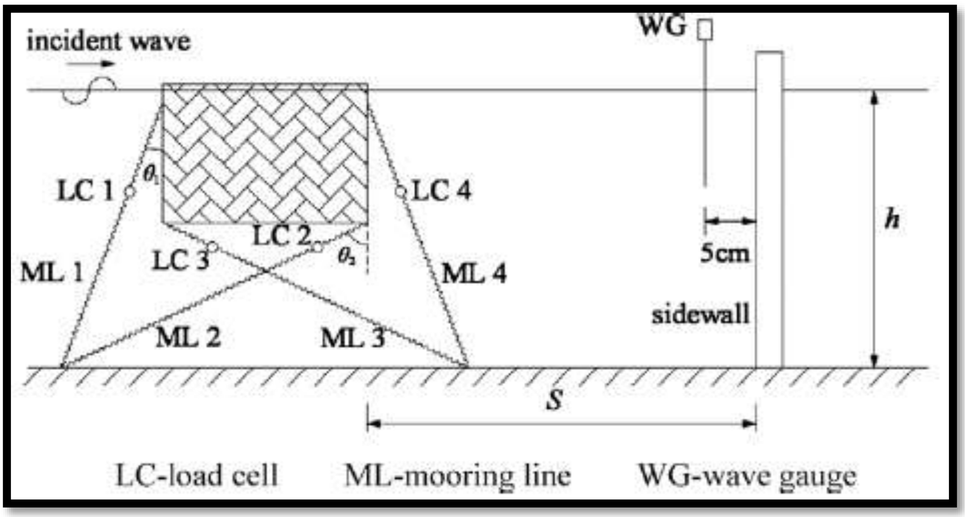


Figure 2.5: The sketch of bidirectional mooring system with impermeable wall
(Source : Wang et al, 2010)

This study also highlight to us that the bidirectional mooring system will help the floating structure. The bidirectional mooring system, which fraps the floating body tighter that the directional mooring system, brings not only preferable transmission coefficient but also enhance mooring force.

2.3.4 Length of Mooring Lines

The taut-leg mooring and the catenary mooring types are determined by the length of the mooring lines provided, as being discussed in section 2.3. The different in the configuration does have an impact in the behaviour of the floating breakwater, both in motion-wise and performance-wise. As being suggested by Whiteside (1994), the changes of the mooring line from slack to taut mooring given a less sway motion on the breakwater, subsequently reduce the mooring forces acting on the mooring lines. These hydrodynamic impacts will then contribute to the performance of the breakwater, as less movement and mooring forces acting on the line will increase the transmission efficiency of the floating breakwater.

Apart from that, the length of the mooring lines will also affect the draft of the floating breakwater. As a result, the wave transmission ability will also be affected. When the draft or mass of the floating breakwater is being manipulated, it will affect the performance of the breakwater, especially on the sway amplitude. Thus, by varying the draft of the floating breakwater accordingly, we can adjust the sway amplitude and the damping resonance accordingly. A larger draft means that larger momentum that will grow faster than the resistance, causing an increase in the resonance peak (Fourset, 2006). With an increasing width to the floating breakwater caused decrease in the draft. This will lead to an increase in the wave sway amplitude motion. Thus in other words we can say that the amplitude of the motion increase when the decrease wave exiting forces is less than the decrease in the hydromechanical forces and vice versa.

The effect of such parameter has also been studied in previous past studies, such as in the studies by Murali and Mani (1997), Diamantoulaki et al (2009), and Hedge et al (2007). The results that have been yielded by these studies do inflicted that there are significant effects of the floating breakwater by changing the width and draft of the floating breakwater accordingly. This theory is also supported by He et al (2012), in which suggested that the increase in the draft of the floating breakwater will produce a less heave, surge and pitch motion up to certain extent.

2.5 Past Studies on Hydrodynamics of Floating Breakwater

In the recent years, there are various studies that have been done in understanding the hydrodynamics of the floating breakwater of various configurations. The hydrodynamics of the floating breakwater gives out different behaviour due to the changes of the configurations. There are several factors that may lead to the lead to the difference in term of the behaviour of the breakwater. Thus, the goal of these studies being done is to obtain the most effective design, in which a minimal hydrodynamics behaviour is obtained, and in the same time, an effective performance is expected from the breakwater behaviour, due to the fact that the subject itself is too subjective, but the combinations of various design together with its testing may give us another new set of point of view towards this matter.

2.5.1 Hydrodynamic of Pontoon-type Floating Breakwater

The studies of the hydrodynamic behaviour of a pontoon floating breakwater have been done in various, such as those that have been done by Sannasiraj *et al* (1996), Abdl Azm and Gesraha (1998), Williams *et al* (2000) and Gesraha (2007). In all these studies, the pontoon shaped floating breakwater was tested under various waves' condition and various configurations were tested. The goal of the studies was to investigate the effects of various configurations towards the hydrodynamics behaviour of the floating breakwater, especially on the heave, sway and roll motions. In the latest studies of the pontoon-shaped floating breakwater, the breakwater was compared with a regular rectangular floating breakwater in order to study the effect of adding the side plate on the performance of the breakwater. It was found out that while the heave damping coefficients increase, the other damping coefficients are lowered up until certain limits. Figure 2.6 shows the result from the study done by Geraha (2007). The figure shows that the heave ROA increase with an increase in the ratio of the side plate length and length of half of the floating breakwater beam (b/a). This happen due to the increase in damping resonance acting on the floating breakwater.

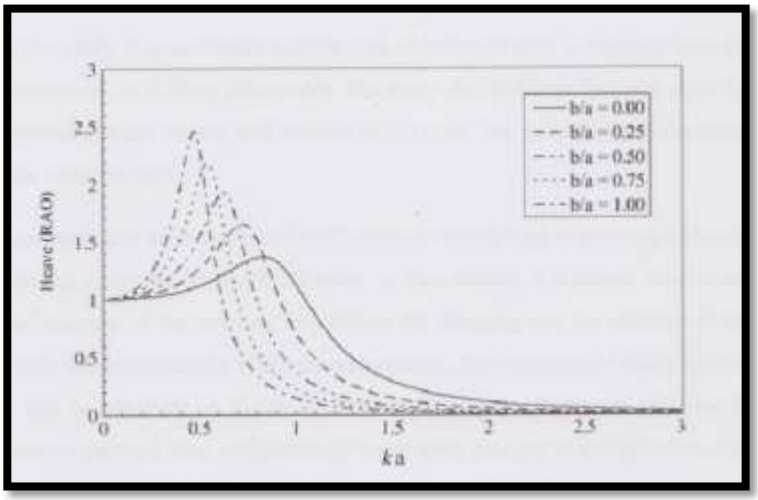


Figure 2.6 : Influence of different side plate height to the Heave RAO (Source: Gesraha,2007)

2.5.2 Effect of Mooring Lines to Floating Breakwater

The ways of connecting the floating breakwater to the mooring system also can affect the performance of the floating breakwater considerably. The mooring configuration may affect the hydrodynamic behaviour of the breakwater as far as the motion and force are concerned (Mays et al, 1998). In the effort to find the effect of different kind of mooring to the performance of floating breakwater, as being mention in the previous section. In this study, different type of mooring lines if different materials and different configuration was tested. The lines configurations that are being used are slack mooring and taut mooring, with crossed and uncrossed configuration. Apart from mooring configurations, the materials were also varied in the study, which synthetic nylon and metal chain is being used. At the end of this study, it is conclude that the type of material used in mooring lines do not affect the performance of the floating breakwater. The study also indicates that with slacker mooring line, the hydrodynamic motion will became much more, but reduce the hydrodynamic forces acted on the mooring lines.

Loukogeorgaki and Angelides (2005) studied various kind of mooring line configurations and how do these effects the floating breakwater. In their studies, it is know that the modification on the configurations of the mooring affects the damping and stiffness of the mooring line, in which will subsequently affect its performance. The variation of heave and roll ROA of the study can be observe in Figure 2.7. From the figure, it can be said that the various configuration of mooring lines will definitely cause some changes in the hydrodynamic behaviour. It is worth to note that from this study, the performance of the floating breakwater such as the wave attenuation potential, is said to be affected by the stiffness and damping of the mooring lines. The stiffness and damping of the mooring line also affect the mooring forces acting on the line, especially of those that involved the taut-leg mooring system.

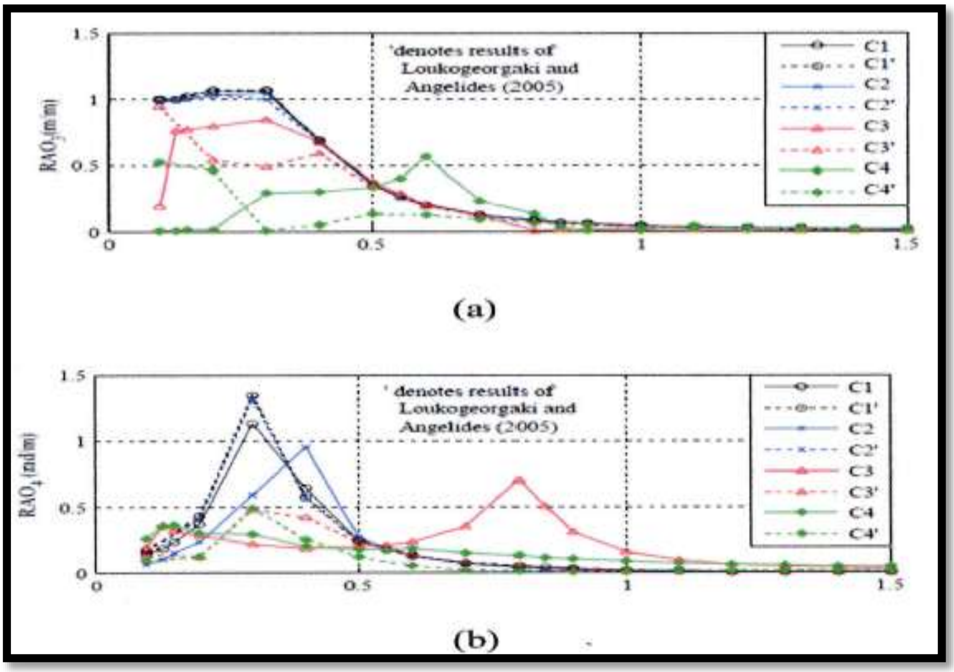


Figure 2.7: Variation of heave and roll RAO from various moore configuration (Source : Loukogeorgaki and Angelides, 2005)

2.5.3 Effect of Mooring Configuration on Hydrodynamics Motion of Floating Breakwater

On the other hand, Diamantoulaki and Angelides (2010) studied the effect of hinged floating breakwater towards the hydrodynamic of the mooring configuration. In this study, the main goal of the study is to investigate the performance of the floating breakwater in respect to the hinged mooring configuration and number of hinged provided.

Based on the study, it is learned that the number of hinges may have an effect on the hydrodynamic behaviour of the floating body. The different in number of hinges may also affect the number of degree of movement of the floating breakwater, as being demonstrated in Figure 2.8. The figure shows that for floating breakwater that is moored using hinged-mooring with only one hinge, there are less degree of freedom for the floating breakwater as compared to such configuration using two hinges.

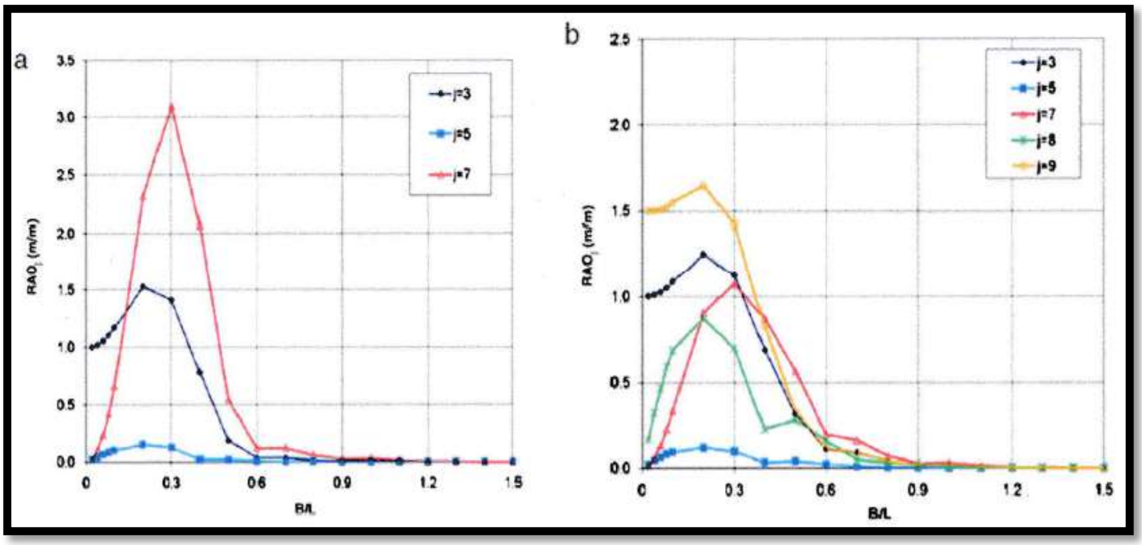


Figure 2.8: The hydrodynamics behaviour of floating breakwater with (a) one hinge and (b) two hinge (Source: Diamantoulaki and Angelides, 2010)

In other study done by Manuel (1995), the effect of pile mooring to the heave motion is being studied. As being said in the previous part of this chapter, pile mooring system will restrict the movement of the floating breakwater to only heave motion. In his study, different factors were taken into consideration to study its effect on the heave motion of the floating breakwater model. Among the parameter that being consider were different gap between two piles as well as the wave steepness. Based on the result it is understood that a bigger gap between one pile and another will cause a higher RAO of heave motion to be recorded. This was the case for higher wave steepness as well. This is said due to the presence of lateral movement within the breakwater model itself. These lateral movements will then may cause some sway and roll movement to occur, which played a role in increasing the heave ROA values.

In the effort of studying the effect of all three mooring system to the movement of the breakwater, Ruol and Martinelli (2006) has developed a test involving these three set up of different pre-tensile stress of the mooring line. The three mooring system which are the pile mooring, the slack or catenary mooring, and the taut-leg mooring, was being tested, with different line stiffness was pre-set prior to the test. At the end of the experiment, it is understand that the movement of the floating breakwater affected by the mooring configuration used. From Figure 2.9, it is understand that the stiffer the mooring line, as it changes from slack mooring to the taut mooring, the higher the heave motion displacement of the floating breakwater. The figure also shows that the heave motion is at the highest when pile mooring is used. It is also being said the study that the dissipation of the waves are directly proportional with the movement of the floating breakwater. Thus, the difference in mooring configuration and tension may have impact towards the performance of the floating breakwater.

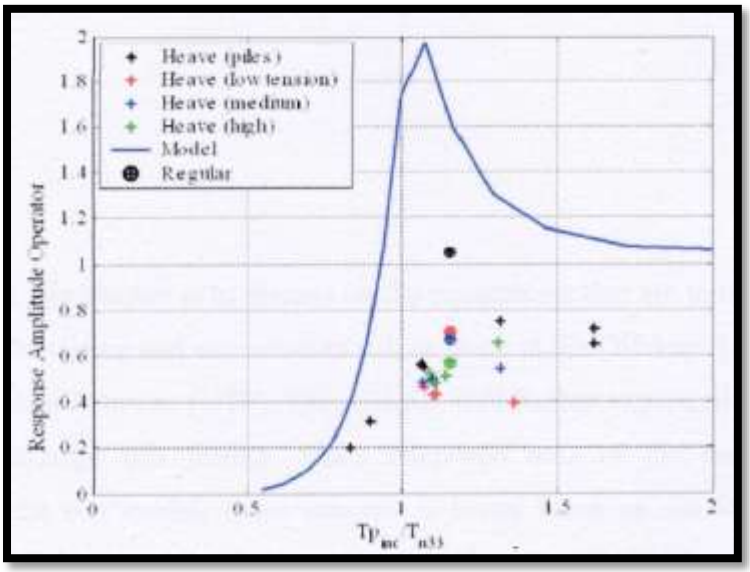


Figure 2.9: ROA values of heave motion with respect to different type of mooring configuration (Source: Roul and Martinelli, 2006)

2.5.4 Hydrodynamic Performance of a Rectangular Floating Breakwater With and Without Pneumatic Chamber: An Experimental Study

In the effort of studying the effect of pneumatic chamber to the hydrodynamic performance of the breakwater, Fang He *et al* (2012) highlight the significant of the pneumatic chambers directly by comparing the result for Model 1 (with pneumatic chamber) and Model 2 (without pneumatic chamber) as shown in Figure 2.10.

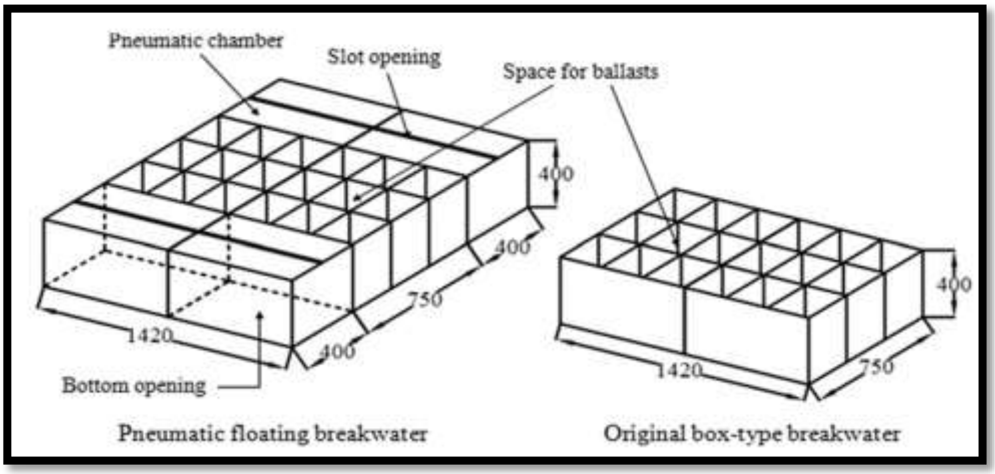


Figure 2.10: Details of the pneumatic floating breakwater and original rectangular box-type breakwater models. (Source: Fang He *et al,* 2012)

The installation of the pneumatic chambers improved the hydrodynamic performance of Model 1, especially the transmission coefficient transmission coefficient and the motion responses. Moreover, Model 1 might dissipate additional energy by the airflow through the opening on the top of each pneumatic chamber besides through the friction and flow separation. The motion responses of Model 1 were in general smaller than those of Model2. In particular, the installation of the pneumatic chambers significantly reduced the surge motion for the long and medium period waves (B/L<0.35) and the pitch motion for the short and medium period waves (B/L>0.24), while the heave motion slightly was reduced throughout the whole range of B/L (refer to Figure 2.11). The smaller motion responses of Model 1 reduced the motion-generated radiated waves in the leeward side of the model. Therefore, the wave transmission was effectively reduced for all wave periods.

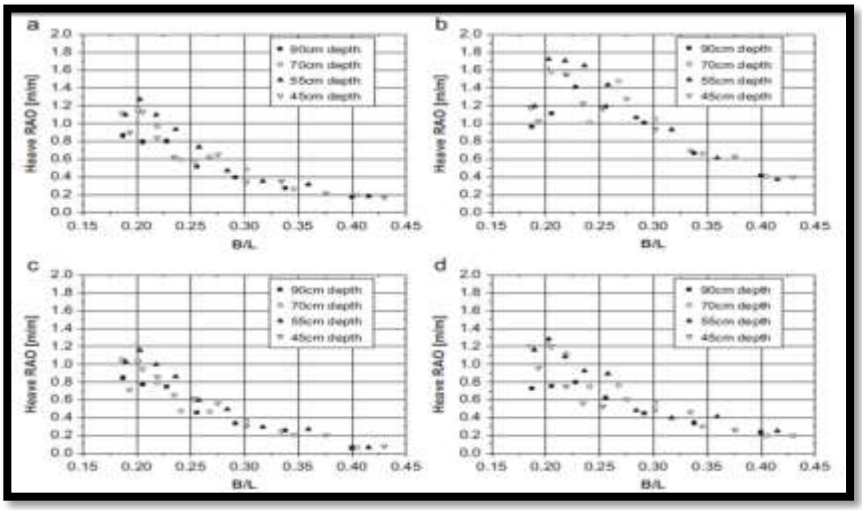


Figure 2.11: Variation of heave RAOs versus B/L under four water depth (Source: Fang He *et al*, 2012)

According to Fang He *et al* (2012) a new design of floating breakwater with pneumatic chamber can mitigated the responses of the floating breakwater by the water mass inside the chambers and the increase momentum of inertia. Increasing the draught of the floating breakwater can reduce the surge, heave and pitch motions but not very much. Overall the result present in this study shows that the installation of pneumatic chamber to a floating breakwater can be effective to improve its hydrodynamic performance for costal protection. Moreover, pneumatic chamber can potentially be turned into device converting wave energy to electricity by installing well turbines to the chamber for the future study.

2.5.5 Hydrodynamic analysis of multi-body floating piers under wave action.

In the present paper, the presented results of a parametric study of varying space and draughts as a function of relative width of breakwater and concluded that the spaces between the pontoons have a definite effect on transmission and reflection characteristics of a floating breakwater system. The modules, which may be used for floating structures such as pontoons, are often sufficiently rigid, and each of them can be treated as a rigid body having six degrees of motion of freedom. To determine the dynamic response of floating structures, rigid body hydrodynamics are typically used to determine the motion response. Various alternative arrangements of pontoons may be necessary when constructing a long pier. Several arrangements, as shown in Figure 2.12, are considered in this study. In order to predict the motion responses, various alternative arrangements are employed such as rigid pontoons, flexible connector (RMFC) in which the connectors that link the pontoons are assumed to be significantly more flexible than the pontoons.

Alternatively, Che et al. (1992) were able to reduce the computational requirements substantially by modelling a multi- body as rigid pontoons joined by flexible connectors (the ‘RMFC’ model) and by completely ignoring the fluid interaction between modules. In the present work, first the pier is modelled as a rigid body platform and effects of various parameters such as mooring system, the beam and draught of pontoon on its motion are investigated. Then, results are used as reference to compare with those of hydrodynamic behaviour of the multi-body floating piers. In the multi-body floating pier, pontoons are connected to each other by hinge.

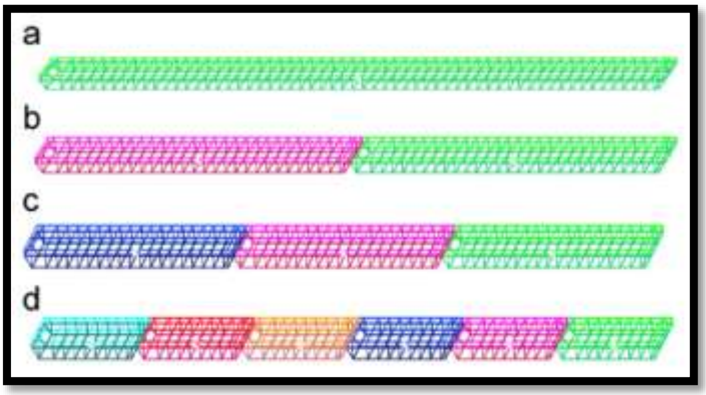


Figure 2.12: Perspective view of the array of pontoons (a) single pontoon (b) two pontoons (c) three pontoons and (d) 6 pontoons.

Analysis results given in previous section show that pitch motion is increased when pontoons with smaller dimensions are used in floating pier construction, because ratio of length/width is decreased in this state. It means that when the pier total length is constant while the length of the individual pontoons is increased, the pitch motion is declined. Also, increasing the number of pontoons–due to a decrease in their length– results in increasing of the heave and roll motions’ amplitude. So, the operability of a multi-body pier is less than a single body pier. As modal period increases, pier motions increase. Motions in the case of single floating pier are smaller than those in the case of multi-body floating pier. Magnitudes of structure motions in multi-body are increased compared with single body. Therefore, it could be said that increasing the number of pontoons gives negative effects on pier motions for the cases considered in this study.

In this paper, hydrodynamic analysis of a floating multi-body pier interacting with incident waves is carried out and results of the wave-induced motions and structural response are described. A computational methodology has been developed to assess the effects of hydrodynamic on array soft hinged floating structures. The wave motions due to the interactions between the wave and pontoon-pier a real so considered. Response motions are investigated in head and beam waves. Results show that, the surge and pitch motions that the motion of the piers is related to the mooring lines, dimension and draught of the pontoons. Also it is observed from the response of the floating pier system that the motion response increases by increasing the number of pontoons for constructing a floating pier. By increasing the number of pontoons – for a fixed length of the pier – the amplitudes of heave and pitch motions of the pontoons are increased.

CHAPTER 3

METHODOLOGY

3.1 General

The focus of this chapter is to discuss on the equipment that are to be used in the testing of the test model. The testing and experiments will be done in the Offshore Laboratory, Block A, at Universiti Teknologi PETRONAS (UTP). This chapter will further explained on the strategy that will be used to undergo this testing. Since interested area of the study is only in the hydrodynamics of the test model, more concern is being focus on the load for the mooring line and the Response Amplitude Operators (ROA) of 6 degree of freedom motion. The chapter will also discuss on the process in conducting the study and the planed Gantt chart for overall study.

3.2 H-shaped Floating Breakwater

A floating breakwater model with a certain design criteria is to be design with the aim a having a floating breakwater with effective wave attenuation ability. The design that is introduced for the study is a continuation to the past studies done in the previous years by other UTP students. The design of the new novel breakwater will introduce some enhancement on the previous design, as well as introduction of new mooring system. This will give the floating breakwater model different sets of data as compared to the previous studies.

3.2.1 Model Description

In this study, an H-type floating breakwater was developing according to model scale. The general dimensions of the test model are 1000mm width x 1480mm length x 1000mm height. The breakwater was constructed by plywood and was made waterproof by a layer of fibreglass coating on the surfaces of the body. Plywood is chosen as the primary construction material because it is a lightweight material that provides high resistance to external force impacts. The fibreglass coating was injected with yellow colouring pigment for better visibility of the model during experiment.

The breakwater has a pair of upwards arm and pair downward legs, with both connected to a rectangular body as shown in Figure 3.0. The seaward arm, body and leg act as the frontal barrier withstanding the incident wave energy mainly by reflection. Some wave energy is anticipated to be dissipated through vortices and turbulent at the 90^0 frontal edges of the breakwater. When confronted by storm wave, the H-type floating breakwater permits water wave to overtop the seaward arm and reach the U-shape body as seen in Figure XX. The overtopped water trapped within the U-shape body heavily interacts with the breakwater body, and the flow momentum is subsequently retarded by shearing stresses (frictional loss) developed along the body surface. The excessive waves in the U-shape body may leap over the shoreward arm and reaches the lee side of the floating body, making new wave behind the breakwater which is termed as the transmitted waves.

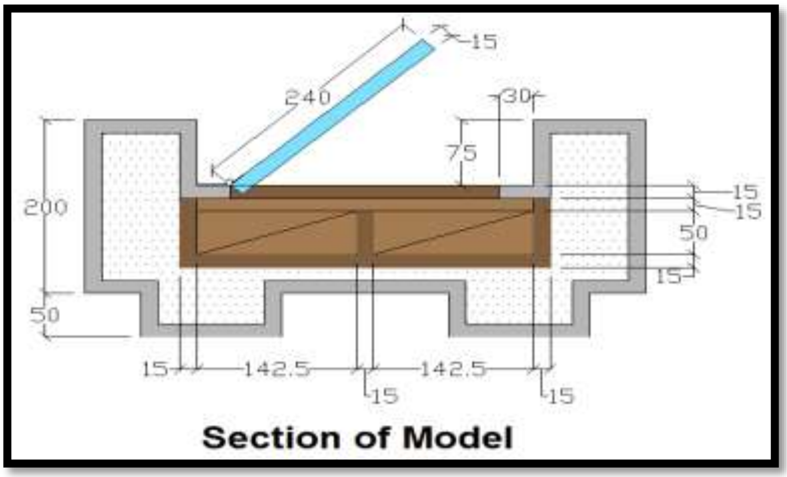


Figure 3.0(a) : Dimension of H-type floating breakwater

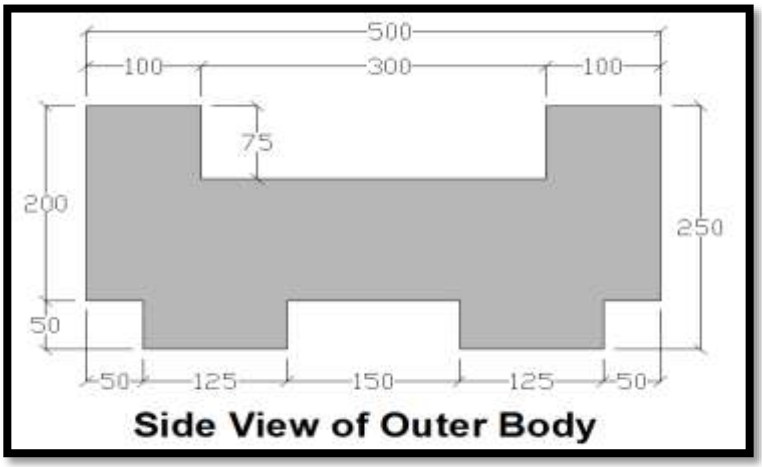


Figure 3.0 (b) : Side view and dimension of the outer body

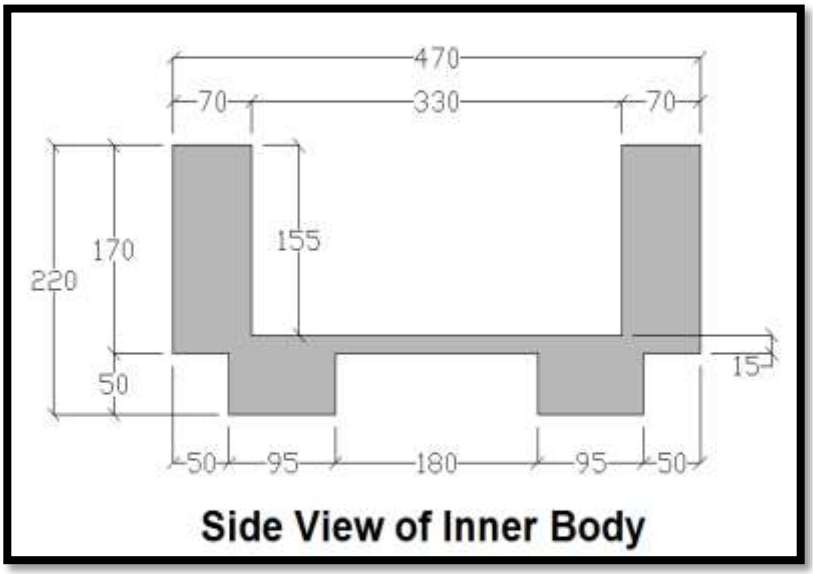


Figure 3.0(c) : Side view and dimension of inner body

Apart from the energy dissipation mechanism exhibited at the upper body of the breakwater exhibited at the upper body of the breakwater, both seaward and leeward legs, which are constantly immersed in water, are particularly useful in intercepting the transmission of wave energy beneath the floating body through formation of bubbles and eddies near sharp edges as well as underwater turbulence. The remaining undisturbed energy past underneath the floating body and contributes to the transmitted waves behind the breakwater.

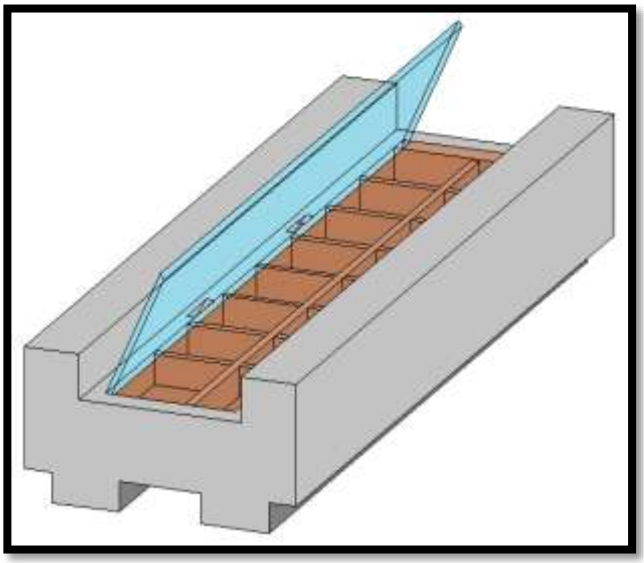
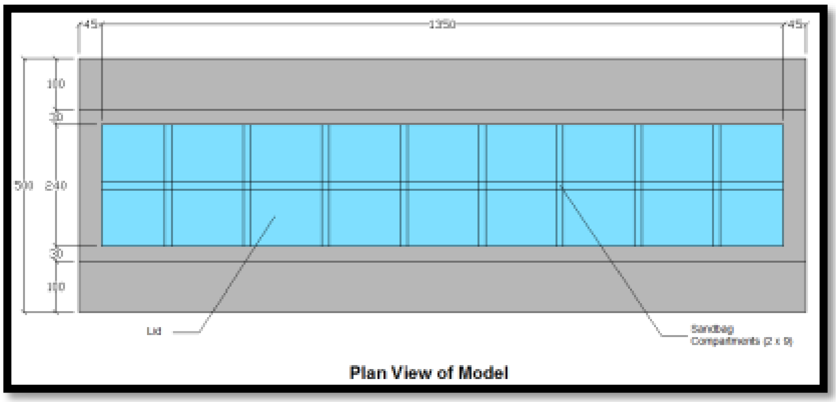


Figure 3.1 : Isometric view of floating breakwater model

As breakwater immersion depth is an important parameter controlling the hydrodynamic performance of the floating breakwater, a ballast chamber located within the breakwater body was design for adjustment if immersion depth of the breakwater with respect to still water level, in a freely floating condition. For the breakwater model, a 5 x 9 matrix wooden grid system was developing for the placement of sandbag for weight control of the draught of breakwater. The ballast chamber was cover by transparent lid was tightly sealed by adhesive tapes so as to prevent the seepage of water to the ballast.

The sides of the floating facing the flume walls were coated with polystyrene foams to prevent direct collision between the concrete wall and the fibreglass coated breakwater body. The implementation of the polystyrene foams at both sides of the breakwater would not pose significant disturbance to the movement of the floating body.



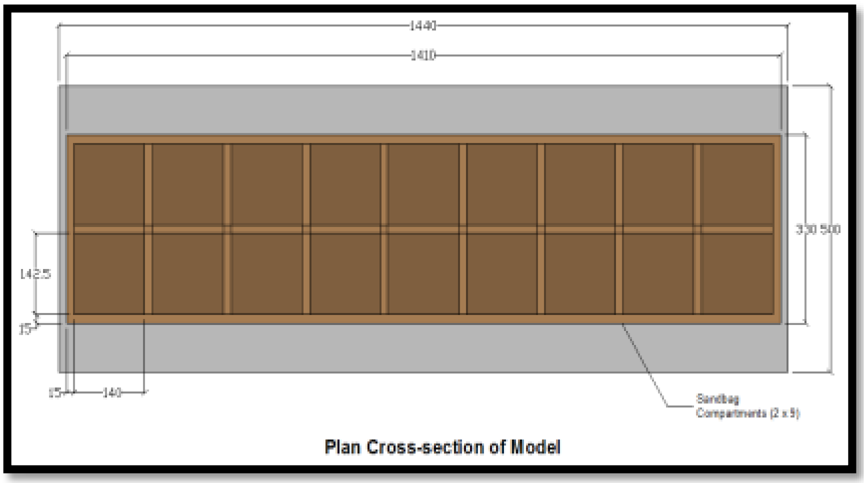


Figure 3.2: Wooden grid for the placement of sandbags into floating breakwater

The proposed materials that are to be used for this new design model are plywood, coated with fibreglass coating which will act as water-proof membrane to the surface of the test model. Plywood is chosen based on its capability to resist high, as well as being light-weight, in which is important in order to ensure the model can float. In process of choosing the materials for the test model, it is important to consider the strength of the model wall due to mooring tension. The wall of the test model must be capable enough to withstand the vertical and horizontal forces due to restriction of mooring tension on the mooring line. Thus, plywood is considered to be one of the suitable choices. Figure 3.4 shows the end product of the test model after fabrications.

Figure 3.3 : Fabricated model

Figure 3.4: Positioning of model

3.2.2 Mooring System

In order to hold the test model in its position, a mooring mechanism is required. In the past studies, the pile mooring system has been opted. However, in this study, a taut-leg mooring system is opted to be used, in which gives the model up to six degree of freedom movement. Due to this, a mooring connection has to be established between the floating breakwater model and the floor.

In taut-leg mooring system, the mooring line is connected in straight line from the floating breakwater model to the anchor located at the floor of the wave flume. Such configuration will give the mooring line a pre-tensile stress prior to the test. The mooring line will be connected to the wall of the floating breakwater by means of hooking the end of the line to the designated hooking point on the wall of the test model. The general configuration of the taut-leg mooring system in shown in the Figure 3.5.

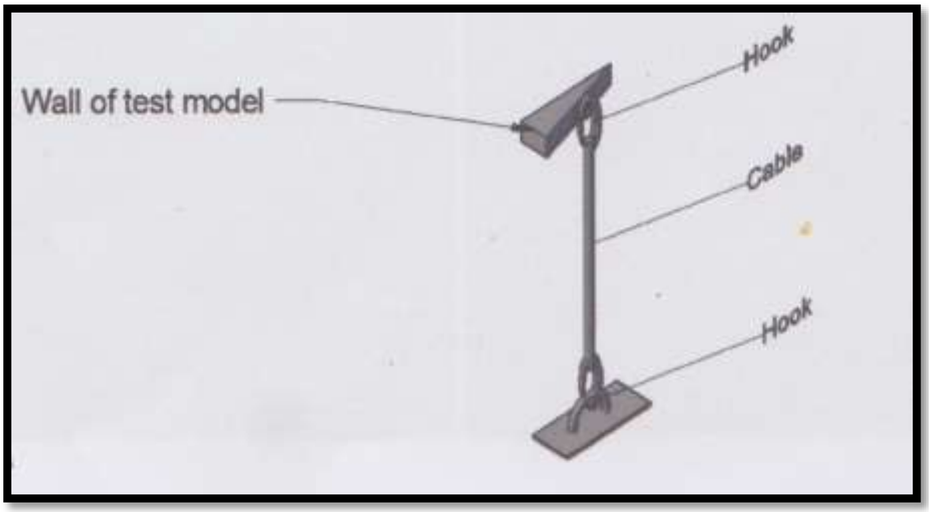


Figure 3.5 : Configuration of Mooring System for test model

Four hooks were attached to the bottom corner of the floating model as shown in Figure 3.6, for mooring purposes. A taut-leg mooring was adopted in this study as it provides greater efficiency to the performance of floating breakwater. The taut-leg mooring lines were almost straight with minimal slacking when in operation in water. For the present experiment, the pre-tensile stress of the mooring cables was set as zero in still water level. The build-up of the tensile stress in the mooring cables during the experiment is mainly posed by the wave force acting on the floating breakwater. The settling of present experiment allows heave, surge, and pitch responses to the floating breakwater, and the other motion responses (*i.e.* sway, yaw and roll) were restricted.

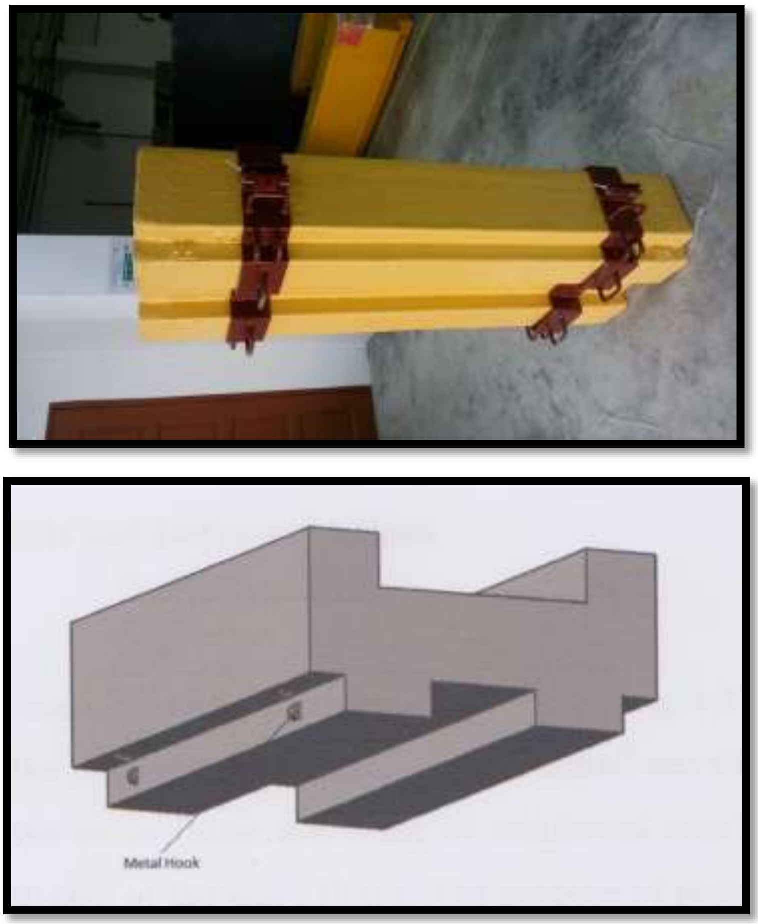


Figure 3.6 : Position of hooking points on the test model

As far as the mooring system is concerned, this will be first time such configuration used on the said test model. Thus, the previous studies by other researcher will be used as benchmarked to the study. A greater movement by the test model will also be expected, together with a higher force on the mooring line, due to the pre-tension configuration; as compared to the previous studies by the other students. In order to hook the test model with the floor of the wave flume a thin metal rope with low elasticity was tied to each hook beneath the breakwater and the other end was attached to the floor of the wave flume. The attachment of the metal cable is shown in Figure 3.7(a). Meanwhile, Figure 3.7(b) shows the position of 4 metal hooks at the bottom of the flume floor. The configuration of the metal hooks will be discussed in the later part if this chapter.

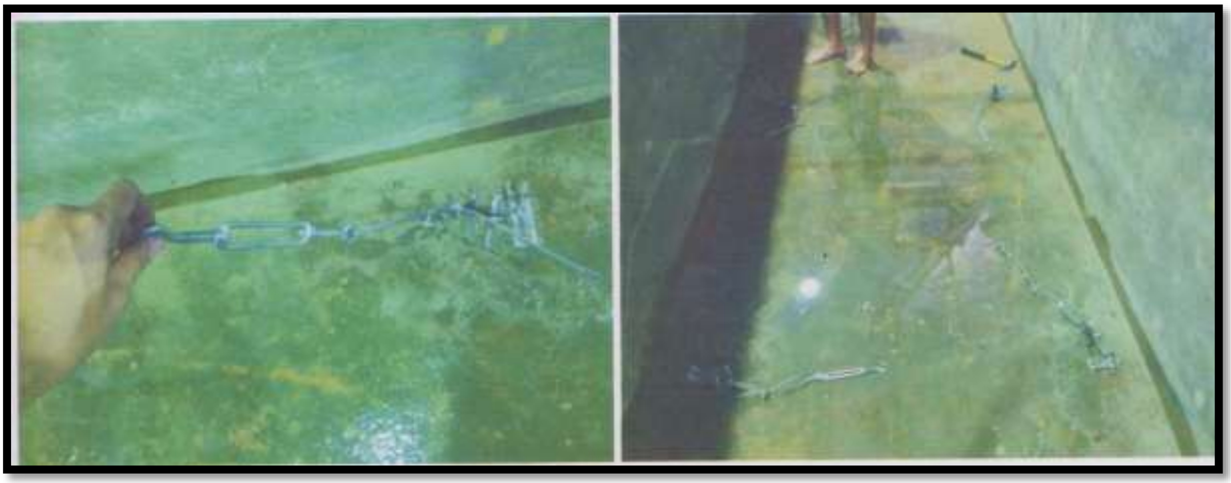


Figure 3.7 : Mooring connection setup

3.3 Laboratory Equipment and Instrumentations

The study was conducted in Offshore Laboratory (Block A) at Universiti Teknologi Petronas (UTP). The main facilities provided in the Offshore Laboratory of UTP are wave tank and wave flume, with the latter part being the key facility for this study. Other equipments and devices that were used in this study are provided in the laboratory as well.

3.3.1 Wave Flume

The experiments took place in a 25m long, 1.5m wide and 1.5m high wave flume as shown in Figure 3.8. The maximum water level permitted by the flume is 0.7m with a maximum allowable wave height of 0.2m. The walls of the wave flume were constructed using reinforced concrete. There are six panels of flexi glasses that were embedded along the flume with 3 on each side. The glass panels are placed to ease the observation and monitoring on the experiments that are being conducted inside the wave flume.

3.3.2 Wave Paddle

The wave paddle is used to generate waves to mimic the real sea condition in a real world. The wave paddle is installed at the one end of the wave flume, as shown in Figure 3.9, and it is able to generate both regular and irregular waves. It is powered by a single motor generator, with a capability of generating waves up to 2 second wave period, and maximum wave height of 0.3m. the wave paddle was fabricated by the Edinburgh Design Ltd., United Kingdom and is capable of absorbing the re-reflected waves.

Figure 3.8 : Wave flume

Figure 3.9 : Wave paddle

3.3.3 Wave Absorber

At the other end of the wave flume, a wave absorber is placed to absorb the remaining wave energy from the incident waves generated by the wave flume, as shown in Figure 3.10. This is to avoid any reflection from the waves that may alter the values of the subsequent waves, which may affect the readings. As a requirement, the wave absorber must be made up of a material that can absorb up to 90% energy from the incident waves.

Figure 3.10 : Wave absorber

3.3.4 Optical Tracking System (OPTITRACK)

In order to record the hydrodynamic motion of the test model, we are using an Optical Tracking System attached at the side of wave flume. The advantage of using this instrument is it can detect all 6 degree of movement immediately during the testing process. The movement of the test model will be detected by the camera (refer Figure 3.11(a)) through the reflective balls (refer Figure 3.11(b)), located at the top of the test model. In the testing, 3 different cameras are used and all the data from all the camera will be used and analysed.

(a)

(b)

Figure 3.11 : (a) Optical Tracking System camera, (b) reflective ball

3.3.5 Wave Probes

The wave probe will be used to measure both the incident and reflected wave heights value throughout the testing. However, in the study, the focus is more on the incident wave heights rather than reflected wave heights. Three wave probes will be placed in front of the test model for such purposes. The decomposition of the wave heights will use the three-point method (Mansard and Funke, 1980). Prior to the test, the wave probes will need to be calibrated beforehand by letting the wave flume runs without any obstruction at different wave period and wave heights. Figure 3.12 shows placement of the probes inside the wave flume

Figure 3.12 : Wave probe

.

Figure 3.13 : Data logger

3.3.6 Data Logger

All of the instrument mentioned above will be connected to a data logger. The data logger will be acted as a central nerve system, where all of the obtained values and data from the instruments will be collected inside the data logger. This data logger will then transmit all the require data into the PC system inside the laboratory, to be analyse accordingly. Figure 3.13 shows the type of data logger that will be used in the study.

3.3.7 Experimental Set-up

The complete experimental set-up is presented in Figure 3.14. The test model was located at the mid-length of the flume, which is 4m apart from the wave paddle. The test model was anchored to the floor of the wave flume by the means of metal cable and hooks. Load cells were installed at the mid-point of the respective mooring lines for the measurement of the mooring forces.

Three wave probe were located both seaward and shoreward of the model (with nearest probe located away from the model at 3.0m) for the measurement of the water level fluctuation at the respective locations. These times series data were then further analysed using computer tools to yield some significant wave parameter, *e.g.* significant wave height, peak wave period, etc. Mansard and Funke's method (1983) was adopted to decomposed the wave signals from the three probes into incident and reflected wave components. To achieve this, the probes were carefully arranged according to the spacing requirement set by Mansard and Funke (1980)

A number of reflective balls were attached to the test model. The movement of these balls, which is equivalent to the movement of the model, was captured by three optical tracking cameras located at close proximity of the model.

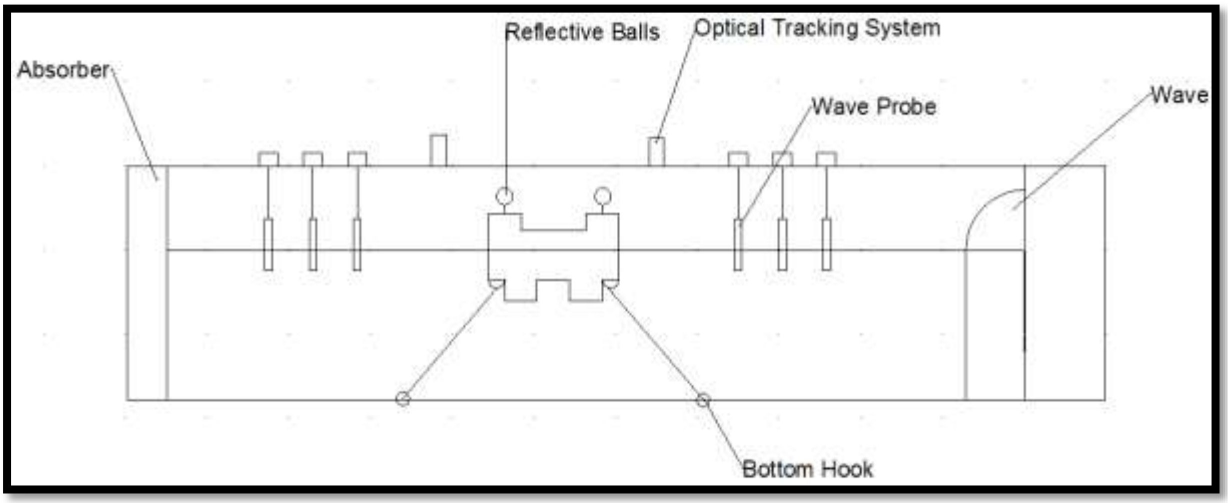


Figure 3.14 (a) : Experimental Set-Up (side view)

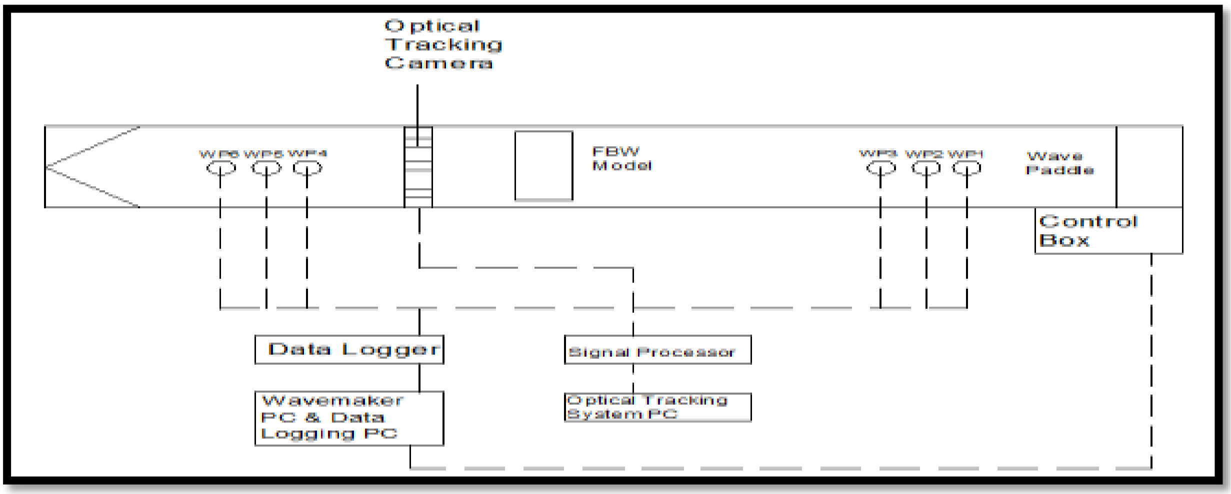


Figure 3.14 (b) : Experimental Set-Up (plan view)

3.4 Experimental Test-Run

In testing the test model, the behaviour of the floating breakwater model under different sets of condition is to be monitored. Thus, all the fixed and manipulated parameter that will be tested is to be established. The variables that are going to be used in these experiments are listed in table 3.1.

FIXED VARIABLES	**DEPENDANT VARIABLES**
Mooring method	Water drafts, *D*
Model orientation	Wave period, *t*
Water depth, *d*	Wave height, *h*

Table 3.1 Variables used in the testing

In each of the dependant variables, the values of each parameter are varied. Noticed that in each wave depth, the test model will be tested at different wave period, which is at 0.1second interval. Furthermore, in each wave period, the floating breakwater model will be tested at different wave height. The number of runs that was conducted throughout the testing is shown in Table .32. Overall, a set of 132 tests were conducted throughout the period of this study for regular wave.

T(s)	Frequency, (*f*)	Wave Steepness						Water Depth (m)	Draught (m)
		$H_i/L= 0.04$		$H_i/L= 0.05$		$H_i/L= 0.06$			
		h(m)	Gain Value	h(m)	Gain Value	h(m)	Gain Value		
0.8	1.25	0.04	0.84	0.05	0.85	0.06	0.86	0.73	0.15
0.9	1.11	0.05	0.86	0.06	0.87	0.08	0.84	0.73	0.15
1.0	1.0	0.06	0.77	0.08	0.77	0.09	0.81	0.73	0.15
1.1	0.91	0.08	0.75	0.09	1.1	0.11	1.07	0.73	0.15
1.2	0.83	0.09	0.96	0.11	1.0	0.13	0.97	0.73	0.15
1.3	0.77	0.10	1.0	0.13	0.90	0.15	0.90	0.73	0.15
1.4	0.71	0.11	0.87	0.14	0.86	0.17	0.89	0.73	0.15

1.5	0.67	0.13	1.03	0.16	1.02	0.19	1.03	0.73	0.15
1.6	0.625	0.14	0.96	0.17	0.95	0.21	0.87	0.73	0.15
1.7	0.59	0.15	0.86	0.19	0.86	0.23	0.89	0.73	0.15
1.8	0.56	0.16	0.97	0.20	1.0	0.25	1.0	0.73	0.15
1.9	0.53	0.18	0.92	0.22	0.93	0.26	0.98	0.73	0.15

Table 3.2 : Number of testing done throughout the experiment

3.5 Key milestone

A progression of a project usually illustrated by using Gantt chart. In Gantt chart, every works need to be done from start to finish are listed and the time proposed is set up tp make sure the project is done within the time given. Key milestone is used as a project checkpoint to certify how the project is progressing. Table 3.3 summarized the important events throughout the Final Year Project I (FYP I) and table 3.4 illustrated the progress of works need to be done within time given according to the guideline for Final Year Project.

NO	Key Milestone	Proposed Week
1	Submission of extended proposal defence	Week 6
2	Submission of interim Draft Report	Week 13
3	Submission of interim report.	Week 14

Table 3.3 : Key Milestone

3.6 Gantt Chart

In the first half of the study, the focus is more on the introduction and preparation towards the further study of the test model. Thus, it is important to have a Gantt chart in which will help in keeping track of the progress and proceed accordingly. The Gantt chart will give a clear indication on the task that will be done and to ensure the feasibility of the study as it is initially planned in the beginning of the study. The extended Gantt chart is shown in Table 3.4.

3.7 Flow Chart of Research Activities

In completing the studies, a series of activities need to be done in order to ensure the feasibility of the study. These set of task will be done in a number of stages in order to ensure the unobstructed flow of the study. The flow chart of the research activities is given in Figure 3.15.

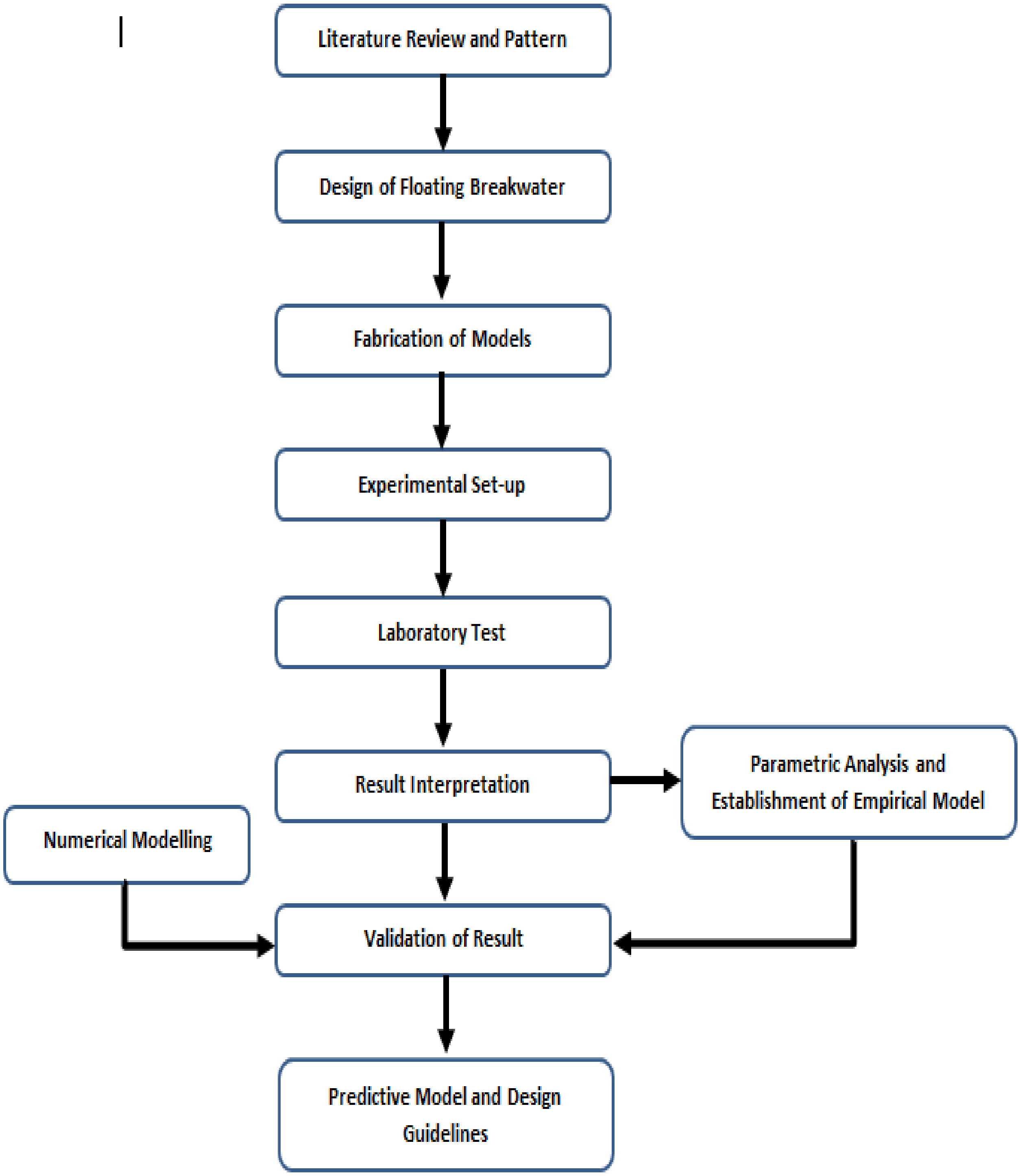
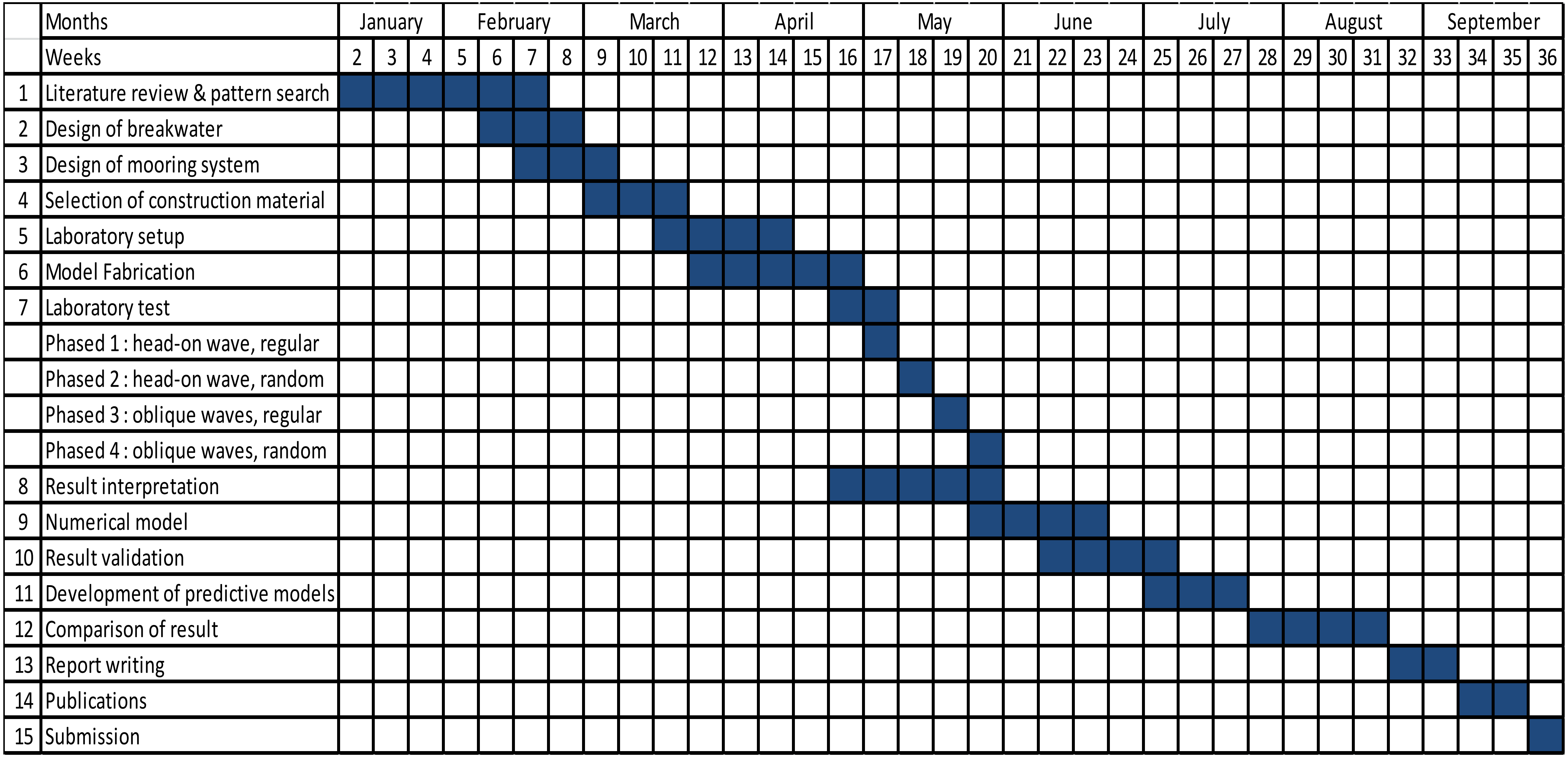


Figure 3.15 : Flow Chart of Research Activities



	Months	January			February				March				April				May				June				July				August				September			
	Weeks	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1	Literature review & pattern search	■	■	■	■	■	■																													
2	Design of breakwater					■	■	■																												
3	Design of mooring system						■	■	■																											
4	Selection of construction material								■	■	■																									
5	Laboratory setup										■	■	■	■																						
6	Model Fabrication											■	■	■	■	■																				
7	Laboratory test															■	■																			
	Phased 1 : head-on wave, regular																■																			
	Phased 2 : head-on wave, random																	■																		
	Phased 3 : oblique waves, regular																		■																	
	Phased 4 : oblique waves, random																			■																
8	Result interpretation															■	■	■	■	■																
9	Numerical model																			■	■	■	■													
10	Result validation																					■	■	■	■											
11	Development of predictive models																								■	■	■									
12	Comparison of result																											■	■	■	■					
13	Report writing																															■	■			
14	Publications																																	■	■	
15	Submission																																			■

Figure 3.4: Extended Gantt chart of research activities

CHAPTER 4

RESULT AND DISCUSSION

4.1 General

This chapter present the measured motion responses of the H-type floating breakwater in the form of time series and frequency domains for each set of experiment conducted in the wave flume. These analyses are particularly important in providing better interpretation of the results in the later stage of the study. The details of the analyses are to be thoroughly discussed in this chapter. The motion responses (i.e. heave. Surge and pitch) of the breakwater model are presented in respective Response Amplitude Operators (RAO). A parametric analysis is also conducted to give complete representation of all the experimental test that were carried out in this study, and some key conclusion are drawn at the end of this chapter.

4.2 Calibration of Wave Probes and Wave Flumes.

The calibration of the wave flume and wave probes will be done by using the three-point method proposed by Mansard and Funke (1985), as being mention in the previous chapter. The basis of this method is to measure simultaneously the wave in the flume at three different points with an adequate distance between one set to another. The wave probes will be located parallel to the wave's direction inside the wave flume. The set-up of all the equipment for the calibration is shown in the figure 4.1, where it indicates the length of the probes from the wave paddle (X12), the length of first probe to the second probe (X2) and the length of first probe to the third probe (x13). As according to the method spacing between, the proposed spacing between the probes is given as follows:

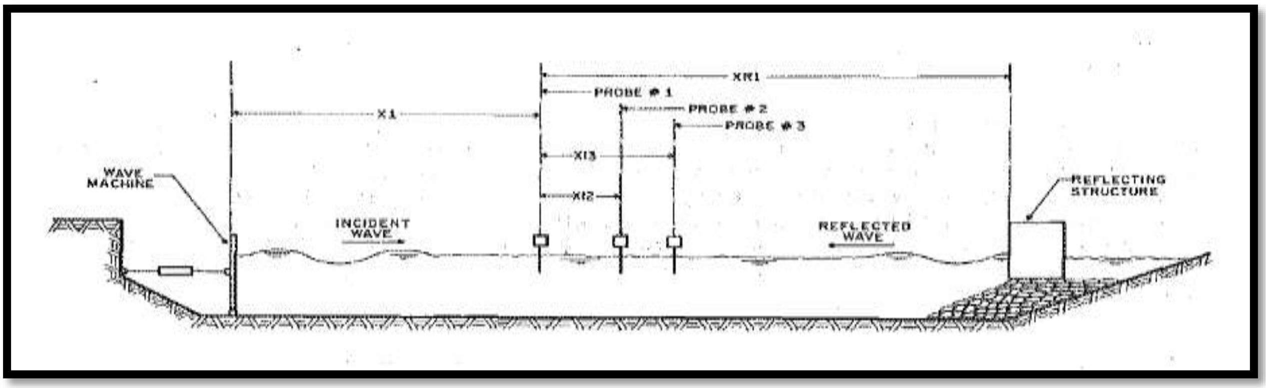


Figure 4.1: Three-point method calibration set up (Source: Mansard and Funke, 1985)

$X12 = L_P/10$ $L_P/6 < X13 < L_P/3$ $X13 \neq L_P/5$ and $X13 \neq 3L_P/10$

Where L_P is the overall length on the wave flume. The importance of the following the spacing requirement as stated in the study is to ensure that there are no singularities in the wave probe readings. The distance between the final wave probes and the reflective structures is also being defined. The recommended distance between the two points must be at least one wave length away from each other. This spacing requirement is important to ensure that there are no singularities in the wave probe readings. The spacing of the wave probes corresponding to the wave period are shown in Table 4.1.

T(s)	f(Hz)	D(m)	Water Condition	X12(mm)	X23(mm)	X13(mm)
0.8	1.25	0.7	Deep	100	130	230
0.9	1.11	0.7	Deep	126	280	406
1.0	1.00	0.7	Transitional	155	280	435
1.1	0.91	0.7	Transitional	186	280	466
1.2	0.83	0.7	Transitional	200	280	480
1.3	0.77	0.7	Transitional	217	280	497
1.4	0.71	0.7	Transitional	249	400	649

1.5	0.67	0.7	Transitional	281	400	681
1.6	0.63	0.7	Transitional	312	400	712
1.7	0.59	0.7	Transitional	343	400	743
1.8	0.56	0.7	Transitional	373	500	873

Table 4.1: Wave probe spacing

Since this study will only be dealing with the regular waves testing, there are two options in which calibrations of the wave flume can be done. The calibration for the regular wave can be done by directly selected the pre=determined values of wave height and wave period for testing into computer software. The paddle will then be automatically adjusted to suit the numbers that have been commanded in the computer. However, the drawback of such method is that there might be some irregularities with the waves that will produce. The actual reading of the wave that will be generated by the wave paddle might vary from the commanded values that have been key-in into the computer software, this happened due to the limitations of the software to get fully accurate value of the wave properties in the wave flume, as well as other external factors that might affect these values. In order to overcome this drawback, the manual command method can be used.

In manual command method, the values of the wave parameters, such as the wave height and the frequencies, can be independently defined by the user itself. The advantage of using the command method is that the user can check the accuracy of the wave being generated by the wave paddle and then adjust them accordingly. This, however, need to be done in a series of trial-and-error method up until the desired value is achieved. This method proved to be more reliable and it helps to maintain the accuracy of the generated waves. The command that will be key-in into the software is a script method, depending on the type of wave wanted to be produced by the user.

As far as the study is concerned, it will only deal with regular waves. Thus, the following script can be used to calibrate the wave flume for a singular regular wave:

```
“begin

run “1 Hz 6 cm wave for 20 secs (1)” with (10)

makewave x=1.0*single (1,0.06) on 1;

end;”
```

In the command given, the wave paddle is expected to produce wave with 6 cm height, at the frequency of 1 Hz, or 1 second of wave period. However, the generate wave that being recorded by the wave probe might not give the similar values as the commanded values. Thus, the values must be corrected accordingly by introducing a gain value, represented by *x*, in which will adjust the parameter value. Since there are no definite ways to determine gain values, trial-and-error method is going to be used to calibrate the wave paddle until the reading on the wave probes result in the desired value. Based on this command, the data that have been collected can be synthesized according to the values needed. Once the gain value had been obtained, it was incorporated into the following script to produce specific type of regular waves. The table 4.2 show the gain value for each desired wave height need to be generated by the wave generator.

T(s)	Frequency, (*f*)	Wave Steepness					
		0.04		0.05		0.06	
		h(m)	Gain Value	h(m)	Gain Value	h(m)	Gain Value
0.8	1.25	0.04	0.84	0.05	0.85	0.06	0.86
0.9	1.11	0.05	0.86	0.06	0.87	0.08	0.84
1.0	1.0	0.06	0.77	0.08	0.77	0.09	0.81
1.1	0.91	0.08	0.75	0.09	1.1	0.11	1.07
1.2	0.83	0.09	0.96	0.11	1.0	0.13	0.97
1.3	0.77	0.10	1.0	0.13	0.90	0.15	0.90
1.4	0.71	0.11	0.87	0.14	0.86	0.17	0.89
1.5	0.67	0.13	1.03	0.16	1.02	0.19	1.03

1.6	0.625	0.14	0.96	0.17	0.95	0.21	0.87
1.7	0.59	0.15	0.86	0.19	0.86	0.23	0.89
1.8	0.56	0.16	0.97	0.20	1.0	0.25	1.0
1.9	0.53	0.18	0.92	0.22	0.93	0.26	0.98

Table 4.2: Gain value for corresponding wave height and steepness

4.3 Experiment Configuration

As being discussed in the previous chapter, the equipment that were used in this study were set-up inside the wave flume, which will generate the required wave condition throughout the testing. The testing of the floating breakwater model will be done as planned, with two different mooring configuration, a number of distinguished wave periods and wave steepness of regular waves were being tested in order to study the effects of these mooring configuration to the movement of the model as far as the RAOs are concerned. The placement of the model and the equipment is illustrated as shown in Chapter 3 (refer section 3.3.7). The full experiment configuration is illustrated in Figure 4.3

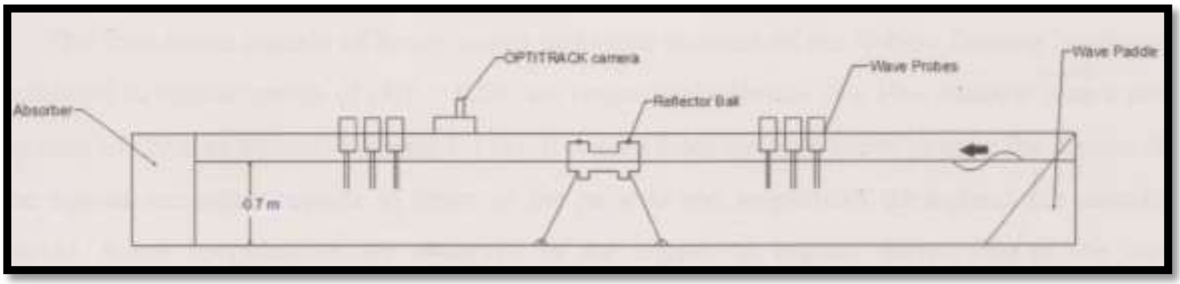


Figure 4.3: Experiment Set-Up

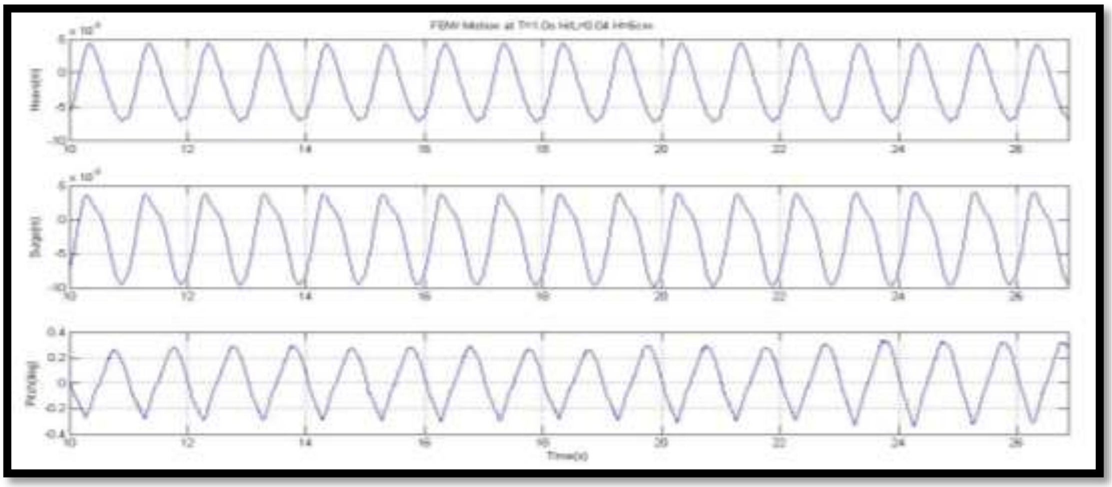
4.4 Measured Result

Series of experiment were rigorously conducted in the wave flume to study the motion responses of the H-type floating breakwater in both regular and random wave. It is worthwhile to mention that only heave, surge and pitch motions are measured whilst the sway, roll and yaw motion are restricted by the setting of the experiment. These motion were recorded by an optical tracking system (OPTITRACK) operated by three high speed cameras (see section 3.3.4 for more details). The present experiment consider two mooring configuration (taut-leg and catenary), three wave steepness (i.e. H_i/L = 0.04, 0.05 and 0.06) and one relative immersion depths (D/d=0.25). Nevertheless, some test involved high steepness waves could not be carried out in the wave flume due to mechanical restriction of the wave paddle. A total of 36 tests were complete within the capabilities of the test facilities and apparatus.

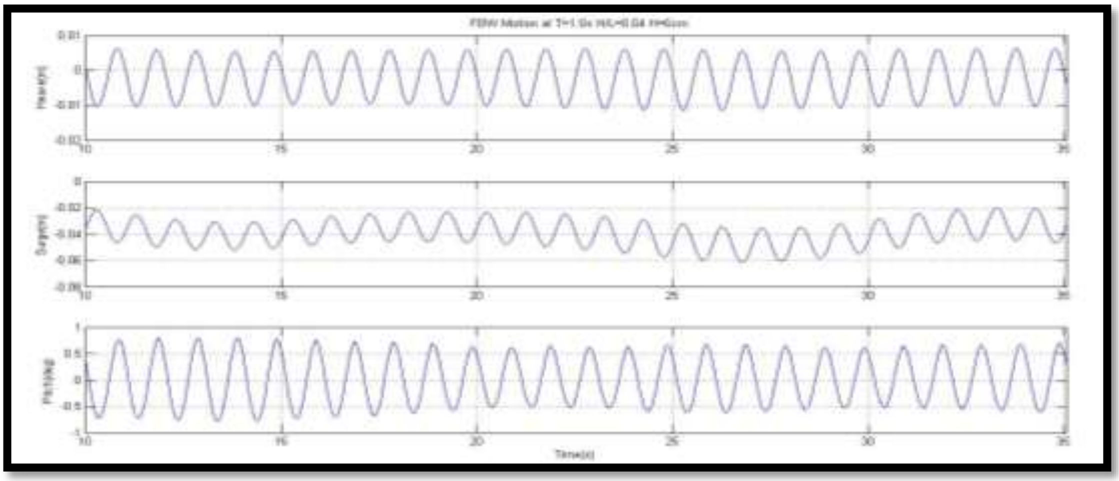
The motions of the H-type floating breakwater are often quantified by the Response Amplitude Operators (RAO), which is amplitude of motion relative to the wave amplitude. Higher RAO values indicate greater motion response at the degree of freedom, and vice versa. This section presents some samples of raw data and the related analyses of the data. Note that it is not possible to display the above result of the entire test conducted here as these will overload the thesis. The measured data were first observed using time series analysis and the characteristics of the data were subsequently assessed by the frequency domain analysis.

4.4.1 Time Series Analysis

The time series signals of heave, surge and pitch motions of the H-type floating breakwater subjected to regular wave of H_i/L=0.04 are respectively plotted in a 10-s window with a start-up time of 20 second, as shown in Figure 4.4. It is seen from the time series plots in the figure that the signals are rather regular in term of the periods and amplitudes throughout the sampling period. Some irregularities are observed in the signals in regular waves due to the wave interference effect resulted by both incident and reflected waves in front of the test model.



(a)



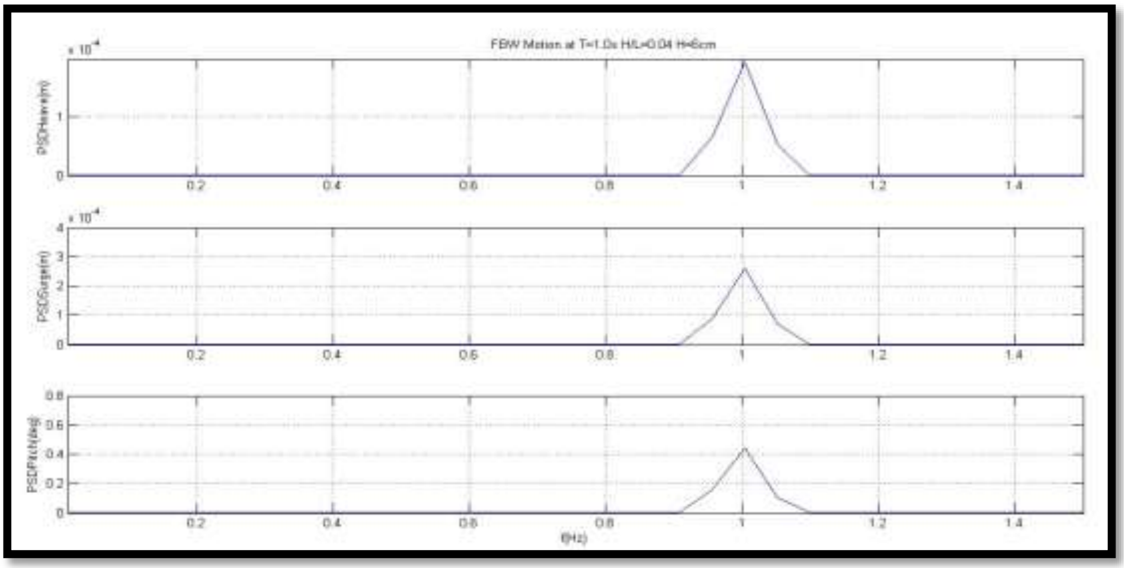
(b)

Figure 4.4 : Time Series Graph for (i) heave, (ii) surge and (iii) pitch responses for H/L=0.04, frequency=1.0Hz and H=6cm using (a) Taut-Leg configuration and (b) Catenary Configuration

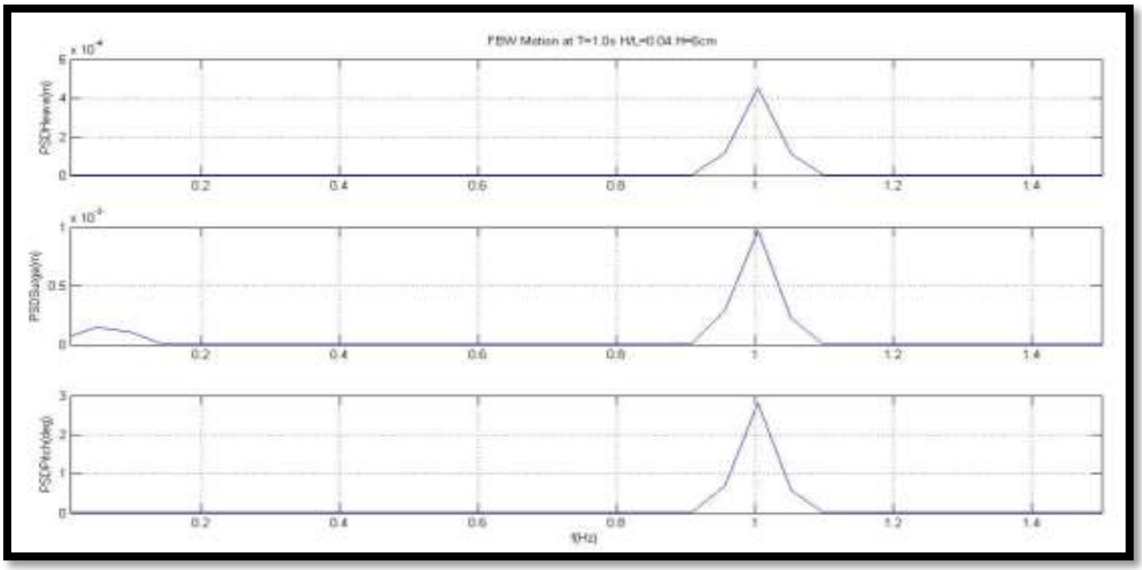
4.4.2 Frequency Domain Analysis

The characteristic of the regular signals might be feasibly and sufficiently evaluated using time series analysis. However, the characteristic of the irregular signals can only be identified by transforming the time series data into a frequency domain, where the x-axis appears to be energy density, S (*f*) (unit: m^2s). For this study, the use of JONSWAP spectrum was utilized in the conversion of the time series graph into frequency domain analysis graphs.

Figure 4.5 shows the corresponding spectral energy density of the time series signals for heave, surge and pitch motion of the H-type floating breakwater as shown in Figure 4.4. The energy of the respective motions surge at a particular frequency, in which the frequency is close to the natural period of the incident waves, and the energy at remaining frequencies are inappreciable. For instance, in Figure 4.5, it can be observe that the amplitude of the spectral graph. The frequency in which this amplitude is found closely corresponded with the natural period of the incident waves.



(a)



(b)

Figure 4.5: Energy Spectral Density for (i) heave, (ii) sway and (iii) pitch responses for H/L=0.04, frequency=1.0 Hz and H=6 cm using (a) Taut-Leg Configuration and (b) Catenary Configuration

4.5 Result Interpretation

Section 4.5.2 presents the variation of RAO in frequency domains for the H-type floating breakwater using both mooring configuration which are Taut-Leg and Catenary. The RAO-peaks of the entire test were recorded and evaluated based on the relative breakwater width, B/L, which is one of most accepted design parameter for breakwater. The RAO result for heave, surge and pitch motions of the test model using both mooring configuration (Taut-Leg and Catenary) subjected to the waves steepness of $H_i/L = 0.04$, 0.05 and 0.06 are to be thoroughly discussed in the following sections.

4.5.1 Response Amplitude Operators

In order to quantify the movement of the floating breakwater model respect to the wave action acting on the model, a dimensionless parameter is used for the study. The dimensionless parameter, known as Response Amplitude Operator (RAO) defined as the motion response of the floating body per wave height amplitude. In the study, the motion response of the floating body per wave height amplitude. In the study, the motion response of the floating breakwater based on the energy spectral density with respect to the wave energy acting upon the floating breakwater model were being considered. As being mentioned in section 4.5, the study will only considered the three degree of freedom for the floating body, namely the heave, surge and pitch responses due to the limitations of the apparatus and equipments. Thus, the formula used to calculate the RAO for heave, surge and pitch motion is defined as follows:

$$\boxed{RAO_n\left(\frac{m}{m}\right) = \sqrt{\frac{Sf,motion}{Sf,wave}}}$$

Where RAO_n is the RAO response of the floating body (n = heave, surge and pitch), $S_{f,\mathrm{motion}}$ is the amplitude of motion spectral energy response and $S_{\mathrm{f,wave}}$ is the energy amplitude based on the spectral energy density graphs.

4.5.2 Heave

The peaked heave-RAO for the H-type floating breakwater with fixed ratio D/d = 0.25 subjected to wave steepness Hi/L = 0.04, 0.05 and 0.06 are demonstrated in Figures 4.6 and Figure 4.7 respectively. The test model was using different mooring configuration which are Taut-Leg mooring and Catenary mooring configuration, which represent by different plots in the figures

By using both mooring configuration to the test model the result have been generated as shown in Figure 4.6 and Figure 4.7 the heave RAOs of Hi/L = 0.04, 0.05 and 0.06 decrease with an increase of B/L. This implied that the heave motion of the test model increase with the increasing period of the wave incident waves. This is sensible because the size (*i.e.* width) of the breakwater is relatively small compared to the wavelength and consequently the breakwater tends to move along with the incoming waves. The usage of the taut-leg configuration give lower value of heave-RAOs compared to the usage of the catenary. This is because the taut-leg configuration has more ability to constrain the heave motion due to its own characteristic that used the mooring tension to constrain the movement of the test model. Different form the catenary that use only self-weight to constrain the movement of the H-type floating breakwater. When comes to the higher wave height means higher wave energy, the self-weight became less effective to constrain the heave movement. Therefore, it is sensible that taut-leg configuration can constrain more heave movement compare to the catenary configuration. It is also observe that for both mooring configuration, the effect of the wave steepness is not significant to the mooring performance.

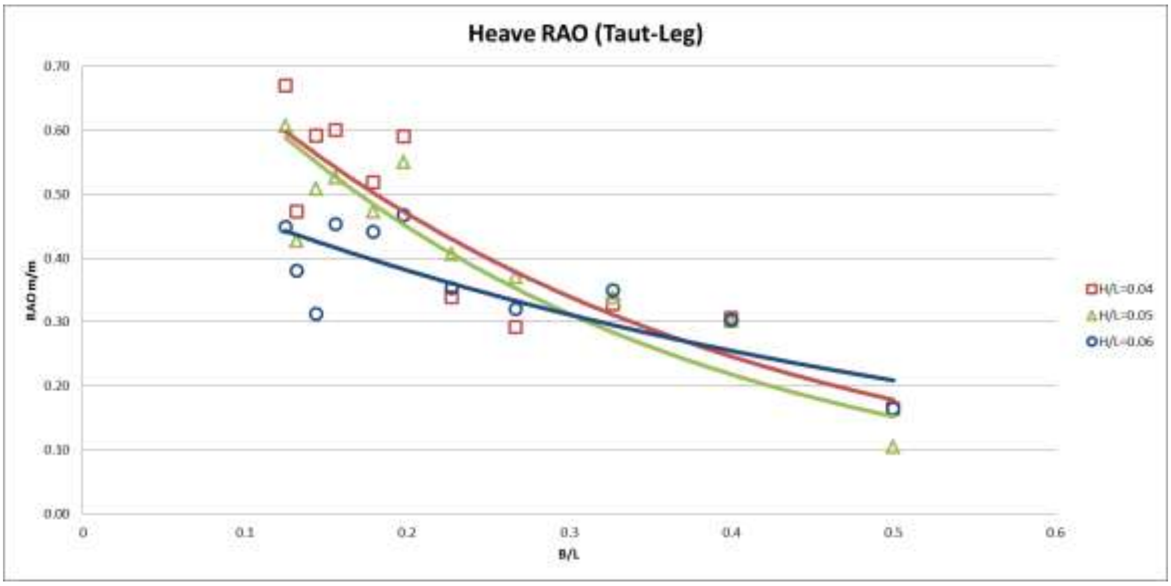


Figure 4.6 : Peaked heave-RAOs of the test model using Taut-Leg Configuration

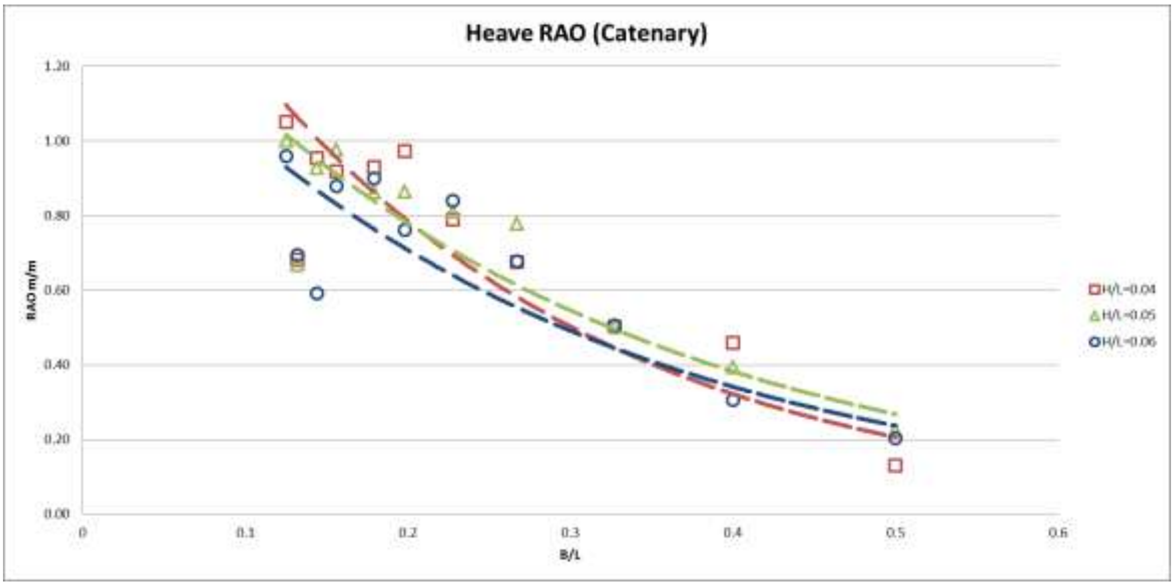


Figure 4.7 : Peaked heave-RAOs of the test model using Catenary Configuration

4.5.3 Surge

The peak surge-RAOs of the H-type floating breakwater derived from the frequency domain analysis as shown in Figure 4.8 and Figure 4.9. The format of the plots is similar to Figure 4.6 and Figure 4.7. For the taut-leg mooring configuration, the surge-RAOs is decrease with increasing of B/L. This can be explained by the fact that the surge motion of the floating structure is strongly governed by the advancing wavelength, *i.e.* the greater the magnitude of the wavelength, the larger will be the surge response of the breakwater. It is sensible result shown by the taut-leg mooring configuration since the concept of the configuration itself prove that the surge motion can be effectively constrains by this type of mooring configuration.

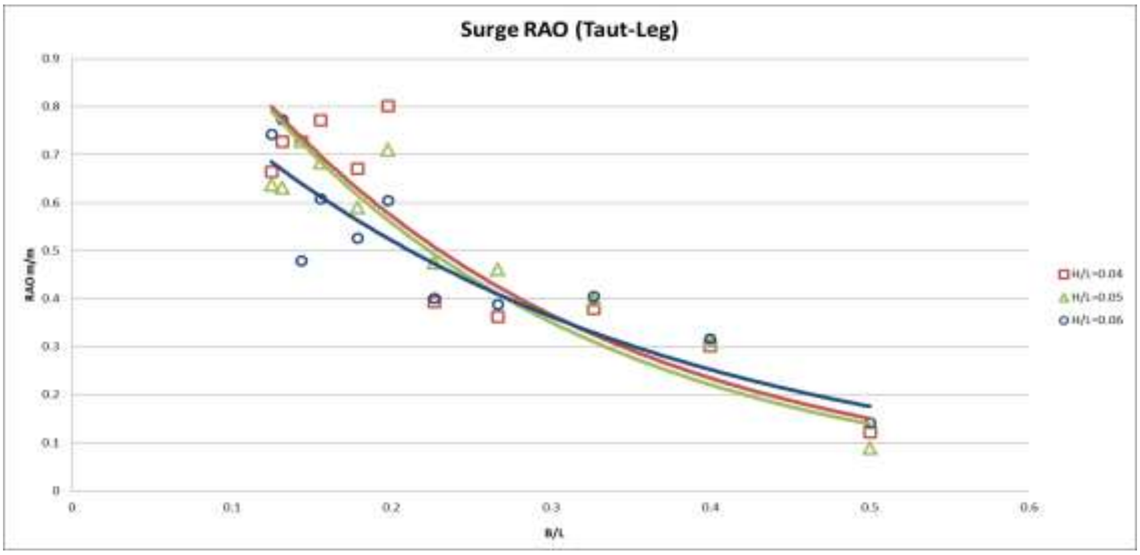


Figure 4.8 : Peaked Surge-RAOs of the test model using Taut-Leg Configuration

For the catenary configuration, the result generated is quite different from the expectation. This is because, catenary configuration show that the surge-RAOs is increase with increasing of B/L. This can be explained by the theory of pounding effect. Pounding effect is affected by the frequency of the wave, therefore, the shorter wave length have more pounding effect compared to the longer wave length, since the shorter wave length have more wave frequency compare to the longer wave length. The pounding affect keep pushing the floating structure further form the original position and the mooring self-weight become less effective when the force (pounding effect) frequently keep pushing the floating structure further. Hence, the result as shown in Figure 4.9 is become sensible and concludes that the catenary mooring configuration is not so good in order to constrain the surge motion.

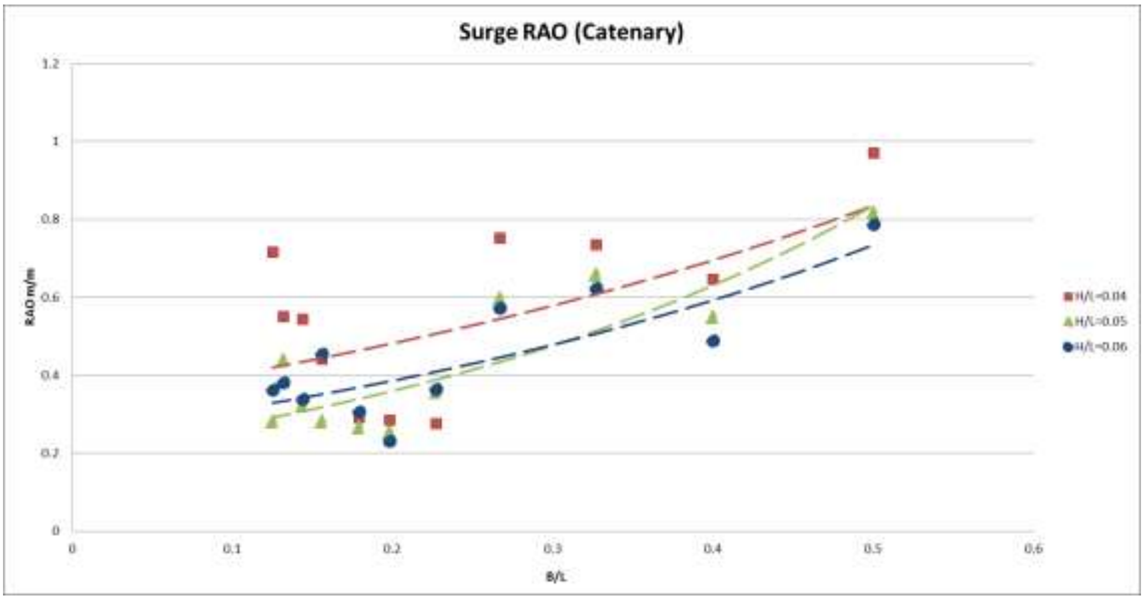


Figure 4.9 : Peaked Surge-RAOs of the test model using Catenary Configuration

For both mooring configurations, the wave steepness again did not give significant affect to the mooring performance to the respective wave.

4.5.4 Pitch

The pitch-RAOs of the H-type floating breakwater of different mooring configuration are demonstrated in Figure 4.10 and Figure 4.11. The comparison of pitch-RAOs between taut-leg and catenary configuration, the taut-leg give lower value of pitch-RAOs about half. This is because the taut-leg have more stable mooring configuration that restrict the pitch movement. Unlike catenary configuration, that less restrict the pitch movement since the mooring setup is loose and the restriction only depend on the self-weight of the mooring cable. Therefore, the pitch-RAOs value became larger compared to taut-leg. For both results, pitch-RAO did not give any trend like surge-RAO and heave-RAO, this may cause by the experimental error due to effect of the wave overtopping on the limited freeboard floating body whereby overtop the crest of the floating breakwater resulting in clock-wise rotation (pitch). Due to this error, several data when missing due to out-range of the OPTITRACK sampling. Sometimes, the splash in front of the model became the main reason for the OPTIRACK sampling went off. As far as the changes for the pitch-RAO is concerned, it is worth to note that the pitch motion carried no specific pattern with the changes in the mooring configuration and the wave period. Thus the pitch motion is considered to be less predictable. Hence it is important to consider the effect of pitch response in the process of designing the breakwater. As being mention in the earlier part, the rotational changes are less sensitive in a stable connection in which cause such pattern as far as pitch-RAO is concerned.

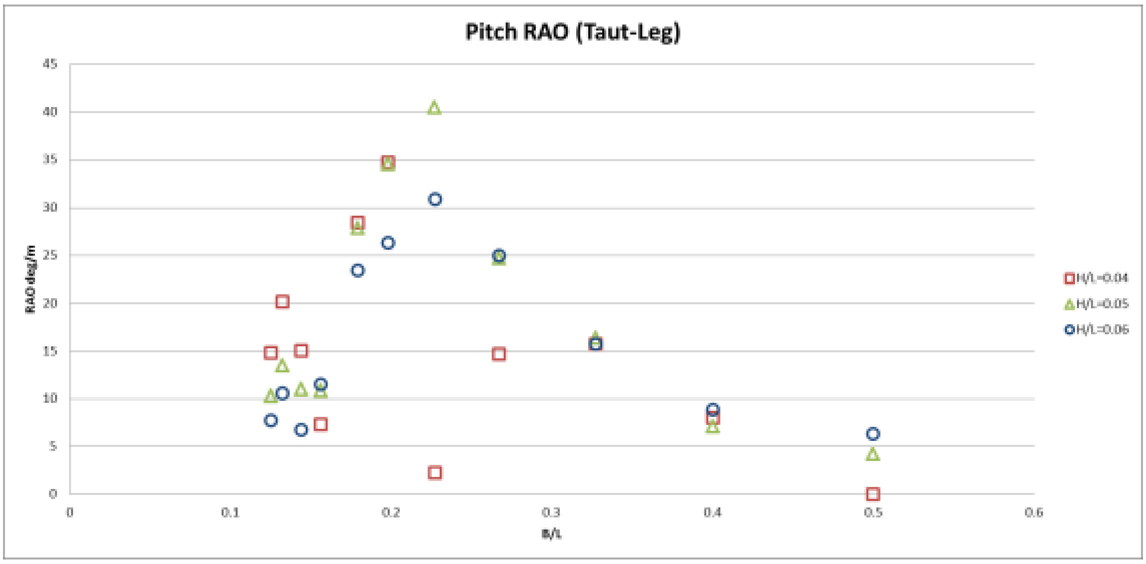


Figure 4.10 : Peaked Pitch-RAOs of the test model using Taut-Leg Configuration

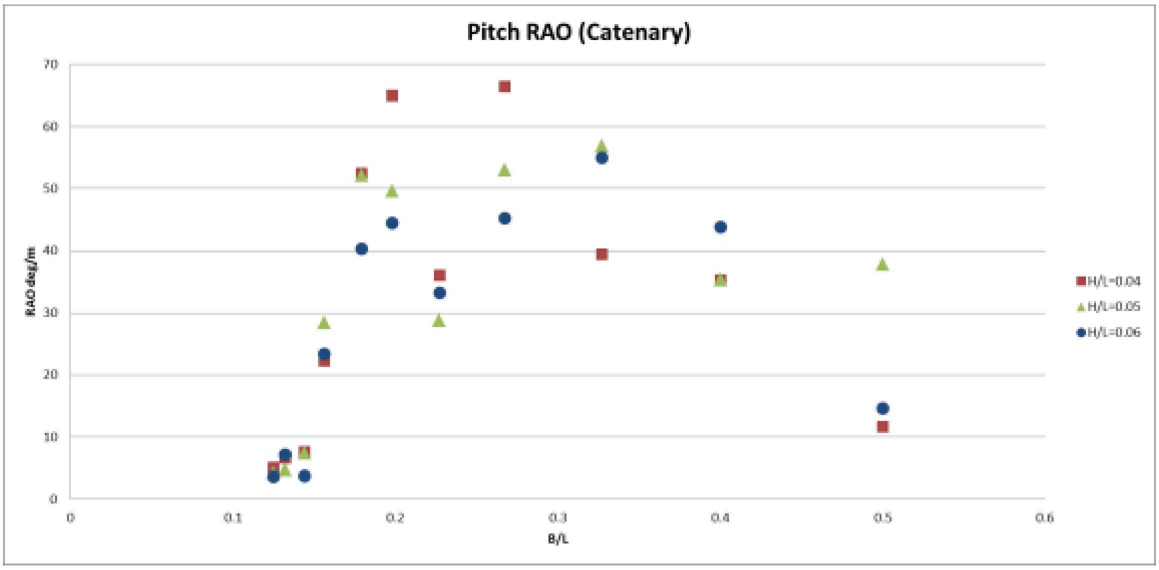


Figure 4.10 : Peaked Pitch-RAOs of the test model using Catenary Configuration

CHAPTER 4

RESULT AND DISCUSSION

5.1 Conclusion

The analysis that has been conducted throughout this study has yielded a few major conclusions. These are the conclusion that can be made based on the end product of the study:

- Taut-leg mooring configuration gives us better performance compared to the catenary mooring configuration. This is clearly shown in the RAO results that have been obtained in the study, particularly of heave and surge. As different mooring configuration used for the floating breakwater, a significant restriction to the movement of the floating breakwater can be observe, causing a significant comparison in the performance of the mooring configuration exposed to the similar wave action.
- Pounding effect present during the experiment and can be seen clearly during the surge motion using the catenary configuration. The present of the pounding effect give some adjustment to the mooring design in the future and real cases because the pounding affect make the mooring configuration became less effective especially in constraining surge motion.

- The effects of the wave steepness are particularly minimal in both heave and surge motion. The difference of heave and surge motion at higher wave steepness is consider to be very minimal. This pattern occurred for both usage of mooring configuration.
- Both heave and surge motion have definite trend with respect to the changes in the system, as far as the mooring configuration and the wave period are concerned. As for pitch motion, no definite trend can be observed with respect to the changes, with the motion responses area acting in a less predictable manner.
- The usage of RAO can help to predict the motion response of the following breakwater with respect to the wave actions. Each motion responses will give different RAO value and this is clearly shown in the data obtained from this study, for both taut-leg and catenary mooring configuration.
- The RAO values obtained in this study is rather significance in providing information in the design of the H-type floating breakwater. The RAO of motion responses of heave, surge and pitch obtained in this study will help the designer in predicting the behaviour of the floating breakwater in real sea and thus, help o decide on the optimum mooring configurations for the H-type floating breakwater depending on the wave conditions of the sea state.
- The experiment produce carried out in this study has shown some promising end product on the response of the H-type floating breakwater with respect to mooring configuration and wave action. The study has also met its primary objective in analyzing the behaviour of the floating breakwater under both mooring configuration.

5.2 Recommendations

The recommended activities that can be done in the future in order to enhance further potential of the study are given as follows:

- In order to verify the potential system used in the study, a separate study of the H-type floating breakwater moored with catenary and consider the weight of the mooring line due to the catenary concept. Such study considered to be helpful, as comparison of the motion response and the performance of the floating breakwater can be evaluate in order to obtain an optimum configuration for the H-type floating breakwater.
- The study can be repeated by using actual material used for the prototype at actual sea. This study also an important study need to be done because, only this study can show the effect of the material to the wave action either the material can give better performance or not. Besides, the study also can be repeated by using different material in order to compare their performance.
- The study of the motion need to be repeated with enhances the sampling scope of the OPTITRACK. This is because during this experiment, the sampling scope of the OPTITRACK gives some technical problem due to missing data especially for the pitch motion; this may be due to the water jump in front of the model. Therefore, the experiment needs to be repeated by enhancing the OPTITRACK sampling.
- The scale effect study of the H-type floating breakwater can be done in the future. This piece of information will help in further verifying the RAO values obtained from this study and tested on the effect of scaling of the testing to the RAO values
- The study can be repeated at a bigger scale by using bigger facilities, such as wave tank, and better equipment with better capabilities. An upgrade version of the study can be done by fully obtained all the 6 degree of freedom response and their RAOs due to various wave condition. The response of the mooring lines during the testing can also be recorded in order to study the hydrodynamics forces acting on the mooring lines for a more advanced analysis of the data

Reference

Chen, X., Zhang, J., Johnson, P. and Irani, M., (2001). Dynamic analysis of mooring lines with inserted springs. *Applied Ocean Research*, **23**(5),pp. 277-284.

Diamantoulaki, I. and Angelides, D.C., (2010). Analysis of performance of hinged floating breakwater. *Engineering Structure*, **33** (5), pp. 2407-2423.

Diamantoulaki, I. and Angelides, D.C., (2011). Modeling of cable-moored floating breakwater connected with hinges. *Engineering Structure*, **33** (5), pp. 1536-1552.

Diamantoulaki, I., Angelides, D.C. and Manolis, G.D., (2008). Performance of pile-restrained flexible floating breakwater. *Applied Ocean Research*, **30** (4), pp. 243-255

Fang, H.,Zhenhua, H. and Adrian, W.L., (2012). Hydrodynamic performance of a rectangular floating breakwater with and without pneumatic chamber: An experimental study. School of Civil and Environmental Engineering, Nanyang Technological University, Singapore.

Garza-Rios, L.,Bernitas, M., Nishimoto,K., (1997). Caternary mooring lines with linear drag and touchdown. Department of Naval Architecture and Marine Engineering, College of Engineering, University of Michigan.

Gobat, J.I. and Grosenbaugh, M.A., (2001). A simple model for heave-induced dynamic tension in catenary moorings. *Applied Ocean Research*, 23 (3), pp. 159-174.

Hedge, A., Kamathan, K. and Magadum, A., (2007). Performance characteristic of horizontal interlaced multilayer moored floating pipe breakwater. *Journal of Waterway, Port, Coastal and Ocean Engineering*, **133** (4), pp. 275-285.

Huang, W., Liu, H., Lian, Y. and Li,L., (2013). Modeling nonlinear creep and recovery behaviour of synthetic fober ropes for deepwater moorings. *Applied Ocean Research*, **39 (0),** pp. 113-120

Leach, P., McDougal, W. and Sollitt, C., (1985). Hinged floating breakwater. *Journal of Waterway, Port, Coastal and Ocean Engineering*, **111**(5), pp.895-909.

Loukogeorgaki, E. and Angelides, D.C., (2005). Stiffness of mooring lines and performance of floating breakwater in three dimension . *Applied Ocean Research*, **27 (**4-5), pp 187-208.

Mani, J. and Jayakumar, S., (1995). Wave transmission by suspended pipe breakwater. *Journal of Waterway, Port, Coastal and Ocean Engineering*,**121**(6), pp 335-338.

Manual, B., (1997). Respond of a pile retrained floating breakwater, Department Civil Engineering, University of Western Ontario, Canada.

Matulea, I.C., Nastase, A., Talmaciu, N., Slamnoiu, G and GOncalves-Coelho, A.M., (2008). On the equilibrium configuration of mooring and towing cables. *Applied Ocean Research*, **30**(2), pp. 81-91.

Mavrakos, S.A., Papazoglou, V.J., Triantafyllou, M.S., Chatjigeorgiou, J., (2006). Deep water mooring dynamics, *Marine Structure,* **9**, pp. 181-209.

McCArtney, B., (1985). Floating breakwater design. *Journal of Waterway, Port, Coastal and Ocean Engineering*, **111**(2), pp 304-318.

Murali, K. and Mani, J., (1997). Performance of cage floating breakwater. *Journal of Waterway, Port, Coastal and Ocean Engineering*,**123** (4), pp 172-179.

Nielsen, F.G. and Bindingbo, A.U., (2000). Extreme loads in taut mooring lines and mooring line induce damping: An asymptotic approach. *Applied Ocean Research,* **22**(2), pp. 103-118.

Ozeren, Y., Wren, D., Altinakar, M. and Work P., (2011). Experimental investigation of cylindrical floating breakwater performance with various mooring configurations. *Journal of Waterway, Port, Coastal and Ocean Engineering,* **38**(10), pp. 1150-1160.

Rahman, M.A., Mizutani, N., Kawasaki, K., (2006). Numerical modelling of dynamic response and mooring force submerge floating breakwater. *Coastal Engineering,* **53**(10), pp 799-815.

Ridge, I.M.L., (2009). Tension-torsion fatigue behaviour of wire ropes in offshore moorings. *Ocean Engineering*, **36**(9-10), pp. 650-660.

Ruol, P. and Martinelli, L., (2007). Wave flume investigation on different mooring system for floating breakwater. *Submitted to Coastal Structure,* **7.**

Sannasiraj, S.A., Sundar, V. and Sundaravadivelu, R., (1998). Mooring force and motion responses of pontoon-type floating breakwater. *Ocean Engineering,* **25** (1), pp. 27-48.

Shazwina, A.R., (2006). Wave attenuation performance of wave suppress system (WSS) with respect to various mooring configuration. Department of Civil Engineering, Universit Teknology PETRONAS.

Tahar, A. and Kim, M.H., (2008). Coupled-dynamic analysis of floating structure with polyester mooring lines. *Ocean Engineering,* **35** (17-18), pp. 1676-1685.

Teh, H.M. and Mohammed, N.I.(2012). Wave interactions with a floating breakwater. *Proceedings of the IEEE Colloquium on Humanities, Science and Engineering 2012.*

Whiteside , N.H., (1994). Performance of a circular cross-section moored floating breakwater. Faculty of graduate studies, Civil Engineering Department, University of Alberta, Canada.

Zahra, T. and Mehdi, S., (2011). Hydrodynamic analysis of multi-body floating piers under wave action. Faculty of graduate studies, Department of Civil Engineering, Tarbiat Modares University,Iran.