Wave Energy Absorption Performance of a Vertical Wave Screen System

by

Noor Hidaya Binti Abdul Halim

A dissertation report submitted in partial fulfillment of
the requirements for the
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CERTIFICATION OF APPROVAL

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Approved by,

(Mr Teh Hee Min)

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

NOOR HIDAYA BT ABDUL HALIM

ABSTRACT

Wave flumes equipped with wave generating facilities are commonly used to perform various types of physical modeling in laboratories. The placement of wave absorbers near reflective boundaries of the flume is aimed to dissipate the energy of incoming waves. Failure to do so could affect significantly the uniformity of wave train and eventually winder the accuracy any of the experiment carried out in the flume. In this study, a Vertical Wave Screen System, (VWSS) is proposed to tackle the problem. Laboratory experiments had been conducted with aim to study the effectiveness of applying the VWSS as a wave absorber in the wave flume. A series of laboratory test was carried out to investigate the wave reflection characteristics corresponding to the different number of wave screen, namely 4-screen, 8-screen and 12-screen. The laboratory investigations were conducted in the wave-only condition in the flume, which are subjected to steady monochromatic non-breaking waves throughout the experiments. A total of 240 experiments runs were conducted relating all variable to the wave characteristics such as, wave height, water depth and wave period. Assessment of results was done to identify the performance and the limitation of the proposed wave absorber. Comparisons of wave energy absorbing performance in term of reflection of coefficient, C_r, were also made in this study.

ACKNOWLEDGEMENT

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ii. Mr Teh Hee Min – Supervisor, Civil Lecturer
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iv. En Mohd Idris B Mokhtar – Laboratory technician
v. Fellow friends

Advices and guidance from my professional supervisor and colleagues are considered seriously to ensure that the best outcome for this study. Lastly to my family who gives moral support, and for their understanding for all the time that we have been away from them. Thank you.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Wave absorber is a defense structure located at the reflective boundaries of wave basin or wave flume to attenuate the incoming wave energy through various wave dissipation mechanisms. Reflection of wave energy from boundaries is one of the most common laboratory effects that plague physical model experiments is. It can alter significantly the incident wave field, and affect the accuracy of experimental results. Well-conducted laboratories studies always attempt to minimize wave reflections by placing wave absorbers at reflective boundaries. Various types of wave absorbers had been proved to be effective in wave energy dissipation. The primary principle of a wave absorber is that part of wave energy is reflected and part of it is dissipated due to turbulence induced inside the wave screen. Vertical wave absorber could effectively be used as they require less material, space and construction time. Vertical wave screen is one such type of permeable barrier, which reduces the reflection of waves on its seaward side, thereby, reducing the wave load on the structures on its leeward side.

1.2 Problem Statement

To furnish the facilities in Hydraulic Laboratory of Universiti Teknologi PETRONAS, the University had purchased a wave flume equipped with a wave generator flap-type. The wave generator is used to generate translation waves in the unidirectional flume. However, no performance test has been carried out ever since the facility was commissioned to the University. Hence, there is a need to have the wave generating system well-calibrated prior to any experimental works in the wave flume. Apart from this, reflection of wave energy from the boundaries of the flume especially at the rear of the flume, should be minimized enhance the accuracy of any test results conducted within the flume. This could be achieved by placing wave absorbers near the reflective boundaries of the wave flume.

1.3 Objectives of the Study

The objectives of the study are as follows:

1. To design and develop an effective wave absorber in dampening the energy of the incoming waves.

2. To study the wave absorption performance of the proposed wave absorber through laboratory tests in a wave flume. The main concern in this study is to determine its effectiveness in dissipating the wave energy and reducing the wave reflection in the wave flume.

1.4 Scope of Study

The objectives in Section 1.3 are skeletonized by the following scope of works:

1. Literature review

   The review of the existing designs would aid in developing a better design which could serves function reasonably well.

2. Development of new design

   A Vertical Wave Screen System (VWSS) is proposed to minimize the wave reflection in the wave flume.

3. Laboratory set up

   The wave generating system was calibrated prior to any experimental tests. All the equipments and apparatus to be used were checked and assured in good condition and functioning well during the experimental tests.

4. Experiments

   A series of laboratory experiments were conducted in a wave flume, to determine the wave spectrums with and without the presence of VWSS with respect to different water depths, stroke adjustments and wave periods.

5. Results interpretation

   Results were analyzed, interpreted and shown in various ways of presentation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Superimposition of incident and reflected waves at the reflective boundaries is a complex problem. As a result, a direct measurement of reflected waves is not practicable in any laboratories investigations. Several methods had been developed to investigate the reflected wave height during the experiment, namely Simple Conventional method, Goda's & Suzuki's method, Least Square method and many more. In this study, the Simple Conventional method is applied to estimate the heights of the reflected waves. The details of the measurement method will be thoroughly discussed in the first part of Chapter 2. The second part of this Chapter will introduce several types of wave absorbers, which had been developed by previous researchers that gave varying degree of attenuation of wave energy.

2.2 Wave Reflection

Wave reflection means turning a wave and directing its energy elsewhere. Waves in coastal physical models are reflected by beaches, coastal structures, floating or submerged solid bodies, and model boundaries. This is especially obvious when the reflected boundary is a smooth vertical wall. As the wave release the energy on the vertical impermeable wall, most of the energy is reflected and transformed in the form of reflected wave, H_r, moving in the opposite direction. As illustrated in Figure 2.1, the incident wave height, H_i generated from the flap-type paddle, moves towards the direction of a vertical impermeable wall in the positive –x direction.

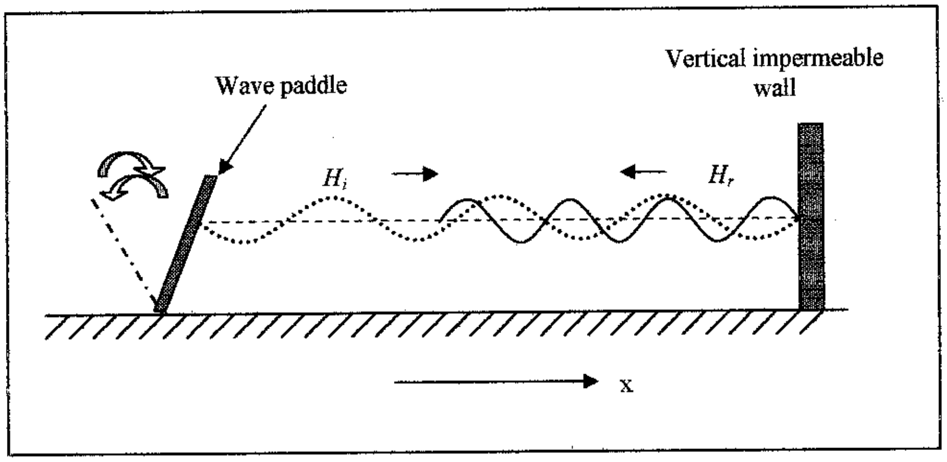


Figure 2.1: Incident wave and reflected wave

Degree of wave reflection is defined by the reflection coefficient, C_r, expressed as,

$$C_r = \frac{H_r}{H_i} \tag{2.1}$$

Figure 2.2 illustrate a total reflection of waves ($C_r = 1$) occurs in front of a smooth vertical wall. This may cause severe agitations to the sea and rough waves formed near the reflective structure.

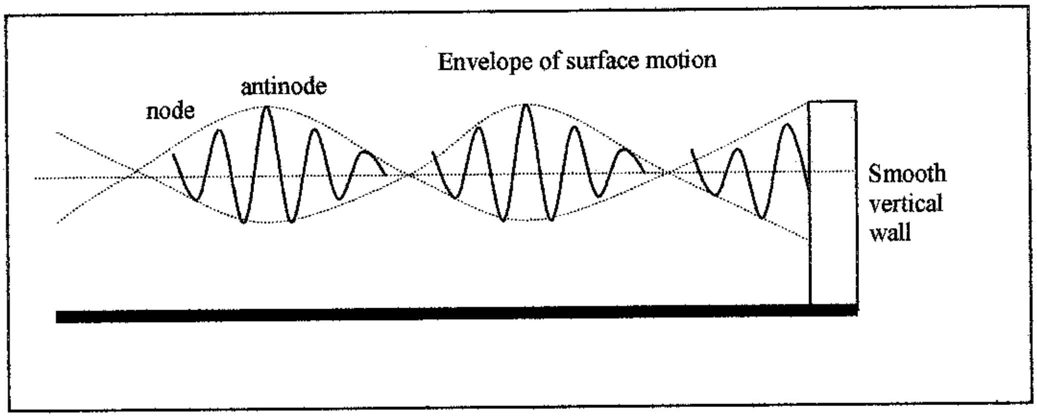


Figure 2.2: Total reflection ($C_r = 1$)

For a wave propagating over a slope or a permeable structure, the reflected wave height is always smaller than the incident wave height. This is a partial reflection phenomenon where $0 < C_r < 1$ as shown in Figure 2.3.

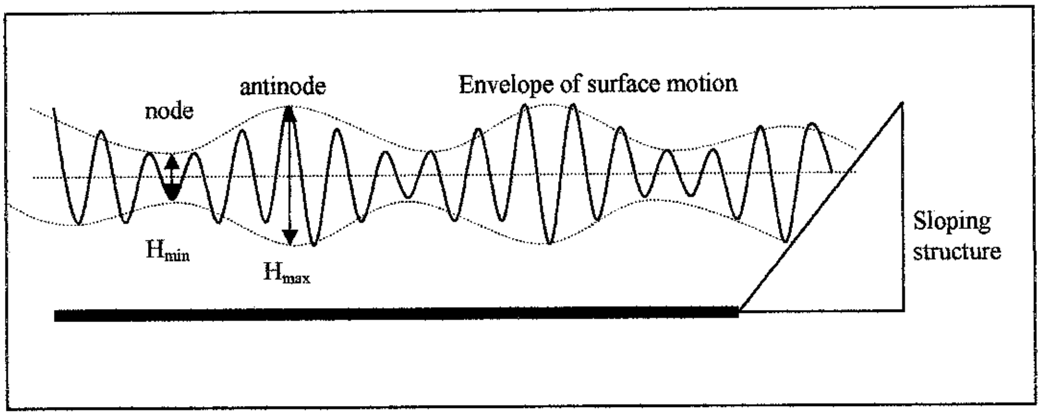


Figure 2.3: Partial reflection ($0 < C_r < 1$)

As for the beaches with very mild slope, as indicated in Figure 2.4, the reflected waves can be ignored ($H_r \approx 0$) as these beaches act as natural wave absorber.

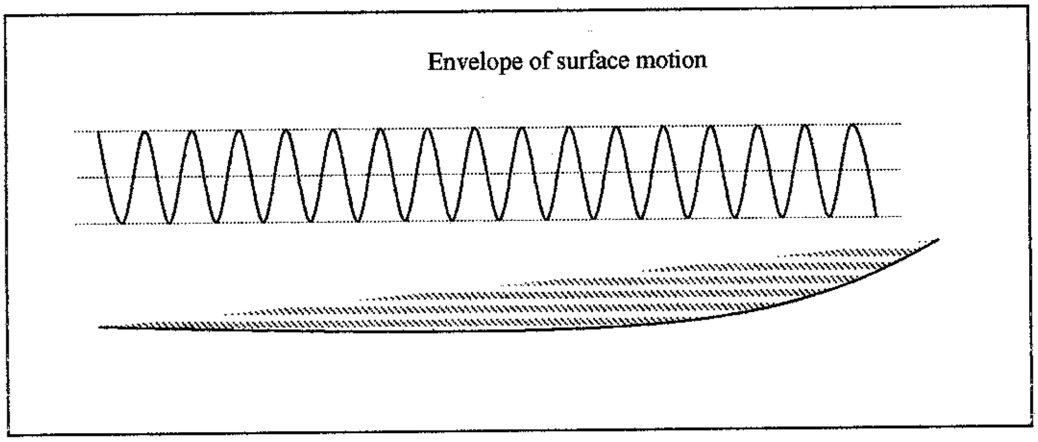


Figure 2.4: No reflection ($C_r = 0$)

Very often the reflected wave energy is less than 10% of the incident wave energy, therefore $C_r \approx 0$. A list of the C_r values for various structures is given in Table 2.1.

Table 2.1: Reflection coefficients 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 to 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

In many laboratory studies, it is desirable to separate the measured wave train into its incident and reflected wave components. Various methods had been reported to estimate the incident and the reflected wave height from the wave train generated in the wave flume. As mentioned in Section 2.1, the Simple Conventional method is adopted is this study in conducting wave reflection analysis for the experimental works.

A normally incident regular wave that is partially reflected can be mathematically represented with first-order wave theory by the expression (Hughes, 1993)

$$\eta(t) = a_I \cos(kx - \sigma t + \varepsilon) + a_I C_r \cos(kx + \sigma t + \varepsilon + \theta) \qquad (2.2)$$

where

$\eta(t)$ – sea surface elevation

a_I – incident wave amplitude

k – wave number

x – horizontal position

σ - angular wave frequency

ε - arbitrary incident wave phase angle

C_r – reflection coefficient

θ - reflection phase shift

The first term in Equation (2.2) is a regular incident wave moving in the positive -x direction, and the second term is the reflected wave moving in the opposite direction.

Expanding the trigonometric functions in Equation (2.2) and rearranging, gives

$$\eta(t) = a_I\left[\cos(kx+\varepsilon) + C_r \cos(kx+\varepsilon+\theta)\right]\cos\sigma t + a_I\left[\sin(kx+\varepsilon) - C_r \sin(kx+\varepsilon+\theta)\right]\sin\sigma t$$

(2.3)

By defining

$$A\cos\beta = \left[\cos(kx+\varepsilon) + C_r \cos(kx+\varepsilon+\theta)\right] \tag{2.4}$$

and

$$A\sin\beta = \left[\sin(kx+\varepsilon) - C_r \sin(kx+\varepsilon+\theta)\right] \tag{2.5}$$

Equation (2.3) can be written as

$$\eta(t) = a_i\ A\cos(\sigma t - \beta) \tag{2.6}$$

The coefficient, A, is found using squaring Equation (2.4) and (2.5) and summing to yield

$$A = \sqrt{1 + C_r^2 + 2C_r \cos\left[2(kx+\varepsilon) + \theta\right]} \tag{2.7}$$

and the phase, β, is given by the ratio in Equation (2.4) and (2.5),

$$\tan\beta = \frac{\sin(kx+\varepsilon)\ -\ C_r \sin(kx+\varepsilon+\theta)}{\cos(kx+\varepsilon)\ +\ C_r \sin(kx+\varepsilon+\theta)} \tag{2.8}$$

Substituting for the coefficient, A, in Equation (2.6) gives an alternate expression for the superimposed incident and reflected waves,

$$\eta(t) = a_i\sqrt{1 + C_r^2 + 2C_r \cos\left[2(kx+\varepsilon) + \theta\right]}\cos(\sigma t - \beta) \tag{2.9}$$

The maximum wave height of the envelope occurs at the antinode of wave system when

$$\cos[2(kx+\varepsilon)+\theta] = 1 \tag{2.10}$$

And its magnitude is given a twice the amplitude, or

$$H_{\max} = 2a_i\sqrt{1+2C_r+2C_r^2} \quad \text{or} \quad H_{\max} = H_i(1+C_r) \tag{2.11}$$

where the incident wave height is defined as $H_i = 2a_i$. Similarly, the minimum wave height of the envelope occurs at the node of the wave systems when

$$\cos[2(kx+\varepsilon)+\theta] = -1 \tag{2.12}$$

$$H_{\min} = 2a_i\sqrt{1-2C_r+2C_r^2} \quad \text{or} \quad H_{\min} = H_i(1-C_r) \tag{2.13}$$

Equation (2.11) and (2.13) can be solved for the

$$H_i = \frac{H_{\max}+H_{\min}}{2} \tag{2.14}$$

reflected wave height,

$$H_r = \frac{H_{\max}-H_{\min}}{2} \tag{2.15}$$

2.3 Performance of Existing Wave Absorber

2.3.1 Double screen breakwater

The performance of two vertical wave screens formed by equally spaced pipes in attenuating the incident wave energy had been investigated through an experimental program by Balaji. R. and Sundar. V(2000). The wave screen model basically consists of a series of horizontal 160 mm diameter pipes over a width of 1.98 m. The height of the screen can be varied such that no overtopping is allowed. On the seaward side wave screens with, two different porosities of 23.8% and 5.9% were adopted by changing the spacing between the pipes. A wave screen with a constant porosity of 5.9% was fixed on the leeward side. The clear distance between the screens was varied from 0.5m to 2.0m with an increment of 0.5m, which gave different width of wave dissipation chamber to study its effect on transmission. The schematic views of the models DSB1 and DSB2 (Double Screen Breakwater) are shown in Figure 2.5

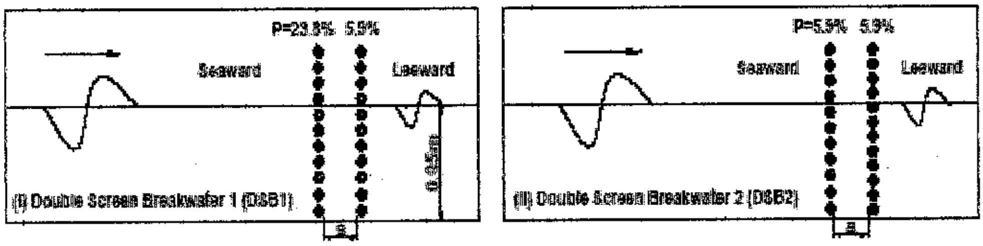


Figure 2.5: Schematic viewed test model (Balaji and Sundar, 2000)

B is the width of wave chamber or clear spacing between screens and d water depth. Average reflection coefficient is noted as K_r and L_p wavelength defined by T_p. The variations of the average K_r obtained based on the three wave-probe method of Mansard and Funke(1980) with B/L_p for the two models for different B/d are shown in Figure 2.6. Both DSB1 and DSB2 models exhibit almost a similar trend in the variation of K_r with B/L_p. The K_r for DSB1 model is observed to be well below 0.5

for all B/L_p values and a minimum of 0.2 is observed at B/L_p=0.12. On the other hand for DSB2 model the K_r is found to range between 0.25 and 0.63 and its minimum value of 0.25 found to occur at the same B/L_p of 0.12. As the spacing of the seaward side screen elements is closer (lesser porosity), the K_r values for DSB2 model is 0.1 to 1.5 times more than that of DSB1 for all the four B/d values.

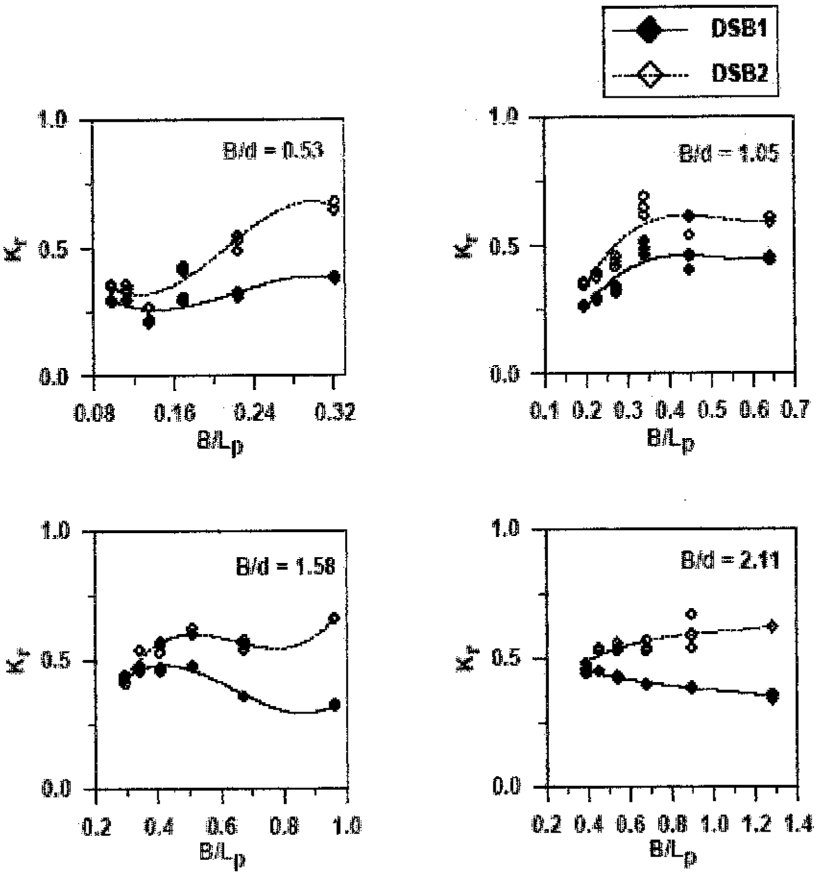


Figure 2.6: Variation of Kr with B/Lp for different values of B/d

Balaji and Sundar concluded that reflection characteristics of double screen breakwaters are function of both screen porosity and screen spacing. As the spacing between screens increases, the dynamic pressures on the leeward side screen elements decrease for both DSB1 and DSB2 models.

2.3.2 Slope wave absorbers

Wave absorbers which are most commonly used in laboratories throughout the world, is the constant-slope beach which are composed of sand and gravel stone. The slopes of these absorbers are usually 1:10 (Ouellet and Datta, 1986). Although these fixed absorbers prove to be effective in reducing wave reflection, they are not easily moved, making them less practical for use in the wave flume.

2.3.3 Upright perforated wave absorbers

Another solution for dissipation of the incident wave energy at the boundaries of a wave flume is using of upright perforated wave absorbers. According Jamieson and Mansard, (1987), the advantage of these absorbers is that they need less space for installation than the slope beach absorbers. An upright perforated wave absorber is composed of rows of vertical perforated sheets installed in front of a solid back wall which would otherwise be highly reflective. It may be made form sheets of the same porosity. In the latter case, the porosity is decreased progressively toward the rear of the absorber.

2.3.4 Vertical mesh screen

Goda and Ippen (1963) theoretically analyzed and tested wave absorbers composed of vertical mesh screens aligned normal to the direction of wave propagation as shown in Plate 2.1. They also stated that the screen absorber must be at least as long as the wavelength of the incident wave. This concept can be designed to ensure a very low reflection coefficient (in order of 5%) without occupying much of the flume or basin space. This type of absorber is particularly suitable for multidirectional wave basins where limited space is available for absorbers, and testing at variable water depths is necessary without adjusting the absorber. Optimum design for specific wave conditions is achieved through appropriate porosity, spacing and number of sheets.

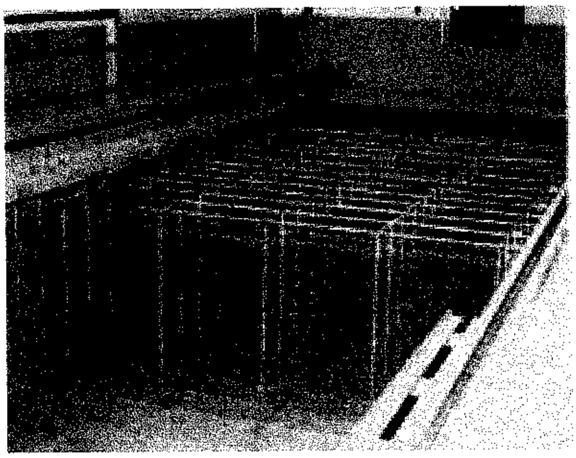


Plate 2.1: Vertical Mesh Screen

For different screen absorbers were tested under deepwater wave conditions, and results compared favorable with theory. Reflection was shown to dependent upon screen spacing, but not so dependent on the number of screens "provided the number is fairly large".

Jamieson and Mansard (1987) described an extensive experimental program to develop efficient wave absorber made of wire mesh of progressively decreasing porosity. The screens were placed normal to the direction of wave propagation on a flat bottom, and they were backed by a solid vertical wall. Their goal was to minimize reflection over a wide range of wave condition and water depths without requiring extensive horizontal absorber length. They conclude that high porosity mesh screens work best absorbing energy from high steepness waves. Mesh screen porosity should decrease toward the rear of the wave absorber. The number of screen in the absorber increases as the range of wave heights and periods to be absorbed increases.

CHAPTER 3

THE VERTICAL WAVE SCREEN SYSTEM (VWSS)

3.1 Introduction

There is no definite guideline in designing an effective wave absorber so far. Therefore, a thorough literature review on the existing type of wave absorber is inevitable prior to the development of a new design. A number of rules of thumb had been identified and would be useful to be general guidelines for design purposes. In this study, it is aimed that the newly proposed design would be kept as simple, durable and maintenance free as possible. This chapter will introduce the development of the Vertical Wave Screen System (VWSS) designed to absorb the wave energy.

3.2 Development of VWSS

The VWSS is proposed to serve as a wave absorber for the newly purchased wave flume. The concept of having a vertical upright wave screen is found to be most preferable. The layout of this wave absorber is suitable for wave flume with limited length. The VWSS is aimed to be a wave dissipating structure that serves its function effectively without having large area occupied for installation purpose.

3.3 Description of VWSS

Plate 3.1 exhibits the 3-dimensional outlook of VWSS that is constructed of steel and square hollow section (SHS). The base frame of VWSS is composed of twenty unit of ½ inches square hollow section (SHS) laid and fixed perpendicularly to two solid steel bars acted as supports. The wave screens are made up of equal angle section with a size of ¾ inches. The dimensions of the base frame and the wave screens are 45 cm x 30 cm and 30 cm x 68 cm, respectively. The details of the VWSS are shown in Figure 3.1. Plate 3.2 shows the wave screens erected to the base frames vertically. To fix the wave screens in place, a steel cap is used to mount on top of these screens. One of the outstanding features of the VWSS is to be able to provide various degree of porosity to the passage of waves. The porosity of a wave screen is found to be 67%. Porosity of a wave screen can be expressed in term of percentage, as follows;

$$\%\ Porosity = \frac{area\ of\ the\ openings}{total\ area\ of\ wave\ screen}$$

The porosity is increase with the increase of the number of wave screen in the system. It is expected that the wave energy absorption performance improves if higher number of screen is considered.

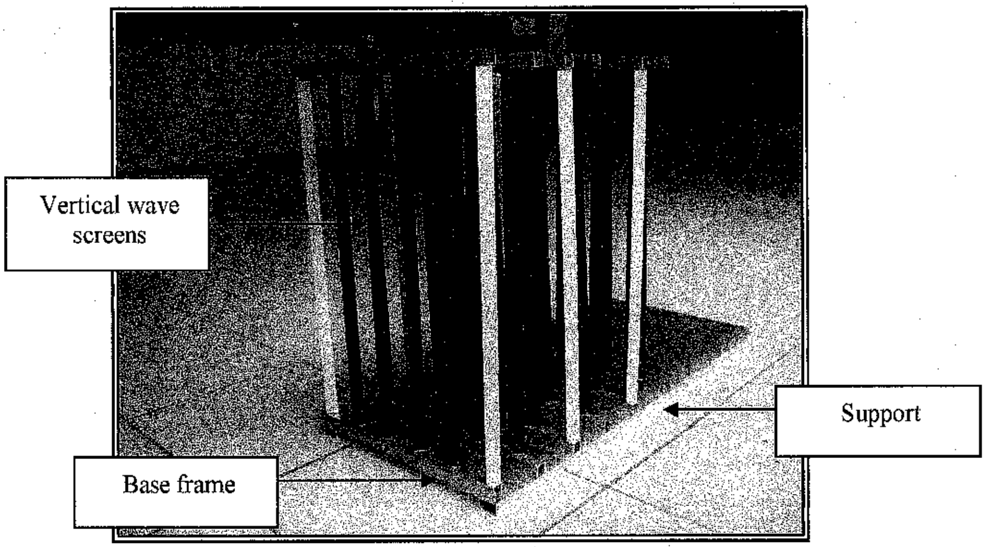


Plate 3.1: 3D view of VWSS structure

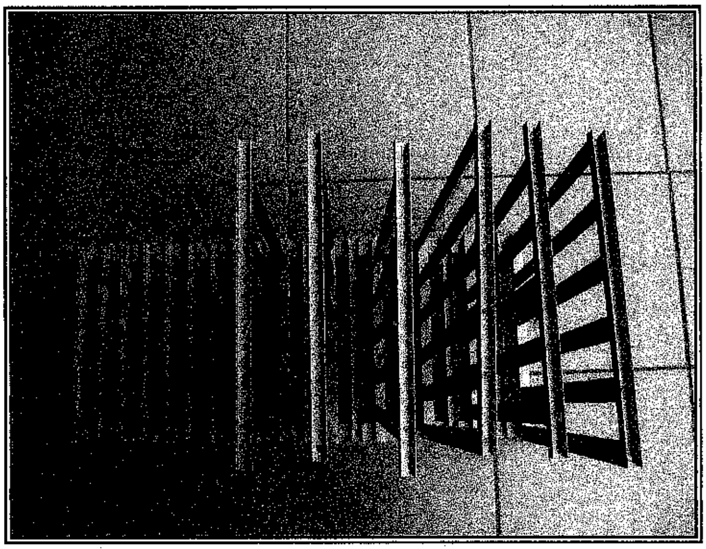


Plate 3.2: VWSS Plan view

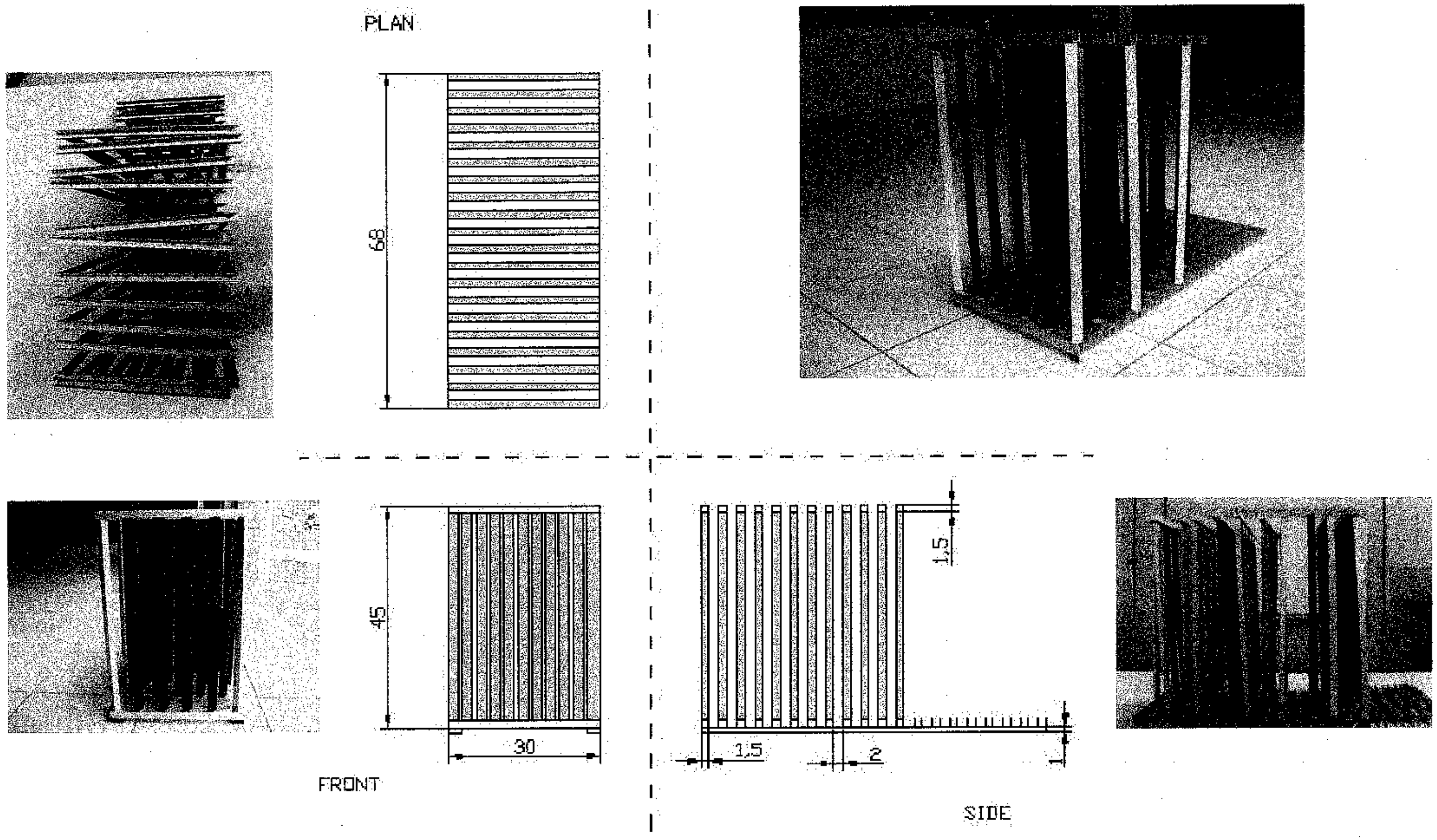


Figure 3.1: Vertical Wave Screen System (All dimension are in cm)

3.4 Advantages of Vertical Screen System

a. Removability

The VWSS can be relocated or rearranged into a new layout with minimal efforts due to its lightness.

b. Flexibility

The space interval or gap between wave screens is adjustable to the requirements. The porosity of the systems will be modified accordingly.

c. Resistance to corrosion

As mentioned, most parts of the VWSS are made of Aluminium which is resistance to corrosion. This characteristic is a paramount importance as the VWSS is constantly in contact with fresh water throughout the operations of experiments. The selection of this material would prolong the life span of the VWSS.

d. Free from space constraint problem

Less space is required to achieve a satisfactory wave absorbing performances.

CHAPTER 4

EXPERIMENTAL SET UP AND PROCEDURE

4.1 Introduction

A good experimental set up is essential to ensure the quality of any laboratory tests. The laboratory equipment and instrumentation used should be well understood so as to reduce the potential technical errors. This chapter describes the apparatus which have been used in the laboratory experimental and method to determine the incident and reflected wave height. In this study, variation in amplitudes of wave which was required for respective analysis of wave reflection due to the presence of VWSS at different wave periods, and water depths, were determined. The experiment is run in the wave only condition in the wave flume.

4.2 Laboratory Equipment and Instrumentation

4.2.1 Modular Flow Channel

The channel has a length of 10 m and flow cross section of 300 mm (width) x 450 mm (depth). The transparent sides of the measuring wall are made of hardened glass which is particularly resistant to scratching and abrasion, does not discolor and easy to clean. The side view of the modular flow channel is shown in Plate 4.1

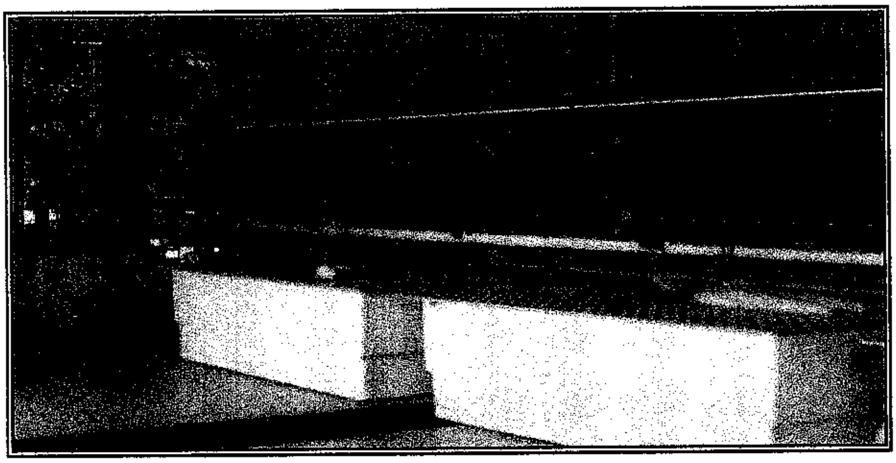


Plate 4.1: Modular Flow Channel

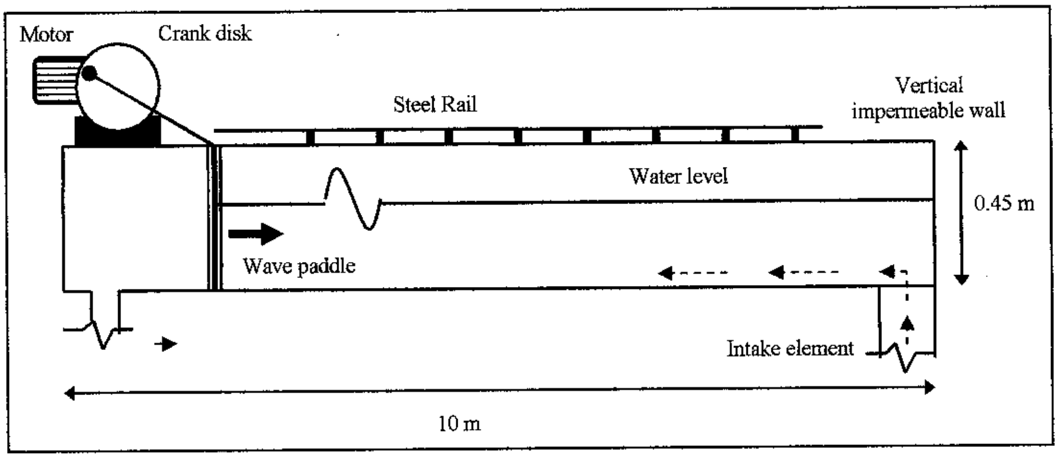


Figure 4.1: Schematic drawing of wave flume

4.2.2 Wave Generator Flap-Type

The wave generator is fixed on a steel supporting base frame that rests on the end of Modular Flow Channel (Plate 4.2). The push rod is connected to holder of the movable wave paddle. The wave generator is driven by a worm gear motor. The rotational speed can be varied by a frequency converter and a potentiometer. The rotary movement of the motor is converted into a harmonic stroke motion of the movable wave paddle via a crank disk with push rod.

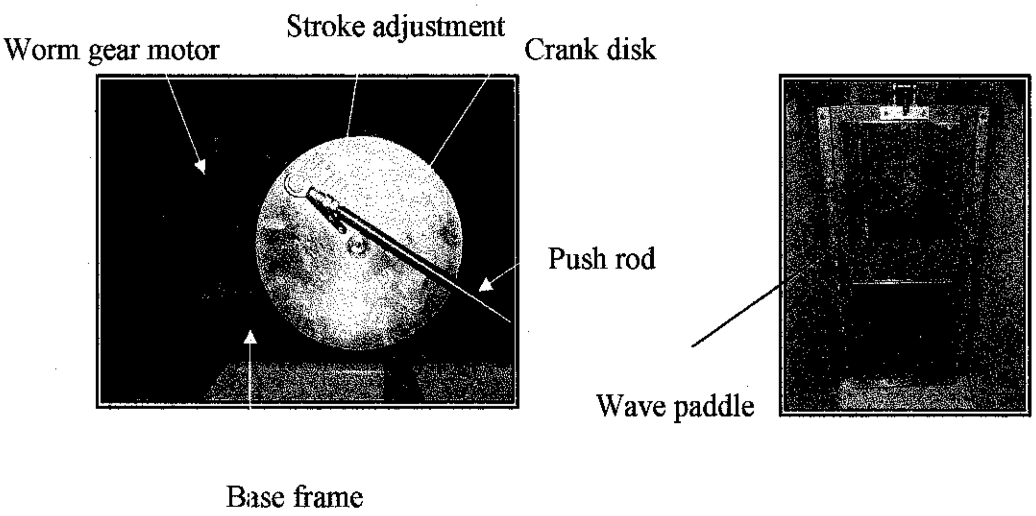


Plate 4.2: Wave Generator Flap-Type

4.2.3 Switch Box

All electrical switching units required for operations are located in the cover of the switch box (Plate 4.3). 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

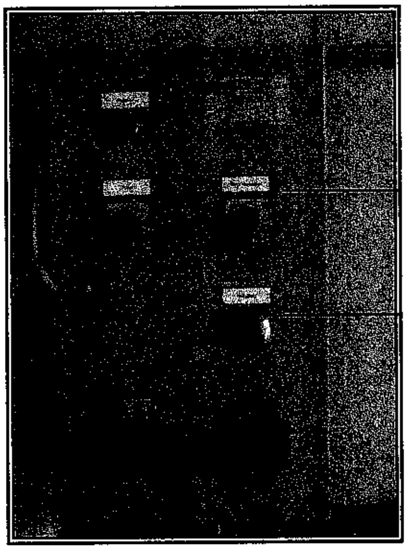


Plate 4.3: Switch Box

4.2.4 Hook and Point Gauge for Modular Flow Channel

The hook and point gauge is used to measure water levels in the modular flow channel (Plate 4.4). 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.

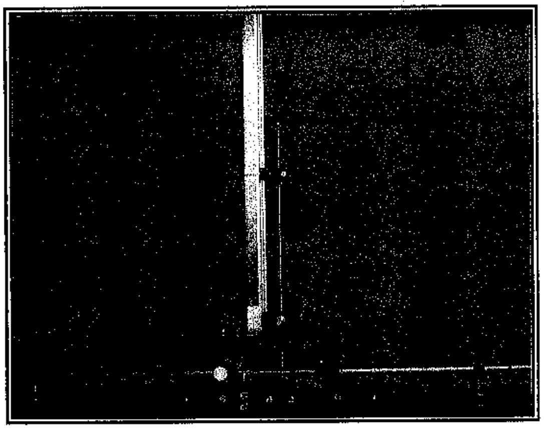


Plate 4.4: Hook and Point

4.3 Determination of Wave Period and Wavelength

Wave period is the time for a wave to travel at a distance of one complete cycle, measured form crest to crest. In this study, the wave period was determined by applying a simple approach in which stroke frequency were selected to represent six wave periods that would be applied throughout the experiments. First, a point was marked on the crank disk as an indicator. A stopwatch was used to measure the time taken by the marked point revolving up to 10 revolutions for each stroke frequency. The wave period, T, can be obtained by,

$$T = \frac{\textit{total time taken}\left(\sec\right)}{10} \tag{4.1}$$

In water wave modeling, a direct measurement of wavelength without the aid of electronic measuring tool or device is considerably difficult. In the absence of such tool, wavelength L can be determined theoretically using linear dispersion relationship;

$$\sigma^2 = gk \tanh kd \tag{4.2}$$

where σ - $2\pi/T$ = angular frequency

k - $2\pi/L$ = wave number

d - still water depth

g - gravitational constant = 9.81 m/s^2

From equation (4.2), σ and d are known from the measurement of wave period and water depth, hence the only unknown k, could be computed using the Bisection method. The wavelength, L, then could be determined by $L = 2\pi/k$.

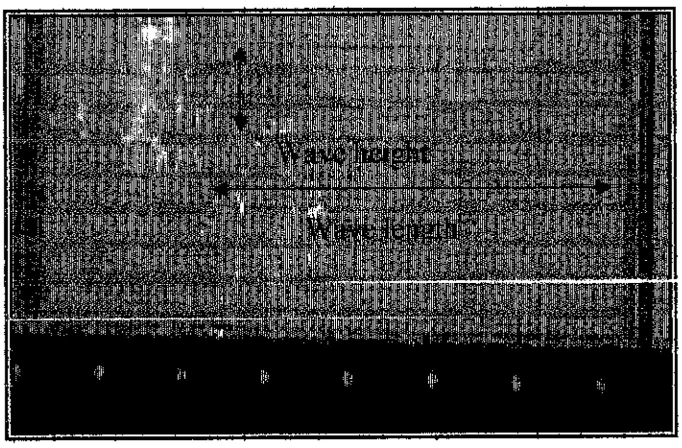


Plate 4.5: Wave height and wave length marked on the flume wall

4.3.1 Preliminary tests

Two water depths 20 cm and 25 cm were considered in the experiments without the VWSS installed in the wave flume. Each set was subjected to the action of regular waves covering a range of wave period of 0.51 second to 1.89 second. The wave periods were controlled by the rotating of crank disk. For each period, two wave heights (minimum and maximum adjustments) were employed by locating the push rod at two marking point along the groove of the crank disk i.e 120 mm and 200 mm from the reference point. A total runs conducted are 40 runs and for each run, a minimum of 10 readings of wave height were taken.

The results are expected to give a standing wave pattern characterized by an envelope having uniform maximums and minimums due to the interaction of the incident and reflected waves. The measurement of maximum and minimum wave heights would result to the determination of incident and reflected wave heights by applying Equation (2.14) and (2.15). The amount of reflection is given by the ratio of the reflected wave height, H_r, to the incident wave height H_i, which is termed as the reflected coefficient, C_r.

4.4 Experimental tests on VWSS

Three sets of experiments of VWSS were carried out in the wave flume which was subjected to non-breaking waves were throughout the experiments. The first experiment consists of 4 screens individually installed at the respective base frame. While the second and the third experiment contained 8 screens and 12 screens, respectively. The setting of the experiment was similar to the preliminary tests in term of the water depths, wave period as well as the stroke adjustments. Measurement of maximums and minimums of the envelope surface motion was carried out for the determination of H_i and H_r. By measuring the maximum and minimum wave heights developed from the surface wave train, in front of VWSS, the incident and reflected wave heights could be identified by applying Equation (2.14) and (2.15), respectively. In total, 120 series of test were carried out in the wave flume. VWSS set up is schematically shown in Figure 4.2.

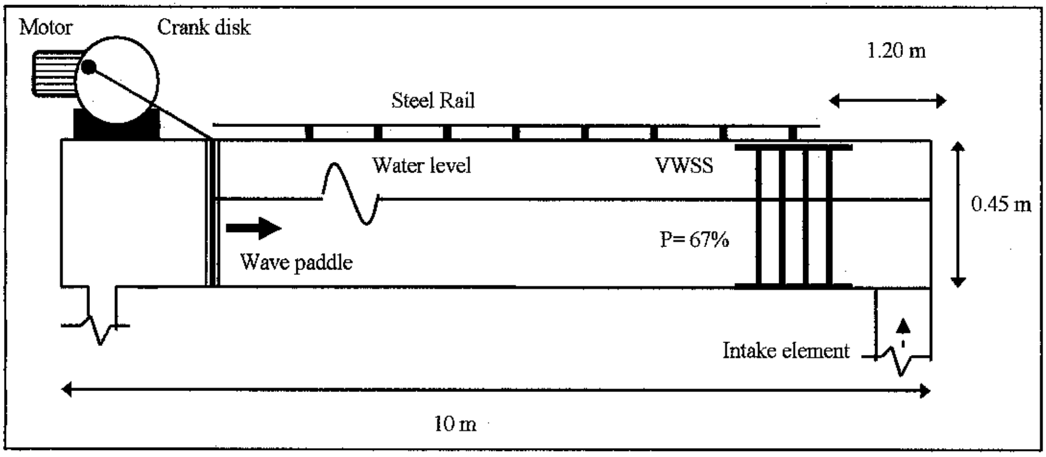


Figure 4.2: VWSS setup in the wave flume

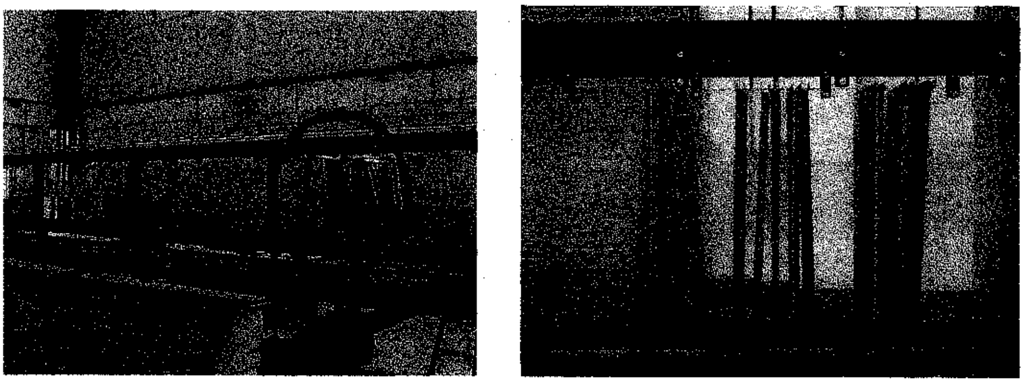


Plate 4.6: Position of VWSS in the wave flume

4.5 Arrangement of VWSS screens

Plate 4.7 to Plate 4.9 demonstrates the arrangement of VWSS in the wave flume, 4-screen, 8-screen and 12-screen accordingly.

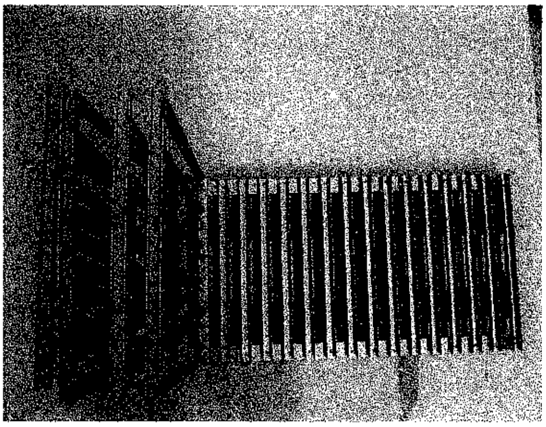


Plate 4.7: 4-screen VWSS

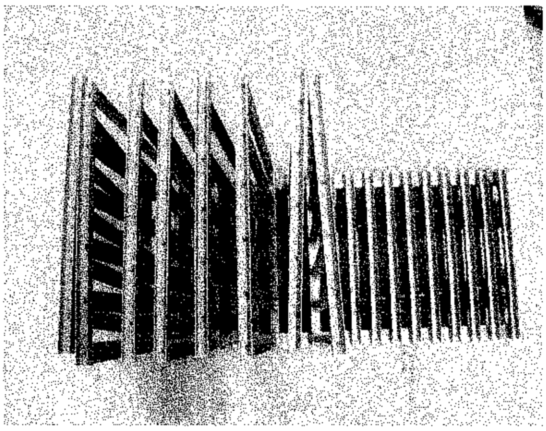


Plate 4.8: 8-screen VWSS

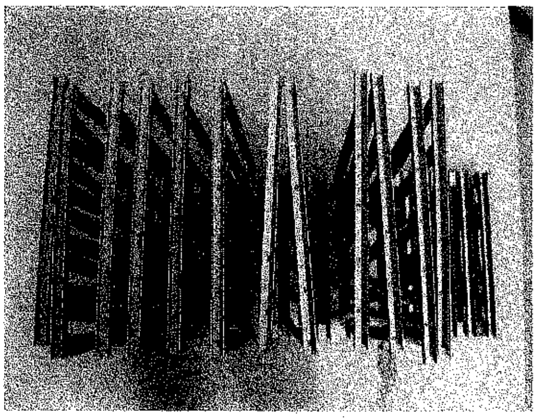


Plate 4.9: 12-screen VWSS

CHAPTER 5

EXPERIMENTAL RESULTS AND ANALYSIS

5.1 Introduction

This chapter discusses the results of the preliminary test which has been described in Section 4.3 As mentioned, the main objective of the test is to investigate the performance of VWSS in wave energy dissipation. The first part presents the results of preliminary test which is the determination of wave period and wavelength, as well as the determination of incident and reflected wave height prior to the installation of VWSS. The next part of this chapter presents the experiments' results of different arrangement of the VWSS. The results of the experiments are tabulated and graphically displayed in the form of coefficient of reflection with respect to wave periods.

5.2 Results on Preliminary Tests

5.2.1 Determination of Wave Period and Wavelength

As being mentioned before, the wave period of the wave generating system is correspond to the rotation speed of the crank disk. An equation that can be derived for this wave generating system is

$$F = 50T^{-0.8} \tag{5.1}$$

where T - wave period

F - speed of wave generating motor

The wavelength for each wave period is calculated using Equation (4.2) For example; a wave with period of 0.70 second is propagates in a water depth of 20 cm

Wave period, T = 0.70 s

Water depth, d = 0.20 m

Angular frequency, σ = $2\pi/T$

= $2\pi/0.70$

= 8.976 rad/s

Gravitational constant, g = 9.81 m/s^2

Converting Equation (4.2) into a functional equation:

$$f(x) = gk\tanh kd - \sigma^2$$

Bi–section method is applied to obtain the k value. The exact value for k will be achieved when $f(x)$ is equal to 0.

k (rad/s)	$f(x)$
8	-8.236
8.6	-1.445
8.7	-0.323
8.72	-0.099
8.728	-0.009
8.7289	0.000

Hence, the value of k is 8.7289. Thus, L can be determined by

$$L = 2\pi/k$$

$$= 2\pi / 8.7289$$

$$= 0.72 \text{ m}$$

It is found that

$$d/L = 0.2 / 0.72$$

$$= 0.278$$

Table 5.1 indicated the wavelength generated by the wave generator in the wave flume derived form the Linear Dispersion method at water depth 20 cm and 25 cm. Therefore, the 20 cm and 25 cm depth of water in the flume is a transitional depth because $0.04 < d/L < 0.5$ when wave period is in the range of 0.6 to 1.4 seconds as shown in Figure 5.1. When T is > 1.4 the water depth is concluded as shallow water while $T < 0.6$ it is deep water.

Table 5.1: Determination of wavelength using Linear Dispersion method

Water depth: 20 cm

T(s)	*d (m)*	*σ (rad/s)*	*k (rad/s)*	*f(x)*	*L*	*d/L*
1.22	0.2	5.15	4.05	0.000	1.55	0.13
1.09	0.2	5.76	4.65	0.000	1.35	0.15
1.05	0.2	5.98	4.87	0.000	1.29	0.15
0.82	0.2	7.66	6.83	0.000	0.92	0.22
0.70	0.2	8.97	8.73	0.000	0.72	0.28
0.60	0.2	10.47	11.42	0.000	0.55	0.36

Water depth: 25 cm

T(s)	*d (m)*	*σ (rad/s)*	*k (rad/s)*	*f(x)*	*L*	*d/L*
1.41	0.25	4.45	2.03	0.000	3.10	0.08
1.10	0.25	5.71	3.32	0.000	1.89	0.13
0.99	0.25	6.35	4.10	0.000	1.53	0.16
0.86	0.25	7.30	5.46	0.000	1.15	0.22
0.63	0.25	9.97	10.13	0.000	0.62	0.40
0.59	0.25	10.65	11.63	0.000	0.54	0.46

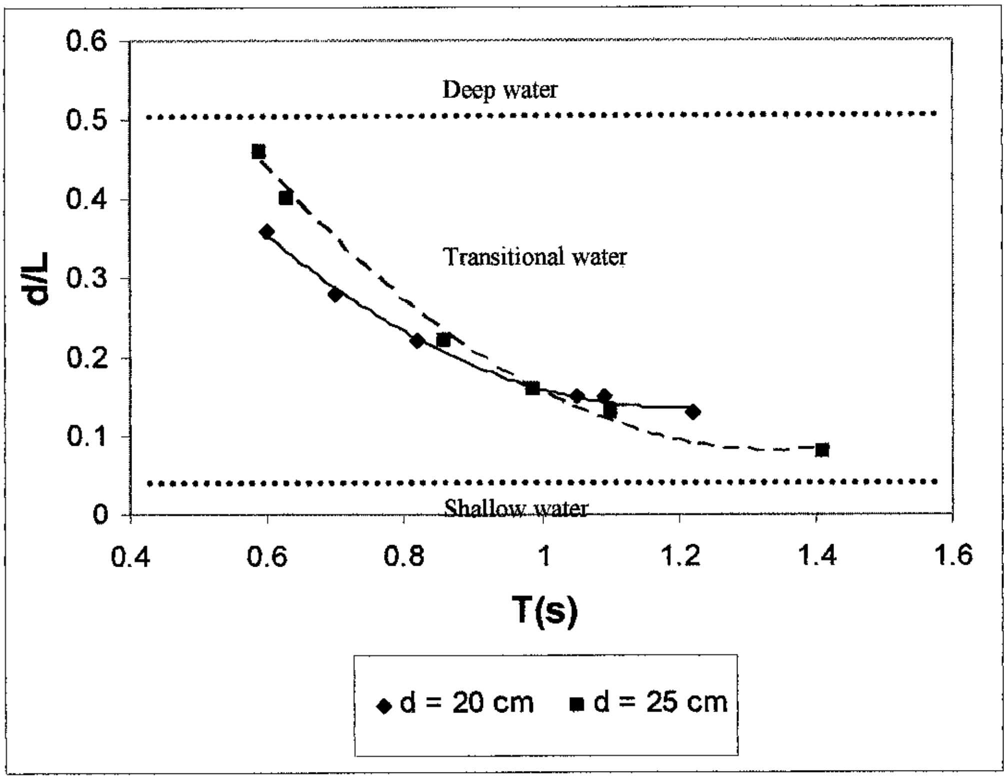


Figure 5.1: Graph of *d/L* versus wave period, *T* for *d* = 20 cm and 25 cm

5.2.2 Preliminary Tests

Table 5.2 shows the reflection coefficient prior to the installation of VWSS in the wave flume, in response to the various wave periods at water depth of 20 cm and 25 cm, respectively.

Table 5.2: Determination of incident and reflected wave height and reflection coefficient prior to the installation of VWSS

20 cm water depth												
Maximum adjustment (200 mm)							Minimum adjustment (120 mm)					
T (s)	H_{max} (cm)	H_{min} (cm)	H_i (cm)	H_r (cm)	C_r		T (s)	H_{max} (cm)	H_{min} (cm)	H_i (cm)	H_r (cm)	C_r
1.89	9.50	3.00	6.25	3.25	0.52		1.89	6.50	2.00	4.25	2.25	0.53
1.56	10.00	3.00	6.50	3.50	0.54		1.56	7.50	2.50	5.00	2.50	0.50
1.32	10.00	3.50	6.75	3.25	0.48		1.32	8.00	3.50	5.75	2.25	0.39
1.14	11.50	3.50	7.50	4.00	0.53		1.14	9.50	4.50	7.00	2.50	0.36
1.00	12.00	4.00	8.00	4.00	0.50		1.00	10.50	5.00	7.75	2.75	0.35
0.89	10.50	4.50	7.50	3.00	0.40		0.89	11.00	3.50	7.25	3.75	0.52
0.80	10.00	3.50	6.75	3.25	0.48		0.80	10.50	3.00	6.75	3.75	0.56
0.72	9.50	3.00	6.25	3.25	0.52		0.72	9.50	3.00	6.25	3.25	0.52
0.65	8.50	3.00	5.75	2.75	0.48		0.65	7.50	2.50	5.00	2.50	0.50
0.51	8.00	2.00	5.00	3.00	0.60		0.51	-	-	-	-	-

25 cm water depth												
Maximum adjustment (200 mm)							Minimum adjustment (120 mm)					
T (s)	H_{max} (cm)	H_{min} (cm)	H_i (cm)	H_r (cm)	C_r		T (s)	H_{max} (cm)	H_{min} (cm)	H_i (cm)	H_r (cm)	C_r
1.89	9.00	3.00	6.00	3.00	0.50		1.89	8.50	3.50	6.00	2.50	0.42
1.56	9.50	3.50	6.50	3.00	0.46		1.56	10.00	4.00	7.00	3.00	0.43
1.32	10.00	4.50	7.25	2.75	0.38		1.32	10.50	4.50	7.50	3.00	0.40
1.14	10.50	4.50	7.50	3.00	0.40		1.14	10.00	6.50	8.25	1.75	0.21
1.00	12.50	3.50	8.00	4.50	0.56		1.00	10.50	5.50	8.00	2.50	0.31
0.89	14.50	4.50	9.50	5.00	0.53		0.89	11.00	6.00	8.50	2.50	0.29
0.80	12.50	5.00	8.75	3.75	0.43		0.80	11.50	3.50	7.50	4.00	0.53
0.72	12.00	4.50	8.25	3.75	0.45		0.72	6.50	3.00	4.75	1.75	0.37
0.65	9.50	4.00	6.75	2.75	0.41		0.65	5.00	2.50	3.75	1.25	0.33
0.51	8.50	2.00	5.25	3.25	0.62		0.51	-	-	-	-	-

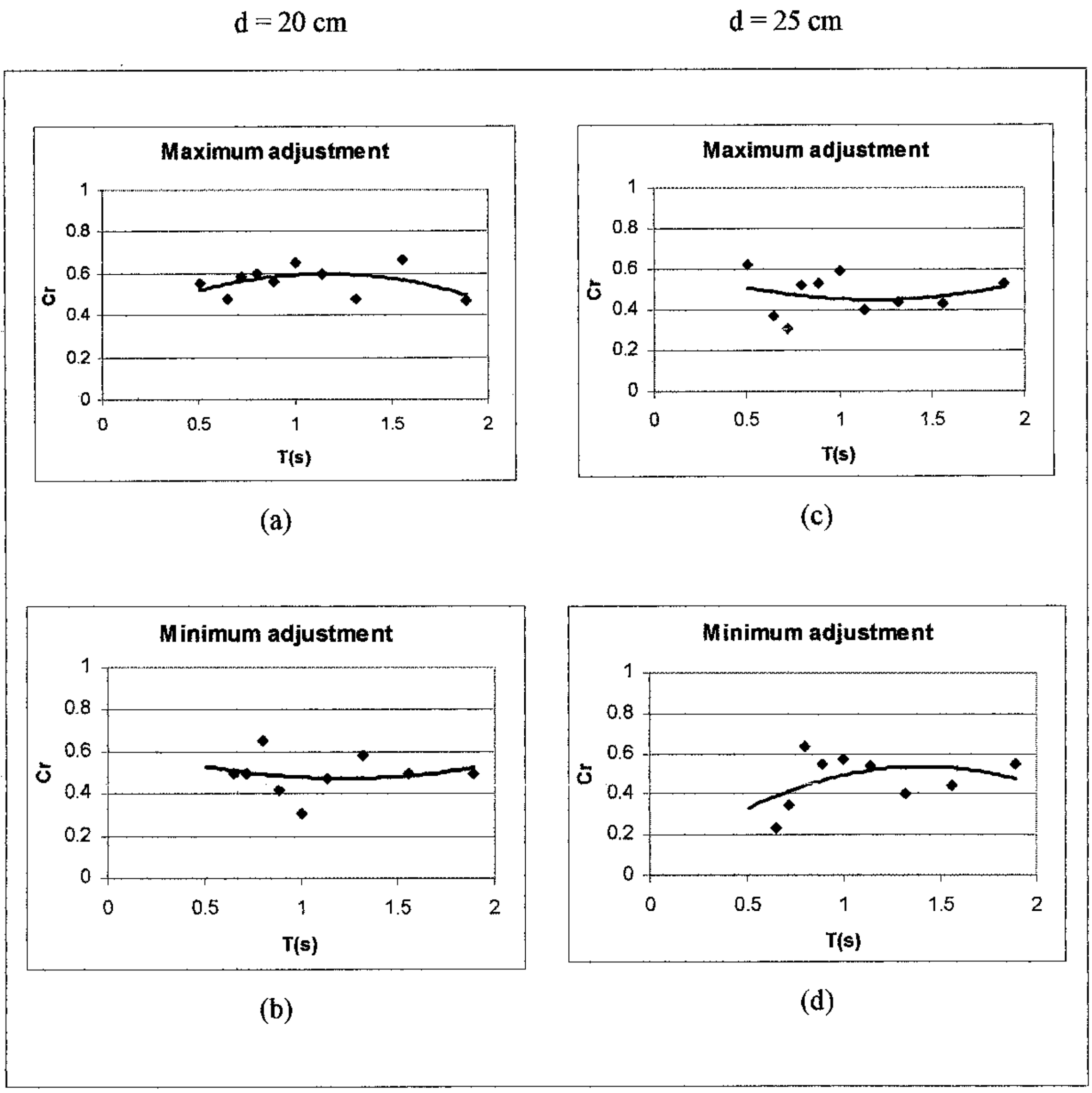
There is no common trend found of C_r variations with respect to stroke adjustment and water depths. In maximum adjustment, no significant change of C_r with respect to increasing wave period as shown in Figure 5.2(a) and (c) in both water depths of 20 cm and 25 cm. In water depth of 20 cm most of the data points are concentrated at $C_r = 0.6$ as exhibit in Figure 5.2(a), whereas, C_r under the maximum adjustment in water depth of 25 cm are mostly ranged from 0.4 to 0.6 (Figure 5.2(c)). The representative curve plotted is significantly lower than that in Figure 5.2(a).

Figure 5.2(b) and (d) indicated the C_r variation with respect to wave period under a minimum adjustment condition in water depth 20 cm and 25 cm, respectively. Both plotted curves have the common trend where C_r points are located between 0.4 and 0.6. A summary of results is tabulated in Table 5.3.

Table 5.3: Range of C_r value in maximum and minimum adjustment

d = 20 cm		
Adjustment	Maximum (200 mm)	Minimum (120 mm)
H_i (cm)	5.0 – 8.0	4.25 – 7.75
C_r	0.4 – 0.6	0.35 – 0.56

d = 25 cm		
Adjustment	Maximum (200 mm)	Minimum (120 mm)
H_i (cm)	5.25 – 9.50	3.75 – 8.50
C_r	0.38 – 0.62	0.21 – 0.53



(a) (c)

(b) (d)

Figure 5.2: Reflection coefficient versus wave period (without VWSS)

5.3 Experimental test on VWSS

Table 5.4 to 5.6 present the results of various number of wave screens in both water depths of 20 cm and 25 cm.

Table 5.4: Determination of incident and reflected wave height and reflection coefficient with 4-screen VWSS

20 cm water depth												
Maximum adjustment (200 mm)							Minimum adjustment (120 mm)					
T (s)	H_{max} (cm)	H_{min} (cm)	H_i (cm)	H_r (cm)	C_r		T (s)	H_{max} (cm)	H_{min} (cm)	H_i (cm)	H_r (cm)	C_r
1.89	4.00	2.00	3.00	1.00	0.33		1.89	2.50	3.00	2.75	0.25	0.09
1.56	5.50	3.00	4.25	1.25	0.29		1.56	5.00	3.00	4.00	1.00	0.25
1.32	7.50	4.00	5.75	1.75	0.30		1.32	5.50	3.50	4.50	1.00	0.22
1.14	7.00	3.00	5.00	2.00	0.40		1.14	6.50	4.00	5.25	1.25	0.24
1.00	9.50	6.00	7.75	1.75	0.23		1.00	8.50	4.50	6.50	2.00	0.31
0.89	9.50	5.50	7.50	2.00	0.27		0.89	7.50	6.00	6.75	0.75	0.11
0.80	9.00	4.00	6.50	2.50	0.38		0.80	6.00	5.50	5.75	0.25	0.04
0.72	8.50	4.00	6.25	2.25	0.36		0.72	5.50	3.50	4.50	1.00	0.22
0.65	9.50	4.00	6.75	2.75	0.41		0.65	5.00	2.00	3.50	1.50	0.43
0.51	4.00	2.50	3.25	0.75	0.23		0.51	-	-	-	-	-

25 cm water depth												
Maximum adjustment (200 mm)							Minimum adjustment (120 mm)					
T (s)	H_{max} (cm)	H_{min} (cm)	H_i (cm)	H_r (cm)	C_r		T (s)	H_{max} (cm)	H_{min} (cm)	H_i (cm)	H_r (cm)	C_r
1.89	4.00	1.50	2.75	1.25	0.45		1.89	3.00	0.50	1.75	1.25	0.71
1.56	4.50	2.50	3.50	1.00	0.29		1.56	3.50	0.50	2.00	1.50	0.75
1.32	5.00	2.00	3.50	1.50	0.43		1.32	3.00	1.00	2.00	1.00	0.50
1.14	6.00	2.50	4.25	1.75	0.41		1.14	3.50	1.50	2.50	1.00	0.40
1.00	6.00	4.50	5.25	0.75	0.14		1.00	7.00	1.50	4.25	2.75	0.65
0.89	6.00	4.00	5.00	1.00	0.20		0.89	8.00	2.50	5.25	2.75	0.52
0.80	7.50	5.00	6.25	1.25	0.20		0.80	8.50	4.00	6.25	2.25	0.36
0.72	7.00	5.00	6.00	1.00	0.17		0.72	7.50	4.00	5.75	1.75	0.30
0.65	7.00	5.00	6.00	1.00	0.17		0.65	7.50	4.00	5.75	1.75	0.30
0.51	-	-	-	-	-		0.51	-	-	-	-	-

5.3.1 4-screen VWSS

Figure 5.3(a) and (b) show the variation of C_r with respect to wave period, T at water depth of 20 cm under maximum and minimum adjustment, respectively. C_r decreases with increasing in wave period T. Further observed found that a constant degree of wave reflection of 0.3 regardless the wave period in maximum adjustment in Figure 5.3(a).

The plots in Figure 5.3(c) and (d) shows the variations of C_r with respect to wave period T in water depth of 25 cm in the flume for maximum and minimum adjustments. It can be noted that C_r are increase with the increase of T. the increase is less obvious in (c) as compared to (d). The results are almost similar to that in (a) which most of the data points scattered within the range of $0.2 < C_r < 0.4$. Wave reflection is significant with $C_r > 0.4$ when T is larger than 1.0 second in Figure 5.3(d). A summary of the wave reflection range is concluded in Table 5.5.

Table 5.5: Range of C_r value in maximum and minimum adjustment

d = 20 cm		
Adjustment	Maximum (200 mm)	Minimum (120 mm)
H_i (cm)	3.0 – 7.75	2.75 – 6.75
C_r	0.23 – 0.41	0.04 – 0.43

d = 25 cm		
Adjustment	Maximum (200 mm)	Minimum (120 mm)
H_i (cm)	2.75 – 6.25	1.75 – 6.25
C_r	0.14 – 0.43	0.3 – 0.75

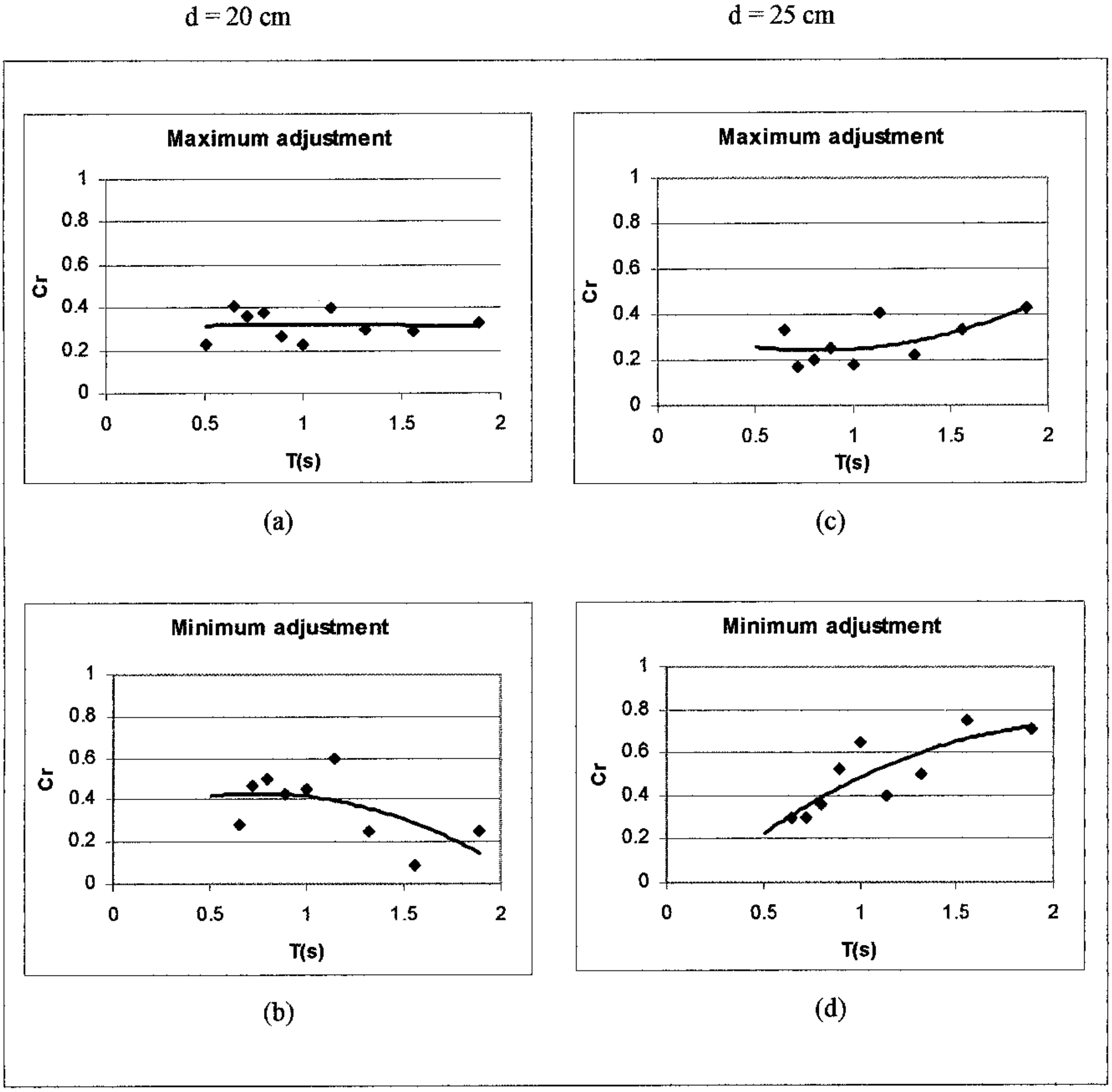


Figure 5.3: Reflection coefficient versus wave period (4-screen VWSS)

Table 5.6: Determination of incident and reflected wave height and reflection coefficient with 8-screens VWSS

20 cm water depth												
Maximum adjustment (200 mm)							Minimum adjustment (120 mm)					
T (s)	H_{max} (cm)	H_{min} (cm)	H_i (cm)	H_r (cm)	C_r		T (s)	H_{max} (cm)	H_{min} (cm)	H_i (cm)	H_r (cm)	C_r
1.89	3.00	1.50	2.25	0.75	0.33		1.89	3.50	1.00	2.25	1.25	0.56
1.56	5.00	2.50	3.75	1.25	0.33		1.56	3.50	2.00	2.75	0.75	0.27
1.32	6.00	3.00	4.50	1.50	0.33		1.32	3.00	1.50	2.25	0.75	0.33
1.14	5.00	2.50	3.75	1.25	0.33		1.14	3.20	1.80	2.50	0.70	0.28
1.00	5.00	2.00	3.50	1.50	0.43		1.00	3.00	1.50	2.25	0.75	0.33
0.89	6.00	3.00	4.50	1.50	0.33		0.89	3.20	1.00	2.10	1.10	0.52
0.80	5.50	2.00	3.75	1.75	0.47		0.80	5.00	2.50	3.75	1.25	0.33
0.72	5.00	2.50	3.75	1.25	0.33		0.72	5.50	2.50	4.00	1.50	0.38
0.65	6.50	2.00	4.25	2.25	0.53		0.65	4.50	2.50	3.50	1.00	0.29
0.51	4.50	1.50	3.00	1.50	0.50		0.51	5.00	2.50	3.75	1.25	0.33

25 cm water depth												
Maximum adjustment (200 mm)							Minimum adjustment (120 mm)					
T (s)	H_{max} (cm)	H_{min} (cm)	H_i (cm)	H_r (cm)	C_r		T (s)	H_{max} (cm)	H_{min} (cm)	H_i (cm)	H_r (cm)	C_r
1.89	3.00	0.30	1.65	1.35	0.82		1.89	3.00	0.50	1.75	1.25	0.71
1.56	4.00	2.50	3.25	0.75	0.23		1.56	3.50	0.50	2.00	1.50	0.75
1.32	5.00	2.00	3.50	1.50	0.43		1.32	3.00	1.00	2.00	1.00	0.50
1.14	6.00	3.00	4.50	1.50	0.33		1.14	3.50	1.50	2.50	1.00	0.40
1.00	6.50	3.50	5.00	1.50	0.30		1.00	7.00	1.50	4.25	2.75	0.65
0.89	7.50	5.00	6.25	1.25	0.20		0.89	8.00	2.50	5.25	2.75	0.52
0.80	7.50	4.00	5.75	1.75	0.30		0.80	8.50	4.00	6.25	2.25	0.36
0.72	7.00	3.50	5.25	1.75	0.33		0.72	7.50	4.00	5.75	1.75	0.30
0.65	3.00	3.00	3.00	0.00	0.00		0.65	7.50	4.00	5.75	1.75	0.30
0.51	3.00	2.50	2.75	0.25	0.09		0.51	-	-	-	-	-

5.3.2 8-screen VWSS

Figure 5.4 contains the C_r results in response to various wave periods at different adjustments in both water depths of 20 cm and 25 cm. All of the plots shown in the figure are sharing the same behavior, where C_r increases with the increasing wave periods, except the plot (s). It could be further observed that $C_r < 0.4$ when $T > 1.5$ s generally for all plotted graph. The 8 screens is no longer an effective wave absorber as $T > 1.5$ s because significant reflected waves resulted from the absorber structure. Table 5.7 summarizes the range value of incident wave height as well as the reflection coefficient for 8-screen VWSS in water depth of 20 cm and 25 cm and both maximum and minimum adjustment.

Table 5.7: Range of C_r value in maximum and minimum adjustment

d = 20 cm		
Adjustment	Maximum (200 mm)	Minimum (120 mm)
H_i (cm)	2.25 – 4.50	2.10 – 4.0
C_r	0.33 – 0.53	0.27 – 0.56

d = 25 cm		
Adjustment	Maximum (200 mm)	Minimum (120 mm)
H_i (cm)	1.65 – 6.25	1.75 – 6.25
C_r	0.09 – 0.43	0.3 – 0.75

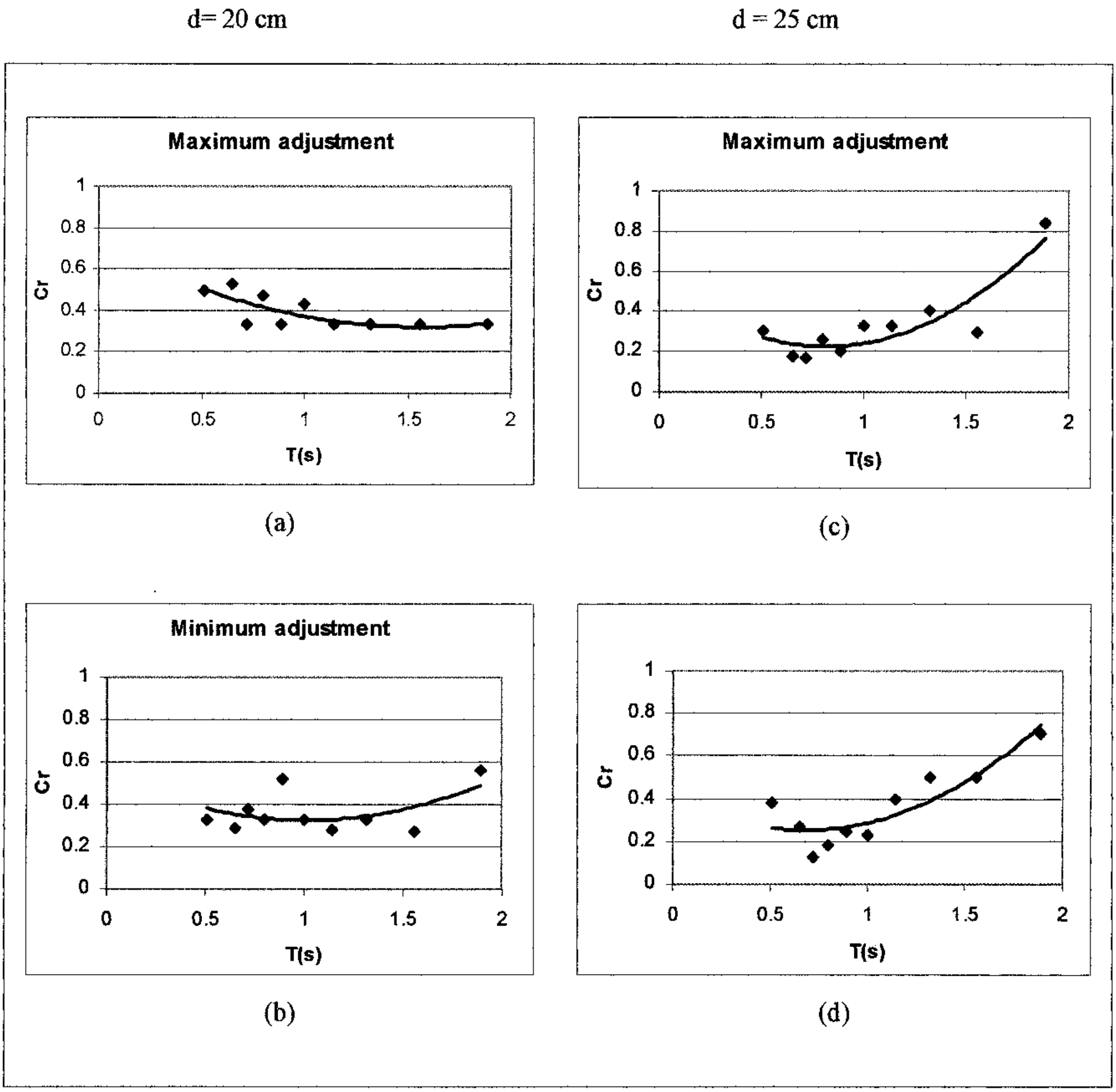


Figure 5.4: Reflection coefficient versus wave period (8-screen VWSS)

Table 5.8: Determination of incident and reflected wave height and reflection coefficient with 12-screen VWSS

20 cm water depth												
Maximum adjustment (200 mm)							Minimum adjustment (120 mm)					
T (s)	H_{max} (cm)	H_{min} (cm)	H_i (cm)	H_r (cm)	C_r		T (s)	H_{max} (cm)	H_{min} (cm)	H_i (cm)	H_r (cm)	C_r
1.89	3.00	0.30	1.65	1.35	0.82		1.89	2.00	0.20	1.10	0.90	0.82
1.56	3.50	1.50	2.50	1.00	0.40		1.56	2.50	1.00	1.75	0.75	0.43
1.32	4.00	2.00	3.00	1.00	0.33		1.32	3.00	1.50	2.25	0.75	0.33
1.14	4.00	3.00	3.50	0.50	0.14		1.14	3.00	1.80	2.40	0.60	0.25
1.00	4.50	3.50	4.00	0.50	0.13		1.00	3.00	2.00	2.50	0.50	0.20
0.89	5.00	3.00	4.00	1.00	0.25		0.89	3.50	2.00	2.75	0.75	0.27
0.80	5.00	2.50	3.75	1.25	0.33		0.80	4.00	2.00	3.00	1.00	0.33
0.72	5.50	3.50	4.50	1.00	0.22		0.72	3.50	2.50	3.00	0.50	0.17
0.65	5.50	4.50	5.00	0.50	0.10		0.65	4.50	2.50	3.50	1.00	0.29
0.51	5.00	2.00	3.50	1.50	0.43		0.51	5.00	3.0	4.00	1.00	0.25

25 cm water depth												
Maximum adjustment (200 mm)							Minimum adjustment (120 mm)					
T (s)	H_{max} (cm)	H_{min} (cm)	H_i (cm)	H_r (cm)	C_r		T (s)	H_{max} (cm)	H_{min} (cm)	H_i (cm)	H_r (cm)	C_r
1.89	6.00	2.00	4.00	2.00	0.50		1.89	3.00	1.00	2.00	1.50	0.50
1.56	7.00	3.50	5.25	1.75	0.33		1.56	4.00	2.00	3.00	1.00	0.33
1.32	7.50	4.00	5.75	1.75	0.30		1.32	5.50	2.50	4.00	1.50	0.38
1.14	7.50	5.00	6.25	1.25	0.20		1.14	5.00	3.00	4.00	1.00	0.25
1.00	8.00	6.00	7.00	1.00	0.14		1.00	5.00	3.50	4.25	0.75	0.18
0.89	8.20	5.50	6.85	1.35	0.20		0.89	5.50	3.00	4.25	1.25	0.29
0.80	9.00	5.00	7.00	2.00	0.29		0.80	6.00	4.00	5.00	1.00	0.20
0.72	7.00	4.00	5.50	1.50	0.27		0.72	7.00	5.00	6.00	1.00	0.17
0.65	6.50	4.50	5.50	1.00	0.18		0.65	5.50	3.50	4.50	1.00	0.22
0.51	5.50	4.50	5.00	0.50	0.10		0.51	6.00	4.50	5.25	0.75	0.14

5.3.3 12-screen VWSS

All the plots are having the same trend line which the larger the wave period, the greater the reflected wave resulting in the wave flume. Overall, most of the C_r data points are concentrated at a value of 0.2 when $T < 1.0$ s. For $T > 1.0$ s, it is observed that there is an obvious increase of C_r with increasing in T. the 12 screens VWSS becomes dysfunctional as $T > 1.6$ s. it can be seen that C_r could reach a value as high as 0.8 when $T \approx 2.0$ s. The VWSS could cause severe wave agitation within the flume due to the high degree of wave reflection taken place. Table 5.9 summarizes the range value of incident wave height as well as the reflection coefficient for 12-screen VWSS in water depth of 20 cm and 25 cm and both maximum and minimum adjustment.

Table 5.9: Range of C_r value in maximum and minimum adjustment

d = 20 cm		
Adjustment	Maximum (200 mm)	Minimum (120 mm)
H_i (cm)	1.65 – 5.0	1.10 – 4.0
C_r	0.1 – 0.82	0.17 – 0.82

d = 25 cm		
Adjustment	Maximum (200 mm)	Minimum (120 mm)
H_i (cm)	4.0 – 7.0	2.0 – 6.0
C_r	0.1 – 0.5	0.14 – 0.5

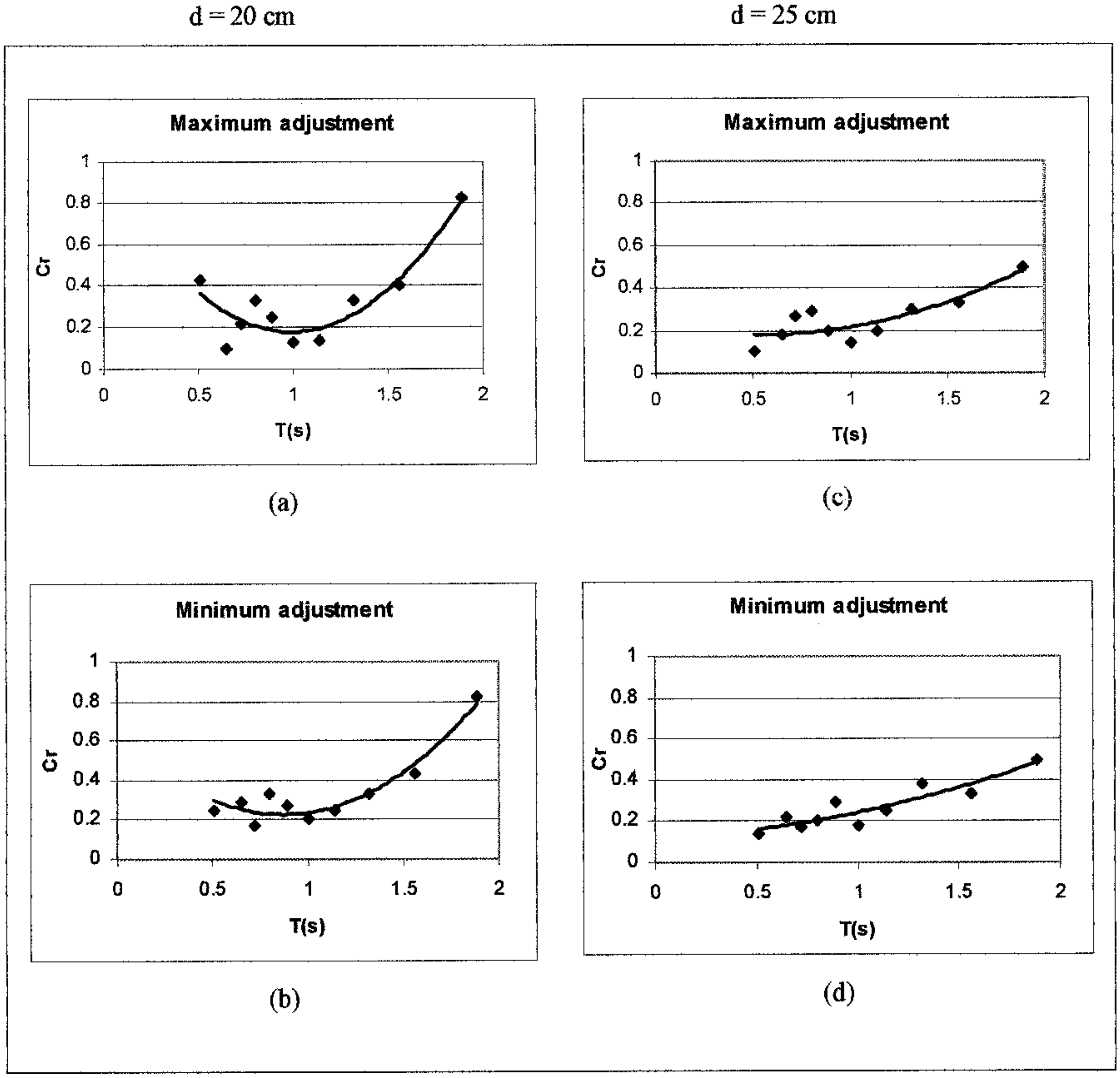


Figure 5.5: Reflection coefficient versus wave period (12-screen VWSS)

5.4 Analysis of VWSS Performance

A summary of various numbers of VWSS screens, with respect of different wave periods for both water depths of 20 cm and 25 cm under maximum and minimum adjustment are tabulated in Table 5.10 and 5.11 respectively.

Table 5.10: C_r of different number of screens at water depths of 20 cm and 25 cm (in maximum adjustment)

d = 20cm	C_r			
T (s)	Without VWSS	4-screen	8-screen	12-screen
1.89	0.47	0.33	0.33	0.82
1.56	0.67	0.29	0.33	0.40
1.32	0.48	0.30	0.33	0.33
1.14	0.60	0.40	0.33	0.14
1.00	0.65	0.23	0.43	0.13
0.89	0.56	0.27	0.33	0.25
0.80	0.60	0.38	0.47	0.33
0.72	0.58	0.36	0.33	0.22
0.65	0.48	0.41	0.53	0.10
0.51	0.55	0.23	0.50	0.43

d = 25cm	C_r			
T (s)	Without VWSS	4-screen	8-screen	12-screen
1.89	0.53	0.43	0.84	0.50
1.56	0.43	0.33	0.29	0.33
1.32	0.44	0.22	0.40	0.30
1.14	0.40	0.41	0.33	0.20
1.00	0.59	0.18	0.33	0.14
0.89	0.53	0.25	0.20	0.20
0.80	0.52	0.20	0.26	0.29
0.72	0.31	0.17	0.17	0.27
0.65	0.37	0.33	0.18	0.18
0.51	0.62	-	0.30	0.10

Table 5.11: C_r of different number of screens at water depths of 20 cm and 25 cm (in minimum adjustment)

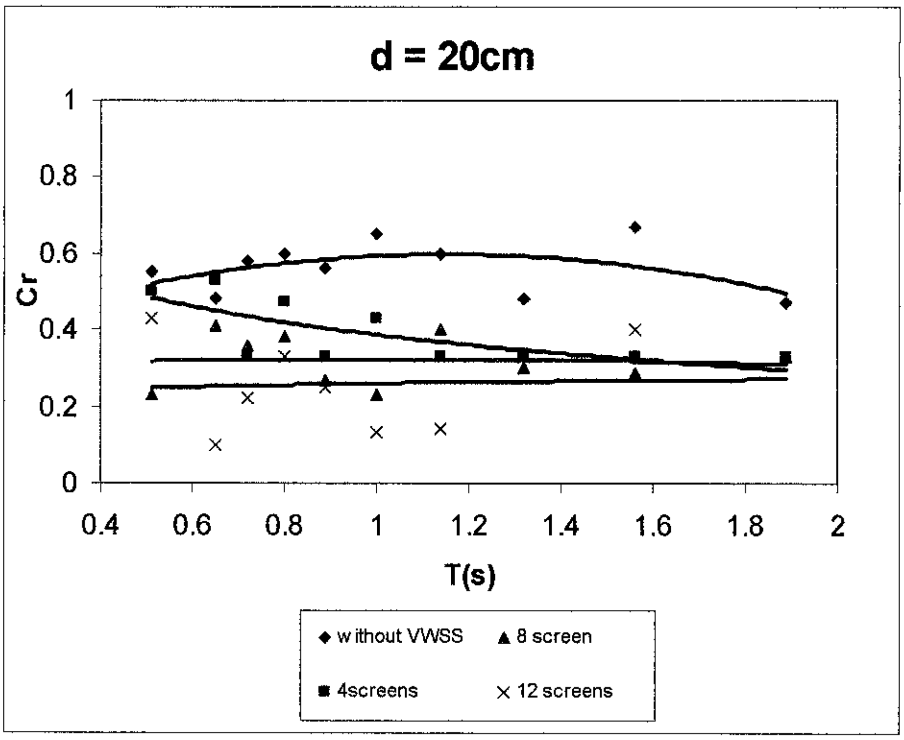
d = 20cm	C_r			
T (s)	Without VWSS	4-screen	8-screen	12-screen
1.89	0.50	0.25	0.56	0.82
1.56	0.75	0.09	0.27	0.43
1.32	0.70	0.25	0.33	0.33
1.14	0.47	0.60	0.28	0.25
1.00	0.31	0.45	0.33	0.20
0.89	0.42	0.43	0.52	0.27
0.80	0.65	0.50	0.33	0.33
0.72	0.50	0.47	0.38	0.17
0.65	0.50	0.28	0.29	0.29
0.51	NIL	NIL	0.33	0.25

d = 25cm	C_r			
T (s)	Without VWSS	4-screen	8-screen	12-screen
1.89	0.55	0.71	0.71	0.50
1.56	0.44	0.75	0.50	0.33
1.32	0.16	0.50	0.50	0.38
1.14	0.54	0.40	0.40	0.25
1.00	0.57	0.65	0.23	0.18
0.89	0.55	0.52	0.25	0.29
0.80	0.70	0.36	0.18	0.20
0.72	0.35	0.30	0.13	0.17
0.65	0.17	0.30	0.27	0.22
0.51	-	-	0.38	0.14

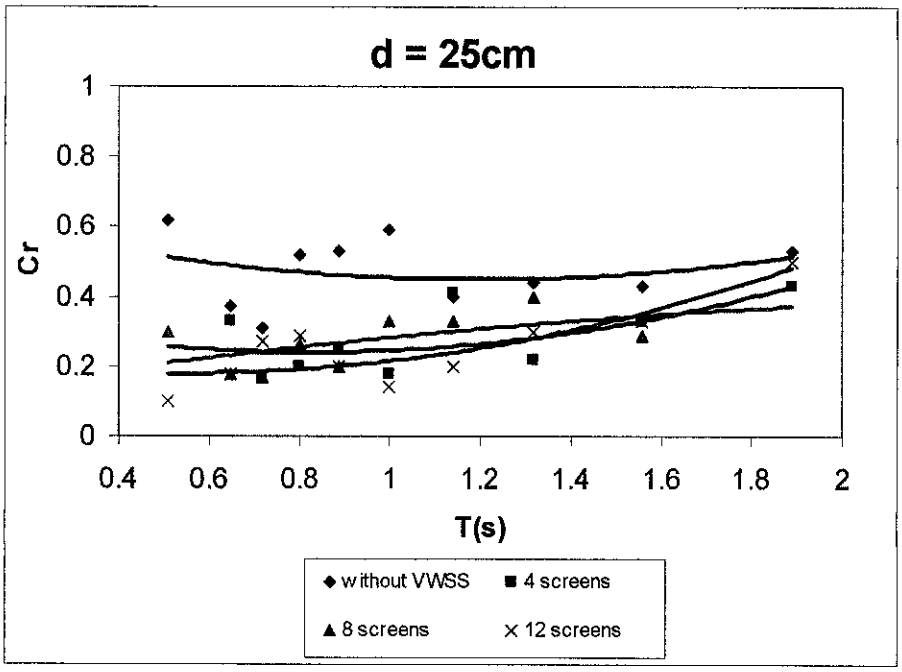
It can be found that the reflected wave height within the flume prior to the placement of VWSS can as high as 60% of the height of incident waves, for $0.4 < T < 2.0$ s at water depth of 20 cm. With installation of the 4-screen VWSS in the flume and at maximum adjustment (200 mm) as shown in Figure 5.6 (a) and highlighted by blue curve line, it is capable to reduce the reflection effect of waves by half, which heights of reflected wave is 30% of incident wave height for $0.4 < T < 2.0$ s.

As for the performance of 8-screen VWSS, the C_r values are decreases with increasing T when $0.4 < T < 2.0$ s. For $1.2 < T < 2.0$ s, it is found that the C_r performance curve laid on the curve of the 4-screen VWSS. The results show that the 8-screen VWSS makes a more efficient wave absorber system as compared to 4-screen VWSS. The 12-screen VWSS performs the best when $0.4 < T < 2.0$ s. It achieved the lowest C_r at 0.2 when $T \approx 1.0$ s. However, the performance of 12 screens VWSS is somewhat similar to the other two system when $T > 1.6$ s.

In water depth of 25 cm, the C_r are constant at an approximate value of 0.45, which is 0.15 lower that in water depth of 20 cm. Increasing the number of screens from 4 to 12 screens, it would not significantly increase the wave absorbing performance of the VWSS as shown in Figure 5.6(b). The system reduce the C_r value to 0.2 when $0.4 < T < 1.2$ s. As $0.4 < T < 2.0$ s, the wave absorbing performance reduces with the increasing T. It is expected that these system are not serving their purpose when $T > 2.0$ s.



(a)



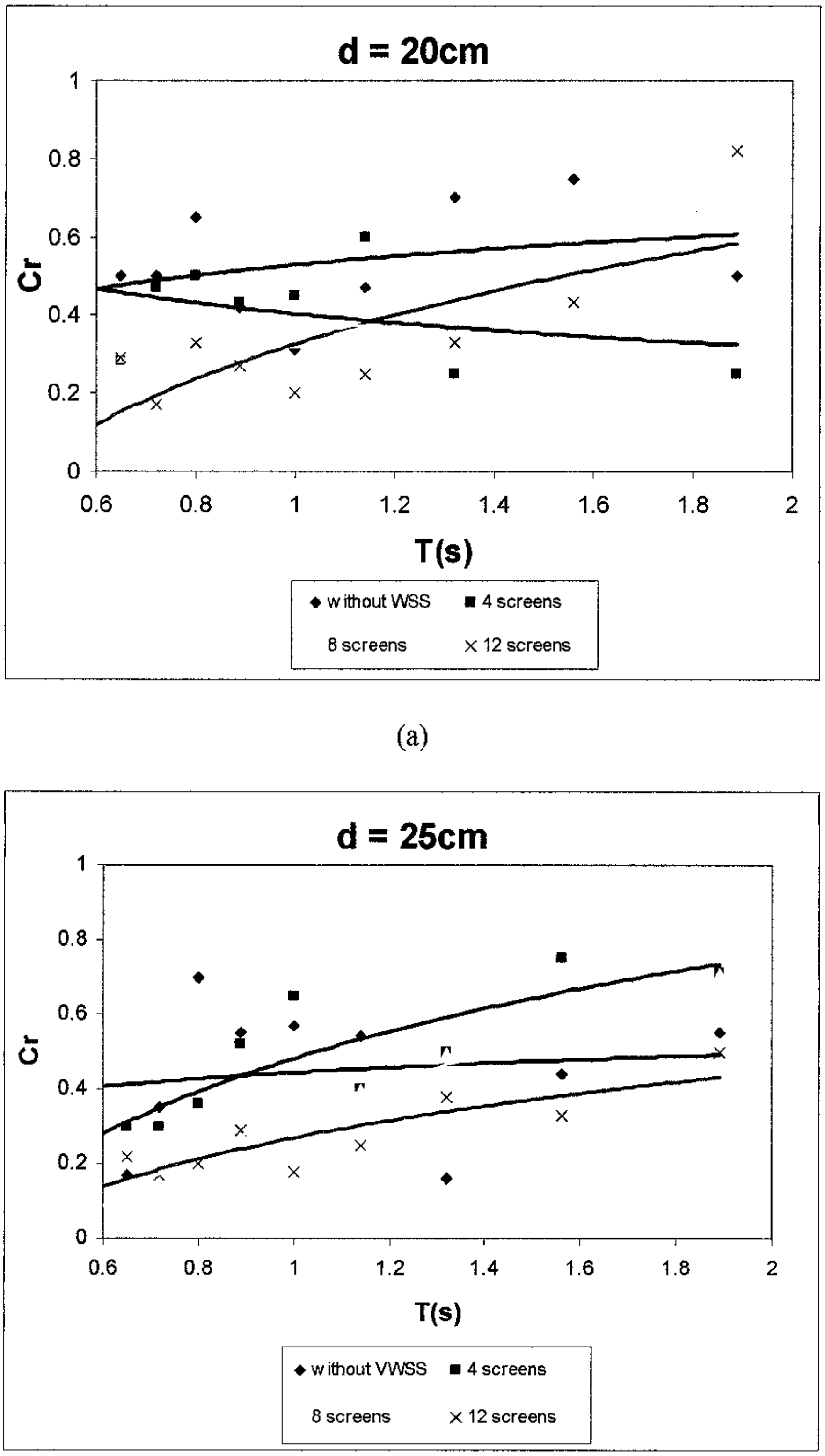
(b)

Figure 5.6: Comparisons of C_r for different number of screens of VWSS versus wave period, T at water depth of 20 cm and 25 cm (maximum adjustment)

Figure 5.7(a) and (b) exhibit the C_r value of various VWSS arrangement with respect to T under minimum adjustment at respective 20 cm and 25 cm water depth. In water depth of 20 cm (Figure 5.7a), the C_r value for 4, 8 and 12 screen VWSS fall below than the average of C_r value before the placement of VWSS.

As for the performance of 8-screen VWSS in water depth 20 cm which been highlighted yellow curve line in Figure 5.7(a), the C_r values are constantly tabulated at 0.3. For 12-screen VWSS, the C_r value is increasing and intersect the other two curve line when $1.1 < T < 2.0$ s. Again the results exhibits that the 12-screen VWSS makes a more efficient wave absorber system as compared to 4-screen and 8-screen VWSS.

Somehow the results obtained for minimum adjustment in water depth of 25 cm were unsatisfied because when VWSS is placed in the wave flume, it showed an increasing in wave reflection for 4 and 8-screen of VWSS. Wave reflection, C_r for 4-screen VWSS is intersect the 'without VWSS's curve at $T \approx 0.9$ s and 8 screens at $T \approx 1.5$ s. Performance of 12-screen VWSS is quite satisfied although it shows slightly increasing with increase in wave period but the curve line lain still remain below the 'without VWSS' curve line.



(a)

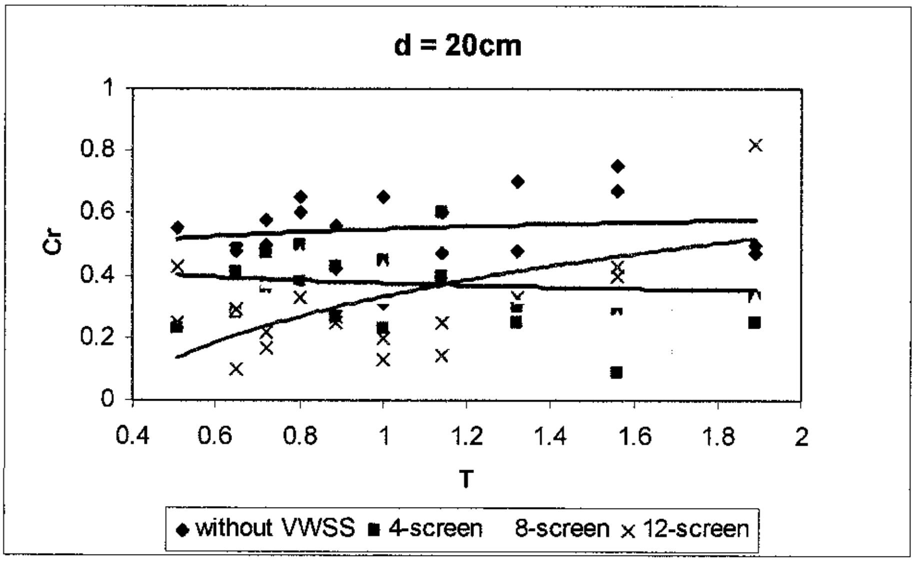
(b)

Figure 5.7: Comparisons of C_r for different number of screens of VWSS versus wave period, T at water depth of 20 cm and 25 cm (minimum adjustment)

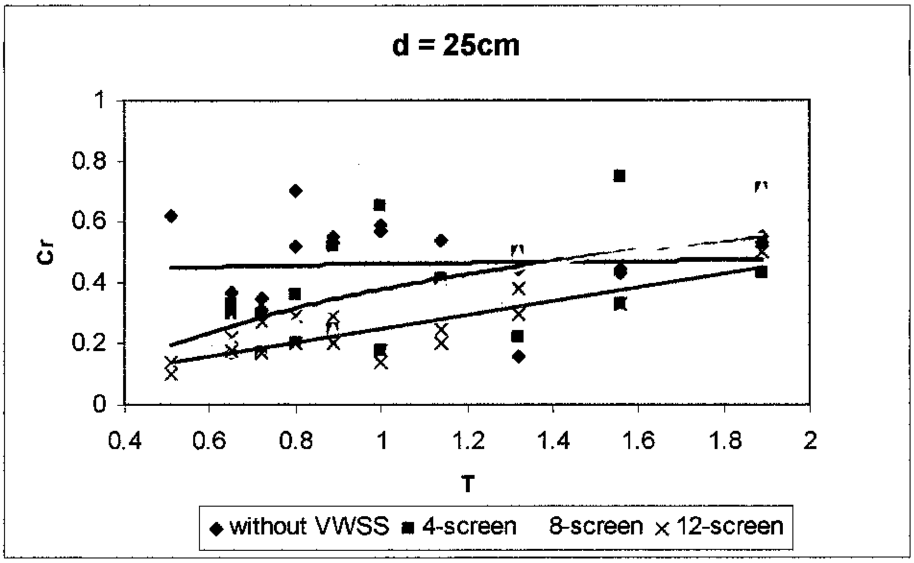
For further analysis, all the data are superimposed regardless of wave height (maximum and minimum adjustment) as presented in Figure 5.8(a) and (b) for two water depths respectively.

For water depth 20 cm (Figure 5.8a), it can be observed that reflection coefficient is constantly ranging from 0.5 to 0.6. When 4-screen and 8-screen VWSS were installed, they exhibit almost similar curve line when T is from 0.5 to 1.9 s. 12-screen VWSS perform best as shown in blue curve line when $T < 1.2$ s. However, the performance drops as C_r tend to increase when T is larger 1.2 s which hence lay above the 4 and 8-screen curve line.

In deeper water depth (25 cm), the VWSS is no longer effective when $T > 1.3$ s for both 4 and 8 screens as proved in Figure 5.8(b). Same goes for 12-screen system because the C_r is increasing with increases in T.



(a)



(b)

Figure 5.8: Comparisons of C_r for different number of screens of VWSS versus wave period, T at water depth of 20 cm and 25 cm

The VWSS is capable in reducing the incident wave energy with mainly by breaking and friction when 12 screens were employed to the Vertical Wave Screen system. The results clearly demonstrate that the attenuation of waves inside the screen is more dominant as the number of screen increases. The wave oscillations inside the screen are high in the case of 12-screen, which obviously allows higher incident waves.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The proposed design of Vertical Wave Screen System (VWSS) is proved to be an effective tool to dissipate the wave energy and reducing the wave reflection in the wave flume in a specific range of wave period.

4-screen and 8-screen VWSS shows quite similar performance which can be seen from their curve which always laid in the same pattern. They are capable in reducing the wave reflection up to 30% when T is in the range of $0.4 < T < 1.0$ second. For all the relative number of screen, 12-screen VWSS performs the best as it can reduce the wave reflection coefficient, C_r up to 50% as long as wave period, T is lower than 2.0 second. This is due to the higher porosity and larger opening on seaward side of the screen, which obviously allows more wave energy to pass through. As wave screen increases, the damping of the oscillations within the screen slowly decays resulting in lesser C_r. Water depth is not a governing factor which affect VWSS's performance and it is believed that VWSS system applicable for a wide range of water depth in the wave flume.

Some of the recommendations are made to enhance the quality of the laboratory test, are listed below;

1. Measurements of wave parameters through observations are subjective and prone to human errors. To improve the accuracy of the experiments, the author suggest to UTP to purchase at least two wave probes and a data acquisition software.

2. An extensive experimental runs, should be conducted in order to yield more comprehensive relationship of reflection coefficient and other parameters such as the spacing of screen and the wavelength.

3. The new arrangement of VWSS can be set up by placing it screens parallel instead of vertically upright in order to further observe its performance.

4. Some modification could be made to the VWSS to improve its performance and durability. A heavier cap should be constructed to increase the stability and rigidity of VWSS and thus to avoid the screen from swaying during experimental under strong wave condition.

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