Wave Attenuation by Wetland Vegetations

By

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Dissertation submitted in partial fulfillment of
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Bachelor of Engineering (Hons)
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
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In partial fulfillment of the requirement for the
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Approved by

(Mr Teh Hee Min)

CERTIFICATION OF ORIGINALITY

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

AIDIL ASS'AD BIN ANUAR

ABSTRACT

Wave attenuation by wetland vegetation is a concept that uses plants and vegetation instead of hard structures such as breakwaters, revetments or seawalls to dissipate the wave energy. The usage of hard structures has been proven to be obstructive and hazardous to the local environment either during the construction or even after the completion of the structures. Another alternative which is more eco friendly and less obstructive is by using vegetation as wave attenuators. The objective of this study is to determine the level of effectiveness of the vegetations in attenuating waves. Another objective of the study is to find a suitable species that will survive in the climate conditions in Malaysia and will have the similar effect on wave attenuation as other species that have been tested before. For the first semester, the concept was studied by using previous researches on the effects of other plants located in countries which have different weather conditions and climate compared to Malaysia. The study was continued the following semester where experiments have been carried out using a wave flume and the determination of the attenuation effect by the mangrove model is based on the *Transmission coefficient,* C_t. The values that were evaluated were the *Incident Wave Height, Hi, actual wave height, H* and wave period, *T*. The variable parameters used in the experiment to determine the transmission coefficient, C_t, were wave period, water depth and the number of mangrove beds. The experiment was done by using mangrove beds, comprising of 100 bamboo sticks with a diameter of 2mm placed in a 300 mm x 200 mm concrete bed placed in the wave flume. The initial wave height and actual wave height was compared.. The initial testing shows that the mangrove model is capable of attenuating up to 40 % of the wave height in various depths thus showing that the concept is practical in wave attenuation. Shallow water depth, low wave period and higher number of the mangrove model beds show a higher reduction in transmission coefficient. Throughout the experiments done and after analyzing the results, it can be concluded that wetland vegetation has the capability of attenuating wave energy even though it is not as effective as hard structures.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Wave attenuation is the process of dissipating the energy of the waves in order to reduce the damaging effect on the coastal lines. Erosion, scouring and direct physical damage are among the most common effects that can occur on the coastal structures such as harbors or ports, and the shorelines which leads to critical damage and risks. In order to attenuate the waves, the energy of the waves is dissipated through disruption in the water particle movements, creating turbulence, wave reflection and friction. Breakwaters and other coastal protection structures are the common solution in order to overcome the problems caused by wave energy to the coastlines but the amount of cost and effect on the surrounding environment are not to be taken lightly. The construction of fixed breakwaters affects the ecological system and sometimes destroys natural coral reefs despite the claims that the breakwater will become an artificial reef. Other coastal protection structures also compromise the natural state of the coastline thus disfiguring the condition and nature of the environment.

To replace the coastal protection structures while still producing a same effect on wave attenuation, wetland vegetation was studied to see their effect on protecting the coastline especially in wave attenuation. The wetland vegetation will give a low cost and natural solution for coastal protection and create a natural look for exposed and endangered coastlines.

1.2 PROBLEM STATEMENT

It has been a common solution for overcoming coastal destruction caused by wave energy using breakwaters, either fixed or floating but recent studies has shown the impact of these structures on coastal environment are devastating. Beginning from the construction of these structures, the site clearing alone causes the destruction of coastal flora and fauna. The progress of the construction will then cause disruption in the ecosystem, increasing Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD) and the Total Suspended Solid (TSS) value which affects the visibility and quality in the water. The construction of breakwaters creates disputes between the local fishermen and the developer claiming the decrease of catch and hardship due to the obstruction for their boats. The view of the coastline will also be disrupted due to the structures.

Wetland vegetation is used as wave attenuators in several countries which has limited space for any construction. The effectiveness of these wetland vegetations can be seen in the recent tsunami incident where many lives were spared by taking shelter behind mangrove trees and holding on to them. The strength of these trees is undeniably strong and reliable. Basically there are two types of wetland vegetation; submerged and emergent. The two type works in different way thus creating flexibility for choice, depending on the type of soil condition, geographical factors, temperature and natural vegetation of a specific area. The wetland vegetations used in other countries are different from those that can be used in Malaysia due to water temperature and soil type. This can be adapted by searching for plants that grow around the region which has the same properties of those used overseas.

Therefore, there is a need for a study to be done on wetland vegetation that is applicable in Malaysian coastal areas. This technology and knowledge is new in Malaysia hence the research will be done using experiments and other proving methods in order to find a more natural solution for wave attenuation.

The basic advantages of using wetland vegetation for wave attenuation are as follows:

1. Natural

   The source of the vegetation can be found and mass produced using nursery method

2. Low cost

   The wetland vegetation does not require any construction or heavy machinery in order to place the area of plantation. Once the plantation area is established, there is virtually no maintenance cost needed

3. Aesthetic values

   The plants creates a natural view relevant to the coastal area without disfiguring the natural beauty of the environment

4. Environmentally Friendly

   The wetland area is a natural breeding area for fishes and other marine fauna. The wetlands also act as a natural water filter.

5. Self adapting

   The vegetation is capable of adapting to the type of waves and water level of the protection area.

There are also some disadvantages of using wetland vegetation such as follows:

1. Plant Disease

   The plants are exposed to plant diseases that might destroy the whole crop once infected.

2. Soil condition or Type

   The plants need suitable soil for them to grow. Different type of vegetation needs different type of soil.

3. Initial Plantation and Short Lifespan

   The initial plantation will be challenging and difficult due to the natural environment of the plantation area. The Vegetation must also reproduce at an optimum rate to avoid a die-out.

1.3 Significance of Study

Being a country that is surrounded by open sea and exposed to destructive wave effect, it has been vital to find ways to protect and reserve the coastline. Breakwaters have done a good job in attending to the needs of coastal protection but new methods must be devised to give options considering factors such as cost, environmental impact and aesthetic values.

Since the tsunami tragedy that affected most of the Asian countries shown the importance and significance of mangrove trees, it can be said that wetland vegetation has shown their reliability and worthiness against combating wave effects on the coastal environment. Since the usage of wetland vegetation as a wave attenuator is not common, especially around the Southeast Asian region, more studies must be done in order to optimize the potential of the method.

The increase in awareness of the environment has also contributed to trigger the usage of natural sources as a solution to continuous effect of waves. The development of this method can also help provide a cheaper method than can be applied by the locals that face wave-triggered destruction such as erosion.

1.4 Objective of the Study

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

1. To identify the dominant species of wetland vegetation in Malaysia and determine the suitability of the growing condition in needed parts of the coastline

2. To simulate the artificial plants with similar characteristic and properties with equivalent materials

3. To determine the attenuation characteristic and the effects according to different arrangement, density of vegetation and effective depth.

1.5 Scope of Study

The study has been divided into 5 major elements in order to achieve the objectives. They are as follows:

1. Literature Review

   The understanding of the process of wave energy dissipation is done by referring to previous researches. Investigating the mechanism of the wave attenuation by the wetland vegetation is also done.

2. Research of Suitable Simulation Material

   The discovery and usage of suitable material which that will simulate the vegetation in order to create a near-real condition of the vegetation movement, durability and flexibility.

3. Laboratory Set Up

   The wave flume function and operation must be familiarized and inspected before any experiment can be done to avoid any malfunction and data compromising. The accuracy and functionality must meet the specifications needed to acquire optimum results.

4. Experiments

   Experiments are conducted in the wave flume in order to see the effects of the vegetation on the wave height and data collecting. The wave height and water depth are the some of the parameters that will be taken account.

5. Analysis of Results

   Data and results are collected, analyzed and interpreted from the experiments done. Comparison is made between the type of vegetation, density of vegetation and depth to determine the most affective condition.

Chapter 2

Literature Review

2.1 Wave Attenuation and Wave Breaking

Both wave attenuation and wave breaking have a similar property which is energy reduction. Though both actions might be caused by different reasons, the energy loss is the most significant result of both actions. Wave attenuation is caused mainly by shoaling where as the wave enters more shallow water, the cyclic movements of the water particles are disrupted thus transforming the wave into an uneven wave. Usually when the water depth reaches close to 1.3 times the wave length, the wave will experience energy loss due to drag and friction. As the wave loses energy, the wave height will be affected thus comes the transmission coefficient, C_t.

$$C_t = H/H_o \tag{2.1}$$

where H is current wave height and H_o is initial wave height

The shoaling factor will be the measurement of the effectiveness of the vegetation in attenuating the waves.

During breaking, a deformation (usually a bulge) forms at the wave crest, either leading side of which is known as the "toe". Parasitic capillary waves are formed, with short wavelengths. Those above the "toe" tend to have much longer wavelengths. There have been a couple non-linear theories of motion (regarding waves). One put forth uses a perturbation method to expand the description all the way to the third order, and better solutions have been found since then. As for wave deformation, methods much like the boundary integral method and the Boussinesq model have been created.

It has been accounted for, that the high-frequencies detail present in a breaking wave play a part in crest deformation and destabilzation. The same theory expands on this, stating that the valleys of the capillary waves create a source for vorticity. It is said that surface tension (and viscosity) are significant for waves up to 2m in wavelength.

These models are flawed, however, as they can't take into account what happens to the water after the wave breaks. Post-break eddy forms and the turbulence created via the breaking is mostly unresearched. Understandably, it might be difficult to glean predictable results from the ocean.

After the tip of the wave overturns and the jet collapses, it creates a very coherent and defined horizontal vertex. The plunging breakers create secondary eddies down the face of the wave. Small horizontal random eddides that form on the sides of the wave suggest that, perhaps, prior to breaking, the water's velocity is more or less two dimensional. This becomes three dimensional upon breaking.

The main vortex along the front of the wave diffuses rapidly into the interior of the wave after breaking, as the eddies on the surface become more viscous. Advection and molecular diffusion play a part in stretching the vortex and redistributing the vorticity, as well as the formation turbulence cascades. The energy of the large vortices are, by this method, is transferred to much smaller isotropic vortices.

2.2 Drag

Drag is a force caused by the dynamic action of a fluid that acts in the direction of the freestream fluid flow. Generally, a drag is a resistance force - a force that slows the motion of a body moving through a fluid. The drag force is computed using the coefficient of drag, the fluid density, the projected area of the body or the surface area of the body oriented perpendicular to the fluid flow, and is the relative velocity of the body with respect to the fluid.

One component of the total drag is known as surface drag or skin friction. Skin friction is derived from the sliding contacts between successive layers of fluid close to the surface of a moving body. The layer of fluid particles immediately adjacent to the moving body is slowed because of the shear stress the body exerts on the fluid. The next adjacent layer of fluid particles moves with slightly less speed because of friction between the adjacent molecules, and the next layer is affected in turn. The number of layers of affected fluid becomes progressively larger as the flow moves in the downstream direction along the body. The entire region within which fluid velocity is diminished be cause of the shearing resistance caused by the boundary of the moving body is the boundary layer. The force of the body exerts on the fluid in creating the boundary layer results in an oppositely directed reaction force exerted by the fluid on the body. This reaction force is known as skin friction.

Several factors affect the magnitude of skin friction drag. It increases proportionally with increases in the relative velocity of fluid flow, the surface area of the body over which the flow occurs, the roughness of the body surface, and the viscosity of the fluid. Skin friction is always one component of the total drag force acting on a body moving relative to a fluid, and it is the major form of drag present when the flow is primarily laminar.

In the case of the usage of vegetation, the water moves through the group of vegetation thus slowing down the motion of the water particle. The coefficient of drag is a non-dimensional number that serves as an index of the amount of drag an object can generate. Its magnitude depends on the shape and orientation of a body relative to the fluid flow, with long, streamlined bodies generally having lower coefficients of drag than blunt or irregularly shaped objects. The formula for the total drag force demonstrates the exact way in which each of the identified factors affects drag. If the coefficient of drag, which can be defined as

$$C_d = D / \tfrac{1}{2} \rho U^2 A$$

Where, D is drag, ρ is density of the fluid, U as the upstream velocity and A as the frontal area, the fluid density, and the projected area of the body remain constant, drag increases with the square of the relative velocity of motion. This relationship is referred to as the theoretical square law.

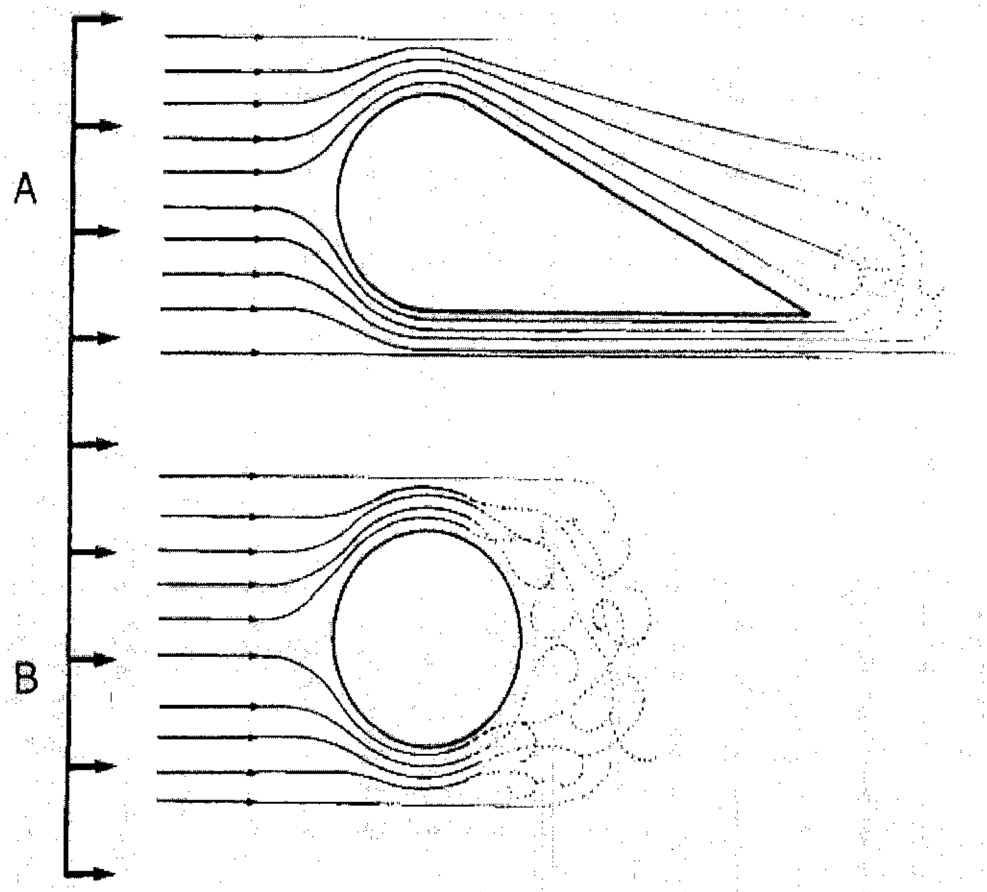


Figure 2.1: Drag profile; A object with streamlining, B without streamlining

As we can observe from the flow profile, the object with the round shape has a downstream flow that is irregular. Without streamlining, turbulence is created and the magnitude of the pressure gradient increases. This turbulence will then cause the disruption in flow and reduces the wave energy. The shape of the vegetation are mostly circular similar to the diagram above. Thus theoretically the effect will be the same on the waves and flow.

2.3 Wave Reflection

Reflection is dependent on the breaking state of the wave as well as the slope and hardness of the surface. It can vary from 0% for breaking waves on low-sloped, porous beaches to nearly 100% for non-breaking waves in deep water on a hard, vertical surface such as a sea wall. In this case, the surface of the vegetation is impermeable, vertical and slightly flexible which gives an elastic effect that will rebound the waves but not fully as such made by a seawall. The gaps between the 'trees' will allow flow but due to the drag, turbulance is produced and theoritically there will be a larger reduction of energy.

2.4 Energy Loss

Energy loss can be caused by several other reasons that happen usually in the shorelines. All of these phenomenon results in wave height reduction and through an extansion of equations, it results in the reduction of energy.

It can be seen that the height of the wave is directly proportional to the energy produced thus proving that energy has been reduced. The dissipation of the energy or height can be described through these events:

1. Turbulence due to the drag
2. Transformation of energy into sound, heat, etc
3. Reflection upon impact with the vegetation
4. Disruption in water particle movement at the bottom of the bed

To elaborate further on the energy loss of the system, the energy equation expansion can be represented by

$$Ei = Er + Et + El \tag{2.2}$$

Where Ei is incident wave energy, Er is reflected wave energy, Et is transmitted wave energy and El is enrgy loss. Expand this further and we will get (2.3) and by simplifying the equation, we get

$$\frac{(\rho g H)^2 i}{8} = \frac{(\rho g H)^2 r}{8} + \frac{(\rho g H)^2 t}{8} + \frac{(\rho g H)^2 l}{8} \tag{2.3}$$

$$H_i^2 = H_r^2 + H_t^2 + H_l^2 \tag{2.4}$$

2.5 Emergent Vegetation

The emergent vegetation environment that will be simulated is mangrove. Mangroves generally are trees and shrubs that grow in saline coastal habitats. The word is used in at least three senses, most broadly to refer to the habitat and entire plant assemblage or *mangal* , for which the terms mangrove swamp and mangrove forest are also used, to refer to all trees and large shrubs in the mangal, and narrowly to refer to the mangrove *family* of plants, the Rhizophoraceae, or even more specifically just to mangrove trees of the genus *Rhizophora*. Mangal is found in depositional coastal environments where fine sediments, often with high organic content, collect in areas protected from high energy wave action.

2.6 Mangrove ecosystems

Mangroves are excellent buffers between the violent ocean and the fragile coast, especially during hurricanes, which can bring powerful storm surges onto shores. The massive mangrove root system is quite efficient at dissipating wave energy. This same root system also helps prevent coastal erosion. As tidal water flows through the root system, it is slowed substantially enough so that it deposits its sediment as the tide comes in, and the return flow is kept slow as the tide goes out to prevent resuspension of some of the finer particles. As a result, mangroves can build their own environment. Because of the uniqueness of the mangrove ecosystems, they are frequently the object of conservation programs.

Specifically, the species that will be tested as the vegetation that will attenuate the wave energy is *Rhizophora* (Figure 2.2) or also known as Red Mangrove. Due to the strength, size and shape of this species, the model that will based on the Rhizophora shape and scale size.

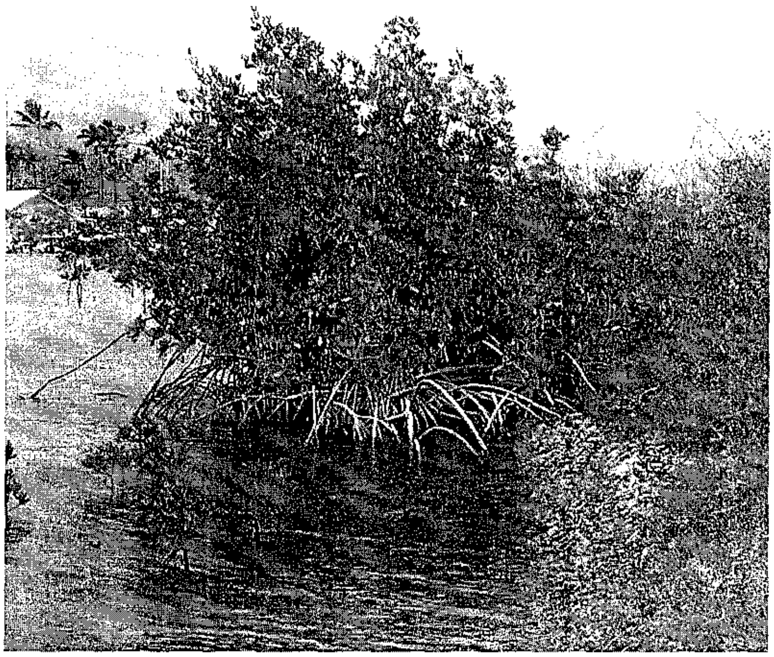


Figure 2.2: Rhizophora

The shape of stem of the plant creates a drag profile like the one mentioned (Figure 2.1) thus creating turbulence in the water flow. The reflection of the waves upon impact with the plant also contributes to the energy dissipation. Though not as significant as a seawall, the reflection of the waves will not result in scouring but still enough to partly counter the energy of the waves from the sea.

2.7 Submerged Vegetation

Another mechanism that will be used to attenuate the wave is by using submerged vegetation. The species that will be simulated is seaweed. Seaweeds are algae and classified into brown (Phaeophyta), red (Rhodophyta) and green algae (Chlorophyta) based on their pigment composition.

The ecology of seaweeds is dominated by two specific environmental requirements. These are the presence of sea-water (or at least brackish water) and the presence of light sufficient to drive photosynthesis. A very common requirement is also to have a firm point of attachment. As a result, seaweeds are most commonly found in the littoral zone and within that zone more frequently on rocky shores than on sand or shingle. The ecological niches utilised by seaweeds are wide ranging. At the highest level are those that inhabit the zone that is only wetted by sea spray through top the deepest living that are attached to the sea-bed under several metres of water. In some parts of the world, the area colonized by littoral seaweeds can extend for several miles away from the shore. The limiting factor in such cases is the availability of sufficient sun-light to support photosynthesis. The deepest living sea-weeds are the various kelps.

A number of species have adapted to the specilised environment of tidal rock pools. In this niche seaweeds are able to withstand rapidly changing temperature and salinity and even occasional drying.

Due to the nature of seaweed, it has become the most suitable sample for a submerged wave attenuator. The seaweed will act as a disruptor for the cyclic motion of the water particle. The seaweed will also 'reduce' the water depth for which will cause the waves to lose energy to. The important aspect in using seaweed is the density of the plantation so that the seaweed will create an effect of a sudden water depth reduction.

2.8 Previous Studies On Effects Of Wetland Vegetation in Wave Attenuation

There have been previous studies on the effect of wetland vegetation in wave attenuation.Though different in species, the usage of the vegetation are relevent with wave attenuation. Some of the findings and performance are discussed in the following section. The studies that are discussed are based from books and revious journals where comparison between the two research is done in terms of the parameter used to measure the effects of the vegetation.

2.8.1 Effects of Salt Marsh in Wave Attenuation

Greater wave attenuation can be achieved by the increased surface roughness which the salt marsh provides.This has three advantages. First, the roughness produces greater energy loss from the waves; second, vegetation binds the sediment, thus creating stability; third, the leaves and stems increase the rate of vertical accretion by acting as wave baffles (French 2001). The data obtained was taken from Knutson(1982) which stated that as wave moves across a vegetated surface, the energy levels and wave height decay exponentially. The decay of wave is a function of wave height approaching the marsh, distance travelled through the marsh, depth of the water, and diameter and spacing of the plants (Knutson *et al.* 1982). In suitably wide areas of vegetation,, this decay may be sufficient to completely remove the impacts of wave activity under certain conditions. Knutson *et al.* (1982) demonstrates the effectiveness of *Spartina* in dampening waves in Gulf coast situation and Knutson(1988) demonstrated attenuation with reference to Cheasapeake Bay. Figure 2.2 illustrates the increasing reduction in wave energy and height with distance travelled across the marsh. In this example it can be seen that under the study conditions, all wave energy had been lost within 30m of the marsh edge. It can also be seen that more than half the energy is lost within the first 2.5 m of the marsh edge, and up to 40 percent of wave height. Waves across a series of salt marsh transects showed effect of a decrease in wave energy of between 47 and 100 percent with a strong corelation between degrees of energy loss and water depth. They concluded that that the marsh vegetation was most effective at energy attenuation at low to intermidiate water depths. At greater water depths, it is likely that wave would be able to move over the top of the vegetation.

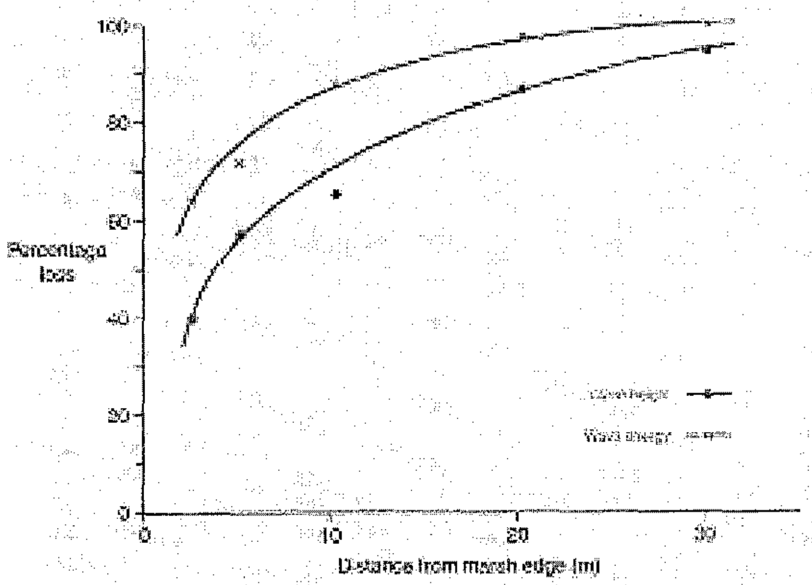


Figure 2.2 Wave height and wave energy reduction with distance travelled across salt marsh surface (Compiled using data from Knutson 1988)

2.8.2 Effects of Bulrush in Wave Attenuation

Tschirky, *et al* (2000) have made a study on the effects of bulrush in wave attenuation. A field monitoring program of a freshwater shoreline wetland located in Collins Bay at the northwest end of Lake Ontario near Kinston, Ontario, Canada was carried over the spring to autumn of 1996, 1997 and 1998. This study site was chosen because of its suitability, accessibility, exposure to wave action and because it was typical of many shorelines marshes in the Great Lakes region. The dominant plant species were soft stemmed bulrushes (*scirpus validus)*. The field investigation included observation and measurement of waves, water levels, substrate conditions, plant density and plant geometry. Plant density and geometry (height and diameter) were measured regularly throughout the the wetland during growing season. The bulrushes varied in height from less than a meter to almost 3 meters tall with an average height of 1.6 meters. The stems were relatively circular in cross section with basal diameter ranging from 2mm to 14 mm with an average of 7.1 mm. Plant desities were greatest in the shallower nearshore waters and decreased with increasing offshore distance and water depth. In general, basal plant diameters and heights were greater in deeper water.

Laboratory Investigation

The field monitoring was complemented by laboratory flume testing at the Queens's University Coastal Engineering Research Laboratory. The laboratory investigation allowed control over the conditions and the observations of the effects of one parameter at a time. Tests were conducted in a 0.91m wide, 1.2m deep, 47m long wave flume equipped with a computer controlled flapper type wave generator. A 10m long bed of bulrushes was installed approximately 20m from the wave paddle. A reflection absorbing permeable beach constructed of several layers of rubberized horsehair' filter fabric was used to minimize wave reflection from the rear wall of the flume. Five capacitance wave probes were used to measure the wave heights immediately in front and behind the plant bed at 2.5m intervals within the bed. The wave probes sampled the water surface elevation at a sampling rate of 20 Hz for a duration equal to at least 100 times the peak wave period. A series of over two hundred irregular wave tests were performed, varying plant density, water depth, significant wave height, and peak wave period.

Tschirky, *et al.* (2000) used wave transmission coefficient to quantify the wave attenuation (equation 2.1). The parametric analysis (Figure 2.6) revealed the following trends:

- Wave transmission varied inversly to plant bed length
- Increased plant density resulted in reduced wave transmission
- Wave transmission was directly proportional to water depth
- Incident wave height was observed to have a slight inverse relationship with transmission
- No clear influence with respect to wave period could be establised.

The trends observed in the laboratory and the field data were in general egreement. Overall, the plant bed length, water depth and density appeared to have a larger influence on the height of the waves passing through the wetland than incident wave height and period. Larger plant bed lengths and densities result in the waves encountering more plants, which results in increased friction and turbulence and in reduced wave transmission. Larger water depths results in larger wave transmission since the waves are influenced less by the lake or flume bottom (friction) and are interacting with the thinner, more flexible upper portions of the bulrushes. Larger incident wave heights come in contact with increased plant surfaces, which potentially aids in wave height reduction.

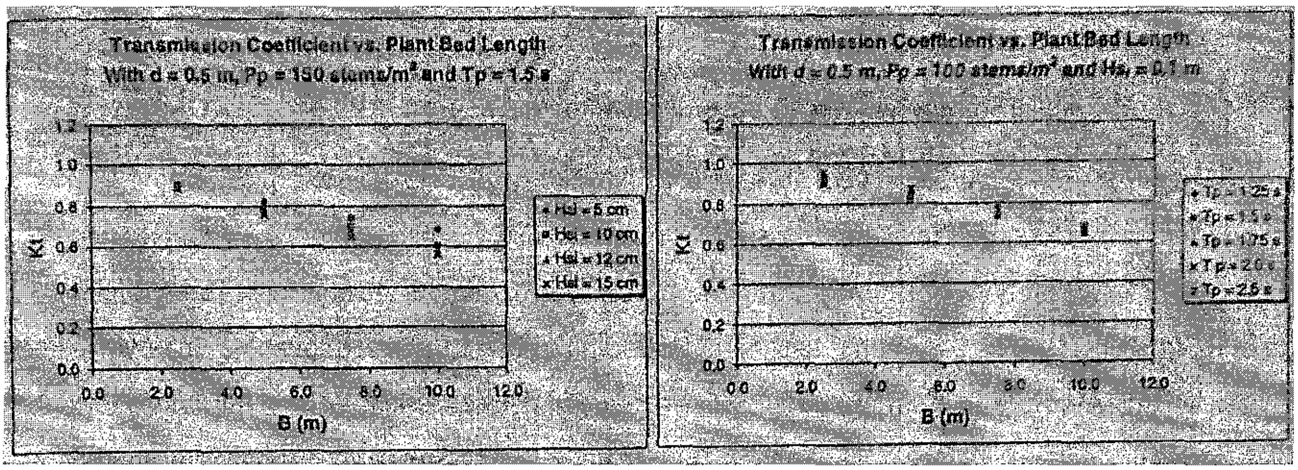
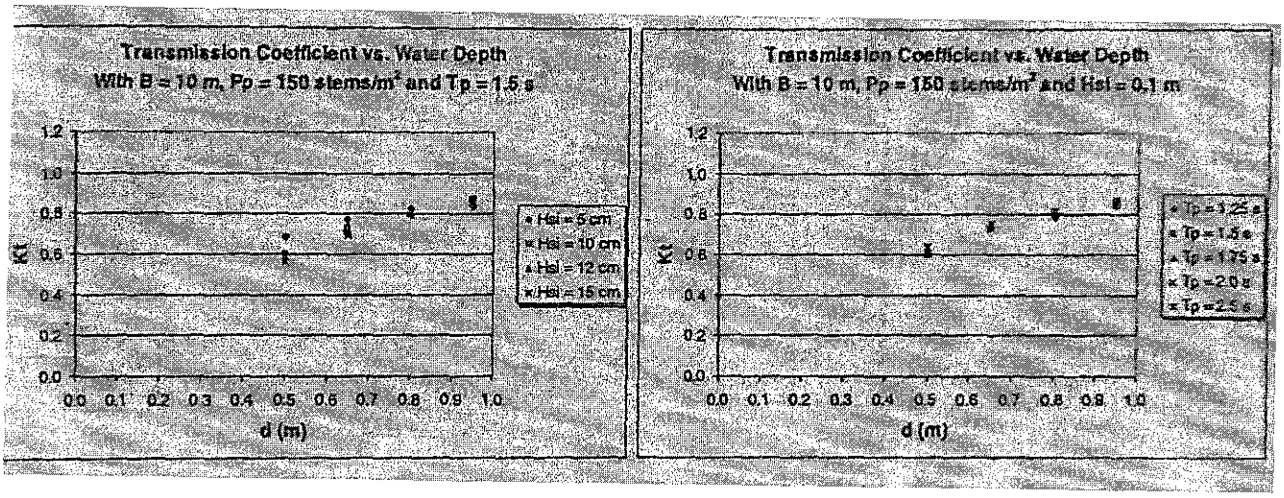
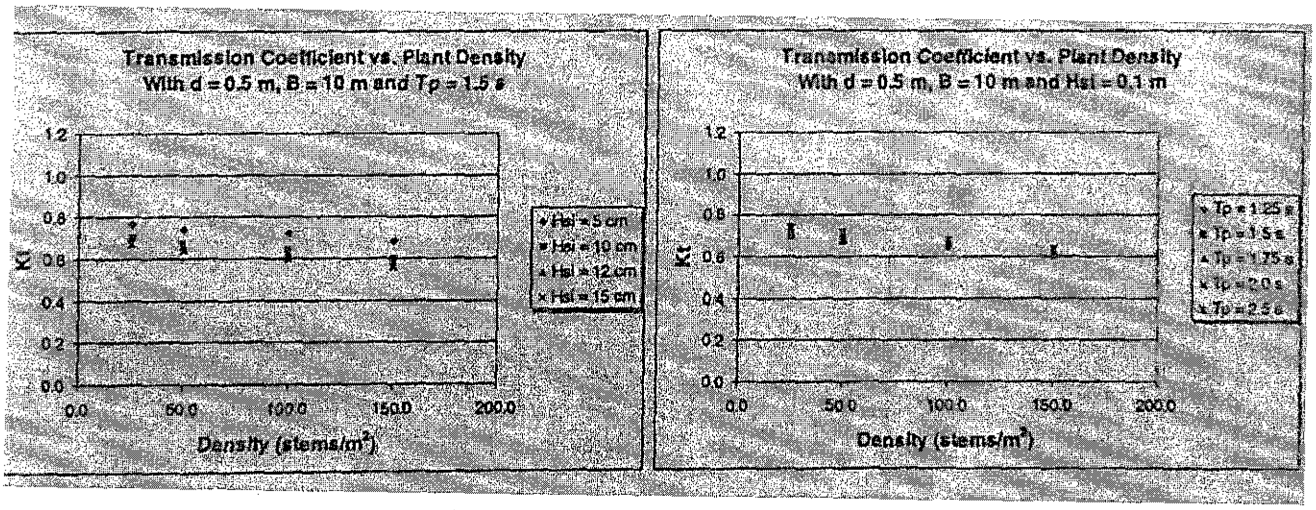


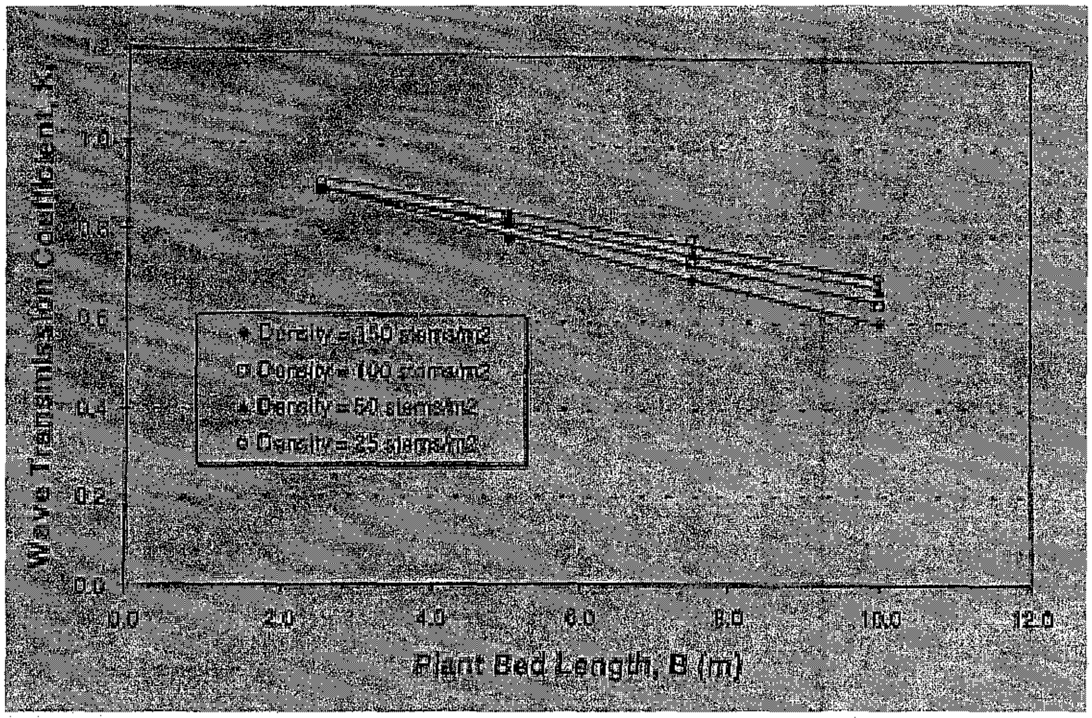
Figure 2.3 Wave Transmission coefficient vs Plant bed length (Tschirky, *et al.* 2000)



igure 2.4 Transmission coefficient vs Water depth (Tschirky, *et al.* 2000)



igure 2.5 Trasmission coeffecient vs Plant density (Tschirky, *et al.* 2000)



igure 2.6 Influence of Plant bed length and plant density on the wave transmission coefficient (Tschirky, *et al.* 2000)

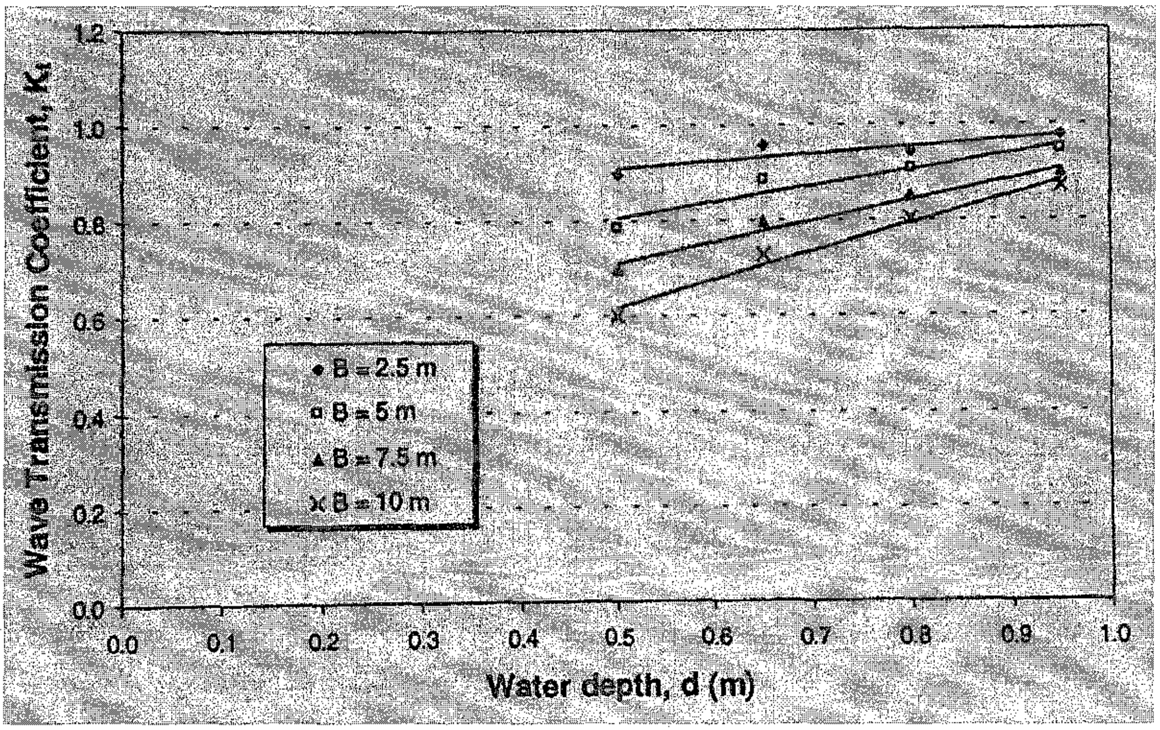


Figure 2.7 The changing influence of water depth on transmission as the plant bed length varies (Tschirky, *et al.* 2000)

2.8.3 Wave reduction in a mangrove forest dominated by Sonneratia sp.

Based on a field observation at the Vinh Quang coast in northern Vietnam, the characteristics of wave reduction due to the drag force of one mangrove species, Sonneratia sp., were quantitatively analyzed. The study was done by Yoshihiro Mazda, *et al.* (2006). According to the study, the reduction rate of sea waves in this area changed substantially with the tidal phase, due to the unique vertical configuration of Sonneratia sp. At the shallow range of water depth, since the shape of pneumatophores of Sonneratia sp. tapers off upward, the effect of drag force by these roots on the wave reduction decreased with the increase in the water level, resulting in a decrease in the rate of wave reduction. On the other hand, when water levels rose above the height of thickly spread branches and leaves of these trees, the rate of wave reduction increased again with an increase in the water level. Further, at this high range of water level, the rate of wave reduction depended strongly on the incident wave height. These results indicate that the thickly grown mangrove leaves effectively dissipate huge wave energy which occurs during storms such as typhoons, and protect coastal areas. Due to the extensive studies done, Mazda have produced graphs that indicates the wave reduction relative to the local time which indicates the tide level in the area of the mangrove forest as shown in Figure 2.8.

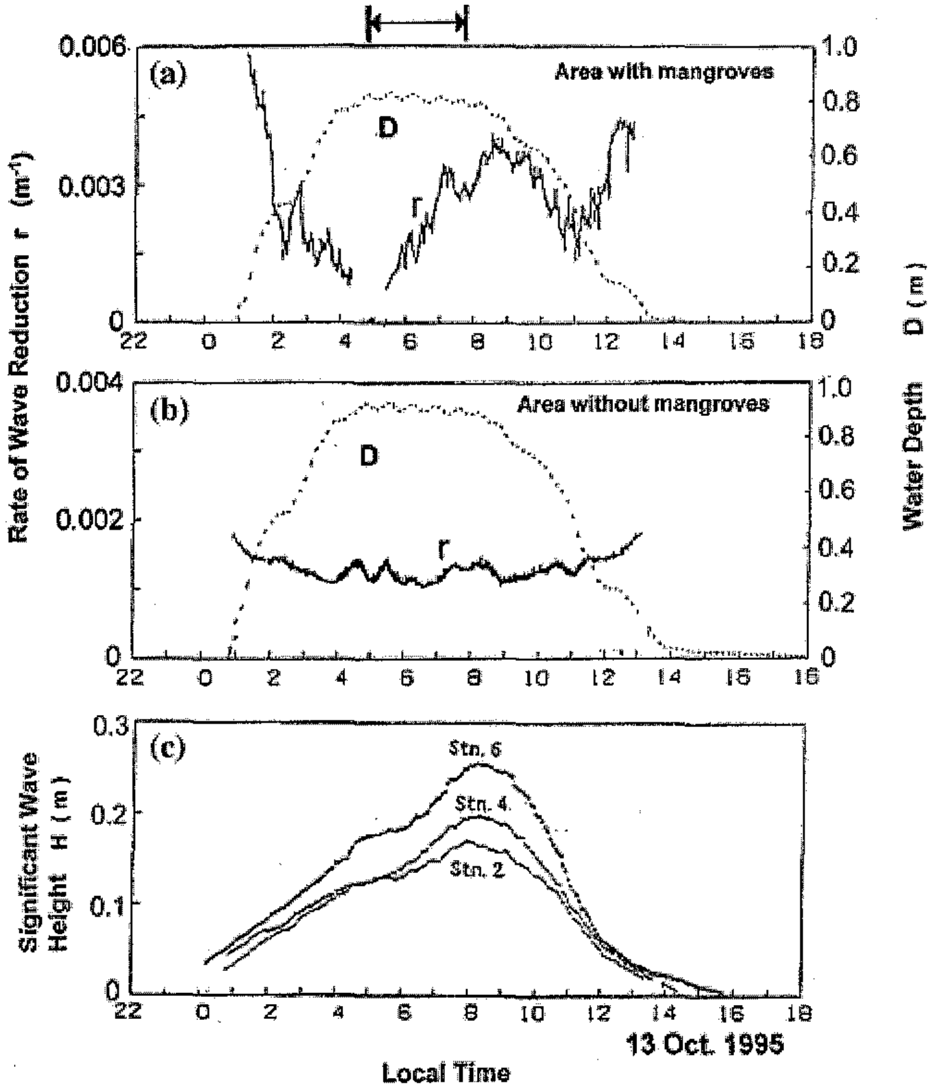


Figure 2.8 Relationships between the rate of wave reduction and water depth in areas with or without mangroves. The water depths at Stns.2 and 4 are used for the areas with and without mangroves, respectively. (Yoshihiro Mazda, *et al.* 2006)

Mazda made more research on the shape of the pneumetophores regarding the effects of water depth and the drag that the pneumetophores impose once in contact with the waves.

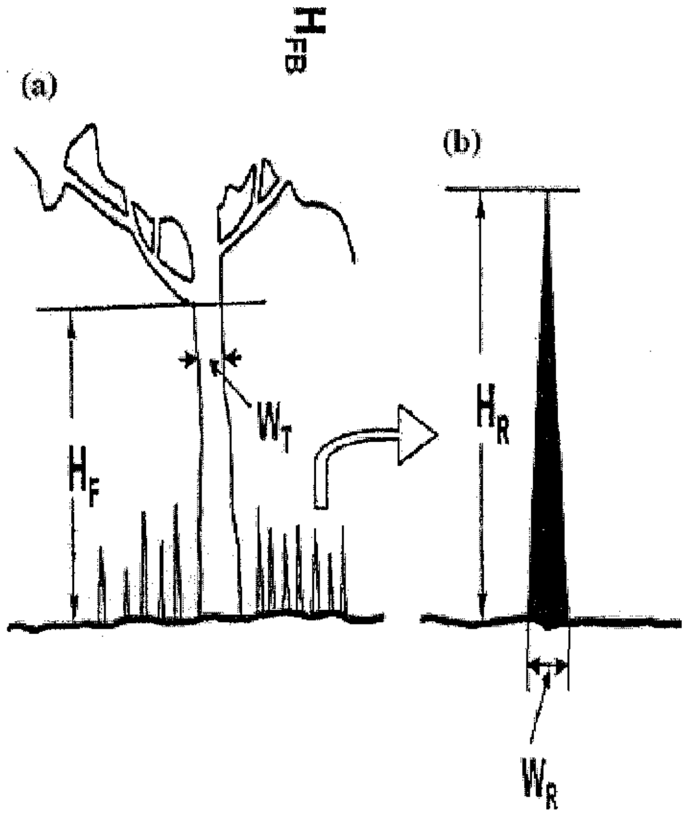


Figure 2.9 Vertical configuration of Sonneratia sp. (a) Cross sectional view of tree and pneumatophores of Sonneratia sp., (b) Enlarged cross section of a pneumatophora. (Yoshihiro Mazda, *et al.* 2006)

The rate of wave reduction per unit length in the direction of wave propagation is defined by Mazda as:

$$r = -\frac{\Delta H}{H}\frac{1}{\Delta x}$$

where H is the significant wave height at an arbitrary sea side station and ΔH is an amount of decrease of the wave height at an inshore station with a distance Δx away from the sea side station along x-axis with the direction of the wave propagation

Mazda also produced a graph as shown in Figure 2.10 showing the relationship between the rates of wave reduction of the water depth. Clearly shown that with lower water depth, the effects of the mangrove is high in reducing the wave height due to the natural shape and density of the mangrove population at shallow waters. The total area of contact is also less when the water level exceeds the aerial root system which contributes to the amount of drag produced therefore reducing the rate of wave reduction.

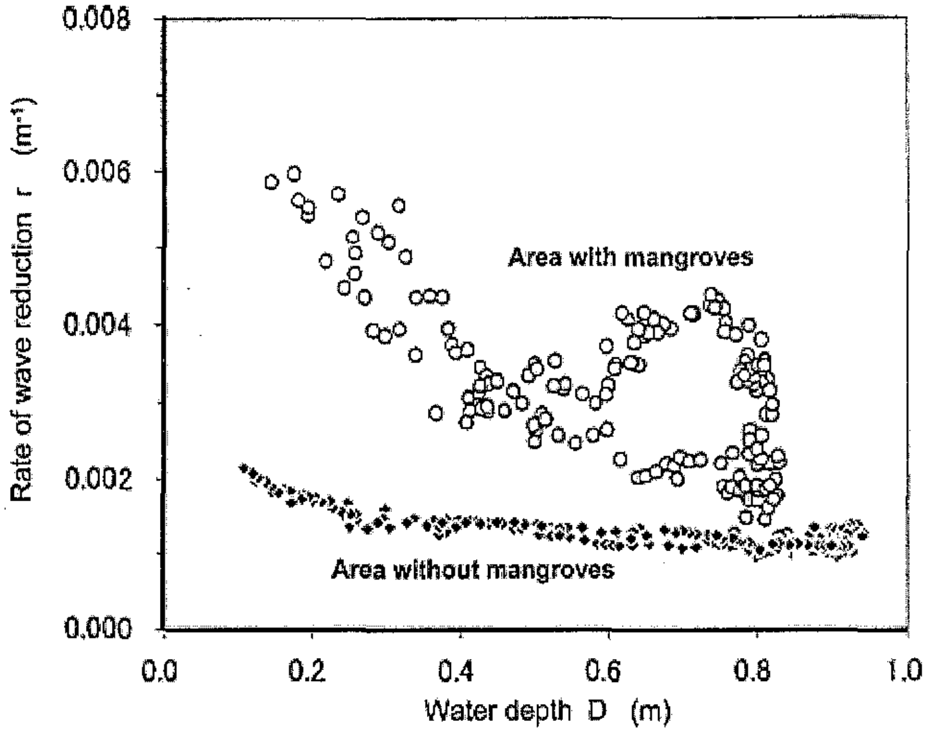


Figure 2.10 Relationships between the rate of wave reduction and water depth in areas with or without mangroves. The water depths at Stns.2 and 4 are used for the areas with and without mangroves, respectively. (Yoshihiro Mazda, *et al.* 2006)

2.8.4 Surface wave propagation in mangrove forests

S.R. Massel, K. Furukawa and R.M. Brinkman presented a technical paper on the propagation of tidal waves in mangrove forests. The purpose of the present paper is to develop a theoretical prediction model for attenuation of wind induced random surface waves, induced by cyclonic winds, and propagated through mangrove forests. A full boundary value problem is solved and the attenuation of the surface wave's spectrum is predicted. Waves penetrating through mangrove forest are subject to substantial energy loss. There are two main energy dissipation mechanisms in the mangrove forests;

multiple interactions of wave motion with mangrove trunks and roots, and bottom friction. Bottom friction can be accommodated through the concept of a bottom friction coefficient. However, at this stage, the bottom friction will be omitted as the bottom friction coefficient for mangrove forests is not known. According to the paper, a diagram can be produced after analyzing the results of the equations. Field test have also been done in mangrove forests at Townsville (Australia) and Iriomote Island (Japan) in order to give an in depth view on how relevant is the theoretical data compare with the actual conditions. As shown in Figure 2.11, the diagram can be explained through elaborated equations on the properties of the attenuation process.

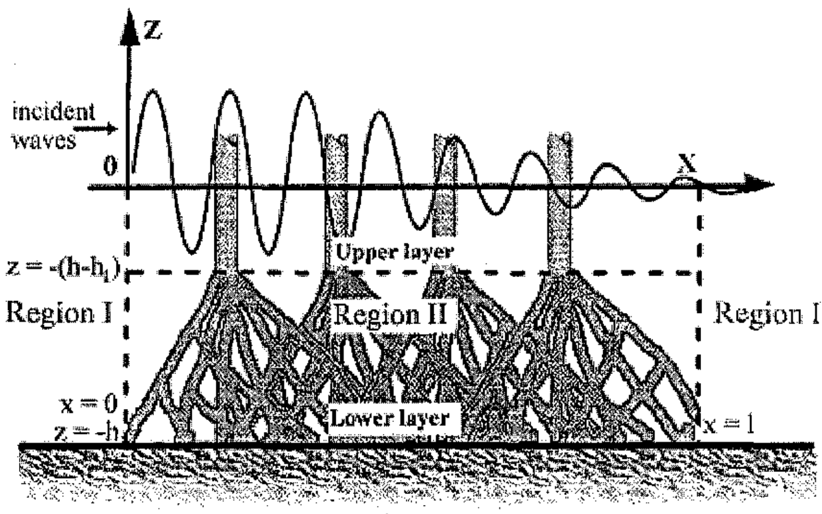


Figure 2.11 Coordinate system. (S.R. Massel *et al.*1999)

This paper presents the theoretical attempt to predict the attenuation of wind induced random waves in the mangrove forest. The energy dissipation in the frequency domain is determined by treating the mangrove forest as a random media with certain characteristics determined using the geometry of mangrove trunks and their locations. Initial nonlinear governing equations have been linearized using the concept of minimalization in the stochastic sense and interactions between mangrove trunks and roots have been introduced through the modification of the drag coefficients. The discrete vortex method was used to determine the modification factor Ki. Resulting rate of wave energy attenuation strongly depends on the density of mangrove forest, diameter of mangrove roots and trunks, and on the spectral characteristics of the incident waves.

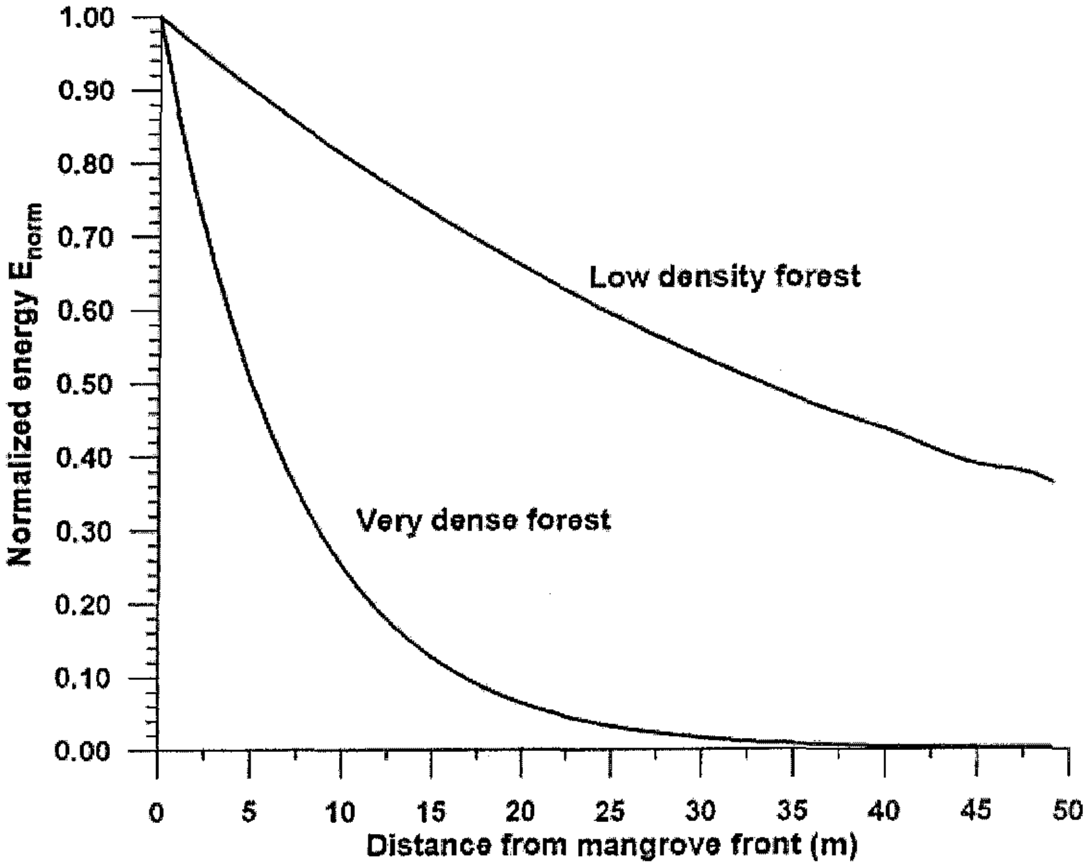


Figure 2.12 Normalized energy E_{norm} in densely and sparsely populated forests.

Figure 2.12 shows the graph that indicates the normalized energy reduction in dense mangrove forest and low density mangrove forest. This data was taken from the field observation. Wave-induced velocities in mangrove forest are of special interest, as water kinematics control the exchange of water, fluxes of nutrients and sediments in mangrove. Both water velocity components change their direction during wave period, however, for practical applications, the most useful characteristics of wave velocity is the mean amplitude. The following figure explains the difference of mean wave amplitude between a dense mangrove forest and low density mangrove forest. These graphs indicates that the degree of wave attenuation highly dependable on the density of mangrove forest that effects the drag force and thus reduces the energy of the waves.

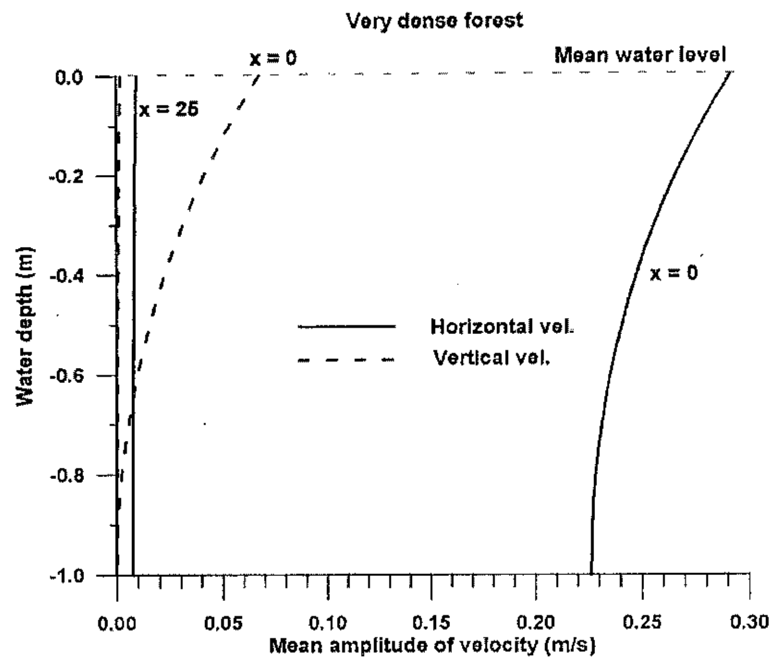


Figure 2.13 Vertical profiles of the mean amplitudes of horizontal and vertical components of orbital velocity at cross-sections (x = 0; 25; 50m) in densely populated forest.

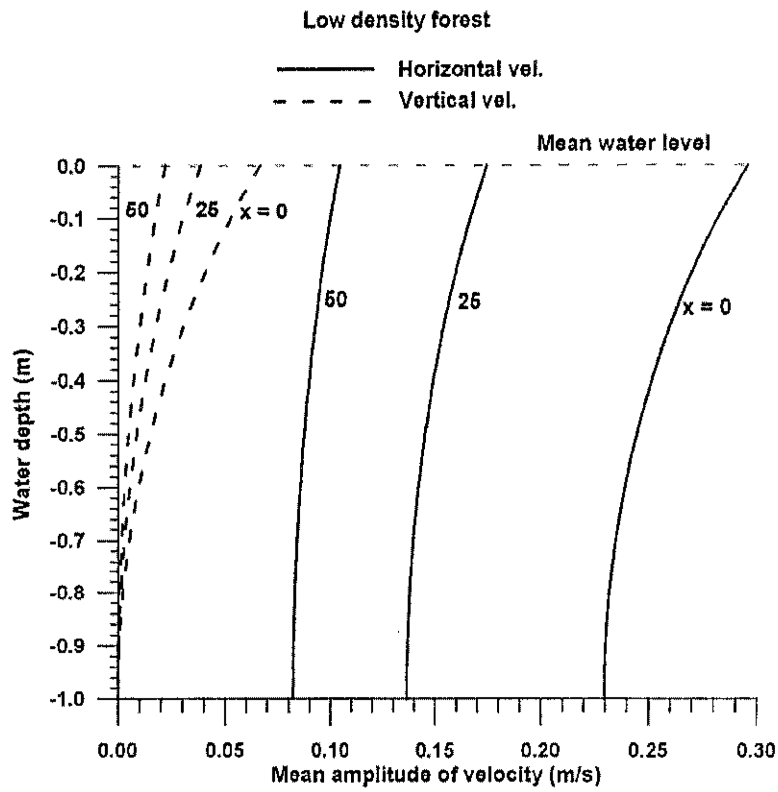


Figure 2.14 Vertical profiles of the mean amplitudes of horizontal and vertical components of orbital velocity at cross-sections (x = 0; 25; 50m) in sparsely populated forest.

Moreover, some field observations of wave attenuation through mangrove forests at Townsville (Australia) and Iriomote Island (Japan) were presented. Both theoretical analysis and field experiments showed that for shallow water depths, the combined effects of drag caused by mangrove roots trunks and bottom friction produced a significant amount of attenuation over a relatively short distance.

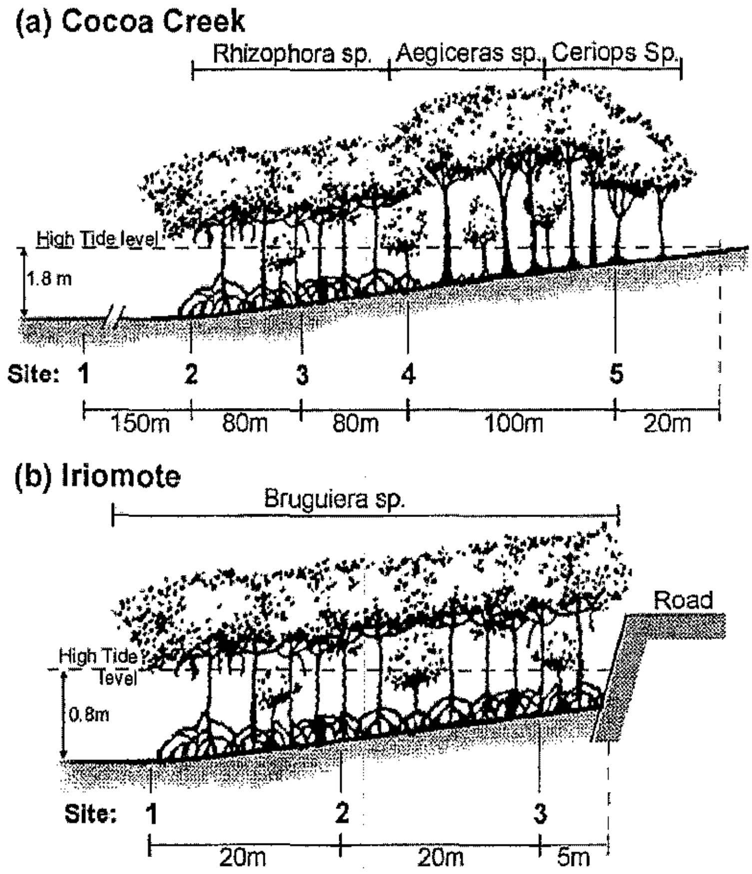


Figure 2.15 Instrument locations: (a) Cocoa Creek, (b) Iriomote Island.

Figure 2.15 shows the structure of the mangrove forest for both of the field test sites. The numbers on the cross section of the figure indicates the site where the measurements of wave energy and normalized energy are taken. Time series of water surface elevation recorded at various locations along the transects at both study sites were analyzed for basic statistical and spectral quantities. For spectral analysis, time series were separated into consecutive 20 min files, with a time step between data of 0.5 s. Standard FFT methods were used.

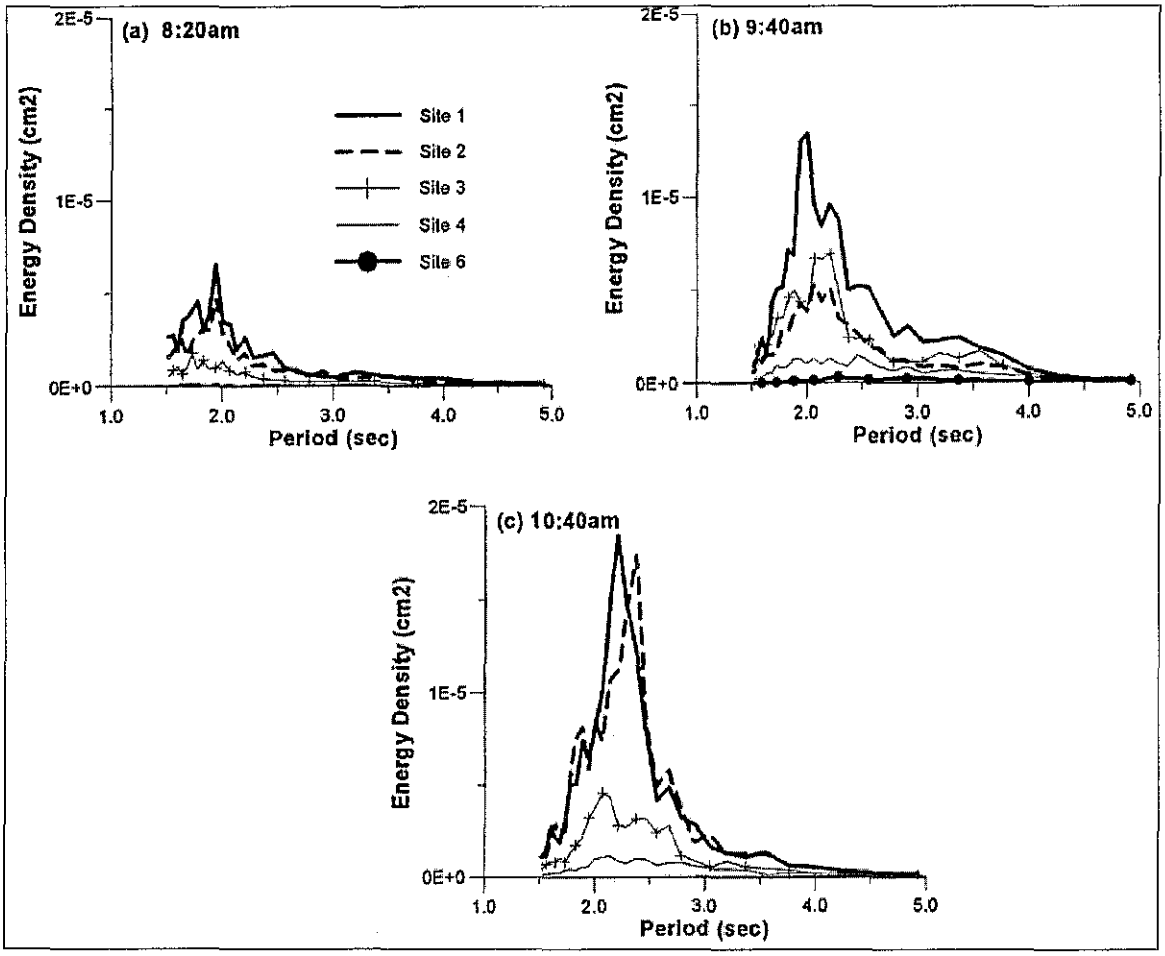


Figure 2.16 Energy spectra at Cocoa Creek on the 10th January 1997: (a) 8:20a.m., (b) 9:40 a.m., (c) 10:40 a.m.

Figure 2.16 shows the wave energy spectrum along the Cocoa Creek transect at three times during a high tide on 10 January. Fig. 2.16a shows the spectrum at 08:20 a.m. when the water level was rising, Fig. 2.16b shows it at 9:40 a.m. at high tide and Fig. 2.16c shows it at 10:40 as the water level was and 0.13 m, respectively, while for Fig. 2.16c the water depths at sites 2, 3 and 4 are 1.5, 0.8 and 0.4 m, respectively.

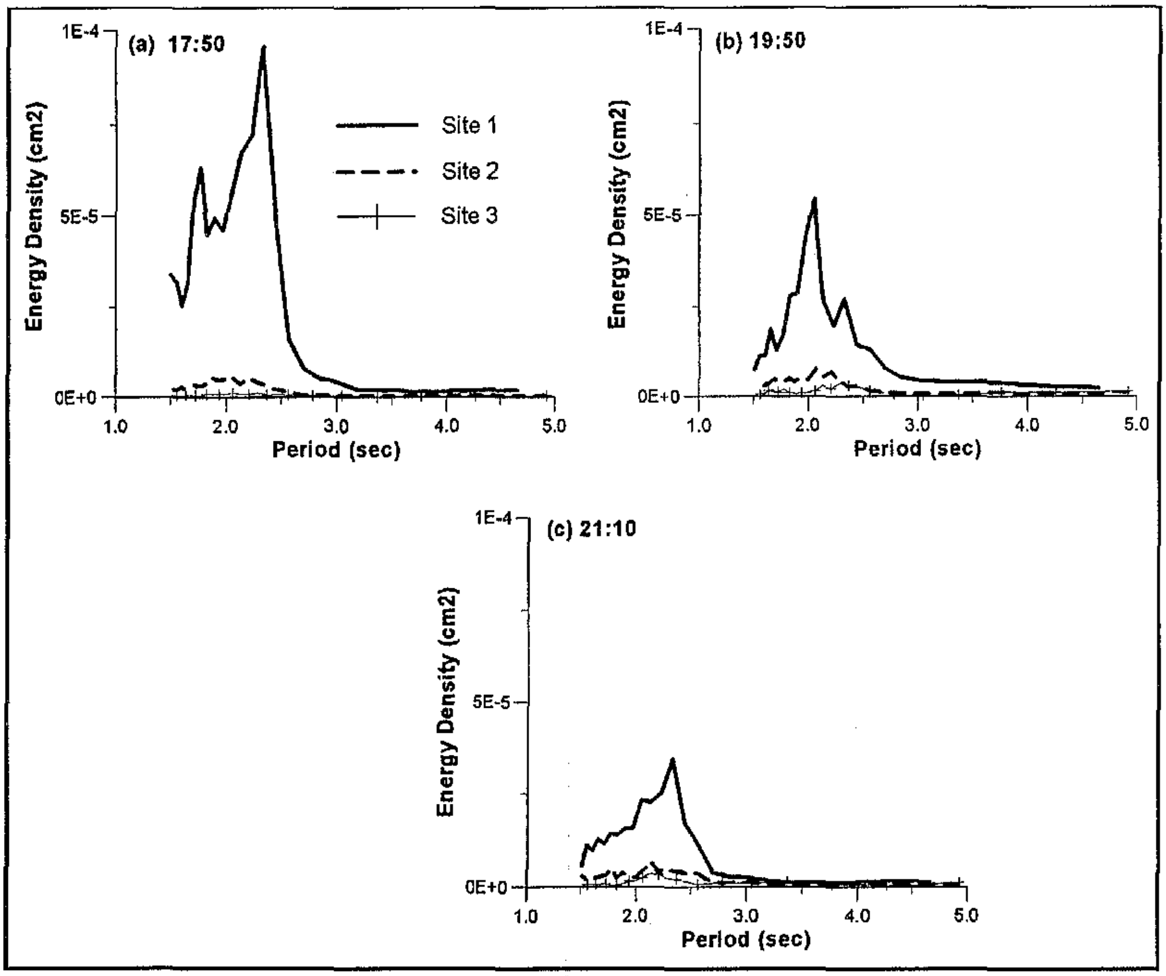


Figure 2.17 Energy spectra at Iriomote Island on the 8th February 1997: (a) 17:50 a.m., (b) 19:50 a.m., (c) 21:10 a.m.

Similar results as described above were also observed in the data recorded at Iriomote and are shown in Fig. 2.17a-2.17c. For this data, the magnitude of attenuation between site 1 and sites 2 and 3, over the first 40m of the forest, seems larger than that observed in Cocoa Creek over a comparable distance. This is probably due to the different characteristics of this site.

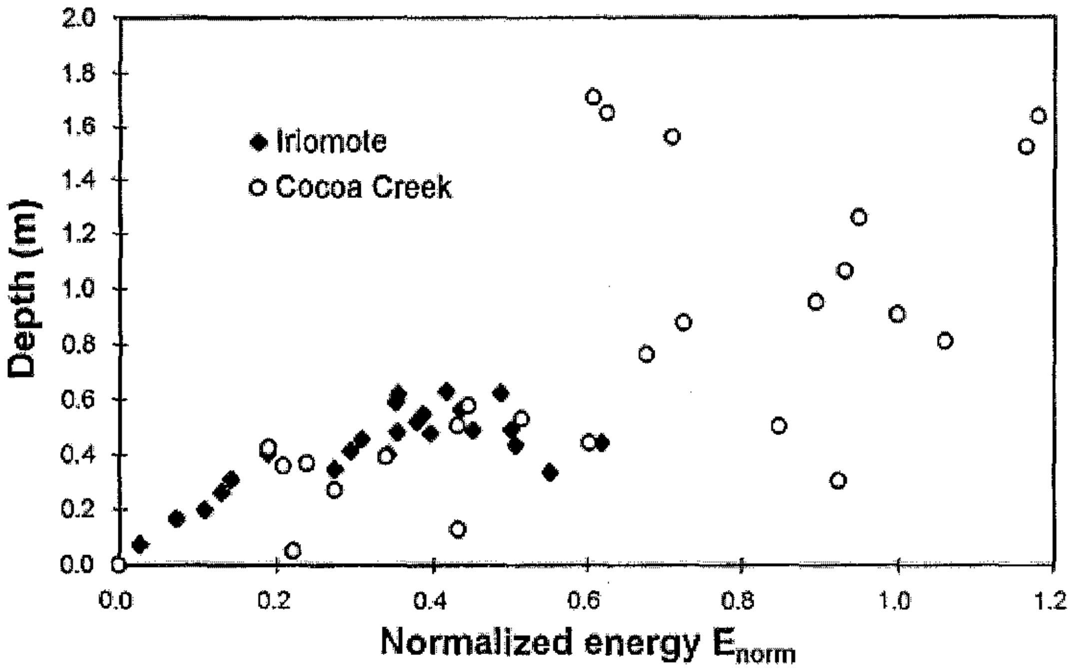


Figure 2.18 Depth vs Normalized Energy in Iriomote and Cocoa Creek

It can be concluded from this paper that mangrove does have an effect on wave attenuating by elaborating relevant equations that detects the energy loss due the existence of the mangrove trees. The data indicates that the normalized energy is reduced to a small fraction once it reaches the mean water level due to the effects of drag and shoaling of the wave. The results also show that the mangrove forest is only effective in water depths of 1 m and below due to the pneumetaphore root system.

2.8.5 Value of mangroves in coastal protection

Muhammad Akhir Othman (1994) presented a paper regarding the importance of the mangrove system in protecting the coastline of Malaysia. In his paper, Othman stresses the importance of mangrove in curbing erosion in coastlines which is happening in 30% of Malaysia's coastline. The wave height along the west coast rarely exceeds 1.5 meters. During the calm seasons the waves are usually below 1.0 metres. Othman's (1994) approach on the effects of the mangrove is mainly in the long term effect where the mangrove (Avicennia) will slow down the currents with their root system. The water usually carries sediments, in the form of suspended sediments and bed loads. As the ability of water to carry sediments depends on the velocity of the flow, slowing the currents result in the sediments settling. In the way, the mangroves consolidate the soil and build up the land.

Through his paper, Othman (1994) explains the mechanism of wave attenuation by the mangrove through the obstruction of the waves with its roots and trunks. As the waves passes by, the orbital motion of the water particles *i.e* the mechanism transmitting the wave energy, is obstructed by the roots and the trunks of the mangrove. As mention by the earlier reviewed papers, density of the plants plays a vital role in wave attenuation. Othman (1994) explains through the Department of Drainage and Irrigation of Malaysia has constructed projects which involve reclamation of mangrove swamps and using mangrove as a natural wave attenuator to protect the bunds being built. During the construction of the bund, a 200 metres width of mangrove belt was considered sufficient to reduce the wave energy such that the waves will not damage the bunds. Observations done in Sungai Besar, Selangor, suggest that even a 50 metre wide belt of Avicennia is sufficient to reduce waves of 0.3 to 1.0 metre high. However the National Coastal Erosion Study 1986 suggested that 150 metre of mangrove width is needed to reduce the energy.

2.9 Wave Attenuation Evaluation Criteria

Comparing the works of the previous studies, it can be seen that the research done by Tschirky, Hall and Turcke were more comprehensive and detailed in terms of the varibles and determining parameters. Although the other papers showed similar results in testing the effectiveness of vegetation in wave attenuation, Tschirky, *et al.* was able to produce results in a controlled environment with more comprehensive data and result. It is relevently decided that plant bed length plays a very important role in creating the ample amount of friction and turbulence in order to effectively attenuate the energy of the waves hitting the shorelines. There are other similarity between the two types of vegetation used which are the ability to grow in heavy densities and that the location of the plants habitat is near to the shore which thus water depth has a high effect on the waves . The plants grow in bushes which is not favourable in terms of asthetic values but the amount of total surface area created by the plants gives an advantage in increasing drag and turbulence which will help in wave attenuating. Although effective, the usage of salt marshes and bulrushes are not relevent in Malaysia. The conditions in Malaysia, geographically and climate-wise are not suitable with respect to the types of vegetation in the previous studies done thus turning to a more practical and common type of plant that can be found in Malaysia is a the only option. The paper produced by Massel *et al.* was more relevant in terms of the environmental conditions in Malaysia as the test sites were located in tropical climate areas. The data collected was comprehensive, which includes the water level of the coastal area where the data was collected and the normalized energy density where it clearly indicates reduction as the wave goes through the mangrove belt. With relevance of the conditions in Malaysia, the study has proven that mangrove is the best candidate for the vegetation that will be used in the process of wave attenuation in Malaysian coastline. With guidelines done by Othman (1994) in the measurement of the width of mangrove belt which is sufficient in order to reduce the wave energy, the effectiveness of vegetation in wave attenuation is both proven and practical.

CHAPTER 3
WAVE ATTENUATION USING MANGROVE (*rhizophora*)

3.1 Introduction

The study of using wetland vegetation as a wave attenuator has became significant due to the need for less obstructive and more softer structures that helps in reducing the effects of wave energy. Through extensive literature review on the previous studies on different types of wetland vegetation effect on wave attenuation, the chosen species for the wave attenuator was the Red Mangrove (*rhizophora).* The reason for the selection of this type of wetland vegetation is that mangrove vegetation is, in fact, a tropical equivalent of the temperate salt marsh. Relatively few species of woody plants are able to thrive under such physiologically adverse conditions and mangrove forests have a very low floristic diversity. Only 90 species are known to exist in the world, of which 55 are, in general, restricted to mangrove swamps. The most important species are *Rhizophora*, with arch-formed supporting roots. Mangroves are favoured by a humid tropical climate, partly because high rainfall is usually accompanied by silt-laden rivers forming suitable mudflats. They arc generally well developed in estuaries. Mangrove trees also grow on extremely arid coasts where they may assume special importance as the only woody vegetation present-and on coral or rocky islands. In the humid tropics, Rhizophora may attain heights of more than 40 meters.

3.2 Development of a Mangrove Profile Model

A full grown normal sized rhizophora has a diameter range from 8 cm to 20 cm with an average of 14 cm. A model was built using bamboo sticks to simulate the spread of rhizophora that would exist in natural conditions. The basic design was taken from the previous studies of wetland vegetation such as the bed size and plant intervals. The aim of the model was to create almost if not less similar result of wave attenuation by the previous tested plants with a species that is coherent to the conditions and climate in Malaysia.

3.3 Description of Mangrove Model

Bamboo was used as a model material due to its less water absorbing, flexible and durable nature. The experiments conducted will be repetitive and the bamboo, acting as the mangrove trees, will continuously be bombarded by trains of waves. After vigorous survey in the market, there were two options for the tree models, the bamboo and a type of dense plastic rods. Although the plastic rods were consistent in terms of diameter, it does not have the natural properties that a normal tree might have such as skin friction and buoyancy.

The bamboo stick varied in diameter size ranging from 0.2 cm to 0.1cm and an average of 0.15 cm this brings down to a scale down factor of 1: 6 which represents the pneumetaphore root system. Previous experiments have been done for the tree barks using the size of the tree bark as 2.5 cm. The results of the experiments were not encouraging and due to the reason that the bamboo used for the tree barks were The reason for having variable diameter sizes is that in the natural conditions, the sizes of the tress will not be the same thus creating different streamlines profile and drag effect. The purpose of having the different diameters is to simulate as close as possible to the natural conditions. Since the wave flume has a depth of 45 cm, the length of the bamboo used is only 20 cm. This is due to the maximum water depth that can be used is 15 cm. The maximum wave height that will be used for the lab testing will be 5.16 cm as it represents the average wave height of the western coastline.

The bed used to place the bamboo sticks is made out of modeling clay measuring 30 cm x 20 cm x 2 cm. Figure 3.1 and Figure 3.2 shows the CAD drawing for the mangrove bed. The bed had no significant effect on the waves so the strength of the bed is not issue that will need detailing. The bamboo sticks will be planted into the modeling clay in groups simulating a pneumetaphore root system of a mangrove tree. The gaps between the groups of bamboo sticks will be varied to further simulate the conditions in the mangrove system and provide different level of density as density plays the most vital role in wave attenuation by vegetation.

Conceptual Wave Attenuation Mechanism of the Mangrove Model

The primary mechanism of energy dissipation of the mangrove model is wave reflection, turbulence and drag. The illustration of the drag and turbulence occurrence can be referred back in Figure 2.1 where the water particles movement will be disrupted. When a wave approaches the model, the bamboo will act as a partial wall and reflects the wave energy back thus causing collision. Some of the wave energy will go through the gaps between the bamboo and due to skin friction and drag, turbulence will occur between the intervals. In real conditions, mangrove will have sprouted roots which will help in creating more drag and friction between the water particles and the plant skin.

The arrangement of the bamboo can be varied with the retractable feature and the effects of the different arrangements can be compared. The bed length or the distance from the beginning of the wave contact with the bamboos to the end plays an important role where by the longer the distance, the more contact the wave will make with the bamboo. This will cause more friction and turbulence thus dissipating more energy.

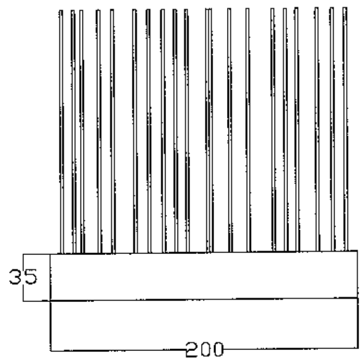


Figure 3.1: side view of the mangrove model

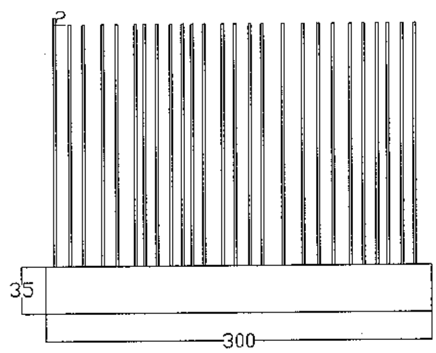


Figure 3.2: front view of the mangrove model

CHAPTER 4
EXPERIMENTAL SETUP AND PROCEDURE

4.1 Introduction

Several model testing sessions was done in the laboratory as an initial step to further understand the extent of effectiveness and performance of the model in the role of wave attenuating. The experiments were done in the Coastal and Hydraulics Laboratory of UTP. In order to assure quality and reliable result, it is important to be familiarized with the equipment that will be used for the experiments. This chapter will describe and explain all the equipment and procedures that will be done for obtaining the results in detail. The measured parameters that were used to evaluate the performance of the wetland vegetation are incident wave height (H_i), water depth *(d)*, wave frequency *(f)* and transmitted wave height (H_t)

4.2 Laboratory Equipment and Instrument

The experiments were conducted in a wave flume with dimensions 10 m long, 30 cm wide and 45 cm high as shown in Plate 4.1. The flume consists of a solid steel bed and glass plates as walls along the whole length of the flume in order to allow observation of the wave process.

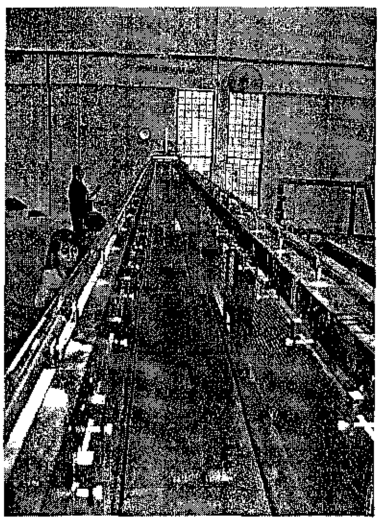


Plate 4.1: Wave Flume

Waves are generated by a flat –type paddle as shown in Plate 4.2. The paddle creates a pushing movement to create waves with consistent frequency.

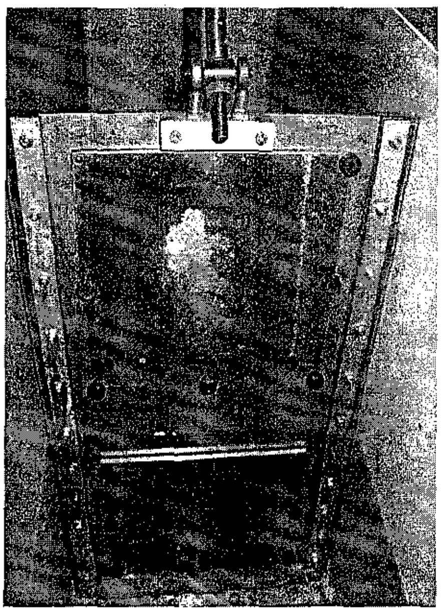


Plate 4.2: Wave Paddle

The wave generator and switch box is shown in Plate 4.3. The wave generator is mounted at the edge of the wave flume. The wave generator functions with a gear motor which rotates a crank connected to the wave paddle through a disk as shown in Plate 4.4 thus creating a harmonic movement stroking the water. All electrical switches and control knobs are located on the switch box located on the cover of the wave generator. The rotational speed knob gives the stroke frequency of the wave generator and can be adjusted by a 10 gear helical potentiometer. At 100%, the rotation speed is 114 rpm. With linear characteristic, the rotational speed at 0% is 0 rpm.

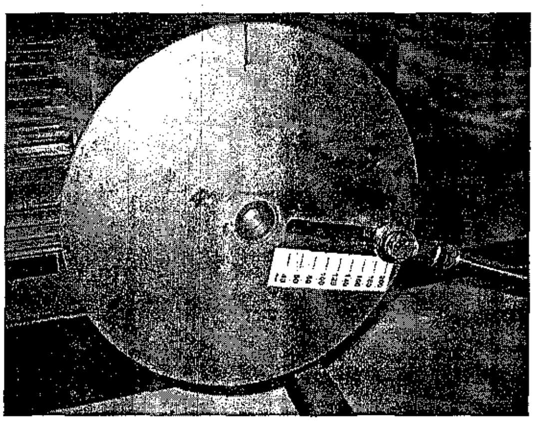


Plate 4.4: Crank and Disk

The water in the wave flume is not stagnant but instead it flows through a pump as shown in Plate 4.5. The pump controls the water flow in and out of the flume thus directly controls the water level. There is a digital meter gauge as shown in Plate 4.6 showing the flowrate of water going through the pump which gives information to control the flowrate into the wave flume.

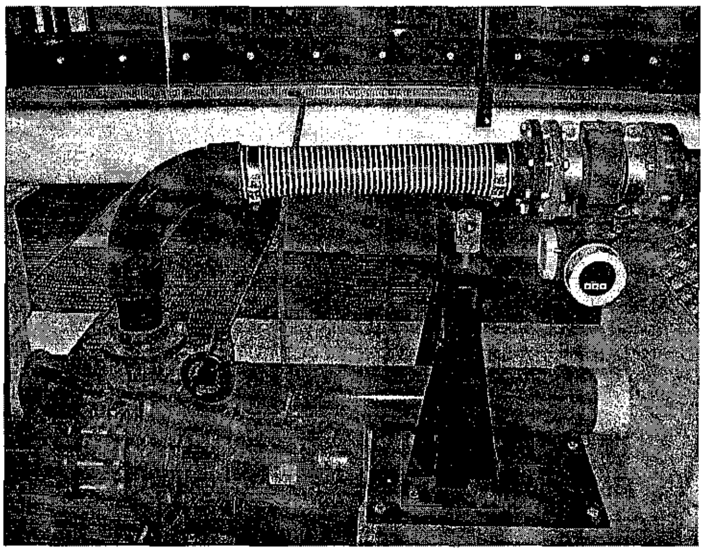


Plate 4.4: Water Pump

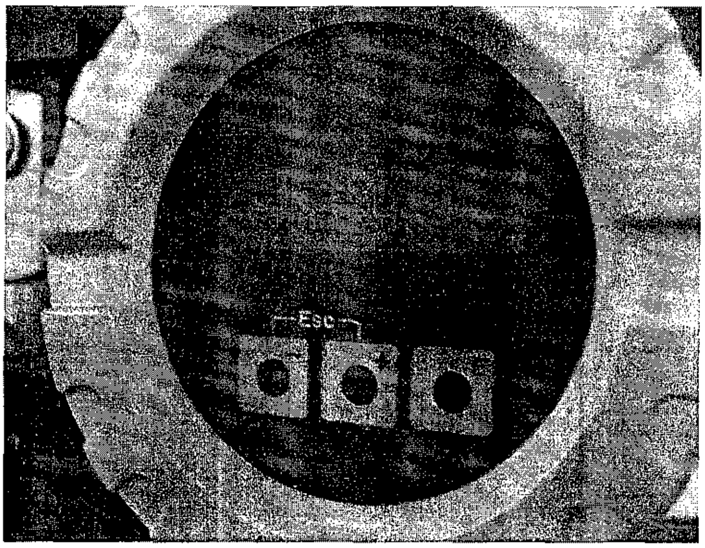


Plate 4.5: Digital meter gauge

Another component used in the experiments is a wave absorber. The wave absorber is structure located at the reflective end of the wave flume to attenuate the wave energy approaching the end of the flume. This is to avoid any wave reflection that might compromise the readings of the wave measurements downstream of the model. The wave absorber is made out of wire mesh absorber with adjustable slope angle ranging from 0° to 90° Plate 4.7 shows the placement of the wave absorber in the wave flume. The design calculations are presented in Appendix 1. The size of the absorber is 120 cm in length, 30 cm in width and 120cm slope length. Through out the experiment, an angle of 15° was used due to its effectiveness in dissipating waves.

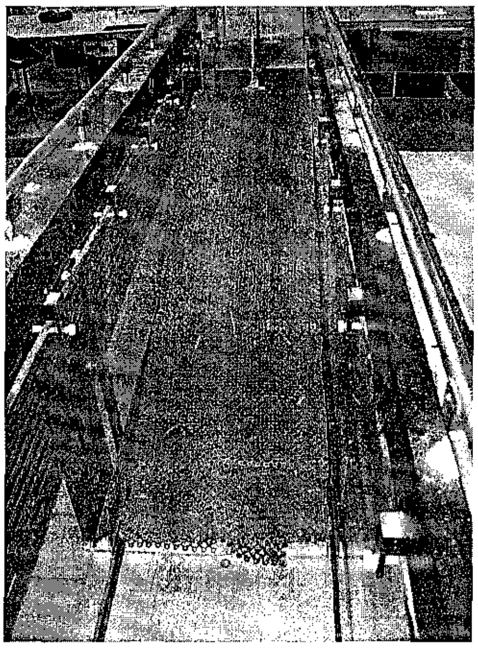


Plate 4.6: Wave Absorber

4.3 Experimental Procedure

Series of experiments were conducted in order to see the effects of the mangrove model in the process of wave attenuation using different wave period, water depth and number of model beds.

4.3.1 Preliminary Test

The main objective of the preliminary tests is to measure the wave period, T with respect to different stroke frequencies for the calibration purposes and to measure incident wave, H_i for the analysis of wave attenuation performances.

The first test is to measure the wave period by obtaining the time taken for the crank disc to revolve 10 cycles. The process has to be repeated at least three times to find the average time.

The second test are conducted without the presence of any obstructions to obtain the incident wave height in five different water depth which are 24 cm, 22 cm, 20 cm, 18 cm, 15 cm and 10 cm. The five different water depth was taken to ensure a more steady and consistent reading of the incident wave height. A higher number of data will show the trend of the wave period in comparison with the wave height.

During the experiment, five readings of the wave height were taken in different locations and tabulated. By assuming that there is no reflection from the wave absorber, the average incident wave height is obtained by calculating the average wave height using the equation (4.1).

$$H_i = \frac{\Sigma H_i}{n}$$

where n is the total number of readings

4.3.2 Experimental Studies on the Mangrove Model

3 sets of experiment were carried out for this project in order to see the effects of the mangrove model. In each set different configuration was used to set which setting has more effect.

Each set of experiments will be conducted in three water depths 18 cm, 15 cm and 10 cm which represent high tide, mean tide and low tide respectively. Each water depth will be tested with different number of beds starting from one bed to 3 beds. For each setting of the increased number of bed will be tested with 16 wave periods from 0.5 seconds to 2.0 seconds. The total number of runs is as follows:

Total number of runs = 3 water depths x 3 different bed configuration x 16 waves period
x 8 different distance
= 1152 runs

The parameters that need to be measured are as follows:

1. Wave heights (8 readings) with an interval of 20 cm from the beginning of the mangrove bed. The values will not be averaged and be taken as individual in other to see the decline of coefficient transmission as the waves move through the mangrove 'forest'
2. After the reading of the wave heights are taken, the Transmission coefficient is calculated by using equation 2.1

CHAPTER 5

EXPERIMENTAL RESULTS AND DISCUSSIONS

5.1 Introduction

The first part is the results for the preliminary tests' the preliminary test consists of determination of wave period, determination of incident wave height, and performance of the model mangrove which has been conducted.

5.2 Determination of Wave Period, *T*

Wave period is defined as the time, in seconds for the passage of successive wave crests from a point to another. In order to determine the wave period in the laboratory, the time for the crank to complete 10 cycles is taken and the time is then divided by 10. This step is repeated 3 times and then averaged out. This method is much more accurate compared to taking averages of one complete cycle. The time taken can be observed in Table 5.1

Table 5.1: Observed wave period for different frequencies

Frequency	Time, t (s)			
f (Hz)	1	2	3	Average
20	45.02	44.93	44.93	4.50
25	31.34	31.22	31.07	3.12
30	23.82	23.88	23.71	2.38
35	19.23	19.07	19.12	1.91
40	16.10	16.19	16.20	1.62
45	13.82	13.84	13.82	1.38
50	10.03	10.03	10.09	1.01
55	9.10	8.89	9.11	0.90
60	8.30	8.31	8.31	0.83
65	7.63	7.56	7.68	0.76
70	6.97	6.92	7.06	0.70
75	6.50	6.54	6.51	0.65
80	6.06	6.03	6.00	0.60
85	5.47	5.40	5.78	0.56
90	5.15	5.23	5.20	0.52
95	4.96	4.86	4.97	0.49
100	4.91	4.86	4.89	0.49

The relation between the time taken for a complete cycle of the crank and the stroke frequency can be expressed in a form f a graph presented in Figure 5.1. From the figure, it can be observed that the wave period decreases exponentially as the frequency of the strokes increases. By using Microsoft Excel, the relation between wave period and stroke frequency can be expressed by the equation

$$\mathbf{y = 280.62x^{-1.4046}} \tag{5.1}$$

where y = wave period, t (s) and x = stroke frequency, f (Hz)

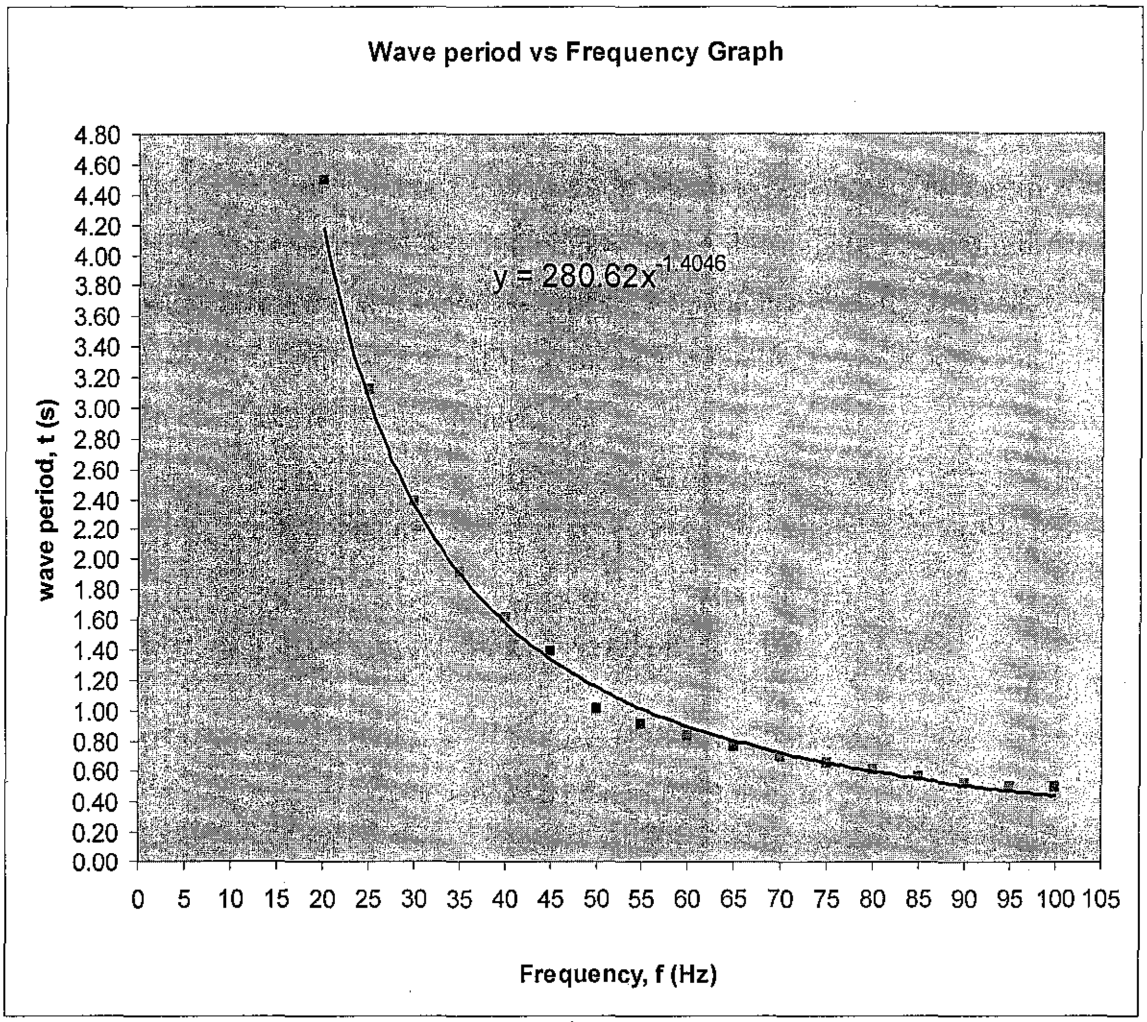


Figure 5.1: Frequency versus Wave Period relation graph

By using the equation that was produced by the graph in Figure 5.1, the frequencies for the required wave period can now be calculated. The results of the calculation is shown in Table 5.2

The results now will give the frequency of wave period for the next experiment that will be tested for the determination of the Incident Wave Height, H_i.

Table 5.2: Frequencies for different Wave Periods

t(s)	f(hz)
0.5	90.62
0.6	79.59
0.7	71.32
0.8	64.85
0.9	59.64
1.0	55.33
1.1	51.70
1.2	48.59
1.3	45.90
1.4	43.54
1.5	41.45
1.6	39.59
1.7	37.92
1.8	36.41
1.9	35.03
2.0	33.78

5.3 Determination of Incident Wave Height, H_i

Determination of incident wave height had been done in a series of sixteen wave period, ranging from 0.5 seconds to 2.0 seconds. The results are presented graphically in tables. The experiment was conducted in six water depths; 10 cm, 15 cm, 18 cm, 20 cm, 22 cm, and 24 cm, and the results can be observed in Table 5.2 for the average incident wave height. The incident wave height of the waves is taken without any model in the wave flume since the wave flume is short to avoid any wave reflection or other disturbance.

As it shows in Figure 5.1, the results of the experiments are expressed in a peak form which indicates that the maximum wave height happens at a wave period of 1 second for all water depth. The graph also indicates that the incident wave height is higher at deeper water depth. This is due to the more stable cyclic particle motion of the waves. Figure 5.2 also shows that the incident wave height decreases as the wave period increases.

The values of the determined incident wave will be vital in determining the Transmission Coefficient, Ct as shown in Equation 2.1. The values of the transmitted wave will be compared and calculated with the incident wave height to see how effective the mangrove bed is in attenuating the waves.

Table 5.3: Average Incident Wave Height at Different Water Depths

t(s)	f(hz)	d = 10	d = 15	d = 18	d = 20	d = 22	d = 24
0.5	90.62	2.17	4.10	3.63	2.90	3.53	3.87
0.6	79.59	2.50	3.87	4.50	4.30	4.93	5.17
0.7	71.32	2.37	4.30	5.53	5.67	6.50	6.90
0.8	64.85	2.33	4.43	5.90	6.00	7.77	7.97
0.9	59.64	2.17	4.67	6.07	6.43	7.90	8.30
1.0	55.33	2.27	4.27	5.73	6.20	8.03	8.73
1.1	51.70	2.50	4.40	5.70	6.37	7.77	8.37
1.2	48.59	2.37	4.37	4.97	5.70	7.70	8.00
1.3	45.90	2.57	3.67	4.67	5.63	6.83	7.63
1.4	43.54	2.60	3.60	4.37	5.23	6.20	6.57
1.5	41.45	2.20	3.83	4.30	4.60	5.30	6.47
1.6	39.59	2.17	3.43	4.27	4.00	5.00	6.30
1.7	37.92	2.10	2.93	3.73	3.77	4.80	5.37
1.8	36.41	2.20	2.70	3.47	3.97	5.07	5.03
1.9	35.03	2.27	3.10	3.53	3.57	4.47	4.87
2.0	33.78	2.70	2.83	3.57	3.53	4.43	4.93

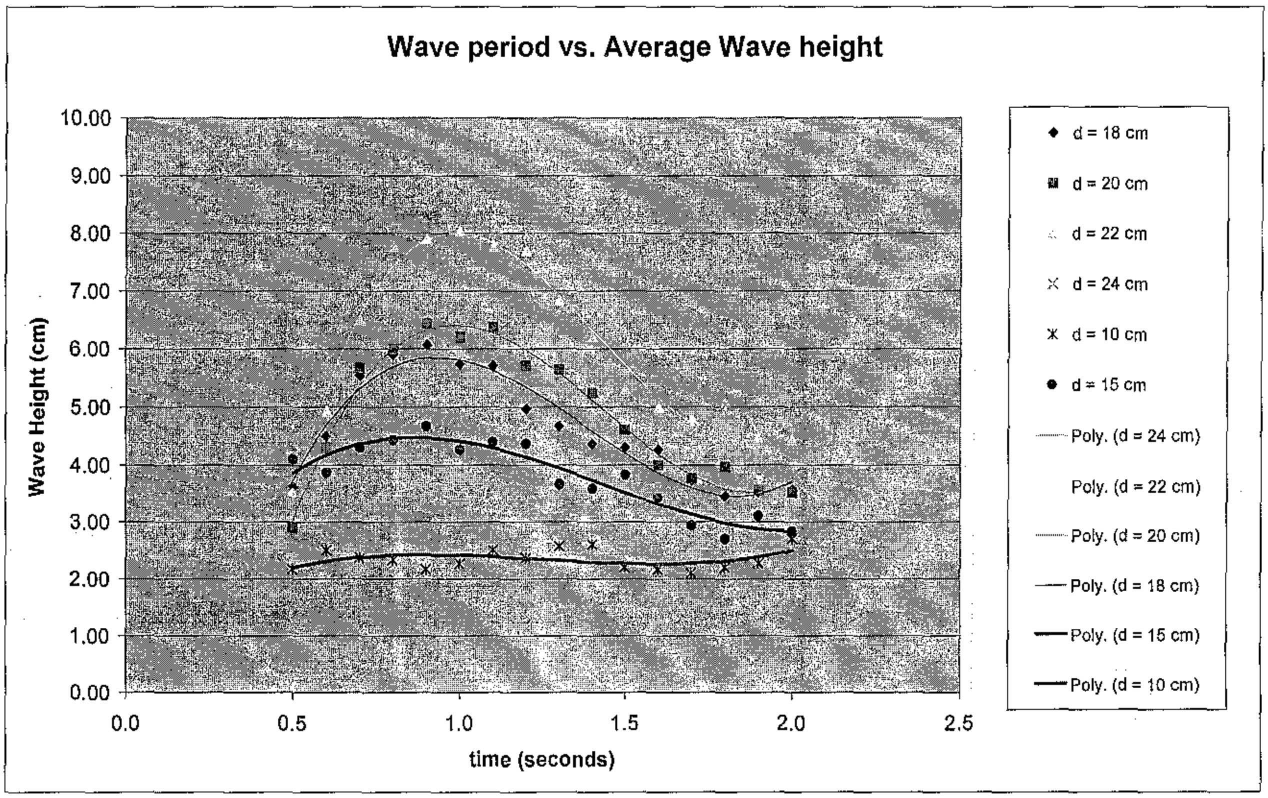


Figure 5.2: Incident Wave Height

5.4 Wave Attenuation by Mangrove Model

The model was tested in three different water depths. The results of the experiments are divided into four wave period for each graph to show different difference of the wave attenuation between short wave period, transitional wave period and long wave period. The wave periods from 0.5 seconds to 0.8 are classified as short wave periods, wave periods from 0.9 to 1.6 seconds are considered as transitional wave period and 1.7 seconds to 2.0 seconds are considered as long wave periods.

5.4.1 Experiment Results in 10 cm Water Depth

The following results show the distance versus transmission coefficient graphs. The trendlines shows the average readings for the data and the direction the data are prone to.

Figure 5.3 shows the transmission coefficient throughout the wave flume with the usage of one mangrove model bed. The short period waves have mixed data and it can be seen in the trendline that there is still decrease in the transmission coefficient although there are points were the values are higher than 1. The values at the points show that most of the wave heights are higher than the incident wave height which will result in a transmission coefficient more than 1. This is caused by the slight shoaling effect due to the sudden increase of bed level. For transitional period waves, the slope for the transmission coefficient smoothly decreases as the distance from the beginning of the bed increases. This indicates that the mangrove model is causing enough drag and turbulence to reduce the energy of the waves. Most of the values of the transmission coefficient are below 1 which shows the wave height with the presence of the mangrove model is lower than the incident wave height.

Figure 5.4 shows the transmission coefficient with the experiment done using two beds. The short period waves have seemed to stabilized and produces a more smooth trendline. The trendline decreases as the distance increases. The shortest wave period, 0.5

seconds has the most drastic decrease in transmission coefficient. The consistent waves produced manage to create drag and turbulence upon impact with the mangrove model. The other short waves has an end point almost the same meaning that the mangrove model increase of number of bamboo was able to stabilize the waves. The transitional period waves have produced transmission coefficient values almost the same as the short period waves. All three graphs show that most of the points gave transmission coefficient values lower than 1. Long period waves had a high transmission coefficient value at the beginning of the mangrove model but decrease rapidly after that.

Figure 5.5 shows the results for the transmission coefficient with the usage of 3 beds. Generally it can be summarized for all four graphs that the trendline indicates a decrease of the transmission coefficient as the distance increases. The data at the end point shows that the values are almost same indicating that the mangrove model has reduced the waves to the maximum comparing to the incident wave height. The values of the transmission coefficients also shows that almost all of the points are below 1, meaning that the recorded wave height is smaller than the incident wave height. The increase in the total surface area increases the amount of contact between the water particle and the surface of the bamboo sticks thus causing the waves to experience a lot of drag and turbulence. This then dissipates the energy of the waves, decreasing the waves' height and stabilizing the waves to a more consistent height.

1 Bed

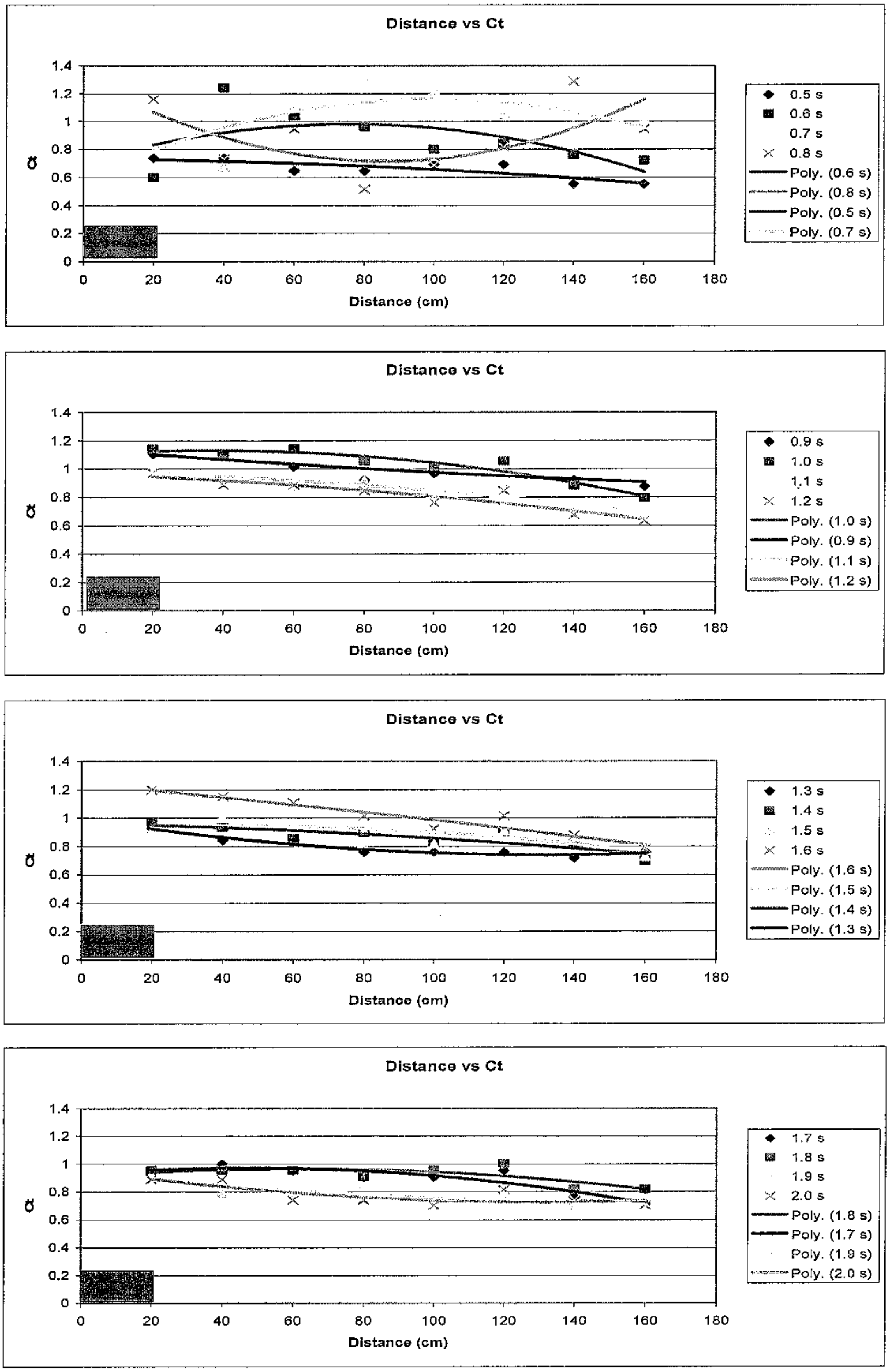


Figure 5.3: Distance vs *Ct* for 1 bed in 10 cm water depth

2 Beds

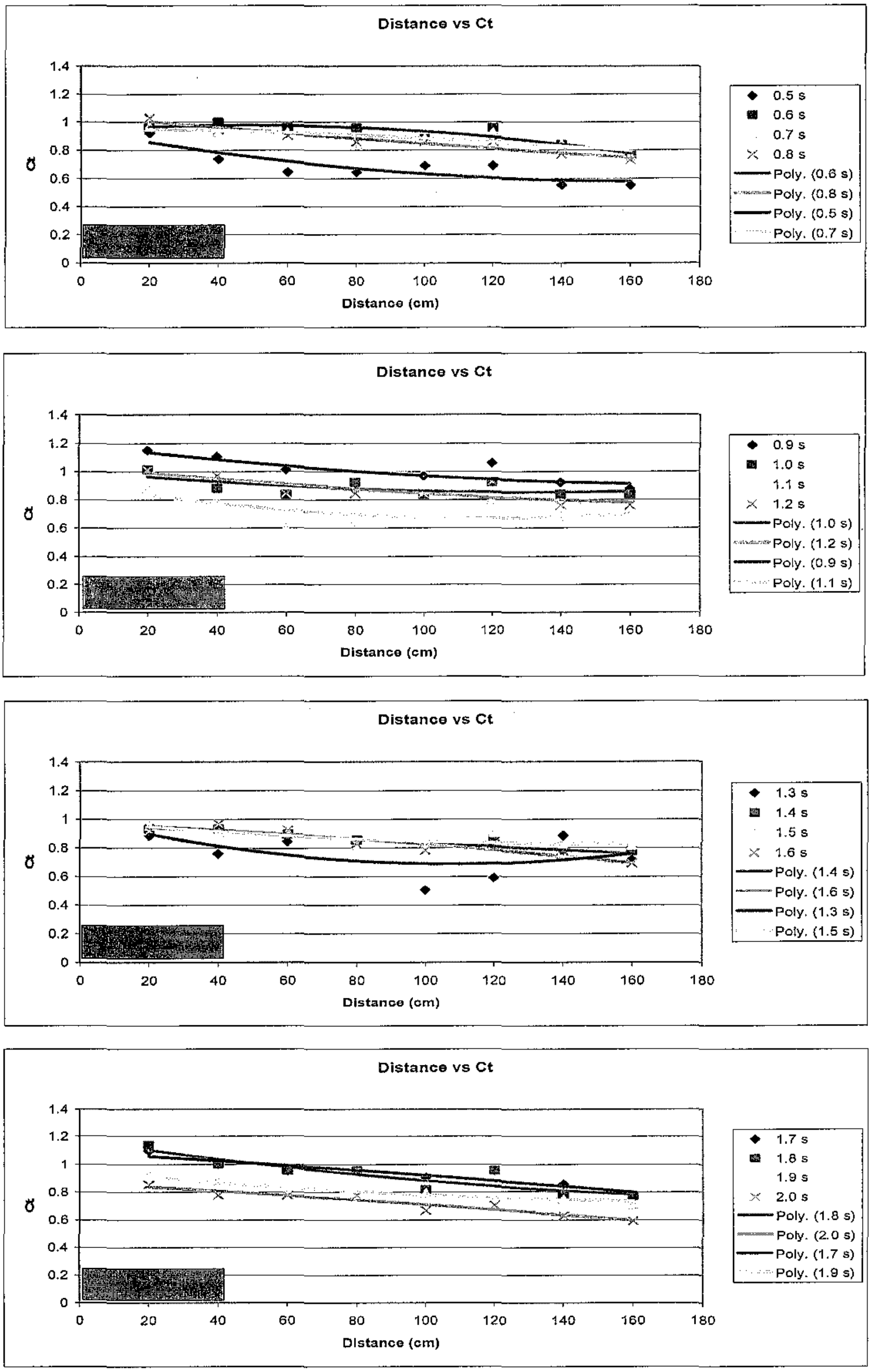


Figure 5.4: Distance vs *Ct* for 2 beds in 10 cm water depth

3 Beds

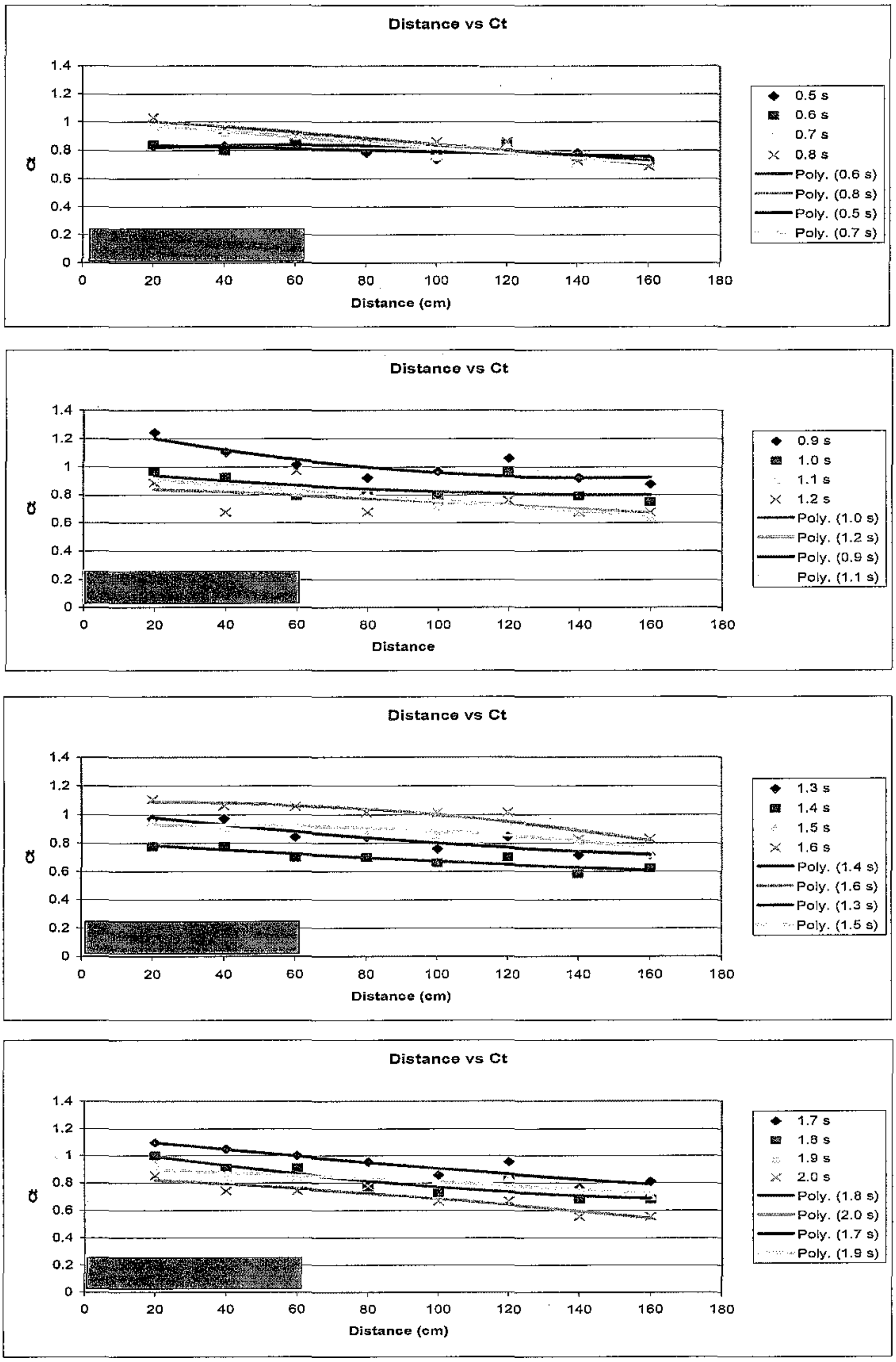


Figure 5.5: Distance vs *Ct* for 3 beds in 10 cm water depth

5.4.2 Experimental Result in 15 cm Water Depth

Figure 5.6 shows the results for the coefficient transmission for the usage of one mangrove model bed in 15 cm water depth. The graph shows that most of the data is more than 1 which means that the recorded wave height is higher than the incident wave height. The shortest wave period which is 0.5 seconds shows a steady decrease in transmission coefficient compared to other short period waves. This is due to stable energy in the waves, with no choppy waves thus giving a more controlled movement in the waves. As the wave period increases, the waves becomes more unstable as they enter the transitional period and most of the data shows that the transmission coefficient exceeds 1. As the wave period increases into the long period waves, the data seem to increase as the distance increases. This is due to the shoaling effect of the bed and splashing in the wave flume. Although exceed transmission coefficient of 1, the results still indicated a decrease of the transmission coefficient until the end points. This shows that the shallower water allows more wave attenuation. It can be seen that the mangrove model has more effect in shallower water.

Figure 5.7 shows the result of the usage of two mangrove beds in 15 cm water. The more stable short period waves are affected more than the long period waves. The trendlines indicate that there is more reduction in transmission coefficient with the shorter period waves due to the turbulence created by the waves as they go through a higher amount of contact area. The increase in the number of beds decreased the energy of the waves drastically. But although showing a larger decrease in transmission coefficient, the short period waves has transmission coefficients higher than 1 which means that the recorded wave height is higher than the incident wave height. On the other hand the long period waves, although do not show a sudden decrease in transmission coefficient value, the values are below 1, which means that the recorded wave height is lower than the incident wave height. The high energy from the shorter period waves caused a higher effect in shoaling and splashing whereas the low energy from the long period waves are dissipated from the beginning of contact with the mangrove mode.

Figure 5.8 shows the result of the usage of 3 mangrove beds in 15 cm water. All of the graphs show a decrease in the transmission coefficient. There is an obvious decrease in the trendline where the slope decreases as the distance increases. For the short period waves, the transmission coefficient is above 1 but decreases nearly to 1. The transitional period waves, which has less energy than short period waves, shows a transmission coefficient decrease from above 1 to les than 1. This shows that the drag and turbulence created has decreased the wave energy more as it is already low. The value of the transmission coefficient at the early part of the mangrove model which exceeds 1 is due to the shoaling effect caused by the sudden change of bed level. Long period waves showed the trendline of transmission coefficient values which are decreasing but starting from a lower value compared to the short and transitional period waves. This is due to the already low energy of the waves being dissipated by the drag and turbulence created by the dense mangrove model. Compared to the usage of 1 and 2 beds of mangrove model, the effects of the mangrove beds are more visible using 3 beds where the amount of energy dissipated is high due to drag and turbulence of the higher number of bamboo sticks thus increasing the total of contact surface area.

1 Bed

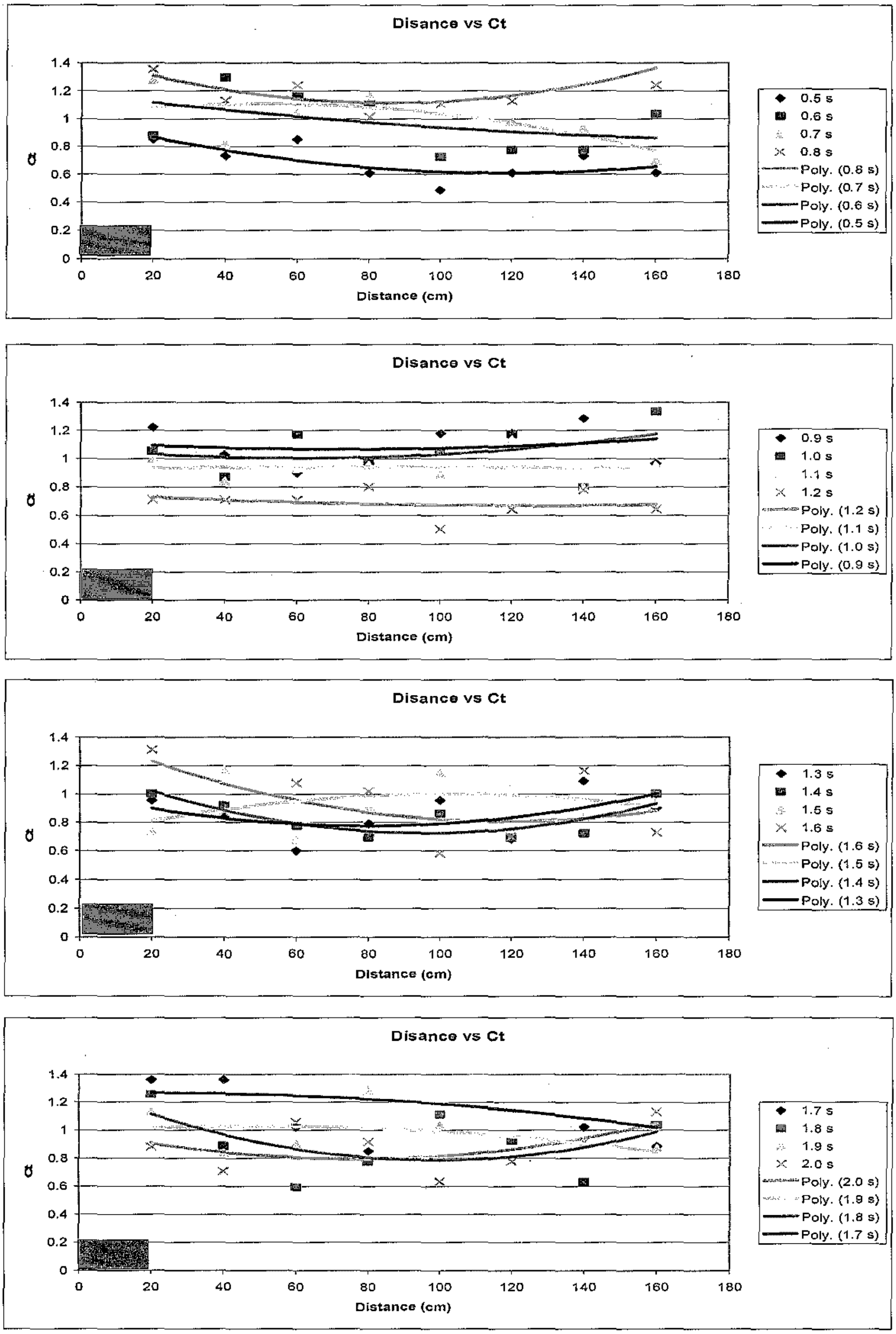


Figure 5.6: Distance vs *Ct* for 1 bed in 15 cm water depth

2 Beds

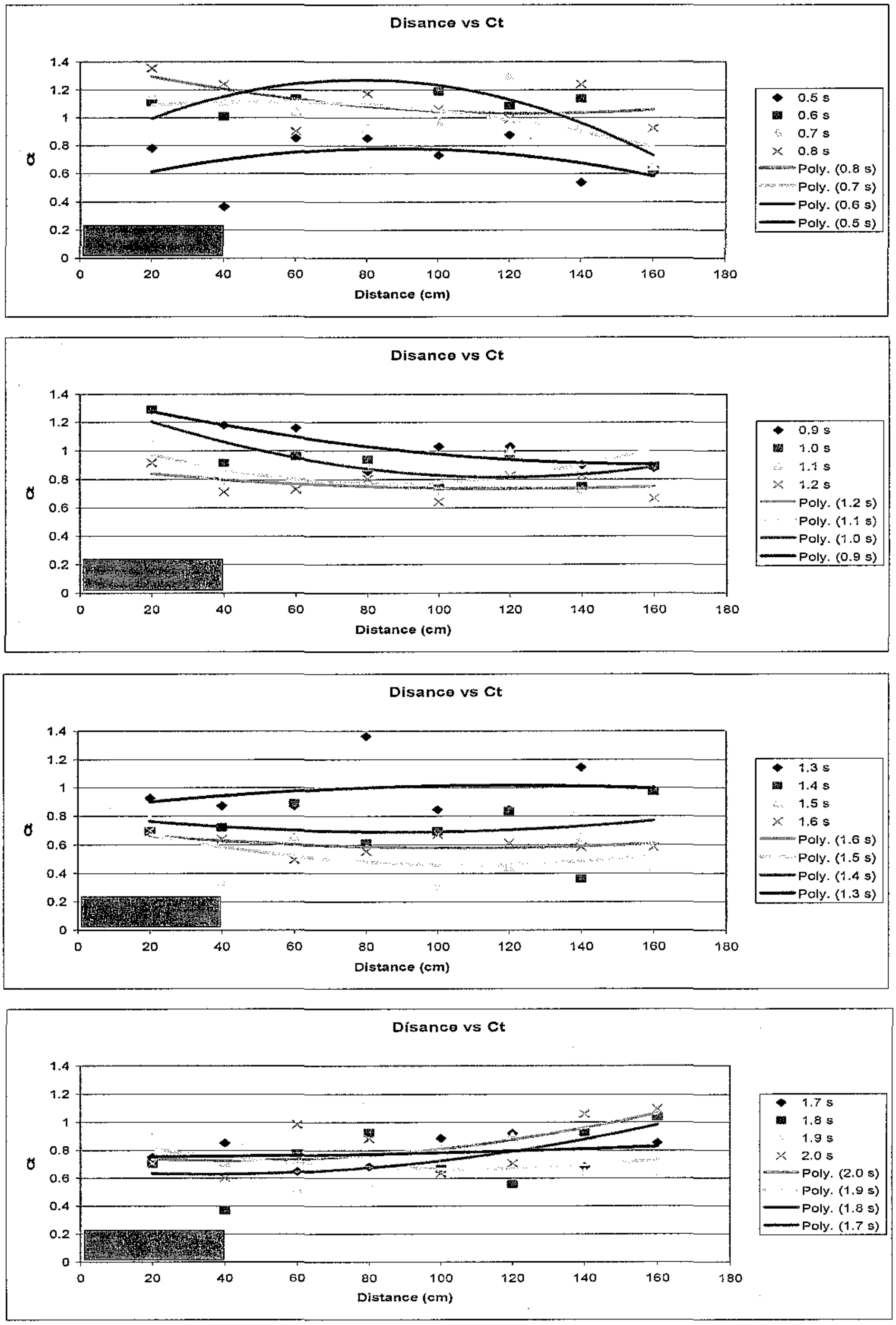


Figure 5.7: Distance vs *Ct* for 2 beds in 15 cm water depth

3 Beds

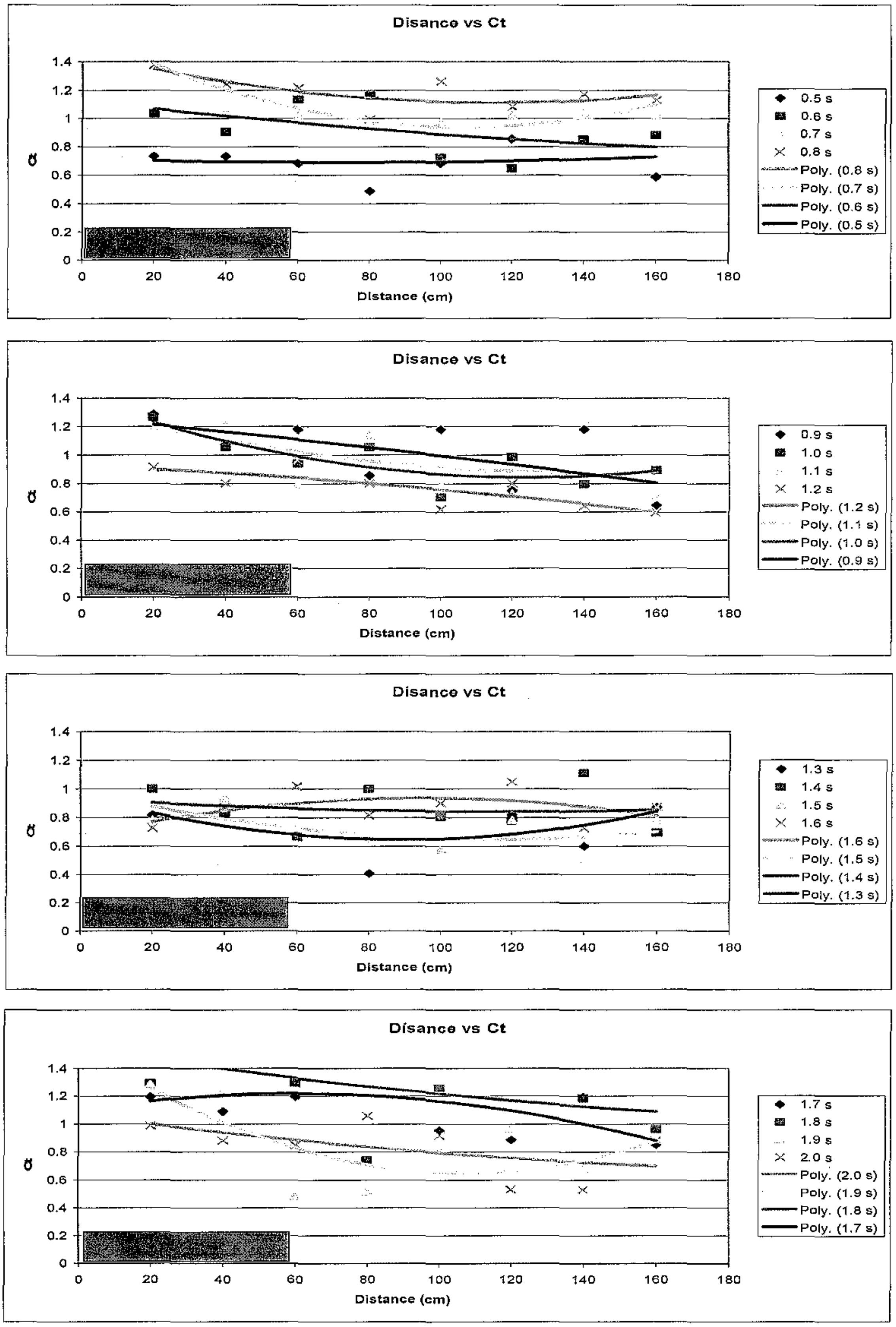


Figure 5.8: Distance vs *Ct* for 3 beds in 15 cm water depth

5.4.3 Experimental Result in 18 cm Water Depth

Figure 5.9 shows the graphs for Distance Vs Transmission Coefficient for 1 bed in a water depth of 18 cm. The transmission coefficient, *Ct* *is* the taken from equation 2.1 which translates as the comparison between the incident wave height and the recorded wave height. In order to see how much difference there is between the waves with no obstruction and with the presence of the mangrove model, the transmission coefficient is used. The transmission will decrease if there is a large difference between the incident wave height and the recorded wave height where as the recorded wave should be smaller than the incident wave height.

From the graphs, it shows that there is a reduction in the transmission coefficient in shorter wave period whereas in longer wave period due to the splashing and shoaling effect, the transmission coefficient seems to be increasing. The trendlines takes the average of the data and shows the prone direction of the data. From the results, in can be seen that the mangrove is effective in attenuating the wave height for shorter wave periods although only 1 bed is used.

Figure 5.10 shows the result for the experiment using 2 beds. The transmission coefficient seems to increase as the distance increase. This is due to splurging and shoaling effect. The wave height recorded is bigger than the incident wave height thus resulting with transmission coefficient bigger than 1. The graph for the transitional wave period shows a steady decrease as the distance increases. The incident wave height for the transitional wave period is higher than the recorded wave height as the wave are not as stable as long and short period waves. Due to the instability, the energy of the waves for transitional wave period is easily dispersed by the mangrove model. The higher amount of surface contact and surface drag encourages wave attenuation and transmission coefficient decrease.

Figure 5.11 shows the result for the experiment using 3 beds of mangrove model. The steady long wave period waves are highly affected by the mangrove model as the energy is low and a lot of drag is experienced and turbulence created. This contributes to a higher decrease of energy level thus giving a more visible result. The graphs shows that there is reduction in the transmission coefficient and that most of the data are below 1 which indicates that the recorded wave height is smaller than the incident wave height. The data that shows transmission coefficient values higher than 1 might be the result of the shoaling effect as the values are mostly at the beginning of the mangrove beds. The sudden increase of the bed level causes the waves to increase in height. This shows that if the mangrove model had a bed that is level throughout the wave flume, there might have been a more drastic decrease in the transmission coefficient.

1 Bed

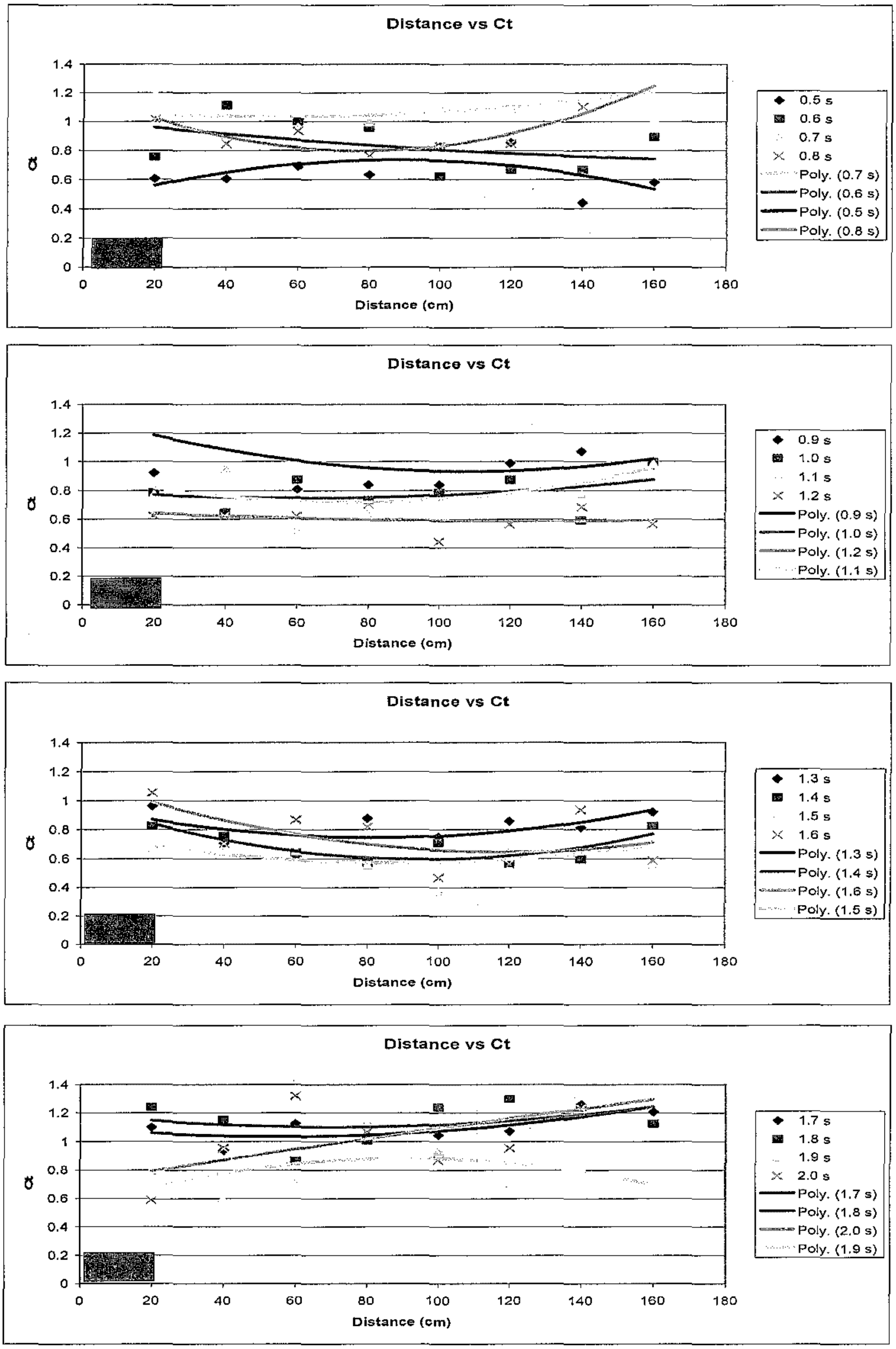


Figure 5.9: Distance vs Ct for 1 bed in 18 cm water depth

2 Beds

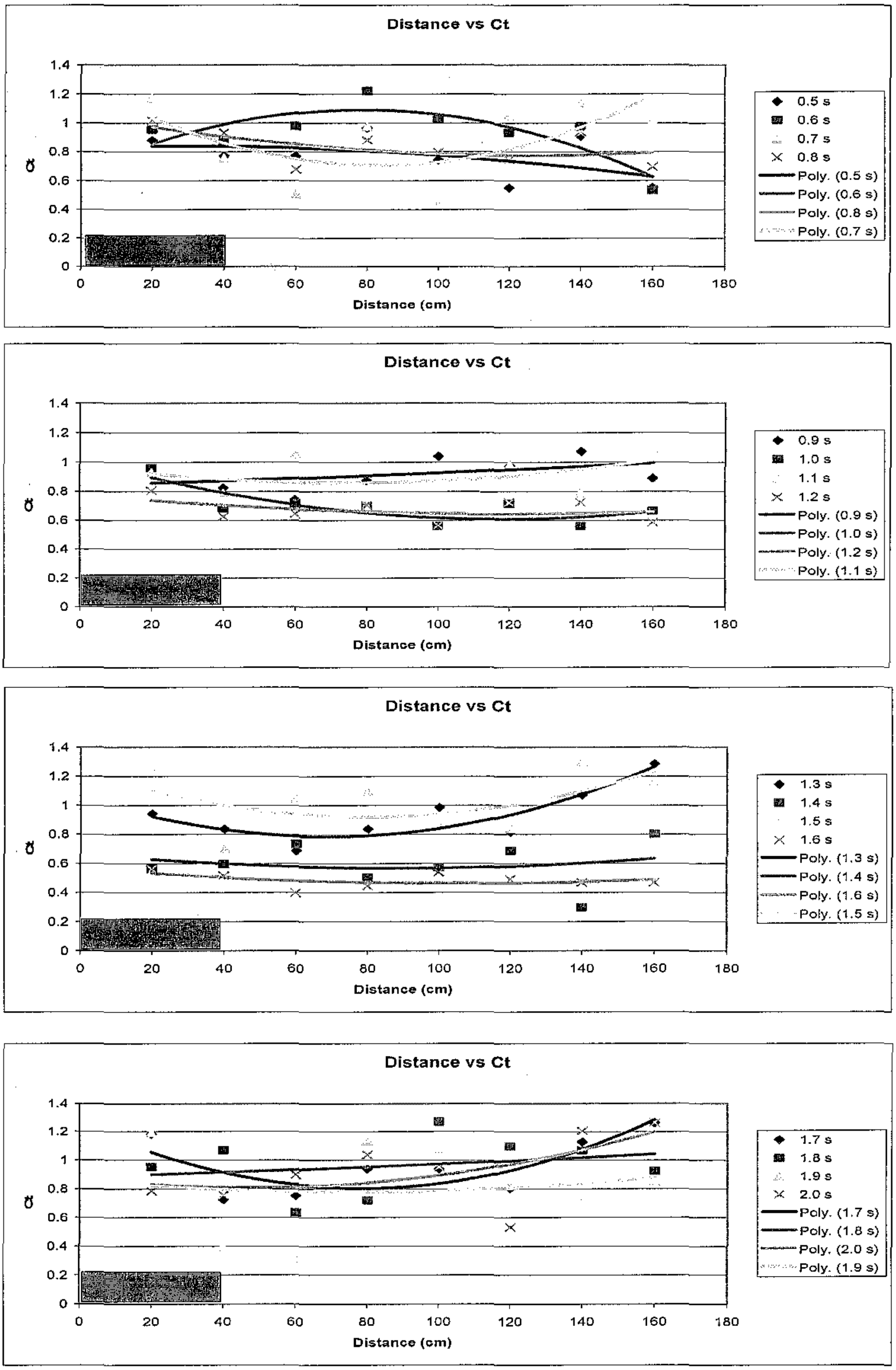


Figure 5.10: Distance vs *Ct* for 2 beds in 18 cm water depth

3 Beds

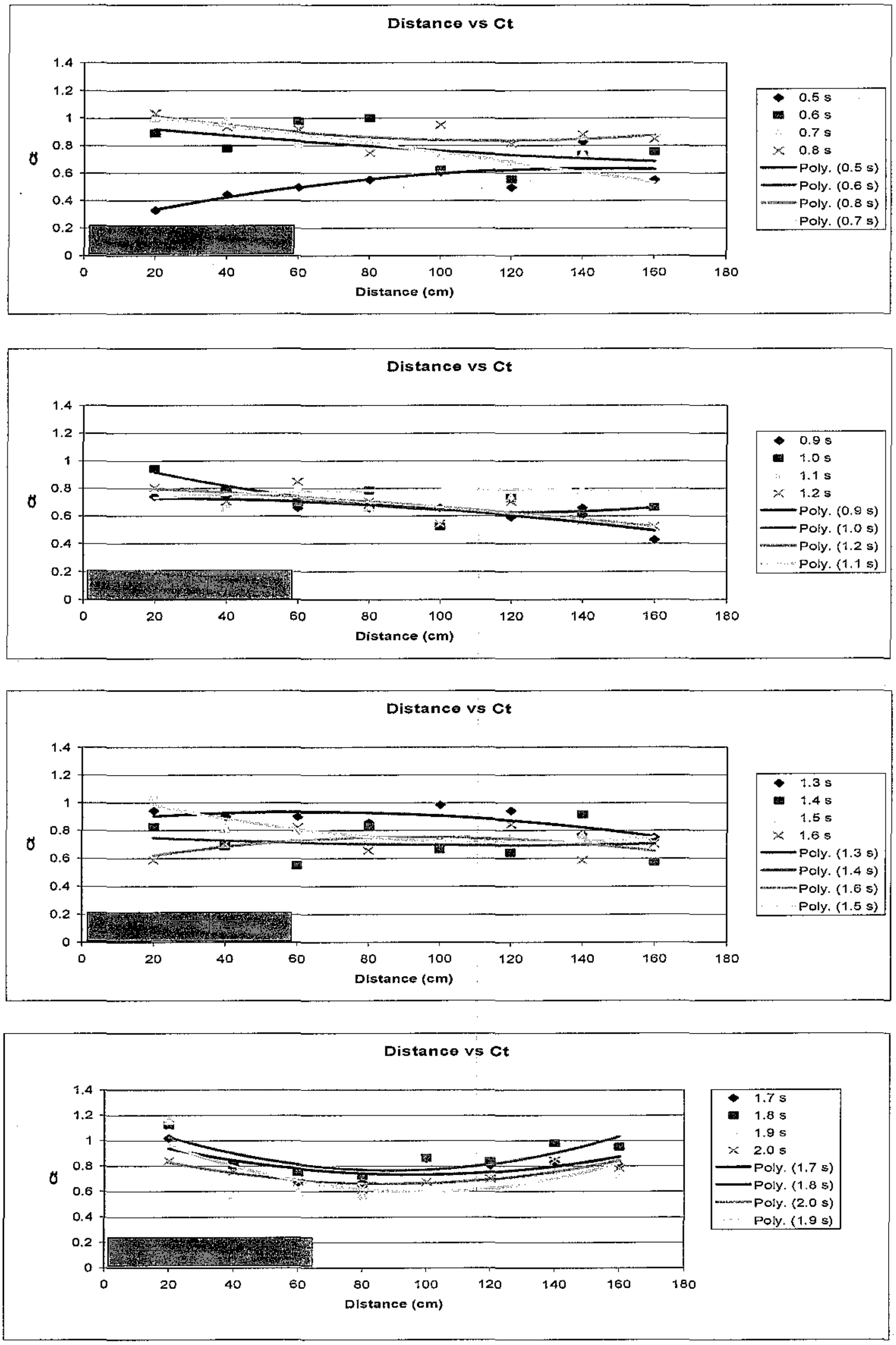


Figure 5.11: Distance vs *Ct* for 3 beds in 18 cm water depth

5.4.4 Comparison of the average *Ct* for different wave period and water depth

As the results showed results in the forms of graphs, it can be seen in Table 5.4, 5.5 and 5.6 the comparison of the average Ct between the different number of beds in water depth of 10 cm, 15 cm and 18 cm. Table 5.7 shows the overall average of Ct for the water depth with different amount of beds.

Table 5.4: Average *Ct* in 10 cm water depth with different number of mangrove bed

1 bed		2 beds		3 beds	
T	Ct	T	Ct	T	Ct
0.50	0.66	0.50	0.68	0.50	0.79
0.60	0.87	0.60	0.92	0.60	0.81
0.70	1.03	0.70	0.89	0.70	0.84
0.80	0.89	0.80	0.87	0.80	0.86
0.90	1.00	0.90	1.00	0.90	1.01
1.00	1.02	1.00	0.89	1.00	0.85
1.10	0.85	1.10	0.72	1.10	0.78
1.20	0.81	1.20	0.87	1.20	0.76
1.30	0.80	1.30	0.75	1.30	0.83
1.40	0.86	1.40	0.85	1.40	0.69
1.50	0.89	1.50	0.87	1.50	0.88
1.60	1.01	1.60	0.84	1.60	0.99
1.70	0.89	1.70	0.93	1.70	0.93
1.80	0.92	1.80	0.92	1.80	0.81
1.90	0.78	1.90	0.80	1.90	0.81
2.00	0.78	2.00	0.72	2.00	0.69

The result shows the comparison of the attenuation process for the experiment in a water depth of 10 cm. the table shows for that for short wave periods, the *Ct* does not vary much as the *Ct* for the longer wave periods. The longer wave period shows a steady decline in *Ct* as the number of beds increases. This further proves that the mangrove model is much more effectives as the number of beds increase which equivalently increases the number of bamboo that makes contact with the waves. As for comparison with other water depths, the results from the tables show that *Ct* decrease more steadily in shallower water compared to deep water.

Table 5.5: Average *Ct* in 15 cm water depth with different number of mangrove bed

1 bed		2 beds		3 beds	
T	Ct	T	Ct	T	Ct
0.50	0.69	0.50	0.70	0.50	0.70
0.60	0.97	0.60	1.09	0.60	0.92
0.70	1.00	0.70	1.02	0.70	1.08
0.80	1.21	0.80	1.11	0.80	1.18
0.90	1.09	0.90	1.04	0.90	1.02
1.00	1.05	1.00	0.93	1.00	0.96
1.10	0.94	1.10	0.87	1.10	0.98
1.20	0.69	1.20	0.76	1.20	0.77
1.30	0.85	1.30	0.98	1.30	0.73
1.40	0.83	1.40	0.72	1.40	0.86
1.50	0.94	1.50	0.53	1.50	0.72
1.60	0.93	1.60	0.60	1.60	0.87
1.70	1.18	1.70	0.78	1.70	1.12
1.80	0.90	1.80	0.75	1.80	1.26
1.90	0.97	1.90	0.71	1.90	0.84
2.00	0.88	2.00	0.83	2.00	0.83

Table 5.5 shows the average *Ct* Ct for each wave period for different amount of mangrove beds. Similar as the results for a water depth of 10 cm, it can be seen that for short wave period does not vary much compared with long wave periods. The decrease of *Ct* can be seen more obvious with the usage of three mangrove beds. For the comparison between water depths, the results show that the wave attenuation process using the mangrove model is still affective within the mean water level range.

Table 5.6: **Average *Ct* in 18 cm water depth with different number of mangrove bed**

1 bed		2 beds		3 beds	
T	Ct	T	Ct	T	Ct
0.50	0.65	0.50	0.77	0.50	0.54
0.60	0.83	0.60	0.94	0.60	0.79
0.70	1.09	0.70	0.88	0.70	0.78
0.80	0.91	0.80	0.83	0.80	0.89
0.90	1.01	0.90	0.92	0.90	0.64
1.00	0.79	1.00	0.69	1.00	0.72
1.10	0.79	1.10	0.91	1.10	0.77
1.20	0.60	1.20	0.67	1.20	0.67
1.30	0.81	1.30	0.93	1.30	0.88
1.40	0.69	1.40	0.59	1.40	0.71
1.50	0.62	1.50	1.03	1.50	0.79
1.60	0.75	1.60	0.49	1.60	0.70
1.70	1.10	1.70	0.97	1.70	0.81
1.80	1.15	1.80	0.97	1.80	0.88
1.90	0.80	1.90	0.81	1.90	0.73
2.00	1.05	2.00	0.93	2.00	0.74

Table 5.6 shows the average *Ct* for each wave period tested with the usage of different amount of mangrove beds. The values for the short wave periods fluctuate between the different amounts of mangrove bed used. The deep water possesses a higher degree of energy which makes it harder to attenuate compared to shallower water. Although, it can be seen from the results that for long wave periods, the *Ct* decreases as the number of bed increases. This shows that the more number of bed used, hence the more bamboo sticks are in contact with water which will result in the reduction of wave height.

Table 5.7 shows the average *Ct* for the three different water depth with the usage of different amount of mangrove beds. The results show that shallower water experience more attenuation compared to deep water.

Table 5.7: The average *Ct* for different water depths

water depth	1 bed	2 beds	3 beds
10 cm	0.86	0.85	0.80
15 cm	0.88	0.84	0.84
18 cm	0.92	0.83	0.85

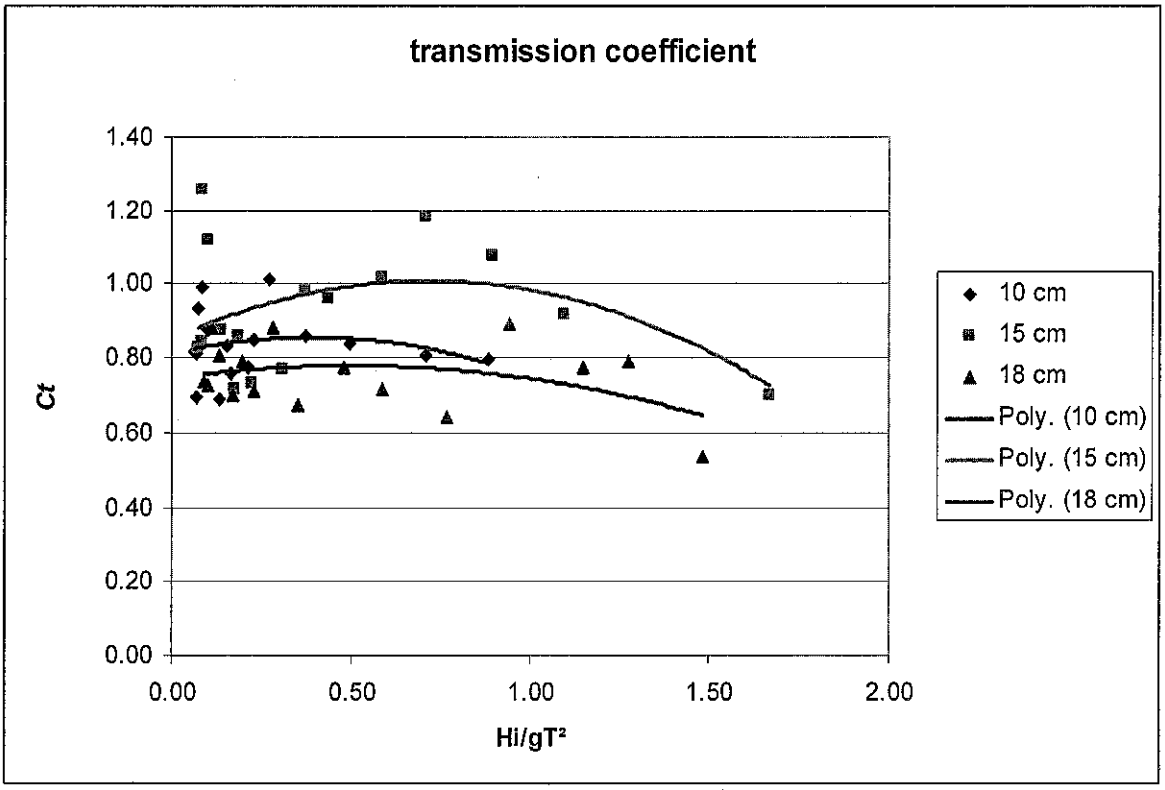


Figure 5.12: Wave steepness vs Transmission coefficient, *Ct*

Figure 5.12 shows the transmission coefficient of the mangrove model against the wave steepness for all three water depths. The figure shows that as the wave steepness increases, the transmission coefficient decreases. The value for the wave steepness in the 10 cm water depth is lower compared to 15 cm and 18 cm water depth which means that the *Ct* decreases more rapidly in shallower water.

CHAPTER 6
CONCLUSION AND RECOMMENDATION

6.1 Conclusions

The application of the mangrove model has been executed throughout several experiments prove that the usage of mangrove is effective in wave attenuation. Throughout the experiments and development of the project, a few conclusions have been made:

- The frequency of the rotation that creates the wave can be converted into the wave period by using the equation

$$\mathbf{y = 280.62x^{-1.4046}}$$

Where y = wave period, t (s) and x = stroke frequency, f (Hz)

- The reflection of the waves by the bamboo dissipates the energy of waves by creating collision. This shows that reflection acts as an important mechanism in the wave attenuation.

- Shorter wave period are less affected by the mangrove model due to the high energy of the waves.

- Long period waves are highly affected by the mangrove model due to the low energy the waves has. The effect of turbulence and drag can be seen more in long period waves.
- The mangroves do not have a high impact in wave attenuating for waves in deep water. The cyclic motions of the water particles are more stable and higher in number thus making the energy higher.

- The mangroves are highly effective in shallow water as the energy is lower in the waves and that the cyclic motion of the water particle are easily interrupted by the drag produced by the surface texture of the mangrove.

- Higher numbers of beds are highly effective compared to 1 or 2 beds of the mangrove model. The total surface area of contact between water particle and the surface of the bamboo increases thus increases the drag and turbulence created.

- The transmission coefficient of the waves should be lower than 1 but due to the sudden increase of the bed level, splashing and shoaling occurred.

62 Recommendations

For improvement of the study on effects of the mangrove model in wave attenuation for the upcoming research, few recommendations are highlighted as below.

- The type of material used as the mangrove trees could be changed and improved. The bamboos used were adequate but a more consistent shape material should be used in order to get a more controlled result

- Experimental studies should be done in a larger wave flume in order to see the total effect of the model and more results can be obtained

- The way data is collected should be improved by rather than using manual eyesight to determine the wave height, a capacitance wave probe should be used to get a more accurate result of the wave height.

- The wave absorber at the end of the flume should be replace with a more effective one as the reflection still compromises the downstream wave height and thus giving a higher reading

- The bed used to place the bamboo sticks should be lower or designed to be as the same level as the base of the wave flume to avoid shoaling effect.

REFERENCES

1. **Ghosh, Subir K.** "Illustrated Aquatic and Wetland Plants in Harmony with Mankind" 2000.

2. **Young, D. F. Munson, B. R., and Okiishi, T.H. "A** Brief Introduction to Fluid Mechanics, 2nd Edition, John Wiley and Sons, Inc. 2001

3. **Brooke, John** "Wave Energy Conversion" Elsevier Ocean Engineering Book Series, Volume 6, 2003

4. **French, Peter W.** "Coastal Defenses. Processes, Problems and Solutions" Routledge, Taylor and Francis Group, 2001

5. **Tschirky, Paul., Hall, Kevin., and Turcke, David.** "Wave Attenuation By Wetland Vegetation" Coastal Engineering 2000, Volume one, Conference Proceedings Sydney, Australia, July 16th - 21st, 2000

6. **Sorensen, Robert M,.** "Basic Coastal Engineering" Second Edition, Chapman & Hall, International Thompson Publishing, 1997

7. **Mohammed, Nuzul Izani.** "Wave Attenuation Performance of Improved Wave Suppress System (IWSS), December 2005, Universiti Teknologi PETRONAS

8. **Mazda, Y., Magi, M., Ikeda, Y., Kurokawa,T., Asano,T.** "Wave reduction in a mangrove forest dominated by Sonneratia sp." Wetlands Ecology and Management 2006 14:365–378

9. **Massel S.R., Furukawa K. , Brinkman R.M.** "Surface wave propagation in mangrove forests" Fluid Dynamics Research 24, 219-249 (1999)

10. **A. Sasekumar, N. Marshall & D. J. Macintosh (eds),** "Value of mangroves in coastal protection Hydrobiologia Ecology and Conservation of Southeast Asian Marine and Freshwater Environments including Wetlands." 285: 277-282, 1994 Kluwer Academic Publishers

11. **Othman, M. A.,** "Sungei Burong Escarpment - A Combined Structural and Natural Method of Coastal Protection", Proceedings of Conference on Coastal Engineering for National Development, IEM-ICE, Kuala Lumpur, March 1991.

APPENDIX

Wave Absorber

Materials: Floor mat, wood, wire mesh, rod, clamp, heavy material to act as weight for the absorber to stay at the bottom

Dimension: 120cm (length) x 120cm (slope) x 30cm (width) 30-90cm (height)

Slope: min: 15°, max: 45°

Calculation:

1. Lean (1967) recommended the absorber length should be at least 75% of incident wavelength to achieve reflection coefficient below 10%.
2. Quellet and Datta (1986) conclude that wire mesh absorbers are more efficient for slope angles greater than 15 degrees.

	Water depth = 20cm		**Water depth = 30cm**	
	T = 0.5s	T = 1.5s	T = 0.5s	T = 1.5s
d/L	0.5144	0.1013	0.7693	0.1281
L	0.389m	1.97m	0.39m	2.34m

75% of 1.97m wavelength = 1.48m. Due to size limitation, design absorber length: 1.2m

For height of absorber, minimum height design is 30cm

For minimum slope of 15°, length of the absorber is 112cm and length of slope is 116cm. So, 120cm design length is adequate.

For maximum slope of 45°with length absorber of 120cm, the height is b5cm. So the design height varies from 30cm to 90cm