INVESTIGATION ON EFFECTIVENESS OF MANGROVE FOREST IN COASTAL PROTECTION

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Investigation on Effectiveness of Mangrove Forest in Coastal Protection

by

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CERTIFICATION OF APPROVAL

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Approved by,

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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.

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SUHAILA BINTI ZAHID

ABSTRACT

Mangroves itself is a unique ecosystem which requires special attention and management. Its location which is between the land and the sea pays an important role in fisheries, coastal protection and conservation of biodiversity of both flora and fauna. Mangroves known as an important ecological function in mitigating coastal erosion by reducing the energy of waves, tidal currents and storms that caused coastline erosion. Mangrove trees have the root systems that help to keep the soil together and protect the coastal zones against erosion and extreme weather.

Studies concerning the characteristics of mangrove vegetations and wave that influence the ability of mangrove forests in dissipating surface wave is presented in this paper. The field assessments were conducted to measure the geometrical features of the mangroves, the wave attenuation, and wind induced surface wave energy in mangrove forest, specifically Rhizophora spp. This study aimed to quantify the wave height reduction of 5 years old mangroves forest with various mangrove densities, water depths and incident wave heights. The dimensions of the mangroves at site were measured to fabricate the mangrove model for subsequent laboratory investigation in the wave flume. The experimental showed that the wave height reduction in the area of 100 m mangroves of age 5 years old was 2 times larger than area without mangroves due to waves could not propagate freely through the gaps between mangrove plants.. Then, the difference of wave reduction between tandem and staggered arrangements was approximately 2% which is not significant. Result of wave reduction with respect to age group on different forest densities have showed that the mangroves of age 10 years old gave larger of wave reduction compare to 5 years old due to larger friction by the trunks and root system. Through laboratory testing, it is shown that the size of trees may affect the incoming wave heights.

At the shallow water depths, the higher the wave heights, the more wave reductions occurred due to more wave energy was dissipated. Even though the root system of a five years old mangrove is not a completely developed aerial root systems, the laboratory experiment revealed that the root structure is still able to provide substantial wave dissipation.

ACKNOWLEDGEMENT

First of all I would like to be grateful to Allah S.W.T by reason of giving me chance to gain knowledge and to complete my final year project in fixed period.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Mangrove forests are a type of wetland rainforest formation that has its own unique characteristics and adapted to deal with a highly saline environment that would normally be uninhabitable for other kinds of trees. The mangrove forests are highly productive ecosystems in reducing erosion rates and flood defense by dissipating incoming wave energy (Hong & Son 1993, Wu et al., 2001). The contribution of mangrove forest for coastline protection, mitigation of wave and storm impacts and mudflat stabilization, and protection of near-shore water quality has been recognized in the recent times. Mangroves are among some of the most productive and biologically important ecosystems of the world because they provide important and unique ecosystem goods and services to humanity, coastal and marine systems.

The tsunami has destroyed the agriculture lands and coastal forests. Based on previous research in Indian Ocean, almost 200,000 people died due to tsunami and the scientist have investigated the mangrove forests had protected villages from the worst destruction. Mazda et al. (2007) stated that the period of tsunami is between 10 min and 1 h as compared with periods of 12-24 h for normal waves. Harada et al. (2002) have investigated the tsunami reduction effect of the coastal permeable structures by using various models such as wave dissipating block, rock breakwater and houses, mangroves and coastal forest in the hydraulic experiment. This experiment has proved that the mangroves species are effective as concrete seawall structures for reduction of tsunami effect on house damage behind the forest. Hiraishi and Harada (2003) studied the attenuation of tsunami energy by mangroves which based on 1998 tsunami (Refer to Figure 1).

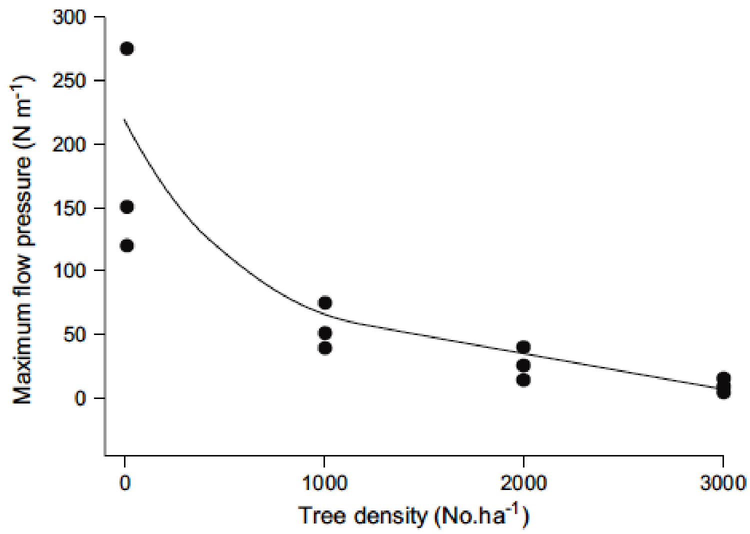


Figure 1: Model simulation of the decline in maximum flow pressure of a tsunami (Hiraishi and Harada, 2003)

The aim of this model simulation is to provide a review of the mangrove vegetation and wave that influence the ability of mangrove forest in dissipating surface wave. Based on this figure, the hydrological experiment have showed 90% reduction in the tsunami flow pressure for a 100 m wide forest belt at a density of 3000 trees ha-1. Moreover, Jusoff et al., (2013) added that the mangroves forest have been observed to play a role in reducing wave heights if the heights are not too high or less that 3m.

This research paper is mainly focuses on the effectiveness performance of mangrove trees Rhizophora spp of age five years old. The field measurements had been conducted to observe the behavior of waves propagating through mangrove forests.

1.2 PROBLEM STATEMENT

Another important feature of mangroves significant for coastal stability is their ability to dissipate surface wave energy, reduce wave heights, and decelerate flow of water, thus minimizing soil erosion and damage to properties along the coast (Brinkman, 1999; Hayes-Conroy, 2000; CCRU, 2005; Burger, 2005). Jan de Voz (2004) stated that several researches on the effectiveness of younger age of mangrove forest in dissipating wave energy have been undertaken but the relationships were still not fully understood. The ability of the mangroves in dissipating the waves varies depending on the mangrove ages. This is supported by Knutson (1998), which he mentioned that the performance of mangrove forest for coastal protection and dissipating waves has been questioned since the research on wave dissipation by mangroves is limited.

The mangrove species widely found in Asian is Rhizophora spp. Several research papers about effectiveness of younger age of mangrove forest in dissipating wave energy still not fully proved. Mazda et al. (1997) studied that the effective effects of mangroves species of Rhizophora on the reduction of sea waves for the age of 10 years and above are due to more complex aerial root structures. Moreover, Wolenski et al. (2001) mentioned that mangrove with different age has their own unique configuration of trunks, aerial roots and vegetation structures which affect the drag force and results in different level of wave reduction rate of the incoming sea waves. The research on the performance of mangrove forest for coastal protection and dissipating waves are still active, especially within this region, to answer the remaining uncertainties.

1.3 OBJECTIVE

Since the mangrove forest is plays an important role for coastal stability and protection, it is rationally relevant to investigate the dynamics of the processes related to it. Thus, the aim of this project is:

a) To provide a review of the effectiveness of mangrove of younger age for coastal protection.
b) To determine and investigate the five years old age of mangrove forests in attenuation the wave height.

c) To figure out the percentage wave height reduction with different densities, water depths, ages, incident wave heights and also the distances from mangrove front.

1.4 SCOPE OF STUDY

The common species of mangroves that widely found in Asian is Rhizophora species due to aerial root structures that contributed to higher drag coefficient. According to Jusoff et al. (2013), the successful regeneration is generally only achieved by the planting of monocultures of fast growing species, such as Rhizophora species. This project consists of field measurements and laboratory experiments which involved modeled of mangrove forest. The field measurement will be carried out to collect the information. The surveying and observations are come out by fabricate the modeled in laboratory. The site assessment will be conducted to gain knowledge about characteristics of mangroves and the ecosystems of the mangrove forests. The experiments will be conducted in a narrow wave flume in Offshore Laboratory to investigate the effect of mangrove age, density, tree arrangement, water depth and incident wave height on wave attenuation. Both of the results in laboratory experiments and field measurements will be finalized into graph for comparison.

1.5 SIGNIFICANCE OF THE PROJECT

Over the past decades, the erosion is the most important issue in the coastal areas all over the world which has threatened human activities in the areas exposed to such hazard. The term ‘‘functionality’’ is taken to mean the ability of restored mangroves to stabilize shoreline, trap sediments, improve shoreline protection, offer suitable habitat for animals, provide timber and firewood, and promote aesthetic value of coastal areas, in a similar way to natural mangroves (Bosire et al., 2008).

Since the role of mangrove forest in coastal protection is gaining attention in recent years, some countries are focusing on mangrove replanting for better coastal protection. It is important to investigate the effective combination of mangrove forests characteristics and their arrangement on wave energy dissipation in order to achieve the optimum energy dissipation by mangroves. All of these information are important in order to be incorporated during mangroves replanting projects in Malaysia.

1.6 RELEVANCY OF THE PROJECT

The coastal ecosystems such as mangroves have been recognized in recent years as natural protectors against coastal erosion. However, the effectiveness of mangrove of younger age in dissipating wave energy and current flow is still not fully understood and proved. Hence, findings and research from this study will provide better understanding on the performance of mangrove forests in coastal protection.

1.7 FEASIBILITY OF THE PROJECT

This research is a fundamental study of performance of mangrove of younger age in coastal protection. This research is feasible in terms of materials availability and it is within time frame according to the schedule from Gantt chart. The equipment required for experiments is available in offshore laboratory in Universiti Teknologi PETRONAS. Prior to conducting the experiments, site assessments to mangrove forest were carried out and the technical papers and journals are studied to enhance the knowledge on performance of mangrove forests in coastal protection. This project has the potential to develop into diverse and wider scope for further research but this will require longer duration of study.

CHAPTER 2

LITERATURE REVIEW

2.1 MANGROVE CHARACTERISTIC

Mangrove trees in Malaysia are the characteristic littoral plants, tough root systems, special bark and leaf structures and other unique feature to enable them to survive in their habitat's harsh conditions. Mangrove ecosystems have been reevaluated and its coastal protection value actually exceeds its direct-use values (such as forest harvesting and mari-culture) by over 97% (Sanford, 2009). The mangrove ecosystem in Malaysia consists of 60 species of trees and shrubs and about 20 additional species associated with the mangrove flora (Hamilton and Snedaker 1984). Moreover, it also widely used as a traditional and commercial for fuel wood, charcoal, timber, a variety of fisheries and the production of tannins for dying and leather production (Qureshi, 1990; Woodroffe, 1992; Siddiqi and Khan, 1990; Bandaranayake, 2002; Glaser, 2003). Mangroves forests are thought to play an important role to protect the coastline against erosion wave action and strong coastal winds. Following the Indian Ocean tsunami of 26 December 2004, it was reported that mangroves and coastal forests are effective in mitigating tsunami waves through hydraulic resistance such as drag and impact force which owing to bottom roughness and vegetation (Hamzah and Sofwan, 2007). According to Mazda et al. (1997), the six year old mangroves forests of 1.5 km width may reduce 1 m high waves at the open sea and 0.05 m at the coast. This is parallel with the findings by Alongi (2008) that the tsunami wave flow pressure was slightly decreased when the mangrove forest was 100 m wide due to wave trunk interactions and wave breaking. Based on Ismail et al. (2012), they had conducted laboratory experiments to investigate the interaction of a tsunami wave on a typical mangrove forest and to determine its performance in reducing the run-up. The experiments had showed that mangrove roots are more effective in reducing the run-up compared to the trunks and canopies.

The mangrove trees have the ability for salt exclusion and salt secretion to adapt with the high salinity water. The membranes of the root hairs are allowed to absorb only freshwater from the saltwater through the process of reverse osmosis to prevent salt from getting into the roots. Susilo (2005) stated that mangroves grow more rapidly in areas often inundated by the tide or growing in lower salinity regions of the estuary compare to those living in regions where groundwater salinity is very high and where the swamp is rarely inundated. The muddy substrates are soft and unstable whereas mangroves have aerial roots that ease the ventilation of the root system and allow mangroves to fix themselves on loose soil. Hashim et al. (2010) investigated that there are few species of mangroves have been found in Sungai Haji Dorani, Malaysia which namely Avicennia, Rhizophora, Bruguiera, Aegiceras, Xylocarpus , Nypa, Excoecaria, Sesuvium and the fern Achrosticum.

2.1.1 Rhizophora (Stilt roots)

Common species contribution of the mangrove that is proved effective is Rhizophora. It is due to fact that this mangrove is relatively faster, grows quicker and taller than other species. Based on field observation and analysis by Tanaka et al (2007), they found that Rhizophora apiculata (Bakau Minyak) and Rhizophora mucronata (Bakau Kurap) is very effective to mitigate the effect of tsunami because they were able to withstand a less than 5 m tsunami even with debris attached to the aerial roots. In the Philippines, Rhizophora sp. was also the preferred choice for mangrove restoration (Primavera and Esteban, 2008).

Due to this mangroves have complex aerial root structures; they were broken for a distance of about 50 m by an 8 m tsunami. These long roots are branch out from the middles of trees to help the trees hold them firmly to the ground and absorb the oxygen. This is further supported by Kathiresan (2003) that the density of this mangrove and their complexity and flexibility of aerial root structures are hypothesized to be the response to the intensity of wind and wave reduction process. Moreover, the trunk used for making good quality charcoal, high quality timber and fuel woods, for piling and the bark used for tanning. Roth (1992) added that the Rhizophora is more resistant to wind damage but once the big branches have broken, the capacity of the mangroves to survive is lower.

Figure 2*: Rhizophora apiculata*

Figure 3*: Rhizophora mucronata*

2.1.2 Avicennia and Sonneratia (Pneumatophores)

The species of Avicennia and Sonneratia have characteristic pneumatophores (breathing roots). This mangroves growing underground and visible erect lateral branches of the horizontal cable roots. These submerged structures have numerous air pockets for breathing and also send roots downward for anchorage and upward for absorption (Jusoff et al., 2013). Duke et al. (2010) mentioned that these mangroves are fast regenerating and fast growing due to easily grow in sandy, stony and rocky coastlines. This both species can show the development of air cavities in root tissues and designs that aid oxygenation of the tissues and grows up until 10m tall.

Hashim et al. (2010) investigated that they found more Avicennia species with common heights up to 11 m in area of Sungai Haji Dorani, Malaysia. According to Othman et al. (1994), the Avicennia can attenuate the waves from 0.3 m to 1 m in Sungai Besar, Malaysia. This is supported by Mazda et al. (2006), the planting Sonneratia in northern Vietnam have increased the wave attenuation in mangrove forest and were reduced in energy by 50% within 100 m into Sonneratia forests.

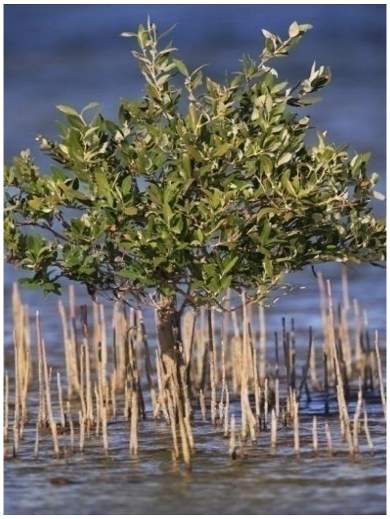


Figure 4: *Avicennia*

Figure 5: *Sonneratia*

2.1.3 Bruguiera and Ceriops (Root knees)

The species of Bruguiera and Ceriops have the root system surfaces periodically while growing away from the tree. Bruguiera have typical knee roots which function to emerge as a root loop from the underground root system and allow the exchange of gases in oxygen-poor sediments. The root is short or shallow buttressed like aerial roots, thickened trunk base. This species is normally found in sandy, riverine mangrove forests and stony soils as well as black soils. Hossain et al. (2008) studied that Bruguiera is dominated mangrove species stand in Malaysia and widely distributed from South and Southeast Asia to tropical Australia. Bruguiera species grows faster than other mangrove species and able to reach height up to 36 m but usually stops between 10 to 20 m.

Different with Ceriops species are a likely stunted tree which grows to 5 m tall and it is buttresses at the base of the trunk and knee roots. This species is a long lived and woody perennial mangrove species. Due to Ceriops species is short, so it vulnerable because this species often form pure stands on salt flat close to the landward zone and more accessible than other seaward species (Huang et al., 2012). Moreover, Ceriops species are used for firewood, tannin, dye, timber for construction, pole for domestic cottage, piles and pillars, and shoot has been used to treat malaria.

Figure 6: *Bruguiera*

Figure 7: *Ceriops*

2.1.4 Xylocarpus Granatum (Plank roots)

This habitat occurs along tropical coastlines towards the high tidal zone in mangroves and within tidal estuaries influenced seasonally by freshwater flows. Yin et al. (2007) stated that the Xylocarpus granatum is widely distributed along the seashore of Southeast Asia and Indian Ocean. This species have horizontal roots which become extended vertically over the entire length. These mangroves are tall, spreading tree growing up to 22 m in height with a buttressed trunk and the bark is reddish and flaky. Moreover, the timber is used for carpentary work, firewood and the bark used to cure dysentery.

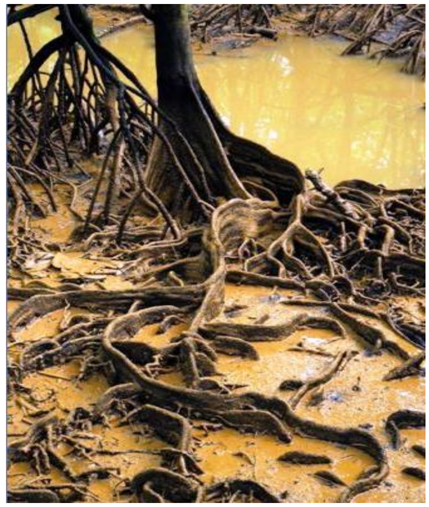


***Figure 8**: Xylocarpus granatum*

2.2 TIDAL LEVELS

Burger (2005) investigated that zonation patterns of mangrove species parallel to the shoreline are usually found within the mangrove forests with transitions zones of mixed species from two adjacent communities. Based on figure 9, the main cause of zonation patterns are due to competition between species in settings established by external forces. Mangrove forest is a complex combination of trunks, prop roots, pneumatophores, branches and leaves (Ismail et al., 2012). The vertical configuration of the mangrove is expected to dissipate more tsunami wave energy by restricts water flow due to drag forces and viscous forces. Avicennia species grows first on the mudflats which function as the resistance to the waves and currents. Othman (1991) stated that the species that can colonize the available space in the tide pool are Rhizophora and Brugeria which caused a zonation pattern.

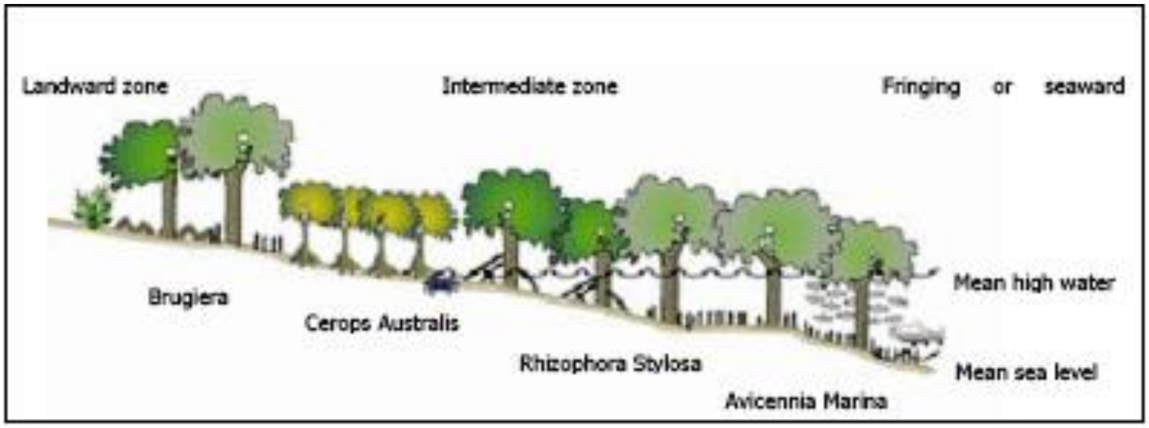


Figure 9: *Hypothetical schematization of zonation in a mangrove forest (Source: Burger, 2005)*

Since Avicennia have breathing roots, it is placed at the seaward zone due to visible erect lateral branches of the horizontal cable roots which may increase the wave attenuation in mangrove forest. The Rhizophora is placed at the first intermediate zone due to looping aerial roots that arise from the trunk. The aerial root structure of Rhizophora may affect the intensity of wind and also wave stresses. The Cerops is placed at the second intermediate zone because of this species is short, small sized and also long lived species. The Brugiera is placed at the landward zone due to root system surfaces periodically while growing away from the tree and may emerge as a root loop from the underground root system.

2.3 WAVE ATTENUATION AND DENSITY

The large water depths correspond with higher incident waves and the small water depths corresponded with small wave heights. According to Quartel et al (2007), at lower water levels, the wave height may reduce per meter cross-shore in the mangrove forest and increased towards high tide. The wave energy dissipation is mainly determined by the resistance of the vegetation, expressed by friction caused by the size and structure of the vegetation exposed to the waves. Referred to figure 10, this is further supported by Mazda et al. (1999) that the wave attenuation energy is mostly dependent on the height of mangrove forest, diameter of mangrove roots and trunks, canopy density and also spectral characteristics of the incident waves.

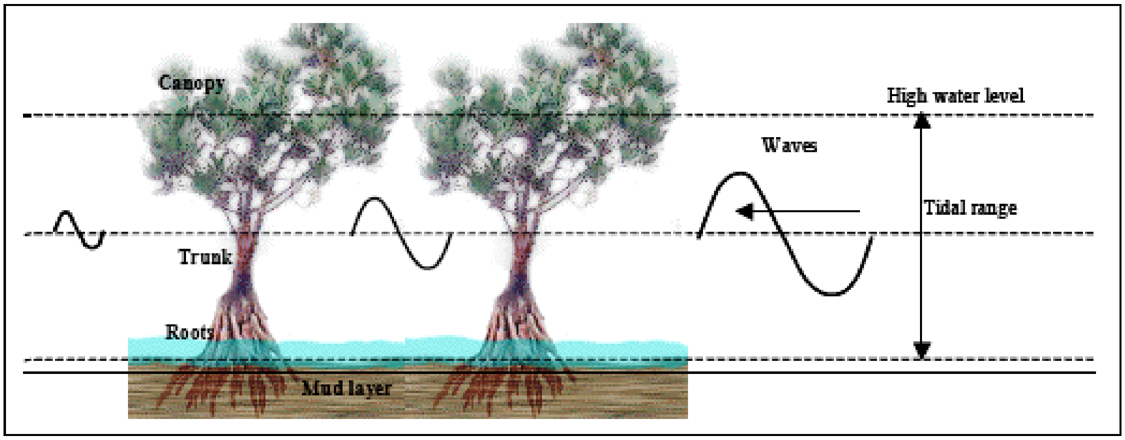


Figure 10: *Schematization of wave attenuation through a mangrove forest. (Burger, 2005)*

The longer the wavelength in a certain time frame, the lower the flow accelerations and decelerations compare to short waves. Besides that, for longer wavelength waves, the energy might be lost during first deceleration and it is not immediately followed by the next acceleration. Thus, the longer waves dissipate less energy compare to short wave that dissipates more energy. These include studies conducted by Harada and Imamura (2002), Hiraishi and Harada (2003), Harada and Kawata (2005) and Irtem et al. (2009). Hiraishi and Harada (2003) stated that a mangrove forest with a density of 0.3 trees/m2 and a 100 m width could dissipate 50 % of the tsunami wave height. Moreover, the network of trunks, branches and above ground roots of the mangrove trees were seen as an increased bed roughness for incoming waves. The densities of the mangrove forest do not influence the run-up reduction as significantly as the forest widths, but mangrove forest densities to be significantly enough to reduce more tsunami run-up (Ismail et al., 2012). Burger (2005) stated that the main factors for wave attenuation processes in the mangrove forest are mostly depending on vegetation properties and hydraulic conditions. At higher water levels there was more vegetation flooded and the drag coefficient increased.

Based on field measurements demonstrated by Brinkman et al. (2006), 82% of average wave energy dissipation rates over a 200 m wide salt marsh and compared with 29% over an adjacent sand flat of similar width. Mazda et al. (1999) conducted a study of wave attenuation for different mangrove densities and they analyzed that mangrove forests as wide of 1000 m have high potential to reduce wave energy about 90% and this was totally depends on tree density rather than spatial extent of trees (Refer to Figure 11). According to Burger (2005), by increasing the density of the mangrove forest at different layers, the wave energy attenuations may decrease as in increasing in water level. This is supported by Jusoff et al., (2013), that the reduction of waves increases with the density of vegetation and the depth of water. Bao (2011) revealed that a wider mangrove band is required when the mangrove forest is shorter because lowness of the tree density. Moreover, Wolanski et al. (1992) analyzed that the density of mangrove trunks and roots is greater in the bottom layer than in the upper layer. Latief and Hadi (2006) also stated that to reduce tsunami is depend on wide, dense and structural of the forest and typical trees.

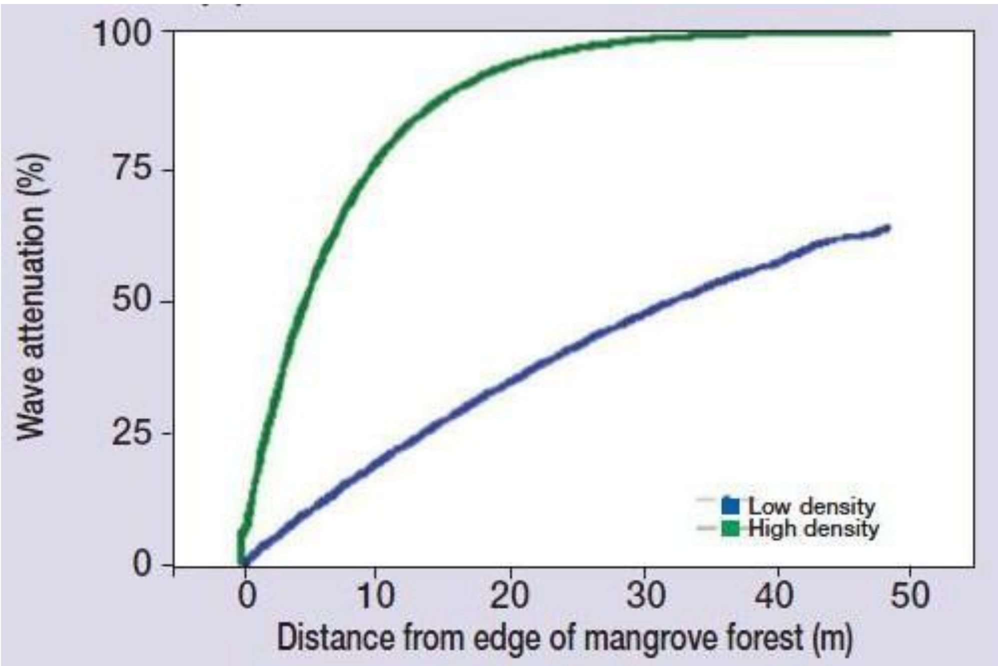


Figure 11: *Wave attenuation for different mangrove densities has been modelled (Massel et al. 1999; Barbier et al. 2009)*

The height of mangroves is one of the important factors that related to the impact from wind and wind related events and in relation to wave attenuation mechanism (Lacambra et al., 2008). Sherman et al. (2001) argued that the taller tress suffer the greatest impact of wind shear and more damaged occurred. Similar with statement by Hensel and Proffitt (2002) mentioned that the taller trees were uprooted and easily broken. There was no clear statement between size of tree and tree damage but there is a relationship between the tree size and mortality were related to species. Mazda et al. (2006) had analyzed about the relation with tree size and they stated that under normal conditions bottom friction attenuates wave energy but during storm conditions it is important in the vertical configuration of ecosystems.

Jan de Voz (2004) conducted a study at Delft University of Technology in Vietnam showed that 5-6 years old trees with over a 1500 m wide mangrove forest might reduced the incident waves to not more than 0.05 m at the landslide of the forest with average height of 1 meter. Referred to Figure 12, if no mangrove forest is present over a 1500 m mudflat, the wave height would still be 0.75 m (Jan de Voz, 2004). The wave energy dissipation of mangrove trees is differ by growth stages. Othman (1991) stated that 5 year old of mangrove forest can effectively and strongly act as wave attenuators. This is supported by Jan de Voz (2004) that the young trees in the mangrove forest have hardly any effect on wave energy reduction compared to tall mangrove trees with rate of 20% of wave reduction per 100 m.

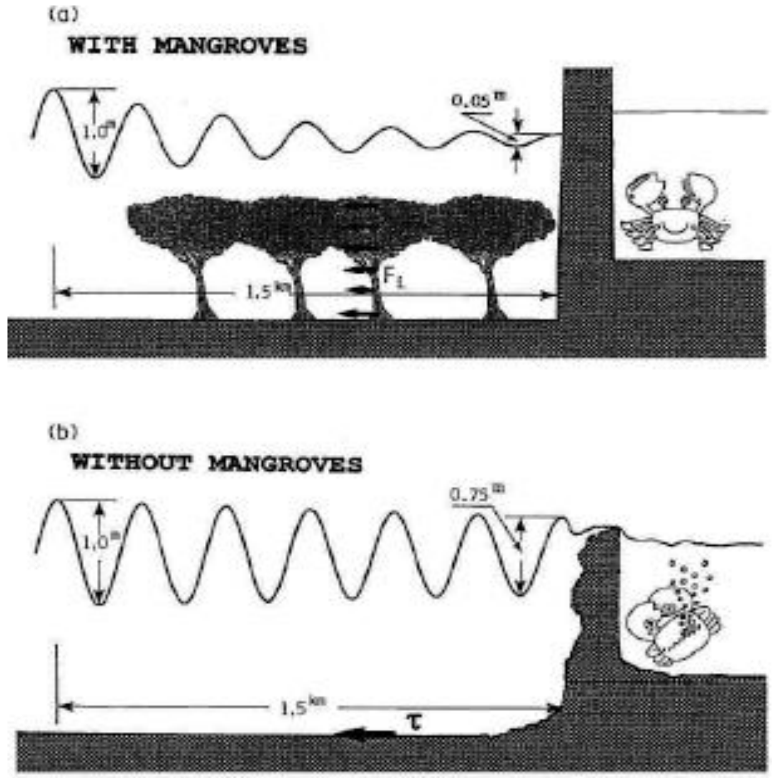


Figure 12*: Variation in the wave attenuation between areas with and without mangroves. (Jan de Voz, 2004)*

2.4 STORM SURGE REDUCTION

The storm surges are obviously dangerous when they coincide with high spring tides and may immediately increase coastal sea levels by several meters. Mclvor et al. (2012) defined that the storm surges is a short-lived atmospheric disturbance such as hurricane or storm due to abnormally high sea water levels in coastal areas. The mangroves as an important role to reduce the storm surge water levels by slowing the flow of water and reducing the surface waves. Baird et al. (2009) argued that even though the mangroves may decrease the deaths but the cost of revegetation is high and the effectiveness of a mangrove barrier is low when compared to an early warning system. Zhang et al. (2012) investigated about the effects of different widths of mangroves being present, and they found that surge attenuation through mangroves was non-linear due to effects of different widths of mangroves. This is supported by laboratory experiments by Ismail et al. (2012), 1 m width of mangrove forest could reduce 23–32 % during high water and 31–36 % during low water. Then, the increasing of mangrove forest width to 2 and 3 m could further increase the average percentage of run-up reduction by 39–50 % during high water and 34–41 % during low water condition. Referred to figure 13, the storm tide refers to the total water depth above a reference level, usually mean sea level (McIvor et al., 2012). It consists of both the storm surge and the tidal level. Moreover, the storm surge consists of the speed of travel the surge which includes the velocity of travel of the peak water level and the storm track.

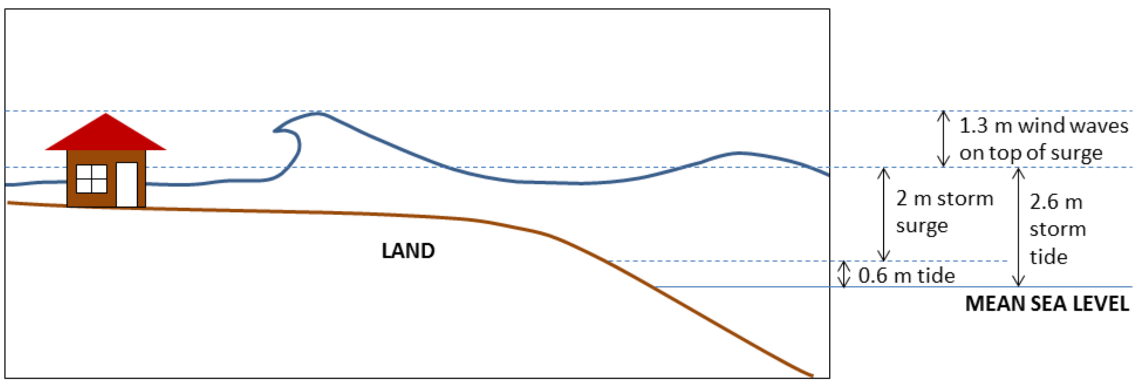


Figure 13: *Schematic diagram of a storm surge (adapted from McIvor et al., 2012)*

McIvor et al. (2012) stated that the measured rates of storm surge through mangroves may reduce from range 5 to 50 cm water level reduction per kilometer of mangroves width. Besides, the surface winds reduction is more than 75% over one kilometer of mangroves. The largest reduction in peak water levels occurred at the seaward edge of the mangroves while further inland the water level changed more slowly (Refer Figure 14). Similar to Krauss et al. (2009), the reduction of water level in the most seaward mangroves will be higher when the measurements start at some distance into the mangroves.

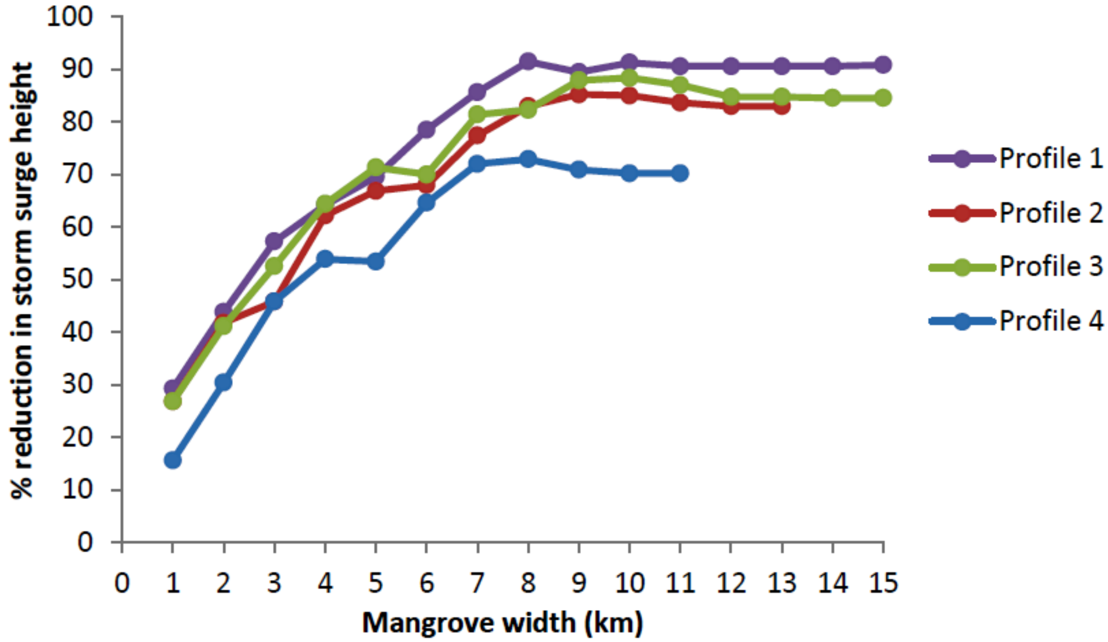


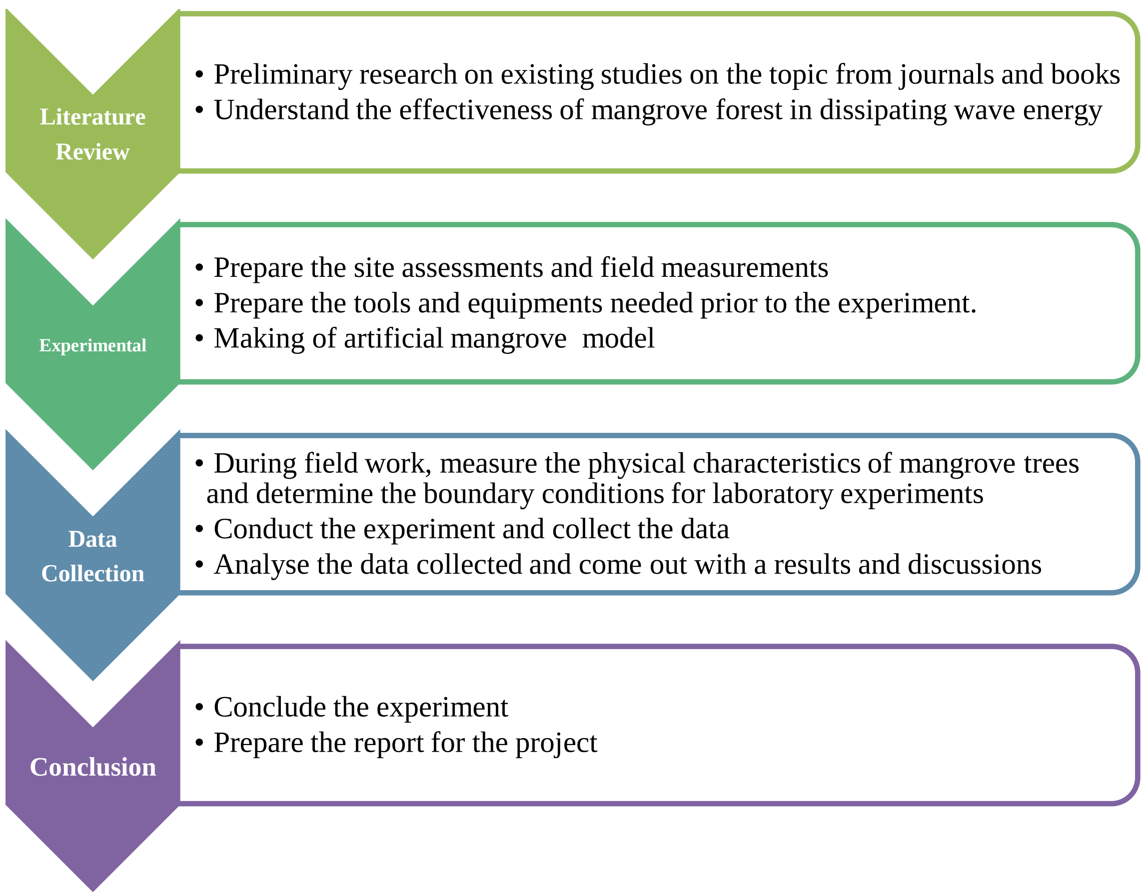
Figure 14: *The reduction in storm surge height as the mangrove belt width increases for four different shore profiles (adapted from Zhang et al., 2012)*

The rises of sea level have caused big threat to mangrove ecosystems through inundation stress, sediment erosion and may increased salinity at landward zones. The mangroves have high efficiency to facilitate sedimentation and attenuate wave energy. Besides, the mangrove forests have a big impact to adjacent ecosystems and also affecting their survival and ecological system. Bosire et al. (2012) stated that the mangroves also known as a shelter and feeding habitats for a wide array of fish and also utilized in commercial and subsistence fisheries. The mangroves have proved may prevent most of land-derived sediment from spreading into the sea, so that the sea grass beds and coral reefs were able to thrive in clear waters. Hayes-Conroy (2000) also mentioned that the coral reefs function as wave breakers which minimizing forceful impacts of high energy waves into the mangrove forest.

CHAPTER 3

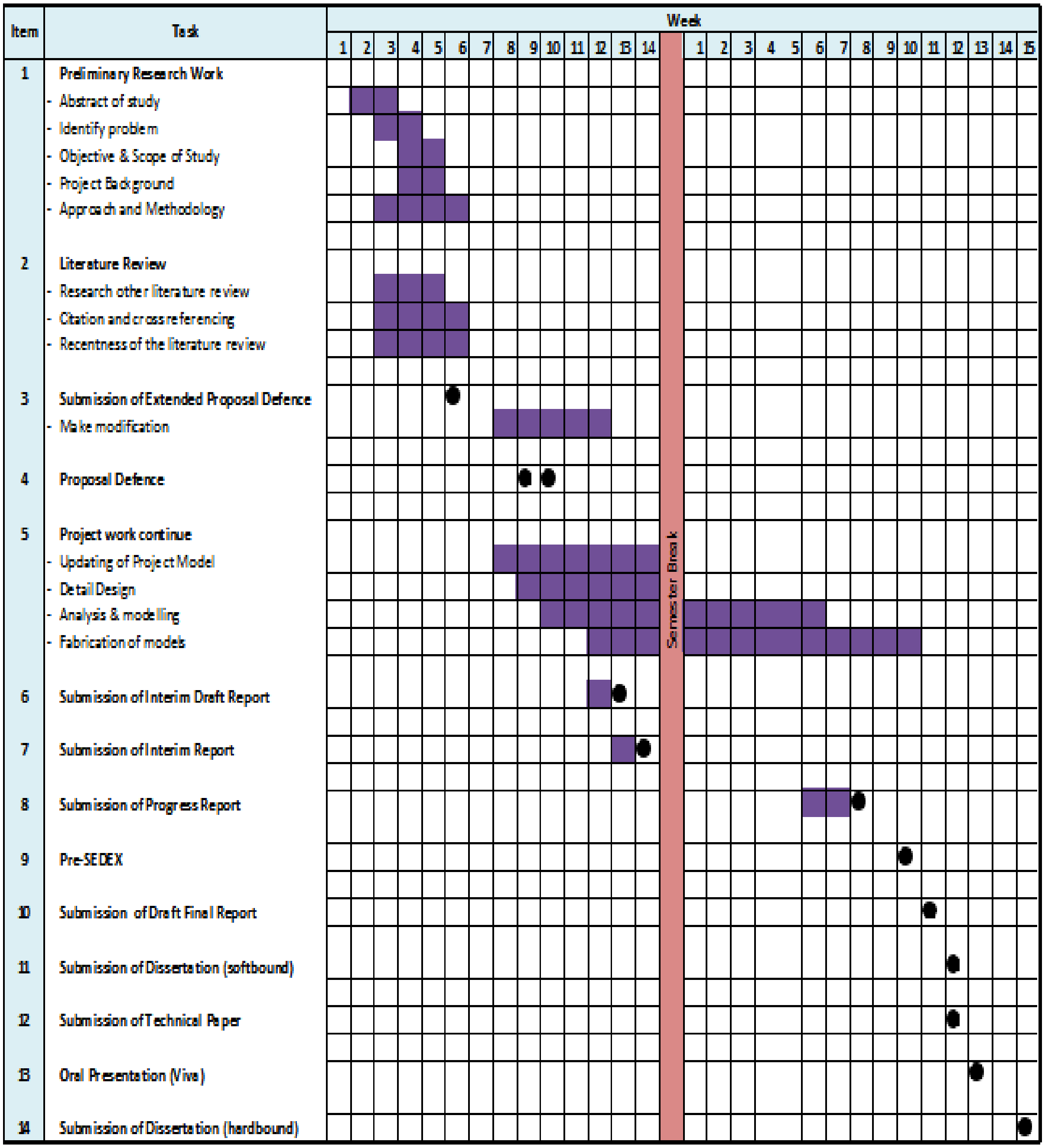
METHODOLOGY

3.1 PROJECT FLOW CHART



3.2 KEY MILESTONE AND GANTT CHART

Timelines for FYP 2



3.3 RESEARCH METHODOLOGY

Mangroves play an important role in estuarine ecosystem, marine coastal ecological systems maintenance, sustaining the aquaculture, tropical shoreline stabilization, land reclamation, shrimp farming, timber and charcoal production. The field work had been conducted to figure out the behavior of waves propagating through mangrove forest as well as to determine the boundary conditions for physical model testing. The data carried out had been modeled in the laboratory. The species that dominate the mangrove forests are Rhizophora, Avicennia, Bruguiera, and Sonneratia. The Rhizophora developed stilt roots that grow radial from the stem, providing stability in all directions. Other species including Avicennia and Sonneratia possessed long cable roots with pneumatophores protruding vertically through the soil. These are breathing roots that also conduct reverse osmosis process, extracting salt and absorbing freshwater from the saline environment. This research paper are focused to the most effective species that had been chosen for tested the various vegetation parameters such as mangrove age, density, tree arrangement and forest band width while maintaining water depth and wave parameters which consist of incident wave height and wave period.

3.4 FIELD WORK AND FIELD MEASUREMENT

Since this project need to come out with field measurements and laboratory experiments, the site visits to mangrove forests had been conducted to measure the physical characteristics of mangrove trees and to determine the boundary conditions for laboratory experiments. The sites visited are:

i. Kuala Sepetang Mangrove Park
ii. Pantai Lekir
iii. Lumut Mangrove Park
iv. Pantai Teluk Tiga
v. Tanjung Kepah
vi. Kg Air Tawar (Amir Chalet)

3.4.1 Kuala Sepetang Mangrove Park

The Kuala Sepetang Wetlands is part of the 40,537.6 hectare Matang Mangrove Forest Reserve in 1906. Today, it is recognized as the best managed sustainable mangrove ecosystem in the world. Near to this reserve are silvicultural programmes of the Rhizophora, Lenggadai and Seaward berus forests carried out professionally by Perak State Forestry Department. At Kuala Sepetang, a few of 15 years old mangroves trees are cut off for charcoal production. Besides, the Rhizophora apiculata and Rhizophora mucronata are planted at the spacing of 1.2 m and 1.8 m for the roots to develop.

(a)

(b)

(c)

(d)

Figure 15: *a) Measuring the dimensions of mangrove tree, b) One year old age of mangrove trees, c) Measuring the dimensions of mangrove tree, d) Mangroves tress of various size and age*

3.4.2 Pantai Teluk Tiga

The fieldwork was conducted at Pantai Teluk Tiga, Perak in order to measure the wave height reduction of the mangrove forest. The location of Pantai Teluk Tiga is approximately 19 km from Sitiawan and 17.4 km from Bagan Datoh which is previously affected by 2004 Indian Ocean Tsunami as in figure below.

This site consists of several of size and various ages of Rhizophora species. We observed the wave heights of mangrove forest during the highest tide of the day.

(a) (b)

Figure 16: *a) Mangroves tress of various size and age during low tide, b) Measuring the dimensions of mangrove tree and wave height during high tide*

3.4.3 Pantai Lekir

Lekir is one of main village in Manjung district, Perak, Malaysia.

(a)

(b)

(c)

Figure 17: *(a), (b), (c) Some of mangroves had diminished due to severe erosion problems*

3.4.4 Pantai Tanjung Kepah

Pantai Tanjung Kepah is a small fisherman's beach in the village. The location of Pantai Tanjong Kepah is approximately 11 km from Sitiawan, Perak and the dominant species at this site is Avicennia spp.

(a) (b) (c)

Figure 18: *(a), (b) Some of mangroves had diminished due to severe erosion problems and failure of mangroves replanting project, (c) Measuring the wave height during high tide*

3.4.5 Kg Air Tawar (Amir Chalet)

Kampung Air Tawar is next to Kampung Baharu and is located at Lumut, Perak. There are some of mangroves are still survive and in preservation in order to protect the coastal. Most of the mangroves are around 15 years old and above.

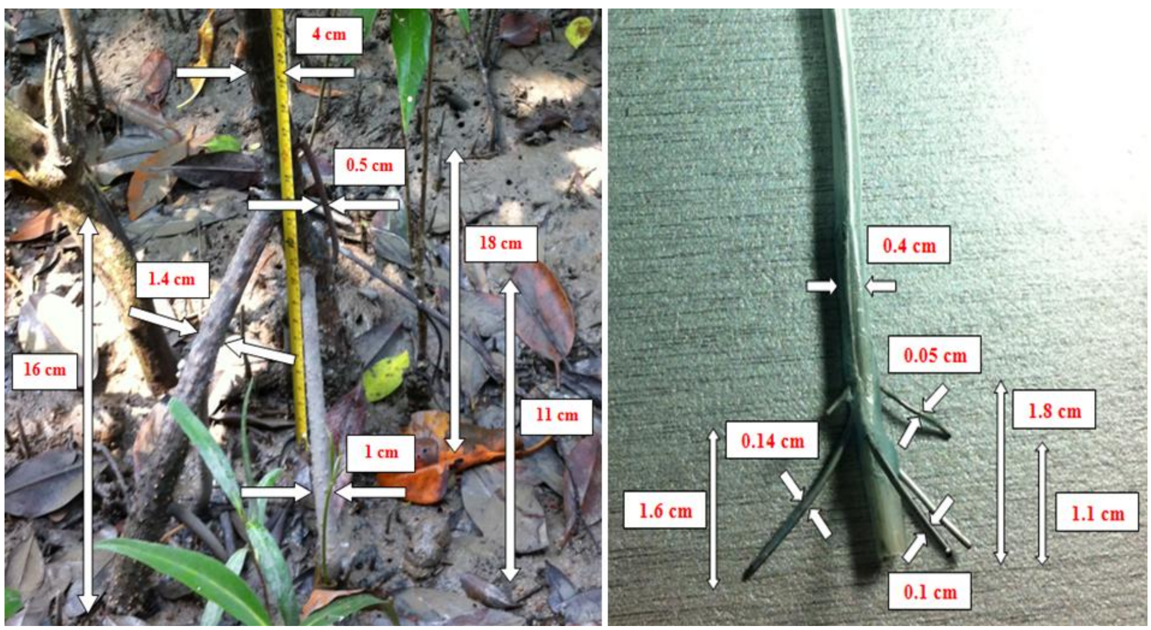
(a) (b) (c)

Figure 19: *(a), (b) Some of mangroves are still survive and in preservation, (c) The mangroves with various ages and sizes*

3.5 ASSUMPTIONS FOR MODELLING WORKS

The dimensions of tree for modelling were collected during field measurement with the help of a forest ranger in Kuala Sepetang Mangrove Park and Lumut Mangrove Park. Based on information from the forest ranger, the five years old age of mangrove can be easily recognized by the roots. It consists of two undeveloped and three fully developed roots.

Some assumptions are made for the modelling of mangroves in laboratory based on collected data and site observations in order to simplify the processes. As in Figure 20, the figure shown the mangrove models are scaled down to a ratio of 1:10.



(a) (b)

Figure 20: *(a) A Rhizophora, (b) An artificial Rhizophora model*

3.6 EXPERIMENTAL SETUP

The laboratory experiments had been conducted in a narrow wave flume in Offshore Laboratory of Universiti Teknologi PETRONAS. Then, the experiment was conducted to determine the effect of mangrove age, density, tree arrangement, water depth and incident wave height on wave attenuation. The narrow wave flume was 23 m long, 1.5 m wide and 1.2 m high. Figure 21 and Table 1 shown the schematic of narrow wave flume setup and the tools and equipments required for this experiment.

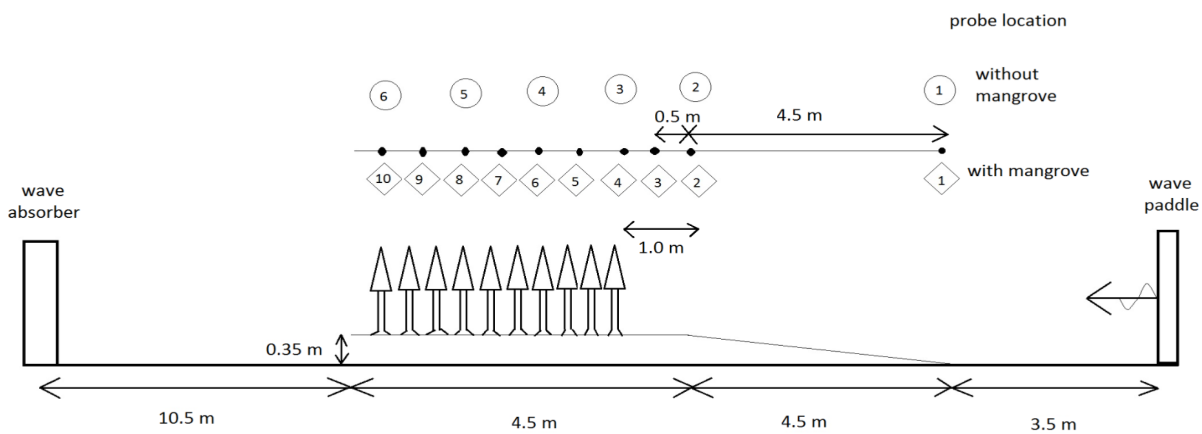


Figure 21: *Schematic of narrow wave flume setup*

Table 1: *Tools and equipments required*

Tools	Purpose
Wave Flume	To model waves propagating through mangrove field
Wave Maker	To generate waves
Wave Energy Absorber	To reduce reflection effects by waves
Artificial Mangrove Plant	To model the real mangrove tree
Resistance Wire Probe Electric Wave Gauges	To measure water surface elevation
Edinburgh Design’s Ocean Software	To control the wave maker, collect and analyze incoming data from the waves

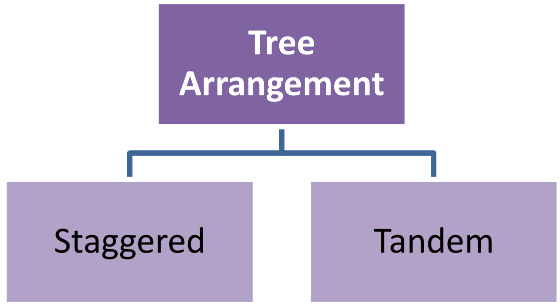
Due to an artificial mangrove models is small in size and can't stand it by its own self, there are alternative that have been proposed in order to ensure the mangroves is stable to stand for dissipation and reduction of wave energy during experiment.

The thumbtack is placed behind the tree trunk and be bound together by using cable ties. The cable ties are pulled tighter to make sure the mangroves are close to thumbtack. Once the cable ties has been pulled through the mangroves, it is prevented from being pulled back and resulting the mangroves been attached to thumbtack and strong enough to stand in vertical condition. This alternative may help the mangroves to stand it stronger in order to prevent it falling during high wave. Figure 22 shows the view of artificial mangrove trees.

Figure 22: *Artificial Mangrove Trees*

3.7 TEST CONDITIONS

a) Test for tree arrangements



b) Test for densities

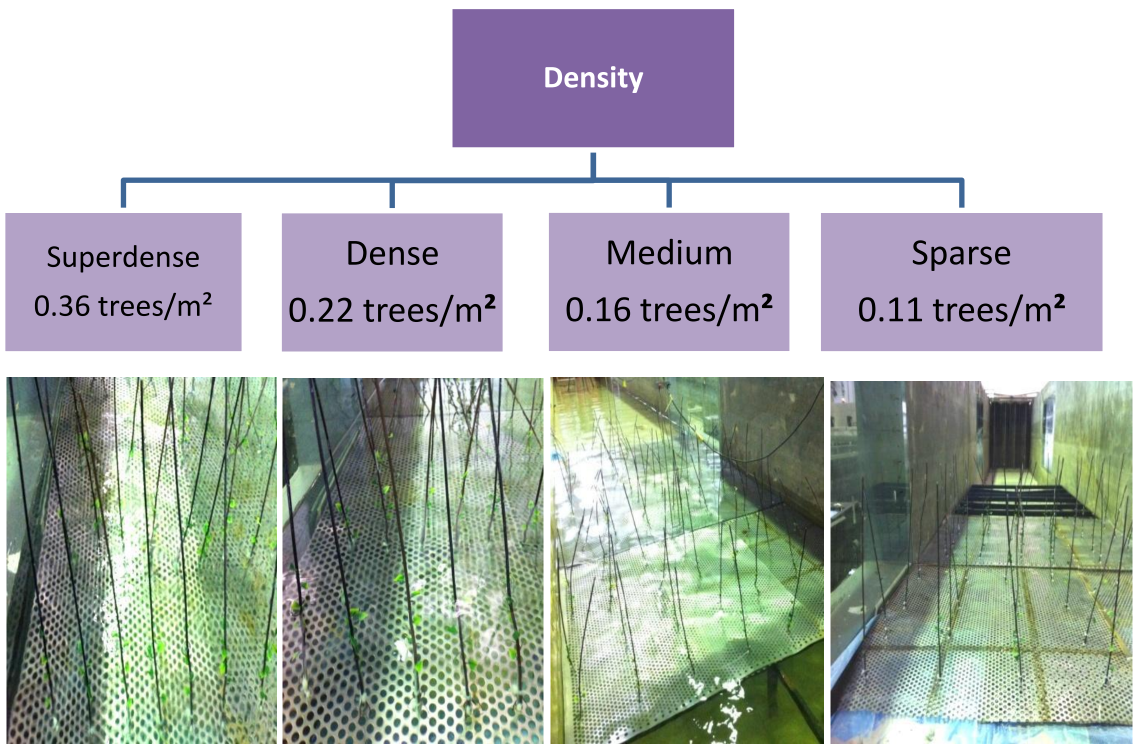
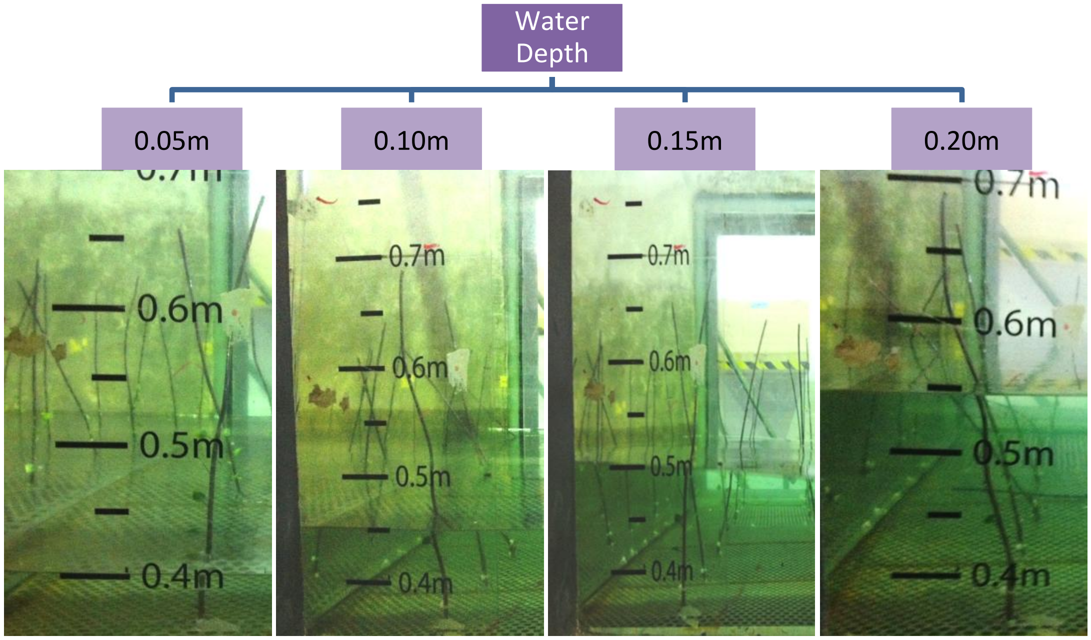


Figure 23: *Test for mangrove densities*

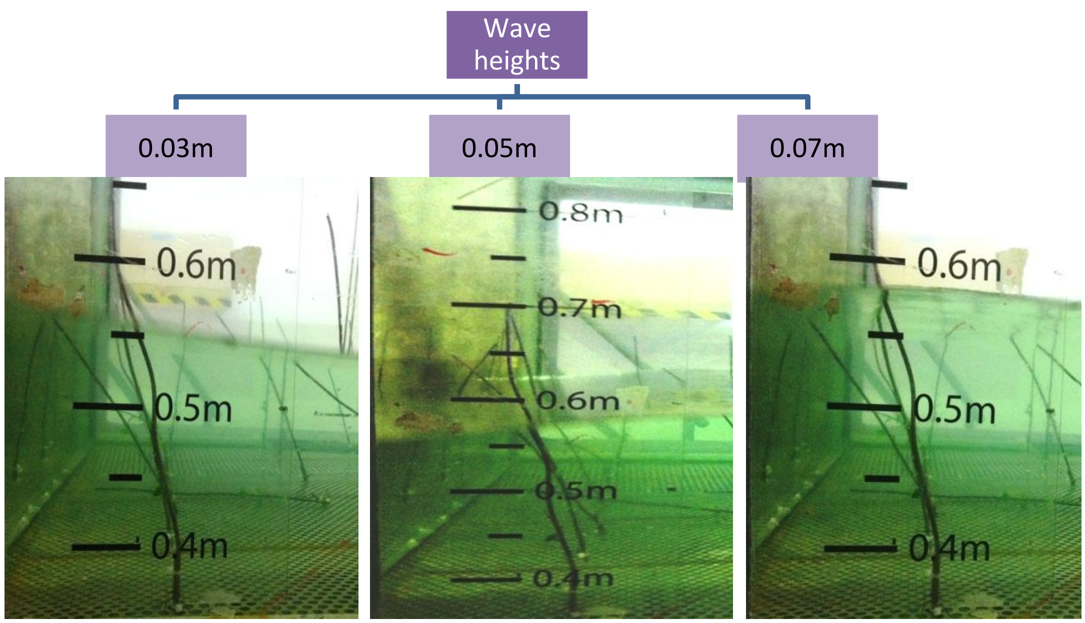
c) Test for water depths



Density = medium; water height = 3 cm

Figure 24: *Test for water depths*

d) Test for wave heights



Density = medium; water depth = 0.20 m

Figure 25: *Test for wave heights*

CHAPTER 4

RESULT AND DISCUSSION

4.1 RESULT

The effect of mangrove age, incident wave heights, density, tree arrangement and water depth on wave heights before and inside mangrove field have been measured and plotted. The wave reduction rate (*r*) was calculated by using Equation (1):

$$H_x = H_0 . e^{(-r \cdot x)} \qquad \textbf{Eqn. 1}$$

The result in wave reduction rate (r) is considered very small throughout the mangrove field. But, it still can be used to evaluate the total wave reduction across 30 m, 50 m, 100 m and 200 m mangrove forest width (Appendix 1 for further calculation).

4.1.1 Effect of tree arrangements on wave reduction

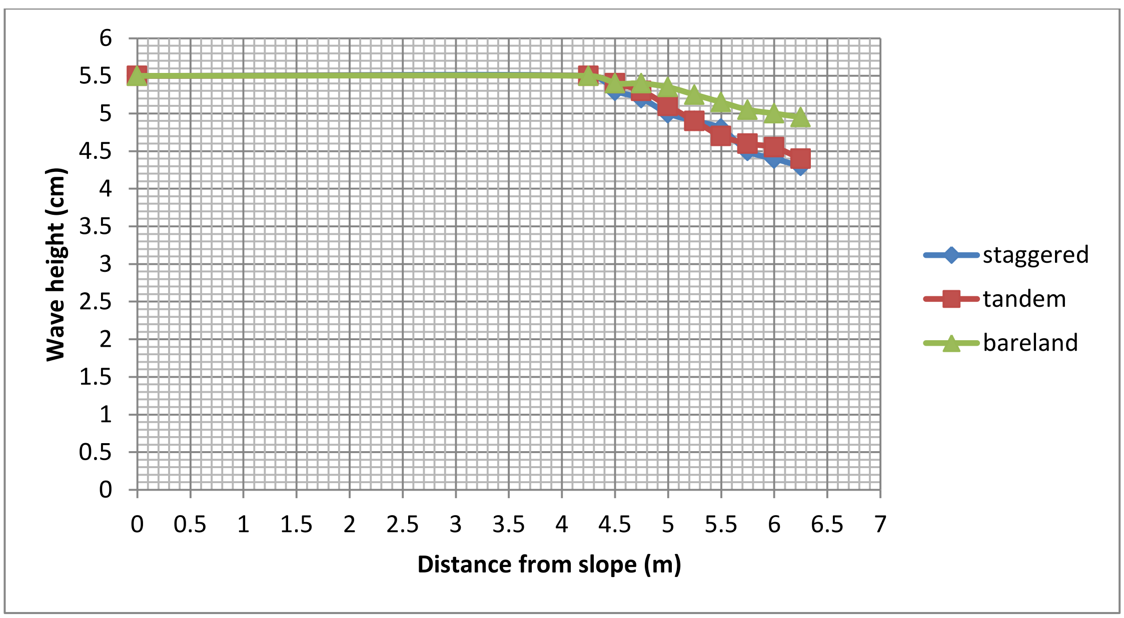


***Figure 26**: Wave reduction in the area with mangroves and without mangroves. The trees were arranged in tandem and staggered order for area with mangroves and the mangrove models were placed from a distance of 5.5 m from slope front.*

Table 2: Wave reduction rate in various tree arrangements

Tree Arrangement	Wave Reduction rate, r (m^{-1})
Bare land	0.01023
Tandem	0.02199
Staggered	0.02467

Table 3: *Estimated total wave reduction (%) for mangrove forest in various widths with different tree arrangements*

Tree Arrangement	Total wave reduction for mangrove forest of width		
	30 m	50 m	100 m
Bare land	3.02 %	6.99 %	14.73 %
Tandem	13.38 %	22.41 %	34.74 %
Staggered	14.13 %	23.60 %	36.86 %

4.1.2 Effect of densities on wave reduction

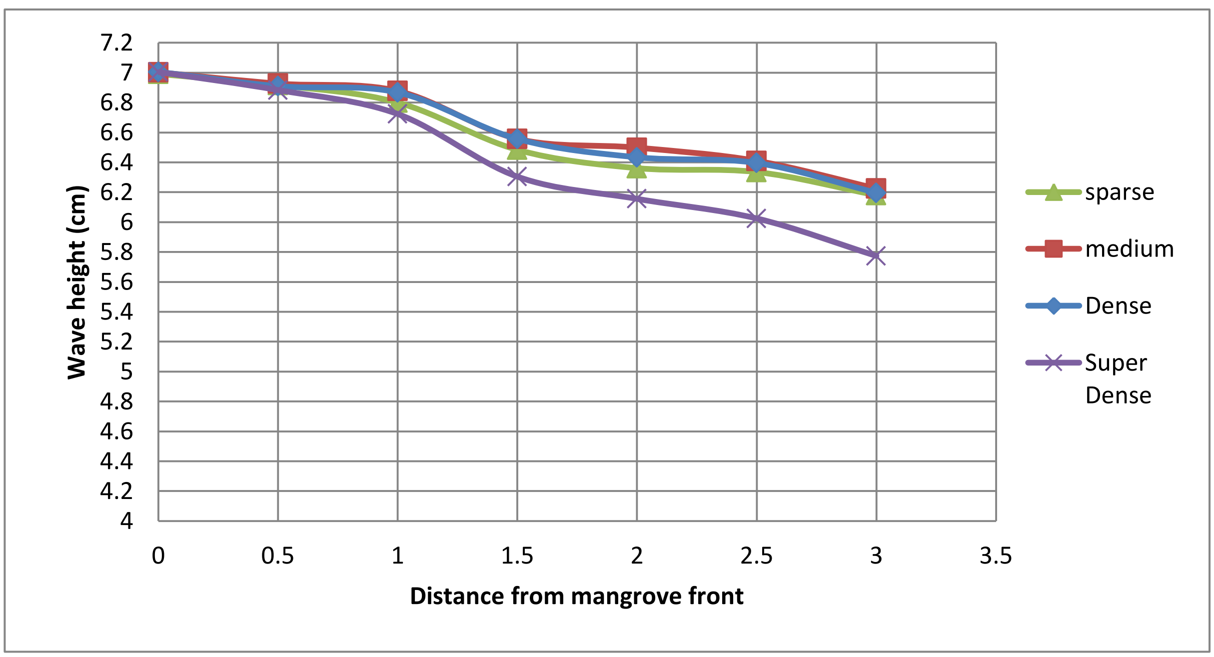


***Figure 27**: Wave reduction for mangroves with various densities. The extended for a length of mangrove models with particular densities were 3.0m.*

__Table 4:__ Wave reduction rate in various densities

Density	Wave Reduction rate, r (m^{-1})
Super Dense	0.048688
Dense	0.035231
Medium	0.032582
Sparse	0.031840

__Table 5:__ Estimated total wave reduction (%) for mangrove forest in various widths with different densities

Density	Total wave reduction for mangrove forest of width		
	50 m	100 m	200 m
Super Dense	21.61 %	38.55 %	62.23 %
Dense	16.15 %	29.69 %	50.57 %
Medium	15.03 %	27.81 %	47.88 %
Sparse	14.72 %	27.27 %	47.10 %

4.1.3 Effect of wave heights on wave reduction

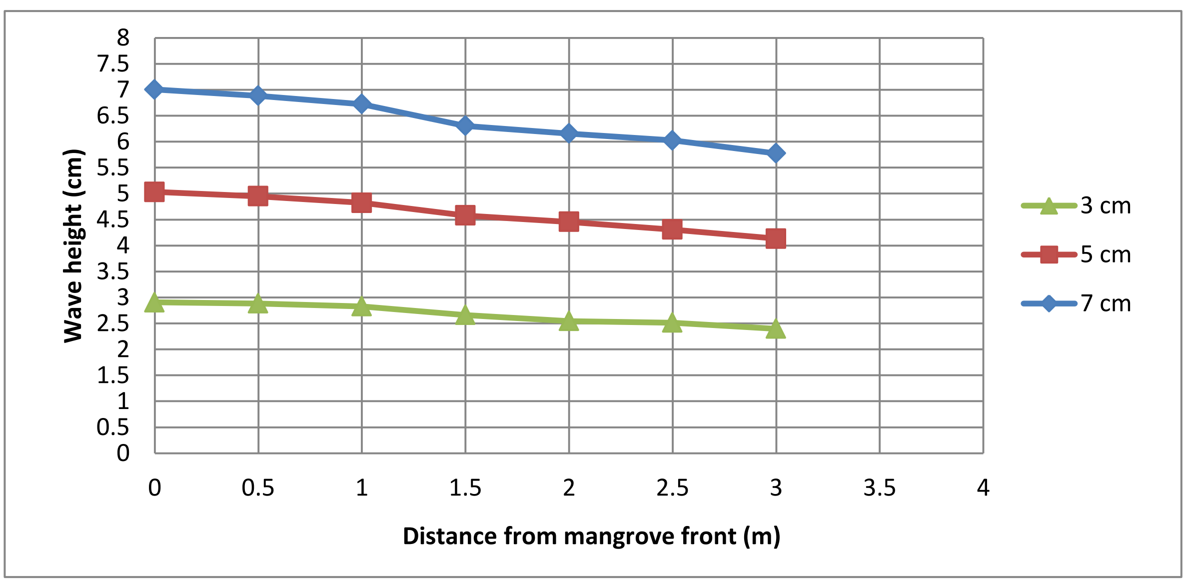


***Figure 28**: Wave reduction for mangroves with various wave heights. The extended for a length of mangrove models with particular densities were 3.0m.*

Table 6: *Wave reduction rate in various wave heights*

Wave height (m)	Wave Reduction rate, r (m^{-1})
0.03	0.048688
0.05	0.054326
0.07	0.055855

Table 7: *Estimated total wave reduction (%) for mangrove forest for various wave heights*

Wave Height (m)	Total wave reduction for mangrove forest of width	
	50 m	100 m
0.03	18.61 %	39.80 %
0.05	20.79 %	38.91 %
0.07	21.37 %	40.00 %

4.1.4 Effect of water depths on wave reduction

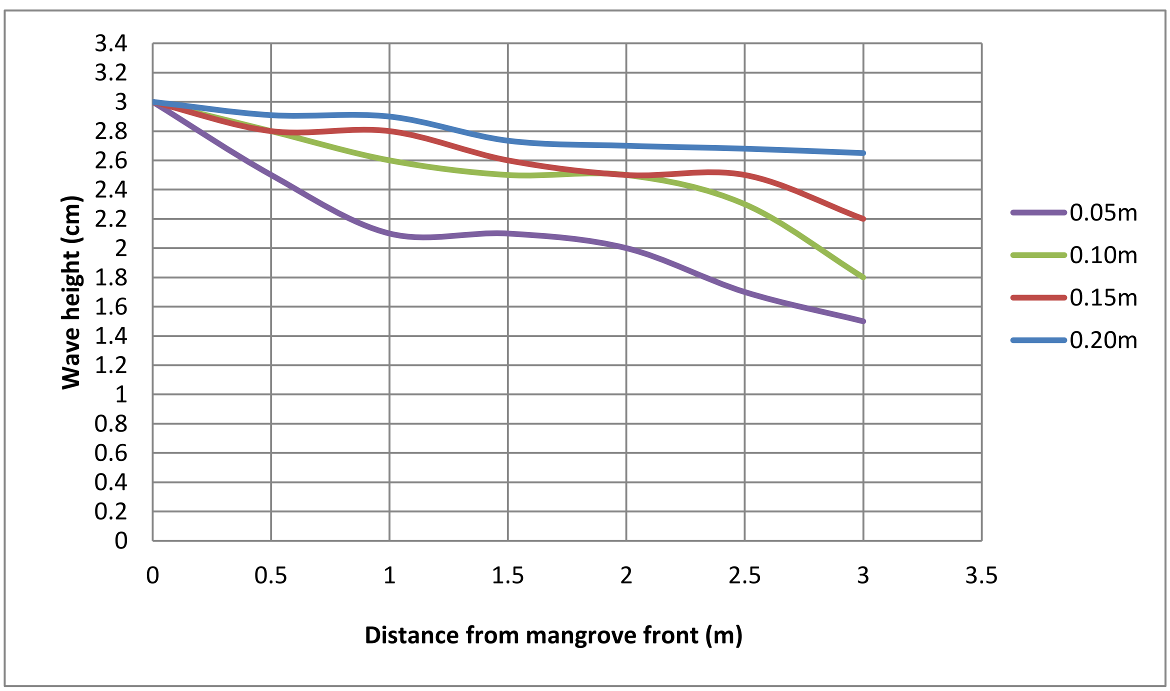


Figure 29*: Wave reduction for mangroves with various water depths.*

Table 8: *Wave reduction rate with different water depths*

Water Depth (m)	**Wave Reduction rate, r (m^{-1})**
0.05	0.27001
0.10	0.12836
0.15	0.09498
0.20	0.04939

Table 9: *Estimated total wave reduction (%) for mangrove forest with various water depths*

Wave Height (m)	**Total wave reduction for mangrove forest of width**	
	50 m	**100 m**
0.05	69.08 %	88.28 %
0.10	42.37 %	67.30 %
0.15	32.81 %	56.32 %
0.20	16.88 %	33.98 %

4.1.5 Comparison of mangrove performance of age 5, 10 and 20 years old on tree arrangement

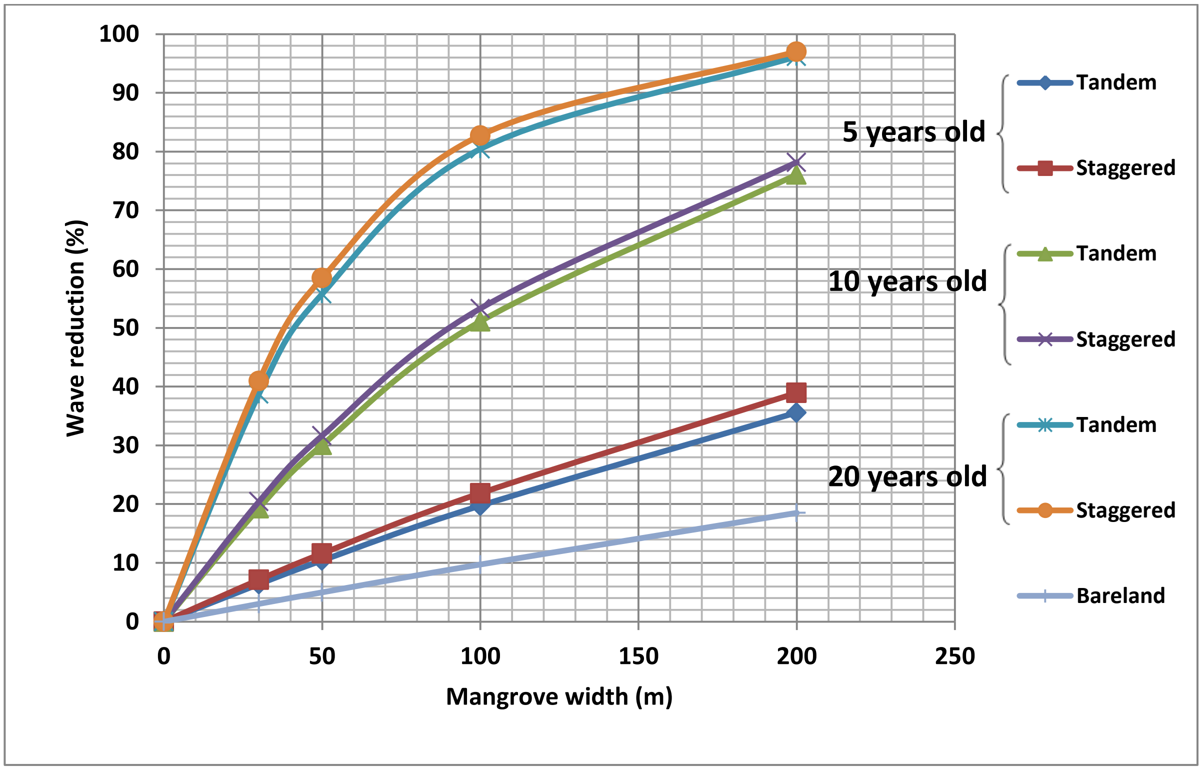


***Figure 30**: Wave reduction with respect to age group with different tree arrangements*

***Table 10:** Wave reduction rate with different tree arrangements*

Tree Arrangement	**Wave Reduction rate, r (m^{-1}) for 5 years**	**Wave Reduction rate, r (m^{-1}) for 10 years**	**Wave Reduction rate, r (m^{-1}) for 20 years**
Bare land	0.01023	0.03766	0.0247
Tandem	0.02199	0.07153	0.1632
Staggered	0.02467	0.07614	0.1758

Table 11: *Comparison of estimated total wave reduction (%) for mangrove forest age 5, 10 and 20 years old on tree arrangement*

Tree Arrangement	**Total wave reduction for mangrove forest of width**								
	30 m			**50 m**			**100 m**		
	5 years	10 years	20 years	5 years	10 years	20 years	5 years	10 years	20 years
Bare land	3.02%	10.68%	7.14%	4.99%	17.16%	11.62%	9.73%	20.38%	21.89%
Tandem	6.38%	19.31%	38.71%	10.41%	30.07%	55.78%	19.74%	51.10%	80.45%
Staggered	7.13%	20.42%	40.99%	11.60%	31.66%	58.48%	21.86%	53.30%	82.76%

4.1.5 Comparison of mangrove performance of age 5, 10 and 20 years old on tree densities

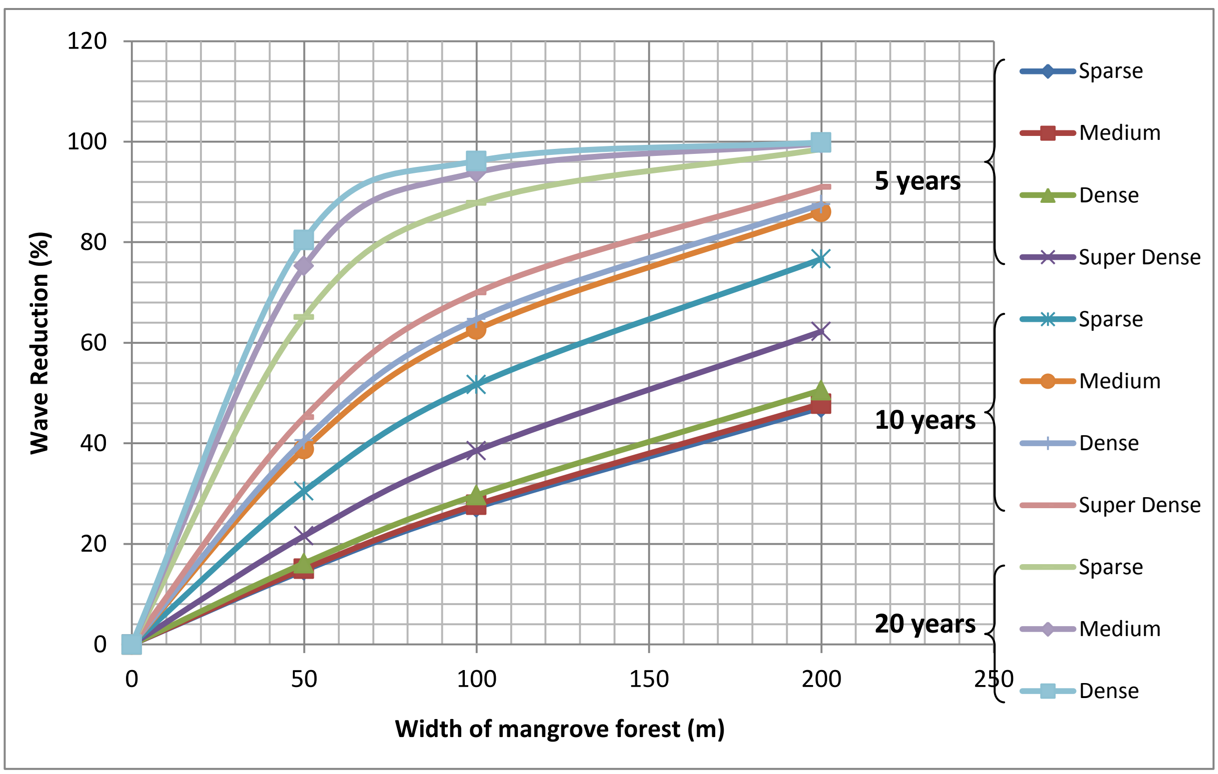


Figure 31: *Wave reduction with respect to age group with different tree densities*

__Table 12:__ Wave reduction rate with various densities

Density	Wave Reduction rate, r (m^{-1}) for 5 years	Wave Reduction rate, r (m^{-1}) for 10 years	Wave Reduction rate, r (m^{-1}) for 20 years
Super Dense	0.04869	0.12034	-
Dense	0.03258	0.10415	0.3261
Medium	0.03523	0.09844	0.2795
Sparse	0.04869	0.07276	0.2106

__Table 13:__ Comparison of estimated total wave reduction (%) for mangrove forest age 5, 10 and 20 years old on various densities

Density	Total wave reduction for mangrove forest of width								
	50 m			10 m			200 m		
	5 years	10 years	20 years	5 years	10 years	20 years	5 years	10 years	20 years
Super Dense	21.61%	45.21%	-	38.55%	69.985	-	62.23%	90.99%	-
Dense	16.15%	40.59%	80.42%	29.69%	64.71%	96.17%	50.57%	87.54%	99.85%
Medium	15.03%	38.87%	75.28%	27.81%	62.63%	93.89%	47.88%	86.04%	99.63%
Sparse	14.72%	30.50%	65.11%	27.27%	51.69%	87.83%	47.10%	76.67%	98.52%

4.2 DISCUSSION

The experimental showed that mangroves arranged in staggered order and high density gave larger reduction rate. The wave reduction was significantly higher in area with mangroves due to the additional friction contributed at the trunks and root system. The area without mangroves had shown a slight reduction in the wave heights because the reduction is mainly caused by the bottom friction because of the sandy surface. The difference of wave reduction between tandem and staggered arrangement was less than 2%, which was not significant. Based on Figure 30, the graph plotted shown that mangrove models of age 20 years in staggered order resulted higher wave reduction compared to tandem arrangement. This is due to waves could not propagate freely through the gaps between mangrove plants when mangroves were arranged in staggered arrangement meanwhile in tandem arrangement, more wave energy was dissipated. This is supported by Hashim et al. (2013) that in mangrove replanting project, the arrangement of mangrove seedlings is not important because the structure of Rhizophora roots spread widely. The wave reduction was still high even in tandem or staggered order.

For a 200 m mangrove forest width, a density of 0.11 trees/m² is sufficient to reduce wave height over 50 %. This findings strengthening the suggestions by Wang et al. (2013) that 5 years of mangrove forest can effectively and strongly act as attenuators due to that hardly any effect on wave energy reduction compared to tall mangrove trees which easily to broke. The height of mangroves is a factor that related to the impact from wind and in relation to wave attenuation. Referred to Table 9, the 0.05m water depth was estimated to give 88.28% of wave reduction across 100 m wide mangrove forest. Significant wave reduction was shown when water level was within the height of the roots. At this shallow water depth, the higher the wave heights, the more wave reduction occurred. Even though the root system of a five years old mangrove is not a completely developed aerial root systems, the laboratory experiment revealed that the root structure is still able to provide substantial wave dissipation.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

As a conclusion, this project is important because it helps to mitigate erosion problem as high waves could wash away the soil, causing higher cost to retreat the coastline. Mangroves are known to dissipate significant amounts of wave energy over relatively short distance, which has significance in the area of coastal protection. The wave attenuation potential of mangrove forests has been seen as highly efficient if certain conditions are satisfied such as density and height of the mangrove forest, diameter of mangrove roots and trunks, and canopy density. Findings from this research have added more understanding on the potential performance of a particular mangrove age in effectively reducing wave impact to the lee-side of the coastal area.

Another study in the Thai Binh Province in Vietnam showed that over a 1500 m wide mangrove forest with 5-6 years old trees and incident waves with average height of 1 meter are slightly reduced to not more than 0.05 meter at the landside of the forest. Thus, this project had investigated that the age of the mangroves plays an important role for the mangrove forests in attenuating surface wave and revealed that the younger trees had contribute in wave reduction. Since Rhizophora species is commonly found in Malaysia, the recommendation for future research is to determine and investigate the performance of the other species mangrove characteristics like Avicennia, Sonneratia, Bruguiera, Ceriops or Xylocarpus Granatum in coastal protection. Rhizophora species have stilt roots to dissipate the wave and other species also have their own unique characteristics in dissipating wave energy that still remain uncertainty.

The mangrove forest reduces the impact of waves in the most natural way for coastal protection. The effort to replanting the mangroves along the coast should be continued especially in the areas that are vulnerable to the impact of waves in order to protect the coastal zones against erosion.

REFERENCES

Alongi, D. M. (2008). Mangrove forests: resilience, protection from tsunamis, and responses to global climate change. *Estuarine, Coastal and Shelf Science, 76*(1), 1-13.

Baird, A. H., Bhalla, R. S., Kerr, A. M., Pelkey, N. W., & Srinivas, V. (2009). Do mangroves provide an effective barrier to storm surges? *Proceedings of the National Academy of Sciences, 106*(40), E111-E111.

Bao, T. Q. (2011). Effect of mangrove forest structures on wave attenuation in coastal Vietnam. *Oceanologia, 53*(3).

Brinkman, R. M. (2006). *Wave attenuation in mangrove forests: an investigation through field and theoretical studies.* James Cook University.

Cui, J., Deng, Z., Li, J., Fu, H., Proksch, P., & Lin, W. (2005). Phragmalin-type limonoids from the mangrove plant< i> Xylocarpus granatum</i>. *Phytochemistry, 66*(19), 2334-2339.

Danielsen, F., Sørensen, M. K., Olwig, M. F., Selvam, V., Parish, F., Burgess, N. D., . . . Hansen, L. B. (2005). The Asian tsunami: a protective role for coastal vegetation. *Science(Washington), 310*(5748), 643.

Davis, J. H. (1940). The ecology and geologic role of mangroves in Florida. *Publications of the Carnegie Institution of Washington*(517), 303-412.

Duke, N. (2006). Rhizophora apiculata, R. mucronata, R. stylosa, R.× annamalai, R.× lamarckii (Indo-West Pacific stilt mangrove), ver. 2.1. *Species profiles for*

Pacific Island Agroforestry. Permanent Agriculture Resources, Holualoa, Hawaii.

Feller, I., & Sitnik, M. (1996). Mangrove ecology: a manual for a field course. A field manual focused on the biocomplexity on mangrove ecosystems. *Smithsonian Institution, Washington*.

Hashim, R., Kamali, B., Tamin, N. M., & Zakaria, R. (2010). An integrated approach to coastal rehabilitation: Mangrove restoration in Sungai Haji Dorani, Malaysia. *Estuarine, Coastal and Shelf Science, 86*(1), 118-124.

Hogarth, P., & Hogarth, P. J. (2007). *The biology of mangroves and seagrasses*: Oxford University Press.

Hossain, M., Othman, S., Bujang, J. S., & Kusnan, M. (2008). Net primary productivity of< i> Bruguiera parviflora</i>(Wight & Arn.) dominated mangrove forest at Kuala Selangor, Malaysia. *Forest ecology and management, 255*(1), 179-182.

Ismail, H., Wahab, A. A., & Alias, N. (2012). Determination of mangrove forest performance in reducing tsunami run-up using physical models. *Natural hazards, 63*(2), 939-963.

Jin-Eong, O. (1995). *The ecology of mangrove conservation & management.* Paper presented at the Asia-Pacific Symposium on Mangrove Ecosystems.

Jusoff, K. (2013). Malaysian Mangrove Forests and their Significance to the Coastal Marine Environment. *Polish Journal of Environmental Studies, 22*(4).

Kangas, P. (2002). Mangrove forest structure on the Sittee River, Belize. *Unpublished manuscript. Natural Resources Management Program, University of Maryland, College Park, Maryland*.

Kathiresan, K., & Rajendran, N. (2005). Coastal mangrove forests mitigated tsunami. *Estuarine, Coastal and Shelf Science, 65*(3), 601-606.

Kerr, A. M., Baird, A. H., & Campbell, S. J. (2006). Comments on "Coastal mangrove forests mitigated tsunami" by K. Kathiresan and N. Rajendran [Estuar. Coast. Shelf Sci. 65 (2005) 601–606]. *Estuarine, Coastal and Shelf Science, 67*(3), 539-541.

Latief, H., & Hadi, S. (2007). *The role of forests and trees in protecting coastal areas against tsunamis.* Paper presented at the Regional Technical Workshop on Coastal Protection in the Aftermath of the Indian Ocean Tsunami What Role for Forests Trees.

Latiff, A., & Faridah-Hanum, I. (2014). Mangrove Ecosystem of Malaysia: Status, Challenges and Management Strategies *Mangrove Ecosystems of Asia* (pp. 1-22): Springer.

Lewis Iii, R. R. (2000). Ecologically based goal setting in mangrove forest and tidal marsh restoration. *Ecological Engineering, 15*(3), 191-198.

Lugo, A. E., & Snedaker, S. C. (1974). The ecology of mangroves. *Annual review of ecology and systematics*, 39-64.

Massel, S., Furukawa, K., & Brinkman, R. (1999). Surface wave propagation in mangrove forests. *Fluid Dynamics Research, 24*(4), 219-249.

Mazda, Y., Magi, M., Kogo, M., & Hong, P. N. (1997). Mangroves as a coastal protection from waves in the Tong King delta, Vietnam. *Mangroves and salt marshes, 1*(2), 127-135.

Mazda, Y., Wolanski, E., King, B., Sase, A., Ohtsuka, D., & Magi, M. (1997). Drag force due to vegetation in mangrove swamps. *Mangroves and salt marshes, 1*(3), 193-199.

McIvor, A., Spencer, T., Möller, I., & Spalding, M. (2012). Storm surge reduction by mangroves. *Natural Coastal Protection Series: Report, 2*, 36.

Othman, M. A. (1994). Value of mangroves in coastal protection *Ecology and Conservation of Southeast Asian Marine and Freshwater Environments including Wetlands* (pp. 277-282): Springer.

Primavera, J. H., & Esteban, J. (2008). A review of mangrove rehabilitation in the Philippines: successes, failures and future prospects. *Wetlands Ecology and Management, 16*(5), 345-358.

Quartel, S., Kroon, A., Augustinus, P., Van Santen, P., & Tri, N. (2007). Wave attenuation in coastal mangroves in the Red River Delta, Vietnam. *Journal of Asian Earth Sciences, 29*(4), 576-584.

Rovai, A. S., Barufi, J. B., Pagliosa, P. R., Scherner, F., Torres, M. A., Horta, P. A., . . . Soriano-Sierra, E. J. (2013). Photosynthetic performance of restored and natural mangroves under different environmental constraints. *Environmental Pollution, 181*, 233-241.

Tamin, N. M., Zakaria, R., Hashim, R., & Yin, Y. (2011). Establishment of< i> Avicennia marina</i> mangroves on accreting coastline at Sungai Haji Dorani, Selangor, Malaysia. *Estuarine, Coastal and Shelf Science, 94*(4), 334-342.

Tanaka, N., Sasaki, Y., Mowjood, M., Jinadasa, K., & Homchuen, S. (2007). Coastal vegetation structures and their functions in tsunami protection: experience of the recent Indian Ocean tsunami. *Landscape and Ecological Engineering, 3*(1), 33-45.

Tomlinson, P. B., & Tomlinson, P. B. (1994). *The botany of mangroves*: Cambridge University Press.

Vogt, J., Skóra, A., Feller, I. C., Piou, C., Coldren, G., & Berger, U. (2012). Investigating the role of impoundment and forest structure on the resistance and resilience of mangrove forests to hurricanes. *Aquatic botany, 97*(1), 24-29.

Wamsley, T. V., Cialone, M. A., Smith, J. M., Atkinson, J. H., & Rosati, J. D. (2010). The potential of wetlands in reducing storm surge. *Ocean Engineering, 37*(1), 59-68.

Wang, G., Guan, D., Peart, M., Chen, Y., & Peng, Y. (2013). Ecosystem carbon stocks of mangrove forest in Yingluo Bay, Guangdong Province of South China. *Forest ecology and management, 310*, 539-546.

Yin, S., Wang, X.-N., Fan, C.-Q., Lin, L.-P., Ding, J., & Yue, J.-M. (2007). Limonoids from the seeds of the marine mangrove Xylocarpus granatum. *Journal of natural products, 70*(4), 682-685.

APPENDIX 1

Calculation of mangrove forest density

Case: Super Dense

Spacing between trees = 0.10 m

Forest width = 1.5 m

Forest length = 4.5 m

Number of trees/models = 245

$$\text{Density} = \frac{245 \text{ models}}{1.5 \text{ m} \times 4.5 \text{ m}} = 36.30 \text{ models/m2}$$

$$\text{Density (real)} = \frac{245 \text{ models}}{15 \text{ m} \times 45 \text{ m}} = 0.363 \text{ models/m2}$$

Case: Dense

Spacing between trees = 0.10 m

Forest width = 1.5 m

Forest length = 4.0 m

Number of trees/models = 132

$$\text{Density} = \frac{132 \text{ models}}{1.5 \text{ m} \times 4.0 \text{ m}} = 22.00 \text{ models/m2}$$

$$\text{Density (real)} = \frac{132 \text{ models}}{15 \text{ m} \times 40 \text{ m}} = 0.22 \text{ models/m2}$$

Case: Medium

Spacing between trees = 0.10 m

Forest width = 1.5 m

Forest length = 3.5 m

Number of trees/models = 84

$$\text{Density} = \frac{84 \text{ models}}{1.5 \text{ m} \times 3.5 \text{ m}} = 16.00 \text{ models/m2}$$

$$\text{Density (real)} = \frac{84 \text{ models}}{15 \text{ m} \times 35 \text{ m}} = 0.16 \text{ models/m2}$$

Case: Sparse

Spacing between trees = 0.10 m

Forest width = 1.5 m

Forest length = 3.0m

Number of trees/models = 50

$$\text{Density} = \frac{50 \text{ models}}{1.5 \text{ m} \times 3.0 \text{ m}} = 11.11 \text{ models/m2}$$

$$\text{Density (real)} = \frac{50 \text{ models}}{15 \text{ m} \times 30 \text{ m}} = 0.11 \text{ models/m2}$$

APPENDIX 2

Sample calculation for wave reduction

Effect of densities on wave reduction: **Sparse**

Distance from mangrove front (m)	0	0.5	1.0	1.5	2.0	2.5	3.0
Wave height (cm)	6.99	6.92	6.80	6.48	6.36	6.34	6.18

Hx = Ho exp (-rx)

At x = 0.5 m,

6.92 = 6.99 exp (- r (0.5))

r = 0.021351

At x = 1.0 m,

6.80 = 6.99 exp (- r (1.0))

r = 0.027717

At x = 1.5 m,

6.48 = 6.99 exp (- r (1.5))

r = 0.050233

At x = 2.0 m,

6.36 = 6.99 exp (- r (2.0))

r = 0.04722

At x = 2.5 m,

6.34 = 6.99 exp (- r (2.5))

r = 0.03941

At x = 3.0 m,

6.18 = 6.99 exp (- r (3.0))

r = 0.041107

$$\text{Average } r = \frac{0.021351 + 0.027717 + 0.050233 + 0.04722 + 0.03941 + 0.041107}{6}$$

$$= 0.03784$$

When x = 0.5 m,

Hx = 6.99 exp (-0.03784 x 0.5) = 6.860 cm

When x = 1.5 m,

Hx = 6.99 exp (-0.03784 x 1.5) = 6.605 cm

When mangrove forest width = 50 m,

In laboratory scale, x = 5 m

Hx = Ho exp (-rx)

Hx = Ho exp (-0.03784 x 5)

Hx = 0.827621Ho

Wave reduction = (1 – 0.827621)*100 = 17.2379%