Experimental Studies of Perforated Plate Breakwaters

By

Mohd Hailmi Bin Othman

Dissertation submitted in partial
fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
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Approved by,

(Dr. Saied Saiedi)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
DECEMBER 2004

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 the original work contained herein have not been undertaken or done by unspecified sources of persons.

Hailmi.

(MOHD HAILMI BIN OTHMAN)

ABSTRACT

The objective of this report is to report the overall view of this project, *Experimental Studies of Perforated Plate Breakwaters* until the end of this semester. This report will discuss about the current status of the project and the theory used to complete this project.

This study is done with the aim to carry out laboratory experiment using various types of perforated plate and calculate the wave transmission and reflection throughout the perforated plates. Several perforated plates will be used in the wave flume of the Hydraulic Laboratory of UTP to evaluate the validity of the existing guides in the literature through systematic experiments. The fundamentals of this project are the physical modeling and its application to coastal engineering.

For this project, the author focuses on detail study of wave characteristics and the development of perforated plate breakwater. A series of experiments using the perforated plate was done in the wave flume of the Hydraulic Laboratory of UTP to measure the reflection and transmission coefficients of wave through single and double perforated plate breakwater.

The first section of this report describes the background of the project as well as the problem statement. The objectives of project also described in this section. All relevant reading materials that used in the project will be discussed in second section. That literature provides background information on the research question and to identify what others have discovered about their finding. In the third and forth section, the experimental setup and result will be described. It will contain the procedure of this experiment and the tools/equipment used. This project requires to do research and design work to tackle the problems that have encountered.

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- Dr Shamsul Rahman Mohamed Kutty (FYP Coordinator)
- Dr. Madzlan Napiah (FYP Committee Chairman)
- Mr. Zaini (Laboratory technician)

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Last but not least, I also would like to say thank you to all my fellow friends and my family who have been giving me courage and advice throughout this course in order to complete this research study.

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CHAPTER 1: INTRODUCTION

1.1 Project Background

Structures are constructed along the coast for a variety purposes. Owing to its nature, there is strong pressure for development of the land and nearshore areas along the coast. There is a commensurate need to protect this development from damage by waves and storm surge. Coastal structures are an important component in any coastal protection scheme. Structures may be designed to act directly to control wave and storm surge action or secondarily to stabilize a beach which, in turn, provides protection to the coast.

Sandy beaches, besides providing for coastal protection, have a significant recreational value. There is a limited amount of sandy available in most coastal areas and the sand is usually moving along the shore as well as on- and offshore. Sand may also be artificially placed on the shore to supplement the sand and that is there naturally. Often, structures are required to control where this sand remains and to protect the beach from losses caused by waves and storm surge.

Navigation and the moorage of vessels are important components of coastal activities. Coastal structures are important to the establishment of safe and efficient navigation channels across the coastline to interior harbor areas. Structures are also important to the development of safe harbor areas on the outer coast as well as in interior bays and estuaries.

There are a variety of structure types that can be constructed to satisfy one or more of the purposes discussed above. These include:

- Long thin cylindrical structures including individual piles and framed structures, pipelines and cables
- Large single-unit submerged and partially submerged structures
- Moored floating structures

- Rubble mound structures, both massive structures and rubble mound veneers to protect embankments
- Vertical-faced rigid structures

There are two primary concerns in the design of any coastal structure. One is the structural aspects which address the stability of the structure when exposed to design hydrodynamic and other loadings. The other is the functional aspects which focus on the geometry of the structure to see that it satisfies the particular design functions such as keeping the wave weights in the lee of the structure reduced to an acceptable level or helping to retain a sufficiently wide beach at the desired location.

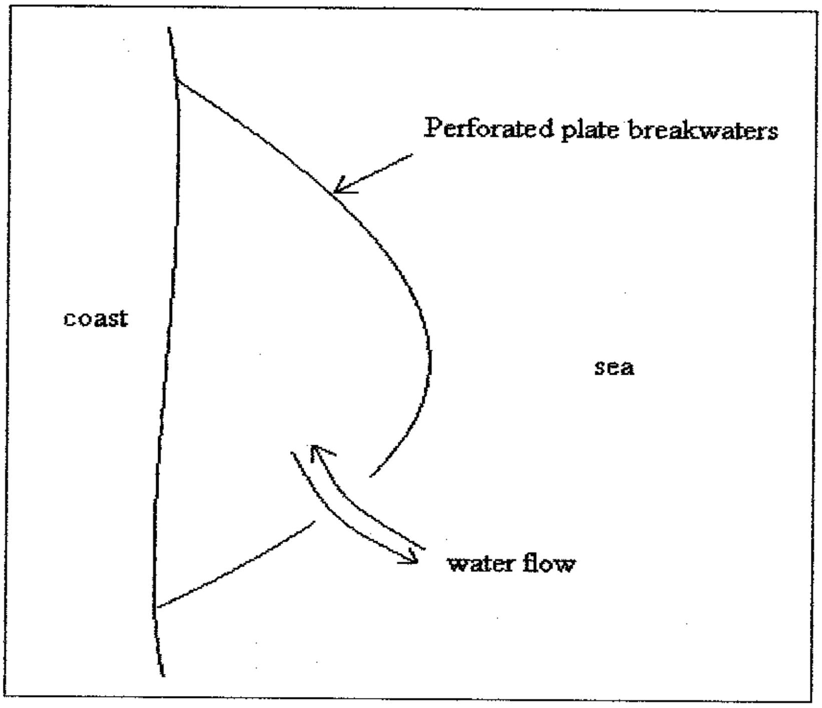


Figure 1.1 - Perforated Plate Breakwaters at Coastal Area

In this study, we are going to test the perforated plate breakwaters that will be installed as shown in the *Figure 1.1*. The breakwaters are arranges like that for several purposes, such as for boat anchoring, for tourism purpose, and also for fishing and agriculture.

Several perforated plates will be used in the wave flume of the hydrology Laboratory of UTP to evaluate the validity of the existing guides in the literature through systematic experiments. The perforated plates with different size of the holes *(Figure 1.2)* will be used in this experiment. The wave transmission and reflection will be observed for the different types of the perforated plates. The energy and the force of the wave will be calculated.

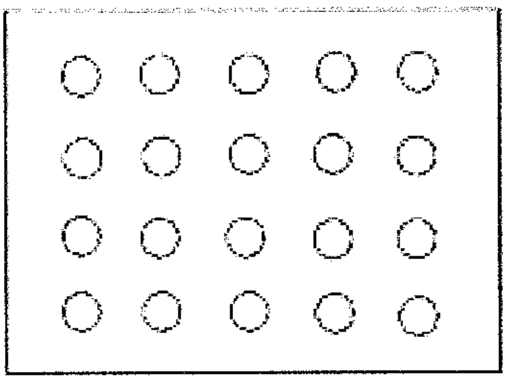


Figure 1.2 - Hollow perforated plate

Two complementary techniques being applied throughout the experiment are *laboratory work* and *mathematical calculation.* Hence variations in wave amplitudes are required for the respective analysis of energy dissipation due to the presence of the wave absorber at different wave period, water depths and stroke adjustment. Analysis and comparison approach will be used to identify the best performance and the limitation of the wave absorbers in this study. A calibration chart also recommended to be provided for others' uses and references purposes in the future

1.2 Problem statement

There are several types and materials are used in construction of breakwaters to absorb wave energy. While enormous data is available on the routine breakwater types, information on breakwaters and water absorbers are made of perforated plates is not sufficient in the literature.

1.3 Objectives and Scope of Study

Objectives

- To carry out laboratory experiment using various types of perforated plate.
- To study and calculate the waves transmission and reflection throughout the perforated plates in the wave flume.

Scope of Study

To achieve the main objectives stated above, the student has to learn and do literature reviews regarding the subject matters.

1. *Study on wave mechanics*

   The student will learn on how to use estimation method of incident and reflected waves in regular wave experiments. Most of the information is gather form existing proceeding or journals of coastal engineering.

2. *Learn on how to use the Wave Generator*

   The student is given an opportunity to explore the usage of Wave Generator Flap-type HM162.41 and other accessory equipment related. Such a new technology like this equipment offers a lot that could be learn. This unit equipment is used to help obtaining information on the behavior of waves in the offshore area as well as the coastal protection

3. *Develop the perforated plate breakwater*

   The conceptual design of the wave screen is based on student's idea and creativity, with the guidance from supervisor. The features of the design are referred to existing studies from the previous proceeding in coastal engineering.

4. *Analyze the experimental results*

   Results and all the data obtained in the experimental are analyzed in order to get the graphs of the perforated plate breakwater in relating variables.

CHAPTER 2: LITERATURE REVIEW

2.1 Rigid Vertical-Faced Structures

Some classes of coastal structures incorporated a rigid vertical face that is exposed to wave action. These include caissons typically consisting of a concrete or steel shell filled with sand and gravel and sitting on gravel based, and vertical concrete or wood panels supported at intervals by vertical and batter piles. The latter have been used at marinas and to control wave action at ferry slips. An important aspect of the design of these structures is determination of the wave loading on the structure. If the wave loading is sufficient, caisson structures can slide off of their base. Vertical panel structures carry the wave-induced force to the supporting piles which can fail if the force is excessive.

2.2 Wave Reflection

When a wave reaches a rigid, impermeable vertical wall it is completely reflected. After some time, under controlled conditions, the reflected waves and the incident waves together form a standing wave. The wave form no longer moves forward in space. A theoretical expression for such a standing wave (*Figure 2.1*) may be obtained by superposition of the equations for an incident and a reflected wave. The small amplitude expressions for a standing wave are given in *Table 2.1*. A maximum wave height (antinode) is present at the structure and at every half wave length away from the structure. A zero wave height (node) is located L/4 from the wall and then at every half wave length. The maximum wave height is twice the height of the original incident wave.

Partial wave reflection will result if the reflecting surface is sloping, flexible or porous. The reflected wave is the smaller than the incident wave, which yields a standing wave that varies in wave height with distance, s shown in Figure 2.2. The partial antinodes (H_{max}) are less than twice the incident wave height, while the partial nodes (H_{min}) are greater than zero. The resulting wave envelope can be used to estimate the reflection coefficient and the incident wave height. For simple sinusoidal waves the relationships are given in Equation 6 and 7 of *Table 2.1*. The envelope can be defines by a number of wave probes that measure waves simultaneously at different locations over half a wave length.

	Complete Reflection	Partial Reflection
1. Water Surface [m]	$\eta = H \cos kx \cos \omega t$	$\eta = \frac{1}{2}(H_I - H_R)\cos(kx + \omega t) + H_R \cos kx \cos \omega t$
2. Nodes [m]	$x_{NODE} = \frac{L}{4}, \frac{3L}{4}$	
3. Horizontal Component of Orbital Velocity [m/s]	$u = \frac{2\pi H}{T} \frac{\cosh k(z+d)}{\cosh kd} \sin kx \sin \omega t$	
4. Vertical Component of Orbital Velocity (m/s)	$w = -\frac{2\pi H}{T} \frac{\sinh k(z+d)}{\cosh kd} \cos kx \cos \omega t$	
5. Pressure Response Factor	$K_P = \frac{\cosh k(z+d)}{\cosh kd}$	
6. Reflection Coefficient	$K_R = 1$	$K_R = \frac{H_R}{H_I} = \frac{(H_{max} - H_{min})}{(H_{max} + H_{min})}$
7. Incident Wave Height (m)	$H_I = H$	$H_I = \frac{(H_{max} + H_{min})}{2}$
8. MWL - SWL [m]	$\Delta_H = \frac{H^2 k}{2} \coth kd$	

Table 2.1 - Common Expressions for Reflected Waves

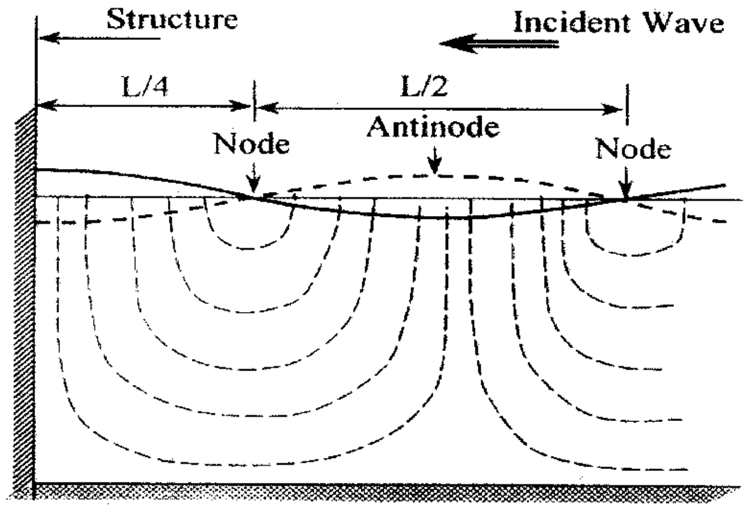


Figure 2.1 - Standing Waves

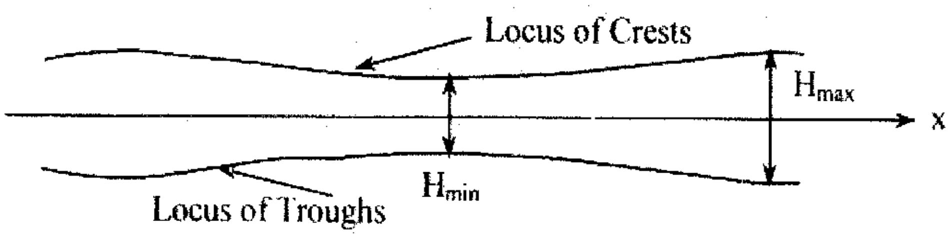


Figure 2.2 - Envelope of Partial Wave Reflection

Bulk reflection coefficients for plain vertical breakwaters on seabed, for vertical breakwaters on rubble foundation, for horizontal composite breakwaters, for sloping top caissons, for single perforated screens and for perforated caissons are given in *Figure 2.3* and *Figure 2.4*.

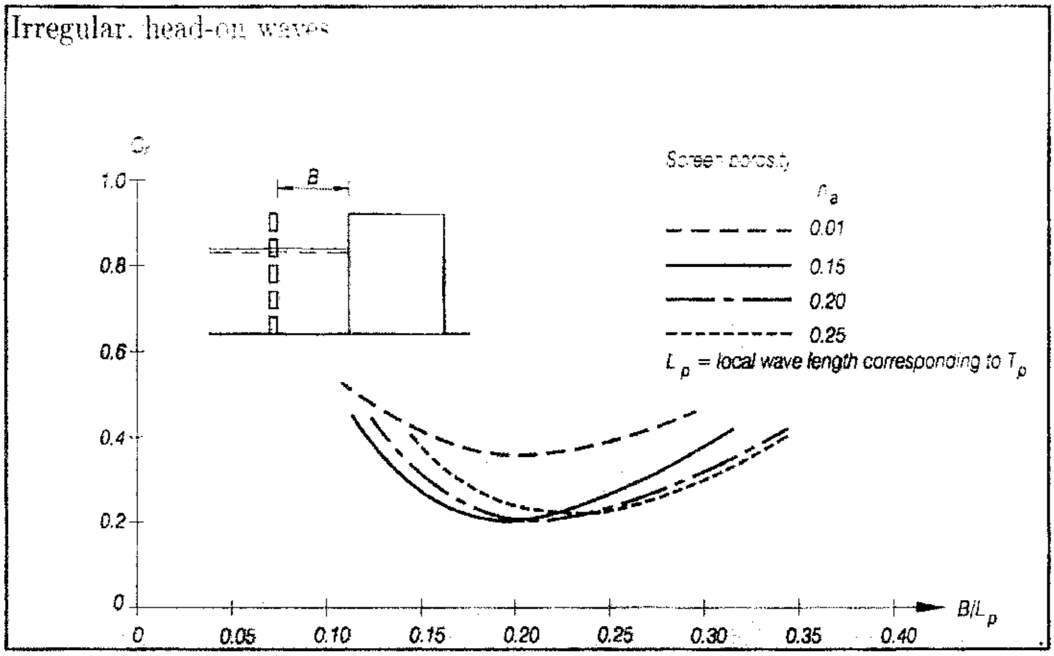


Figure 2.3 - Wave reflection coefficient for perforated caissons (adapted from Allsop and Hettiarachchi 1998)

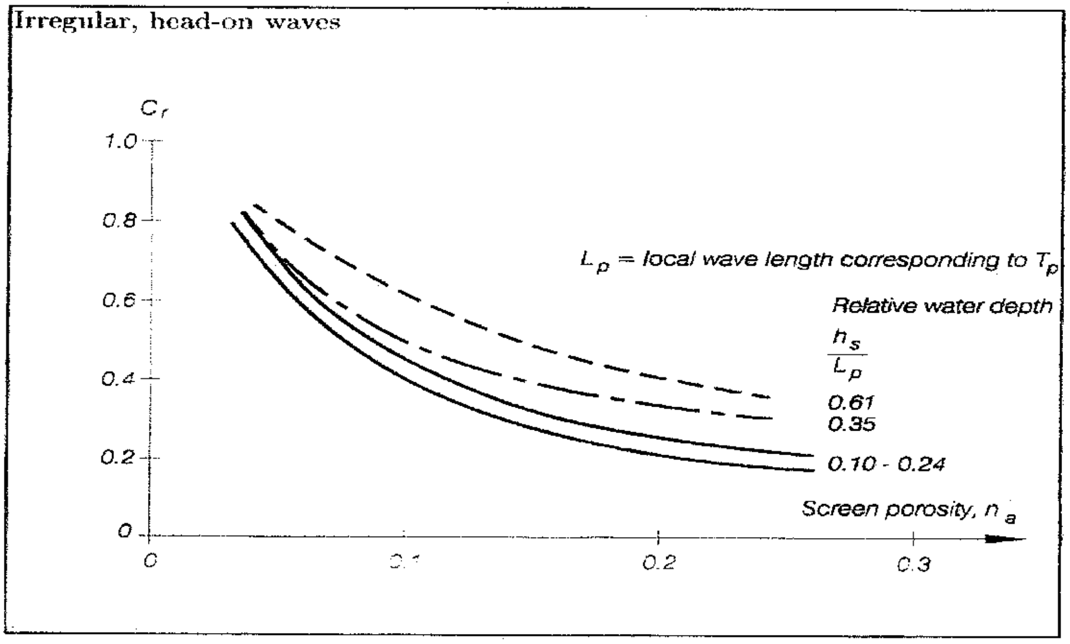


Figure 2.4 - Wave reflection coefficients for single perforated screen (adapted from Allsop and Hettiarachchi 1998)

2.3 Wave Transmission

Wave action behind a structure can be caused by wave overtopping and also by wave penetration if the structure is permeable. Waves generated by the falling water from overtopping tend to have shorter periods than the incident waves. Generally the transmitted wave periods are about half than of the incident waves.

Wave transmission can be characterized by a transmission coefficient, C_t, defined as the ratio of transmitted to incident characteristic wave heights (e.g., H_t and H_i) as given in equation below:

$$C_t = \frac{H_t}{H_i} \qquad (1)$$

Wave transmission for vertical breakwaters is mainly the result of wave overtopping. Therefore the ratio of the breakwater crests height (R_c) to the incident wave height (H_i) is the most important parameter. Wave transmission coefficients for plain vertical breakwaters, horizontal composite breakwaters, sloping top breakwaters and perforated walls are given in Figure 2.5.

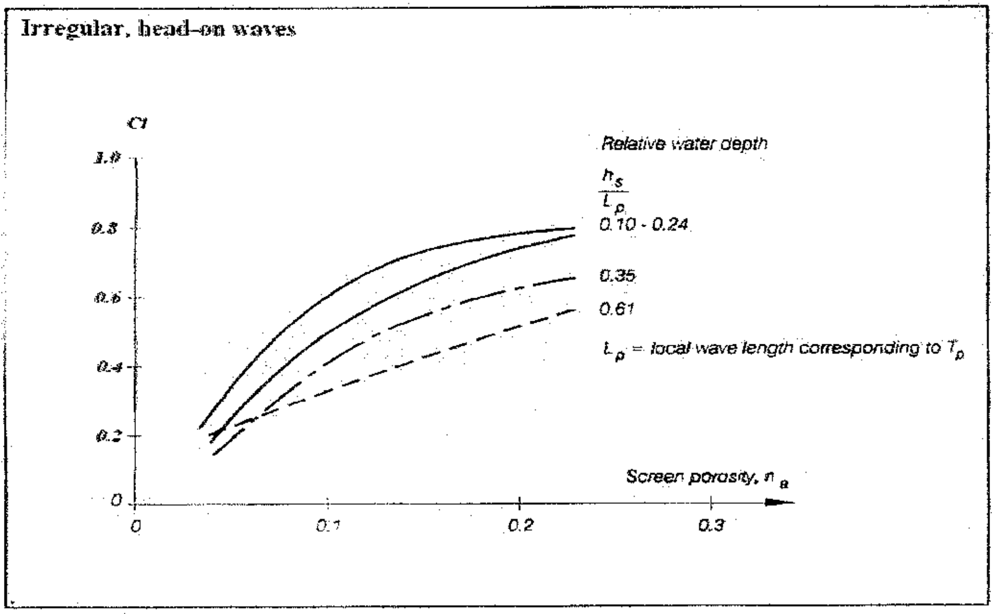


Figure 2.5 - Wave transmission through perforated single wall (adapted from Allsop and Hettiarachchi 1998)

2.4 Wave Energy

The energy possessed by a wave is in two forms:

1. Kinetic energy, which is the energy inherent in the orbital motion of the water particles.
2. Potential energy possessed by the particles as a result of being displaced from their mean (equilibrium) position.

From a water particle in a given wave, energy is continually being converted from potential energy (at crest and trough) to kinetic energy (as it passes through the equilibrium position), and back again.

The total energy *(E) per unit area* of a wave is given by:

$$E = \frac{1}{8}\left(\rho g H^2\right) \qquad (2)$$

where ρ is the density of the water (in kg m^{-3}), g is 9.8 ms^{-2} and H is the wave height (m). The energy (E) is then in joules per square meter (J m^{-2}). The equation shows that wave energy is proportional to the square of the wave height.

<u>Propagation of wave energy</u>

Waves travel in groups in deep water, with area of minimal disturbance between groups. Individual waves die out at the front of each group. It is obvious that no energy is being transmitted across regions where there are no waves, i.e. between the groups. It follows that the energy is contained within the wave group, and travels at the group speed. The rate at which energy is supplied at a particular location (e.g. a beach) is called wave power, and is the product of group speed (c_g) and wave energy per unit area (E), as expressed per unit length of wave crest.

$$P = E \times C_g \qquad (3)$$

Attenuation of wave energy

Wave attenuation involves loss or dissipation of wave energy, resulting in a reduction of wave height. Energy is dissipated in four main ways:

1. White capping, which involves transfer of wave energy to the kinetic energy of moving water, thus reinforcing the wind-driven surface current
2. Viscous attenuation, which is only important for very high frequency capillary waves and involves dissipation of energy into heat by friction between water molecules
3. Air resistance, which applies to large steep waves soon after they leave the area in which they were generated and enter regions of calm or contrary winds
4. Non-linear wave-wave interaction, which involves no loss of energy in itself because energy is simply 'swapped' between different frequencies. However, the total amount of energy available for such 'swapping' will gradually decrease, because higher frequency waves are more likely to dissipate energy in the ways described under 1 and 2 above

Uses of wave energy

Wave energy is a potential source of pollution-free 'alternative energy', and has been used for some time on a small scale, e.g. to recharge batteries on buoys carrying navigation lights.

CHAPTER 3: DEVELOPMENT OF PERFORATED PLATE BREAKWATER

3.1 Design and fabrication

A background of literature review on design criteria of the existing designs by previous researchers is prerequisite for development of a new design. From the literature review given, the author has to design the frame for the breakwaters, which is used to support the breakwaters during the test.

The material selected for the frame is made of aluminum. Aluminum is chosen because it can resist corrosion as the structure will submerge in the water throughout the experiments. Other features and advantages of this design are listed below:

- The frame is fit with the flume dimension so that we can get better wave characteristics with less error
- The weight of the frame is approximately 3 kg, so it is heavy and can resist the force from wave
- The frame uses the 1x1 inch and 2x1 inch square hollow section aluminum which is strong enough to support the breakwater

Several foundries and hardware shops were surveyed for the fabrication purpose. Beside the frame, the student also had to choose the best materials which are going to be used for breakwater. For this project, it is decided to use plywood as the materials for breakwater. There are two factors that have been considered, which are:

- *Cost*

  Cost of the plywood is lower compared to other materials such as fiber and glass
- *Easy to drill*

  The plywood can be cut into pieces easily using the machines in UTP Workshop and also easier to drill holes compared to others.

3.2 Porosity

The reason why we need to drill holes on the plates is because we have to consider the porosity of the plate. The porosity will be one of the subjects that we will analyze in the laboratory work. We assume that perforated holes in the plates are uniformly distributed over the surface of plates. The porosity of the plates is defined by the ratio of the perforated area to the total surface area of the plates.

The sample calculation for plate porosity of 20 mm diameter holes,

$$\text{Porosity, } \text{Ø} = \frac{\text{Area of pore space}}{\text{Total area}} \times 100\% \qquad (4)$$

$$\text{Total area of a plate} = 275 \times 400$$
$$= 110\,000 \text{ mm}^2$$

$$\text{Total number of holes} = 13 \times 8$$
$$= 104$$

$$\text{Area of pore space} = \frac{\pi d^2}{4}$$
$$= \frac{\pi (20)^2}{4}$$
$$= 314.2 \times 104$$
$$= 32676.8 \text{ mm}^2$$

$$\text{Porosity, } \text{Ø} = \frac{32676.8}{110\,000} \times 100\%$$
$$= 29.7\% \approx \mathbf{30\%}$$

The table below shows the percentages of porosity for different diameters of the plate. There also a picture to show some of the plates with different porosity.

Diameter of holes (mm)	Porosity (%)
10	7
12	10
14	15
20	30
24	43

Table 3.1 - Porosities for different plate diameters

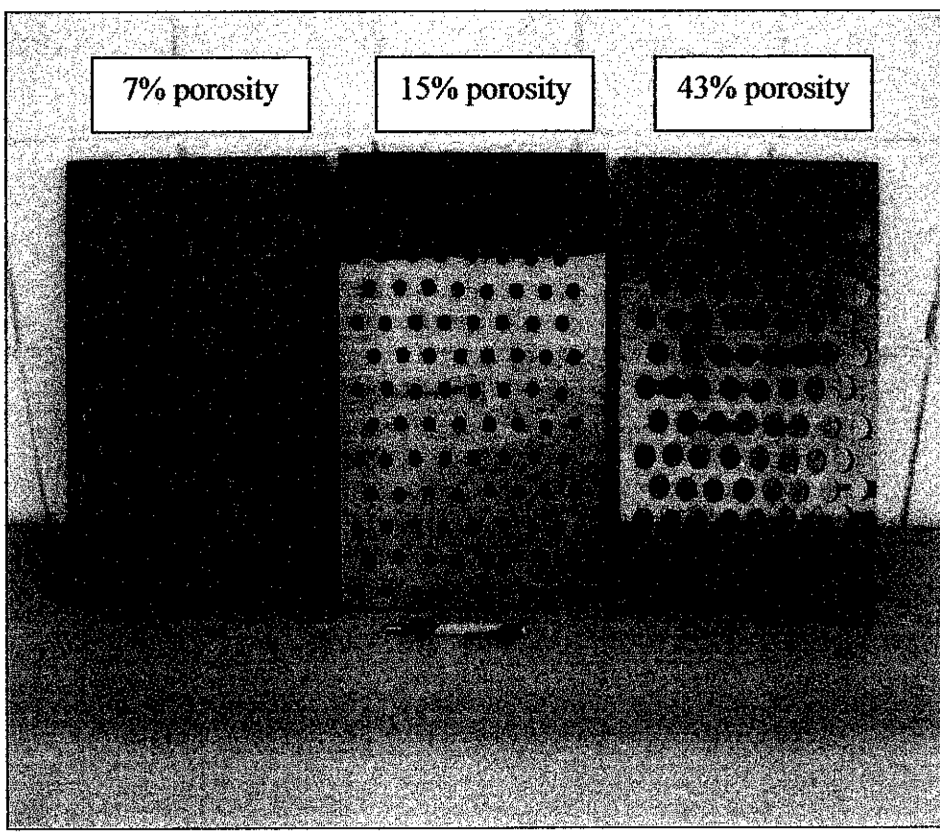


Figure 3.1 - Perforated plates with different porosity

The figures below show the technical drawing for the breakwater frame and some pictures of the model from different angle.

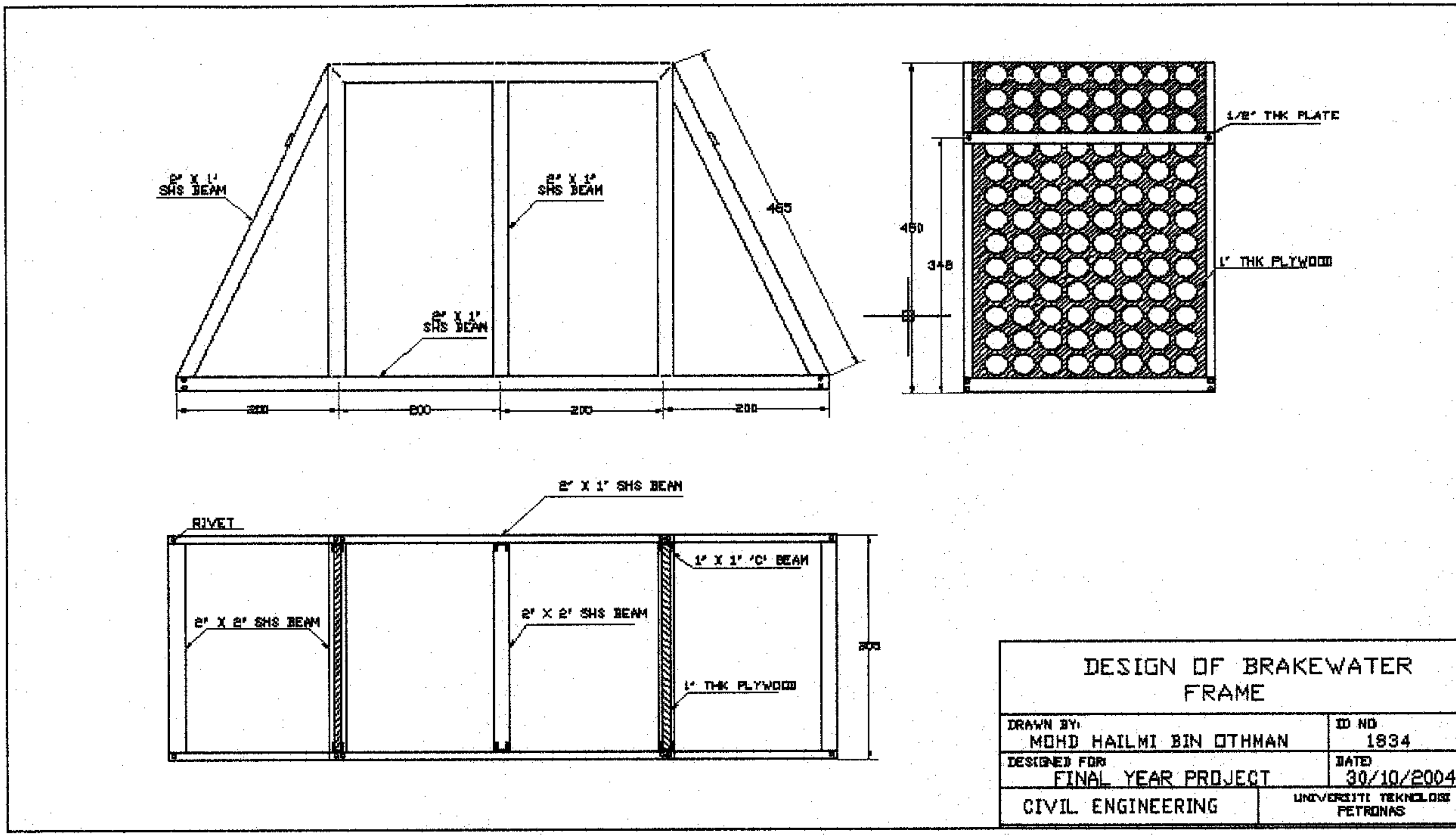
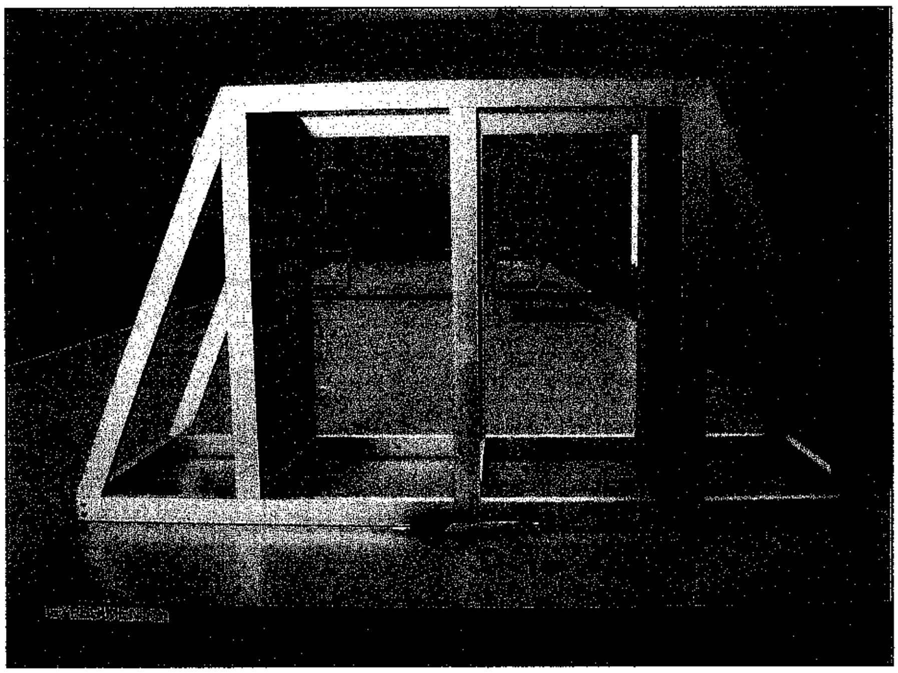
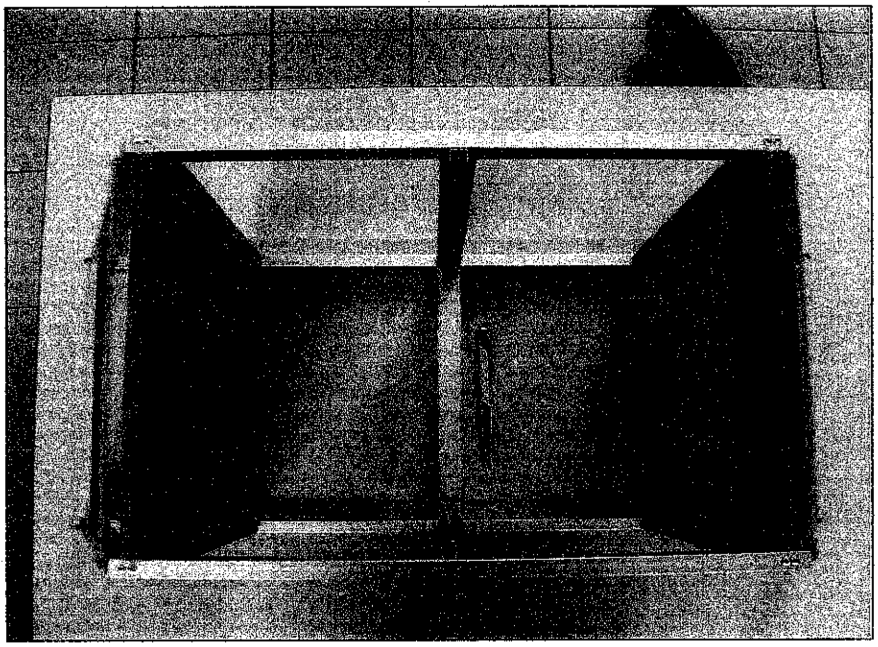


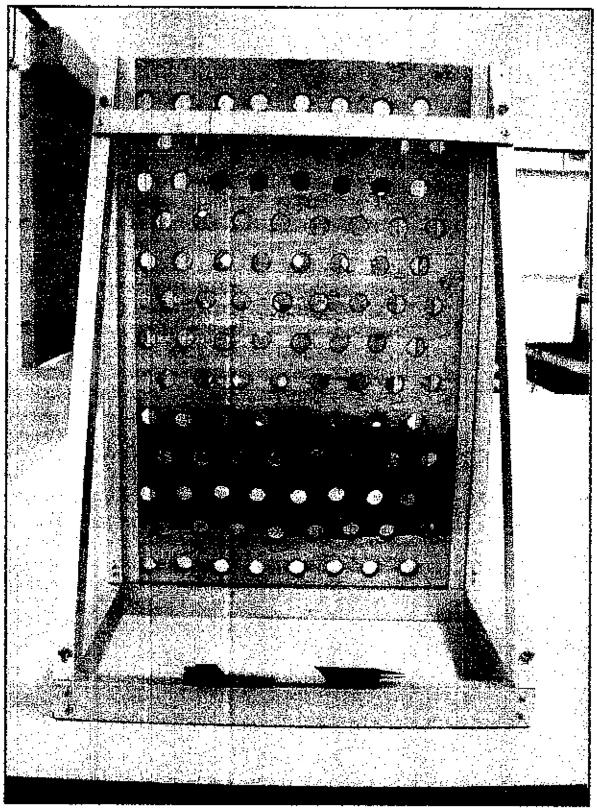
Figure 3.2 – Technical Drawing of the Model



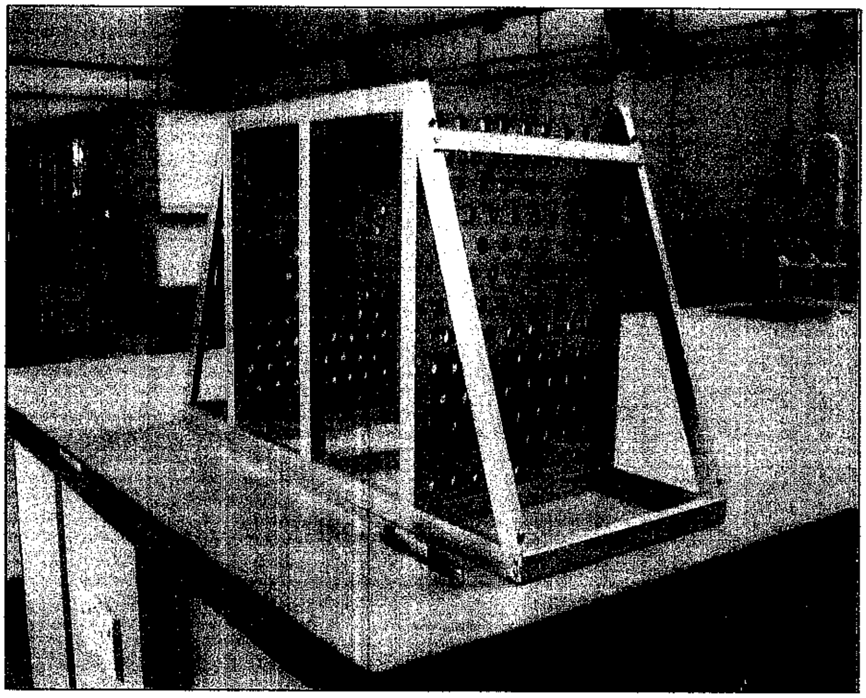
(a). Side View of the Model



(b). Plan View of the Model



(c). Front View of the Model



(d). 3-D View of the Model

Figure 3.3 – Pictures of the Model from Different Views

CHAPTER 4: EXPERIMENTAL SETUP AND PROCEDURE

4.1 Laboratory Equipments and Instrumentation

Modular Flow Channel HM 162

Modular Flow Channel HM 162 is a basic unit for experimentation possibilities in open flume such as weirs, overflows, sluices oceanography, and offshore engineering such as measurement on waves and also coastal protection measures e.g. dyke construction and beach simulation.

The elements have a length of 2.4 m and flow cross section of 300mm (width) x 450 mm (depth). The transparent sides of the measuring are made of hardened glass which is particularly resistant to scratching and abrasion, does not discolor and easy to clean.

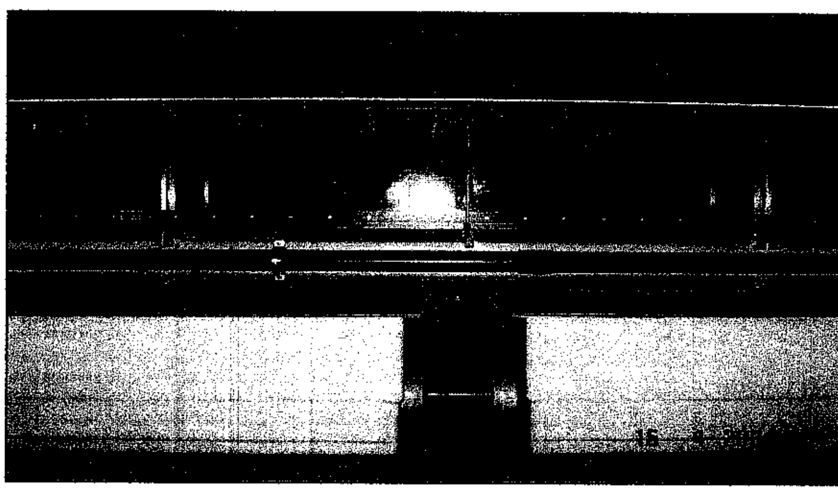


Figure 4.1 - Modular Flow Channel

Wave Generator Flap-Type HM 162.41

The Wave Generator HM 162.41 is used to create waves of various types at the Modular Flow Channel HM 162. This accessory unit is used to help obtain information on the behavior of waves in the offshore area as well as in coastal protection. In conjunction with some units form the accessory form G.U.N.T, the following experiments are possible:

- Height (amplitude) and length (frequency)
- Forces
- Absorption of waves forces
- Velocity
- Different wave shapes
- Wave breaking on coastal structures
- Wave reflection
- Behavior of structures in the seaway

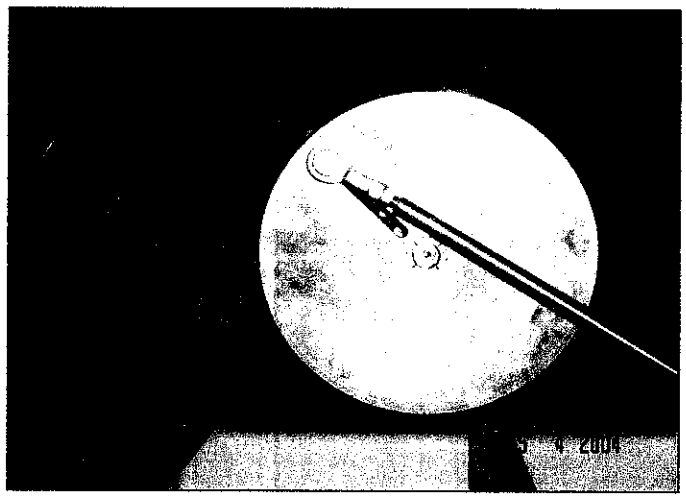


Figure 4.2 - Wave Generator Flap-Type

The wave generator is bolted onto the surrounding edge of the outlet element of the Modular Flow Channel HM 162. The push rod is connected to holder of the movable overflow weir of HM 162. The wave generator is driven by a worm gear motor. The rotational speed can be sleeplessly varied by a frequency converter and a potentiometer. The rotary movement of the motor is converted into a harmonic stroke motion of the movable over-flow weir via a crank disk with push rod.

Switch Box

All electrical switching units are required for operations are located in the cover of the switch box. The rotational speed gives the stroke frequency of the wave generator and can be adjusted via a 10-gear helical potentiometer. The potentiometer has a scale disk for guaranteeing assignment of the rotational speed. At 100%, the rotation speed is 114 rpm, corresponding to 1.9 Hz. With a linear characteristic, the rotational speed at 0% is 0 rpm

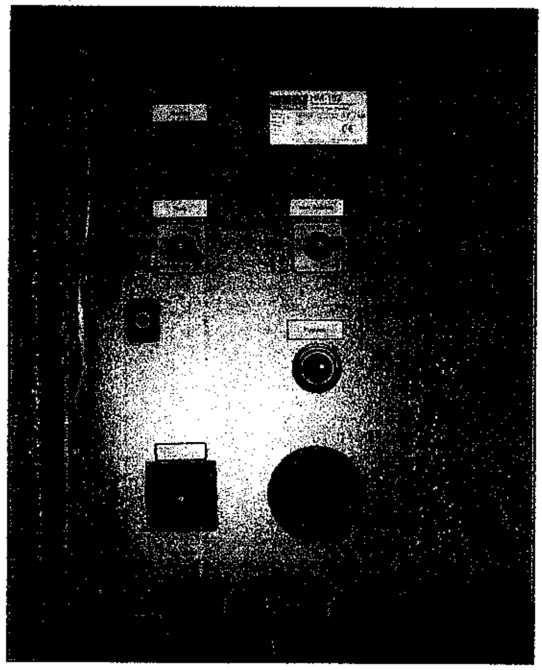


Figure 4.3 - Switch Box

Hook and Point Gauge for Modular Flow Channel HM 162.52

The hook and point gauge HM 162.52 is used to measure levels and water levels of the modular flow channel HM 162. It is possible to carry out measurements over the entire working range of the flow channel, since the measuring point can be traced in the longitudinal direction, across the width and in the depth of the flow cross section.

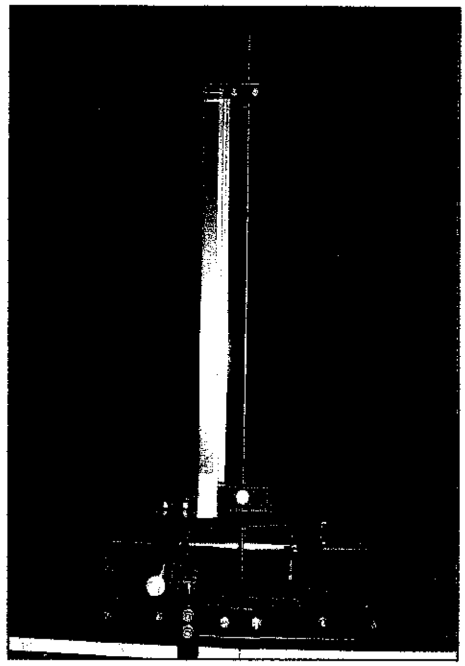


Figure 4.4 - Hook and Point Gauge

Pump Unit

The pump unit consists of a base plate of securely setting up and fixing in the substrate and a centrifugal pump with a flanged-on-three phase motor, onto which are flanged a shut-off valve DN 125 with lever on the suction side and a shut-off valve DN 100 with gears and handwheel on the pressure side. The flow rate is adjusted at the pressure-side shut-off valve during subsequent operation.

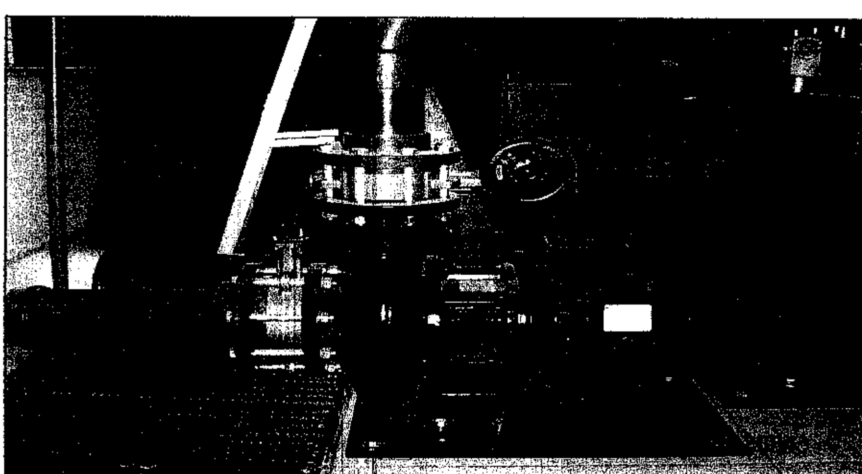


Figure 4.5 - Pump Unit

CHAPTER 5: EXPERIMENTAL RESULTS AND ANALYSIS

5.1 Preliminary Experiment on the Wave Properties

<u>Objective</u>

To determine the condition of the wave in the laboratory flume

<u>Procedure</u>

1) The wave flume was filled with water by opening the valve, until the canning point of the gauge first touched a water depth of 15 cm.
2) Frequency of the wave generator was set to a rotational speed of 15 rpm by adjusting the 10-gear helical potentiometer.
3) A digital camera captured a scene of wave profile once the propagation was found stable or consistent.
4) The measurement of the above mentioned parameters were repeated at respective stroke frequency of 20, 30, 40, 45, 50, 60, 70, 80 and 85 rpm at the assigned water depth.
5) The experimental procedures were repeated in water depth of 20 cm, 25 cm and 30 cm, respectively.
6) The measurement of wave height is only by taking the maximum stroke frequency, which is 200 mm.

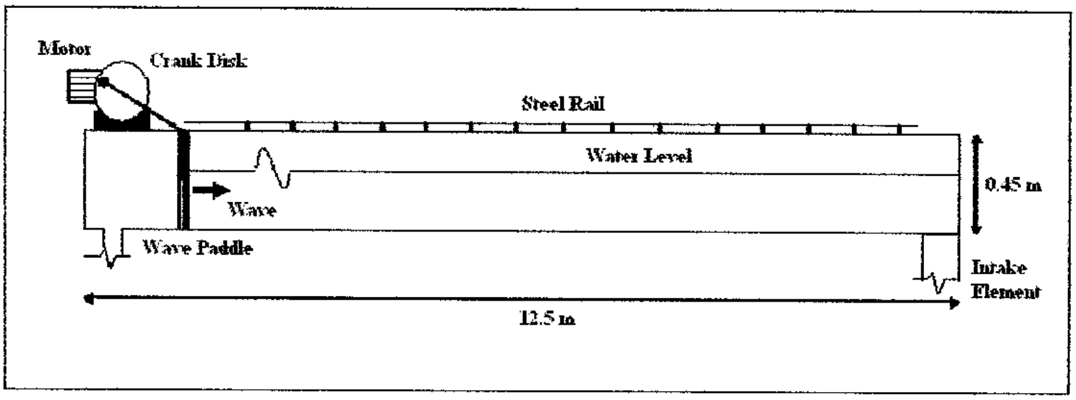


Figure 5.1 - Schematic drawing of the wave flume

Result

No.	Stroke frequency (rpm)	L (m)	d/L
1	15	2.10	0.07
2	20	1.87	0.08
3	30	1.69	0.09
4	40	1.21	0.12
5	45	1.15	0.13
6	50	1.13	0.13
7	60	0.89	0.17
8	70	0.62	0.24
9	80	0.50	0.30
10	85	0.34	0.44

(a). Water depth = 15 cm

No.	Stroke frequency (rpm)	L (m)	d/L
1	15	2.45	0.08
2	20	1.90	0.11
3	30	1.77	0.11
4	40	1.55	0.13
5	45	1.35	0.15
6	50	1.29	0.16
7	60	0.92	0.22
8	70	0.72	0.28
9	80	0.55	0.36
10	85	0.39	0.51

(b). Water depth = 20 cm

No.	Stroke frequency (rpm)	L (m)	d/L
1	15	3.10	0.08
2	20	2.52	0.10
3	30	2.25	0.11
4	40	2.16	0.12
5	45	1.89	0.13
6	50	1.53	0.16
7	60	1.15	0.22
8	70	0.62	0.40
9	80	0.54	0.46
10	85	0.40	0.63

(c). Water depth = 25 cm

No.	Stroke frequency (rpm)	L (m)	d/L
1	15	3.15	0.10
2	20	2.66	0.11
3	30	2.45	0.12
4	40	1.90	0.16
5	45	1.51	0.20
6	50	1.43	0.21
7	60	1.06	0.28
8	70	0.79	0.38
9	80	0.60	0.50
10	85	0.54	0.56

(d). Water depth = 30 cm

Table 5.1 - Determination of wavelength and Water Condition

The wave period, T can be determined using the calculation. The sample calculation for stroke frequency = 20 rpm is shown below:

$$\text{Stroke Frequency (rpm)} = \frac{20 \text{ rev}}{60 \text{ s}}$$

$$= 0.333 \text{ rev/s}$$

$$\text{Wave Period, } T = 1 / 0.333$$

$$= 3.0 \text{ s}$$

The table below shows the wave period values gathered from theoretical calculation for five different stroke frequencies which will be used for the main experiments.

No.	Stroke frequency (rpm)	Wave Period, T (s)
1	20	3.0
2	25	2.4
3	30	2.0
4	40	1.5
5	50	1.2

Table 5.2 – Wave Period Values for Different Stroke Frequencies

Discussion

For wave height and wave length measurement, this could be achieved by measuring the vertical and horizontal distances from the wave crest to trough of the subsequent. The measurement could be done by counting the number of boxes of the grid system available on the glass wall, as shown in *Figure 5.2*.

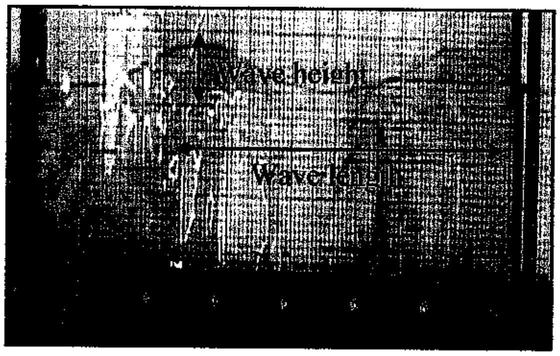


Figure 5.2 - Measurement of wave height and wave length through observations

From the values of d/L for each water depth (15 cm, 20 cm, 25 cm and 30 cm), we can say that the wave are in transitional water depth condition, which is between 0.05 and 0.5. However, when the stroke frequency is increased to 80 rpm and 85 rpm, the values of d/L exceed 0.5 and the wave is in deep water condition.

From the result, we can conclude that the values of d/L increase when the stroke frequency is increased. The water depth is not affecting much of the d/L values, so it just need to lower the stroke frequency if experiments have to be done in shallow water or transitional water depth. *Figure 5.3* shows the values of d/L versus the stoke frequency for different water depth.

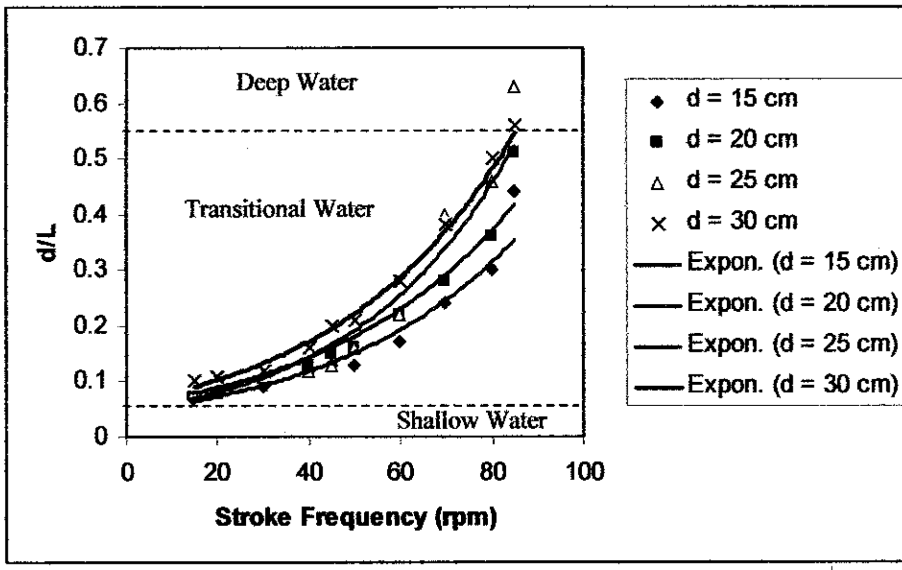


Figure 5.3 - *d/L* against Stroke Frequency for 15, 20, 25 and 30 cm water depths

Conclusion

From the experiment, it can be proved that the flume is transitional depth since $0.04 < d/L < 0.5$. The results of wavelength calculation for various stroke frequencies for each 15, 20, 25 and 30 cm water depth are tabulated in *Table 5.1* and presented in *Figure 5.3*. The tests must be carried out in transitional water depths. Hence the stroke frequency of 80 and 85 rpm have to be eliminated, so that the results are applicable only for transitional water depth condition.

5.2 Experimental Laboratory on Wave Reflection and Transmission

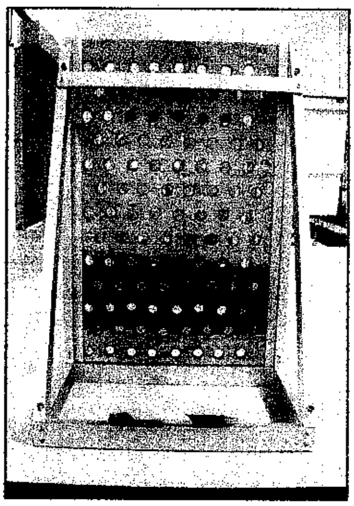
Objectives

To measure the reflection and transmission coefficients of waves through single and double perforated plate breakwater

Procedure

1) The perforated plate breakwater with 7% porosity is put inside the frame, as shown in *Figure 5.4*.

(a). The frame without plate



(b). The frame with plate

Figure 5.4 - The Preparation of Model

2) The wave absorber is installed at the end of the flume to minimize the reflection effect. The picture of wave absorber is shown in *Figure* 5.5.

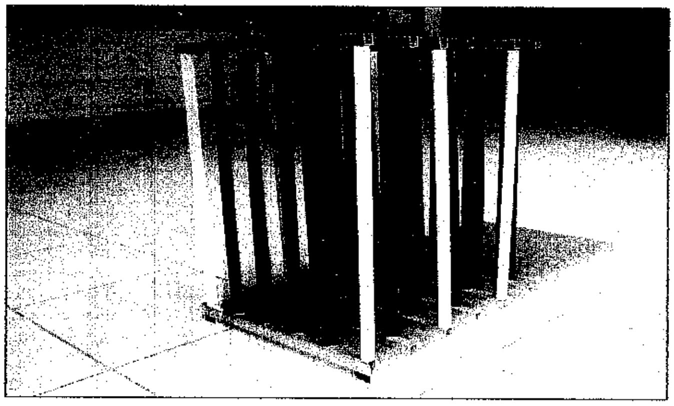


Figure 5.5 - Wave absorber

3) Then, the frame with the plates is put inside the flume. The arrangement of the breakwater and the wave absorber is shown in *Figure* 5.6.

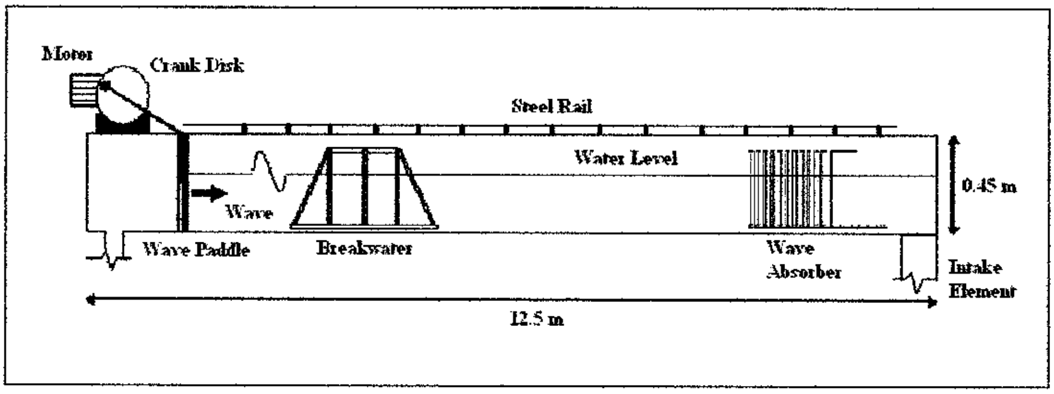


Figure 5.6 - Schematic drawing of the wave flume

4) Flume is filled with the water by controlling the valve, until the canning point first touches the assigned water level. (Ripples may be formed around the contact point).
5) Frequency of the wave generator is set to a rotational speed of 20 rpm by adjusting the 10-gear helical potentiometer.
6) Maximum height and minimum height of the wave: capture the water surface profile via a video camera once the waves are found to be stable in the flume.
7) Above step are repeated at respective frequency of 25, 30, 40 and 50 rpm.
8) Take some time to calm the water (Make sure the still water level is achieved) before proceed for another 'frequency'.
9) Repeat above steps with 10%, 15%, 30% and 43% plate porosity as shown in *Figure 5.7*.

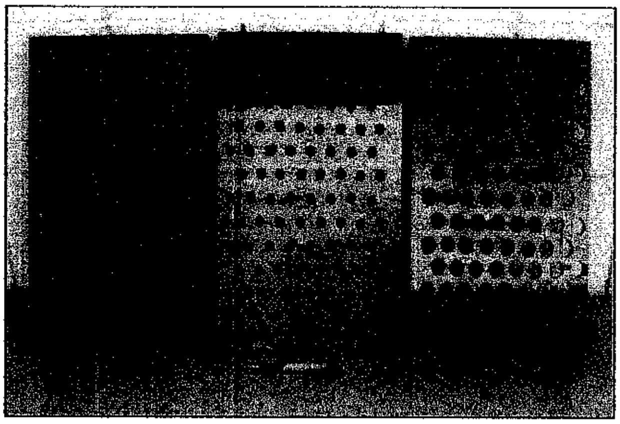
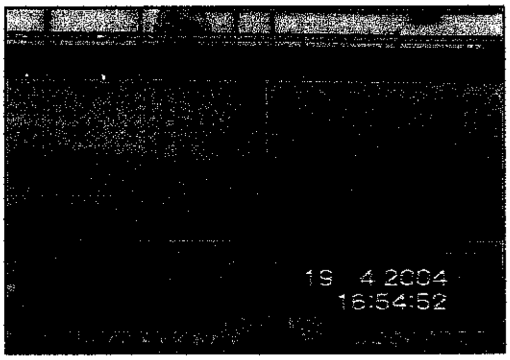
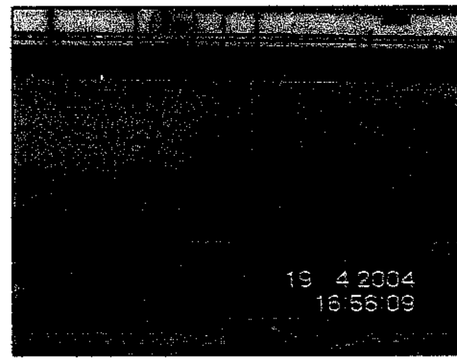


Figure 5.7 – Various perforated plates

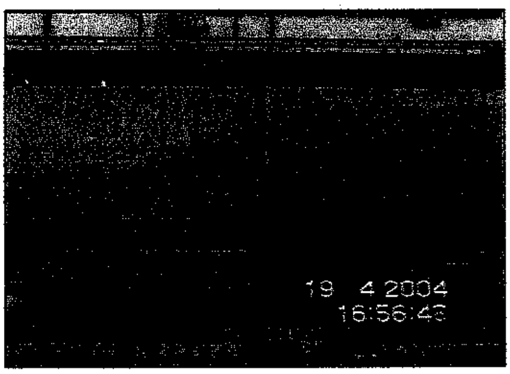
Result



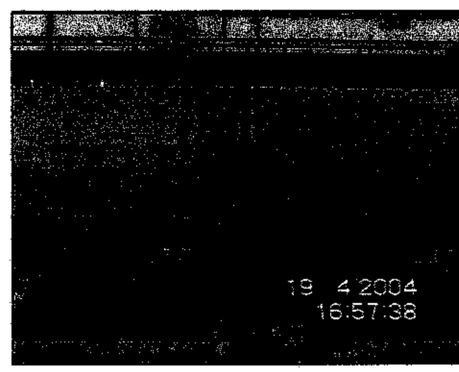
(a). T = 3.0 s



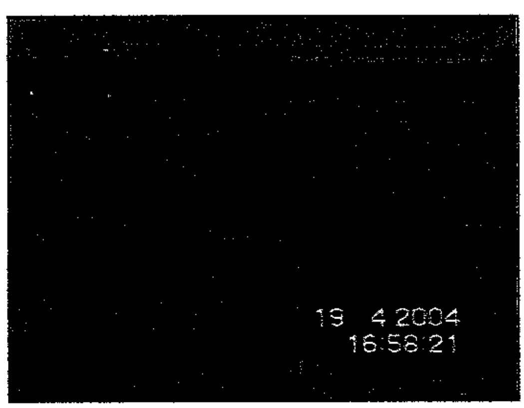
(b). T = 2.4 s



(c). T = 2.0 s

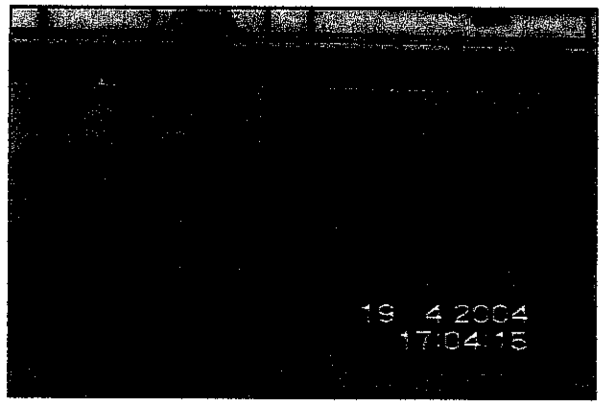


(d). T = 1.5 s

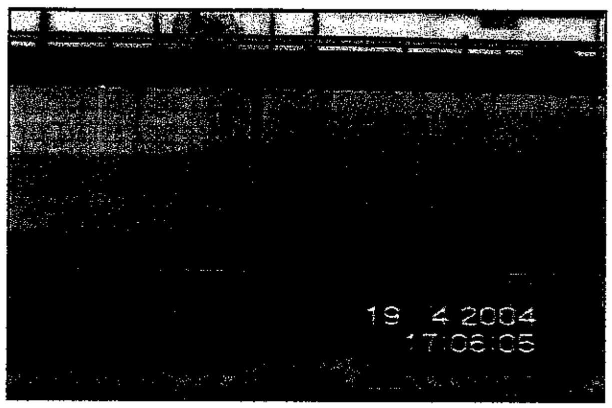


(e). T = 1.2 s

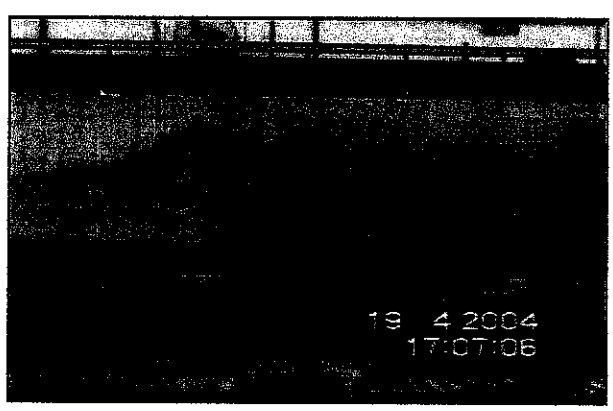
Figure 5.8 - Pictures taken during experiments for 10% plate porosity at 20 cm water depth



(a). T = 3.0 s

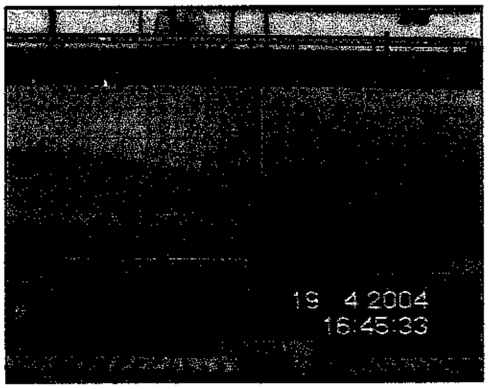


(b). T = 2.4 s

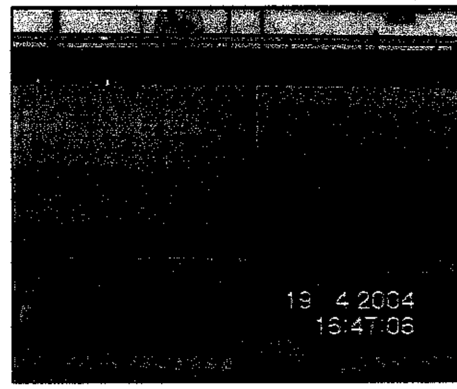


(c). T = 2.0 s

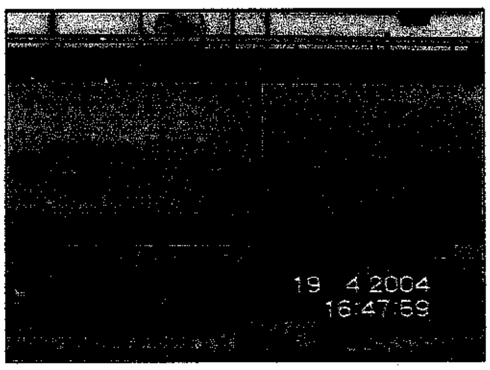
Figure 5.9 - Pictures taken during experiments for 10% plate porosity at 25 cm water depth



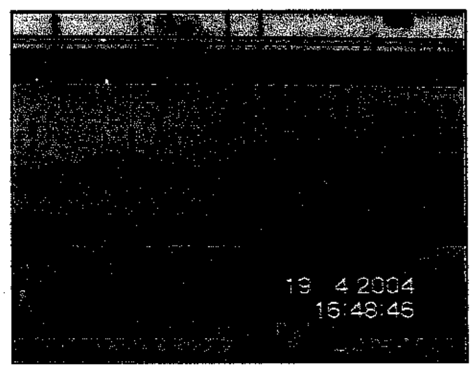
(a). T = 3.0 s



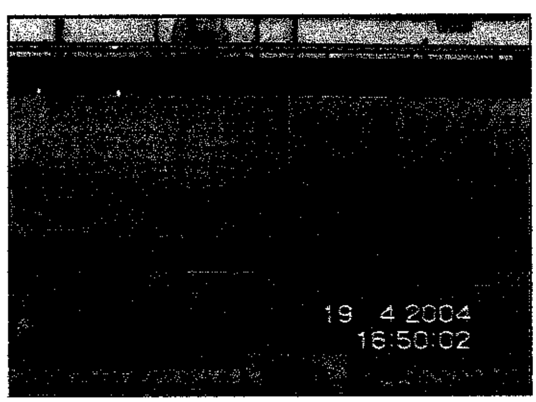
(b). T = 2.4 s



(c). T = 2.0 s

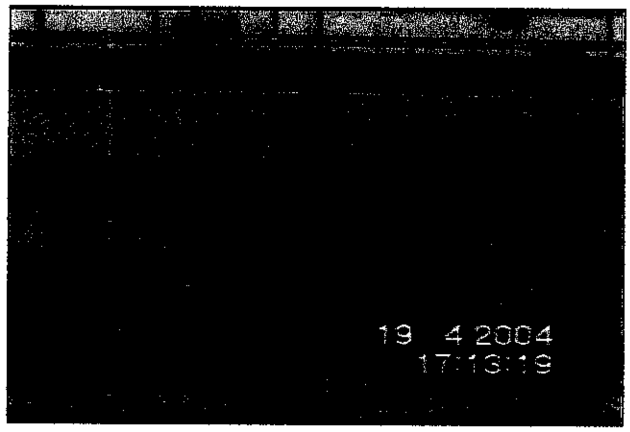


(d). T = 1.5 s

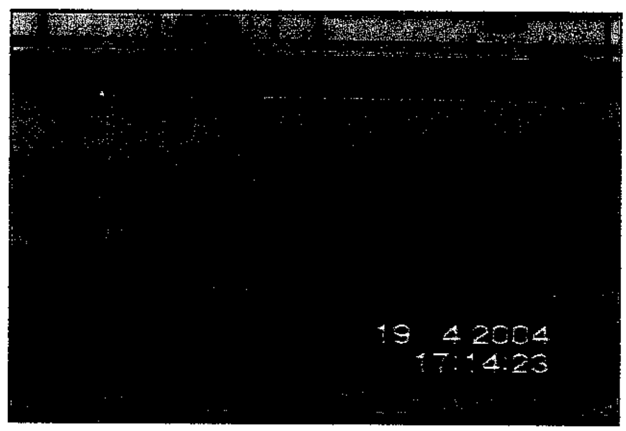


(e). T = 1.2 s

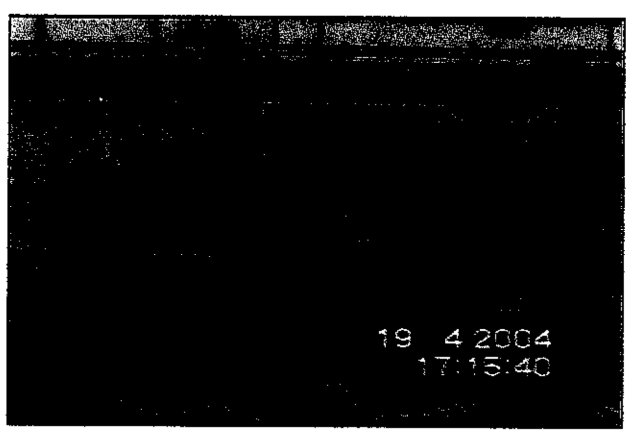
Figure 5.10 - Pictures taken during experiments for 15% plate porosity at 20 cm water depth



(a). T = 3.0 s

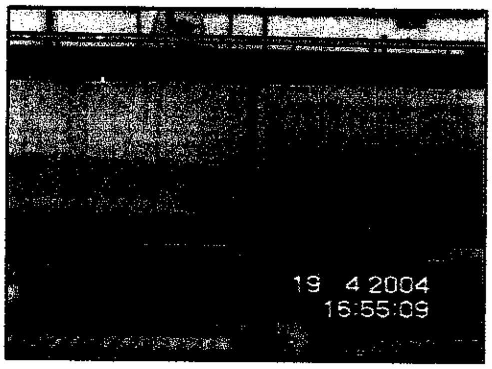


(b). T = 2.4 s

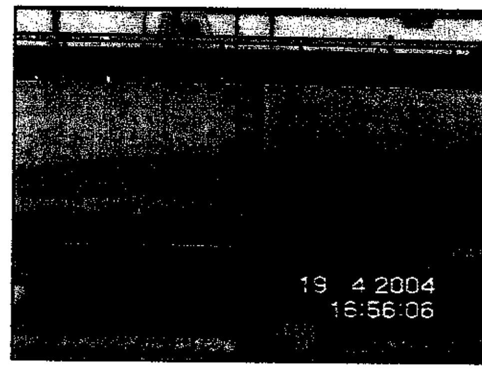


(c). T = 2.0 s

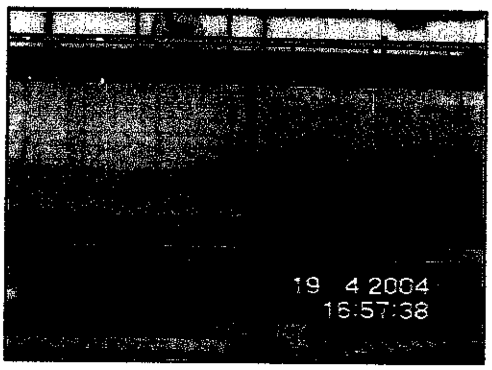
Figure 5.11 - Pictures taken during experiments for 15% plate porosity at 25 cm water depth



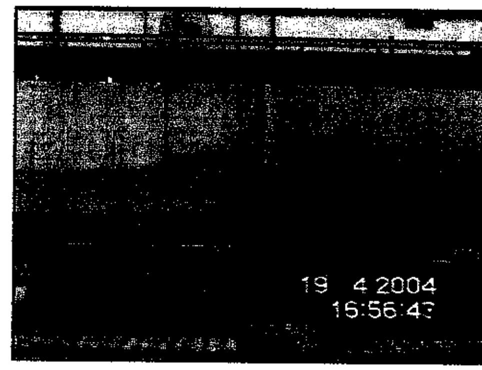
(a). T = 3.0 s



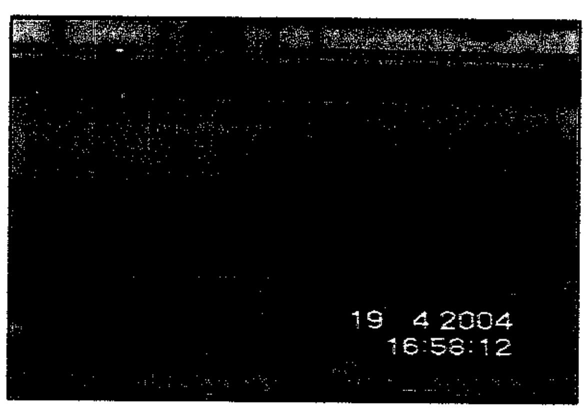
(b). T = 2.4 s



(c). T = 2.0 s

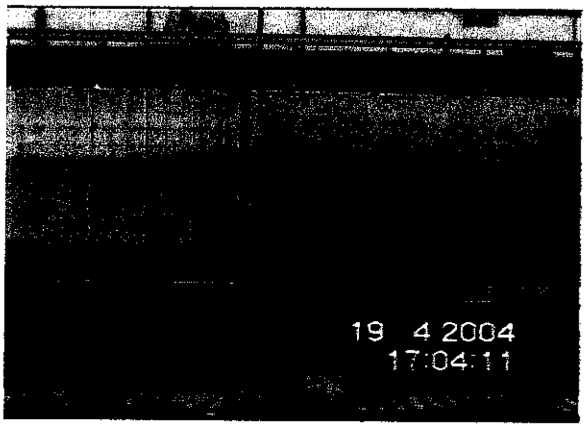


(d). T = 1.5 s

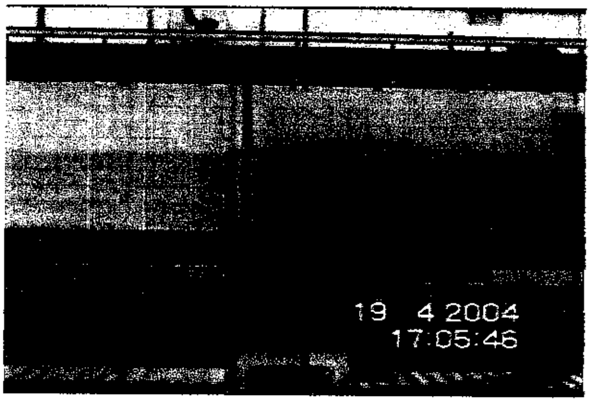


(e). T = 1.2 s

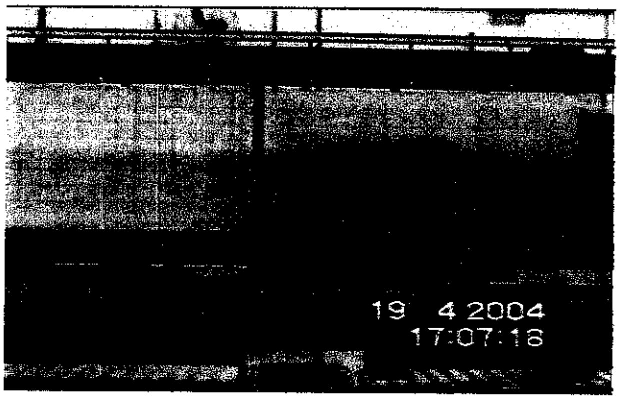
Figure 5.12 - Pictures taken during experiments for 30% plate porosity at 20 cm water depth



(a). T = 3.0 s



(b). T = 2.4 s



(c). T = 2.0 s

Figure 5.13 - Pictures taken during experiments for 30% plate porosity at 25 cm water depth

Porosity	Plate Arrangement		Water Depth, d (cm) 15					20					25					30				
			Wave Period, T (s)																			
			3.0	2.4	2.0	1.5	1.2	3.0	2.4	2.0	1.5	1.2	3.0	2.4	2.0	1.5	1.2	3.0	2.4	2.0	1.5	1.2
7%	Single	H_{max}	0.9	1.3	2.8	3.8	5.6	1.3	3.3	4.4	5.0	6.1	2.4	3.8	4.4	6.6	10.5	3.7	4.1	6.3	9.4	11.3
		H_{min}	0.4	0.9	1.5	2.7	3.5	0.9	2.0	2.5	3.6	4.3	1.5	2.5	3.0	4.7	7.3	2.4	2.5	4.6	6.2	8.2
	Double	H_{max}	1.1	2.1	2.7	3.7	4.2	1.9	2.1	2.4	3.2	6.6	3.3	3.6	4.1	6.0	13.8	3.0	5.2	6.5	8.8	13.7
		H_{min}	0.5	1.2	1.6	2.6	3.1	1.2	1.4	1.5	2.2	4.5	2.0	2.1	2.4	3.1	6.4	1.3	2.2	3.7	6.4	8.3
10%	Single	H_{max}	0.8	2.2	2.1	2.2	2.7	2.0	2.2	2.2	3.6	4.4	2.4	2.5	4.3	6.2	16.1	3.5	5.6	5.8	8.7	9.6
		H_{min}	0.5	1.7	1.2	1.6	1.8	1.5	1.4	1.5	2.7	3.2	1.6	1.7	3.1	4.6	11.8	2.7	3.6	4.5	6.1	7.4
	Double	H_{max}	1.7	2.2	2.5	6.6	7.9	3.2	4.1	4.9	5.8	6.9	3.9	5.2	5.6	13.8	16.3	6.0	7.8	9.0	16.0	18.8
		H_{min}	0.9	1.4	1.9	5.0	5.8	2.1	3.0	3.4	4.1	5.0	2.4	3.6	4.1	10.4	10.2	4.7	5.1	6.7	12.5	11.7
15%	Single	H_{max}	0.8	1.5	1.6	2.5	2.9	1.9	2.6	2.9	3.0	3.8	2.8	5.2	5.3	6.7	9.8	3.2	3.9	6.5	9.0	13.5
		H_{min}	0.5	1.2	1.1	1.9	2.2	1.6	1.7	2.1	2.3	2.9	1.9	3.8	3.9	5.1	7.3	2.7	2.8	5.1	6.2	10.6
	Double	H_{max}	1.1	1.2	1.3	1.6	3.2	1.8	2.0	2.3	2.7	5.3	2.3	2.4	2.9	4.0	9.7	3.4	3.7	5.8	9.8	11.0
		H_{min}	0.7	0.9	1.0	1.2	2.4	1.3	1.5	1.7	2.0	4.1	1.4	1.8	2.2	3.1	6.1	2.3	2.6	4.6	8.0	7.1
30%	Single	H_{max}	1.1	1.4	2.1	2.6	3.2	2.0	2.9	3.3	3.8	4.8	2.8	5.2	5.4	6.8	9.6	3.5	4.6	6.4	10.4	12.6
		H_{min}	0.8	1.1	1.5	2.0	2.4	1.7	2.0	2.4	2.9	3.8	1.9	3.8	4.1	5.3	7.5	3.0	3.4	5.1	8.2	10.4
	Double	H_{max}	1.5	1.8	2.5	2.9	3.3	2.5	2.9	3.6	3.9	5.6	1.9	2.4	4.0	5.1	8.9	3.2	3.6	5.9	10.4	12.2
		H_{min}	1.0	1.4	2.0	2.3	2.7	1.8	2.3	2.7	3.1	4.4	1.2	1.9	3.3	4.3	6.0	2.5	2.7	4.8	8.9	8.3
43%	Single	H_{max}	0.9	1.6	1.7	2.3	3.0	2.1	2.7	2.9	3.1	3.9	2.9	5.1	5.6	6.9	9.4	3.3	3.5	6.8	9.2	12.8
		H_{min}	0.7	1.3	1.2	1.9	2.3	1.8	1.9	2.2	2.4	3.1	2.1	3.9	4.5	5.6	7.5	2.8	2.9	5.7	7.4	10.6
	Double	H_{max}	1.2	1.3	1.3	1.6	3.2	1.9	2.4	2.5	2.9	4.9	2.3	3.8	4.2	7.3	10.2	3.3	3.8	5.6	9.6	11.4
		H_{min}	0.9	1.1	1.1	1.3	2.6	1.4	1.9	2.1	2.4	4.0	1.5	3.1	3.6	6.1	7.8	2.8	2.9	4.8	8.2	8.0

Table 5.3 - Comparisons of H_{max} and H_{min} for different plate porosities (reflected waves)

Porosity	Plate Arrangement		Water Depth, d (cm)																				
			15					20					25					30				
			Wave Period, T (s)																			
			3.0	2.4	2.0	1.5	1.2	3.0	2.4	2.0	1.5	1.2	3.0	2.4	2.0	1.5	1.2	3.0	2.4	2.0	1.5	1.2
7%	Single	H_{max}	0.9	1.1	1.1	1.2	1.4	1.8	2.1	2.0	2.2	2.4	2.0	2.2	2.9	3.6	3.8	3.5	3.8	4.1	4.5	6.0
		H_{min}	0.7	0.9	0.8	1.0	1.1	1.6	1.9	1.8	1.9	2.2	1.8	2.0	2.3	3.3	3.2	3.1	3.2	3.8	4.1	5.5
	Double	H_{max}	0.6	0.9	1.0	1.0	1.1	0.9	1.0	1.1	1.2	1.5	1.1	1.3	1.6	1.7	1.8	1.6	2.0	2.0	2.2	2.4
		H_{min}	0.5	0.7	0.7	0.8	0.9	0.8	0.8	0.9	1.0	1.3	0.8	1.1	1.2	1.5	1.6	1.4	1.8	1.7	2.1	2.2
10%	Single	H_{max}	0.7	1.0	1.1	1.2	1.4	1.4	1.8	2.0	2.2	2.3	1.9	2.1	2.7	3.2	4.5	2.8	3.2	3.7	4.4	5.2
		H_{min}	0.5	0.8	0.8	1.0	1.1	1.2	1.6	1.7	1.8	2.0	1.7	1.8	2.1	2.8	3.7	2.2	2.6	3.2	3.7	4.6
	Double	H_{max}	0.7	0.9	1.0	1.2	1.5	1.0	1.3	1.9	2.0	2.1	2.0	2.0	2.3	2.5	2.5	2.0	2.6	2.9	3.2	3.5
		H_{min}	0.5	0.7	0.7	0.9	1.2	0.8	1.0	1.5	1.6	1.8	1.4	1.7	1.6	2.2	1.9	1.7	2.2	2.4	2.9	3.1
15%	Single	H_{max}	0.7	0.9	1.3	1.3	1.7	1.5	1.9	2.0	2.3	2.8	2.3	3.4	3.7	4.6	5.1	2.6	3.1	4.1	4.8	7.4
		H_{min}	0.4	0.7	0.9	1.0	1.3	1.2	1.7	1.2	1.8	2.4	2.0	2.8	2.7	3.9	4.0	1.9	2.4	3.4	3.7	6.3
	Double	H_{max}	0.7	0.8	0.9	1.1	1.1	1.4	1.4	1.5	1.7	1.8	1.5	1.6	2.1	2.3	2.5	2.4	3.2	3.2	3.5	4.1
		H_{min}	0.5	0.6	0.6	0.8	0.8	1.1	1.0	1.1	1.3	1.4	0.9	1.3	1.4	2.0	1.9	1.9	2.6	2.5	3.1	3.6
30%	Single	H_{max}	0.9	1.2	1.3	1.2	1.5	1.4	2.0	2.2	2.1	2.3	2.0	2.1	2.6	3.5	4.8	2.9	3.3	3.9	4.3	5.4
		H_{min}	0.5	0.9	0.9	0.9	1.1	1.1	1.7	1.3	1.6	1.9	1.6	1.7	1.9	2.8	3.7	2.0	2.5	3.1	3.1	4.3
	Double	H_{max}	1.2	1.2	1.5	1.7	1.9	1.2	1.2	2.2	2.3	2.4	2.3	2.4	2.4	2.6	2.7	2.2	2.8	3.1	3.3	3.7
		H_{min}	0.8	0.7	0.9	1.1	1.2	0.9	0.8	1.4	1.7	1.7	1.2	1.9	1.5	2.1	2.0	1.6	2.0	2.3	2.7	3.2
43%	Single	H_{max}	0.9	1.1	1.2	1.4	2.0	1.8	2.1	2.2	2.4	2.9	2.4	3.6	3.8	4.4	5.2	3.1	3.2	4.2	4.5	7.5
		H_{min}	0.4	0.7	0.8	1.0	1.4	1.3	1.7	1.3	1.3	2.2	1.7	2.7	2.6	3.3	3.8	1.7	2.1	3.3	3.1	5.4
	Double	H_{max}	0.8	0.8	1.1	1.1	1.3	1.5	1.5	1.5	1.7	2.0	1.6	1.8	2.4	2.5	2.9	2.8	3.5	3.3	3.7	4.4
		H_{min}	0.5	0.4	0.5	0.7	0.8	1.1	1.0	0.9	1.2	1.4	0.7	1.4	1.4	1.9	2.0	1.9	2.4	2.1	3.0	3.4

Table 5.4 - Comparisons of H_{max} and H_{min} for different plate porosities (transmitted waves)

Calculation

The reflection coefficient, C_r is obtained from the formulas:

$$C_r = \frac{H_{max} - H_{min}}{H_{max} + H_{min}} \qquad (5)$$

The reflection coefficient C_r is the ratio of reflected wave height to incident wave height, H_{max} and H_{min} correspond to wave heights respectively at an antinode and a node of the corresponding combined wave system. However this simplification assumes that the locations of the antinode and node are known. Degree of wave reflection is defined by the reflection coefficient, C_r, when

$C_r = 1$	-	total reflection
$C_r = 0$	-	no reflection
$0 < C_r < 1$	-	partial reflection

Wave transmission can be characterized by a transmission coefficient, C_t, defined as the ratio of transmitted to incident characteristic wave heights (e.g., H_t and H_i) as given in equation below:

$$C_t = \frac{H_t}{H_i} \qquad (6)$$

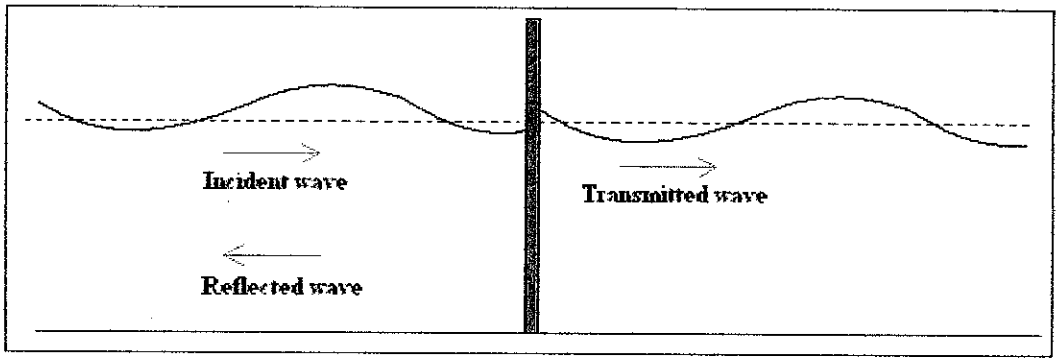


Figure 5.14 – Definition Sketch for Waves in the Flume

For a wave propagating over a slope or a permeable structure, the reflected wave energy is usually small and this phenomenon is called partial reflection where $0 < C_r < 1$, as shown in *Figure 5.15*

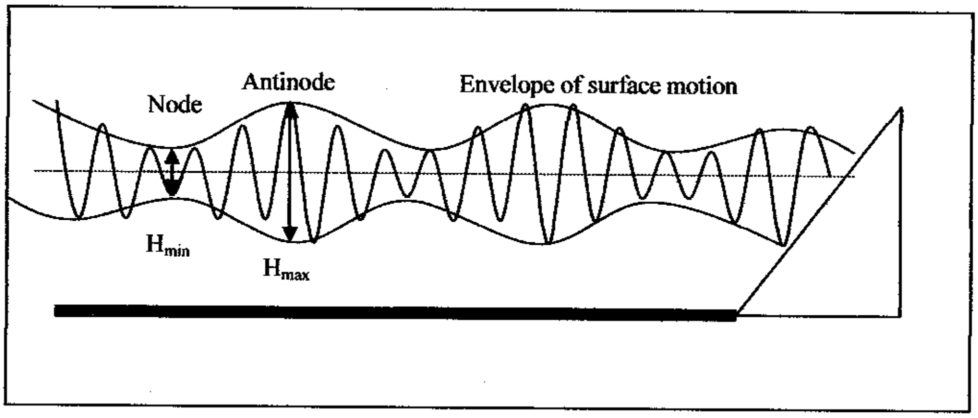


Figure 5.15 - Partial reflection ($0 < C_r < 1$)

The measurements of wave height, H, and wave length, L, could be done by counting the number of boxes of the grid system available on the glass wall, as shown in *Figure 5.16.*

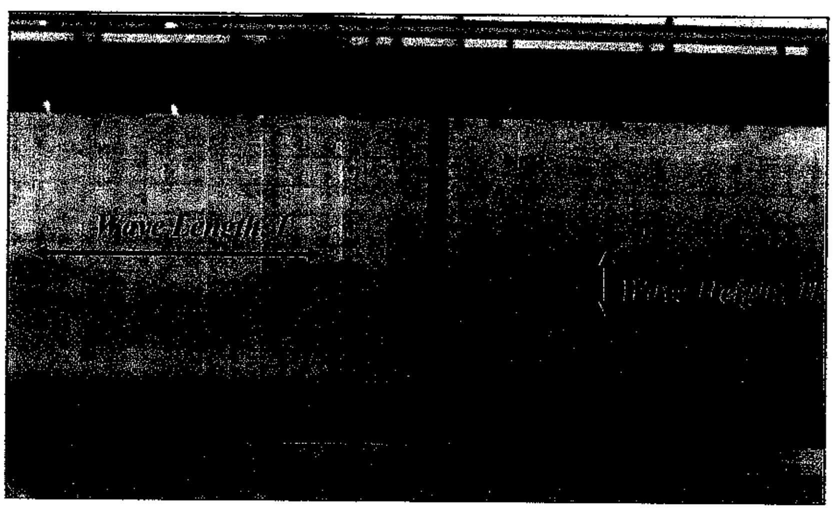


Figure 5.16 - Wave height and wave length marked on the flume wall

		Water Depth, d (cm)																			
		15					20					25					30				
Porosity	Plate Arrangement	Wave Period, T (s)																			
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7%	Single	0.38	0.18	0.12	0.17	0.23	0.18	0.25	0.28	0.13	0.17	0.23	0.21	0.19	0.17	0.18	0.21	0.08	0.10	0.21	0.16
	Double	0.38	0.27	0.26	0.10	0.08	0.23	0.20	0.09	0.19	0.19	0.21	0.26	0.26	0.32	0.37	0.40	0.41	0.27	0.16	0.25
10%	Single	0.23	0.13	0.17	0.16	0.20	0.14	0.22	0.19	0.13	0.16	0.20	0.19	0.16	0.15	0.15	0.13	0.13	0.13	0.18	0.13
	Double	0.31	0.22	0.14	0.12	0.12	0.21	0.15	0.14	0.17	0.16	0.23	0.18	0.15	0.14	0.23	0.12	0.21	0.15	0.12	0.23
15%	Single	0.23	0.11	0.25	0.14	0.14	0.09	0.21	0.16	0.13	0.13	0.19	0.16	0.15	0.14	0.15	0.08	0.16	0.12	0.18	0.12
	Double	0.22	0.14	0.13	0.14	0.14	0.16	0.14	0.15	0.15	0.13	0.24	0.14	0.14	0.13	0.23	0.19	0.17	0.12	0.10	0.22
30%	Single	0.16	0.12	0.27	0.13	0.14	0.08	0.18	0.16	0.14	0.12	0.19	0.16	0.14	0.12	0.12	0.08	0.19	0.18	0.12	0.10
	Double	0.20	0.13	0.11	0.14	0.16	0.16	0.12	0.18	0.11	0.12	0.24	0.12	0.10	0.09	0.19	0.12	0.14	0.10	0.08	0.19
43%	Single	0.13	0.10	0.28	0.10	0.13	0.08	0.17	0.14	0.16	0.11	0.16	0.13	0.11	0.10	0.11	0.08	0.20	0.20	0.11	0.09
	Double	0.14	0.08	0.08	0.17	0.10	0.15	0.12	0.23	0.09	0.10	0.25	0.10	0.08	0.09	0.13	0.08	0.13	0.08	0.08	0.18

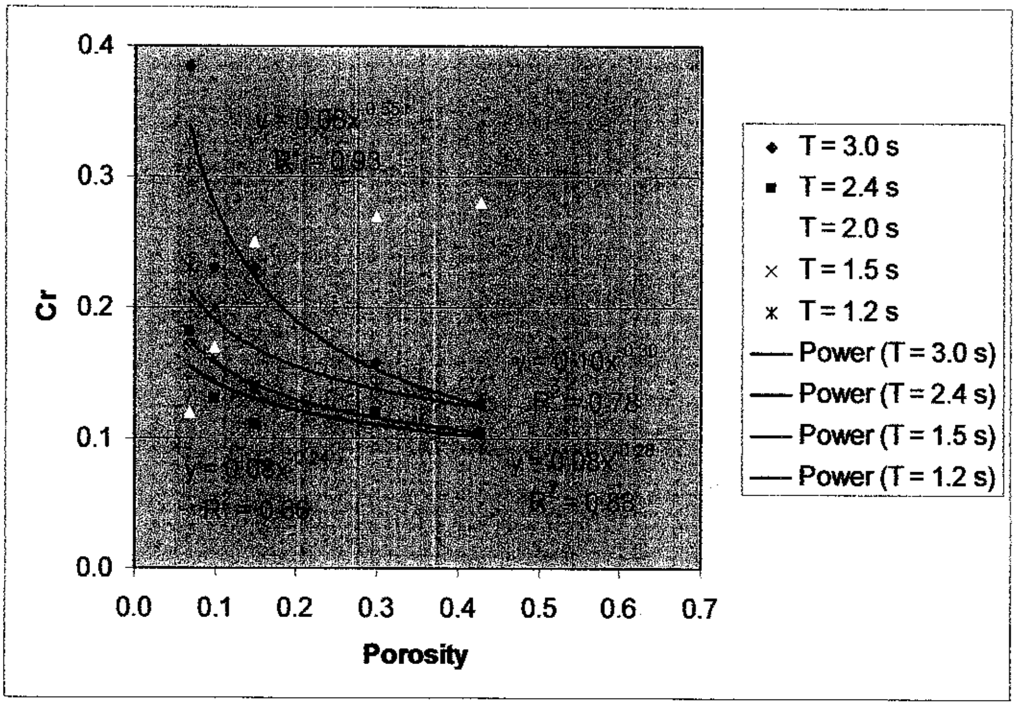
Table 5.5 - Comparison of C_r for different plate porosities at maximum adjustment

Porosity	Plate Arrangement	Water Depth, d (cm): 15					20					25					30				
		Wave Period, T (s)																			
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7%	Single	0.29	0.10	0.16	0.09	0.12	0.06	0.05	0.05	0.07	0.04	0.05	0.05	0.12	0.04	0.09	0.06	0.09	0.04	0.05	0.04
	Double	0.23	0.13	0.28	0.11	0.10	0.15	0.11	0.10	0.09	0.07	0.16	0.08	0.14	0.06	0.06	0.07	0.05	0.08	0.11	0.13
10%	Single	0.27	0.11	0.16	0.09	0.12	0.08	0.06	0.08	0.10	0.07	0.06	0.08	0.13	0.07	0.10	0.12	0.10	0.07	0.09	0.06
	Double	0.20	0.13	0.25	0.14	0.11	0.14	0.13	0.12	0.11	0.08	0.18	0.08	0.18	0.06	0.14	0.08	0.08	0.09	0.10	0.07
15%	Single	0.20	0.13	0.18	0.13	0.13	0.11	0.06	0.25	0.12	0.08	0.07	0.10	0.16	0.08	0.12	0.16	0.13	0.09	0.13	0.08
	Double	0.17	0.14	0.20	0.16	0.16	0.12	0.17	0.15	0.13	0.13	0.25	0.10	0.20	0.07	0.14	0.12	0.10	0.12	0.06	0.06
30%	Single	0.17	0.14	0.18	0.14	0.15	0.12	0.08	0.26	0.14	0.10	0.11	0.11	0.16	0.11	0.13	0.18	0.14	0.11	0.16	0.11
	Double	0.17	0.26	0.18	0.21	0.23	0.11	0.20	0.22	0.15	0.17	0.31	0.12	0.23	0.11	0.15	0.16	0.17	0.15	0.05	0.06
43%	Single	0.13	0.22	0.20	0.17	0.18	0.16	0.11	0.26	0.30	0.14	0.17	0.14	0.19	0.14	0.16	0.29	0.21	0.12	0.18	0.16
	Double	0.09	0.33	0.16	0.22	0.24	0.09	0.20	0.25	0.17	0.18	0.39	0.13	0.26	0.14	0.18	0.19	0.19	0.22	0.02	0.04

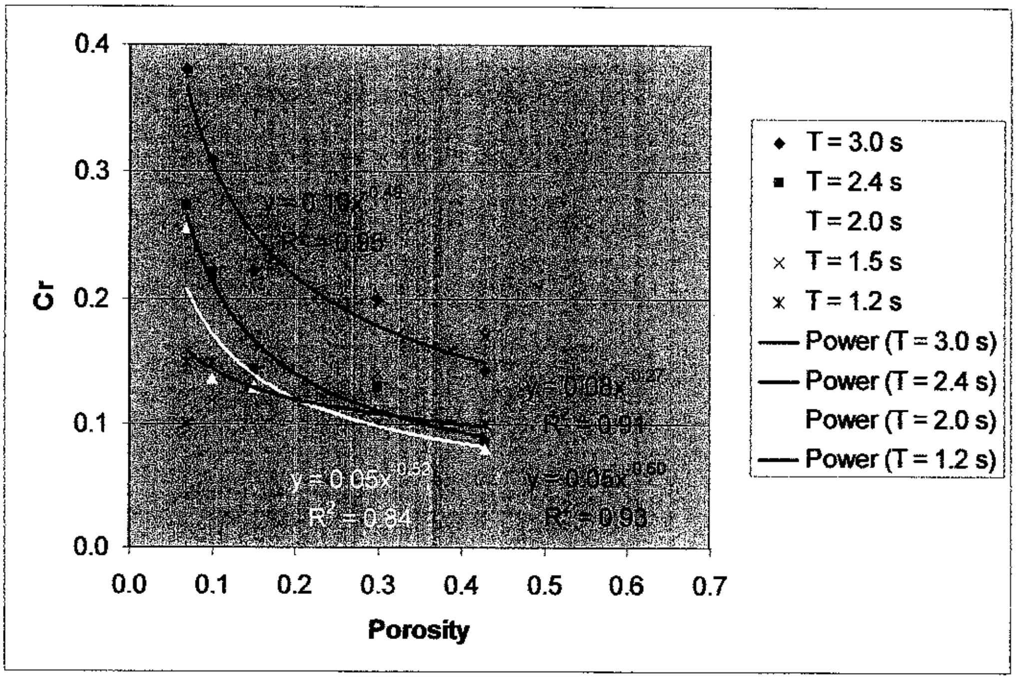
Table 5.6 - Comparison of C_t for different plate porosities at maximum adjustment

5.2.1 Reflected waves

At water depth, d = 15 cm

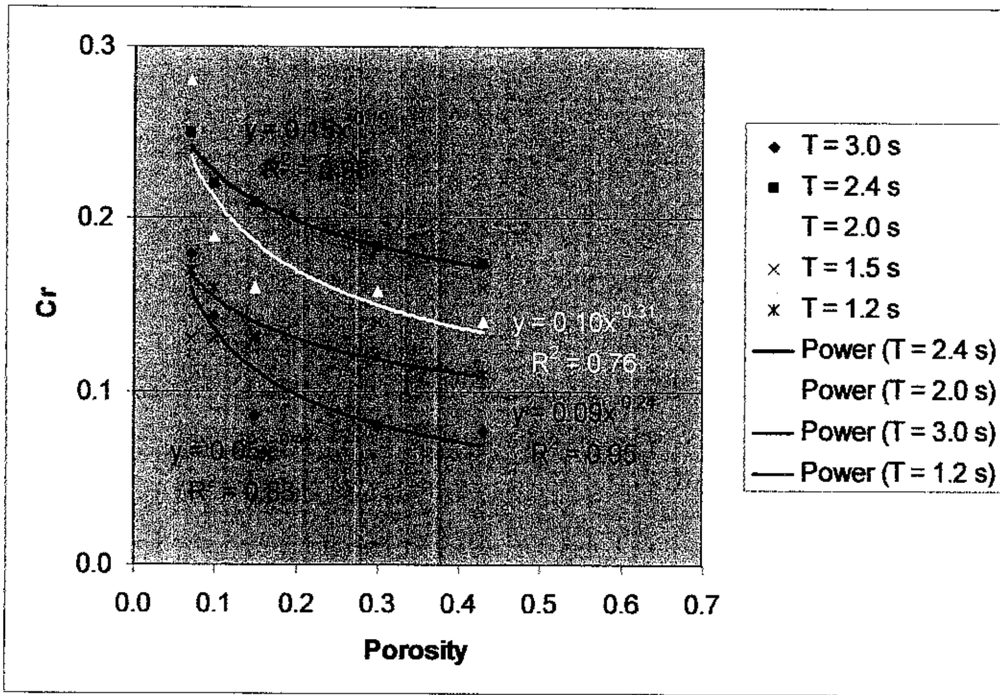


(a). Wave Reflection Coefficients for Single Perforated Plates

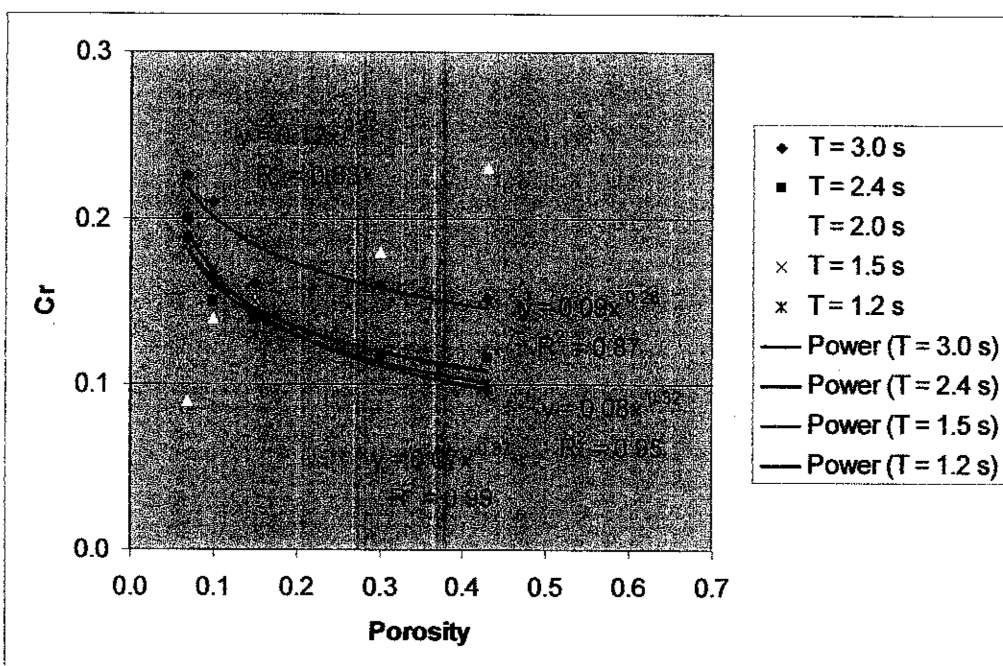


(b). Wave Reflection Coefficients for Double Perforated Plates

At water depth, d = 20 cm

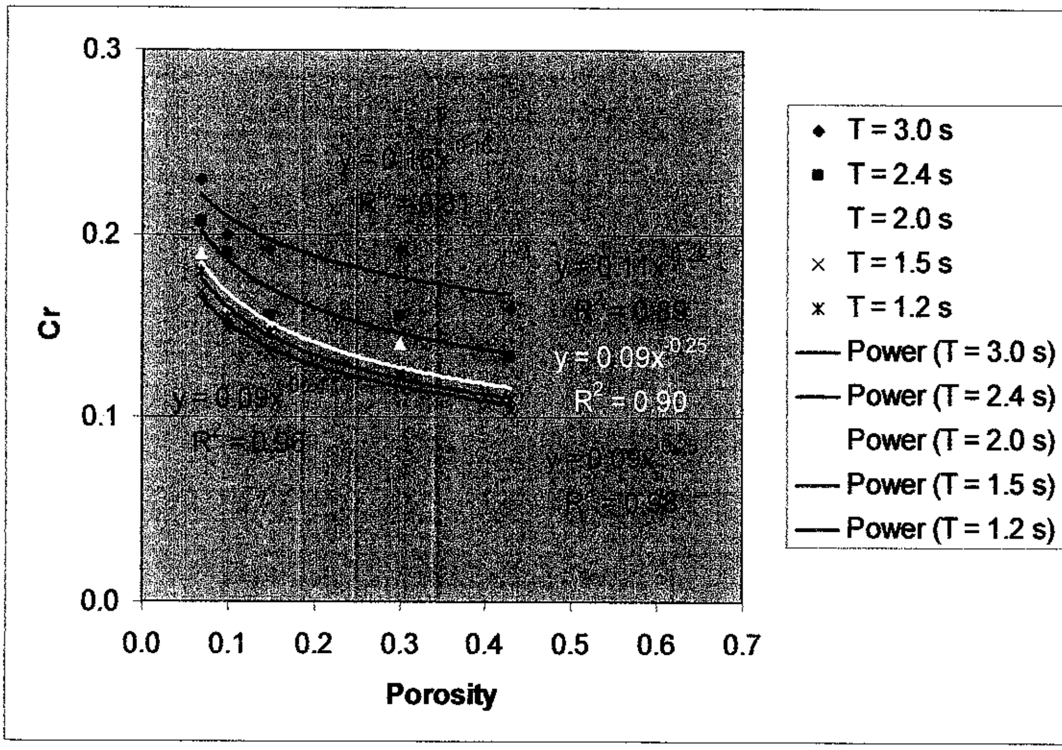


(c). Wave Reflection Coefficients for Single Perforated Plates

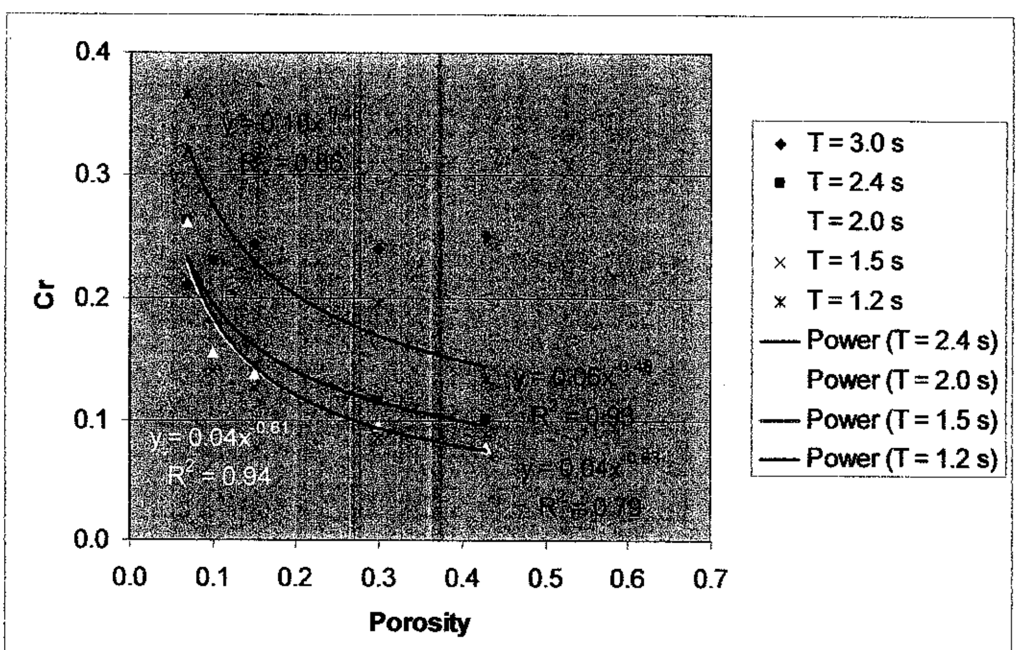


(d). Wave Reflection Coefficients for Double Perforated Plates

At water depth, d = 25 cm

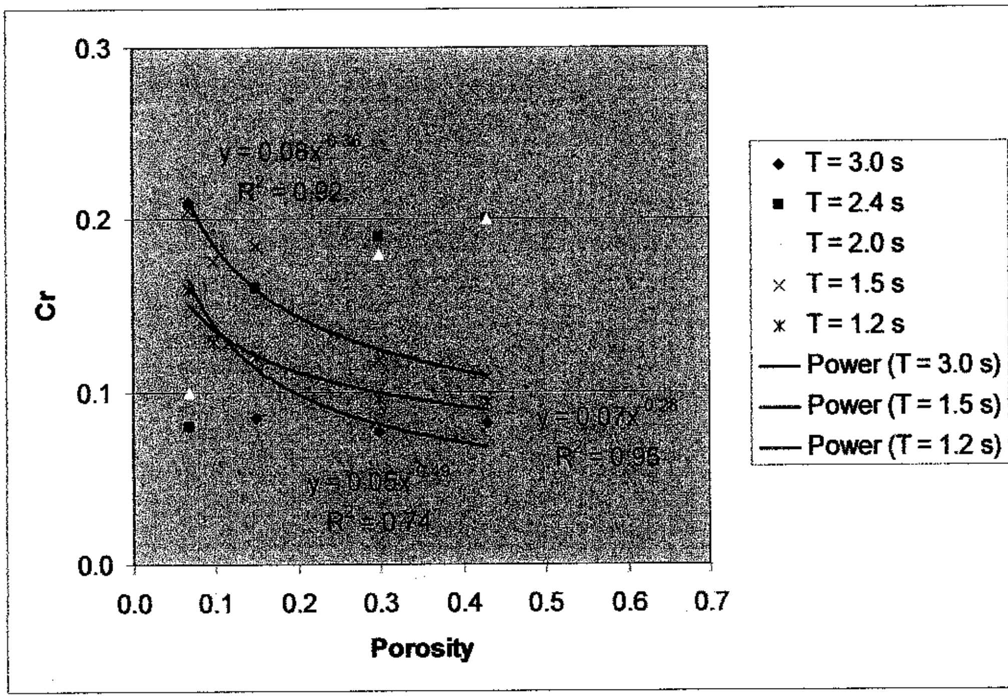


(e). Wave Reflection Coefficients for Single Perforated Plates

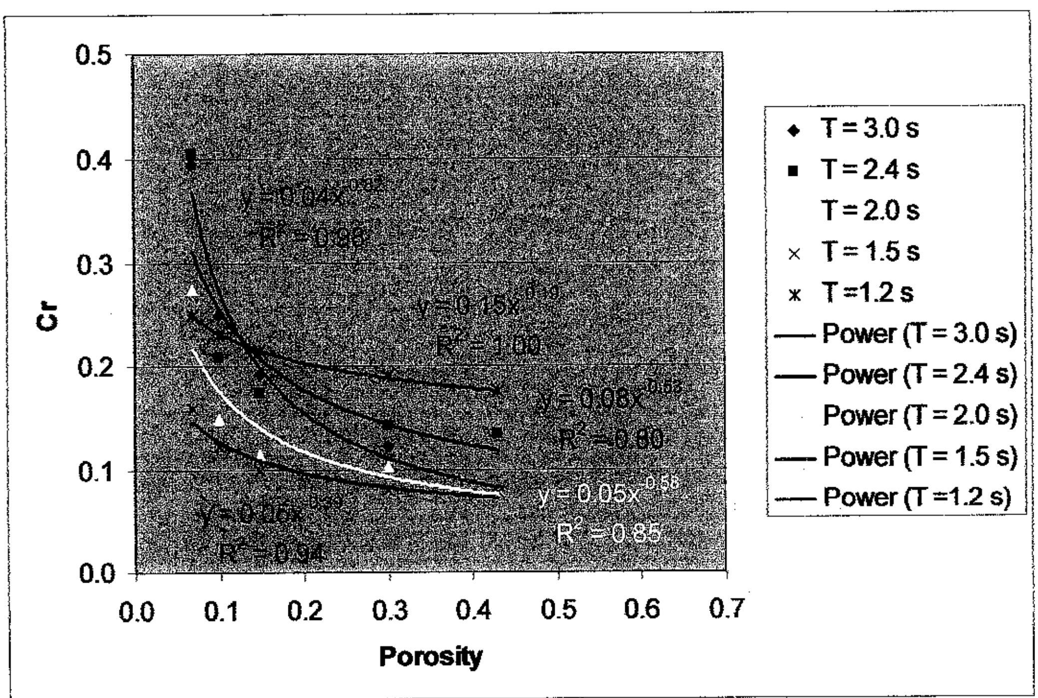


(f). Wave Reflection Coefficients for Double Perforated Plates

At water depth, d = 30 cm



(g). Wave Reflection Coefficients for Single Perforated Plates



(h). Wave Reflection Coefficients for Double Perforated Plates

Figure 5.17 - Wave Reflection Coefficients for Single and Double Perforated Plates at Various Water Depths

Discussion

From the data gathered in the experiment, there are four graphs plotted for single perforated plate and other four graphs for double plates. Each graph represents reflection coefficients, C_r against porosities, Ø at various water depths, d.

Based on the results, a standing wave pattern characterized by an envelope having uniform maximum and minimum due to interaction of the incident and reflected wave, could be observed. The measurement of maximum and minimum wave heights would result to the determination of incident and reflected wave height by applying the equations. The amount of reflection is given by the ratio of the reflected wave height, H_r, to the incident H_i, which is termed the reflected coefficient, C_r

From the literature adapted from Allsop and Hettiarachchi 1998, the curves obtained in the graphs should exponentially decrease, which means that the C_r will decrease when the plate porosity is increased. From the result, it is found that shape of the experimental curves similar with the shape of curves from literature. However, there are some curves that are not complying with the literature.

For single perforated plate, there are some curves which do not decrease exponentially. The curves are T = 2.0 s for 15 cm water depth and T = 1.5 s for 20 cm. For 30 cm water depth, there are two curves that do not comply with the literature which are curves at T = 2.4 s and at T = 2.0 s. For single perforated plate, the best graph plotted is for 25 cm water depth where all the curves in this graph decrease exponentially, thus comply with the literature.

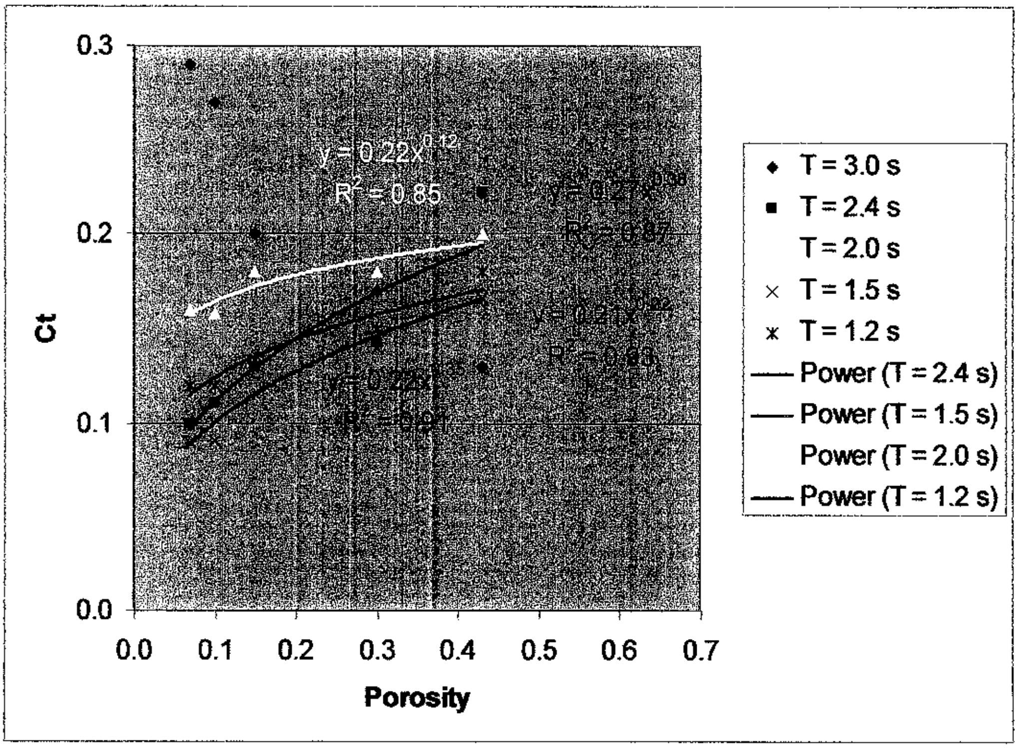
For double perforated plate, there are also some curves that not decrease exponentially. The curves are T = 3.0 s for 15 cm water depth, T = 2.0 s for 20 cm. and T = 1.5 for 25 cm water depth. For double perforated plate, the best graph plotted is at 30 cm water depth where all the curves in this graph comply with the literature.

From the literature, the curves plotted must start at 1.0 for C_r at $Ø = 0$ which are at total reflection. However, the curves do not intercept this point when they are extended to Y-axis. There may be some errors occur throughout the experiment which effect the result. The errors might be human error and also the mechanical error.

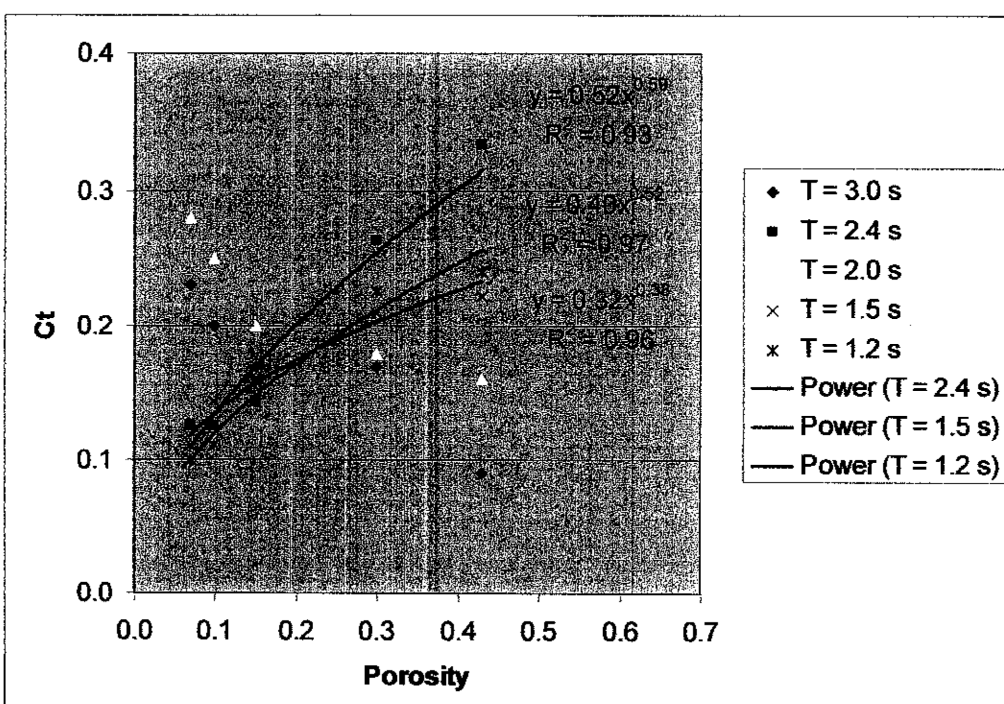
From the results, it is also found that the reflection coefficient, C_r, for both single and double perforated plates can be defined as partial reflection because the values of C_r are between 0 and 1.

5.2.2 Transmitted waves

At water depth, d = 15 cm

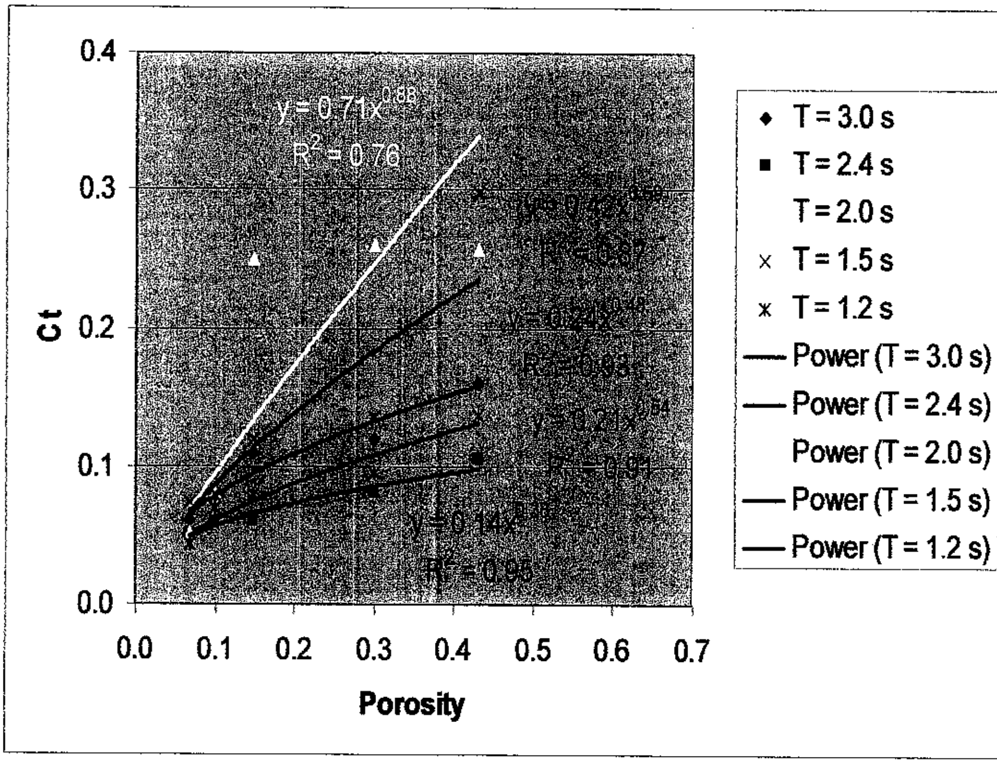


(a). Wave Transmission Coefficients for Single Perforated Plates

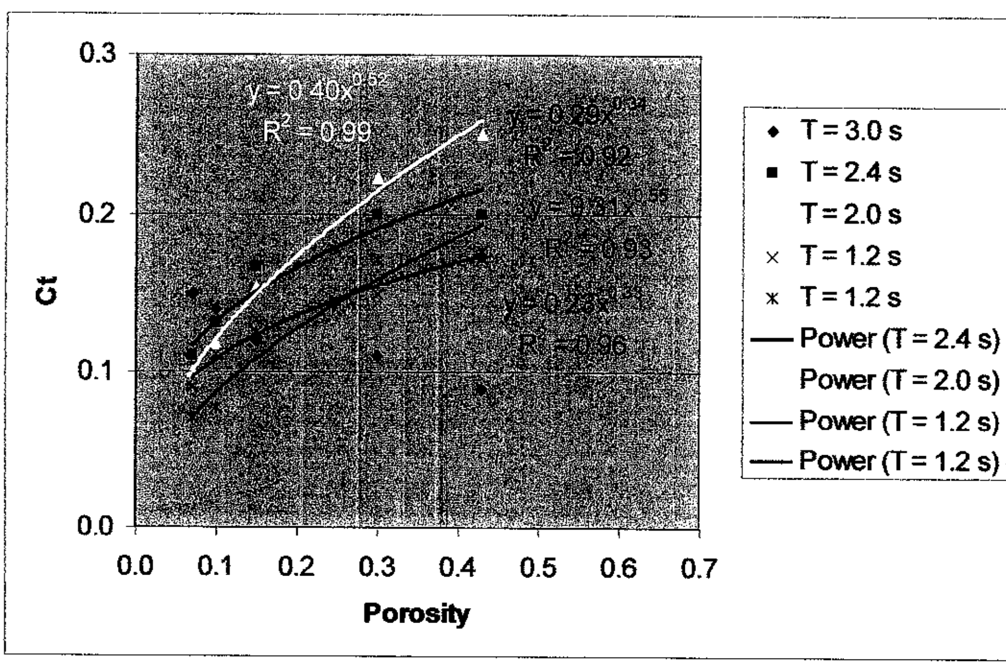


(b). Wave Transmission Coefficients for Double Perforated Plates

At water depth, d = 20 cm

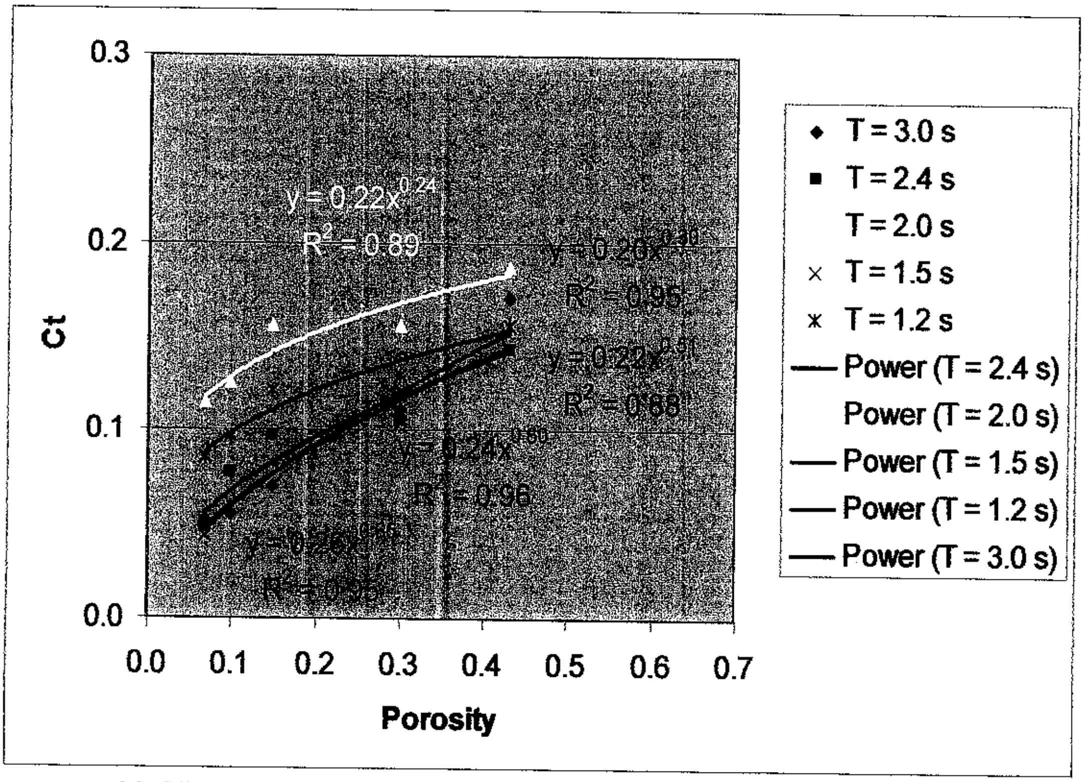


(c). Wave Transmission Coefficients for Single Perforated Plates

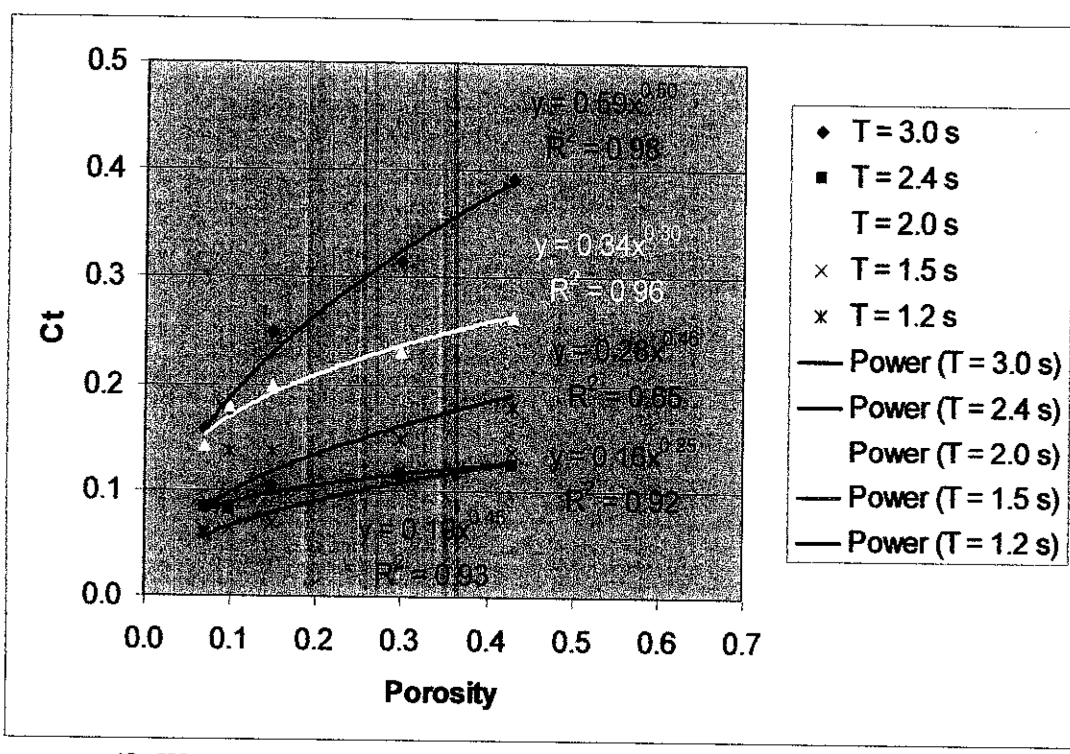


(d). Wave Transmission Coefficients for Double Perforated Plates

At water depth, d = 25 cm

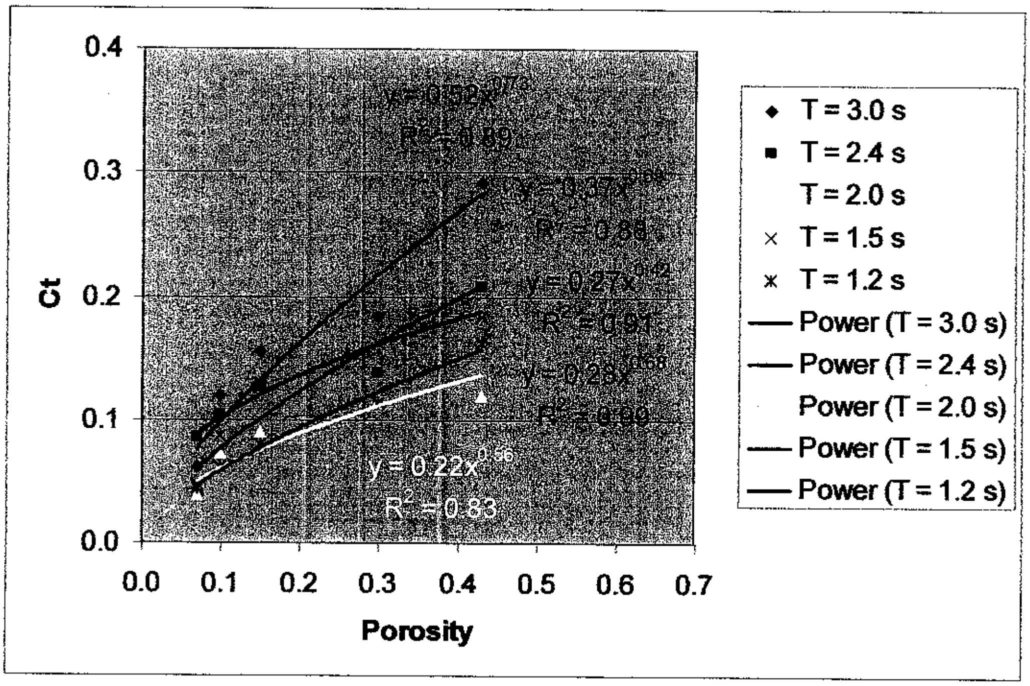


(e). Wave Transmission Coefficients for Single Perforated Plates

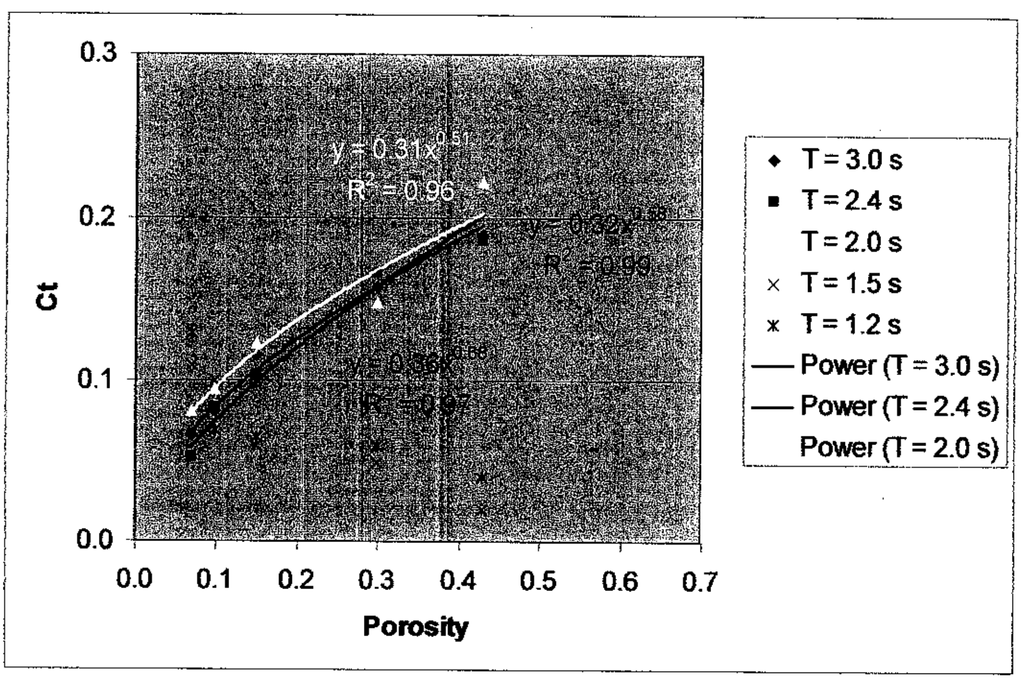


(f). Wave Transmission Coefficients for Double Perforated Plates

At water depth, d = 30 cm



(g). Wave Transmission Coefficients for Single Perforated Plates



(h). Wave Transmission Coefficients for Double Perforated Plates

Figure 5.18 - Wave Transmission Coefficients for Single and Double Perforated Plates at Various Water Depths

Discussion

From the data gathered in the experiment, there are four graphs plotted for single perforated plate and four graphs for double perforated plates as well. Each graph represents transmission coefficients, C_t against porosities, Ø at different water depths, *d*.

From the literature adapted from Allsop and Hettiarachchi 1998, the curves obtained in the graphs should longitudinally increase, which means that the C_t will decrease when the plate porosity, Ø is increased. From the result, it is found that shape of the experimental curves similar with the shape of curves from literature. However, there are some curves that are not complying with the literature.

For single perforated plate, there is only one curve that does not increase longitudinally. The curve is T = 3.0 s for 15 cm water depth. All the curves for 20 cm, 25 cm and 30 cm water depths are increase longitudinally, thus comply with the literature.

For double perforated plate, there are more curves which do not increase longitudinally. The curves are T = 3.0 s and T = 2.0 c for 15 cm water depth, and T = 1.5 and T = 1.2 s for 30 cm water depth. There is another curve which do not increase longitudinally that is T = 3.0 for 20 cm water depth. For double perforated plate, the best graph plotted is at 25 cm water depth where all the curves in this graph comply with the literature.

From the literature, the curves plotted must start at 0 for C_t at Ø = 0 which are at total reflection. However, the curves will not intercept this point when they are extended to Y-axis. There may be some errors occur throughout the experiment which effect the result. The errors might be human error and mechanical error of the instrument used.

5.2.3 Dissipation of wave energy

The total energy *(E) per unit area* of a wave is given by:

$$E = \frac{1}{8}\left(\rho g H^2\right) \qquad (7)$$

where ρ is the density of the water (in kg m^{-3}), g is 9.8 ms^{-2} and H is the wave height (m). The energy (E) is then in joules per square meter (J m^{-2}). The equation shows that wave energy is proportional to the square of the wave height.

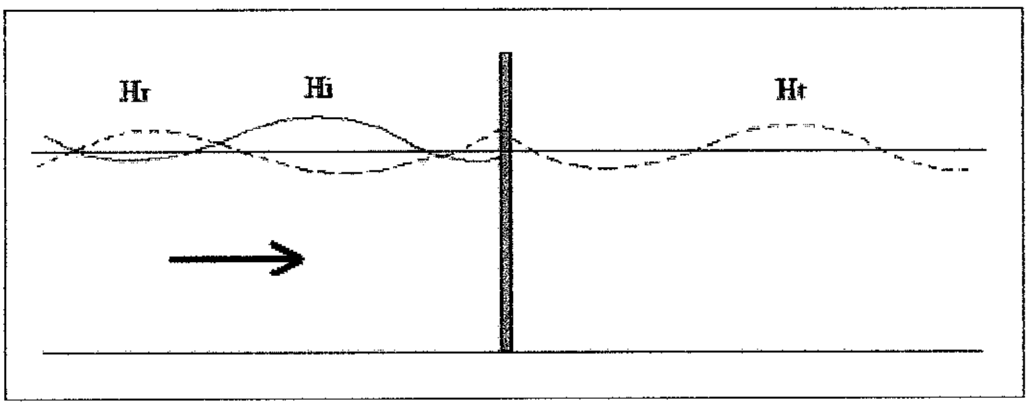


Figure 5.19 – Definition sketch for H_i, H_r and H_t

The incident wave height, H_i, reflected wave height, H_r and transmitted wave height, H_t are obtained from the formulas:

$$H_i = \frac{H_{max} + H_{min}}{2} \qquad (8)$$

$$H_r = \frac{H_{max} - H_{min}}{2} \qquad (9)$$

$$H_t = \frac{H_{max} - H_{min}}{2} \qquad (10)$$

The graphs below show the comparisons of Hi, Hr and Ht at maximum adjustment. The values in the tables are gathered from the formulas above.

		Water Depth, d (cm)																			
		15					20					25					30				
Porosity	Plate Arrangement	Wave Period, T (s)																			
		3.0	2.4	2.0	1.5	1.2	3.0	2.4	2.0	1.5	1.2	3.0	2.4	2.0	1.5	1.2	3.0	2.4	2.0	1.5	1.2
7%	Single	0.65	1.1	2.15	3.25	4.55	1.10	2.65	3.45	4.30	5.20	1.95	3.15	3.70	5.65	8.90	3.05	3.30	5.45	7.80	9.75
	Double	0.80	1.65	2.15	3.15	3.65	1.55	1.75	1.95	2.70	5.55	2.65	2.85	3.25	4.55	10.10	2.15	3.70	5.10	7.60	11.00
10%	Single	0.65	1.95	1.65	1.90	2.25	1.75	1.80	1.85	3.15	3.80	2.00	2.10	3.70	5.40	13.95	3.10	4.60	5.15	7.40	8.50
	Double	1.30	1.80	2.20	5.80	6.85	2.65	3.55	4.15	4.95	5.95	3.15	4.40	4.85	12.10	13.25	5.35	6.45	7.85	14.25	15.25
15%	Single	0.65	1.35	1.35	2.20	2.55	1.75	2.15	2.50	2.65	3.35	2.35	4.50	4.60	5.90	8.55	2.95	3.35	5.80	7.60	12.05
	Double	0.90	1.05	1.15	1.40	2.80	1.55	1.75	2.00	2.35	4.70	1.85	2.10	2.55	3.55	7.90	2.85	3.15	5.20	8.90	9.05
30%	Single	0.95	1.25	1.80	2.30	2.80	1.85	2.45	2.85	3.35	4.30	2.35	4.50	4.75	6.05	8.55	3.25	4.00	5.75	9.30	11.50
	Double	1.25	1.60	2.25	2.60	3.00	2.15	2.60	3.15	3.50	5.00	1.55	2.15	3.65	4.70	7.45	2.85	3.15	5.35	9.65	10.25
43%	Single	0.80	1.45	1.45	2.10	2.65	1.95	2.30	2.55	2.75	3.50	2.50	4.50	5.05	6.25	8.45	3.05	3.20	6.25	8.30	11.70
	Double	1.05	1.20	1.20	1.45	2.90	1.65	2.15	2.30	2.65	4.45	1.90	3.45	3.90	6.70	9.00	3.05	3.35	5.20	8.90	9.70

Table 5.7 - Comparisons of H_i for different plate porosities at maximum adjustment

		Water Depth, d (cm)																			
		15					20					25					30				
Porosity	Plate Arrangement	Wave Period, T (s)																			
		3.0	2.4	2.0	1.5	1.2	3.0	2.4	2.0	1.5	1.2	3.0	2.4	2.0	1.5	1.2	3.0	2.4	2.0	1.5	1.2
7%	Single	0.25	0.20	0.65	0.55	1.05	0.20	0.65	0.95	0.70	0.90	0.45	0.65	0.70	0.95	1.60	0.65	0.80	0.85	1.60	1.55
	Double	0.30	0.45	0.55	0.55	0.55	0.35	0.35	0.45	0.50	1.05	0.65	0.75	0.85	1.45	3.70	0.85	1.50	1.40	1.20	2.70
10%	Single	0.15	0.25	0.45	0.30	0.45	0.25	0.40	0.35	0.45	0.60	0.40	0.40	0.60	0.80	2.15	0.40	1.00	0.65	1.30	1.10
	Double	0.40	0.40	0.30	0.80	1.05	0.55	0.55	0.75	0.85	0.95	0.75	0.80	0.75	1.70	3.05	0.65	1.35	1.15	1.75	3.55
15%	Single	0.15	0.15	0.25	0.30	0.35	0.15	0.45	0.40	0.35	0.45	0.45	0.70	0.70	0.80	1.25	0.25	0.55	0.70	1.40	1.45
	Double	0.20	0.15	0.15	0.20	0.40	0.25	0.25	0.30	0.35	0.60	0.45	0.30	0.35	0.45	1.80	0.55	0.55	0.60	0.90	1.95
30%	Single	0.15	0.15	0.30	0.30	0.40	0.15	0.45	0.45	0.45	0.50	0.45	0.70	0.65	0.75	1.05	0.25	0.60	0.65	1.10	1.10
	Double	0.25	0.20	0.25	0.30	0.30	0.35	0.30	0.45	0.40	0.60	0.35	0.25	0.35	0.40	1.45	0.35	0.45	0.55	0.75	1.95
43%	Single	0.10	0.15	0.25	0.20	0.35	0.15	0.40	0.35	0.35	0.40	0.40	0.60	0.55	0.65	0.95	0.25	0.30	0.55	0.90	1.10
	Double	0.15	0.10	0.10	0.15	0.30	0.25	0.25	0.20	0.25	0.45	0.40	0.35	0.30	0.60	1.20	0.25	0.45	0.40	0.70	1.70

Table 5.8 - Comparisons of H_r for different plate porosities at maximum adjustment

Porosity	Plate Arrangement	Water Depth (d) 15					20					25					30				
		Wave Period, T (s)																			
		3.0	2.4	2.0	1.5	1.2	3.0	2.4	2.0	1.5	1.2	3.0	2.4	2.0	1.5	1.2	3.0	2.4	2.0	1.5	1.2
7%	Single	0.10	0.10	0.15	0.10	0.15	0.10	0.10	0.10	0.15	0.10	0.10	0.10	0.30	0.15	0.30	0.20	0.30	0.15	0.20	0.25
	Double	0.05	0.10	0.15	0.10	0.10	0.05	0.10	0.10	0.10	0.10	0.15	0.10	0.20	0.10	0.10	0.10	0.10	0.15	0.05	0.10
10%	Single	0.10	0.10	0.15	0.10	0.15	0.10	0.10	0.15	0.20	0.15	0.10	0.15	0.30	0.20	0.40	0.30	0.30	0.25	0.35	0.30
	Double	0.10	0.10	0.15	0.15	0.15	0.10	0.15	0.20	0.20	0.15	0.30	0.15	0.35	0.15	0.30	0.15	0.20	0.25	0.15	0.20
15%	Single	0.15	0.10	0.20	0.15	0.20	0.15	0.10	0.40	0.25	0.20	0.15	0.30	0.50	0.35	0.55	0.35	0.35	0.35	0.55	0.55
	Double	0.10	0.10	0.15	0.15	0.15	0.15	0.20	0.20	0.20	0.20	0.30	0.15	0.35	0.15	0.30	0.25	0.30	0.35	0.20	0.25
30%	Single	0.20	0.15	0.20	0.15	0.20	0.15	0.15	0.45	0.25	0.20	0.20	0.20	0.35	0.35	0.55	0.45	0.40	0.40	0.60	0.55
	Double	0.20	0.25	0.30	0.30	0.35	0.15	0.20	0.40	0.30	0.35	0.55	0.25	0.45	0.25	0.35	0.30	0.40	0.40	0.30	0.25
43%	Single	0.25	0.20	0.20	0.20	0.30	0.25	0.20	0.45	0.55	0.35	0.35	0.45	0.60	0.55	0.70	0.70	0.55	0.45	0.70	1.05
	Double	0.15	0.20	0.30	0.20	0.25	0.20	0.25	0.30	0.25	0.30	0.45	0.20	0.50	0.30	0.45	0.45	0.55	0.60	0.35	0.50

Table 5.9 - Comparisons of H_t for different plate porosities at maximum adjustment

For 15m water depth,

Porosity	Plate Arrangement	Wave Period, T (s)					Average
		3.0	2.4	2.0	1.5	1.2	
7%	Single	517.56	1482.25	5662.56	12939.06	25360.56	9192.40
	Double	784.00	3335.06	5662.56	12155.06	16320.06	7651.35
10%	Single	517.56	4658.06	3335.06	4422.25	6201.56	3826.90
	Double	2070.25	3969.00	5929.00	41209.00	57480.06	22131.46
15%	Single	517.56	2232.56	2232.56	5929.00	7965.56	3775.45
	Double	992.25	1350.56	1620.06	2401.00	9604.00	3193.58
30%	Single	1105.56	1914.06	3969.00	6480.25	9604.00	4614.58
	Double	1914.06	3136.00	6201.56	8281.00	11025.00	6111.53
43%	Single	784.00	2575.56	2575.56	5402.25	8602.56	3987.99
	Double	1350.56	1764.00	1764.00	2575.56	10302.25	3551.28

Table 5.10 - Comparisons of wave energy for incident waves, E_i

Porosity	Plate Arrangement	Wave Period, T (s)					Average
		3.0	2.4	2.0	1.5	1.2	
7%	Single	76.56	49.00	517.56	370.56	1350.56	472.85
	Double	110.25	248.06	370.56	370.56	370.56	294.00
10%	Single	27.56	76.56	248.06	110.25	248.06	142.10
	Double	196.00	196.00	110.25	784.00	1350.56	527.36
15%	Single	27.56	27.56	76.56	110.25	150.06	78.40
	Double	49.00	27.56	27.56	49.00	196.00	69.83
30%	Single	27.56	27.56	110.25	110.25	196.00	94.33
	Double	76.56	49.00	76.56	110.25	110.25	84.53
43%	Single	12.25	27.56	76.56	49.00	150.06	63.09
	Double	27.56	12.25	12.25	27.56	110.25	37.98

Table 5.11 - Comparisons of wave energy for reflected waves, E_r

Porosity	Plate Arrangement	Wave Period, T (s)					Average
		3.0	[illegible]	2.0	1.5	[illegible]	
7%	Single	12.25	12.25	27.56	12.25	27.56	18.38
	Double	3.06	12.25	27.56	12.25	12.25	13.48
10%	Single	12.25	12.25	27.56	12.25	27.56	18.38
	Double	12.25	12.25	27.56	27.56	27.56	21.44
15%	Single	27.56	12.25	49.00	27.56	49.00	33.08
	Double	12.25	12.25	27.56	27.56	27.56	21.44
30%	Single	49.00	27.56	49.00	27.56	49.00	40.43
	Double	49.00	76.56	110.25	110.25	150.06	99.23
43%	Single	76.56	49.00	49.00	49.00	110.25	66.76
	Double	27.56	49.00	110.25	49.00	76.56	62.48

Table 5.12 - Comparisons of wave energy for transmitted waves, E_t

Wave attenuation involves loss or dissipation of wave energy, resulting in a reduction of wave height. Wave dissipation is given by:

$$E_{loss} = E_i - E_r - E_t \qquad (11)$$

Porosity	Water depth, d (cm)							
	15		20		25		30	
	Plate Arrangement							
	Single	Double	Single	Double	Single	Double	Single	Double
7%	8701.18	7343.88	15419.69	11151.79	32768.14	32052.74	48704.78	51294.43
10%	3666.43	21582.66	8103.38	22987.13	58701.39	88315.76	43944.43	134272.86
15%	3663.98	3102.31	7637.88	8868.39	36914.76	20859.91	61406.19	49059.41
30%	4479.83	5927.78	11277.35	14010.33	37884.96	23181.29	67109.18	58627.89
43%	3858.14	3450.83	8352.05	9477.83	38916.41	37645.48	63534.01	52876.51

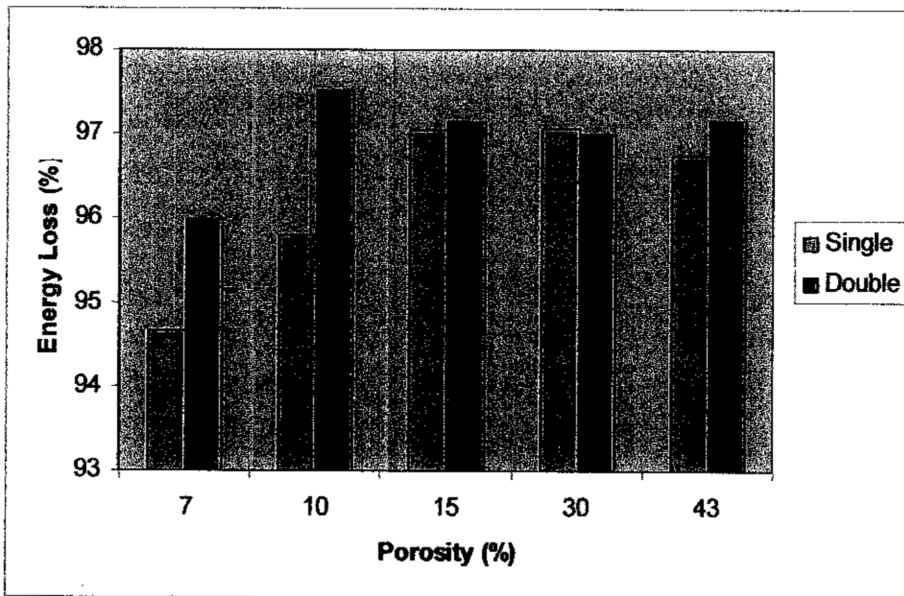
Table 5.13 - Comparisons of wave energy loss, E_{loss} for different plate porosities

The percentage of wave energy losses is given by energy losses per wave energy for incident waves,

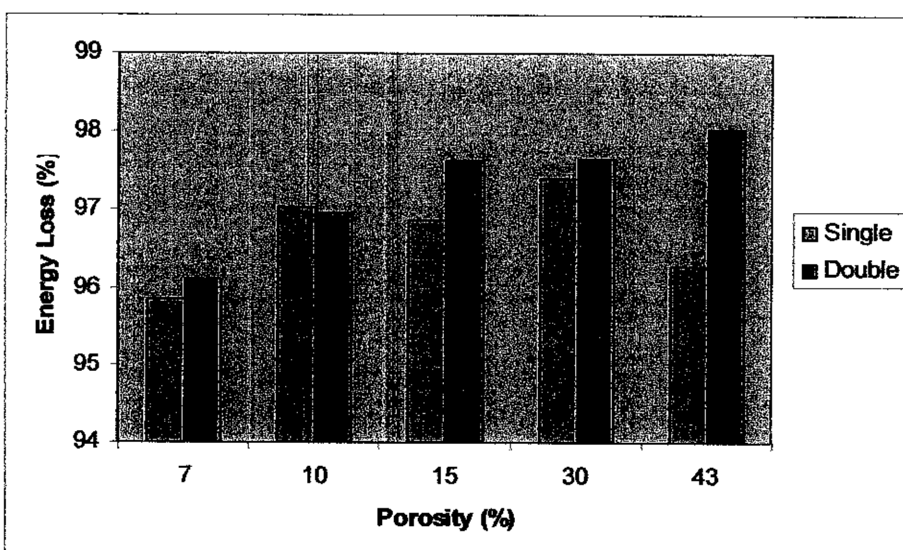
$$E_{loss}(\%) = \frac{E_{loss}}{E_i} \qquad (12)$$

Porosity	Water depth, d (cm)							
	15		20		25		30	
	Plate Arrangement							
	Single	Double	Single	Double	Single	Double	Single	Double
7%	94.66	95.98	95.85	96.11	96.54	88.15	96.60	93.85
10%	95.81	97.52	97.03	96.97	97.45	96.18	97.32	96.58
15%	97.05	97.14	96.88	97.63	97.31	95.29	97.70	97.11
30%	97.08	96.99	97.40	97.66	97.84	96.61	98.40	97.73
43%	96.74	97.17	96.28	98.04	97.77	98.11	98.09	97.72

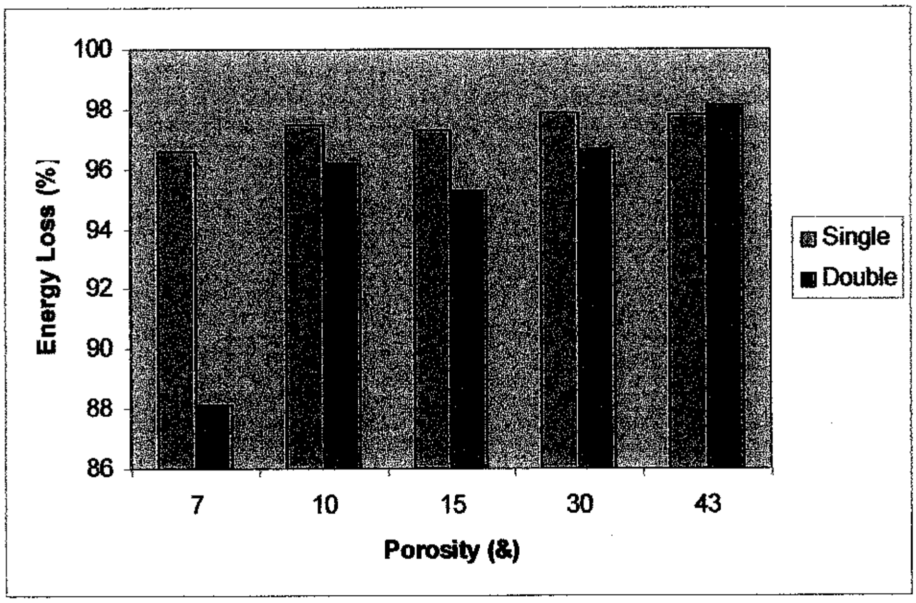
Table 5.14 - Percentages of wave energy loss, E_{loss} for different plate porosities



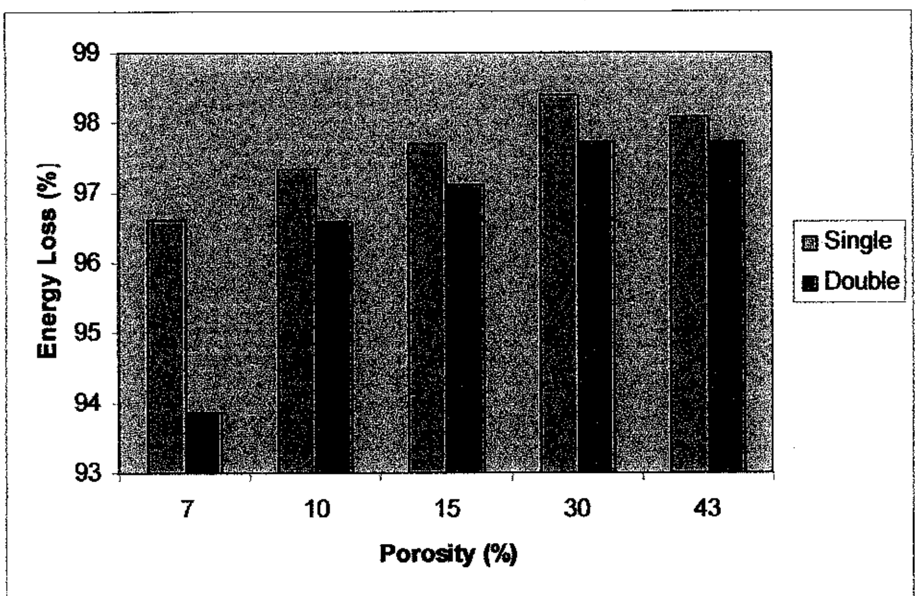
(a). Water depth = 15 cm



(b). Water depth = 20 cm



(c). Water depth = 25 cm



(d). Water depth = 30 cm

Figure 5.20 – Dissipation of Wave Energy through Breakwater at Various Water Depths

Discussion

Wave attenuation involves loss or dissipation of wave energy, resulting in a reduction of wave height. The energy loss due to perforated wall is considered to be analogous to a sudden enlargement of the cross-section in pipe flows.

From the calculation of experimental results, four graphs were plotted as shown above. Each graph represents percentage of wave energy loss through breakwater at different water depths.

For 15 cm and 20 cm water depth, the wave energy losses for double perforated plate are higher compared to the losses in single perforated plate. This result satisfies the expected result which is the energy losses for double perforated plates are higher than for single perforated plate. Beside that, it is also expected that the highest wave loss recorded must be at 7% plate porosity for double perforated plate. This is because the wave loss must be higher when using more perforated plate with lower plate porosity. However, from the result, the highest wave losses are recorded at 10% plate porosity (97.52%) for 15 cm water depth and at 43% plate porosity (97.17%) for 20 cm water depth. This result does not satisfy the expected result.

For 25 cm and 30 cm water depth, the results totally not satisfy the expected result. This is because the results show that the energy losses for single perforated plate are higher compared to the losses for double perforated plate for both water depths. This is due to some error throughout the experiment. The errors might be as follow:

1. Human error - While measuring the H_{max} and H_{min} from the video recorded, the parallax error may happen. Thus, it affects the accuracy on the result obtained and the graph plotted.
2. Mechanical error – The instruments used in the laboratory may have some mechanical error which can affect the result. The wave generated in the flume may not

3. Some of the holes of the plates might not drill symmetrically, as shown in *Figure 5.21*. The distribution of the holes alignment may affect the reflection and transmission of the waves, thus the result may be affected.

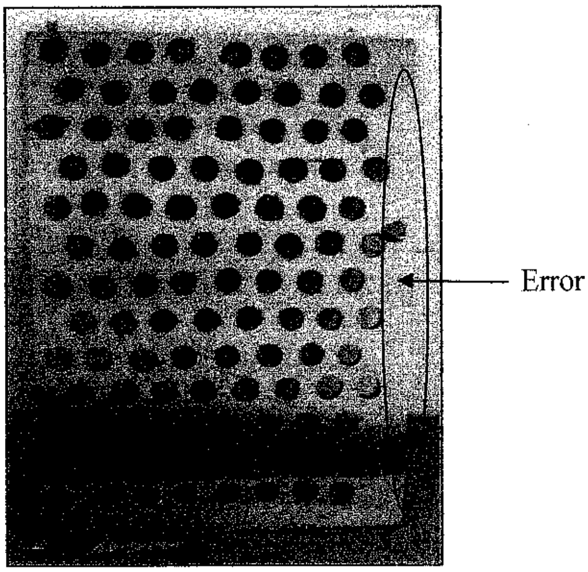


Figure 5.21 – Plate with non-symmetrical holes

4. For 30 cm water depth, the water splashed out from the flume when the frequencies are set at 50 rpm. So, the readings gathered are not so accurate.

From the graph, it can be concluded that the perforated plates use in the flume can dissipate the wave energy very well. This is because the wave losses recorded, as shown in *Table 5.19*, are very high (more than 90%) and approaching 100%, which is totally dissipated. It is recommended that the perforated plates to be used as breakwaters at coastal areas due to the performance of the plates from the laboratory result.

Conclusions

1. The reflection and transmission coefficients of the perforated wall are considered as the significant parameter representing hydraulic performances of the plates.
2. The performance of perforated plates against energy loss is impressive and it is recommended to use perforated plate as breakwater at coastal areas.
3. Although some differences between the theory and experimental results are found, the experiments agree approximately with the calculated results.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATION

As a conclusion, from the completed parts design, calculation and experiment made, the project shows a bright future in order for further studies and expansions. There are still much more improvements can be made. It shows that there are a lot of things that need to be considered first before implementing a project that looks easy at first glance. This is because there are many limitations and considerations need to be taken care although it was against the project requirement.

At the end of the project, it can be concluded that this project has succeeded in accomplishing its objective in order to develop a model for perforated plate and setup a series of experiments to measure the reflection and transmission coefficients of wave through single and double perforated plate breakwater.

In the experiment, a conventional method for determining the wave characteristics was applied, but it is quite difficult to obtain the expected output and data. There are so many errors which contribute throughout the investigations. Therefore, Civil Engineering Department is recommended to purchase a wave probe to record the wave profile.

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APPENDICES

APPENDIX 1 - GANTT CHART
APPENDIX 2 - EXPERIMENTAL RESULTS

APPENDIX 1

GANTT CHART

Suggested Milestone for the First Semester of 2 Semester Final Year Project

Appendix 1-A

No	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	SW	EW
1	Selection of Project Topic																
	-Propose Topic																
	-Topic assigned to students																
2	Preliminary Research Work																
	-Introduction																
	-Objective																
	-List of references/literature																
	-Project planning																
3	Submission of Preliminary Report																
4	Project Work																
	-Reference/Literature																
	-Practical/Laboratory Work																
5	Submission of Progress Report																
6	Project work continue																
	-Practical/Laboratory Work																
7	Oral Presentation																
8	Submission of Interim Report																

SW – Study Week
EW – Exam Week

Process

Suggested milestone

Suggested Milestone for the Second Semester of 2 Semester Final Year Project *Appendix 1-B*

No	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	SW	EW
1	Project Work Continue																
	-Practical/Laboratory Work																
2	Submission of Progress Report 1																
3	Project Work Continue																
	-Practical/Laboratory Work																
4	Submission of Progress Report 2																
5	Project Work Continue																
	-Practical/Laboratory Work																
6	Submission of Dissertation Draft																
7	Oral Presentation																
8	Submission of Project Dissertation																

SW – Study Week
EW – Exam Week

Process

Suggested milestone

APPENDIX 2

EXPERIMENTAL RESULTS

Porosity	Plate Arrangement	Wave Period, T (s)					Average
		3.0	2.4	2.0	1.5	1.2	
7%	Single	1482.25	8602.56	14580.56	22650.25	33124.00	16087.93
	Double	2943.06	3751.56	4658.06	8930.25	37733.06	11603.20
10%	Single	3751.56	3969.00	4192.56	12155.06	17689.00	8351.44
	Double	8602.56	15438.06	21097.56	30015.56	43368.06	23704.36
15%	Single	3751.56	5662.56	7656.25	8602.56	13747.56	7884.10
	Double	2943.06	3751.56	4900.00	6765.06	27060.25	9083.99
30%	Single	4192.56	7353.06	9950.06	13747.56	22650.25	11578.70
	Double	5662.56	8281.00	12155.06	15006.25	30625.00	14345.98
43%	Single	4658.06	6480.25	7965.56	9264.06	15006.25	8674.84
	Double	3335.06	5662.56	6480.25	8602.56	24258.06	9667.70

Table 2-A1 - Comparisons of wave energy for incident waves, E_i, at 20 cm water depth

Porosity	Plate Arrangement	Wave Period, T (s)					Average
		3.0	2.4	2.0	1.5	1.2	
7%	Single	4658.06	12155.06	16770.25	39105.06	97032.25	33944.14
	Double	8602.56	9950.06	12939.06	25360.56	124962.25	36362.90
10%	Single	4900.00	5402.25	16770.25	35721.00	238388.06	60236.31
	Double	12155.06	23716.00	28815.06	179352.25	215064.06	91820.49
15%	Single	6765.06	24806.25	25921.00	42642.25	89550.56	37937.03
	Double	4192.56	5402.25	7965.56	15438.06	76452.25	21890.14
30%	Single	6765.06	24806.25	27639.06	44838.06	89550.56	38719.80
	Double	2943.06	5662.56	16320.06	27060.25	67990.56	23995.30
43%	Single	7656.25	24806.25	31240.56	47851.56	87468.06	39804.54
	Double	4422.25	14580.56	18632.25	54990.25	99225.00	38370.06

Table 2-A2 - Comparisons of wave energy for incident waves, E_i, at 25 cm water depth

Porosity	Plate Arrangement	Wave Period, T (s)					Average
		3.0	2.4	2.0	1.5	1.2	
7%	Single	11395.56	13340.25	36385.56	74529.00	116451.56	50420.39
	Double	5662.56	16770.25	31862.25	70756.00	148225.00	54655.21
10%	Single	11772.25	25921.00	32490.06	67081.00	88506.25	45154.11
	Double	35062.56	50963.06	75487.56	248751.56	284889.06	139030.76
15%	Single	10660.56	13747.56	41209.00	70756.00	177873.06	62849.24
	Double	9950.06	12155.06	33124.00	97032.25	100330.56	50518.39
30%	Single	12939.06	19600.00	40501.56	105950.25	162006.25	68199.43
	Double	9950.06	12155.06	35062.56	114075.06	128701.56	59988.86
43%	Single	11395.56	12544.00	47851.56	84390.25	167690.25	64774.33
	Double	11395.56	13747.56	33124.00	97032.25	115260.25	54111.93

Table 2-A3 - Comparisons of wave energy for incident waves, E_i, at 30 cm water depth

Porosity	Plate Arrangement	Wave Period, T (s)					Average
		3.0	2.4	2.0	1.5	1.2	
7%	Single	49.00	517.56	1105.56	600.25	992.25	652.93
	Double	150.06	150.06	248.06	306.25	1350.56	441.00
10%	Single	76.56	196.00	150.06	248.06	441.00	222.34
	Double	370.56	370.56	689.06	885.06	1105.56	684.16
15%	Single	27.56	248.06	196.00	150.06	248.06	173.95
	Double	76.56	76.56	110.25	150.06	441.00	170.89
30%	Single	27.56	248.06	248.06	248.06	306.25	215.60
	Double	150.06	110.25	248.06	196.00	441.00	229.08
43%	Single	27.56	196.00	150.06	150.06	196.00	143.94
	Double	76.56	76.56	49.00	76.56	248.06	105.35

Table 2-B1 - Comparisons of wave energy for reflected waves, E_r, at 20 cm water depth

Porosity	Plate Arrangement	Wave Period, T (s)					Average
		3.0	2.4	2.0	1.5	1.2	
7%	Single	248.06	517.56	600.25	1105.56	3136.00	1121.49
	Double	517.56	689.06	885.06	2575.56	16770.25	4287.50
10%	Single	196.00	196.00	441.00	784.00	5662.56	1455.91
	Double	689.06	784.00	689.06	3540.25	11395.56	3419.59
15%	Single	248.06	600.25	600.25	784.00	1914.06	829.33
	Double	248.06	110.25	150.06	248.06	3969.00	945.09
30%	Single	248.06	600.25	517.56	689.06	1350.56	681.10
	Double	150.06	76.56	150.06	196.00	2575.56	629.65
43%	Single	196.00	441.00	370.56	517.56	1105.56	526.14
	Double	196.00	150.06	110.25	441.00	1764.00	532.26

Table 2-B2 - Comparisons of wave energy for reflected waves, E_r, at 25 cm water depth

Porosity	Plate Arrangement	Wave Period, T (s)					Average
		3.0	2.4	2.0	1.5	1.2	
7%	Single	517.56	784.00	885.06	3136.00	2943.06	1653.14
	Double	885.06	2756.25	2401.00	1764.00	8930.25	3347.31
10%	Single	196.00	1225.00	517.56	2070.25	1482.25	1098.21
	Double	517.56	2232.56	1620.06	3751.56	15438.06	4711.96
15%	Single	76.56	370.56	600.25	2401.00	2575.56	1204.79
	Double	370.56	370.56	441.00	992.25	4658.06	1366.49
30%	Single	76.56	441.00	517.56	1482.25	1482.25	799.93
	Double	150.06	248.06	370.56	689.06	4658.06	1223.16
43%	Single	76.56	110.25	370.56	992.25	1482.25	606.38
	Double	76.56	248.06	196.00	600.25	3540.25	932.23

Table 2-B3 - Comparisons of wave energy for reflected waves, E_r, at 30 cm water depth

Porosity	Plate Arrangement	Wave Period, T (s)					Average
		3.0	2.4	2.0	1.5	1.2	
7%	Single	12.25	12.25	12.25	27.56	12.25	15.31
	Double	3.06	12.25	12.25	12.25	12.25	10.41
10%	Single	12.25	12.25	27.56	49.00	27.56	25.73
	Double	12.25	27.56	49.00	49.00	27.56	33.08
15%	Single	27.56	12.25	196.00	76.56	49.00	72.28
	Double	27.56	49.00	49.00	49.00	49.00	44.71
30%	Single	27.56	27.56	248.06	76.56	49.00	85.75
	Double	27.56	49.00	196.00	110.25	150.06	106.58
43%	Single	76.56	49.00	248.06	370.56	150.06	178.85
	Double	49.00	76.56	110.25	76.56	110.25	84.53

Table 2-C1 - Comparisons of wave energy for transmitted waves, E_t, at 20 cm water depth

Porosity	Plate Arrangement	Wave Period, T (s)					Average
		3.0	2.4	2.0	1.5	1.2	
7%	Single	12.25	12.25	110.25	27.56	110.25	54.51
	Double	27.56	12.25	49.00	12.25	12.25	22.66
10%	Single	12.25	27.56	110.25	49.00	196.00	79.01
	Double	110.25	27.56	150.06	27.56	110.25	85.14
15%	Single	27.56	110.25	306.25	150.06	370.56	192.94
	Double	110.25	27.56	150.06	27.56	110.25	85.14
30%	Single	49.00	49.00	150.06	150.06	370.56	153.74
	Double	370.56	76.56	248.06	76.56	150.06	184.36
43%	Single	150.06	248.06	441.00	370.56	600.25	361.99
	Double	248.06	49.00	306.25	110.25	248.06	192.33

Table 2-C2 - Comparisons of wave energy for transmitted waves, E_t, at 25 cm water depth

Porosity	Plate Arrangement	Wave Period, T (s)					Average
		3.0	2.4	2.0	1.5	1.2	
7%	Single	49.00	110.25	27.56	49.00	76.56	62.48
	Double	12.25	12.25	27.56	3.06	12.25	13.48
10%	Single	110.25	110.25	76.56	150.06	110.25	111.48
	Double	27.56	49.00	76.56	27.56	49.00	45.94
15%	Single	150.06	150.06	150.06	370.56	370.56	238.26
	Double	76.56	110.25	150.06	49.00	76.56	92.49
30%	Single	248.06	196.00	196.00	441.00	370.56	290.33
	Double	110.25	196.00	196.00	110.25	76.56	137.81
43%	Single	600.25	370.56	248.06	600.25	1350.56	633.94
	Double	248.06	370.56	441.00	150.06	306.25	303.19

Table 2-C3 - Comparisons of wave energy for transmitted waves, E_t, at 30 cm water depth