PHYSICAL MODELLING OF ARTIFICIAL REEF FOR COASTAL PROTECTION

By

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FINAL PROJECT REPORT

Submitted to the Civil Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Civil Engineering)

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CERTIFICATION OF APPROVAL

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2529

A project dissertation submitted to the
Civil Engineering Programme
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in partial fulfillment of the requirements for the
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Approved by,

Mr Teh Hee Min
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

DECEMBER 2005

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 person.

MOHD IRWAN BIN MOHD SAARI

ACKNOWLEDGEMENT

I would like to express my gratitude to my UTP supervisor, Mr Teh Hee Min, lecturer of Civil Engineering Department, University Technology of PETRONAS, who has guided me throughout this project. Mr Teh is always determine to share his knowledge and opinions which has helped me a lot with this project I am working on. I also would like to thank him for reviewing my works and corrected my mistakes so that it can be better presented.

I am also grateful to two students, Miss Wong Siew Lee and Miss Nuzul Izani who have helped me a lot while conducting the experiments throughout this year. With the help from both of them, I manage to complete my experiments correctly.

Lastly, an appreciation also goes to the technicians and any other personnel that have been involved in helping me to carry out this project successfully.

ABSTRACT

A study on the artificial reef and to propose a newly designed artificial reef is carried out for this project. This project involves two phases where the first phase is to be carried out in the first semester involving designing the artificial reef and preliminary experiments. For the second phase, experiments on the proposed design of artificial reef will be conducted as to obtain the effectiveness of the design in attenuating waves. This paper represents the second phase of the project where the experiments and the analysis of result for the designed artificial reef is conducted.

The reefs dissipate wave energy and at the same time act as the sandy materials that nourishes the beach. Human intervention and activities which include sea water pollutions, mining and exploitation of the coral reefs frequently damage natural reef and leave the beach prone to direct wave attack

Long lasting artificial reefs are useful tools for restoring our reef systems to a natural and productive balance. As a result, a newly designed artificial reef has been proposed for this project named 'Trape Reef'. This artificial reef is expected to reduce the wave reflection in nearshore area. The design for this artificial reef is made in trapezoidal shape with a hollow cross section. On the surface of the structure there are holes created to dissipate the wave parameters and to make a path for the marine lives to get into the hollow cross section.

The experiments on performance of newly designed artificial reef were done to observe the effectiveness of 'Trape Reef'. It can be seen that 'Trape Reef' can gives C_T as low as 0.1. However, the C_T values increase through increasing water depth. Results that show the most effectiveness of 'Trape Reef' is at water depth 20 cm. The experiment on the 'Trape Reef' conducted indicated that as water depth increases, the reflection and transmission coefficient increase, while loss coefficient decreases.

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CHAPTER 1
INTRODUCTION

1.1 General

Every ecosystem on earth has unique characteristics, and some ecosystems can fairly be called more unusual than others. However, there is no ecosystem on Earth is as unusual as a coral reef. The coral reef is the only ecosystem constructed by, and composed entirely of, animals. This coral reef is not only the main beauty of the ocean but act as a contributor for wave attenuation in the tropical area. The extinction of coral reef has resulted to the construction of various types of artificial reef that has the main objective to serve the purpose as same as the coral reef. A lot of artificial reef such as Reef Ball, concrete reef, tire reef, and rig reef have been constructed and the study of the effectiveness of these artificial reefs is still ongoing throughout these years. This project is another study in order to create more alternative for this field. A newly designed artificial reef is the outcome of this project and the study of the effectiveness of this design is very crucial. However, the study is mainly based on the set of experiments conducted in the wave flume.

1.2 Problem Statement

Tourism boom has some detrimental effect and put severe pressure on many sandy beaches. Unwise development of beach resort often cause coastal erosion in some adjacent areas. Many sandy beaches in tropical countries are often naturally sheltered by barrier reef. The reefs dissipate wave energy and at the same time act as the sandy materials that nourishes the beach. Human intervention and activities which include sea water pollutions, mining and exploitation of the coral reefs frequently damage natural reef and leave the beach prone to direct wave attack. Once exploited and destroyed, the coral reefs will take a long period of time to generate. Thus they will unable to support other marine lives and deprived of protection from wave attack. Significant losses in material and natural resources under such conditions has occurred in many places in Malaysia as well as other tropical countries. Human's activities and natural disasters have led to a reduction in our natural reef systems. Recreationally, growth in sports fishing, scuba diving, and boating has increased the pressures on these systems. Commercially, our seafood industry is dependent on developing the ocean to enable ever larger, yet sustainable, harvests. The loss of our natural systems, coupled with increased use, made the society to do everything to save the natural reefs. Even so, the natural reefs cannot rebuild themselves fast enough to meet human demands. Long lasting artificial reefs are useful tools for restoring our reef systems to a natural and productive balance.

1.3 Objectives

The objectives of the study are as follows:

1. To develop an artificial reef system that is environmental and ecological friendly and effective in reducing the height of incident waves

2. To study the effectiveness of applying the proposed design as a coastal protection system via laboratory experiments.

1.4 Scope of Study

To achieve the objectives mentioned in section 1.3, the scopes of work are skeletonized as follows:

1. Literature review

   To study the existing types of artificial reefs used for marine habitat enhancement tool. A thorough study on both natural and artificial reefs has to be done in order to understand the nature of the coral reefs to ease the designing works of artificial reef.

2. Development of new artificial reef

   A new design of artificial reef is developed primarily used to minimize the wave height.

3. Laboratory set up

   The apparatus and equipment used for the experiment purpose are checked and calibrated to ensure the integrity of those equipment. The equipments then will be set up according to the requirements for the experiment which is to to determine the efficiency of the artificial reef.

4. Experiments

   To investigate the behavior of the newly developed artificial reef, a series of experiments will be carried out in the wave flume, with respect to different wave heights, wave periods, and water depths.

5. Results Analysis

   Results of the experiment will be analyzed and interpreted in the forms of graphical presentations. The experimental results also will be compared with those results of the artificial reef models proposed by other researches

1.5 Significance of the study

Artificial reefs issue is reefs that are made to serve the same purpose of the natural coral reefs that is decreasing in population mainly due to human's activities. A lot of artificial reefs have been created and studied to serve this purpose. Until now, the works to create more artificial reefs is still ongoing as to make the artificial reefs become better.

Moreover, there are studies nowadays to make the artificial reefs not just as a replacement of the coral reefs, but also as a breakwater to protect the beach. A lot of researchers still precede their research and the outcomes are discussed in conferences to clarify the effectiveness of the designs. By doing this project, it can provide more alternative to this scenario.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The literature review done to have a clear view of what the project is all about. A basic understanding on wave dissipation mechanisms such as wave reflection and wave transmission needs to be fully understood in order to complete this project. In addition, research on the nature of the coral reef also should be done. By studying the nature of coral reef, it will be easier to design an artificial reef which not only have the capability to act as a breakwater, but also can preserve the nature of coral reef.

2.2 Wave Dissipation Mechanisms

2.2.1 Wave Transmission

The term "wave transmission" is used in reference to the wave energy that does travel past a breakwater, either by passing through and/or by overtopping the structure (U.S. Army Corps of Engineers, 1984). The effectiveness of a breakwater in attenuating wave energy can be measured by the amount of wave energy that is transmitted past the structure. This means if the greater the wave transmission coefficient, the less the wave attenuation performance. The wave transmission coefficient, C_t, can be expressed as

$$C_t = H_t / H_r \qquad (2.1)$$

where H_t is the height of the transmitted wave on the landward side of the structure, and H_i is the height of the incident wave on the seaward side of the structure (U.S. Army Corps of Engineers, 1984).

2.2.2 Wave Reflection

Wave reflection means reflecting the wave and directing the energy of the wave elsewhere. The energy then reflected and formed the reflected wave, H_r which moving on the opposite direction. The reflection coefficient, C_r is stated by

$$C_r = H_r / H_i \qquad (2.2)$$

where H_r is reflected wave height and H_i is the incident wave height. If 100% of wave energy is reflected (total reflection), the C_r is equal to 1. This is generally valid for impermeable vertical wall of infinite height. The reflection coefficient for sloping, rough or permeable structures are smaller. Goda (1985) concluded reflection coefficient for various structures as listed in Table 2.1.

Table 2.1: Reflection Coefficient for Various Structures (Goda,1985)

Type of structure	Reflection Coefficient, C_r
Vertical wall with crown above water	0.7 – 1.0
Vertical wall with submerged crown	0.5 – 0.7
Slope of rubble stones (slope of 1 on 2 and 3)	0.3 – 0.6
Slope of energy dissipating concrete block	0.3 – 0.5
Vertical structure of energy dissipating type	0.3 – 0.8
Natural beach	0.05 – 0.2

2.2.3 Loss Coefficient

From *equation 2.1 and 2.2*, another coefficient can be obtained which is loss coefficient. This is representing the wave energy that has been dissipated by the structure. Loss coefficient is represented by

$$C_L = (1- C_L^2 - C_L^2)^{0.5} \qquad (2.3)$$

2.2.4 Wave breaking, turbulence and friction

There are two criteria that determine when a wave will break. The first is a limit to wave steepness, and the second is a limit on the ratio of wave height to water depth. Wave steepness is the ratio of wave height to the wave length, *H/L*. the ratio of wave height to water depth is also known as breaking index. The ratio is *H/d*. in practice, breaking index can vary from about 0.4 to 1.2.

Different materials exhibit different degrees of roughness (e.g. plastic or concrete). The higher the roughness of the surface, the higher the friction would be provided. As the higher friction provided, the effectiveness of the wave attenuation should be more effective.

2.2.5 Degree of submergence

One of the most important parameters for the design and effectiveness of a submerged breakwater is the degree of submergence. This can be expressed by three different dimensionless terms:

1. The degree of submergence = d/h ;
2. The relative structure height = h/d ; and
3. The relative freeboard to water depth ratio = F/d .

The degree of submergence is the ratio of the water depth to the height of the structure. For a submerged structure, this ratio is greater than one ($d/h > 1.0$). These three dimensionless quantities, d/h, h/d, and F/d, indicate the relative height of the breakwater compared to the water depth, and are used to determine the magnitude of the wave and current forces on the breakwater, and the effectiveness of the structure in attenuating wave energy. The description of the submerged breakwater to show the related parameters is shown in *Figure 2.1.*

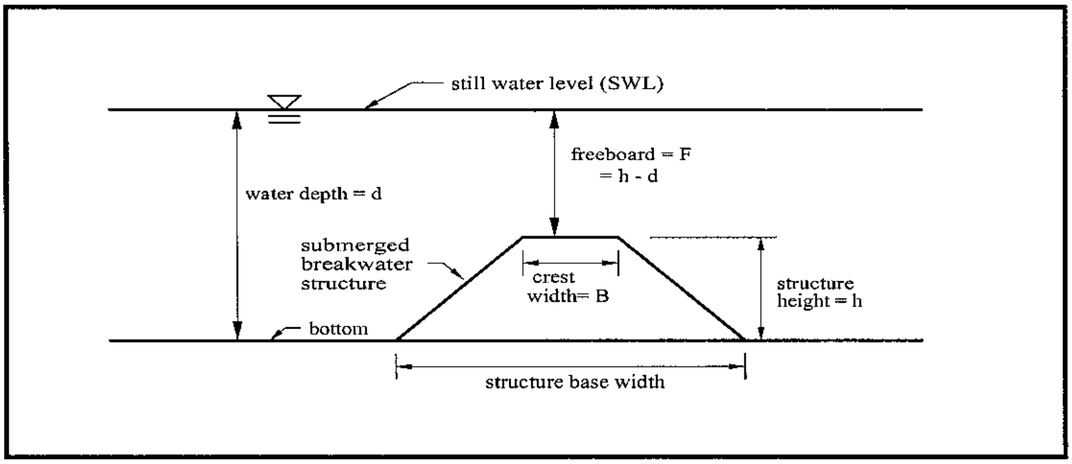


Figure 2.1: Definition sketch for a submerged breakwater

2.3 Natural coral reef

2.3.1 General

Coral reefs are massive structures made of limestone that is deposited by living things. Although thousands of species inhabit coral reefs, only a fraction produce the limestone that builds the reef. The most important reef building organisms are corals.

Coral reefs support over twenty-five percent of all known marine species. As one of the most complex ecosystems on the planet, coral reefs are home to over 4,000 different species of fish, 700 species of coral and thousands of other plants and animals.

A good way to imagine a coral reef is to think of it as a bustling city or community, with the buildings made of coral, and thousands of inhabitants coming and going, carrying out their business. In this sense, a coral reef is like a metropolis under the sea.

As the coral colonies build up on top of each other, they gradually form a coral reef. Individual coral colonies may be up to 1000 years old. Coral reefs may be many thousands of years old, forming slowly over time, responding to changes in sea level and other environmental conditions.

2.3.2 Types of reef

Scientists generally divide coral reefs into four classes: fringing reefs, barrier reefs, atolls and patch reefs.

- *Fringing reefs* grow near the coastline around islands and continents. They are separated from the shore by narrow, shallow lagoons. Fringing reefs are the most common type of reef that we see.
- *Barrier reefs* also parallel the coastline but are separated by deeper, wider lagoons. At their shallowest point they can reach the water's surface forming a

"barrier" to navigation. The Great Barrier Reef in Australia is the most famous example and is the largest barrier reef in the world.

- *Atolls* are rings of coral that create protected lagoons and are usually located in the middle of the sea. Atolls usually form when islands surrounded by fringing reefs sink into the sea or the sea level rises around them (these islands are often the tops of underwater volcanoes). The fringing reefs continue to grow and eventually form circles with lagoons inside.
- *Patch reefs* are small, isolated reefs that grow up from the open bottom of the island platform or continental shelf. They usually occur between fringing reefs and barrier reefs. They vary greatly in size, and they rarely reach the surface of the water.

Figure 2.2 illustrates the classes of coral reefs stated above. The figure shows the cross-section and map view for the reefs.

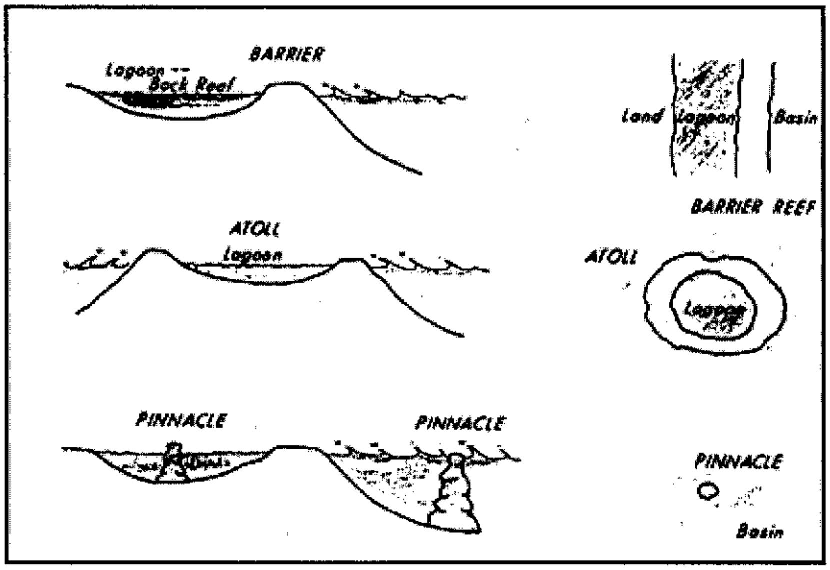


Figure 2.2: Reef types in cross-section and map view.

Although there are hundreds of different species of corals, they are generally classified as either "hard coral" or "soft coral".

Hard corals (*Plate 2.1*) grow in colonies and are the architects of coral reefs. They include such species as brain coral and elkhorn coral. Their skeletons are made out of calcium carbonate (also known as limestone) which is hard and eventually becomes rock. Generally, when we talk about "coral" we are referring to hard corals.

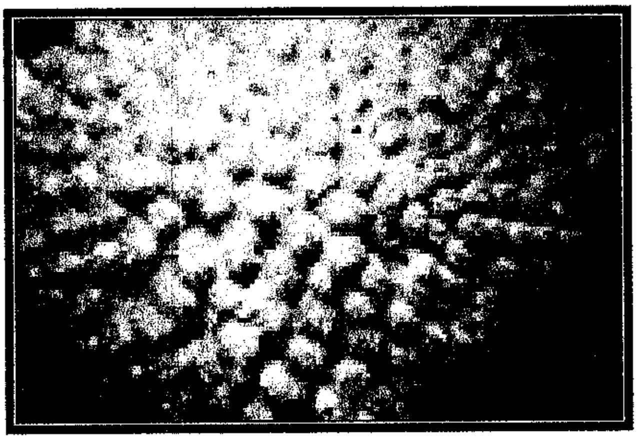


Plate 2.1: Shape and colour of coral reefs;flat shape and green in colour

Soft corals such as sea fingers and sea whips, as shown in *Plate 2.2*, are soft and bendable and often resemble plants or trees. These corals do not have stony skeletons, but instead grow wood-like cores for support and fleshy rinds for protection. They are referred to as non-reef building corals. Soft corals are found in both tropical seas and in cool, dark regions.

Plate 2.2: Shape and colour of coral reefs; pointed shape and brown in colour

The variety of shapes and sizes of coral colonies largely depends on their species. Some form hard, pointed shapes, while others form soft, rounded shapes. The shape of coral colonies also depends on the location of the coral. For example, where there are strong waves corals tend to grow into robust mounds or flattened shapes (*Plate 2.1*). In more sheltered areas the same species may grow in more intricate shapes such as delicate branching patterns (*Plate 2.3*).

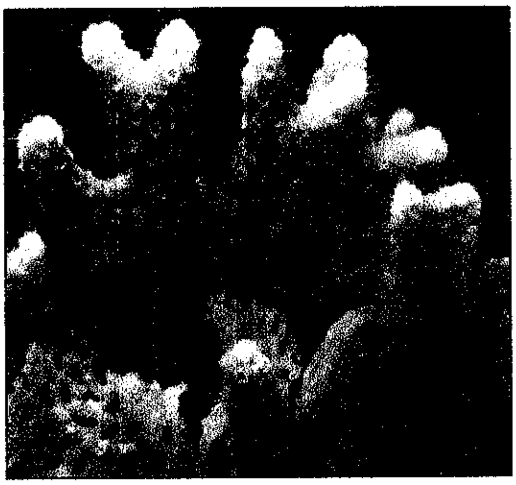


Plate 2.3: Shape and colour of coral reefs;delicate branching shape and pink in colour

The shape of the coral reefs also affected the wave dissipation. In example, for hairy-shaped coral reef (*Plate 2.4*), the surface is soft and can absorb wave energy.

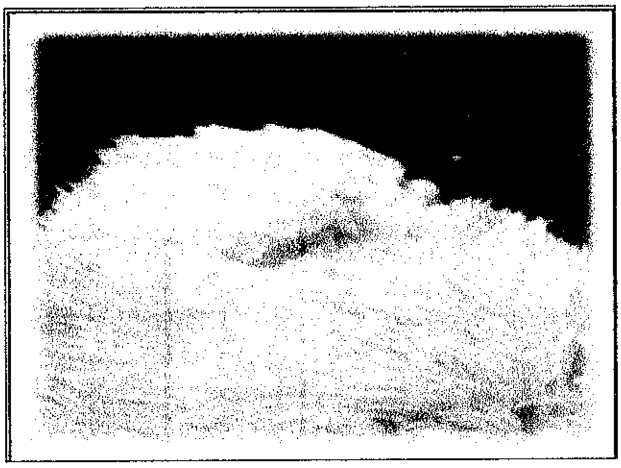


Plate 2.4: Shape and colour of coral reefs; hairy and orange in colour

2.3.3 Worldwide distribution

Coral reefs are found in over 100 countries. Most reefs are in places such as the Pacific Ocean, the Indian Ocean, the Caribbean, the Red Sea and the Arabian Gulf. Corals are also found farther from the equator in places where warm currents flow out of the tropics, such as Florida and southern Japan. As from the distribution, it is proved that the coral reefs are found in tropical countries. Worldwide, coral reefs cover an estimated 284,300 square kilometers (110,000 square miles).

For tropical ecosystem, coral reefs grow in warm, sunny, regions, extending further north and south only where there are warm currents. They cover an estimated 300,000 - 600,000 sq km, and are found in the waters of over 100 countries. *Figure 2.3* shows the distribution of coral reefs in South East Asia. The area that has been marked with red is the distribution of coral reefs.

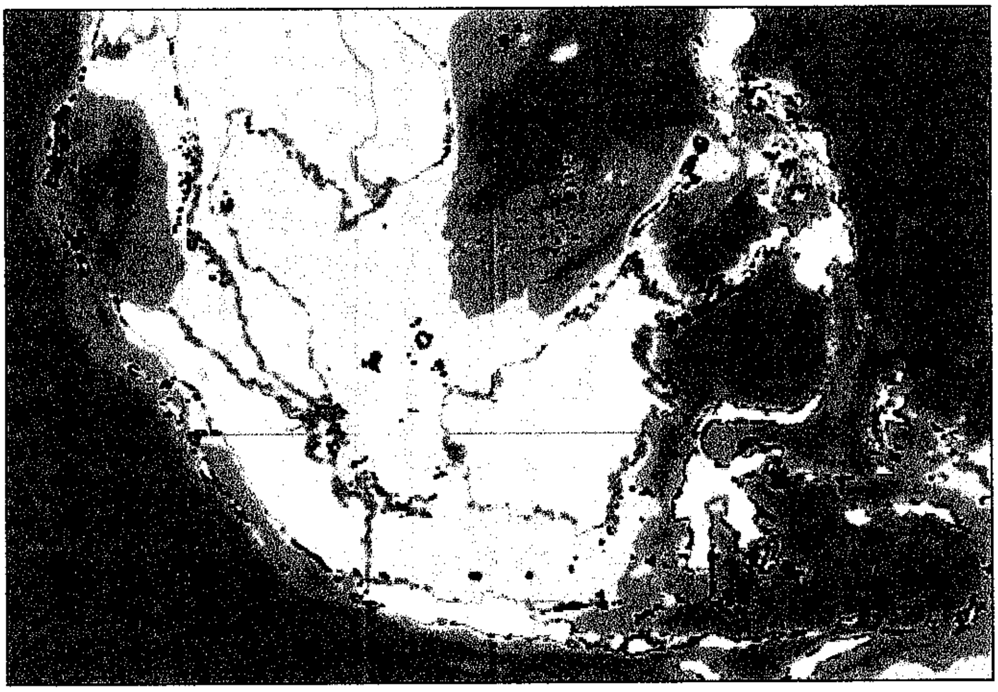


Figure 2.3: Distribution of Coral Reefs in South East Asia.

2.4 Existing Types of Artificial Reef

The coral reef distribution is only at tropical region. As Malaysia is one of the tropical countries, the study for artificial reef also done in Malaysia. Artificial reefs have been created in Malaysian fisheries waters as a marine resource enhancement as well as one of the steps to alleviate the problem of depleting fish resources in the coastal waters. A total of 54 artificial tire reefs, 10 boat reefs and 10 concrete reefs have been constructed in Malaysia. There are a few recommendations for material that can be used as artificial reefs. The recommendation is summarized in *Table 2.2*.

Almost every type of scrap or discarded object has been used to construct reefs.

Type	Life time	Recommended
cars and streetcars	≈6 years	No, they are subject to corrosion to debris
wooden materials	< 1-6 years	No, they collapse even sooner from wave surge and destruction by marine borers.
household appliances (stoves, refrigerators and freezers)	≈6 years	Not recommended because they are buoyant and difficult to sink and keep in place
tires, rock, concrete rubble and others	Very durable	Yes
ships, barges, dry docks, culverts, toilet bowls, trees, bricks prefabricated shelters and artificial seaweed	Varies	Yes

Table 2.2: Recommendation on types of scraps that can be used as Artificial Reef.

2.4.1 Reef Balls

Reef Balls are state of the art designed artificial reefs modules. Reef Ball projects emphasize on-going research, public education, community involvement, and reefs that promote and support natural species diversity and population density. 40,000 Reef Balls have been deployed in over 400 projects worldwide. The Reef Ball comes in many sizes from 6 inches to 6 feet and ranging from 6 to 6,000 pounds. *Plate 2.5* shows one of the designed reef ball available. The designed is practically a shape with the holes made on the surface of the Reef Balls. Eventhough the name is Reef Balls, it is not mainly just ball shape. The Reef Balls can be obtained in various shapes but the main signature of this design is the holes.

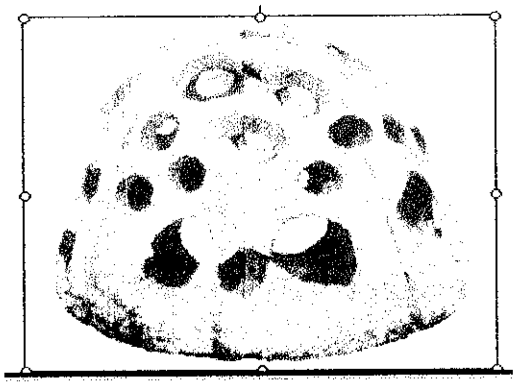


Plate 2.5 : This is the **Reef Ball** that come in many sizes from 6 inches to 6 feet and ranging from 6 to 6,000 pounds

The results shown in *Table 2.3* below, shows the predicted wave transmission coefficients. Note that these values are more indicative of observations of the Dominican Republic Reef Ball submerged breakwater.

Table 2.3 Wave Transmission Coefficients			
wave height = H (meters)	**4 rows**	**5 rows**	**6 rows**
0.50	0.33	0.31	0.30
0.75	0.31	0.29	0.27
1.00	0.33	0.29	0.27
1.25	0.36	0.31	0.28
1.50	0.39	0.34	0.30

This result was obtained from wave tank physical model tests using rubble mound armor stone, not Reef Ball units, so that the results provide more of a design guidance and comparison than actual expected wave transmission. The values in Table 1 show that in order to reduce the wave heights by at least 70% for all of the given wave conditions, 6 rows of Reef Ball units are required. This is the recommended minimum width of the Reef Ball breakwater for wave attenuation sufficient to provide shoreline stabilization in the project area. Five rows of Reef Ball units reduce the wave heights by 66% providing slightly less effective wave attenuation and shoreline protection. Four rows reduce the wave height by 61%, which is less than that recommended for adequate shoreline stabilization. The experimental setup in the flume channel for these reef balls is shown in *Plate 2.6*.

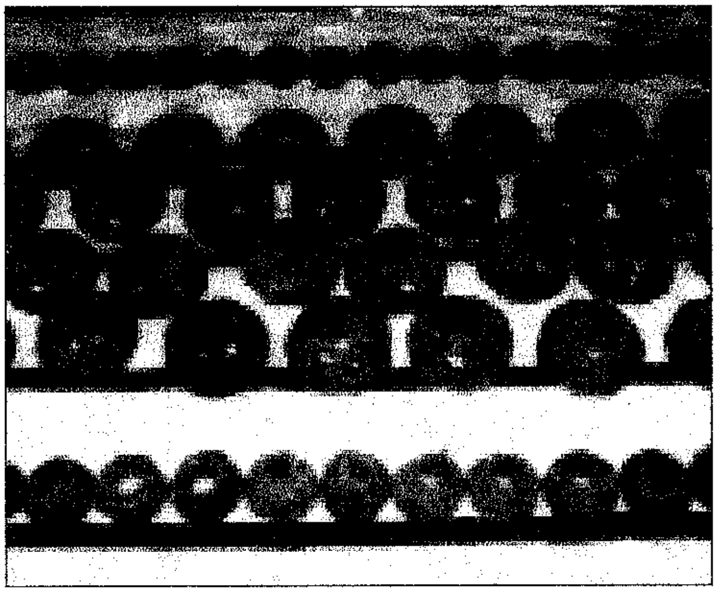


Plate 2.6: Reef Balls tested in wave flume.

2.4.1 Tire Reefs

Tire reefs were us as tool for study on community structure and behaviour of fishes was conducted for ten months at artificial reefs in the waters off Kuala Terengganu.

This study showed that the number of species in the reefs decreased after the rainy season and tended to increase close to the rainy season. Species richness and abundance were influenced by availability of natural food and shelter for fishes around the reefs. Residents species comprised about 67% in tire reef.

It showed that the artificial reefs in this study provide benefits to a few species especially the schooling fish that have large numbers of individuals. Competition occurred between dominant resident fishes because of overlap on food consumption. This situation made the species in a large groups dominate the habitat, which then drove out the species in a small groups.

2.4.2 Concrete reefs

The concrete reefs applied in Terengganu waters used to help multiply fish stocks to improve the earnings of fishermen. The reefs would also ensure the conservation of fish resources in the state's waters as they would serve as breeding grounds for the fishes. The authorities have created 300 cuboid-shaped concrete reefs, made using local technology. The cuboid shape of the concrete reefs is as shown in Plate 2.7

Plate 2.7: Cuboids shaped of concrete reef

CHAPTER 3
MODEL DESCRIPTION

3.1 Introduction

A thorough literature reviews on the existing types of artificial reef would provide a general platform for development of new designs. This chapter introduces a newly designed artificial reef named 'Trape Reef' used to dampen waves and restore the eroded beaches. Descriptions on the design and the rational of the design proposed also included in this chapter. A scaled-down model of 'Trape Reef' had also been proposed for the experimental testing purpose. By testing the model in the wave generating facilities, the resulting outcomes are expected to show the true behavior of the design proposed

3.2 Objectives of the Design

The development of the artificial reef in this study is aimed to serve the following objectives:

1. Improve the recreational value of the windward beach by reducing the wave energy sufficiently to allow the creation of a stable new beach using natural sand.
2. Maintain sufficient environmental flow and water exchange behind the artificial reef to ensure the survivability of existing seagrass
3. Provide wave attenuation to reduce the average turbidity of the water
4. Minimize visual impact by remaining below the waterline.
5. Minimize the loss of existing seagrass within the footprint of the artificial reef.
6. Mimic as closely as possible a natural coral reef system.

3.3 Trape Reef

An artificial reef named as 'Trape Reef' is developed to serve the objectives as mentioned in Section 3.2. It has a trapezoidal shape with hollow cross section as shown in Figure 3.1. The 50 cm long x 29 cm wide x 150 cm high artificial reef is targeted to provide a certain degree of wave protection in the nearshore area, thereby promoting the growth of natural reef at the seaward region of the structure.

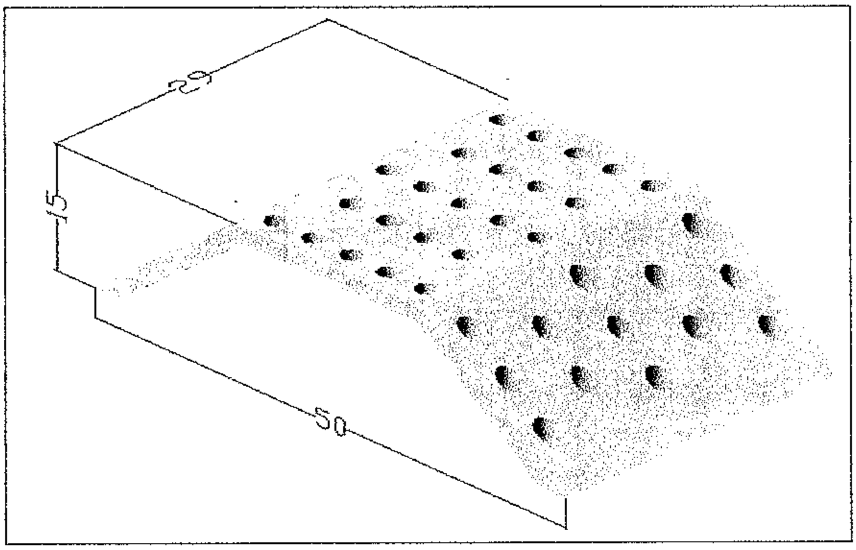


Figure 3.1: Isometric view of 'Trape Reef' (all dimensions in cm)

The design chosen has a few characteristics that will contribute to the effectiveness of the artificial reef. The characteristics and advantages of 'Trape Reef' are as follows:

3.3.1 Hollow cross-section

The hollow cross-section is designed to give space for the marine growth. It also protects these marine species from the severe wave attack. The hollow cross-section can be a good habitat for marine life.

3.3.2 Holes on the surface of the structure

The holes on the body of the structure are believed to be capable attenuating the waves as. Additional benefits of the design include improved habitat for marine life due to the penetration of sunlight through the holes. Eventually, the structure becomes covered with marine growth, in which it provides recreational benefits as a snorkeling trail. The other purpose is also to make path to the marine habitat to get into the hollow cross-sectional area of the structure.

3.3.3 Surface roughness

Surface roughness appears to be a governing factor that contributes to wave attenuation. The roughness of the surface can be created by adding the rough mortar on the external surface of the structure. The rougher the surface, the greater the ability of the artificial reef to dissipate the wave energy.

3.3.4 Materials

'Trape Reef' is constructed of reinforced concrete and mortars. The lower the water/cement ratio, the more durable is the concrete. A water/cement ratio of 0.50 is chosen as it is recommended in British Standards. As for this design, the use of reinforced concrete is crucial. The strength of this structure would be higher compared to plain concrete, suppressing the probability of getting damaged when reacting with waves. By reinforcing the concrete, the durability of the structure will be higher. Marine growth on concrete has generally been considered beneficial as it keeps the concrete wet, thereby resisting diffusion of gases which means lowered the corrosion rates of the concrete. From this situation, it means that if concrete used as the main material for the structure, it can act both ways. The concrete can courage marine growth and at the same time maintain the wetness of the concrete.

3.4 Model Design

'Trape Reef' is modeled so that it can be fitted in the wave flume for the testing purpose. The dimensions of the model are 50 cm long, 30 cm wide and 15 cm high, as shown in *Figure 3.2 – 3.4*. The figures show the model designed from three main views which are plan, side, and front view as to give clearer view on this design. The dimensions, in cm, are also attached in the figures. The model is to be constructed of concrete, covered by a layer of rough mortar to increase the surface roughness.

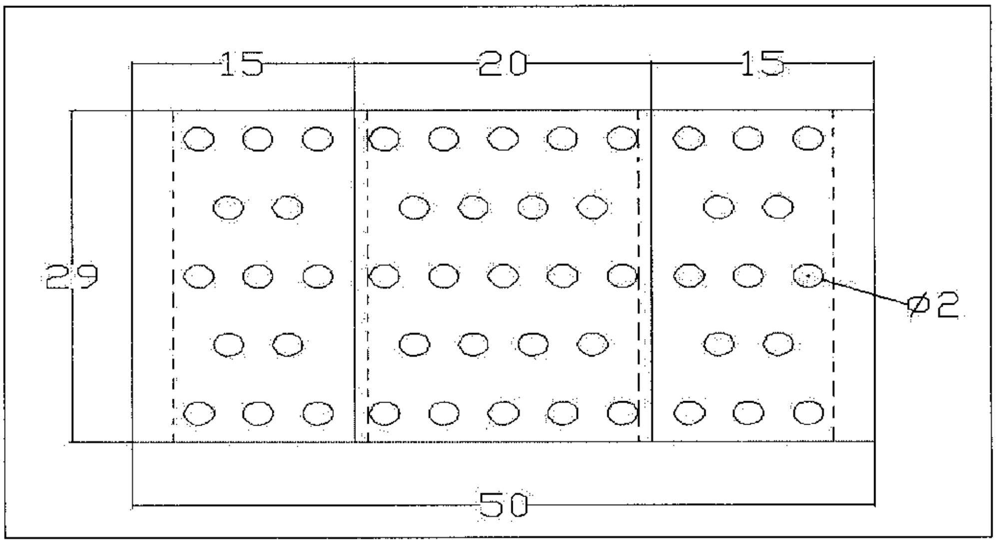


Figure 3.2: Plan view of 'Trape Reef'

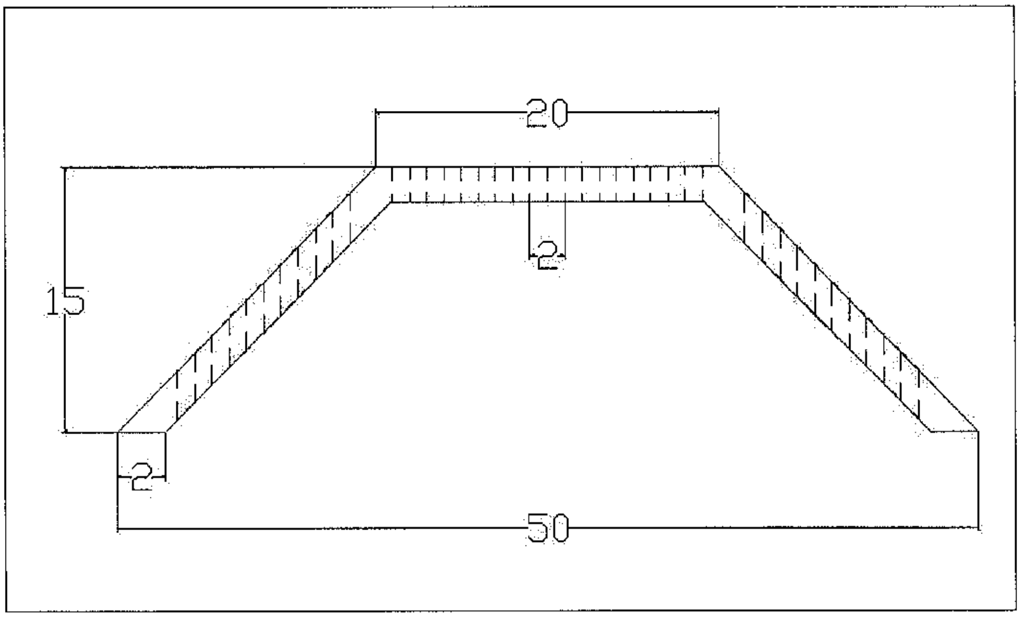


Figure 3.3: Side view of 'Trape Reef'

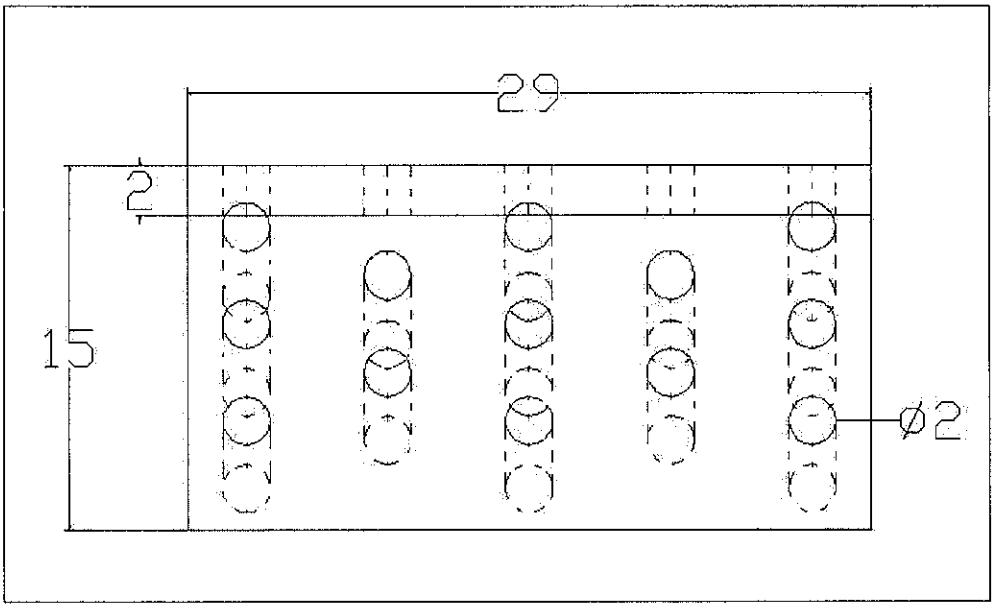


Figure 3.4: Front view of 'Trape Reef'

3.5 Construction of 'Trape Reef' Model.

In order to construct a working model of 'Trape Reef', a mould has to be constructed first. The mould is constructed using plywood. After the construction using plywood completed, pipes with the specified height of 5 cm are attached to the plywood. *Plate 3.1* shows the mould that has been constructed. Two moulds have been constructed as two set of models. One model used for the experiment whiles the other one act as substitute if any damage happens to the first model.

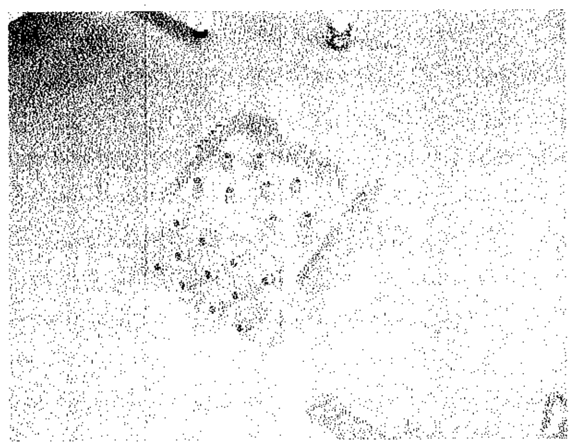


Plate 3.1: Mould to construct 'Trape Reef' Model.

After the completion of the mould, the mixture of mortar then poured into the mould as shown in *Plate 3.2*. Compaction was then done by using vibrator. After the compaction process completed, the mixture then left to for curing. After the curing stage, the model now can be applied for experiment.

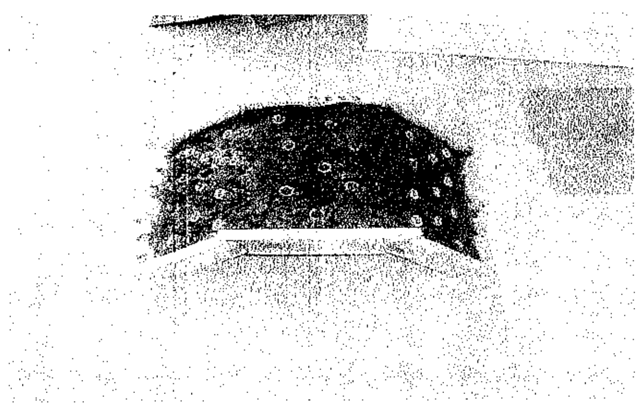


Plate 3.2: Mixture in mould.

CHAPTER 4
EXPERIMENTAL SETUP

4.1 Introduction

A comprehensive model testing has to be done in the laboratory to monitor the performance of the model designed. The experimental works will be done in the Hydraulic Laboratory of UTP. To obtain quality result, it is essential to be familiarized with the equipment and instrumentation used. The application of the apparatus will be explained in this chapter. Before running the experiment with the designed artificial reef model, preliminary tests were done to investigate the incident wave spectrums in the wave flume. A series of experiment had been carried out to study the effectiveness of the 'Trape Reef' in transmitting the wave energy. The setup for 'Trape Reef' also explained in this chapter.

4.2 Laboratory Tools and Equipments

The laboratory experiments are conducted in wave flume with a 10 m long, 0.3 m wide, and 0.45 m high wave flume as shown in *Plate 4.1*. It has a rigid steel bed and the sides are lined with glass panels for the entire length of flume for observation of the processes inside the flume. Unidirectional regular waves are generated by flap-type wave paddle as shown in *Plate 4.2*.

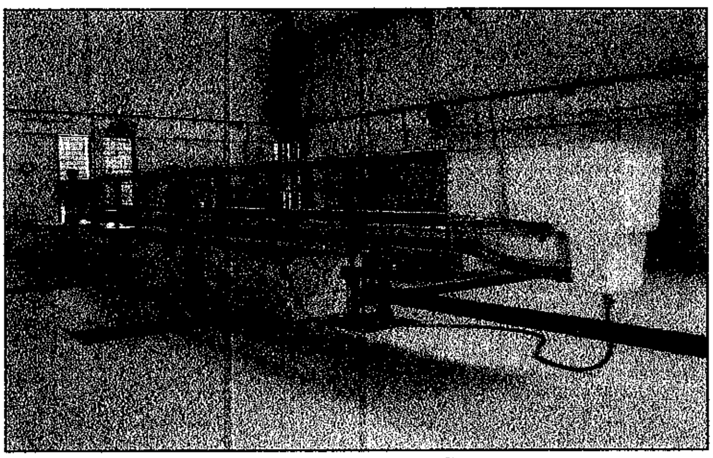


Plate 4.1: Wave flume

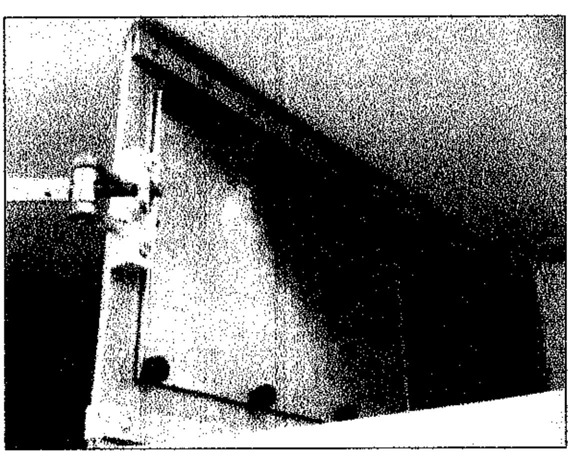


Plate 4.2: Flap-type wave paddle

Plates 4.3 illustrate the wave generator driven by a worm gear motor. The rotary movement of the motor is converted into a stroke motion of the movable overflow weir via a crank disc with push rod. All electrical switching units required for operations are located in the cover of the switch box (*Plate 4.4*). The rotational speed gives the stroke frequency of the wave generator and can be adjusted via a 10-gear helical potentiometer.

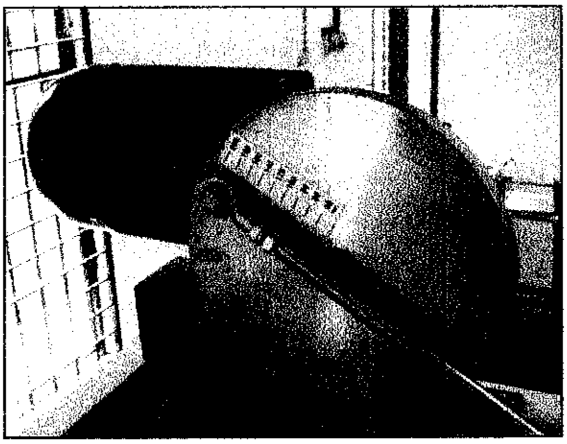


Plate 4.3: Wave generator

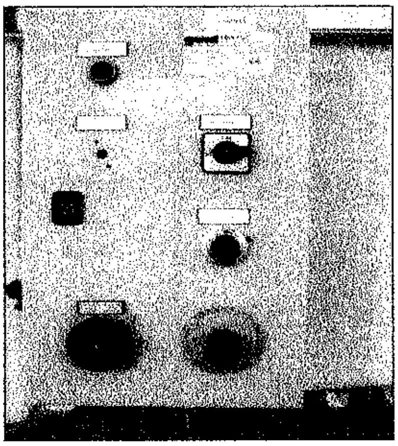


Plate 4.4: Switch box

The hook and point gauge, as shown in *Plate 4.5*, are used to measure water level in the wave flume. The vertical distance between the measured water level and the bed level of the flume gives the water depth.

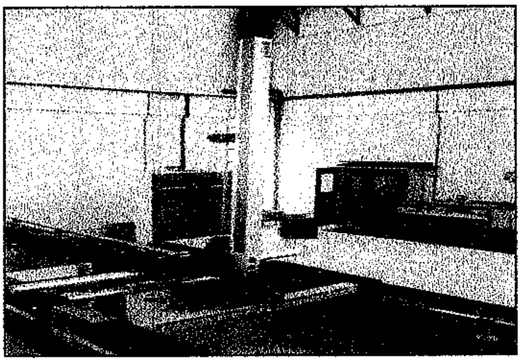


Plate 4.5: Point gauge

4.3 Preliminary Tests

For this project, the incident wave heights will have to be determined by conducting experiments in the laboratory. The incident wave heights are determined under the regular wave condition in the wave flume. There are two stages for this experiment, which are without any structure in the wave flume, and with a wave absorber attached into it. For this phase, the 'Trape Reef' is not attached yet into the wave flume.

The approach to determine the incident wave height is by observing the wave propagation in the wave flume marks are put using the whiteboard marker. There are at least ten marks for each wave frequency as it is better to have a lot of data to ease the analysis in the future.

The procedures to conduct the preliminary tests are:

1. The wave flume floor bed is ensured to be level with no tilting.
2. The height of the scanning point is fixed to an assigned level (20 cm, 25 cm, and 30 cm) above the flume base with the aid of a knurled screw.
3. The wave flume is filled with water by controlling the valve, until the scanning point touches the required water level.
4. The valve is closed once the water has reached the required level.
5. The stroke adjusted to a predetermine4d value.
6. The frequency of the generator is set to a rotational speed of 23 rpm by adjusting the 10-gear helical potentiometer.
7. The wave parameters such as water depth, stroke frequency and stroke adjustment are recorded.
8. To measure the wave heitg, a marker pen and measuring tape is used. However, this can only be done once the waves in the flume are founde to be stable, which

usually takes 2-3 minutes. 10 measurements are obtained to reduce the measurement error.

9. To measure the wave period, a point is marked on the crank disk and then, the time taken by the marked point to revolve 10 revolutions is recorded. 3 measurements are obtained to reduce measurement error. Another method to measure the wave period is to observe the motion of the paddle. Each time the paddle moves back and forth is equivalent to a revolution made by the crank disk.
10. The point gauge is checked constantly to ensure that the water depth is always maintained at the required level.
11. The above steps are repeated by using different stroke frequencies which are 24 rpm, 25 rpm, 27 rpm, 29 rpm, 31 rpm, 34 rpm, 37 rpm, 40 rpm, 44 rpm, 50 rpm, 56 rpm, 64 rpm, 74 rpm, 88 rpm, and 108 rpm.
12. The same procedures also applied after the placement of wave absorber.

The data gathered during the experiment is the wave heights obtained with respect to the frequency and stroke adjustment set in three water depths which are 20 cm, 25 cm, and 30 cm. The stroke adjustments are 80 mm, 140 mm, and 200 mm. The data then used to find the maximum wave height, H_{max} and minimum wave height, H_{min}.

From the H_{max} and H_{min} obtained, incident wave height, H_i and reflection wave heitgh, H_r can be directly obtained from the equation

$$H_i = (H_{max} + H_{min}) / 2 \qquad (4.1)$$

$$H_r = (H_{max} - H_{min}) / 2 \qquad (4.2)$$

By obtaining the H_i and H_r, the most crucial value for this experiment which is coefficient of reflection, C_r is obtained from equation

$$C_r = H_r / H_i \qquad (4.3)$$

4.3.1 Wave Absorber

Reflection of wave energy from boundaries is one of the common laboratory effects that will lessen the accuracy of the experimental results. Researchers should ensure the testing facilities are free from significant reflected waves prior to any experimental activities. Wave absorber is a defense structure located at the reflective boundaries of wave basin or wave flume. The purpose of this structure placed in the wave flume is to attenuate the incoming wave energy through various wave dissipation mechanisms which have been discussed in Chapter 2.

An attempt had been made to develop a wave absorber that to be located at the rear of the flume as mentioned in Section 4.2. The wave absorber will be placed at the end of the wave flume as shown in *Plate 4.6*. The angle of interest for this preliminary test is 15 degree. The wave absorber is made of galvanized iron covered by a layer of grass-like floor mat, as shown in *Plate 4.7*. The placement of the floor mat on the galvanized iron frame is shown in *Plate 4.8*.

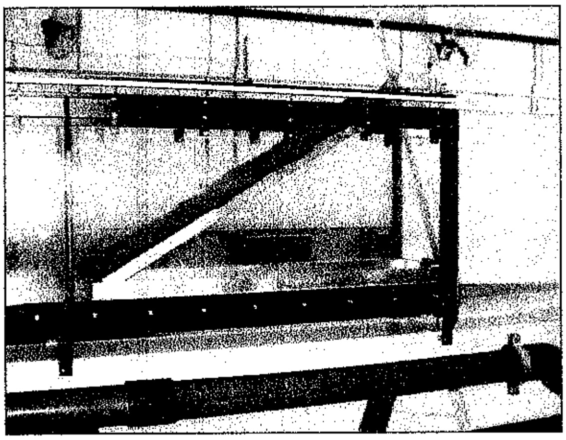


Plate 4.6: Placement of the wave absorber in the wave flume.

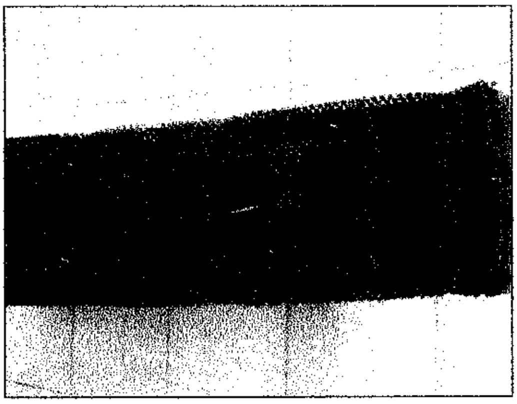


Plate 4.7: Wave absorber designed

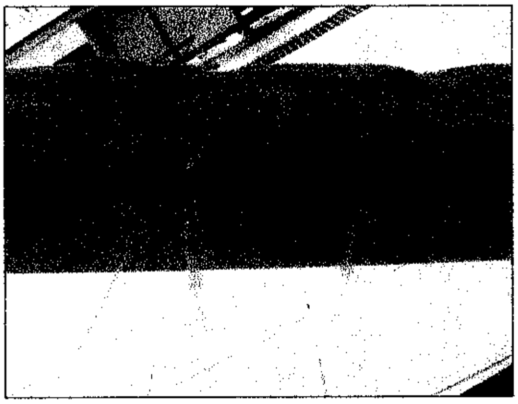


Plate 4.8: Placement of the floor mat

Some other features are also incorporated in the existing design of wave absorber, so as to make it a more flexible and durable structure. These features are listed as follows:

Foldable when not in use

This newly designed wave absorber is easy to handle. When it is not in use, it can be easily folded for storage. The folded wave absorber is shown in *Plate 4.8.*

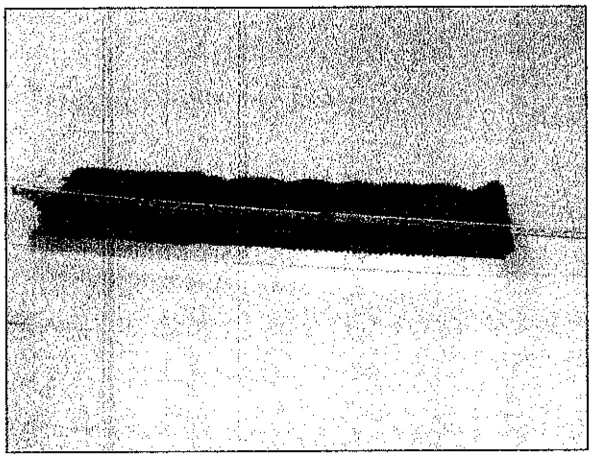


Plate 4.9: Folded wave absorber

Adjustable slope

The wave absorber is designed for the purpose to find the most optimum angle to reduce the wave reflection. The slope angle of the wave absorber can be adjusted from 0 to 90 degree. *Plate 410* shows the wave absorber with a 15° slope while wave absorber for 30° slopes shown in *Plate 4.11*. The inclination angle of the wave absorber plate can be fixated by locking the bolt and nut onto an iron bar with slots as shown in *Plate 4.12*.

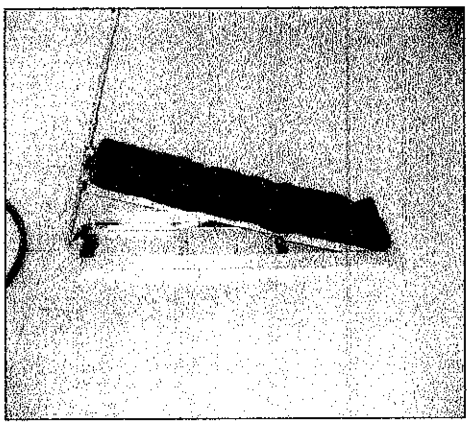


Plate 4.10: 15 degree wave absorber

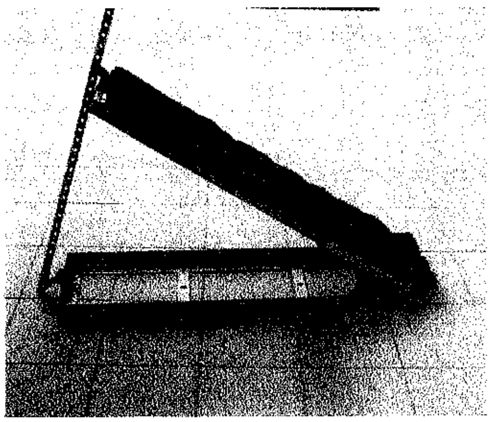


Plate 4.11: 30 degree wave absorber

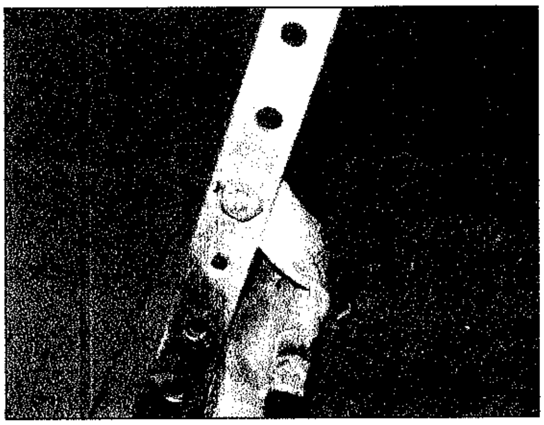


Plate 4.12: Locked with bolt and nut

Anti-corrosion

As the wave absorber will be in contact with water in the wave flume during the experiment stage, the frames of the wave absorber, which is made of steel, is prone to corrosion. Therefore, the steel frames need to be covered with Galvanized Iron, that will last for 10 years.

4.4 Tests on 'Trape Reef'.

The model of 'Trape Reef' is placed in the middle of the flume in order to gather data of reflected wave height and transmitted wave height as shown in *Plate 4.13.* Reflected wave height is measured at the front of the model. For transmitted wave height, the measurement taken at the leeside of the model. However, the measurement should be done 30 cm from the back of the model. *Figure 4.1* summarized the explanation that has been given.

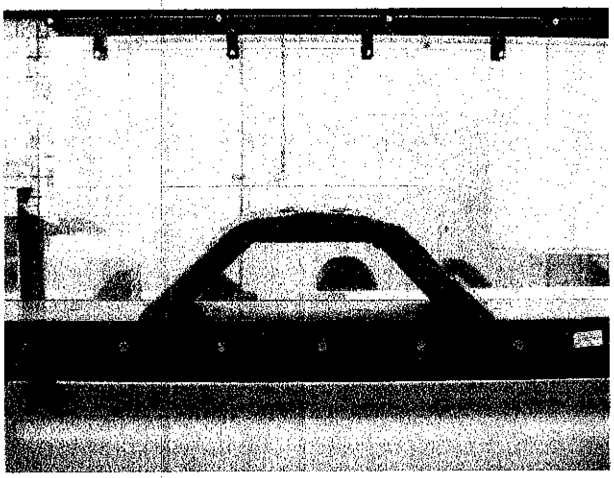


Plate 4.13: Placement of Model in Wave Flume.

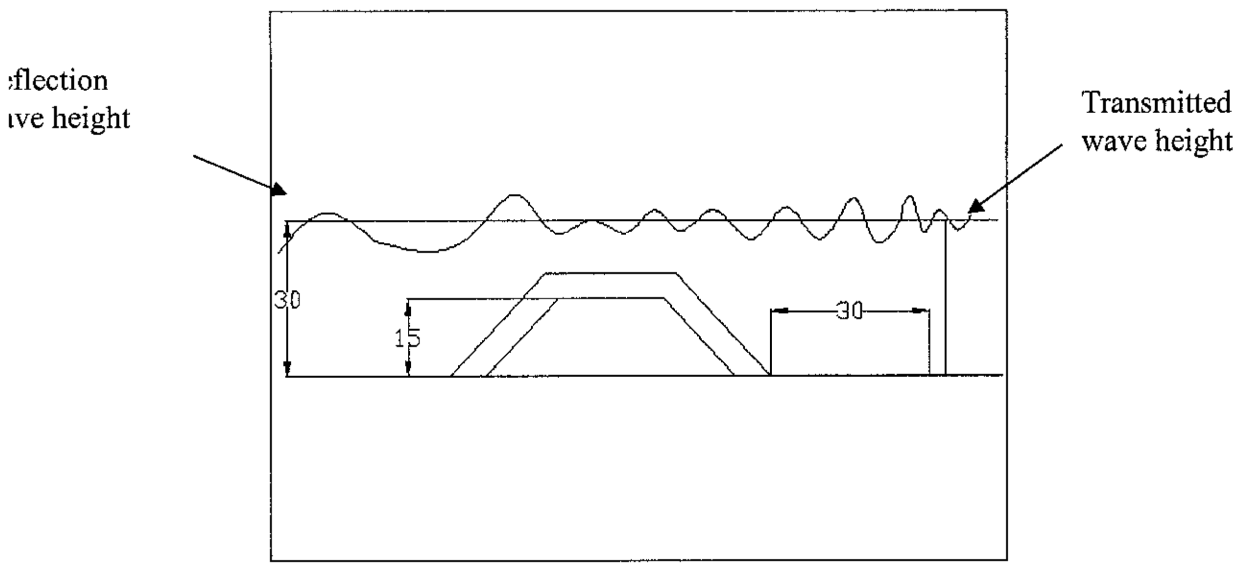


Figure 4.1: Experimental setup for ‘Trape Reef’.

CHAPTER 5
RESULTS AND ANALYSIS

5.1 Introduction

As discussed in Chapter 4, reflection of wave energy from boundaries is the most common laboratory effects that can affect the accuracy of experimental results. Therefore, before conducting the experiment to evaluate the performance of the artificial reef, the first task that needs to be done is to minimize the wave reflections in the wave flume. A wave absorber was designed to reduce the wave reflection in the wave flume. The performance of the wave absorber was tested in the Hydraulic Laboratory of UTP and the experimental results were analyzed and interpreted with the aids of graphical presentations.

5.2 Determination of Wave Period

Wave period is usually related to the stroke frequency that is generated from a wave generating system. Experiments were carried out to determine the observed wave period corresponding to a range of stroke frequency yielded from the wave generating system of the wave flume. For each stroke frequency, 3 measurements of the observed wave period were done using stop watch for the stroke adjustments of 80 mm, 140 mm, and 200 mm, respectively. Since wave period is not subjected to the change of stroke adjustment, an average of the three measurements for each stroke frequency was obtained. Table 5.1 shows the summary of the average observed wave periods with respect to various stroke frequencies.

Table 5.1: Relationship between stroke frequency, stroke adjustment and wave period.

Stroke frequency (rpm)	Predicted wave period (s/rev)	Observed wave period, T (s)			
		S = 80 mm	S = 140 mm	S = 200 mm	Average
108	0.56	0.50	0.47	0.50	0.49
88	0.68	0.64	0.61	0.61	0.62
74	0.81	0.75	0.74	0.75	0.75
64	0.94	0.89	0.87	0.89	0.88
56	1.07	1.04	1.03	1.05	1.04
50	1.20	1.15	1.18	1.21	1.18
44	1.36	1.37	1.36	1.38	1.37
40	1.50	1.55	1.52	1.56	1.54
37	1.62	1.70	1.68	1.73	1.71
34	1.76	1.90	1.88	1.92	1.90
31	1.94	2.14	2.10	2.17	2.14
29	2.07	2.34	2.38	2.40	2.37
27	2.22	2.58	2.64	2.65	2.63
25	2.40	2.88	2.95	2.94	2.92
24	2.50	3.07	3.13	3.11	3.11
23	2.61	3.27	3.34	3.37	3.32

NOTE: S = Stroke Adjustment

Figure 5.1 illustrates the graph of wave period against stroke frequency. The observed wave periods of the stroke adjustments of 80 mm, 140 mm, and 200 mm for stroke frequency ranging from 23 to 108 rpm were plotted in the figure. To relate the observed wave period and stroke frequency, an exponential curve was plotted. From the graph, it can be concluded that the wave period decrease exponentially with the increasing stroke frequency. This calibration chart is a useful reference to the researches to determine the stroke frequency that needs to be set on the wave generating system for a predetermined wave period

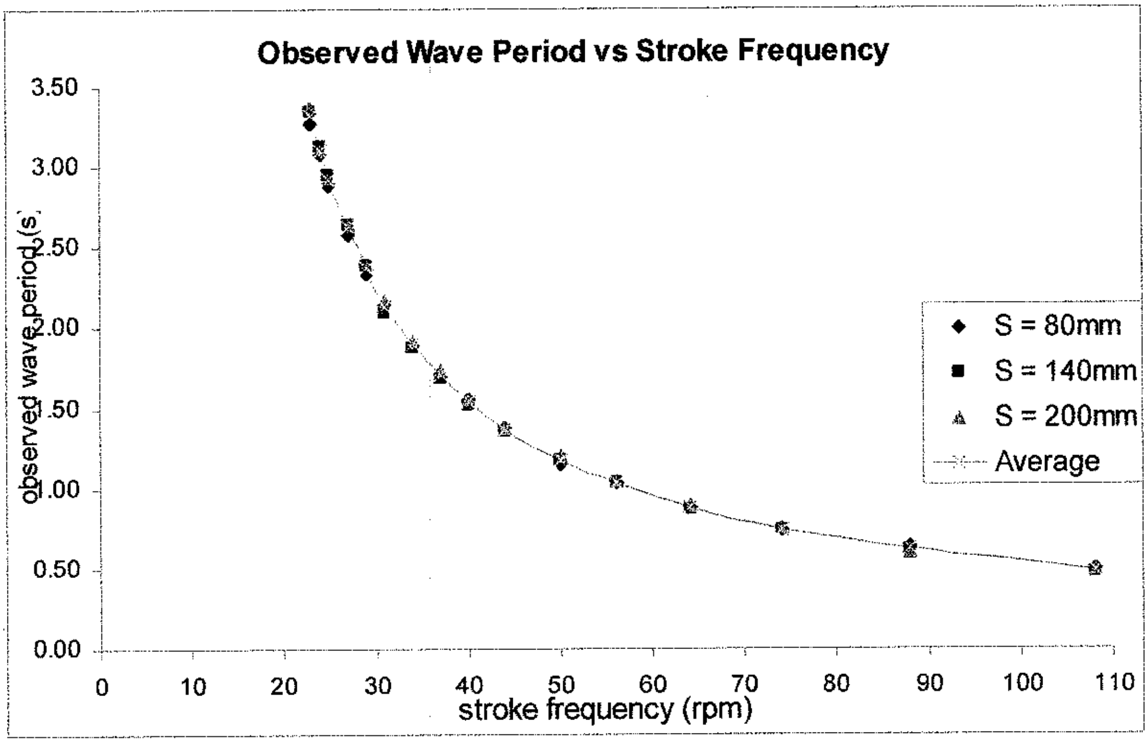


Figure 5.1: Observed wave period vs stroke frequency

5.3 Preliminary Tests

Preliminary tests were conducted prior to the actual experiments to study the incident wave characteristics with respect to various water depths, wave periods, and stroke adjustment. A series of experiments were carried out in the unidirectional wave flume without the tested structures, to study the degree of wave reflection produced from the vertical wall at the rear of the flume.

Figure 5.2 shows coefficient of reflection, C_R versus wave period, T without the tested structure in the flume.

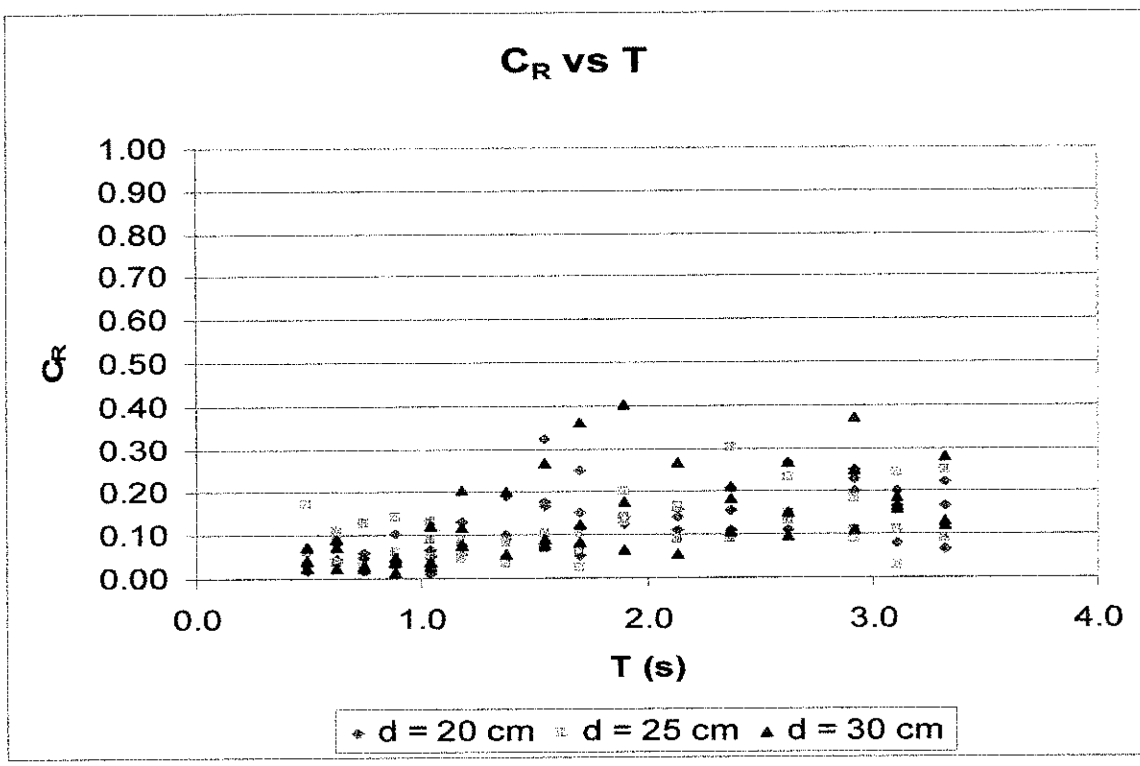


Figure 5.2: Coefficient of Reflection, C_R versus wave period, T

It can be seen that the C_R value for each water depth are rather scattered than those in *Figure 5.2* within the tested range of wave period. No similar trend can be observed from the C_R values with respect to different water depth. However, it can be seen that C_R is subjected to the stroke adjustment when T > 1.0 s. the highest C_R value recorded in the figure is 0.40 when T = 1.90 s and d = 30 cm. Overall, it can be said that C_R increase with the increasing wave period, regardless of water depth. The ranges of C_R value with respect to water depths are summarized in *Table 5.2.*

Table 5.2: Range of C_R with respect to T in different water depth

Water depth (cm)	C_R value
20	0.01 – 0.32
25	0.03 – 0.30
30	0.01 – 0.40

An attempt is also made to relate C_R with wave steepness parameter, H_i / gT^2 for water depth of 20 cm, 25 cm, and 30 cm. it is noticed that the greater the water depth, the more significant the wave reflection to be. However, variation of C_R with respect to H_i / gT^2 is less appreciable. For $0 < H_i / gT^2 < 0.02$, the average C_R for water depth of 20 cm, 25 cm, and 30 cm are 0.55, 0.40 and 0.30, respectively. The graph plotted is shown in *Figure 5.3.*

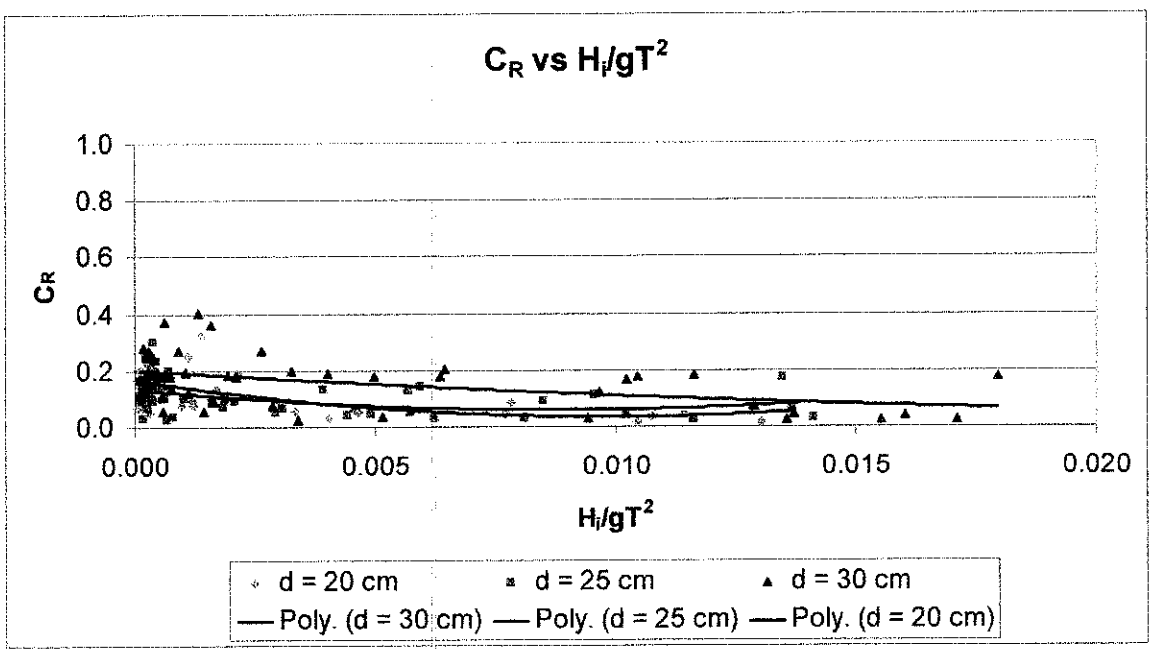


Figure 5.3: Coefficient of Reflection, C_R versus H_i / gT^2

Figure 5.3 indicates the C_R points for 3 water depths exhibited with respect to H_i / gT^2. It shows the C_R values are less dependent on H_i / gT^2 due to the small variation of C_R recorded for a range of H_i / gT^2. However, the trend of decreasing of C_R with increasing H_i / gT^2 is still applicable in the case where wave absorber is installed. The deeper the water, the more significant is the reflected waves occurred in the wave flume. The highest value of C_R also obtained at water depth of 30 cm. most of the data points are scattered within $0 < H_i / gT^2 < 0.2$, in which the reflected energy is only 4% of the incident wave energy.

5.4 Experimental Test on 'Trape Reef'.

After the placement of the 'Trape Reef', as explained in Chapter 4, reflected wave height and transmitted wave height are measured. From the set of data gathered from the experiment done, reflection coefficient, C_R transmission coefficient, C_T and loss coefficient, C_L can be calculated and analyzed by applying a few parameters to observe the pattern that produced by the model designed. The parameters applied are H_i/gT^2, d_i/gT^2, and B/L.

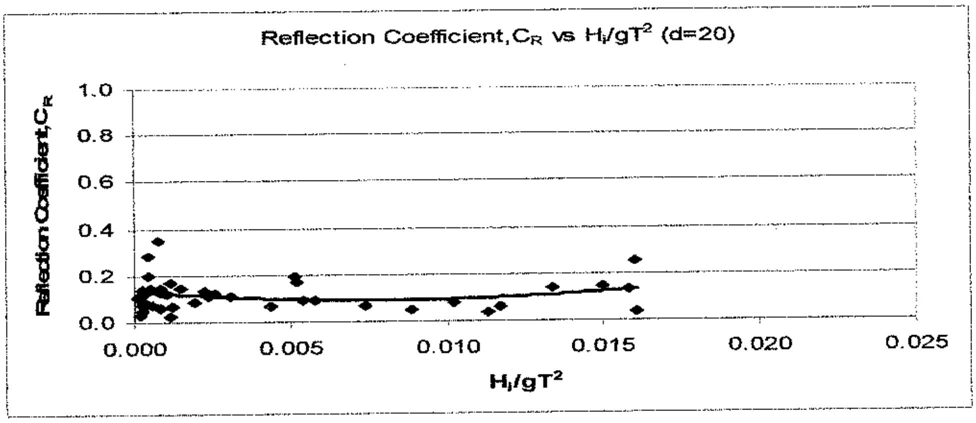
5.4.1 Reflection Coefficient, C_R vs H_i/gT^2

An attempt is made to relate C_R with wave steepness parameter, H_i / gT^2 for water depths of 20 cm, 25 cm, and 30 cm. The graphs relating these two parameters in the 3 water depths are shown in *Figure 5.4. Figure 5.4a* presents the C_R value for water depth of 20 cm. The range of C_R values are $0.10 < C_R < 0.35$. The lowest C_R value obtained from this graph is 0.1 which is the lowest C_R value among the three graphs presented in *Figure 5.4.* The range of the C_R values for water depth of 25 cm (*Figure 5.4b*) is $0.10 < C_R < 0.40$, which is slightly greater than that of 20 cm water depth. From the scattered data points shown in *Figure 5.4c*, it yields the greatest C_R range ($0.1 < C_R < 0.45$) compared to those in 20 cm and 25 cm water depth. Generally, from the observation from these three figures, it can be said that C_R points are inorderly scattered when H_i / gT^2 ranging from 0.000 to 0.005. Most of all, *Figure 5.4* shows that C_R increases when water depth increases.

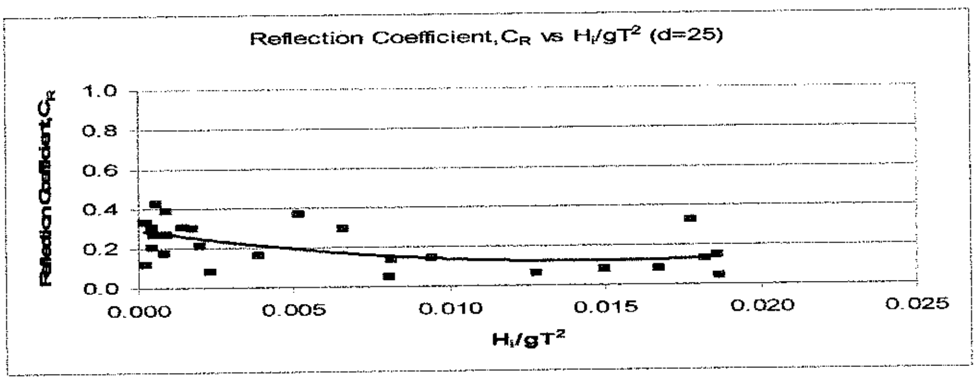
Table 5.3 summarizes the range of C_R in 20 cm, 25 cm, and 30 cm water depths..

Table 5.3: Summary of C_R value range

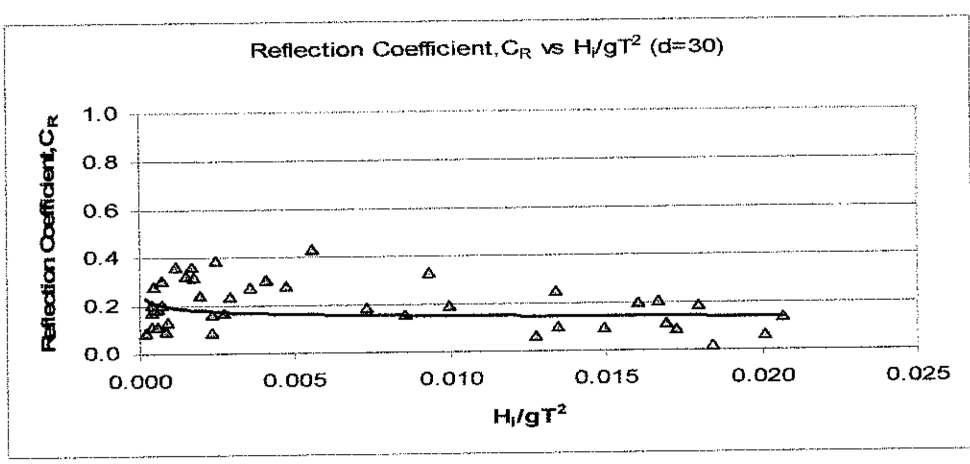
Water depth (cm)	Range of C_R values
20	0.05-0.35
25	0.05-0.40
30	0.05-0.45



(a)



(b)



(c)

Figure 5.4: Reflection Coefficient, C_R vs H_i/gT^2 (a) d = 20cm; (b) d = 25cm; (c) d = 30cm

5.4.2 Reflection Coefficient, C_R vs d/gT^2

An attempt is also made to relate C_R with relative depth parameter, d / gT^2. The range of C_R values for 3 water depths are similar as those given in *Table 5.3. Figure 5.5a, 5.5b, and 5.5c* present the relationship for water depth 20 cm, 25 cm, and 30 cm, respectively. In *Figure 5.5b,* the highest d / gT^2 value that reached by C_R values is at 0.11. However, the same pattern of scattered C_R values is quite the same as *Figure 5.5a* which is the C_R points scattered between 0 and 0.2. When it comes to higher range of d / gT^2, the amount of scatter C_R values decrease. Generally, from those three graphs, it can be said that C_R value increases as the water depth increases.

5.4.3 Reflection Coefficient, C_R vs B/L

Most of the C_R points scatter between 0.00 and 0.20 as shown in *Figure 5.6*. 'Trape Reef' is not an effective reflector of wave. This is because there is less significance that has been shown by the figure. The line constructed for each graph (*Figure 5.6a, b, c*) are all showing almost a flat lines. Nevetheless, this figure shows that as water depth increases, C_R also increases.

Table 5.4 below summarizes what has been discussed above.

Table 5.4: Range of C_R and B/L values

Water depth (cm)	Range of C_R values	Range of B/L values
20	0.05-0.35	0.1-1.3
25	0.05-0.40	0.1-1.3
30	0.05-0.45	0.1-1.3

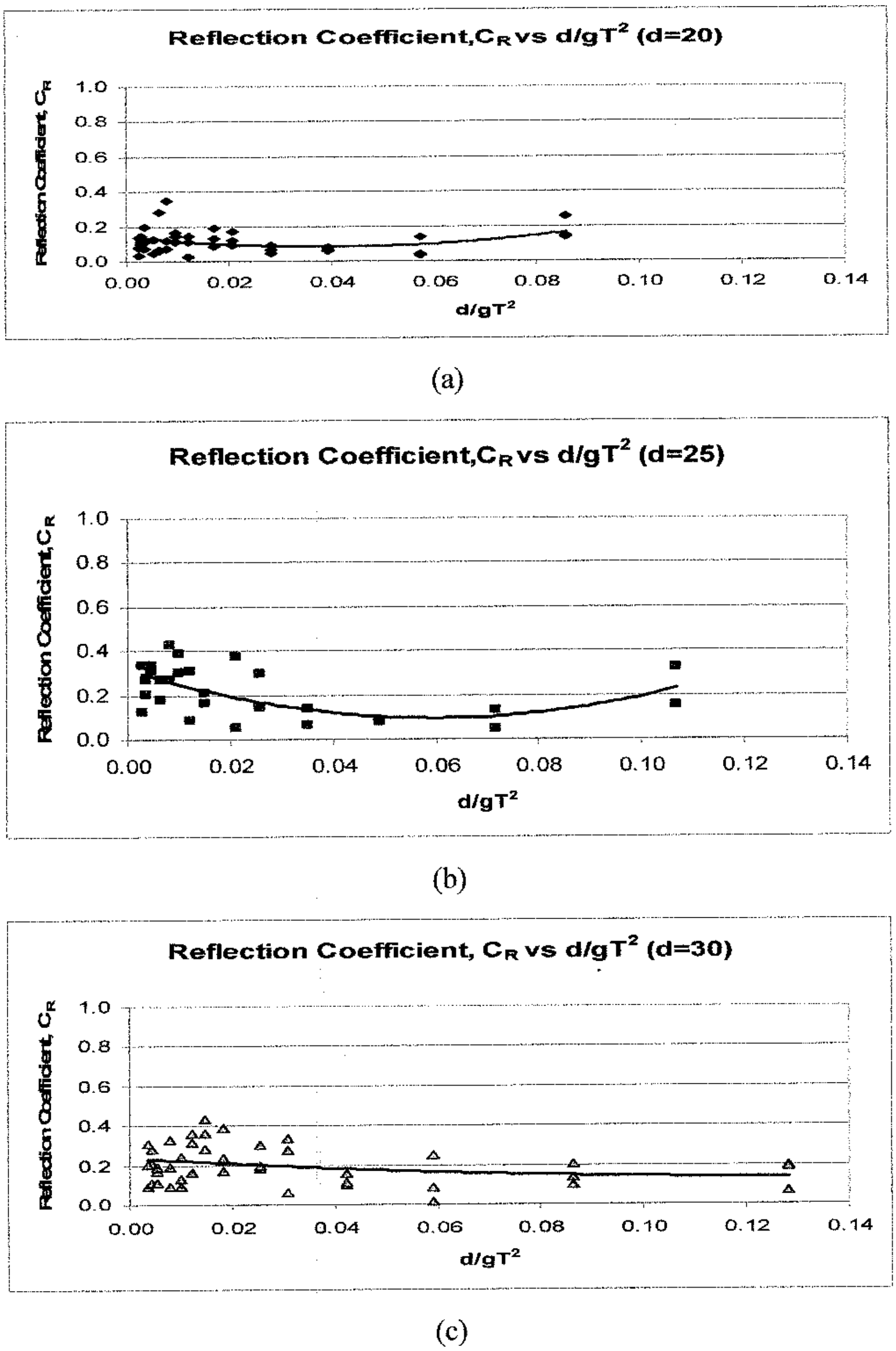
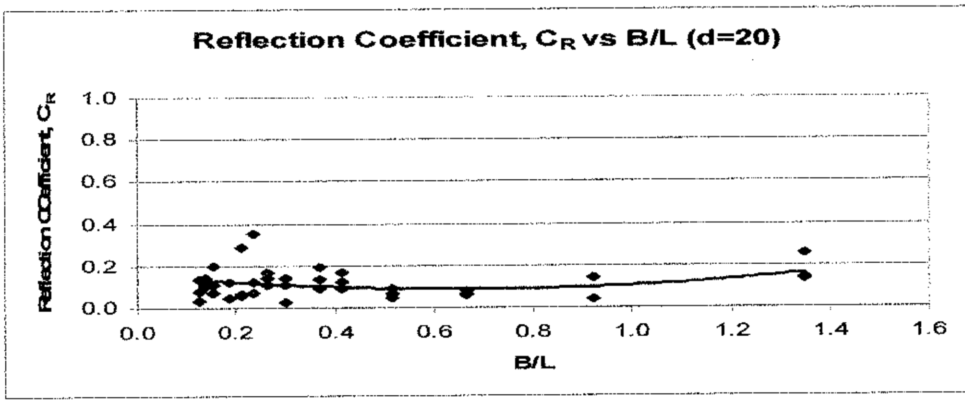
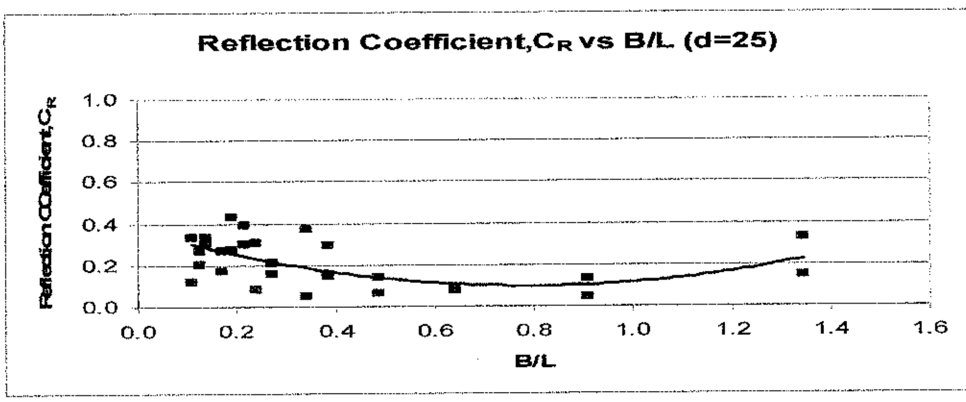


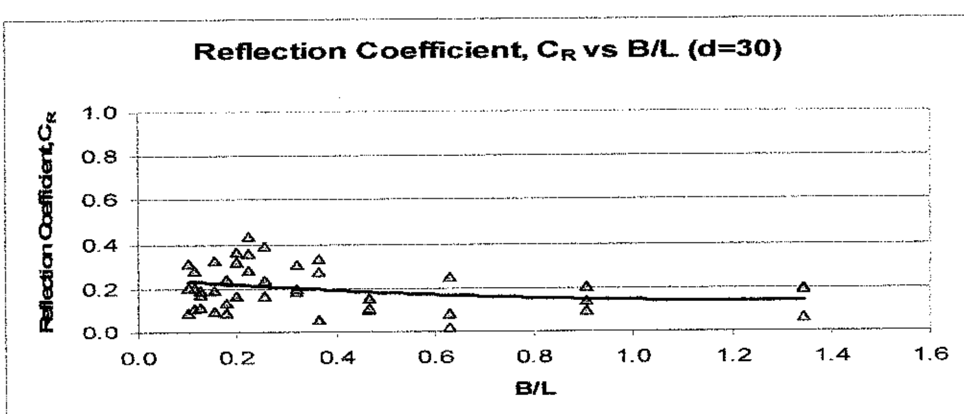
Figure 5.5: Reflection Coefficient, C_R vs d/gT^2 (a) d = 20cm; (b) d = 25cm; (c) d = 30cm



(a)



(b)



(c)

Figure 5.6: Reflection Coefficient, C_R vs B/L (a) d = 20cm; (b) d = 25cm; (c) d = 30cm

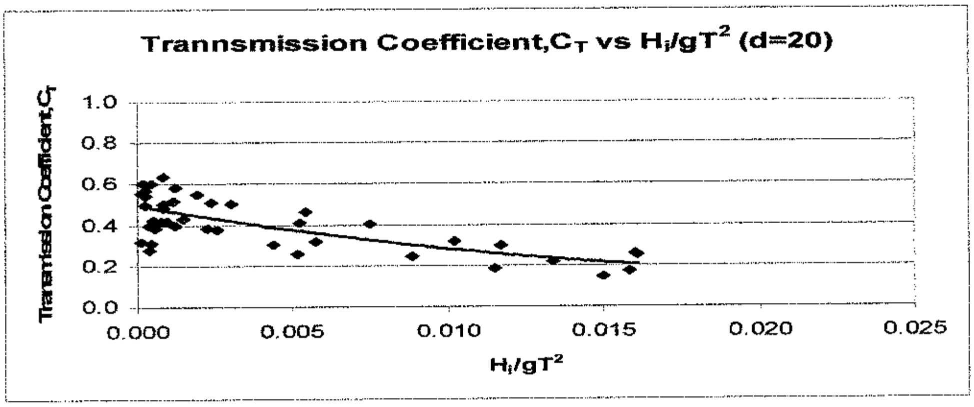
5.4.4 Transmission Coefficient, C_T vs H_i/gT^2

The C_T graphs (*Figure 5.7*) in all water depths present a similar trend when responding to a range if Hi/gT^2. The C_T is almost linearly decreasing with the increasing Hi/gT^2. However, the trend becomes less significant in greater water depth. For instant, in water depth of 30 cm (*Figure 5.7c*), the data point inorderly scatter when $0 < Hi/gT^2 < 0.005$. No definite conclusion can be made at this range of Hi/gT^2. Nevertheless, C_T points are mostly scattered when $0.4 < C_T < 0.6$, when $Hi/gT^2 > 0.005$. At this stage, C_T becomes less dependent on Hi/gT^2.

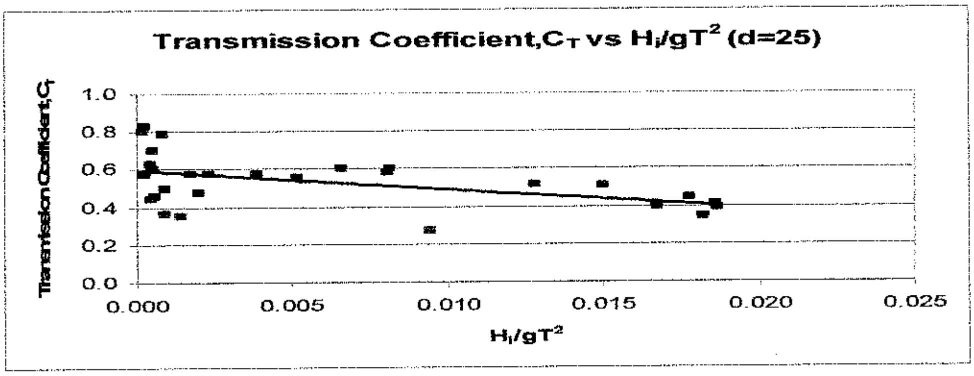
The summarization of explanations above is presented in *Table 5.5* below.

Table 5.5: Summarization of C_T range and H_i/gT^2 range of mostly scattered C_T values

Water depth (cm)	Range of C_T values	H_i/gT^2 range of mostly scattered C_T values
20	0.1-0.6	0.000-0.003
25	0.3-0.8	0.000-0.0002
30	0.3-0.9	0.000-0.004



(a)



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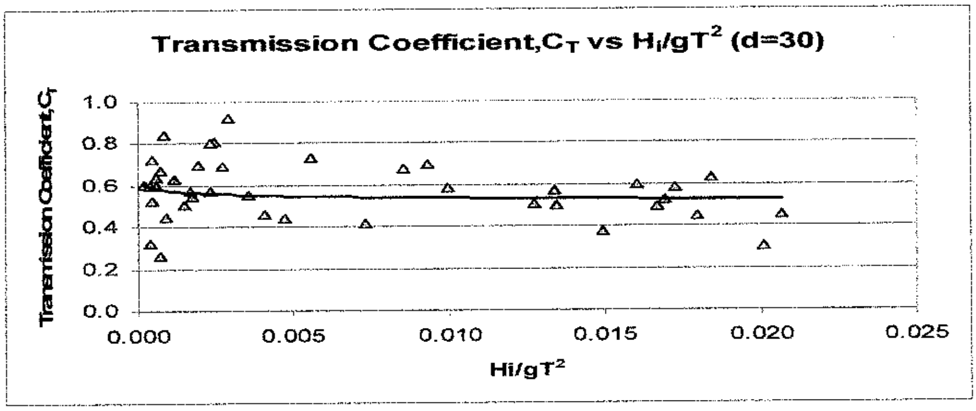


(c)

Figure 5.7: Transmission Coefficient, C_T vs H_i/gT^2 (a) d = 20cm; (b) d = 25cm; (c) d = 30cm

5.4.5 Transmission Coefficient, C_T vs d/gT^2

From *Figure 5.8*, it was observed that as d / gT^2 increases, C_T decreases for all water depths. In d = 30 cm (*Figure 5.8c*), C_T value are mostly scattered at 0.5 when $d / gT^2 > 0.002$. The significance of d / gT^2 becomes lesser as water depth increases. It can be seen that when it comes to *Figure 5.8c*, the line becomes flatter. From the observation of the figure, it can be concluded that the greater degree of submergence, the lesser will be the wave attenuation performance.

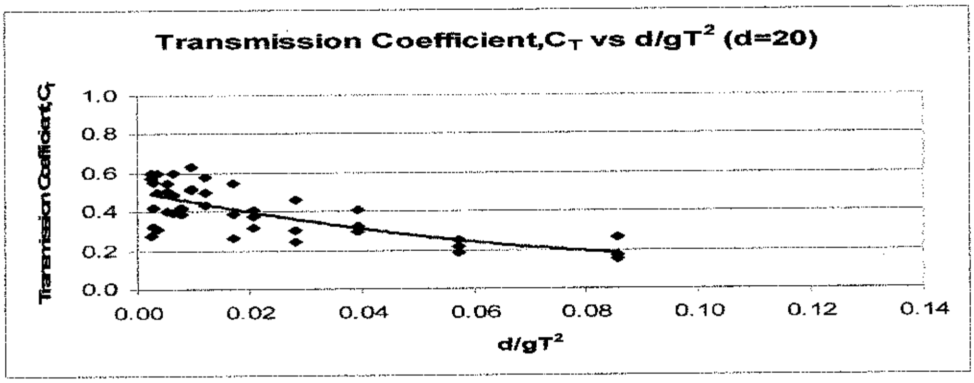
Summarization is presented in *Table 5.6* below.

Table 5.6: Range of d / gT^2 and mostly scattered C_T values.

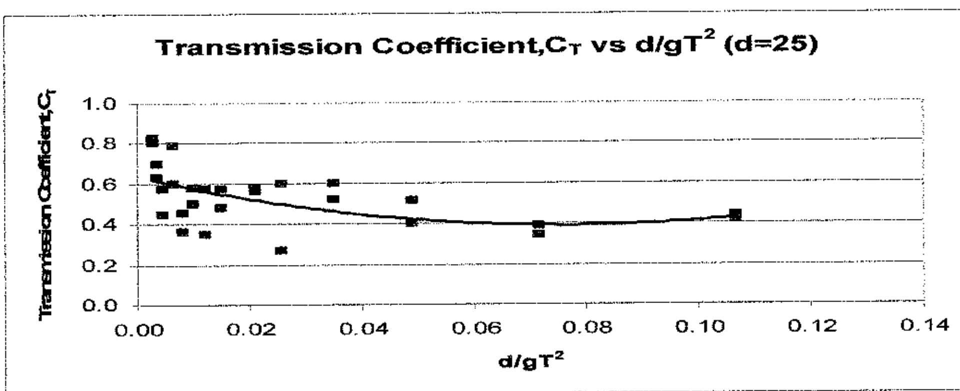
Water depth (cm)	Range of d / gT^2 values	Range of mostly scattered C_T values
20	$0.00 < d / gT^2 < 0.09$	0.00-0.02
25	$0.01 < d / gT^2 < 0.11$	0.00-0.02
30	$0.01 < d / gT^2 < 0.13$	0.00-0.02

5.4.6 Transmission Coefficient, C_T vs *B/L*

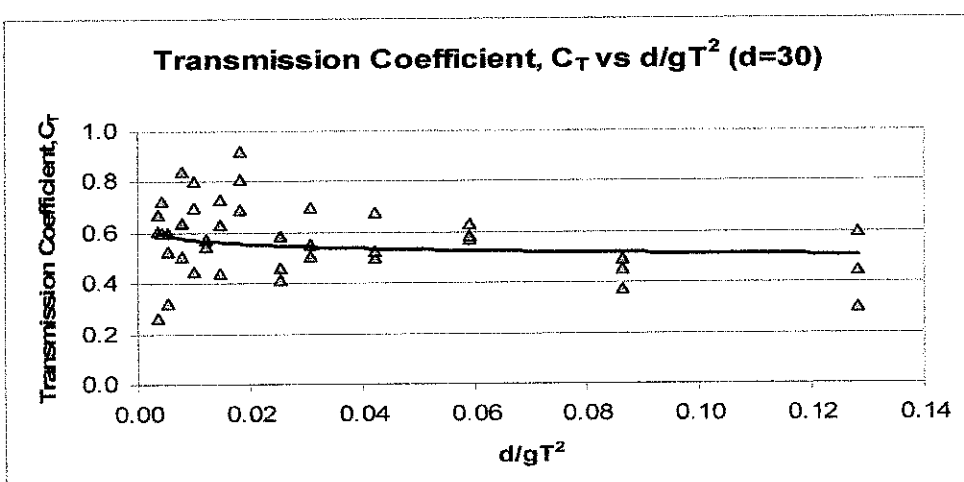
The ratio of width to wavelength, *B/L* is a significant perimeter that affects the wave damping ability of 'Trape Reef'. From the result obtained in *Figure 5.9*, by increasing *B/L*, decreasing C_T will be obtained. Also, by increasing the width, 'Trape Reef' will further diminish the incoming wave energy. However, in water depth of 30 cm (*Figure 5.9c*), an optimum *B/L* value of 0.6 is obtained when $C_T = 0.5$. As a result, it can be said that the wave attenuation performance of the model will not be enhanced by increasing the width of the model.



(a)

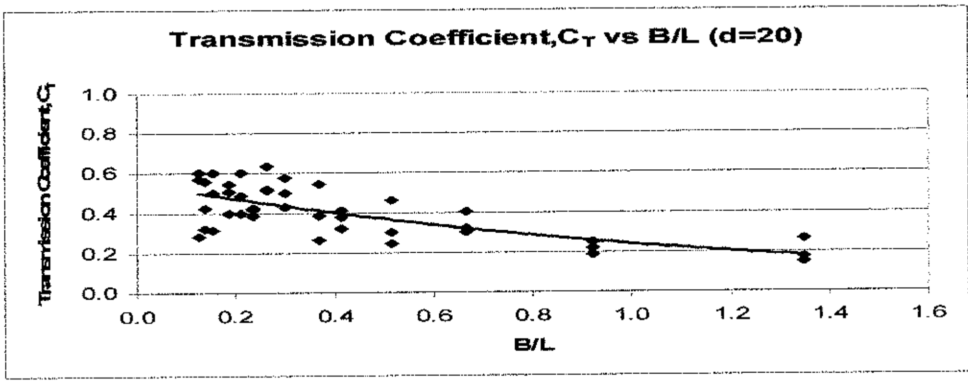


(b)

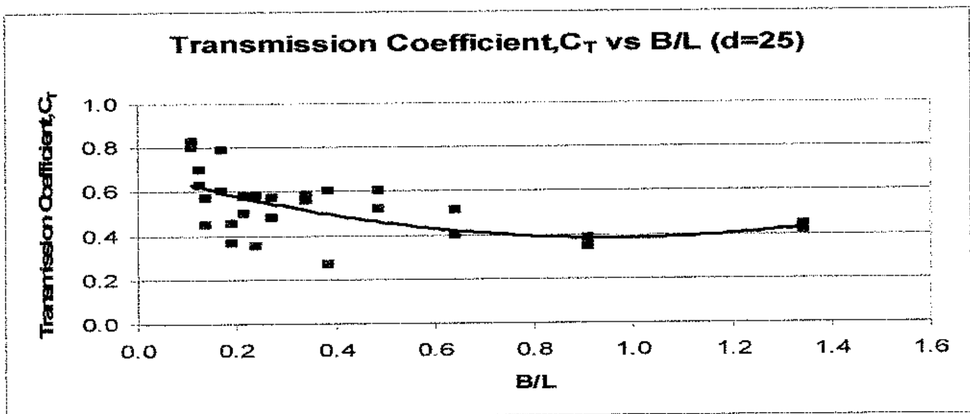


(c)

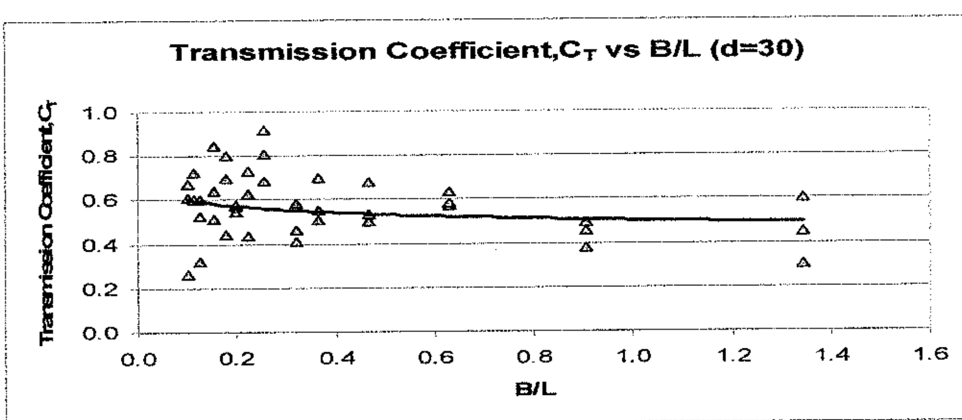
Figure 5.8: Transmission Coefficient, C_T vs d/gT^2 (a) d = 20cm; (b) d = 25cm; (c) d = 30cm



(a)



(b)



(c)

Figure 5.9: Transmission Coefficient, C_T vs *B/L* (a) d = 20cm; (b) d = 25cm; (c) d = 30cm

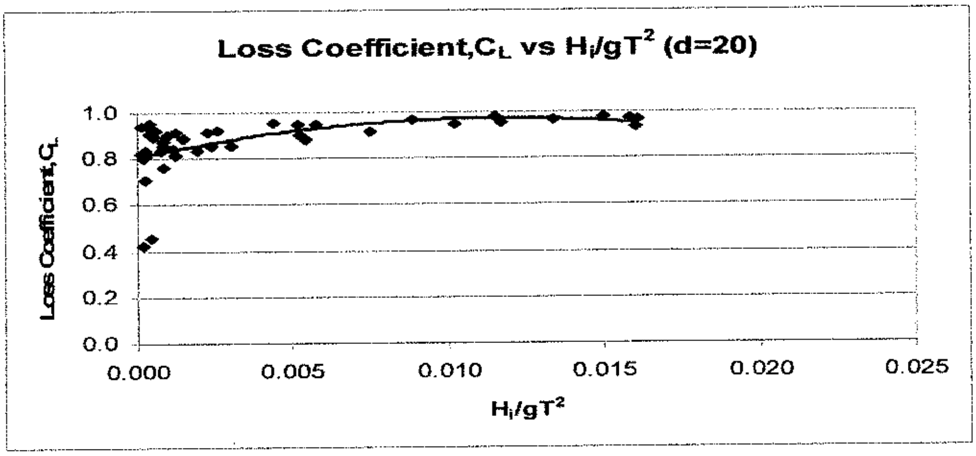
5.4.7 Loss Coefficient, C_L vs H_i/gT^2

From *Figure 5.10*, it shows that as Hi/gT^2 increases, C_L increases. This is because as water depth increases, the degree of submergence also increases, hence the C_L value decreases. This means that wave will easily past through the crest of the model as water depth increases. It also means that less wave energy is dissipated through the friction occurred between the flowing water and the surface of the model. At d = 20 cm (Figure 5.10a), degree of submergence is 0.75. Most of the wave energy is interrupted by the model. Waves break at the seaward edge of the model, causing the wave energy dissipated. The broken waves will proceed on the journey in reduced wave size.

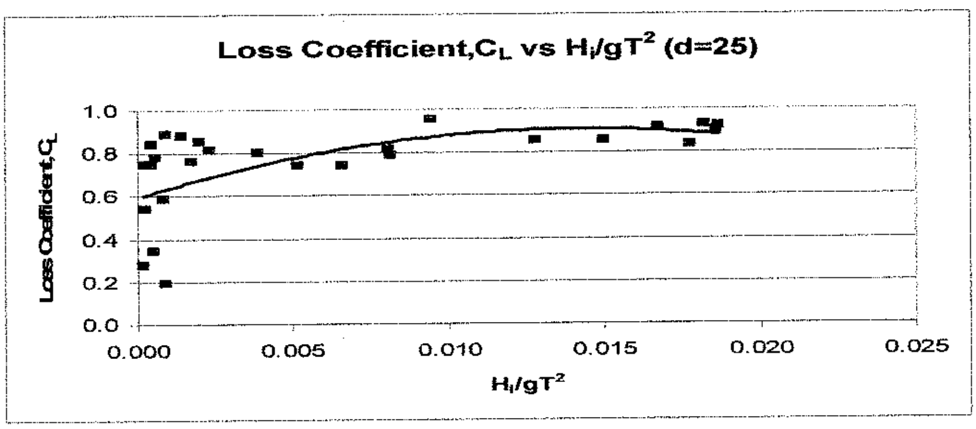
The range of C_L values and range of mostly scattered C_L values are shown in *Table 5.7* below.

Table 5.7: Range of C_L value and most scattered C_L values

Water depth (cm)	Range of C_L values	Range of Hi/gT^2 for mostly scattered C_L values
20	0.4-0.9	0.000-0.005
25	0.2-0.9	0.000-0.005
30	0.3-0.9	0.000-0.005



(a)



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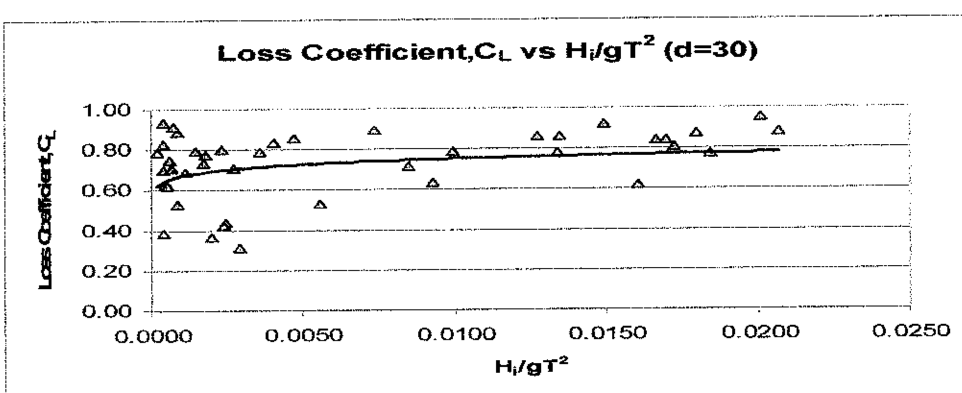


(c)

Figure 5.10: Loss Coefficient, C_L vs H_i/gT^2 (a) d = 20cm; (b) d = 25cm; (c) d = 30cm

5.4.8 Loss Coefficient, C_L vs d/gT^2

As d/gT^2 increases, C_L also increases. This is what has been represented by *Figure 5.11*. Furthermore, it also discovered that when *h/d* increases, C_L increases. It can be seen as at d = 20 cm (*Figure 5.11a*), the *h/d* value is the highest while the lowest *h/d* value is from d = 30 cm (*Figure 5.11c*). The other explanation would be that most of the wave energy is distributed at the upper part of the column of water. Therefore C_L increases when *h/d* increases.

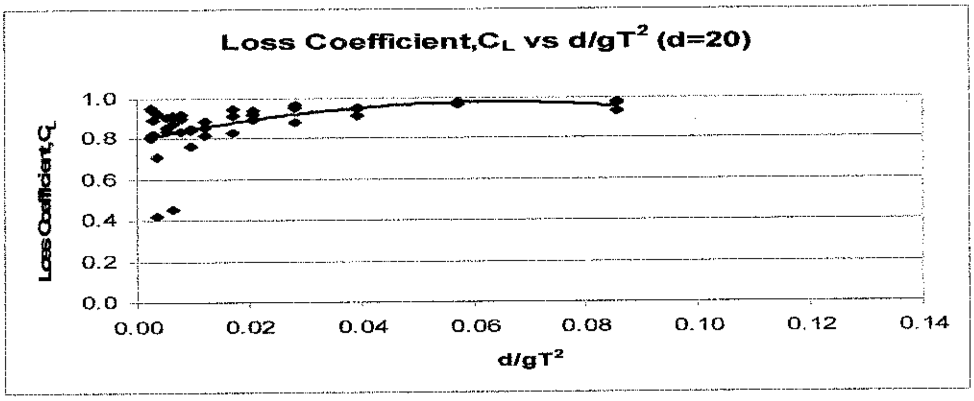
Summarization is presented in *Table 5.8* below.

Table 5.8: Range of d/gT^2 values and mostly scattered C_L values

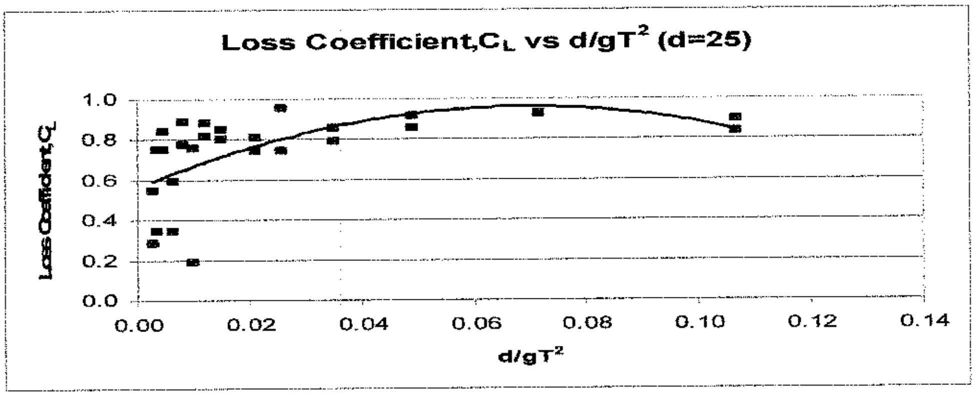
Water depth (cm)	Range of d/gT^2 values	Range of mostly scattered C_L values
20	$0.00 < d/gT^2 < 0.09$	0.00-0.02
25	$0.01 < d/gT^2 < 0.11$	0.00-0.02
30	$0.01 < d/gT^2 < 0.13$	0.00-0.02

5.4.9 Loss Coefficient, C_L vs *B/L*

In *Figure 5.12*, it shows that when *B/L* increases, C_L increases. This is because as *B* increases, surface roughness, friction, and wave dissipation also increases. However, C_L value decreases as water depth increases. An explanation would be as *d* increases, an increasing in degree of submergence also found. This also means less interaction between waves and the model, hence less energy reduction occur. *Figure 5.12* shows that 'Trape Reef' is a good wave dissipater as most of the wave energy is dissipated through friction, and turbulence.



(a)



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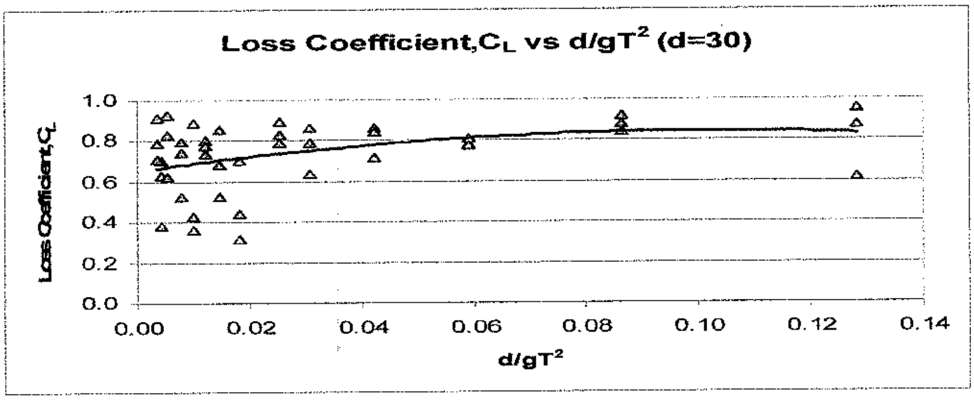
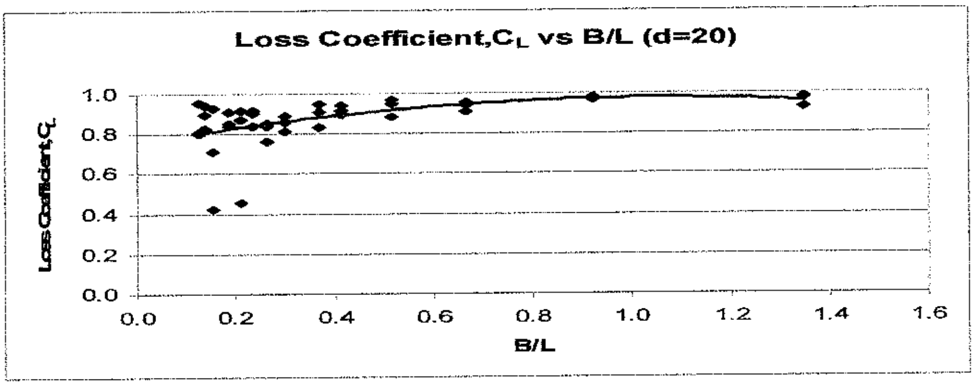
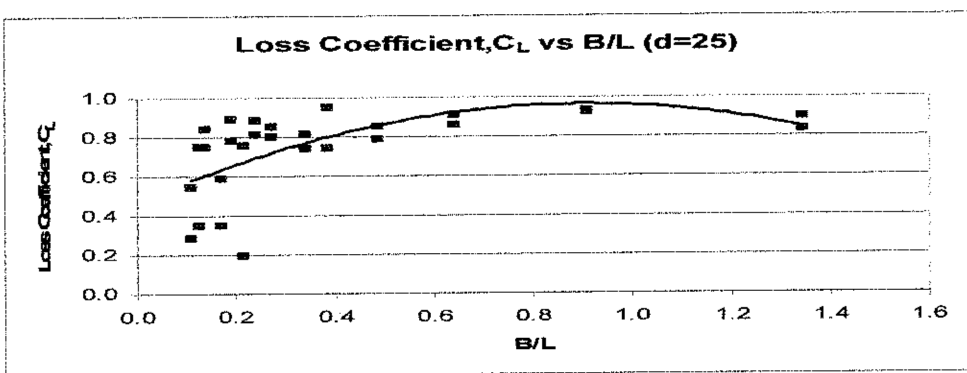


(c)

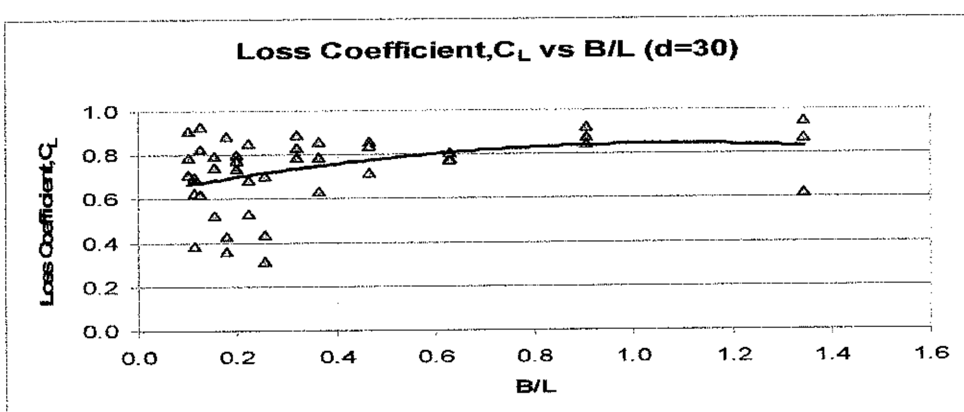
Figure 5.11: Loss Coefficient, C_L vs d/gT^2 (a) d = 20cm; (b) d = 25cm; (c) d = 30cm



(a)



(b)



(c)

Figure 5.12: Loss Coefficient, C_L vs H_i/gT^2 (a) d = 20cm; (b) d = 25cm; (c) d = 30cm

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1: Conclusion

- The main objective, which is to prove the effectiveness of the design, has been done as throughout the semester as preliminary tests have to be conducted first.

- The preliminary tests such as experiments on performance of newly developed wave absorber has been done on the first semester to ensure that the experimental results for 'Trape Reef' would be less affected by the wave reflection generated in the wave flume.

- The newly designed wave absorber has been proved to be an effective tool to reduce the wave reflection effect occurred in the wave flume. The absorber will be applied when the experiments on the performance of 'Trape Reef' are conducted in the flume. After the experiment run on the 'Trape Reef', it can be concluded that the design contributed higher as the water depth increases.

- The ranges of C_R, C_T, and C_R after the placement of the 'Trape Reef' are indicated in *Table 6.1*.

Table 6.1 Coefficient variation for various water depths

Water depth (cm)	C_R	C_T	C_L
20	0.05-0.35	0.1-0.6	0.4-0.9
25	0.05-0.40	0.3-0.8	0.2-0.9
30	0.05-0.45	0.4-0.9	0.3-0.9

- C_R and C_T increases with the increasing water depth.
- C_L decreases with the increasing water depth.

- It is further noticed that the absorber is effectively dissipate the wave energy on its brushy slope and it is capable to bring down the C_R value as low as 0.02 in which the reflected wave s are inappreciable in the wave flume.

6.2: Recommendations

Some of the recommendations are made as to enhance the accuracy of the experimental results on both laboratory and 'Trape Reef'. These recommendations are as follows:

1. An electronic probe to capture the wave profile is needed. The measurements of wave parameters in the wave flume using manual approaches (by observations) are prone to human error. By using the probe equipped with a data acquisition system, errors in readings the data would be reduced and the results of the experiments would be more accurate and precise.

2. A better type of cement additives should be added to the model (eg. Pulverized fuel ash, lightweight aggregates) as to enhance the durability by avoiding the reduction of fatigue endurance of the structure.

3. A longer wave absorber with milder slope should be constructed in order to further improve the wave absorbing performance of the structure. The existing wave absorber is constructed to catch the waves in a maximum water depth of 30 cm in the flume.

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