STUDY OF MOTION RESPONSES OF THE H-TYPE FLOATING BREAKWATER

by

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Dissertation submitted in partial fulfillment of
the requirements for the
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CERTIFICATION OF APPROVAL

Study of Motion Responses of the H-Type Floating Breakwater

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Muhammad Syahmi Maarof bin Azizan

A project dissertation submitted to the
Civil Engineering Department
Universiti Teknologi Petronas
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(Civil Engineering)

Approved by,

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(Dr. Teh Hee Min)

CERTIFICATION OF ORIGINALITY

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

……………………………………………………………..

(MUHAMMAD SYAHMI MAAROF BIN AZIZAN)

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ABSTRACT

This study focuses on the hydrodynamics behavior 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 and the effects of the mooring system on the motion responses of the floating breakwater. This study focuses only on the heave, surge and pitch movements, whilst the other motion responses were restricted. In order to quantify the motion responses of the floating breakwater, the Response Amplitude Operator (RAO) was utilized in the 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 conditions. The results show that the motion responses of the floating breakwater are heavily affected by the breakwater's drafts and the wave period. The recorded RAO values show that the motion responses of heave and surge decreased with an increase of the breakwater draft. However, as for the case of pitch RAOs, no specific pattern can be recorded; a clear indication that the pitch responses are less significant as far as changing the drafts is concerned. All of the RAO values of the heave, surge and pitch are rather sensitive to the change of wave period, as the RAOs vary significantly with the increasing wave period. The motion responses for all the heave, surge and pitch also show significant differences when subjected to different wave steepness, with lower RAO values recorded milder wave steepness (H/L = 0.04). However, the RAOs are less sensitive at higher wave steepness (H/L = 0.05 and H/L = 0.06) and the effect are rather scarce. The RAO's patterns for both regular and random waves are almost identical; with the RAOs for regular waves tend to produce larger values as compared to random waves.

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CHAPTER 1

INTRODUCTION

1.1 Background of study

There is increased population of coastal areas due to love affection for beaches. Thus, developments around this area have to be made. Buildings and structure along the coast will have problems with the environmental nature, which are the wind and the waves. To counter this problem, another structure must to build to protect the buildings, at least not directly. Structures such as breakwater, groin and jetties with the function of a similar manner in that they act as a physical barrier in the shoreline zone and block the flow of sea waves. Coastal structures are built to alter the effects of ocean waves, currents and sand movement. Seawalls, groins, jetties and other shoreline maintenance structures have had terrific impacts on beaches. They are usually built to reduce the potential of waves hitting buildings that were built on a beach that is losing sand. Sometimes they are built to convey rivers and streams. Other times they are constructed to shelter boats in calm water.

The most common and effective measure to deal with the destructive force of waves is by breakwaters. The construction of breakwaters reduces wave energy, by creating a shadow zone behind the breakwater, thus acting as a guard to other shoreline structures. Depending on the nature of the areas that are being protected, breakwaters are classified into two categories: jetty protection and shore protection structures. Breakwaters made to protect jetties are usually connected to the shore, while those designed to protect shores are usually detached offshore structures. Breakwaters create calm water, however, if they are not properly plan, they can do more harm than good. Small and permeable breakwaters which are made of rocks and/or rubble allow transmission of some wave energy and drifting of sediment. An over-designed breakwater may be too effective and turn a beach into a mud flat.

There are two types of breakwater namely fixed breakwater and floating breakwater. The conventional type that most of countries used is fixed breakwater. Despite excellent wave protection by the fixed breakwaters, they however, contribute to several problems to the environment. Fixed breakwater can provide total barricade to prevent the entrance of wave, thus causing faster river flow in the incident area and debris will build up.

Another shortcoming of a fixed breakwater is that its wave dampening power decreases rapidly as the tide level rises 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 than 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 the design of fixed breakwaters and its effects on the physical system in which it is to be placed because, once constructed, very few are ever removed. They become a 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.

Floating breakwaters have some unique points of interest. The advantages of floating breakwater are as follows

1. Floating breakwaters are effortlessly versatile to huge water level fluctuations,
2. The cost does not quickly build with an increment in water depth as is the situation for lowest part mounted settled structures
3. Floating breakwaters are portable and can moderately effectively moved
4. Floating breakwaters offer less impediment to water circulation and fish migration
5. Floating breakwaters are less reliant on bottom soil conditions.

Due to the short-comings of the fixed breakwaters, engineers have come up with various types of floating breakwaters. The development of floating breakwaters has been enormous throughout these years, as the technology being recognized even more. According to McCartney (1985), there are four general types of floating breakwaters, namely pontoon type, mat type, box type and tethered float type of floating breakwater. Some of the advantages of floating breakwaters are its low construction cost, quick installation at sites, less environment impact, removable and easy to be fixed. At present, the increase demand for the application of floating breakwater at sites has led to 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. A lot of factors have to be considered in the design of a floating breakwater, such as its overall design and geometry, the mooring orientation and etc. As far as this study is concerned, the main focus of the study is to investigate the effect of mooring design in the hydrodynamic performance of a floating breakwater.

1.2 Problem Statement

In year 2005, the H-type floating breakwater was developed to meet a wave protection issue with a functional cost-effective engineering design. Preliminary studies showed that it was capable of attenuating the incident wave height up until 80%.

It is worthwhile to note that the floating breakwater was tested using a small scale experiment which was subjected to the following drawbacks:

i) Scale Effects

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 experiments is the risk of the scale effects, in which the test model in reduced size does not behave in the similar manner to the prototype that it is intended to emulate. The problem can only be minimized by adopting a model in a larger or similar scale as the proposed prototype. Therefore, there is a need for us to outline breakwater properties which affect most in scale effects, thus the prototype breakwater can execute effective as possible.

ii) Inadequate measurement technique for wave hydrodynamics

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

iii) Poor understanding of hydrodynamics and motion responses of the breakwater

A study of energy dissipations and movements 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 ideas on how does the system works. A lack in this field of study might affect our judgment in providing good final findings

iv) Limited test cases

Due to the limitation of study in the field, especially in the case of mooring configurations that are opted to be used in the study, there are limited numbers of references that can be used to compare the results of the test. Thus, this may limit the validity of the testing results, as there are limited benchmark values that can be used.

The present research is aimed at attempting the abovementioned limitations of the previous experiments. 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 Significance of study

Apart from suppressing waves for temporary ports and marinas, breakwater also functions to perform the following tasks:

- 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 provides good hydraulic performance and is particularly suitable to be installed in Malaysian 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 procedures in providing quick response in withstanding the storm waves. The results obtained in this study will provide a 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.

With a developing number of bays and harbours advanced onto every part of the nation, there are expanding requests of establishment of a financial jetty in addition to this improvement. In this manner, it is the authority of specialists to concoct a skimming sea wall outline that will help in satisfying this interest, by guaranteeing that the plan that have been furnished can secure the structure for a long time of time, and in addition can carter the requirements of the customers.

1.4 Objective of the study

The objectives of this study are as follows:

a) To design the mooring configurations of the H-type floating breakwater, and
b) To investigate the motion responses of the floating breakwater in both regular and random waves

1.5 Scope of study

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

1. Literature survey

   - The existing investigation of the floating breakwater in the past by different specialists was utilized as references. The different sorts of arrangement of the breakwater and their consequent impacts were given a genuine consideration from the studies since this criterion is basic before experiment can be conducted. The problem about scale effects will be subjected based on past research.

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/sand. The test model must be waterproof and has high resistance to wave impact

4. Fabrication of the breakwater models and the mooring systems

    - The H-type floating breakwater model of scale 1:10 is to be constructed using plywood. Froude similitude is to be applied as the tests mostly deal with gravity, free surface waters

5. Laboratory set-up for physical modeling simulation

    - All test apparatus and equipment are to be calibrated with care so as to prevent systematic error during measurements. These measurement equipment include optical tracking system, wave probes and velocimeters. The wave-structure interactions and underwater activities will be captured by a water-proof still camera and a video-camera.

6. Laboratory tests

    - Extensive laboratory tests are to be carried out to quantify the hydrodynamic behavior of the test models. Some of the dependant variables considered in this study is wave heights breakwater drafts and water depths. Both head-on and oblique waves will be considered in physical modeling.

CHAPTER 2

LITERATURE REVIEW

This chapter discusses the fundamental concepts on the hydrodynamics of a floating structure. This part will likewise stress on the past studies that have been carried out by different analysts on this particular subject, the extent that hydrodynamics of floating breakwater is concerned. Besides, the chapter will measure up all the past outcomes of these studies and attempt to identify the significance of the scale effects into our study. These outcomes will be the foundation and will go about as the benchmark of our studies in place for us to figure out the unwavering quality and nature of our effects.

2.1 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 behavior. The 6 degree of freedom concept will be further discussed in this section.

2.1.1 Six Degree of Freedom of a Floating Body

For a floating body in a 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 degrees of freedom are acting at the centre of its gravity and every motion is based on its own axis, as shown in **Figure 2.1**.

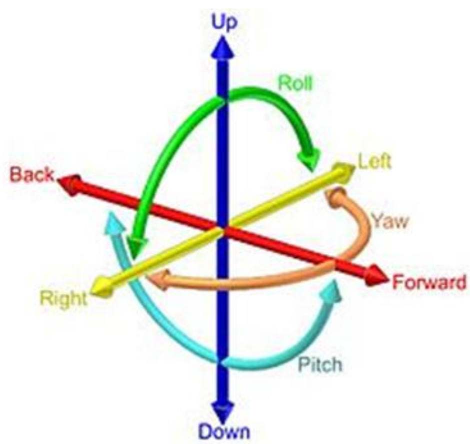


Figure 2.1: Six degree of freedom movement

These degrees of movement for a floating body can be summarized in the following ways:

Translation:

a. Moving up and down (heaving);
b. Moving left and right (swaying);
c. Moving forward and backward (surging);

Rotation

a. Tilting forward and backward (pitching);
b. Turning left and right (yawing);
c. Tilting side to side (rolling).

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 2.1: Movement of degree of freedom with respect to its axis

. In every axis, there are two types of movement involved, which are the plane movement parallel to the axis, and rotational to the axis itself. 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).

$$RAO_j = \frac{\xi_j}{A}$$

Where: ξ_j = Amplitude of motion in 6 degree of freedom

A = Wave Amplitude

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

2.2 Types of Mooring

Mooring denotes to the way the floating breakwater is anchored to the seabed by means of using a line to lock up the movement of the floating breakwater. There are several types of mooring configurations that are commonly used for floating breakwater applications, such as the pile moorings, hinged moorings, caternary moorings, taut-leg moorings, and taut-line with spring support

2.2.1 Pile Moorings

Pile mooring is one of the three most common types of mooring system used in the application of floating breakwater, as being proposed by McCartney (1985). In this system, the floating breakwater is hold onto its position by a set of pile moored into the bottom of the seabed. This type of mooring restrains the lateral movement of the breakwater, which allows the breakwater to move only in vertical axis direction. It is more suitable to be used in a shallow area due to its economical limitations. **Figure 2.2** illustrate the set up of pile moorings, with a set of piles is connected from the breakwater to the bottom of the seabed. The studies of application of piled mooring in floating breakwater were done by Mani and Jayakumar (1985) and Diamantoulaki *et al* (2009). Both studies indicate that the stiffness of the piled system plays an important part in the performance of the breakwater, as well as forces acted on the support itself.

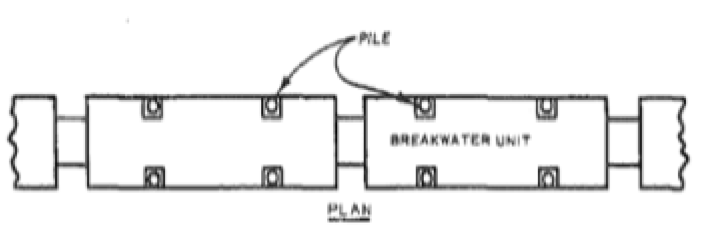


Figure 2.2: Pile-restrained floating breakwater (Sources: Diamantoulaki *et al*, 2009)

2.2.2 Hinged Moorings

Apart from of those proposed by McCartney, Leach *et al* (1985) also proposed another mooring configuration for a floating breakwater, namely the hinged mooring. Hinged mooring uses the idea of a piled mooring system, with an additional hinged mechanism added at the bottom of the pile, as shown in **Figure 2.3**. The introduction of hinge at the bottom of the pile gives the pile the ability to incline itself when the wave hits. This system will give the floating breakwater more degree of freedom than of that in a pile mooring system. The hinged pile is held by mooring lines, as being illustrated in **Figure 2.3**. The incline-ability of the piles will help to reduce mooring forces acting on the lines. The application of using hinged moorings has been also supported by the study done by Diamantoulaki and Angelides (2010), which confirms the practicality of the hinged moorings.

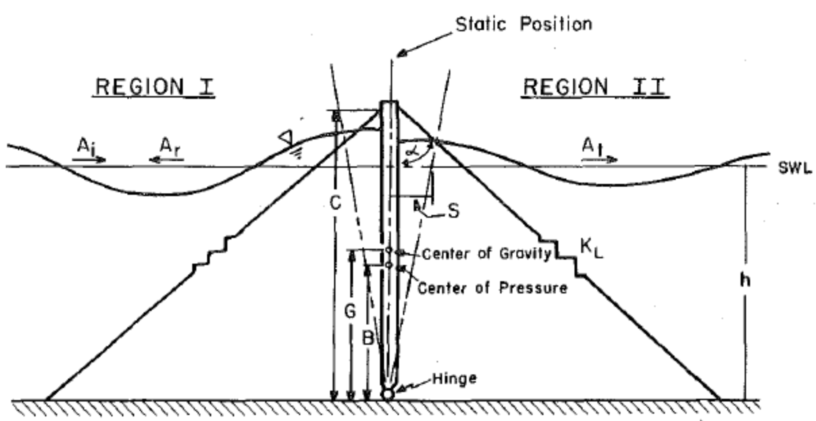


Figure 2.3: A hinge floating breakwater (Source: Leach *et al*, 1985)

2.2.3 Caternary Moorings

Caternary mooring is one of the conventional ways of connecting the taut line to the floating breakwater. Caternary mooring consists of a mooring line, connected to the anchor or a pile stake, located at the bottom of sea bed. In this type of mooring system, some part of the mooring line lay on the bed of the sea. Given this condition, the tension of the line is higher than the weight of the submerged line itself, as being described in the study by Nielsen and Bidingbo (2000). The illustration of such configuration is described in **Figure 2.4**, in which some part of the mooring line is shown laying at the bottom of the seabed

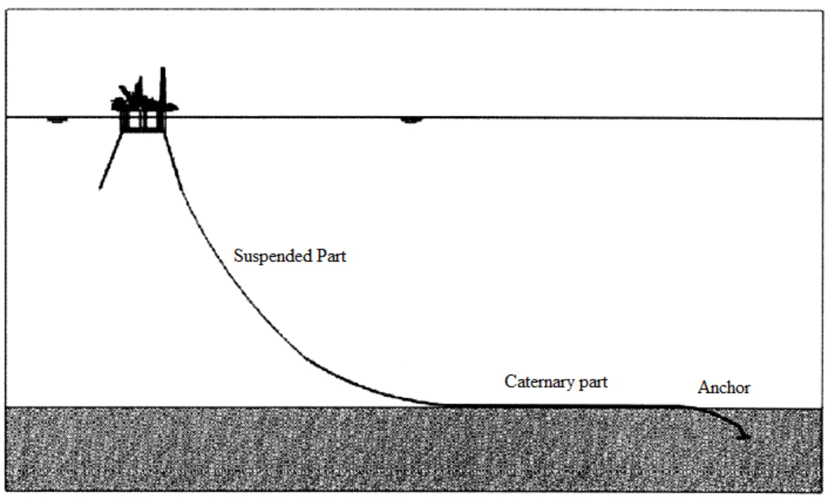


Figure 2.4: Catenary mooring system (Source: Nielsen and Bidingbo, 2000)

The caternary mooring system is the most common mooring system used in the floating breakwater applications. The length of the caternary line must be longer than the depth of the water, as some of the line needs to be horizontally laid on the seabed. Due to this condition, the mooring lines only need to withstand the horizontal tension from the weight of the lines. However, this kind of mooring system is not suitable for deep water, as a longer line means a higher loading from the floating breakwater will act upon the mooring lines. Thus, as the water gets deeper, the less significant the usage of caternary mooring system will be

In the study done by Garza-Rios *et al* (1997), it is concluded that the horizontal tension of a caternary mooring line can be found by using the following formula:

$$\frac{T_o}{P}\sinh\left(\frac{Pl}{T_o}\right) = \sqrt{\mathrm{h}(\mathrm{h} + 2\ \frac{\mathrm{T_o}}{\mathrm{P}})}$$

Where: T_o = Horizontal tension of catenary line

P = Vertical force unit per catenary length

l = horizontally projected length of the suspended portion of the cartenary

h = water depth

The equation shows a relationship between the amount of horizontal tension of the caternary line and the length of suspended portion of the caternary. Based on the equation, it is understood that the horizontal tension decreases when the length of suspended caternary increases. This happens due to the presence of more vertical tension acting on the lines with respect to the suspended carternary lines.

2.2.4 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 caternary mooring system, as described in the following **Figure 2.5**. Note that in the figure, the mooring line is completely suspended with no lines being rested on the seabed.

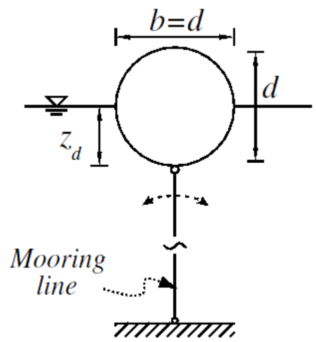


Figure 2.5: Taut Mooring system (Source*:* Ozeren *et al*, 2011)

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 2.6**, 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.

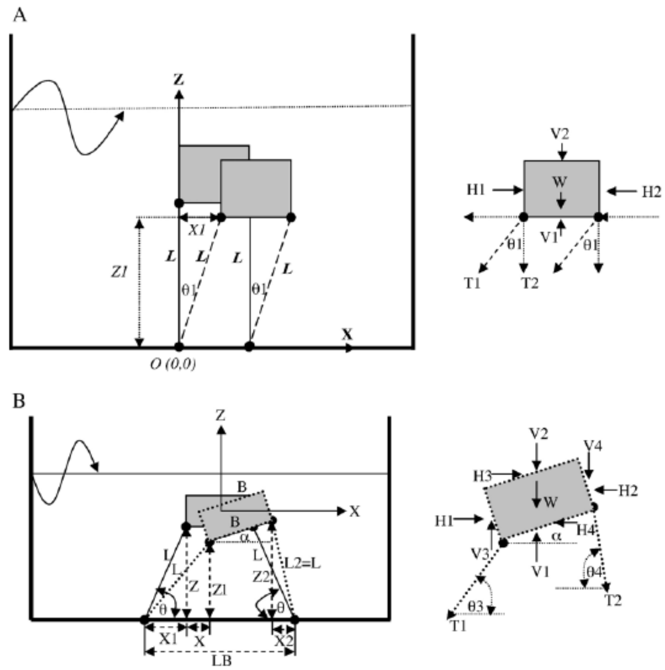


Figure 2.6: Instantaneous movement for submerged body for (A) Vertical moored body and (B) Inclined moored body (Source: Rahman *et al*, 2006)

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 terms of withstanding capability in handling the vertical and horizontal forces acting on the 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 whole. These factors will be discussed further in this chapter in order to understand their effects towards floating breakwater behavior.

2.2.5 Taut-leg with Spring Support

This mooring system is the least used in the real-life application of the floating breakwater. The insertion of spring or suspended materials will help to reduce the damping effects and impact loads on the mooring lines. Mavrakos *et al* (1994) and Chen *et al* (2001) have developed a study on the insertion of a spring in the mooring lines system. The purpose of adding the spring is to help to increase the overall stiffness of the mooring lines. The addition of the springs will help to increase the trajectory of the mooring lines, in which will help them to be able to withstand the forces acting on the mooring line. The addition of springs to the mooring line also helped when there are no suitable materials available in the market to adopt the required forces acted on the lines

There are many factors that may affect the performance of these mooring lines as a whole, and stiffness is one of the things that need to be considered. Thus, the introduction of the spring inside the mooring lines will give the mooring line extra advantage. The nature of the string will help to adjust the stiffness of the line accordingly, and thus, helps to maintain or adjust the stiffness of the line depending on the condition required.

2.3 Factors Affecting Hydrodynamics of the Floating Breakwater

As being mentioned in the previous chapter, there are some parameters that may affect the hydrodynamics behavior 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, moore tension and etc. Various studies and experiments has been done to determine the effect of such parameters and what are the optimum values of these parameters in order for us to get maximum efficiency of the floating breakwater.

2.3.1 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 correct 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 2.7**. In the figure, the graph C1 denotes the base case of the study, which is at 0 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 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.

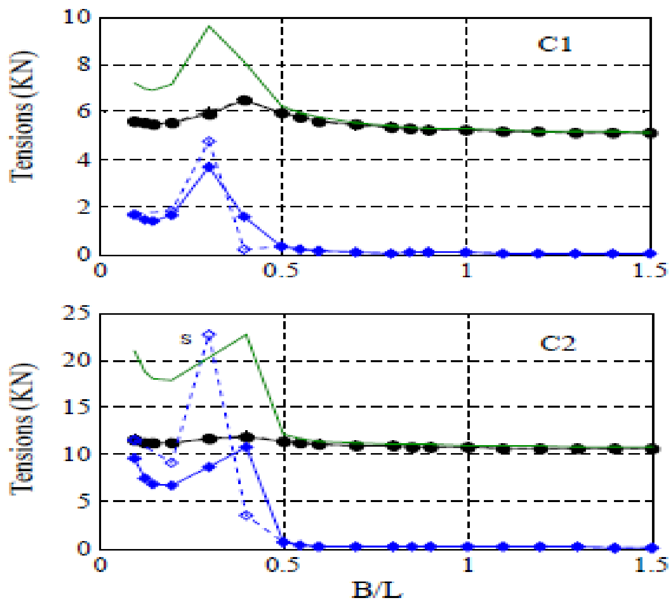


Figure 2.7: Variation of mooring line tension based on different stiffness (Source: Loukogeorgaki and Angelides, 2005)

2.3.2 Mooring Lines Materials

In the configuration of the mooring system by using lines, the type of lines that being used might affect the hydrodynamics behavior of the mooring line. The mooring lines is the material that connected the floating breakwater with the anchor at the sea bottom, in which holding the breakwater in its place. The suitability of the material that need to be used as the mooring lines are dependent on many factors, such as the elasticity and stiffness of the material, as well as the type of mooring configuration itself. The two common types of the materials that conventionally used are chains and synthetic lines.

a) **Chain**

Chain mooring line is made up of heavy steel and was used in most of the mooring line. Chains come in different grades and diameters, which will be used in different situations. Chains are preferably used in the catenary mooring line, in which some part of the lines need to lay on the sea bottom in order to give the line only horizontal force acting on it, as shown in **Figure 2.8**. Furthermore, chains are more preferable to be used for permanent moorings, as it gives the mooring line extra strength in withstanding the movement of the breakwater structures

Due to the heavy nature of the chains, it is not preferable to use the chains in the mooring line for a modern floating breakwater. The heavy nature of the chain caused some difficulties in installing the mooring system, especially in a deep water condition. While the usage of chain in mooring line might be a suitable material in the catenary mooring system, it is less preferable to be used in other kind of mooring systems, especially in the taut leg mooring system. The requirement of additional buoyancy in a taut leg system makes the mooring system using chain lines seem to be less preferable. The hydrodynamic behavior of a taut chain line, which may exert an extra vertical and horizontal force on the mooring line, makes this option less preferable. Thus, there is a need of having alternative options as far as the mooring line materials is concerned

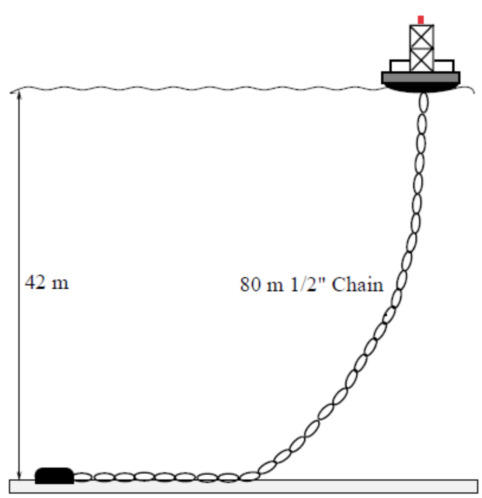


Figure 2.8: Chain mooring line for a catenary mooring (Source: Gobat and Grosenbaugh, 2001)

b) Synthetic Line

In order to overcome the weaknesses of the chain lines, researchers have came up with another options as far as the mooring line materials is concerned, which is by using synthetic lines. Synthetic lines are cables that are made up of a set of materials with different composition in order to give the lines extra characteristics that can overcome the weakness of the chain mooring lines. The synthetic lines might be produced form a completely different materials, such as synthetic fiber, or a composition of two or more materials, such as in a polymer lines. The synthetic lines are more preferable in a straight vertical connection, such as the taut leg mooring system, as it does not exert too much pressure on the anchor in which can avoid the line to break loose from the anchorage bond, but in the same time, provide strength strong enough to withstand the vertical and horizontal tension. The characteristics of a mooring line can be modified accordingly, which gives the mooring line advantages to be used under various sort of wave and sea conditions.

Ridge (2009) has tested a few synthetic mooring lines of different materials and configurations in a study to test for the strength of different materials subjected to axial loading. Figure 2.9 denotes the result of the experiment. And based on the figure, it is known that the different composition of synthetic lines do behave differently, in which signals that the different type of materials do affect the performance of the mooring system accordingly

Apart from that, Tahar and Kim (2008) also tested a synthetic polymer line in order to compare the performance of such lines as compared to a normal synthetic line. Based on the study, it can be said that a polymer-enhanced synthetic lines do give an upgraded performance to the normal synthetic line up to a certain extend. Huang *et al* (2012) also tested a synthetic fibre line enhanced in a polyster case to check for the strength of such configuration. In the end of the study, it is found that the presence of polyster-case helps to increase the tension capability of a synthetic fibre line. This is important feature, as tension capability is important to ensure that the mooring line that we provide do not snap easily once it is exposed to the hydrodynamic forces acting on the line when it is being installed.

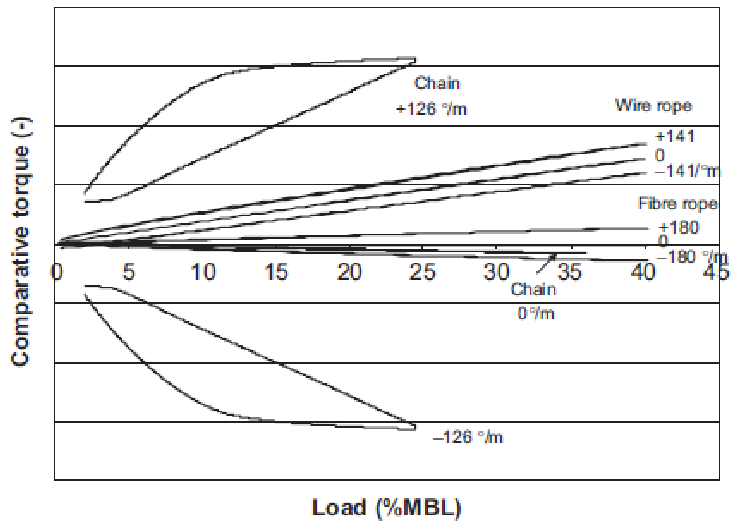


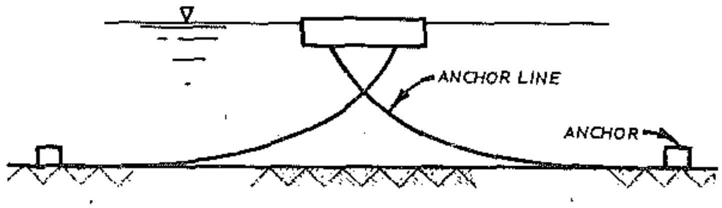
Figure 2.9: Torsional response of different lines under axial load (Source: Ridge, 2009)

Another advantage of using synthetic line is that the stiffness and elasticity of the mooring line can be adjusted to ensure that the mooring line can be enhanced to allow less hydrodynamic effects acting on it. As being said in the previous section, stiffness is one of the parameters that may affect the hydrodynamic performance of a breakwater (see section 2.3.1). Thus the introduction of spring line as being studied by Chen *et al* (2001) will help to bring more stiffness factor in the mooring lines, thus helps it to perform accordingly.

2.3.3 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 2.10**. 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 caused an increase in the heave and sway motion of the breakwater, subsequently affecting the performance 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 moorings, 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 number of attachment points provided 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.



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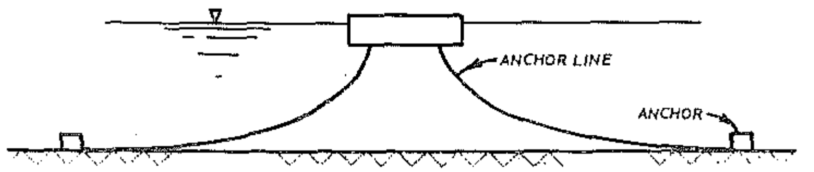


(b)

Figure 2.10 Crossed (a) and uncrossed (b) mooring lines (Source: McCartney, 1985)

2.3.4 Length of Mooring Lines

The taut-leg moorings and the carternary mooring types are determined by the length of the mooring lines provided, as being discussed in section 2.3. The difference in the configuration does have an impact in the behavior 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 give a less sway motion on the breakwater, subsequently reduced 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 a larger momentum that will grow faster than the resistance, causing an increased in the resonance peak (Foursert, 2006). With an increasing width to the floating breakwater caused a decrease in the draft. This will lead to an increase in wave sway amplitude motion. Thus, in other words, we can say that the amplitude of the motion increases when the decrease of 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.

2.4 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 behavior due to the changes of the configurations. There are several factors that may lead to the difference in terms of the behavior of the breakwater (refer section 2.3). Thus, the goal of these studies being done is to obtain the most effective design, in which a minimal hydrodynamics behavior is obtained, and in the same time, an effective performance is expected from the breakwater. Although it is near impossible to find the ultimate configurations of the floating breakwater behavior, 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

2.4.1 Hydrodynamics of Pontoon-type Floating Breakwater

The studies of the hydrodynamics behavior of a pontoon floating breakwater have been done in various studies, 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 behavior 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 plates on the performance of the breakwater. It was found out that while the heave damping coefficients increases, the other damping coefficients are lowered, up until certain limits. **Figure 2.11** shows the results from the study done by Gesraha (2007). The figure shows that the heave RAO increases with an increase in the ratio of the side plate length and length of half of the floating breakwater beam (b/a). This happens due to the increase in damping resonance acting on the floating breakwater.

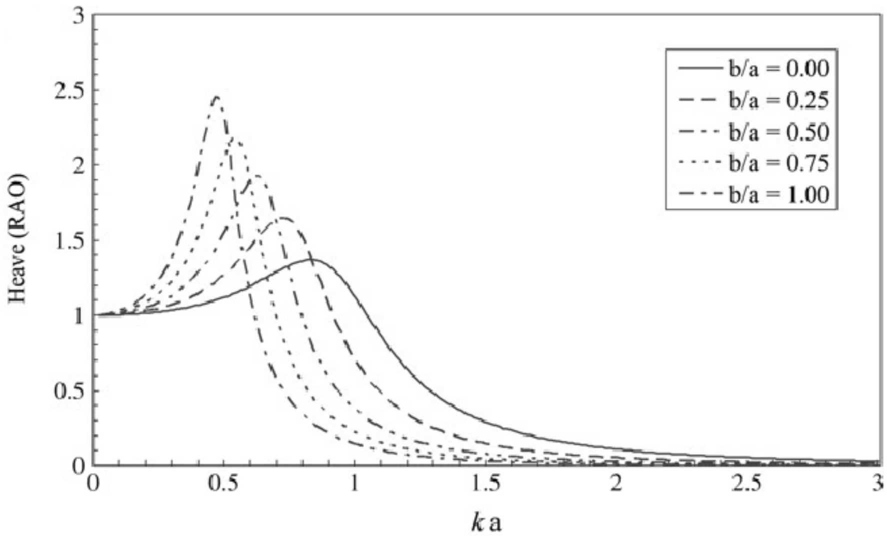


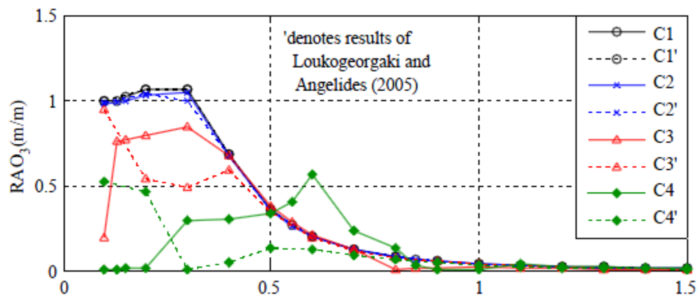
Figure 2.11: Influence of different side plate height to the Heave RAO (Source: Gesraha, 2007)

2.4.2 Effect of Mooring Lines to Floating Breakwater

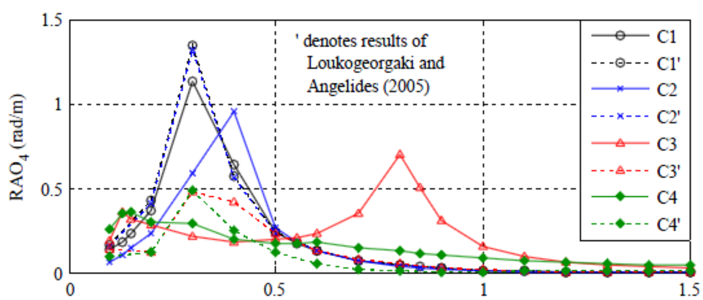
The ways of connecting the floating breakwater to the mooring system also can affect the performance of the floating breakwater considerably. The mooring configuration may affect the hydrodynamic behavior of the breakwater as far as the motion and forces are concerned (Mays *et al*, 1998). In the effort to find the effect of different kind of moorings to the performance of a floating breakwater, Whiteside (1994) has done a study in comparing the result of different kind of moorings to the performance of a floating breakwater, as being mentioned in the previous section. In this study, different type of mooring lines of 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 the 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 concluded that the type of materials used in mooring lines do not affect the performance of the floating breakwater.

The study also indicates that with a slacker mooring line, the hydrodynamics motion will become much more, but reduced the hydrodynamic forces acted on the mooring lines.

Loukogeorgaki and Angelides (2005) studied various kind of mooring lines configuration and how do this affect the floating breakwater. In their studies, it is known that the modification on the configuration of the mooring line affects the damping and the stiffness of the mooring line, in which will subsequently affect its performance. The variation of heave and roll RAO of the study can be observed in **Figure 2.12**. From the figure, it can be said that the various configuration of mooring lines will definitely cause some changes in the hydrodynamic behavior. 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 systems.



(a)



(b)

Figure 2.12: Variation of heave and roll RAO from various moore configuration (Soucre: Loukogeorgaki and Angelides, 2005)

2.4.3 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 hydrodynamics of the mooring configuration. The configuration of the hinged floating breakwater has been discussed in the section 2.3.3. 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 the number of hinges provided. Based on the study, it is learned that the number of hinges may have an effect on the hydrodynamics behavior of the floating body. The difference in number of hinges may also affect the number of degree of movement of the floating breakwater, as being demonstrated in **Figure 2.13**. 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.

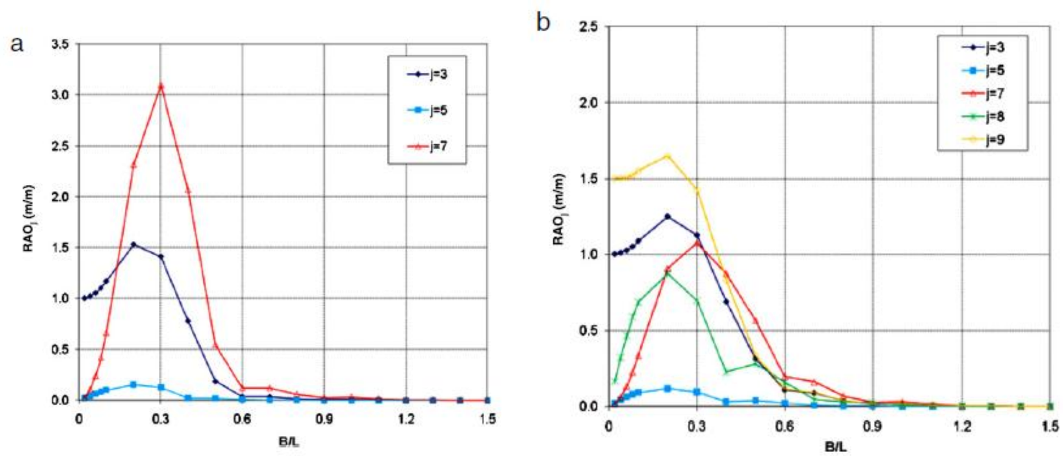


Figure 2.13: The hydrodynamics behavior of floating breakwater with (a) one hinge and (b) two hinges (Source: Diamantoulaki and Angelides, 2010)

In another 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 this study, different factors were taken into consideration to study its effect on the heave motion of the floating breakwater model. Among the parameters that being considered 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 caused some sway and roll movement to occur, which played a role in increasing the heave RAO values

In the effort of studying the effect of all three mooring systems to the movement of the breakwater, Ruol and Martinelli (2006) has developed a test involving these three set ups of different pre-tensile stress of the mooring line. The three mooring systems, which are the pile mooring, the slack or caternary mooring, and the taut leg mooring, was being tested, with different line stiffness was pre-set prior to the tests. At the end of the experiment, it is understood that the movement of the floating breakwater affected by the mooring configuration used. From **Figure 2.14**, it is understood that the stiffer the mooring lines, as it changes from slack mooring to taut-leg 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 in 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 a direct impact towards the performance of the floating breakwater.

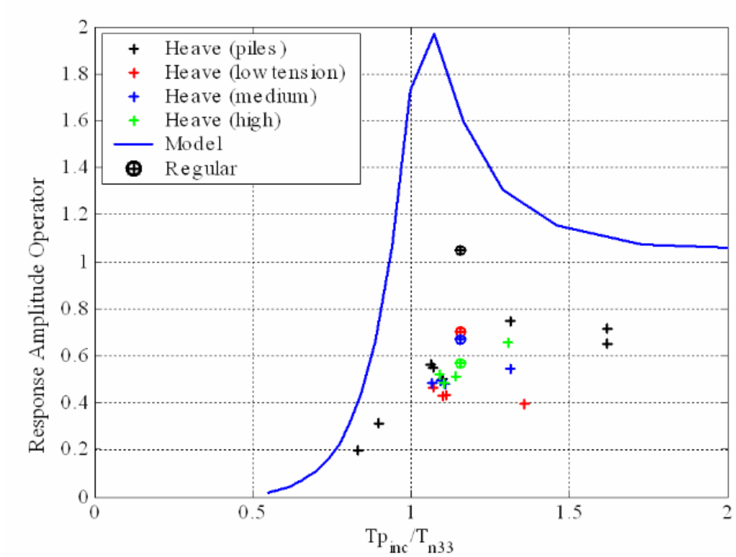


Figure 2.14: RAO values of heave motion with respect to different type of mooring configurations (Source: Ruol and Martinelli, 2006)

CHAPTER 3

METHODOLOGY

The focus of this chapter is to discuss on the equipment and instrument that are to be used in the experiment of the test model. The experiments will be done in the Offshore Laboratory, Block A, at Universiti Teknologi Petronas (UTP). Response Amplitude Operators (RAO) of 6 degree of freedom motion and the mooring forces acting on the mooring line tests will be focused on since interested area of the study is only in the scale effects on hydrodynamics of the test model. The chapter will also discuss on the process in conducting the study and the planned Gantt chart for the overall study.

3.1 H-shaped Floating Breakwater

A floating breakwater model with a certain design criteria is to be designed with the aim of having a floating breakwater with effective wave attenuating 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 include 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.

3.1.1 Model Description

In this study, an H-shape floating breakwater was developed according to model scale. As previous 1:5 scale of model, the proposed materials that are to be used for this model are plywood, coated with fibre-glass 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 external force impacts, as well as being light-weight, in which is important in order to ensure our model can float. The coating was added with colouring pigment for better visibility of the model during experiment. In the 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. The general dimensions of the test model are 500 mm width x 1440 mm length x 500 mm height. The breakwater was constructed by plywood and was made waterproof by a layer of fiberglass 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 fiberglass coating was injected with yellow colouring pigment for better visibility of the model during experiment.

The breakwater has a pair of upward arms and a pair of downward legs, with both connected to a rectangular body as shown in **Figure 3.1**. The seaward arm, body and leg act as the frontal barrier in withstanding the incident wave energy mainly by reflection. Some wave energy is anticipated to be dissipated through vortices and turbulence at the 90^o frontal edges of the breakwater. When confronted by storm waves, the H-type floating breakwater permits water waves to overtop the seaward arm and reaches the U-shape body as seen in **Figure 3.2.** 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 surfaces. The excessive waves in the U-shape body may leap over the shoreward arm and reaches the lee side of the floating body, making a new wave behind the breakwater which is termed as the transmitted waves.

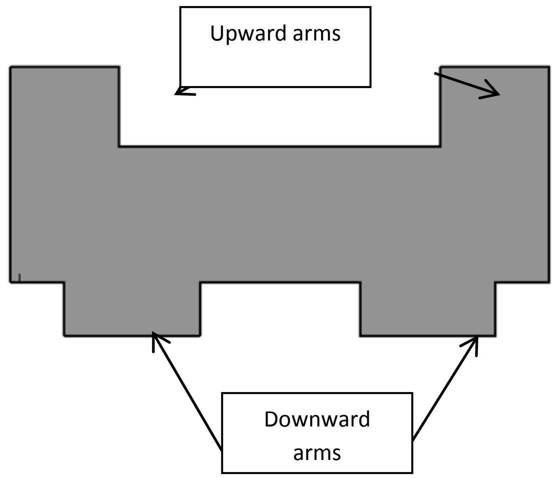


Figure 3.1: Cross section of the outline of breakwater

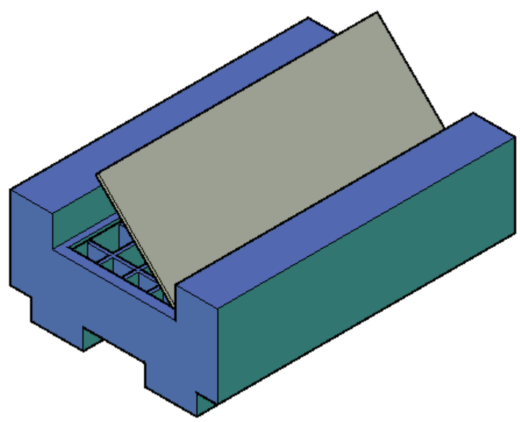


Figure 3.2: Isometric view of novel breakwater design drawing

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 designed for adjustment of immersion depth of the breakwater with respect to still water level, in a freely floating condition. For the breakwater model, a 2 x 9 matrix wooden grid system was developed for the placement of sandbags for weight control of the breakwater.

The ballast chamber was covered by transparent lid made of Plexiglas, as shown in **Figure 3.3**. The gap between the breakwater body and the transparent lid was tightly sealed by plasticine so as to prevent the seepage of water to enter the ballast chamber.

The sides of the floating body facing the flume walls were coated with polystyrene foams to prevent direct collision between the concrete wall and the fiberglass 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 3.3 Wooden grid chambers for the placement of sandbags into floating breakwater

Figure 3.4: Fabricated test model

3.1.2 Mooring Systems

Mooring system is important in floating breakwaters since it holds the breakwater in a desire position. Most floating breakwaters used the pile mooring system. However, because of cost constraints, in this study, the experiments used a taut-leg system, same as the model at the scale of 1:5. This mooring system is chosen since it gives the test model up to six degree of freedom movement. In taut-leg mooring system, the mooring line is connected in a 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 is shown in the **Figure 3.5**.

The test model will be moored at four different points beneath the breakwater model. 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. Beside strengthen the test model, the purpose of having four mooring points is to avoid excessive movement experienced by the test model. Such mooring configuration will help to avoid the test model from overturning. 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 setting 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.

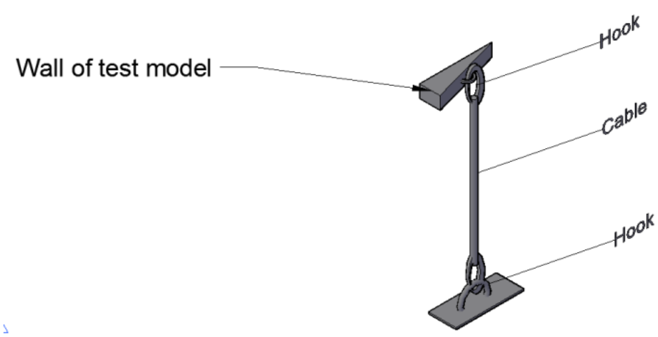


Figure 3.5: Configuration of mooring system for test model

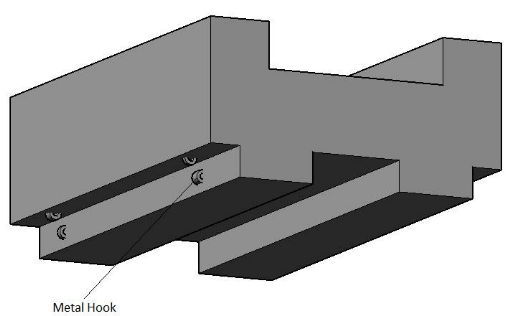


Figure 3.6 Position of hooking points on the test model

As far as the mooring system is concerned, this will be the first time such configuration used on the said test model. Thus, the previous studies by other researchers 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.**

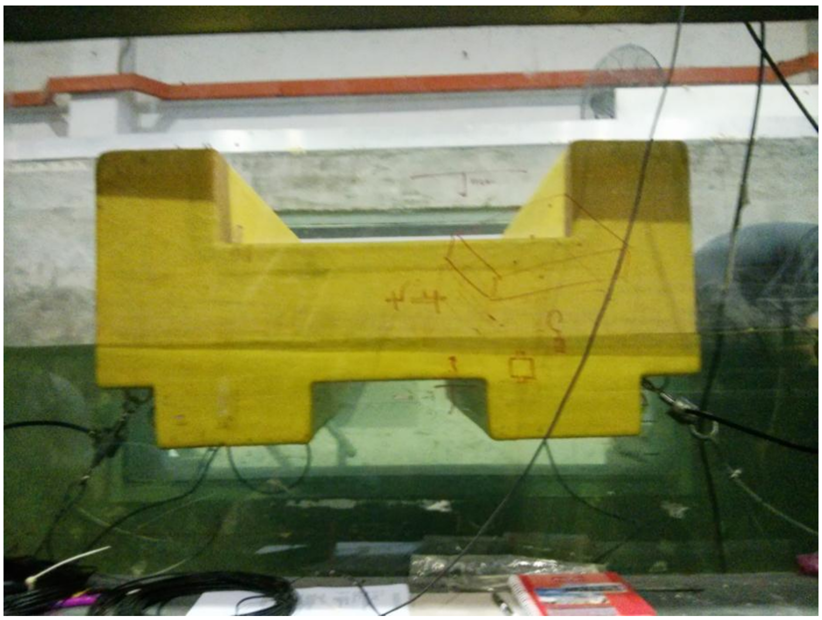


Figure 3.7: Mooring connection set up

3.2 Laboratory Equipments and Instrumentations

3.2.1 Wave Flume

A series of experiment are to be conducted in a 25 m long, 1.5 m width and 3 m high wave flume as shown in the Figure 3.8. The maximum permitted wave depth in the flume is up to 1.2 m. The walls of the wave flume are made of reinforced concrete, with 6 transparent flexiglasses located at both side of the wave flume. The purpose of providing these glasses is to easily monitor the test models during the experiment

3.2.2 Wave Paddle

A wave paddle is installed at the one end of the wave flume and is used to generate waves to mimic the real sea condition. The wave paddle is able to generate both regular and irregular waves in the flume. It is powered by a single motor generator, with a capability of generating waves up to 2 second wave period, and maximum wave heights of 0.3 m. The wave paddle was manufactured by the Edinburgh Design Ltd., United Kingdom. The wave paddle actively absorbs the reflected waves in the flume through the use of a force feedback system. The control of the wave paddle is operated using ocean and wave software supplied by Edinburgh Design Limited. To generate waves in the wave flume, command signals coded using WAVE program needs to be properly compiled to facilitate the computation of a wave elevation time series corresponding to the desired state.

Figure 3.8: Wave fume

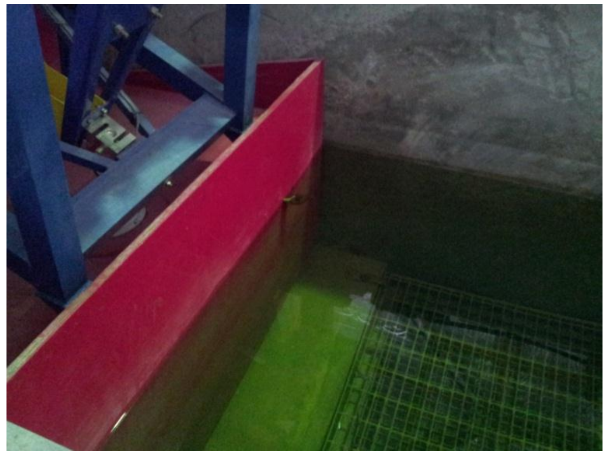


Figure 3.9: Wave paddle

3.2.3 Wave Absorber

At another 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 a requirement, the wave absorber must be made up of a material that can absorb up to 90% energy from the incident waves. This is to avoid any reflection from the waves that may alter the values of the subsequent waves, which may affect our readings.

Figure 3.10: Wave absorb

er

3.2.4 Optical Tracking System (OPTITRACK)

In order to record the hydrodynamic motion responses of the test model an optical tracking system called OPTITRACK is used as shown in **Figure 3.11 (a)**. OPTITRACK is attached at the side of wave flume. This tracking system is able to detect all 6 degree of movements of an floating object during the testing process using 3 units of camera that capture the image of the reflective balls (as shown in **Figure 3.11 (b)**) located at the top of the test models.

(a) (b)

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

3.2.5 Wave Probes

Wave probes are used to measured water level fluctuation which in turn the representative wave heights could be identified. Three wave probes will be placed in front of the test model for the measurement of both incident and reflected wave heights derived from Mansard and Funke Method (1980). The wave probes are resistance type and made by stainless rod. The sample rate of the probe is up to 128hz, and the controller can support upt to 8 gauges. 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 the placement of the wave probes inside the wave flume.

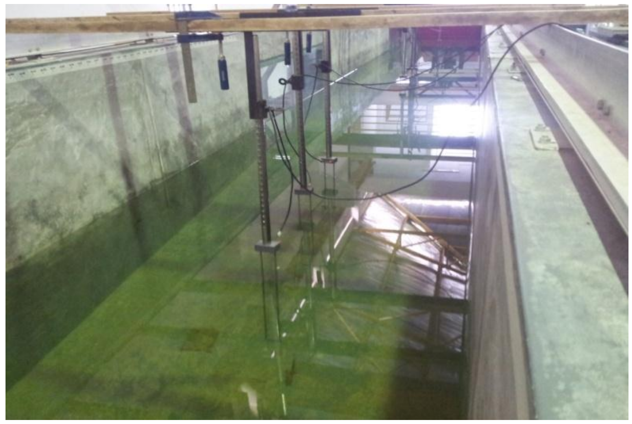


Figure 3.12: Wave probes

3.2.6 Data Logger

The wave paddle, OPTITRACK and wave probes are connected to a data logger named Smart Dynamic Strain Recorder. The data logger will then transmit all the required data, which is strain, DC voltage and thermocouples to a computer for further analysis. The frequency response of this logger is 10kHz and sampling speed to 200kHz at the fastest. In addition to numerical monitor and wave form display, dynamically variable amount can be displayed in analog form and in real time. At the same of measurement, measured data are automatically store on a compact flash card up to 2GB. Figure 3.13 shows the type of data logger that will be used in the study.

Figure 3.13: Data logger

3.2.7 Experimental Set up

Figure 3.14 shows the experimental set-up and the location of each equipment and instrument. The test model was located at the mid-length of the wave flume, which is 4 m apart from the wave paddle. The test model is anchored to the floor of the wave flume by the means of metal cables and hooks. The mooring system will be attached to a roller at the bottom of the wave flume, and the end of the mooring line will be attached to the wall of the wave flume. This is to ensure that the pre-tensile stress of the mooring line can be controlled easily without having to alter the mooring line configuration from inside of the wave flume.

The reflective balls are put on top of 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. These cameras located on the top of the wave flume's wall at close proximity of the model.

Three wave probes were located both seaward and shoreward of the model for the measurement of water level fluctuation at the respective locations. These time series data were then further analyzed using computer tools to yield some significant wave parameters, e.g. significant wave height, peak wave period, etc. Mansard and Funke's method (1983) was adopted to decompose 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).

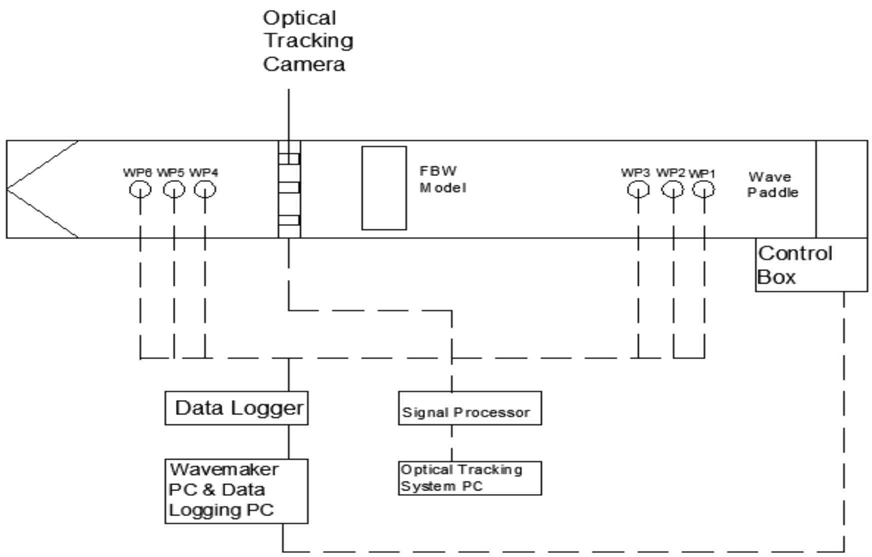


Figure 3.14: Experimental Set-Up

3.2.8 Experiment Configuration

As being discussed in the previous chapter, the equipment that were used in this study were set-up inside a wave flume, which will generate the required wave conditions throughout the testing. The testing of the floating breakwater model will be done as planned, with four different water drafts, a number of distinguished wave periods and wave steepness of random and regular waves were being tested in order to study the effect of these drafts 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 3.2.8). The full experiment configuration is illustrated in Figure 4.3.

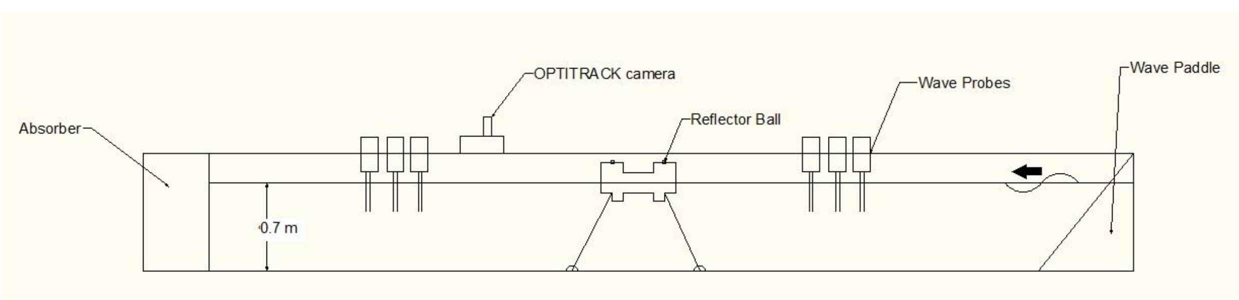


Figure 3.15: Experiment Configuration

3.3 Experimental Test-Run

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

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 0.2 second interval. Furthermore, in each wave period, the floating breakwater model will be tested at different wave height, corresponds to the H/L values. It is worth to note that in this study, both regular waves and random waves are to be considered. The number of runs that was conducted throughout the testing is shown in **Table 3.2**. Overall, a set of 74 tests were conducted throughout the period of this study for both regular and random waves.

Fixed Variables	**Dependant Variables**
Mooring method	Water drafts, *D*
Model orientation	Wave period, *t*
Water depth, *d*	Wave height (*H/L*)

Table 3.1 Variables used in the testing

Breakwater Draft, D (m)	Water depth (m)	Wave type	Wave Period	Wave steepness (H/L)
0.08, 0.12, 0.16	0.7	Random	0.8	0.04
				0.05
				0.06
			1.0	0.04
				0.05
				0.06
			1.2	0.04
				0.05
				0.06
			1.4	0.04
				0.05
				0.06

Table 3.2: Number of testing done throughout the experiment (D/d = 0.243)

3.4 Measurement of Incident & Reflected Waves

As being mentioned in the previous chapter, calibrations wave probes were done by using the three-point method (Mansard and Funke, 1985). The basis of this method is to measure simultaneously the waves in the flumes at three different points with an adequate distance between one set of probe to another. The wave probes were located parallel to the wave's direction in the wave flume. **Figure 3.16** shows the set-up of the wave probes in a wave flume. The Probe 1 the wave paddle is denoted as X1, the length of Probe 1 to the Probe 2 is denoted as X12 and the length of Probe 1 to Probe 3 is denoted as X13.

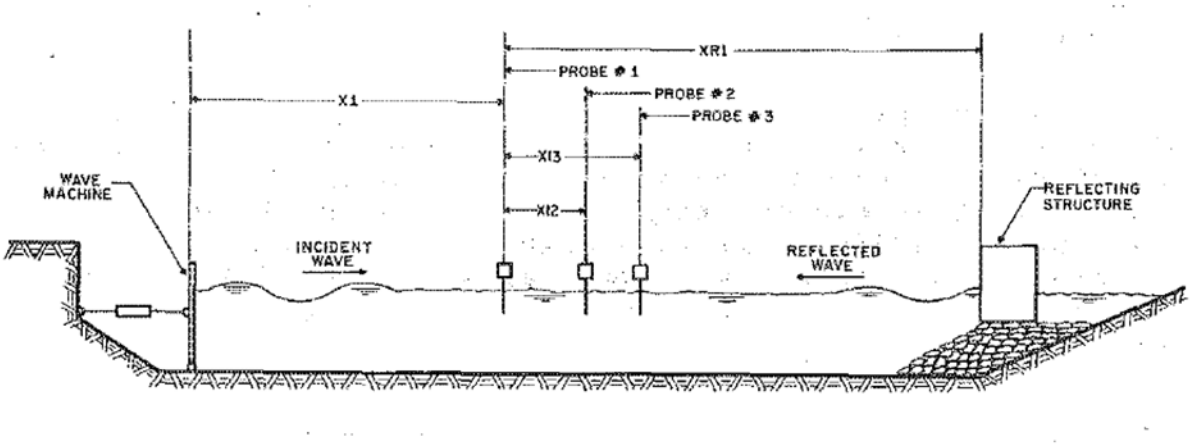


Figure 3.16: **Three-point method calibration set up (Mansard and Funke, 1985)**

The prob spacing requirments set by Mansard and Funke (1985) are as follows:

X12 = Lp/10 Lp/6 < X13 < Lp/3 X13 ≠ Lp/5 and X13≠3Lp/10

where Lp is the wavelength corresponding to the peak wave period. The importance of following the spacing requirement as stated in the study is to ensure that there are no singularities in the wave probe readings.

3.5 Project Management

In the first half of the study, the focus is more on the introduction and preparation towards the further study of the problem of scale effects test model. Besides that, observation on experiment also being done for the existing model conducted by previous student. This help to understand how the experiment is being conducted so that in near future, the experiment can be conducted as efficiency as possible. Gantt chart will help this study in keeping track of the progress and proceed accordingly. In the Gantt chart, feasibility of the study will ensured as it is initially planned in the beginning of the study and task will be cleared. The Gantt chart includes time element to the respective project activities. This is to ensure that the study can completed within the given time frame, which is 2 semester. The Gantt chart for the whole project is given in **Figure 3.17.**

Phase	FYP I														FYP II														
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Selection of Project Work	■																												
Preliminary research work		■	■	■	■																								
Submission of extended proposal defence						■	■																						
Proposal defence								■	■																				
Design and fabrication of Floating Breakwater										■	■	■	■	■															
Submission of interim draft report													■																
Submission of interim report														■															
Calibration equipments and experiments															■	■	■	■	■	■	■								
Submission of progress report																						■							
Continuation of project report																							■	■	■				
Pre-SEDEX																									■				
Submission of draft report																										■			
Submission of Dissertation (soft bound)																											■		
Submission of technical paper																											■		
Oral Presentation																												■	
Submission of dissertation (hard bound)																													■

Figure 3.17: Gantt chart

In completing the studies, a series of activities need to be done in order to ensure the feasibility of the study. These set of tasks are 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 3.18.**

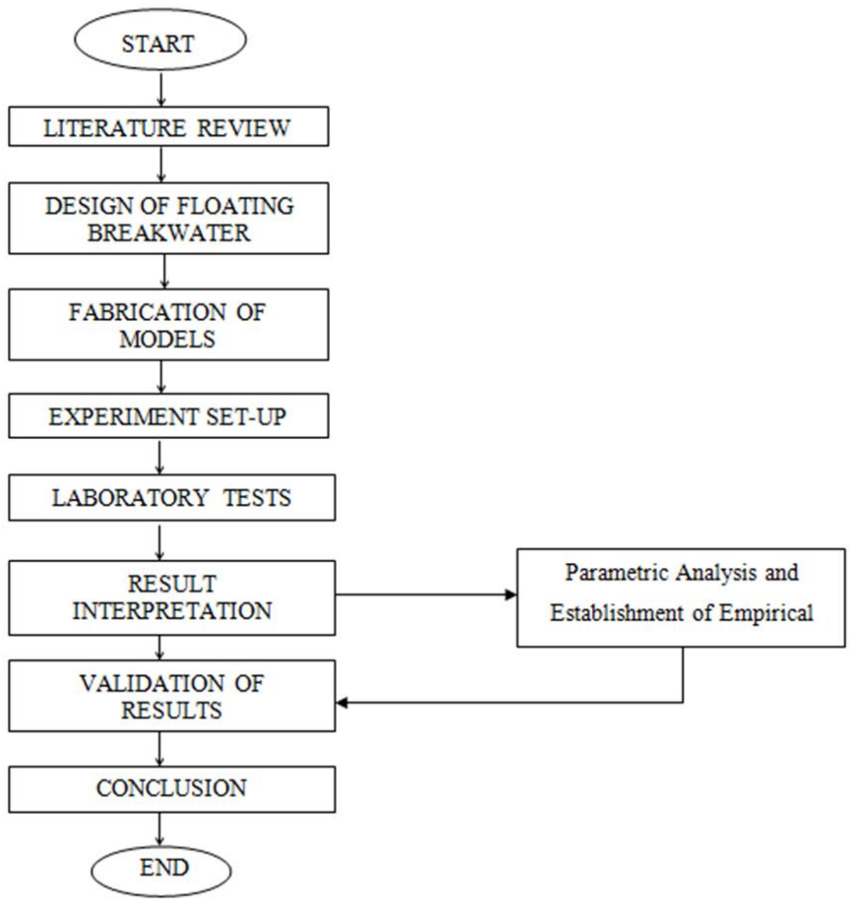


Figure 3.18: Project activities

CHAPTER 4

RESULTS AND DISCUSSIONS

This chapter presents the measured motion responses of the H-type floating breakwater in the forms of time series and frequency domains for each set of experiment conducted in the wave flume. These analyses are particularly important in providing better interpretations 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 pictch) of the breakwater model are presented in respective Response Amplitude Operators (RAO). A parametric analysis is also conducted to give a complete representation of all the experimental tests that were carried out in this study, and some key conclusions are drawn at the end of this chapter.

4.1 Measured Results

Series of experiments were rigorously conducted in the wave flume to study the motion responses of the H-type floating breakwater in both regular and random waves. It is worthwhile to mention that only heave, surge and pitch motions are measured whilst the sway, roll and yaw motions are restricted by the setting of the experiment. These motions were recorded by an optical tracking system (OPTITRACK) operated by 3 high speed cameras (see Section 3.2.4 for more details). The present experiments considers a wave type (random waves), three wave steepness (*i.e.* H_i/L = 0.04, 0.05 and 0.06) and 3 relative breakwater immersion depths (*i.e.* D/d = 0.114, 0171 and 0.229). Nevertheless, some tests 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 completed within the capability 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 results of all the tests 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.

4.1.1 Time Series Analysis

The time series signals of heave, surge and pitch motions of the H-type floating breakwater subjected to random waves of H_i/L = 0.04 are respectively plotted in a 50-s window with a start-up time of 0 s, as shown in **Figure 4.1**. It can be observed from the plots that the motion signals of the model become highly irregular, in which the amplitude of the waves are in a less uniform manner and are difficult to be quantified in time series manner.

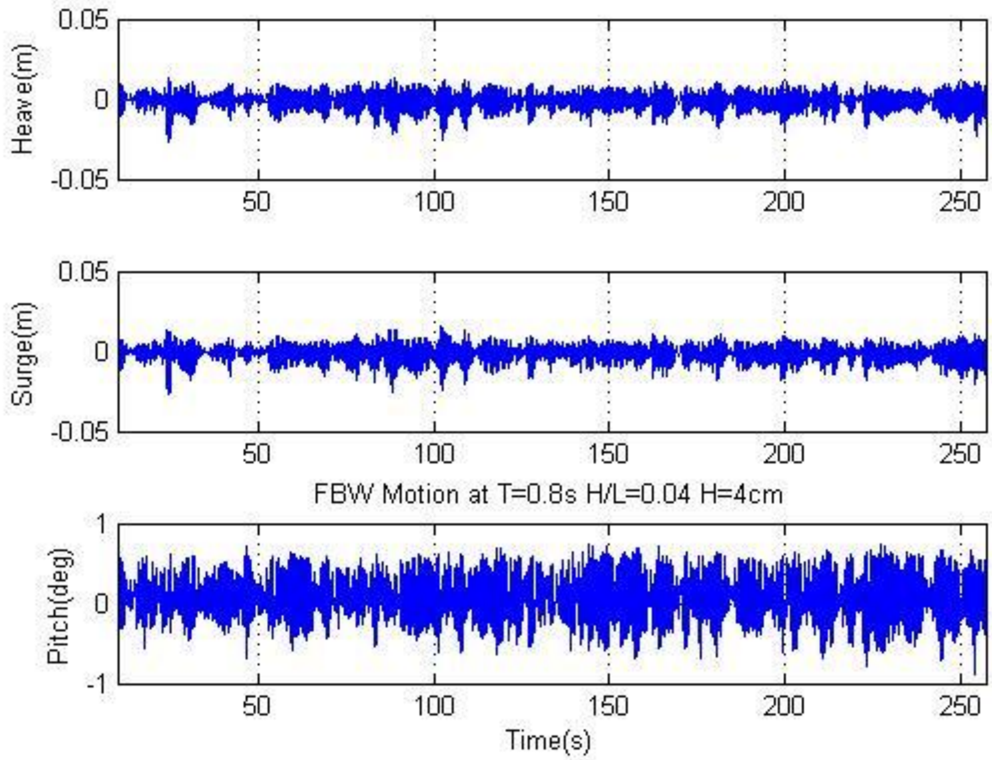


Figure 4.1: Time Series graph for (i) heave, (ii) surge and (iii) pitch responses for H/L = 0.04, frequency = 1.25 Hz, and D/d = 0.114 subjected to random waves

4.1.2 Frequency Domain Analysis

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

Figure 4.2 shows the corresponding spectral energy densities of the time series signals for heave, surge and pitch motions of the H-type floating breakwater as shown in **Figure 4.1**. For the case of random waves, an inverted bell shape curve is distributed across the frequency domain whereby signals of various periods/frequencies and amplitudes are observed and the peak of the curve refers to the peak frequency of the motion mode. For instance, a significant energy density peak can be observed in all of the motion response graphs for heave, surge and pitch in frequency domain analysis, as can be observed in **Figure 4.2**. However, whilst the peak is positioned almost at the same frequency as the natural period of the incident waves, the spectral energy peak for random waves are less obvious, with the existence of some other energy spectral readings at both lower and higher frequency than the natural frequency of the incident waves.

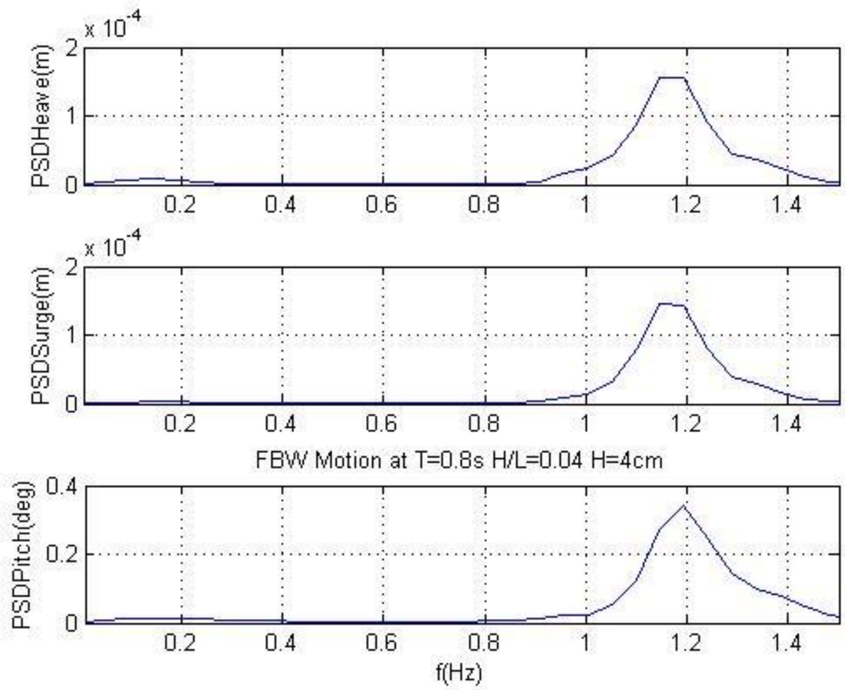


Figure 4.2: Energy Spectral Density graphs for (i) heave, (ii) sway and (iii) pitch responses for H/L = 0.04, frequency = 1.25 Hz, and D/d = 0.114 subjected to random waves

4.2 Result Interpretation

Section 4.2.1 presents the variations of RAO in frequency domains for the H-type floating breakwater exposed to random waves. The RAO-peaks of the entire tests were recorded and evaluated based on the relative breakwater width, *B/L*, which is one of the most accepted design parameter for breakwaters. The RAO results for heave, surge and pitch motions of the test model exposed to regular and random waves of H_i/L = 0.04, 0.05 and 0.06 are to be thoroughly discussed in the following sections.

4.2.1 Response Amplitude Operators

In order to quantify the movement of the floating breakwater model with 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 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 4.4, 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:

$$RAO_n(m/m) = \sqrt{\frac{S_{f,motion}}{S_{f,wave}}} \qquad (4.1)$$

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

4.2.2 Heave

The peaked heave-RAOs for the H-type floating breakwater with taut leg mooring subjected to regular and random waves of H_i/L = 0.04, 0.05 and 0.06 are demonstrated in **Figures 4.3**, **4.4** and **4.5**, respectively. The test model was immersed at four different ratios whereby *D/d* = 0.114, 0.171 and 0.229, which are represented by different plots in the figures.

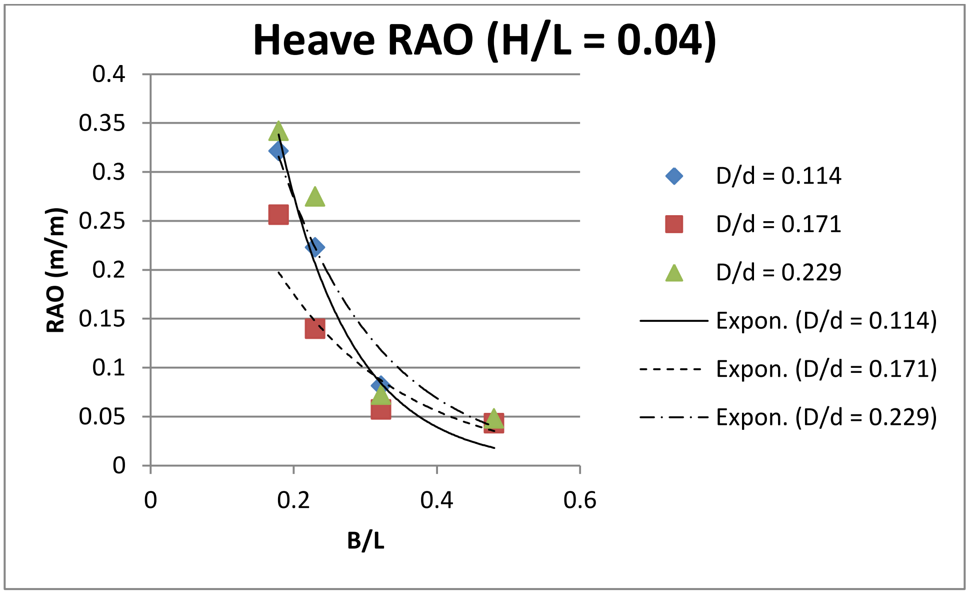


Figure 4.3: Peaked heave-RAOs of the test model subjected to milder wave condition (H_i/L = 0.04) subjected to random waves

The heave-RAOs of the test model for random waves of mild condition (H_i/L = 0.04) is illustrated in **Figure 4.3**. This implies that the heave motion of the test model increase with the increasing period of the incident waves. This is sensible because the size (i.e. the width) of the breakwater is relatively small compared to the wavelength, and consequently the breakwater tends to move along with the incoming waves.

On the other hand, the breakwater has more resistance towards smaller waves with shorter wavelength due to its higher effective mass in the water. It is also observed that the heave-RAOs of all tested D/d closely relate to each other, indicating that the influence of B/L on heave motion of the test model is minimal when the wave condition is relatively mild.

The heave-RAOs of the test model subjected to higher steepness waves (H_i/L = 0.05 and 0.06) are presented in **Figures 4.4** and **4.5**. Similarly, the heave-RAOs of the test model decreases with an increase of *B/L* and *D/d* in random waves.

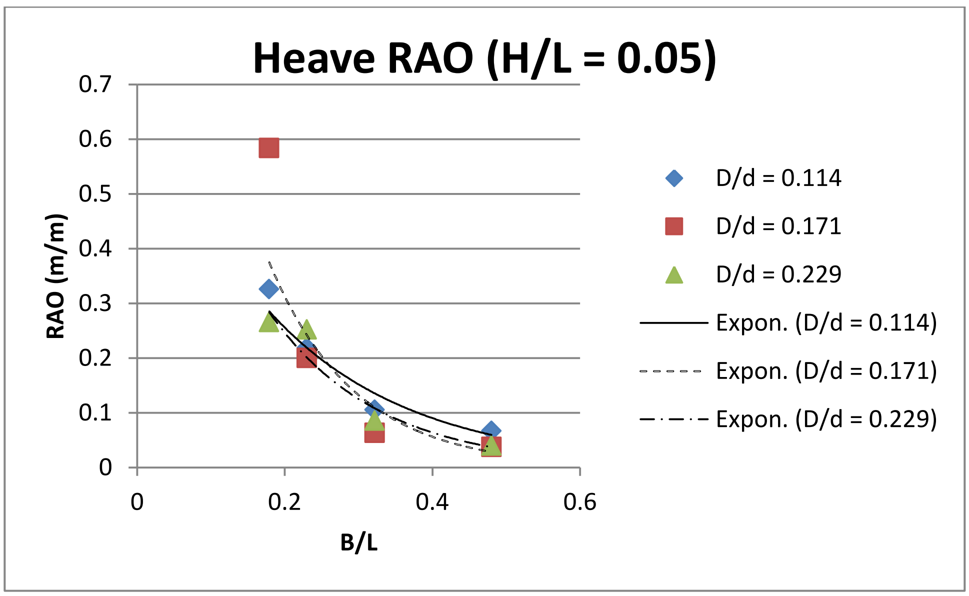


Figure 4.4: Peaked heave-RAOs of the test model subjected to moderate wave condition (H_i/L = 0.05) subjected to random waves

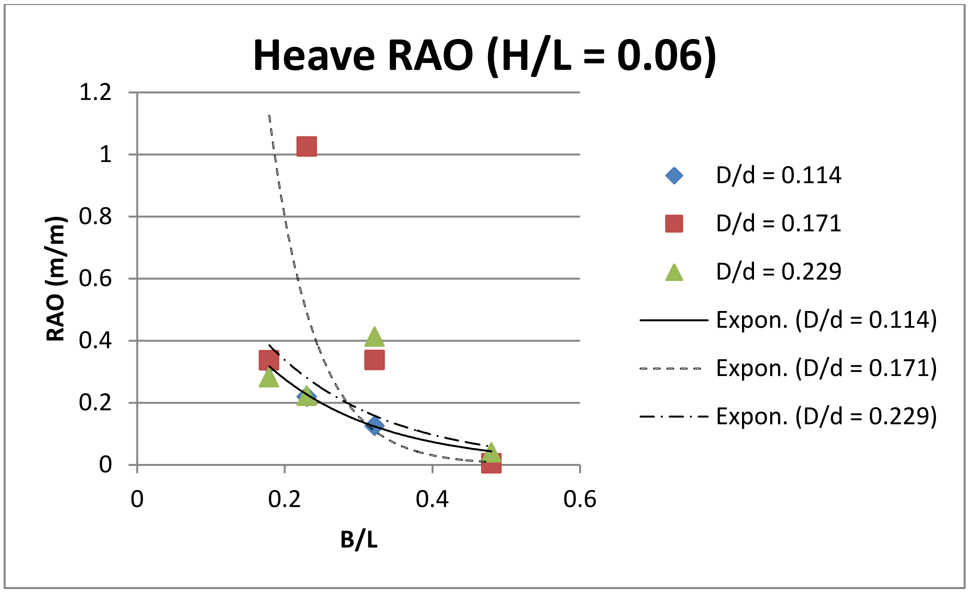


Figure 4.5: Peaked heave-RAOs of the test model subjected to severe wave condition (*H_i/L* = 0.06) subjected to random waves

As wave steepness increases to 0.05, the test model is subjected to higher heave-RAOs (refer **Figure 4.5**). Similarly, the heave-RAOs of the test model decreases with an increase of B/L and they are less affected by the change of D/d. Similar findings were obtained for Hi/L = 0.06. It is interesting to observe that the heave-RAOs for D/d = 0.18 at B/L < 0.2 are relatively large in higher steepness wave environments (0.05 < Hi/L < 0.06). This might be due to some changes of length of the mooring line. The mooring line getting looser from its position as more run being conducted. Because of time constraint, the next set of run is continued without repeatition, which produce a such result.

4.2.3 Surge

The peaked surge-RAOs of the H-type floating breakwater exposed to random waves derived from the frequency domain analysis are shown in **Figures 4.6-4.8**. The format of the plots is similar to **Figures 4.3-4.5**. In mild wave environments (0.04 < Hi/L < 0.05) as indicated in **Figures 4.7** and **4.8**, the surge-RAOs of the tested D/d decrease with the increasing 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. The surge-RAOs for D/d = 0.11 and 0.23 are both overlapped when corresponding to B/L; whereas, the surge-RAO for D/d = 0.17 is relatively higher particularly at smaller range of B/L. This is due to at this steepness, new model being used. The first model was broke down due to the hook at model is easily snapped from the model. To make the model stronger, bracing system is used. The mooring line is hooked at bracing instead of the model. By doing this, the result might different than expected since using different system and the mooring line is altered for the bracing sytem. Similar observations were also obtained for the case of Hi/L = 0.06 as shown in **Figure 4.12**.

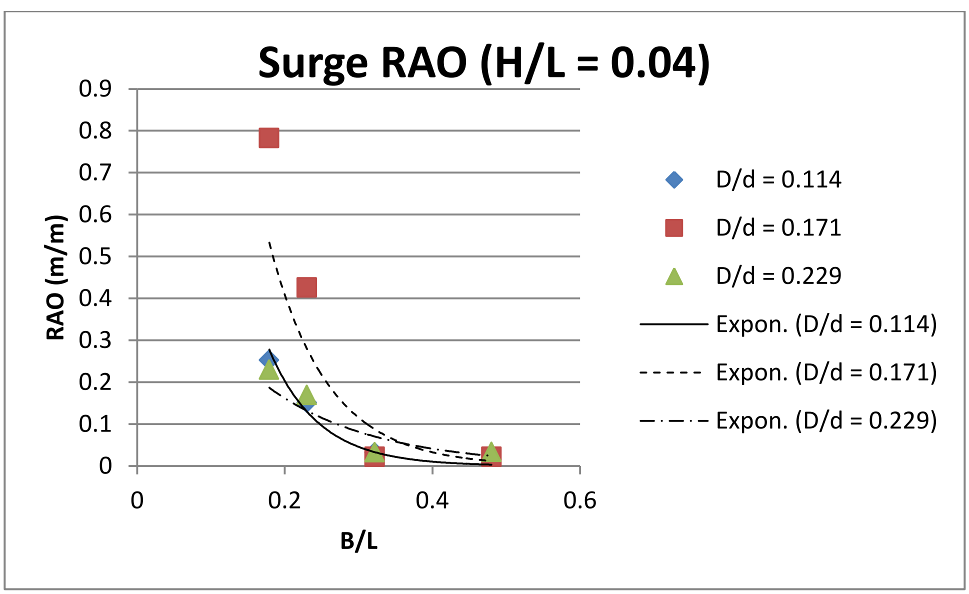


Figure 4.6: Peaked surge-RAOs of the test model subjected to milder wave condition (H_i/L = 0.04) subjected to random waves

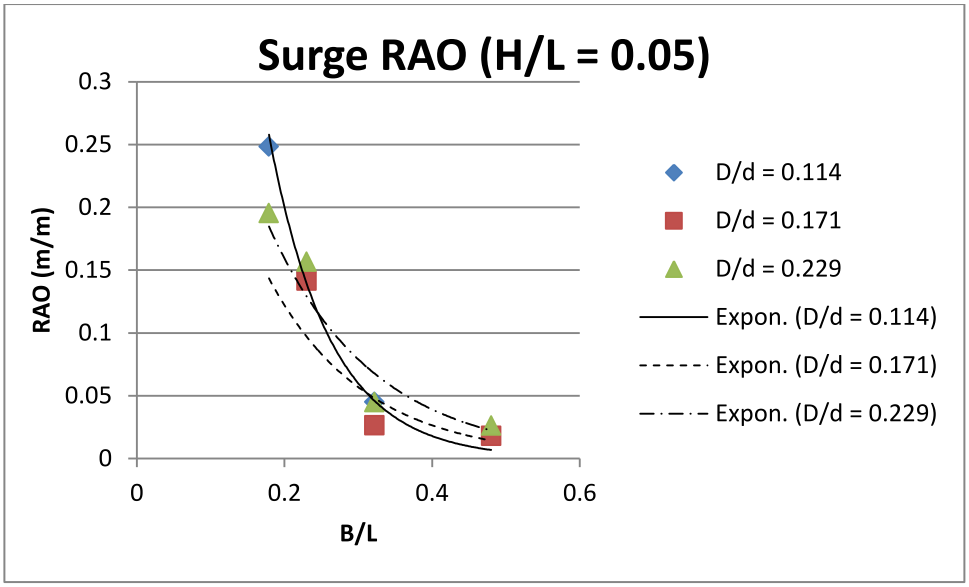


Figure 4.7: Peaked surge-RAOs of the test model subjected to moderate wave condition (H_i/L = 0.05) subjected to random waves

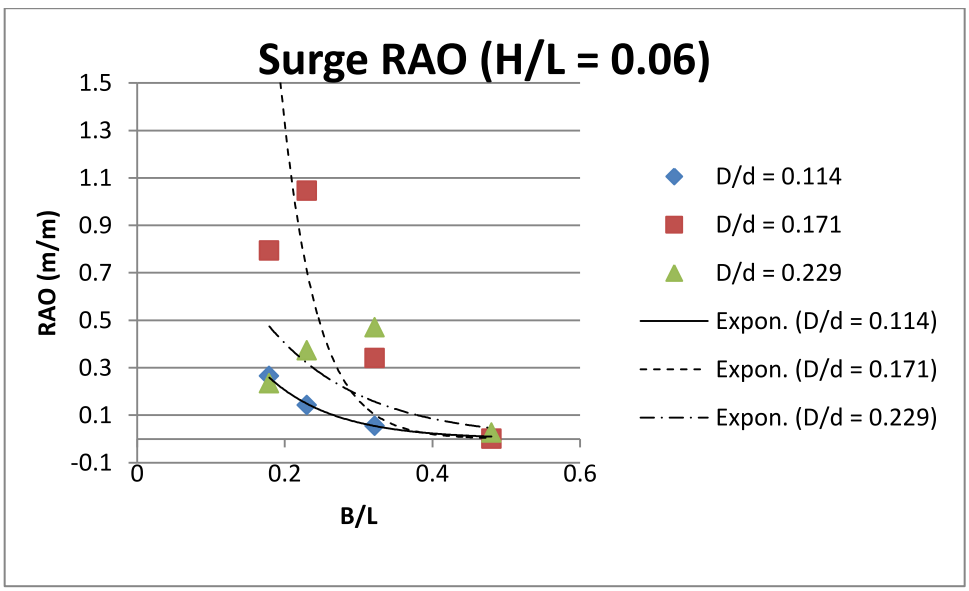


Figure 4.8: Peaked surge-RAOs of the test model subjected to severe wave condition (H_i/L = 0.06) subjected to random waves

4.2.4 Pitch

The pitch-RAOs of the H-type floating breakwater of different immersion depths subjected to random wave environments are demonstrated in Figures 4.9-4.11. For the case of mild steepness waves (Hi/L = 0.04) as shown in Figure 4.9, an increasing pitch-RAOs is seen for $0.11 \leq D/d \leq 0.343$ as B/L decreases. The pitch response of the model is found to be significant when deeply immersed. This is due to the effect of wave overtopping onto the limited freeboard of the floating body, i.e. the waves overtop the crest of the floating breakwater which in turn result in clock-wise rotation (pitch).

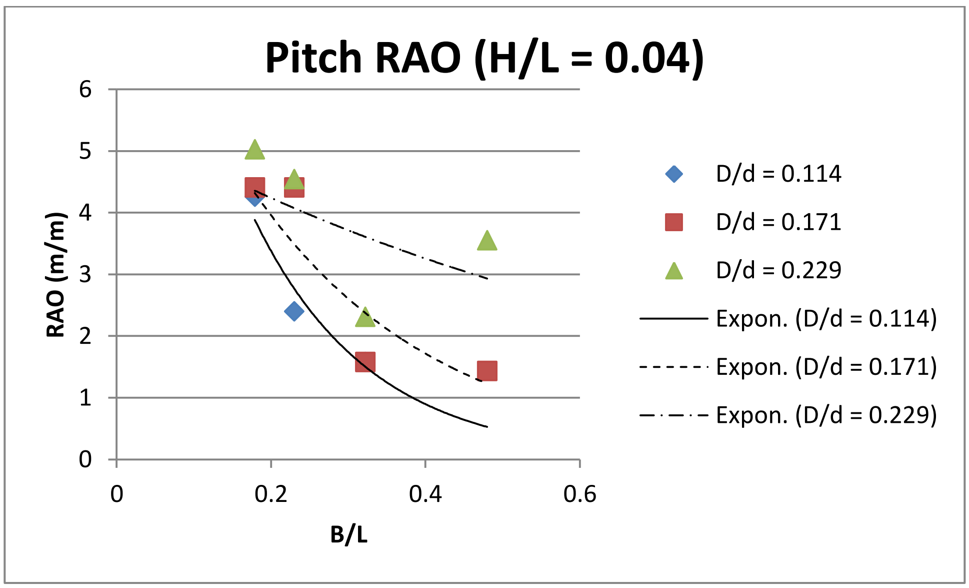


Figure 4.9: Peaked pitch-RAOs of the test model subjected to milder wave condition (H_i/L = 0.04) subjected to random waves

At harsher wave conditions (H_i/L = 0.05 and 0.06), similar observations of the pitch-RAOs were obtained. The reason is same as Section 4.4.3. The bracing system is not entirely enclosed the model, causing a gap for the model to rotate in the bracing itself. This gives such a result for the harsher wave conditions. In overall, it can be seen that as higher the water draft, the higher RAO will be.

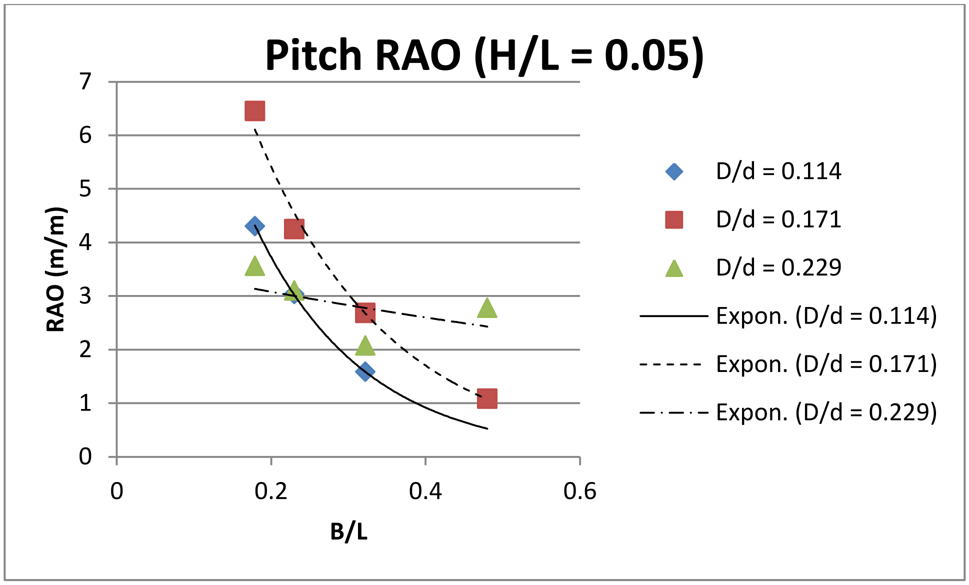


Figure 4.10: Peaked pitch-RAOs of the test model subjected to moderate wave condition (H_i/L = 0.05) subjected to random waves

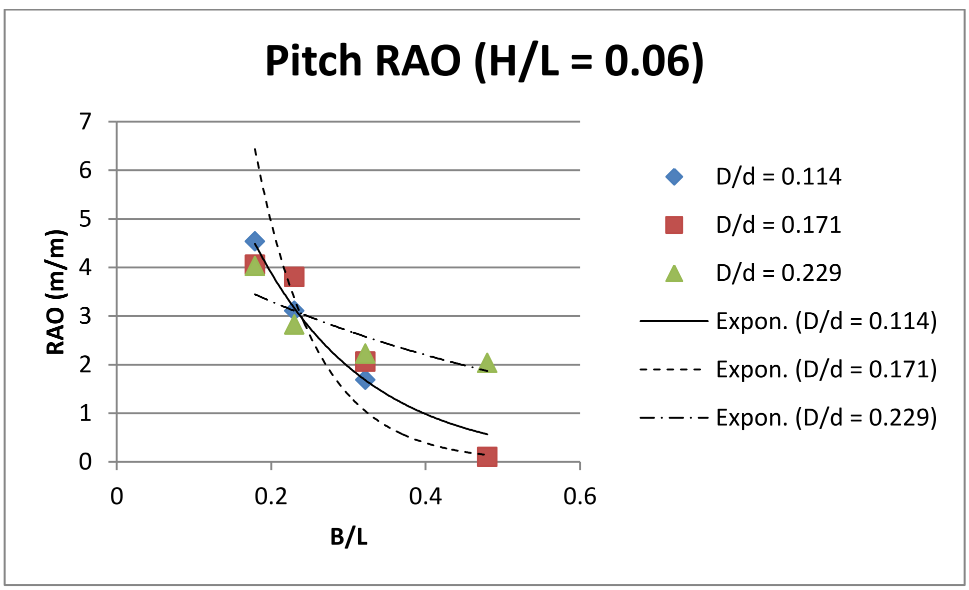


Figure 4.11: Peaked pitch-RAOs of the test model subjected to severe wave condition (H_i/L = 0.05) subjected to random waves

As far as the changes pattern for the pitch-RAO is concerned, it is worth to note that the pitch responses carried no specific pattern with the changes in the breakwater draft and the wave period. Thus, the pitch motion is considered to be less predictable. Hence, it is important to consider the effect of pitch responses in the process of designing the breakwater. As being mentioned in the earlier part, the rotational changes are less sensitive in a stable connection, in which causes such pattern as far as pitch-RAO is concerned.

4.3 Concluding Remarks

The study of motion responses of the H-type floating breakwater is important in understanding the movement behavior of the structure when subjected to different wave conditions. This information serves as a basis or reference to the floating breakwater design in which the performance is not merely based on the structure configurations. The raw data of the existing experiment were evaluated by both time series and frequency domain analyses, for which the peaked-RAOs for heave, surge and pitch were identified numerically. These data were subsequently represented in a dimensionless design graphs for the ease of interpretation. In comparison with the primary motions of the floating breakwater, it was found that the surge response of the structure is more severe than the heave response particularly at smaller immersion depths. Pitch response of the breakwater is another important aspect to be considered in the design of the mooring lines to the H-type floating breakwater if wave overtopping is allowed. The motion responses in terms of RAO obtained from this study will help to provide valuable information, especially in the design of the mooring connection of the breakwater. Each RAO values obtained in the study carried a unique representation on the motion responses and the wave actions based on different set of conditions of the floating breakwater. The heave, surge and pitch RAOs can be used to predict the respective motion responses of the floating breakwater given the particular wave conditions.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

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 products of the study:

- The motion responses of the floating breakwater vary significantly with the changes in the water draft. This is clearly shown in the RAO results that have been obtained in the study, particularly of heave and surge RAOs. As the draft of the floating breakwater increases, a significant restriction to the movement of the floating breakwater can be observed, causing a significant decrease in RAO values.
- As the wave period increases, causing a decreased in the wave frequency, the motion of the floating breakwater can be seen significantly increasing. The increased in the motion responses particularly can be observed through the increasing values of the RAO recorded based on the study. The increment in the wave period caused a higher energy within the wave system, in which causes more vigorous movement of the floating breakwater. The trend is recorded in all three degree of motions, regardless of the water draft.
- The effect of wave steepness are particularly minimal in both heave and surge RAOs, especially at more severe wave condition (H/L = 0.05 and H/L= 0.06). The difference of the heave and surge RAOs at higher wave steepness is considered to be very minimal. However, in the case of pitch RAO, the effect of

wave steepness for all the three cases that have been tested (*H/L* = 0.04, 0.05, 0.06) is appeared to be very significant. Both heave and surge RAO have a definite trend with respect to the changes in the system, as far as the breakwater draft and the wave period are concerned. As for pitch RAO, no definite trend can be observed with respect to the changes, with the motion responses are acting in a less predictable manner.

- The usage of RAO can help to predict the motion responses of the floating 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.
- 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 response of heave, surge and pitch obtained in this study will help the designer in predicting the behavior of the floating breakwater in real sea and thus, help to decide on the optimum mooring configurations for the H-type floating breakwater depending on the wave conditions of the sea state.
- The experimental procedure carried out in this study has shown some promising end products on the response of the H-type floating breakwater with respect to wave actions. The study has also met its primary objectives in analyzing the behavior of the floating breakwater under both regular and random waves.

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:

- The study of the forces in the mooring lines can be done in order to study the effect of the mooring lines towards the motion responses of the floating breakwater. The mooring lines recorded data, coupled with the data obtained from this study, will produce a valuable information which will assist in the design of the floating breakwater in real life applications
- In order to verify the potential of the system used in the study, a separate study of the H-type floating breakwater moored with other type of mooring configurations can be done. Such study considered to be helpful, as comparison of the motion responses and the performance of the floating breakwater can be evaluated in order to obtain an optimum configurations for the H-type floating breakwater
- 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 upgraded version of the study can be done by fully obtained all of the 6 degree of freedom responses and their RAOs due to various wave conditions. The response of the mooring lines during the testing can also be recorded in order to study the hydrodynamic forces acting on the mooring lines for a more advanced analysis of the data.
- The mooring line has to design such a way that it can withstand very large waves and can last longer.

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