Study on Coral Reefs Influences on Wave Runup Using LABSWE™

by

Hafizul Fahmi bin Zulkifli
19122

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)
(Civil)

SEPTEMBER 2017

Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Study on Coral Reefs Influences on Wave Runup Using LABSWE™

by

Hafizul Fahmi bin Zulkifli
19122

A project dissertation submitted to the
Civil Engineering programme
Universiti Teknologi PETRONAS
In partial fulfilment of the requirement for
BACHELOR OF ENGINEERING (Hons)
(CIVIL)

Approved by,

____

(DR SITI HABIBAH BINTI SHAFIAI)

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
32610, Teronoh
Perak Darul Ridzuan
September 2017

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.

(HAFIZUL FAHMI BIN ZULKIFLI)

ABSTRACT

Wave runup is one of the factor which is related to coastal erosion. As the height of wave runup increases, more area of the coastline will be exposed to erosion. Coral reef is known to be a natural protection for the coastline. This research discusses about the effect towards the wave runup when coral reef is present. The hypothesis for this study is when the height of coral increases, the height of wave runup decreases. The simulation of wave runup using numerical model, in this case LABSWE™, is carried out in order for us to predict the changes and effects which occurs to the wave runup when there is presence of coral which shall be varied by height. The simulation is compared to a similar experimental simulation which is done in the laboratory. The results show how the wave runup reacts to coral reef and also the reliability of LABSWE™ in predicting the wave runup.

ACKNOWLEDGEMENT

First and foremost, all praise to God the Almighty for He has given the permission and strength for me to complete this research. It is undeniable that without His permission, I would not be able to finish this research.

Next, I would like to express my highest gratitude to my beloved Final Year Project supervisor, Dr. Siti Habibah binti Shafiai as she had guided and assisted me in completing this study. Although some of the things that I faced while doing this research are new to me, she has given me enough guidance. Motivation is also an element which she has given me from the very beginning until my research is completed.

Next, I would like to thank my mother for giving me her full support both in the forms of financial as well as moral support. Lastly, thank you to my colleagues as they have helped me a lot in giving ideas for me to finish this research.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Coral reefs are often called the rainforests of the sea. It is estimated that around 1,868,000 known species of coral inhabiting the ocean all over the globe (Reaka-Kudla, 1997). Reaka-Kudla (1997) also stated that there are various types of coral reefs existing which act as habitats to over 9 million species of aquatic organisms all around the world. The coral reefs spread vastly across the open ocean and along coasts in tropical and subtropical waters.

Darwin (1842) stated that there are 3 principal types of coral reefs; barrier reefs, fringing reefs and atoll reefs (table 1.1). A barrier reef is a reef separated from a mainland or island shore by a deep channel or lagoon. As for fringing reef, it is directly attached to a shore, or borders it with an intervening shallow channel or lagoon. An atoll reef is more or less circular or continuous barrier reef extends all the way around a lagoon without a central island.

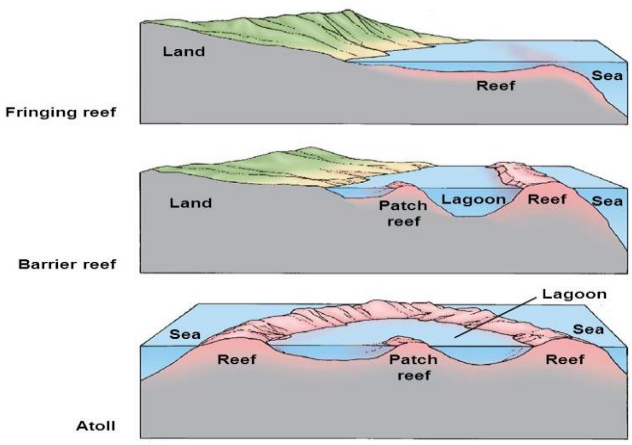


FIGURE 1.1 3 Principal types of reefs.

Nowadays, coastal erosion has become a world-wide phenomenon (Williams, 2017). Sorensen (1997) stated that wave runup is a vital procedure in causing as well as promoting bluff erosion. Sorensen (1997) described wave runup as the maximum vertical extent of wave uprush on a beach or structure above the still water level (SWL). Figure 1.2 below briefly describes wave runup,

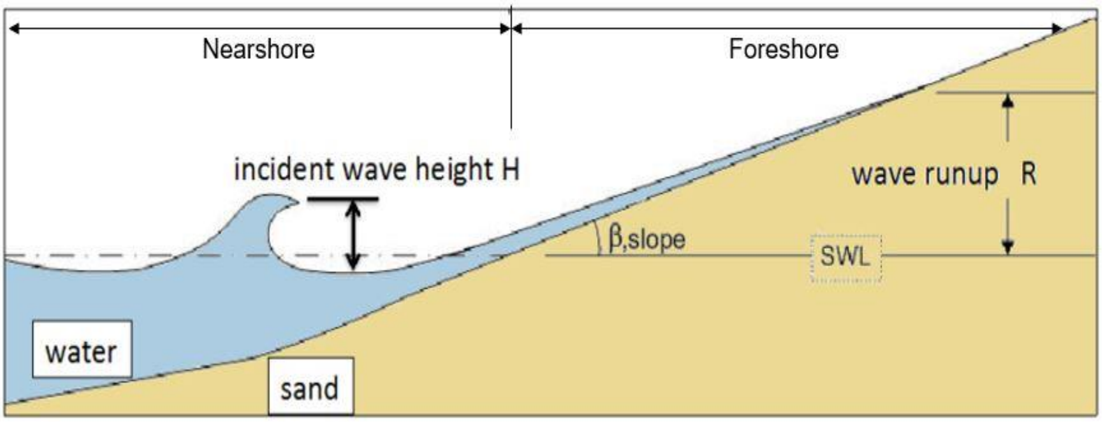


FIGURE 1.2 Wave profile for wave runup.

Sorensen (1997) further explained that wave runup causes coastal erosion upon contact with the bluff where it removes the materials at the coast and redistributes it to the foreshore and nearshore.

According to Ferrario et al. (2014), the presence of coral reefs contributes to the protection of mainland and island coasts from the effects of severe storm waves, storm surges and tsunamis. Moreover, it also helps in limiting erosions in coastal areas. Hence, in order to further study this current phenomenon, LABSWE^{TM} has been chosen to be used to simulate the wave runup with presence of coral reefs.

LABSWE^{TM} stands for Lattice-Boltzmann Shallow Water Equation for Turbulence Modelling. LABSWE^{TM} is an extension from the original Lattice-Boltzmann Shallow Water Equation where its only difference is in the eddy viscosity added in the momentum equation for LABSWE^{TM} (Zhou, 2004). LABSWE is an expansion from the original Lattice-Boltzmann Method (LBM), a modern numerical technique which can be used to solve for flow equations.

The Lattice-Boltzmann Method (LBM), consequently LABSWE^{TM}, carries some advantages as compared to other traditional computational fluid dynamic methods such as finite element method, finite difference method and finite volume method. Zhou (2004) described the advantages to be:

i. easier to program as it consists of only simple arithmetic calculations;
ii. has only one single variable that is unknown and required to be determined which is the microscopic distribution function;
iii. current value of the distribution function depends only on the previous conditions which is ideal for parallel computations;
iv. easy implementation of boundary conditions, making it suitable for flow in complex geometry;
v. easy to simulate complex flow.

1.2 PROBLEM STATEMENT

Nowadays, coastal erosion has indeed become an alarming issue. Francesco et. al. (2014) claimed that coastal erosion is a natural phenomenon which is increasingly occurring worldwide. The higher the wave runup, the more the area of the beach that is exposed to erosion. Table 1.1 shows the data for beach erosion in Malaysia for the latest year updated of 2013. The data was obtained from Department of Irrigation and Drainage (DID) of Malaysia. Based on the data provided, the percentage of erosion for several states can be seen to be quite significant. It is believed that the presence of coral reefs along a shoreline as a natural barrier may contribute in limiting coastal erosion. Hence, this study is significant in helping to decide the optimum height of coral to be grown, nurtured and preserved along shorelines in order to create a natural barrier for the coastal areas.

TABLE 1.1 Data for beach erosion in Malaysia according to states (latest update: 2013).

State	**Beach Length (km)**	**Number of Beach Eroded**	**Percentage of Erosion %**
Perlis	20	8	72.50
Kedah	148	20	29.40
Pulau Pinang	152	15	41.60
Perak	230	10	61.00
Selangor	213	20	71.30
N. Sembilan	58	7	42.20
Melaka	73	9	50.30
Johor	492	29	47.70
Pahang	271	22	46.30
Terengganu	244	22	62.50
Kelantan	71	11	73.40
W. P Labuan	59	6	51.90
Sarawak	1035	25	4.80
Sabah	1743	19	17.00
TOTAL	**4,809**	**223**	

1.3 SCOPE OF STUDY

Location: Pantai Chendering, Kuala Terengganu

The study for influences of coral reefs towards wave runup will be based on Pantai Chendering, Kuala Terengganu. The wave data for the particular location is obtained from Malaysian Meteorological Department (MMD). The water profile, on the other hand, is obtained from the Department of Irrigation and Drainage (DID) of Malaysia.

Coral Reef: Acropora Millepora sp.

There are a vast range of coral species existing in this world. For the purpose of this study, the species Acropora Millepora sp.**,** has been chosen to be modelled in the LABSWE^{TM}. The coral comes from the Animalia kingdom, Cnidaria phylum, Anthozoa class, Scleractinia order and Acroporidae family. Being in the Scleractinia order categorizes the Acropora Millepora sp. as a stony coral. The coral habitat extends from the Red Sea, Kenya, South Africa, India, Malaysia, Indonesia, Japan and Australia (Richard et al., 2014). An example of the chosen coral type can be seen in figure 1.3 below:

FIGURE 1.3 Acropora Millepora sp. in its natural habitat.

The Acropora Millepora sp. lives in shallow water which is between two meters to twelve meters deep, usually in the reef flat region (Richard et al., 2014). Acropora Millepora sp. is chosen due to the suitability of its habitat with the water profile of Pantai Chendering as well as due to the species being commonly found in the coasts of Malaysia.

Wave Runup Model: Regular Sine Waves on a Plane Beach

For the wave runup, some of the parameters considered for the runup are beach slope, β, wavelength, L, runup height, R, wave frequency, f and wave period, T. The parameters for the wave runup are illustrated in figure 1.4 below,

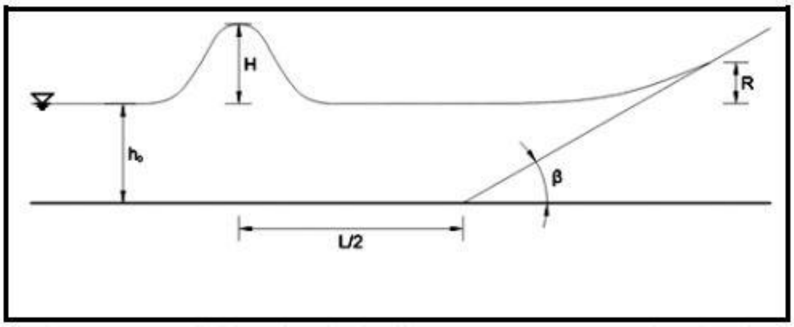


FIGURE 1.4 Sketch of wave profile for wave runup.

Regular sine waves with frequency, f of 1.8Hz are considered in the simulation. As for the beach slope, the slope value used is 1:3.

LABSWE^{TM}: Moving Shoreline

Moving shoreline involves the wetting and drying, which is a feature of flows in shallow coastal areas as well as in embayment and inlets (Shafiai, 2011). Shafiai also stated that in extreme tides, the process of wetting and drying may affect the local navigation routes. Hence, it is plausible to carry out a study for the wave runup.

In locating the wet-dry front in the swash zone, the moving shoreline algorithm is used. This will determine the wave runup on the beach. In present study, LABSWE^{TM} is used to simulate wave runup for a regular sine wave runup at a plane beach with the presence of the Acropora Millepora sp..

The validation for the simulation shall be done by comparing the simulation results with experimental results.

1.4 OBJECTIVES

i. To simulate wave runups with presence of Acropora Millepora sp. coral species at laboratory.
ii. To simulate wave runups with presence of Acropora Millepora sp. coral species using MATLAB software.
iii. To analyse maximum runup & water profile by using LABSWE^{TM}.

CHAPTER 2

LITERATURE REVIEW

2.1 MATLAB: Matrix Laboratory

MATLAB, which stands for Matrix Laboratory is an interactive program that serves the purpose as a "laboratory" for numerical computations involving matrices (Ruscio, 2009). Apart from being one of the most essential tools for numerical computations in universities and communities of research all around the globe, it is also widely used in for industrial applications. MATLAB, which utilizes the C and C++ language, has many graphical capabilities which can be extended through the programs coded in its own language (Rodriguez, n.d).

2.2 Previous Studies Involving Wave Runup

There are various studies conducted which involve modelling of the wave runup to study the maximum runup and water profile. However, not many studies take into account the effects of coral reefs onto the condition of the wave runup using LABSWE^{TM}.

A study was carried out by Ha et al. (2014) using the Immersed Boundary (IB) method to analyse the maximum runup of wave around an island. This method uses the basic of the Navier – Stokes Equation where it also involves a numerical or mathematical model. In this study, the Numerical Wave Tank (NEWTANK) model was applied. The result of the research was compared with experimental results conducted in a laboratory. It was concluded from the study that the Immersed Boundary (IB) method is a good method to be used to study wave runups. Nevertheless, no parts of their study include any contributions from coral reefs to the wave runup.

Another research was done by Milanian (2017) based on numerical modelling performed using Flow-3D software to study effect of berm breakwater on wave runup. The Navier – Stokes Equation was directly applied in this study. The result of the study where wave runup decrease in height as berm breakwater size increase was compared with experimental results carried out in a laboratory. Similar to the previous research stated, no effect from coral reefs was taken into consideration in this study as well.

Shafiai (2011) also conducted a research to study the Lattice-Boltzmann method (LBM) which applications include different types of free surface flows and long wave runup problems. In this study, Lattice-Boltzmann Shallow Water Equation for Turbulence Modelling (LABSWE^{TM}) was used to simulate the wave flow. As the aims of this study is to improve the LBM, it highlights many advantages as well as disadvantages of the LBM (consequently LABSWE^{TM}) which is open for improvements. The results of this study are water profiles based on various conditions. The results of the simulations are also compared to experimental results. There were also no parts of this study which involve coral reefs influences on wave runup. However, this study is quite related to the proposed study as it utilizes the same computational fluid dynamic method which is LABSWE^{TM}.

2.3 Coral Reef Effects on Wave

Eliff and Silva (2017) in their research, stated that coral reefs are "responsible for a wide array of ecosystem services including shoreline protection". They described that the coral reefs are essential for the well-beings of humankind especially how we are living our lives near the coastal area. Based on their research, wave energy attenuation can be seen as a way for the coral to limit the erosion on coastal areas.

Principe et. al. (2012) claimed that the wave breaking over the reef crest as well as the friction caused by the reef flat's rugosity are able to weaken the energy of offshore waves as shown in figure 2.1. The effect may vary significantly with different types of coral reefs. According to UNEP-WCMC (2006), the wider the reef flats, the higher the attenuation rates of wave energy and wave height. This statement is supported by Quartaert et. al. (2015) where they stated that the breadth of the reef flat is expected to influence the rates of energy dissipation caused by friction along the reef.

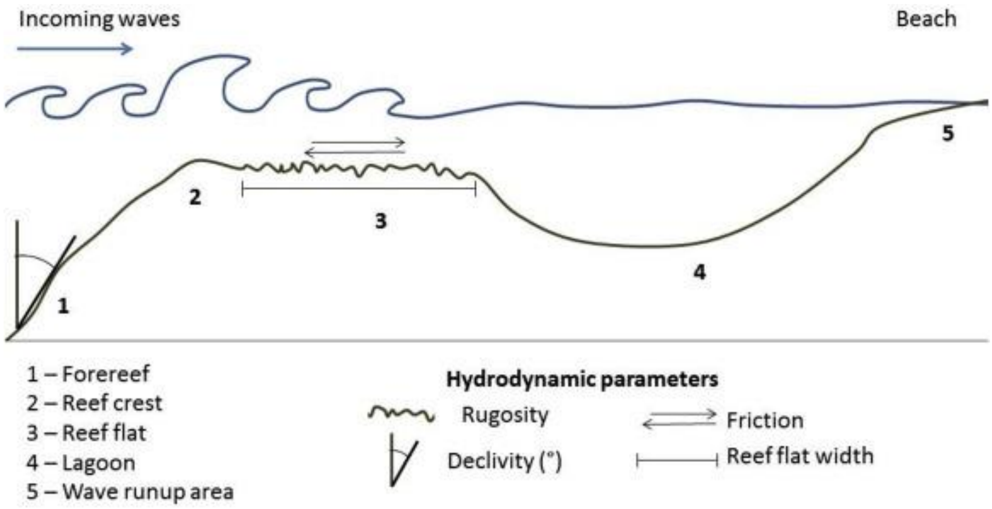


FIGURE 2.1 Reef zones and hydrodynamic parameters involved in the attenuation of wave energy and wave height.

On the other hand, Ferrario et. al. (2014) believed that attenuation of waves can also be promoted by narrow reef flats. This is because 50% of the attenuation of energy occurs along the first 150m of the reef flats. They also found that an average of 97% of incoming wave energy is able to be attenuated by coral reefs throughout the globe. This translated to a reduction of an average of 84% of the waves heights.

The attenuation effect of the coral reef towards the wave energy might differ with conditions of wave. UNEP-WCMC (2006) stated that the coral reefs are essential for protection of the shoreline under normal conditions including during hurricanes and tropical storms. However, in the case of tsunamis which have a greatly varied capacity as compared to normal waves in term of their force, structure and form, reduces the buffering capacity of the coral reefs.

Since no studies were found which directly relates to the influences of coral reefs towards wave runup, it is completely plausible to conduct this current proposed research as it will be very beneficial to understand how and how far coral reefs actually influence wave runup. This will absolutely help to widen the knowledge and understanding regarding this matter and open up more windows for future studies which will surely contribute significantly to survivability of our coastal areas as well as mankind itself.

CHAPTER 3

METHODOLOGY

3.1 Lattice Boltzmann Shallow Water Equation for Turbulence Modelling (LABSWE^{TM})

In order to analyse the maximum runup and water profile, a conceptual model is constructed using the software MATLAB based on the LABSWE^{TM}. This is to create an idealized 1D cross-section of the bathymetry in order to study the flow of wave for the area intended.

According to Shafiai (2011), the LABSWE^{TM} is a numerical method which is derived from the two (2) equations, which are:

Continuity Equation:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{z\partial} \tag{3.1}$$

Navier – Stokes Equation (each for the respective axis x, y & z):

$$\frac{\partial u}{\partial t} + \frac{\partial uu}{\partial x} + \frac{\partial uv}{\partial y} + \frac{\partial uw}{\partial z} = \frac{1}{\rho}\frac{\partial p}{\partial x} + v\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) + f_x \tag{3.2}$$

$$\frac{\partial u}{\partial t} + \frac{\partial uv}{\partial x} + \frac{\partial vv}{\partial y} + \frac{\partial wv}{\partial z} = \frac{1}{\rho}\frac{\partial p}{\partial y} + v\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right) + f_y \tag{3.3}$$

$$\frac{\partial w}{\partial t} + \frac{\partial uw}{\partial x} + \frac{\partial vw}{\partial y} + \frac{\partial ww}{\partial z} = \frac{1}{\rho}\frac{\partial p}{\partial z} + v\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right) + f_z \tag{3.4}$$

LABSWE^{TM} can be described by extending the original Lattice-Boltzmann Shallow Water Equation, which is given by:

$$f_{\alpha}(X + e_{\alpha}\Delta t, t + \Delta t) - f_{\alpha}(X,t) = -\frac{1}{\tau}\left(f_{\alpha} - f_{\alpha}^{eq}\right) + \frac{\Delta t}{N_{\alpha} e^{2}} e_{\alpha i} F_{i} \qquad (3.5)$$

The only difference between the LABSWE and LABSWE^{TM} is in the momentum equations, specifically in the eddy viscosity, v_e (Zhou, 2004). Comparing the momentum equations for the basic LABSWE and LABSWE^{TM}, a slight difference can be seen as shown below:

Momentum equation for LABSWE:

$$\frac{\partial h}{\partial t} + \frac{\partial(hu_j)}{\partial x_j} = 0 \qquad (3.6)$$

$$\frac{\partial(hu_i)}{\partial t} + \frac{\partial(hu_i u_j)}{\partial x_j} = -g\frac{\partial}{\partial x_i}\left(\frac{h^2}{2}\right) + v\frac{\partial^2(hu_i)}{\partial x_j \partial x_j} + F_i \qquad (3.7)$$

Momentum equation for LABSWE^{TM}:

$$\frac{\partial h}{\partial t} + \frac{\partial(hu_j)}{\partial x_j} = 0 \qquad (3.6)$$

$$\frac{\partial(hu_i)}{\partial t} + \frac{\partial(hu_i u_j)}{\partial x_j} = -g\frac{\partial}{\partial x_i}\left(\frac{h^2}{2}\right) + (v + v_e)\frac{\partial^2(hu_i)}{\partial x_j \partial x_j} + F_i \qquad (3.8)$$

The eddy viscosity is included in the momentum equation for LABSWE^{TM}. This can be further backtracked into the redefinition of relaxation time, τ for LABSWE^{TM}. The redefined relaxation time for LABSWE^{TM} is as follows:

$$\tau_t = \tau + \tau_e \qquad (3.9)$$

which gives a total viscosity v_t,

$$v_t = v + v_e \qquad (3.10)$$

Comparing the above viscosity equation used in LABSWE^{TM} with the viscosity equation used in LABSWE shown below:

$$v = \frac{e^2 \Delta t}{6}(2\tau - 1) \qquad (3.11)$$

Finally, at the Lattice-Boltzmann Shallow Water Equation for Turbulence Modelling (LABSWE^{TM}), given by the equation:

$$f_{\alpha}(X + e_{\alpha}\Delta t, t + \Delta t) - f_{\alpha}(X,t) = -\frac{1}{\tau_t}(f_{\alpha} - f_{\alpha}^{eq}) + \frac{\Delta t}{6_{\alpha} e^2} e_{\alpha i} F_i \qquad (3.12)$$

3.2 Experiment for Influence of Coral towards Wave Runup

In order to validate the results obtained from the numerical method, an experiment to study the effect of coral toward the height of wave runup is carried out. The details for the experiment are as shown below.

Apparatus and materials:

i. Wave flume (L=10m, H=0.48m, W=0.32m).

FIGURE 3.1 Wave flume used for experimental process.

ii. Wave Generator.

FIGURE 3.2 Wave Generator inside wave flume.

iii. Artificial beach slope. (Slope = 1:3)

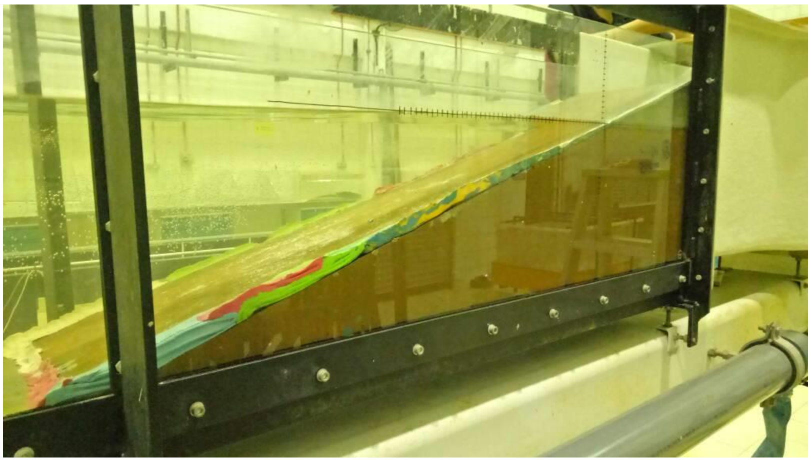


FIGURE 3.3 Artifical beach slope set up inside wave flume.

iv. Acropora Millepora sp. and Plywood stand for coral with adjustable height thread screws as feet.

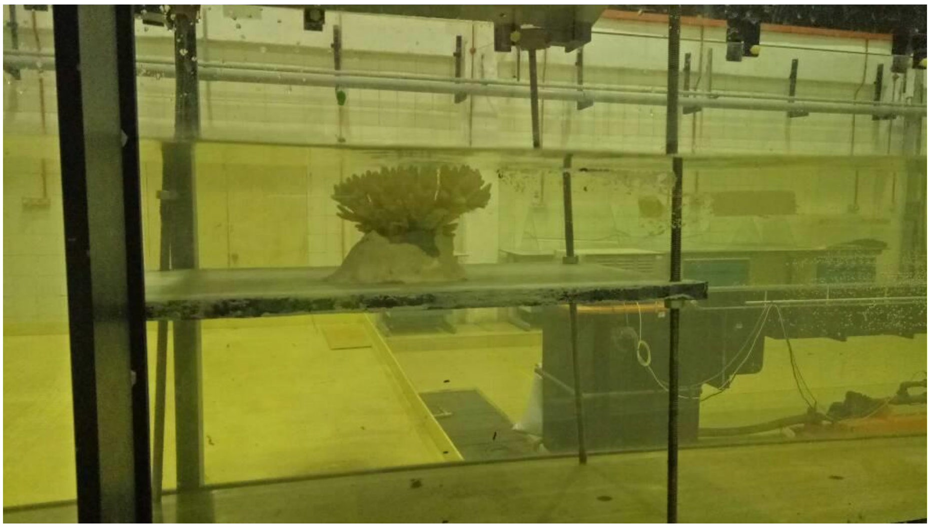


FIGURE 3.4 Acropora Millepora sp. coral fixed on adjustable plywood stand.

The apparatus and material setup for the experiment are as follows,

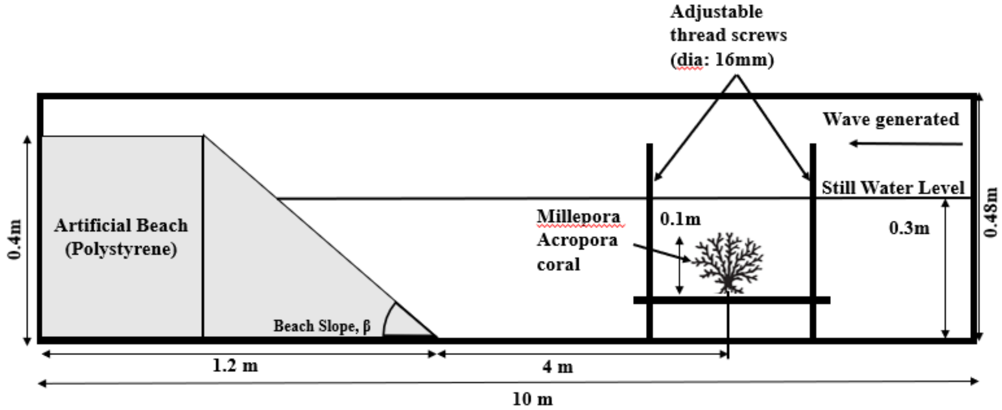


FIGURE 3.5 Layout for experiment setup (side view).

Procedure:

i. The items are set up inside the wave tank as shown in the layout.

ii. The Still Water Level is adjusted to height of 0.3 meter.

iii. An Acropora Millepora sp. coral is put on the plywood with adjustable thread screws.

iv. The height of the thread screws is set to 0 m.

v. Regular sine waves with frequency, f = 1.8Hz shall be generated using the wave generator.

vi. As the wave reaches the artificial beach, the runup height, R is taken and recorded.

vii. Steps (v) to (vi) are repeated 3 times and the average is taken.

viii. The experiment is repeated using thread screw heights of 0.05m, 0.10m, 0.15m and without coral.

3.3 Gantt Chart

TABLE 3.1 FYP I Gantt Chart

Project Activities	**Week**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Confirmation of research topic and supervising lecturer	■													
Briefing regarding research topic by supervising lecturer		■	■											
Introduction to MATLAB and LABSWE^{TM} coding			■											
Gathering information required for the study			■	■	■	■								
Preparing extended proposal for the study				■	■	■								
Submission of extended proposal						■								
Sketching layout and preparing method statement for experiment setup							■	■						
Producing flowchart and pseudocode for MATLAB coding							■	■						
Coding of LABSWE^{TM} using MATLAB								■	■					
Running trials for MATLAB coding								■	■	■				
Proposal defense								■	■					
Preparation of interim report									■	■	■	■	■	
Submission of interim report (draft)													■	
Submission of interim report (final)														■

TABLE 3.2 FYP II Gantt Chart

Project Activities	Week													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Preparing model for validation experiment (coral)	■	■												
Setting up of experiment materials and apparatus			■											
Run experiment & collect data			■	■										
Modelling of simulation in MATLAB				■	■	■								
Final simulation in MATLAB						■								
Preparation for progress report						■	■							
Submission of progress report							■							
Preparation for Pre-SEDEX								■	■	■				
Pre-SEDEX										■				
Preparation for final report 1st draft										■	■			
Submission of final report 1st draft											■			
Submission of final report (soft bound)												■		
FYP Presentation / VIVA													■	
Submission of final report (hard bound)														■

CHAPTER 4

RESULTS & DISCUSSION

4.1: Experimental Results

The experimental stage is carried out in order to validate the results obtained from the MATLAB simulation. Based on the experiment that had been carried out at the laboratory, following results were obtained:

Without coral:

TABLE 4.1.1 Experimental results for wave runup simulation without coral.

Repetition	**Wave Height, h (cm)**	**Runup Height, R (cm)**	**Travel time from generator to beach slope, t (s)**
1st	3.7	5.5	5.25
2nd	4.5	7.5	5.77
3rd	4.5	8.0	5.59
Average	4.23	7.0	5.54

Average celerity, c_{avg} = 9m / 5.54s = 1.625 m/s

With coral:

i. **Height of coral, h_{coral} = 0.1 m,**

TABLE 4.1.2 Experimental results for wave runup simulation with height of coral = 0.1m.

Repetition	Wave Height before coral, h_{before} (cm)	Wave Height after coral, h_{after} (cm)	Runup Height, R (cm)	Travel time from generator to beach slope, t (s)
1st	3.9	3.7	4.8	5.91
2nd	3.8	4.2	6.5	5.83
3rd	3.8	3.4	8.0	5.83
Average	3.83	3.77	6.43	5.86

Average celerity, c_{avg} = 9m / 5.86s = 1.536 m/s

ii. **Height of coral, h_{coral} = 0.15 m,**

TABLE 4.1.3 Experimental results for wave runup simulation with height of coral = 0.15m.

Repetition	Wave Height before coral, h_{before} (cm)	Wave Height after coral, h_{after} (cm)	Runup Height, R (cm)	Travel time from generator to beach slope, t (s)
1st	3.3	2.5	4.5	5.96
2nd	4.0	3.5	6.5	5.79
3rd	2.5	3.7	7.5	6.02
Average	3.27	3.23	6.17	5.92

Average celerity, c_{avg} = 9m / 5.92 s = 1.52 m/s

iii. Height of coral, h_{coral} = 0.20 m,

TABLE 4.1.4 Experimental results for wave runup simulation with height of coral = 0.20m.

Repetition	Wave Height before coral, h_{before} (cm)	Wave Height after coral, h_{after} (cm)	Runup Height, R (cm)	Travel time from generator to beach slope, t (s)
1st	4.0	2.5	3.5	6.24
2nd	3.5	2.9	6.7	6.18
3rd	3.0	3.2	6.8	5.96
Average	3.5	2.87	5.67	6.13

Average celerity, c_{avg} = 9m / 6.13. s = 1.468 m/s

iv. Height of coral, h_{coral} = 0.25 m,

TABLE 4.1.5 Experimental results for wave runup simulation with height of coral = 0.25m.

Repetition	Wave Height before coral, h_{before} (cm)	Wave Height after coral, h_{after} (cm)	Runup Height, R (cm)	Travel time from generator to beach slope, t (s)
1st	3.9	3.0	3.9	6.34
2nd	3.3	3.3	5.2	6.52
3rd	3.1	3.3	7.0	6.91
Average	3.43	3.2	5.37	6.59

Average celerity, c_{avg} = 9m / 6.59. s = 1.366 m/s

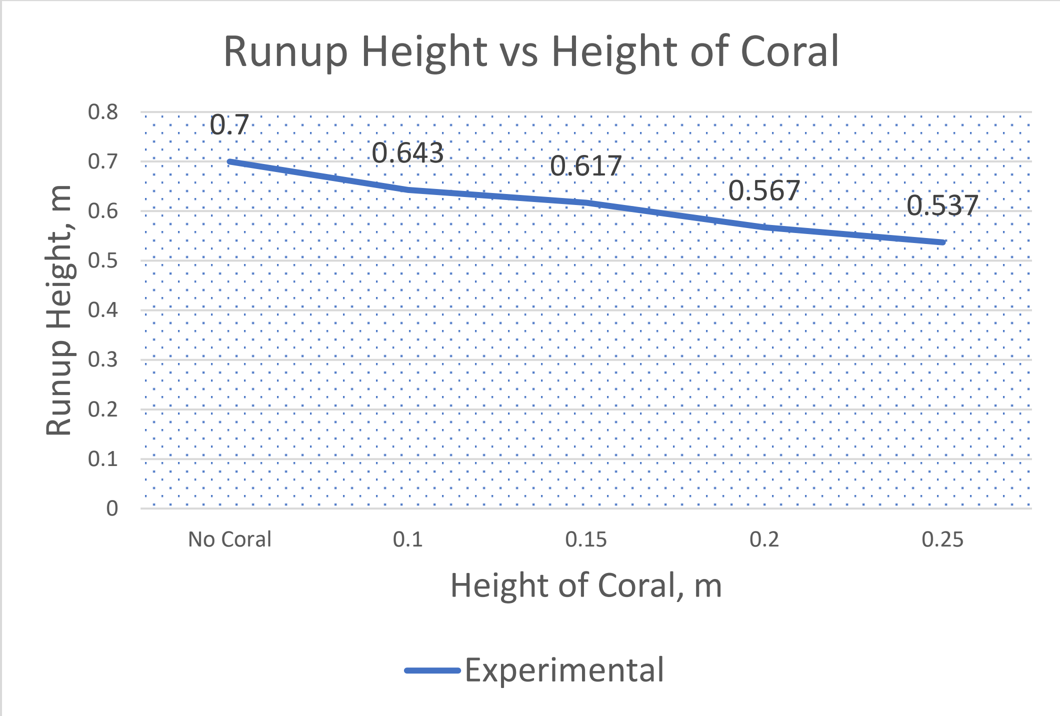


FIGURE 4.1 Trend of wave runup with different coral conditions.

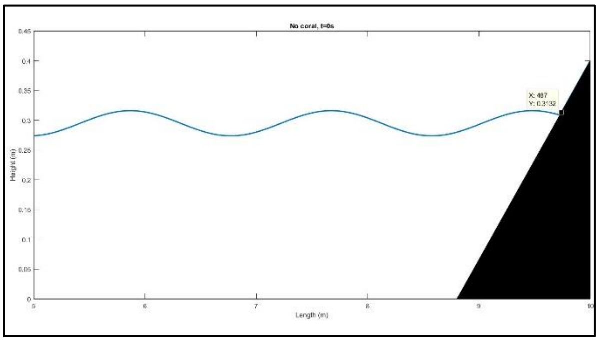
Based on the results above, it can be seen that the highest average wave runup, R is 7.0 cm which is during without the presence of Acropora Millepora sp. while the lowest average wave runup, R is 5.37 cm which is when the height of coral is at 25cm. This might be due to overtopping of the wave which causes the celerity of the wave to be reduced, thus, resulting in a lower wave runup. The average celerity of the wave without the presence of coral is 1.625 m/s while with height of coral = 25cm, the celerity is 1.366 m/s. This can further prove that the celerity of the waves undergo reduction when overtopping occurs at the coral.

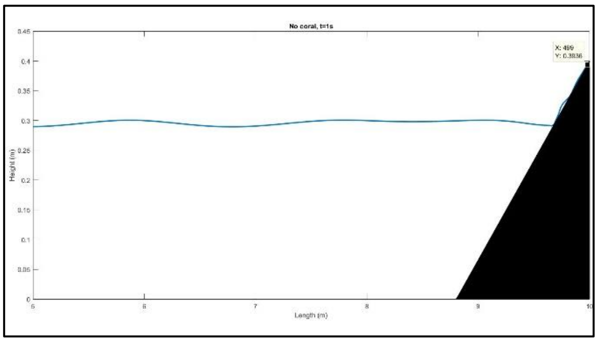
The graph in figure 4.1 above shows a decreasing trend of the average wave runup, R as the height of coral increases. The reason for this might be due to the height of overtopping. When the height of coral increases, the height of overtopping will also increase. Overtopping causes energy transmitted by the wave to be lost during upward motion. Hence, the higher the height of coral, the higher the overtop, thus, resulting in higher upward motion that the wave needs to travel. This may result in more energy lost, hence, lower celerity and lower runup height.

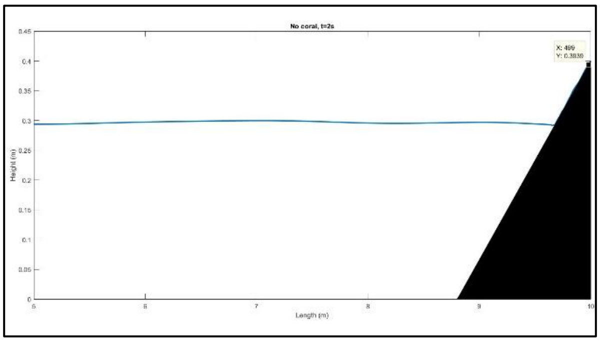
4.2 Simulation Results

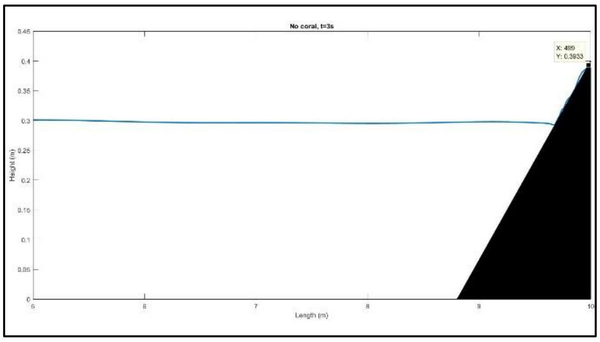
The wave runup simulations are carried out using regular sine waves with frequency of 1.8Hz at different time levels. The initial water level is set to be 0.3m for all simulations. The height of coral for the simulations are at 0.1m, 0.15m, 0.2m, 0.25m and no coral. Figure 4.2.1 until figure 4.2.5 shows the results of regular sine waves with frequency of 1.8 Hz running up a slope of 1:3, using varying heights of coral, for non-dimensional time of t = 1s until t = 10s.

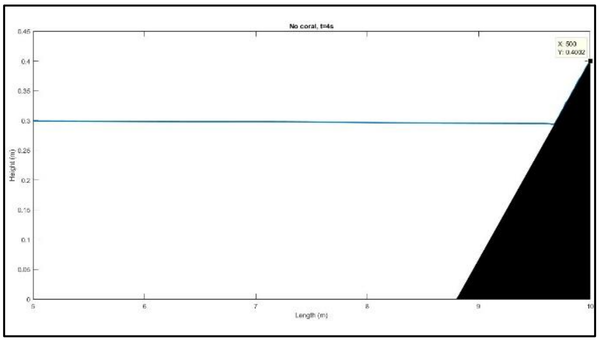
i. **No coral:**

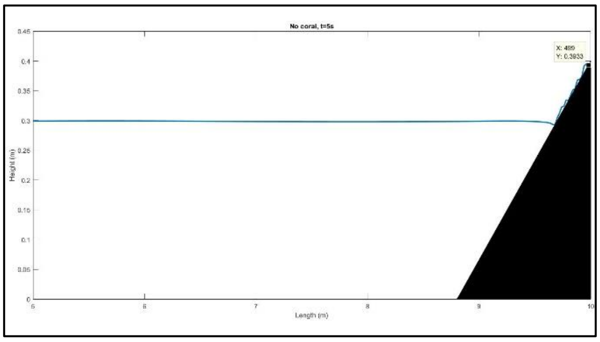


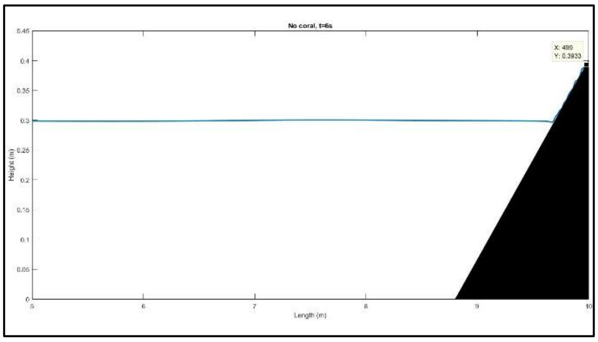


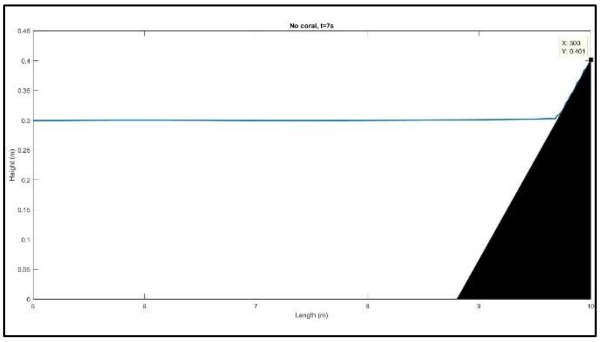



No coral, t=3s
X: 499
Y: 0.3933
Height (m)
Length (m)


No coral, t=4s
X: 500
Y: 0.4002
Height (m)
Length (m)


No coral, t=5s
X: 499
Y: 0.3933
Height (m)
Length (m)


No coral, t=6s
X: 499
Y: 0.3933
Height (m)
Length (m)


No coral, t=7s
X: 500
Y: 0.401
Height (m)
Length (m)

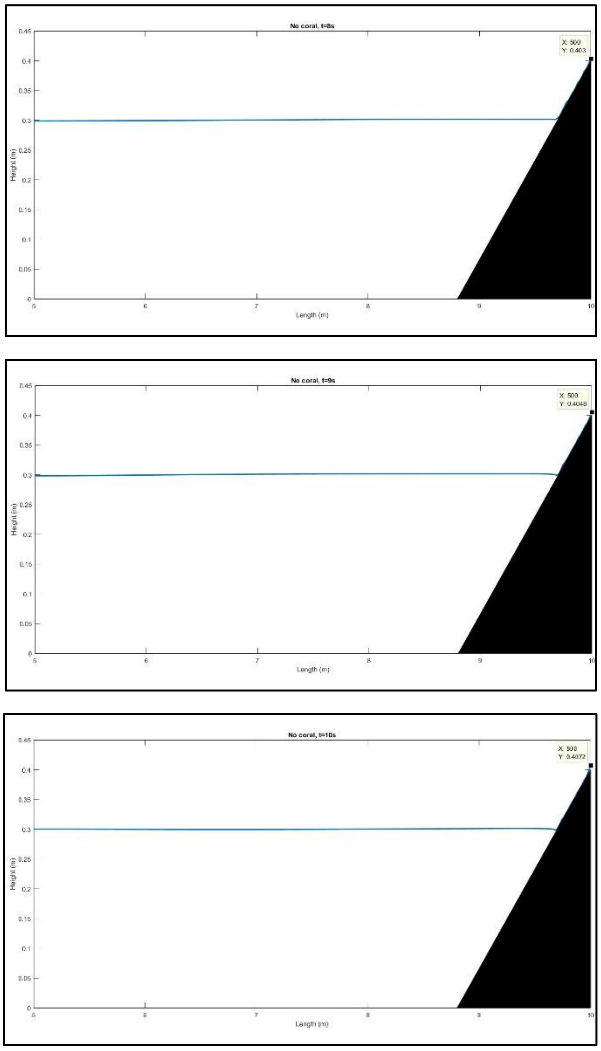
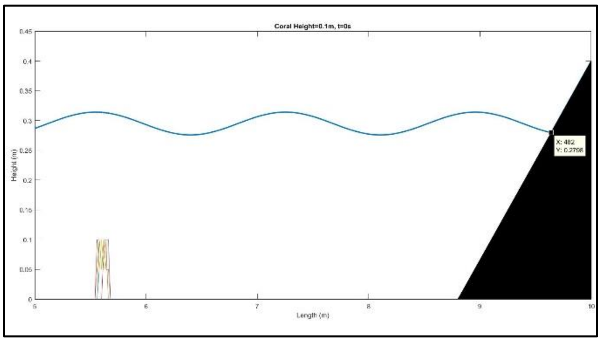
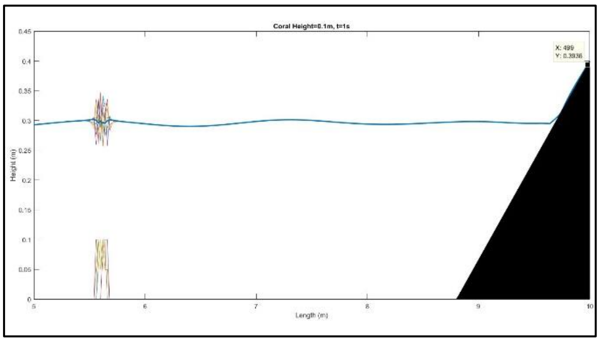
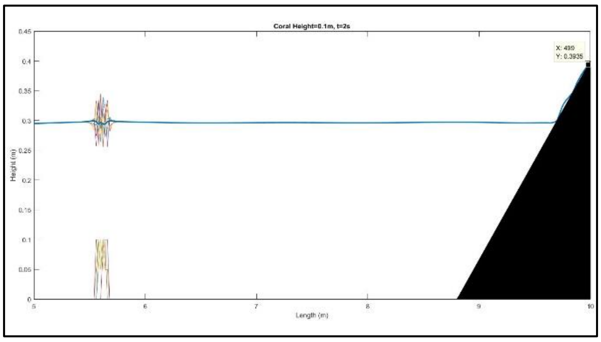


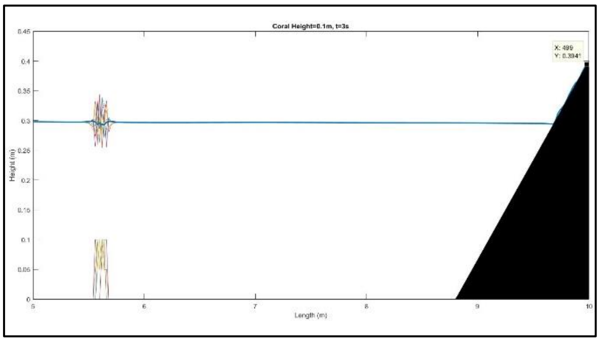
FIGURE 4.2.1 Water profiles for regular sine wave runup with no coral at t = 0s until t = 10s.

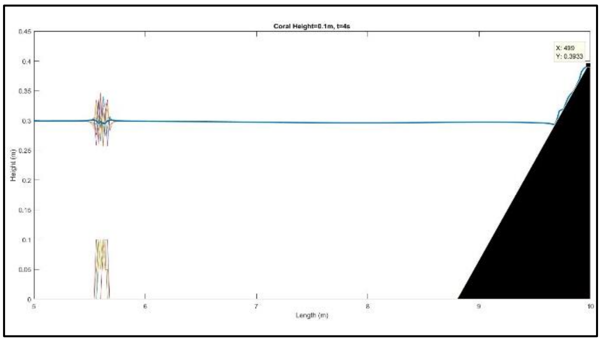
ii. Height of coral = 0.1m

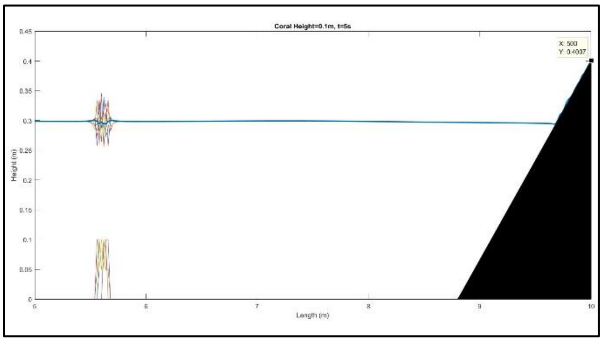


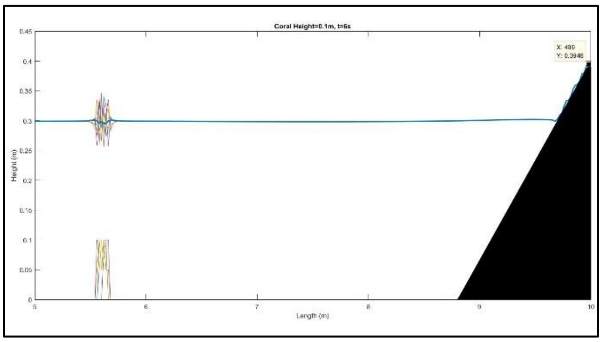


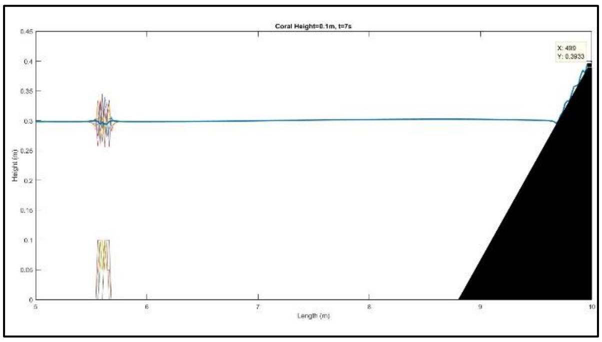


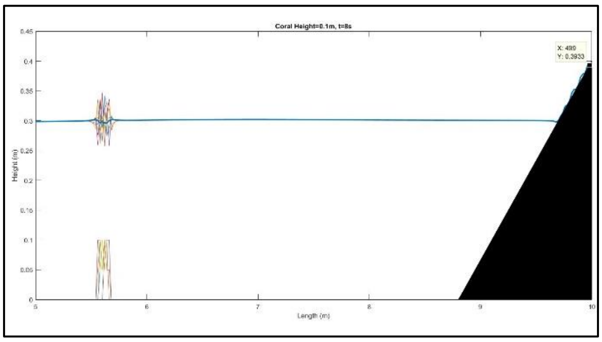



Coral Height=0.1m, t=4s
X: 499
Y: 0.3933
Height (m)
Length (m)


Coral Height=0.1m, t=5s
X: 503
Y: 0.4007
Height (m)
Length (m)


Coral Height=0.1m, t=6s
X: 499
Y: 0.3946
Height (m)
Length (m)


Coral Height=0.1m, t=7s
X: 499
Y: 0.3933
Height (m)
Length (m)


Coral Height=0.1m, t=8s
X: 499
Y: 0.3933
Height (m)
Length (m)

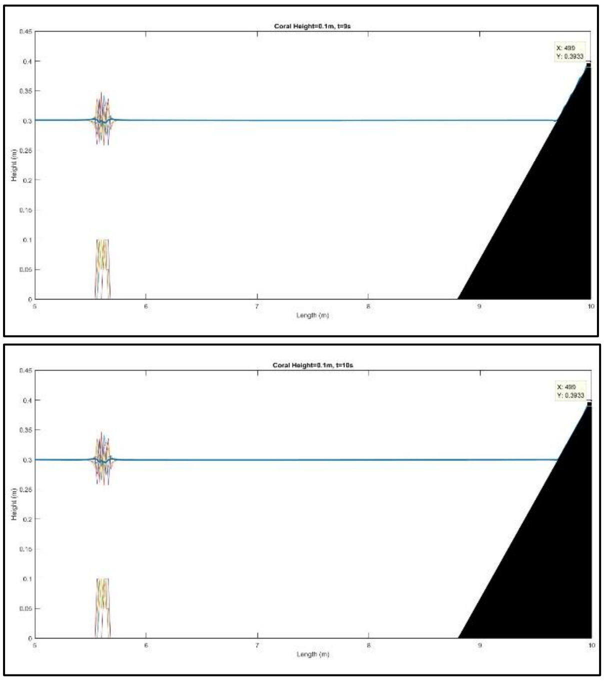
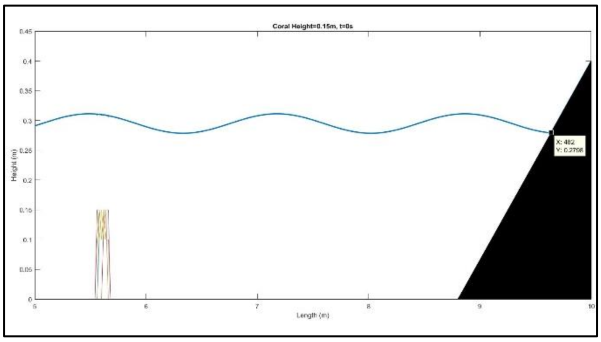
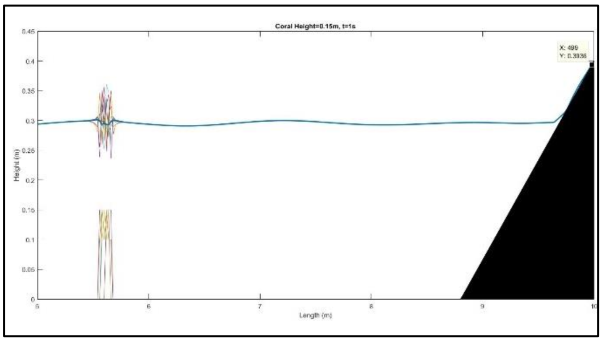
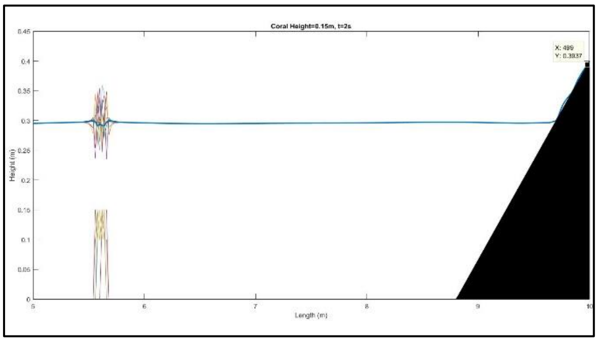


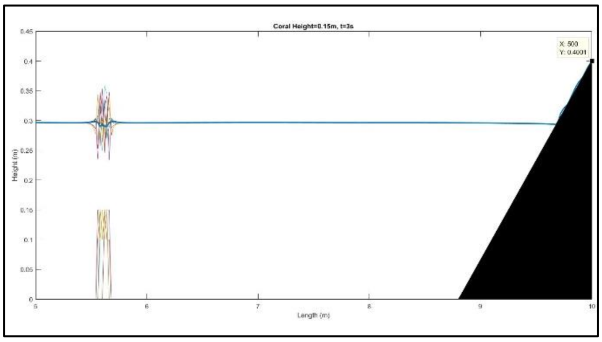
FIGURE 4.2.2 Water profiles for regular sine wave runup with height of coral = 0.1m at t = 0s until t = 10s.

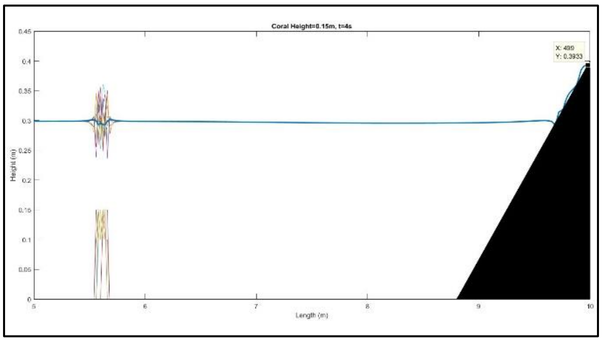
iii. Height of coral = 0.15m

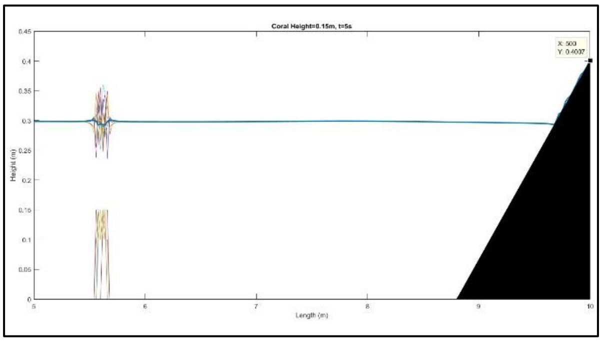


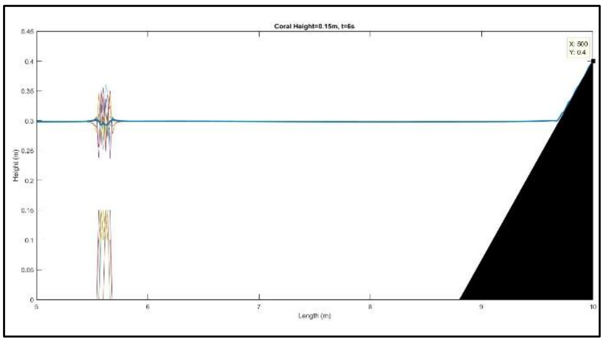


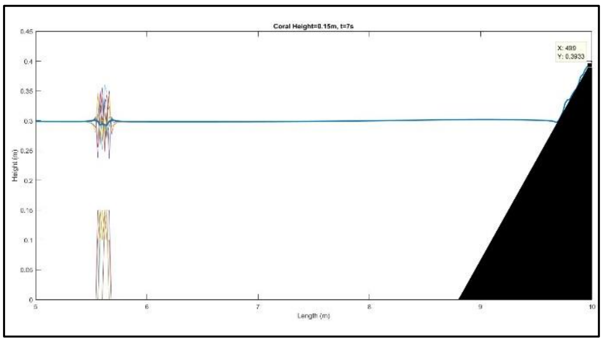


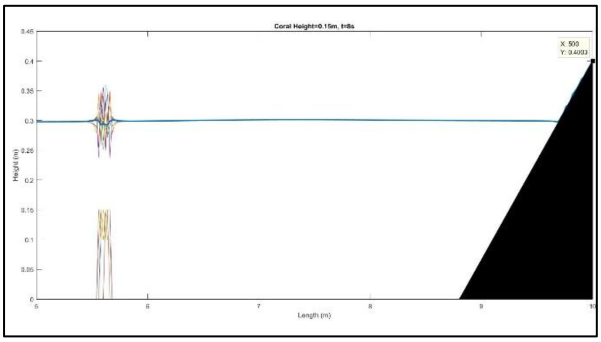



Coral Height=0.15m, t=4s
X: 499
Y: 0.3933
Height (m)
Length (m)


Coral Height=0.15m, t=5s
X: 500
Y: 0.4007
Height (m)
Length (m)


Coral Height=0.15m, t=6s
X: 500
Y: 0.4
Height (m)
Length (m)


Coral Height=0.15m, t=7s
X: 499
Y: 0.3933
Height (m)
Length (m)


Coral Height=0.15m, t=8s
X: 500
Y: 0.4003
Height (m)
Length (m)

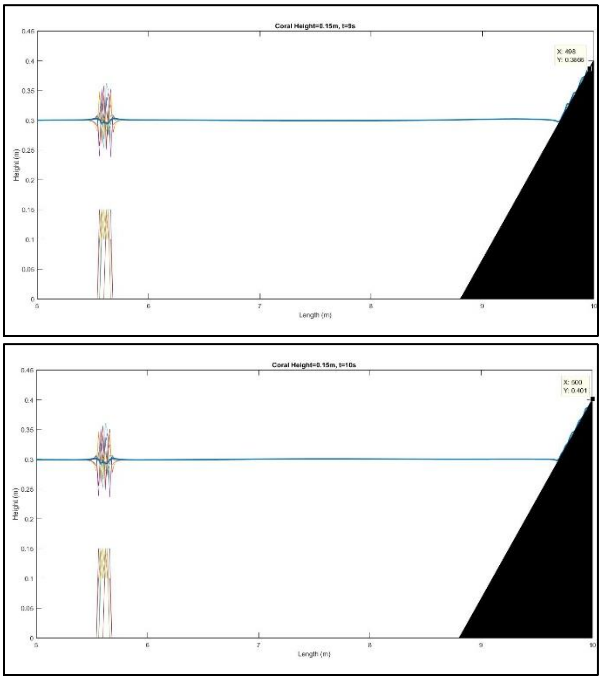
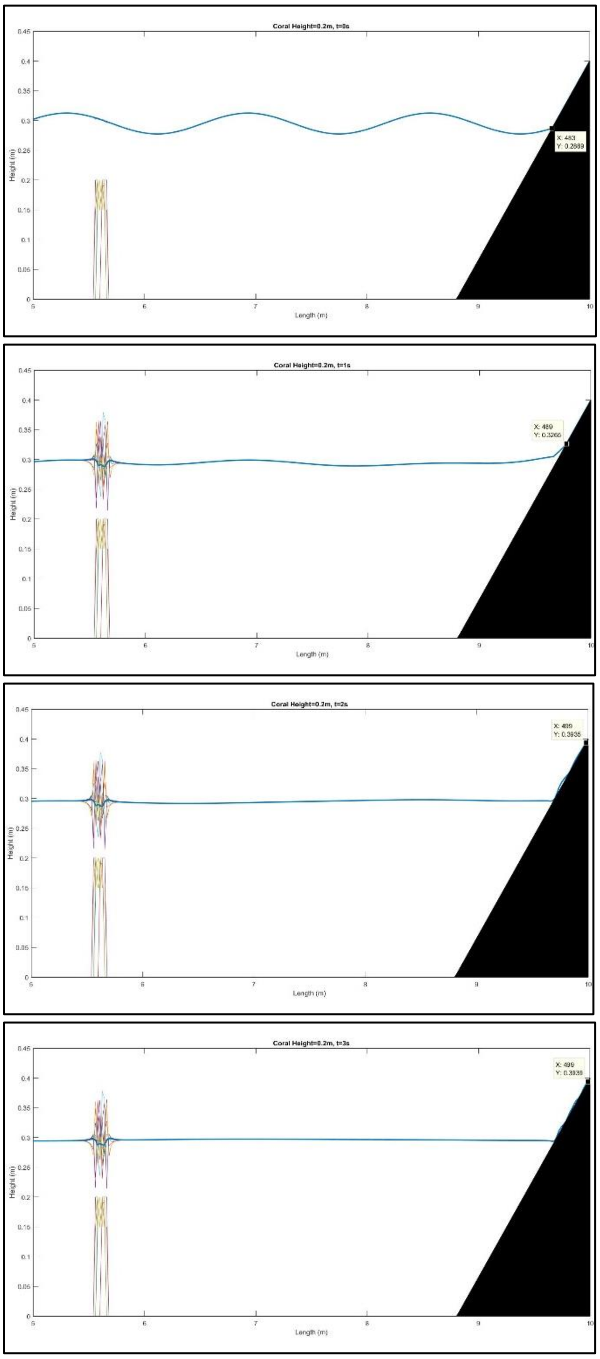
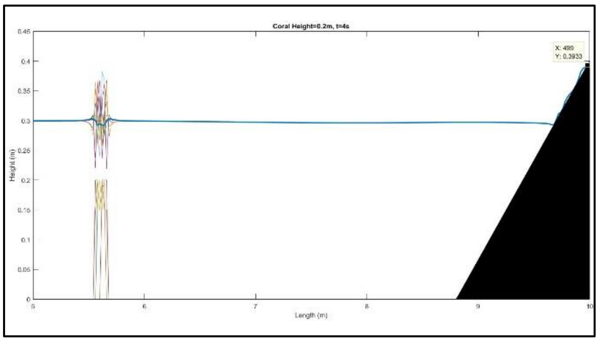
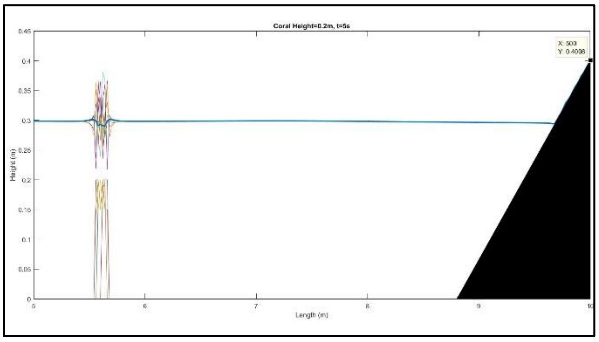


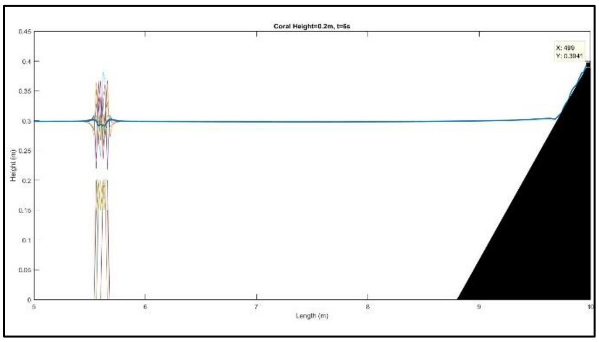
FIGURE 4.2.3 Water profiles for regular sine wave runup with height of coral = 0.15m at t = 0s until t = 10s.

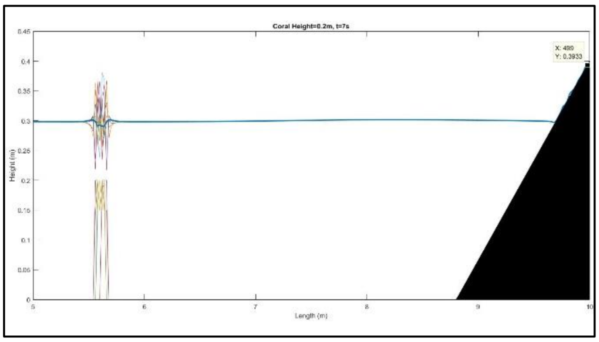
iv. Height of coral = 0.2m

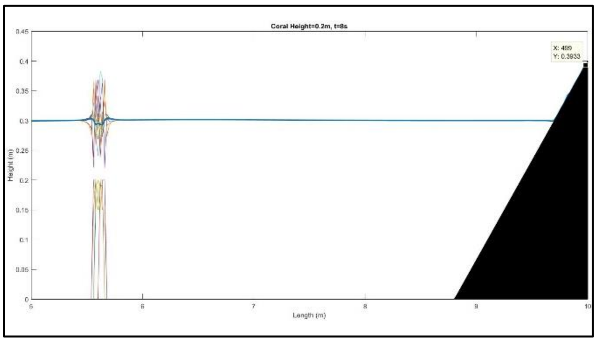



Coral Height=0.2m, t=4s
X: 499
Y: 0.3933
Height (m)
Length (m)


Coral Height=0.2m, t=5s
X: 500
Y: 0.4006
Height (m)
Length (m)


Coral Height=0.2m, t=6s
X: 499
Y: 0.3941
Height (m)
Length (m)


Coral Height=0.2m, t=7s
X: 499
Y: 0.3933
Height (m)
Length (m)


Coral Height=0.2m, t=8s
X: 499
Y: 0.3933
Height (m)
Length (m)

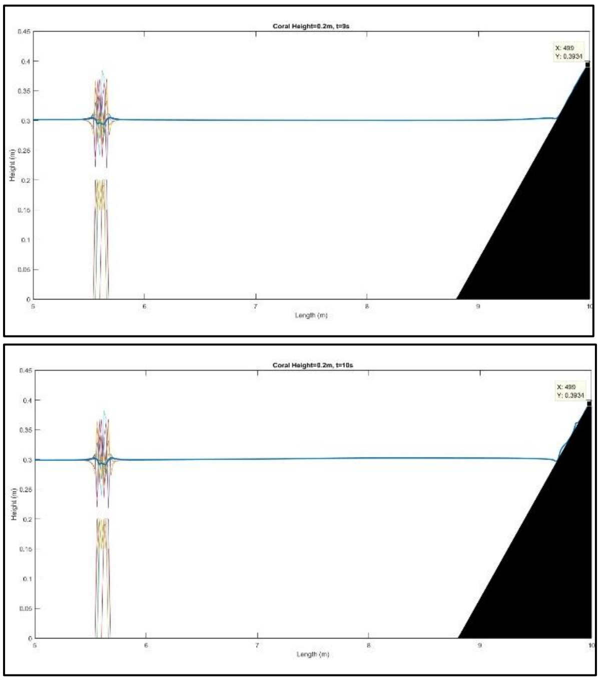
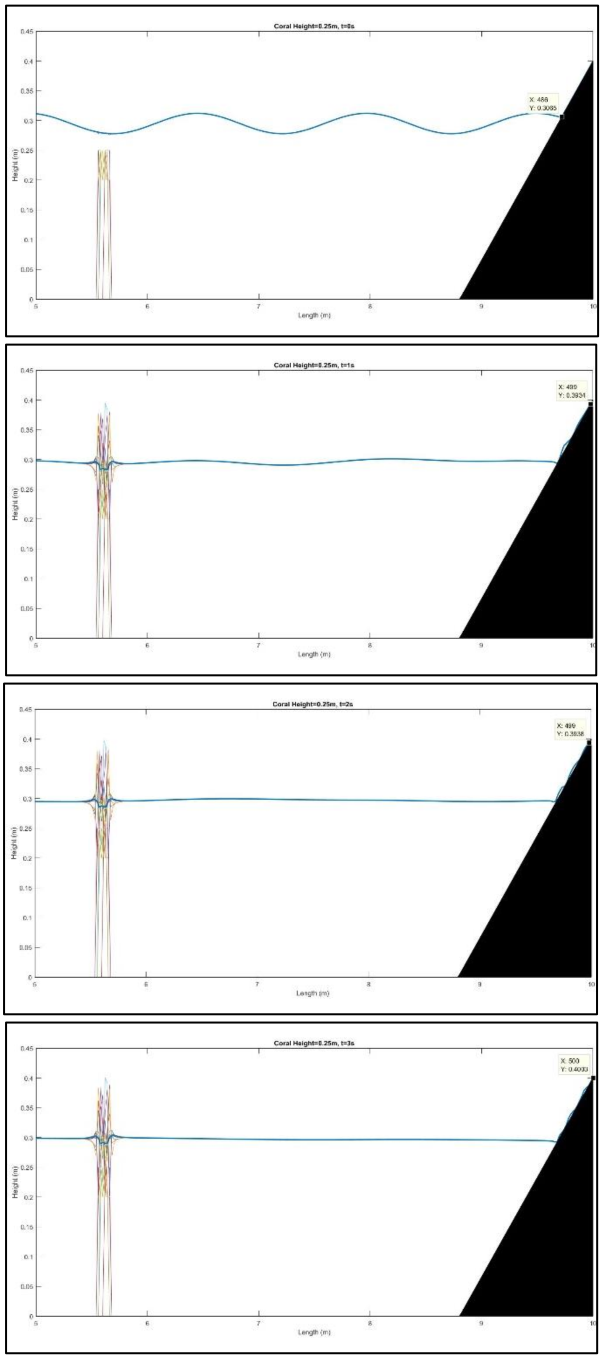
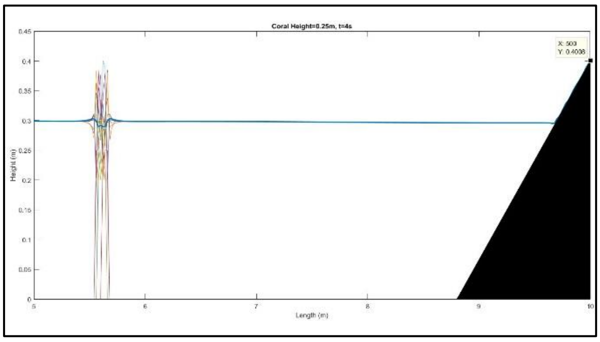
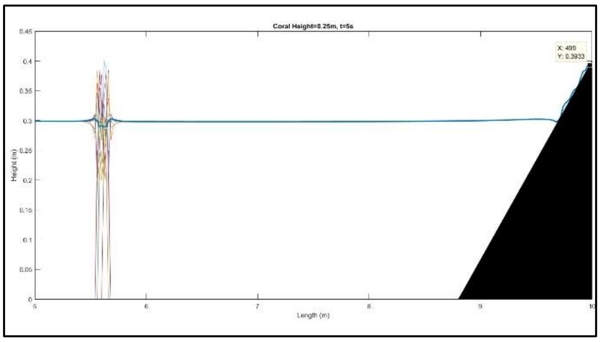


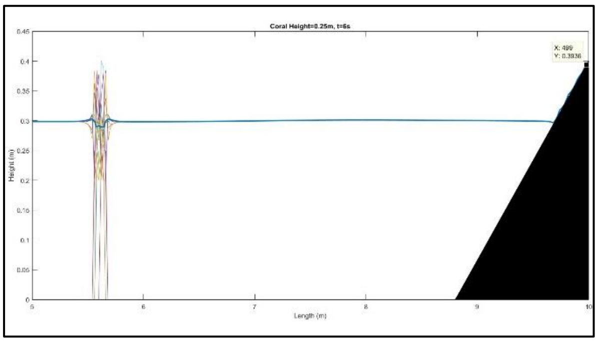
FIGURE 4.2.4 Water profiles for regular sine wave runup with height of coral = 0.2m at t = 0s until t = 10s.

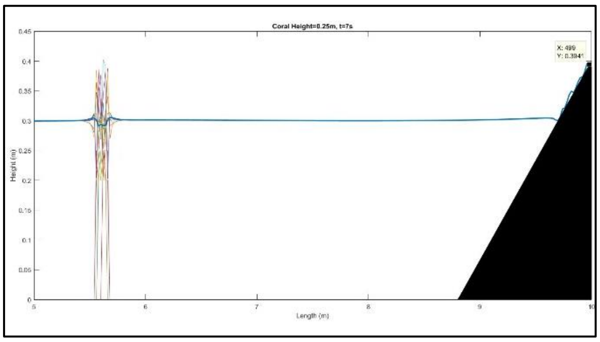
v. Height of coral = 0.25m

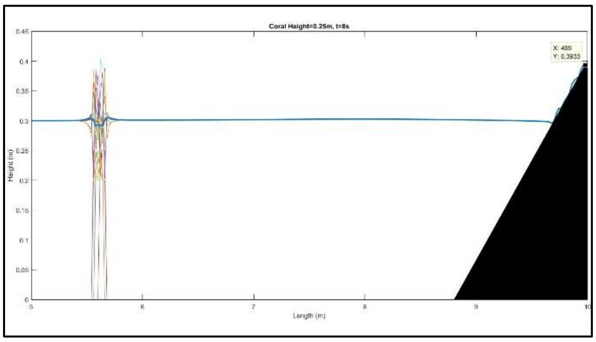



Coral Height=0.25m, t=4s
X: 500
Y: 0.4008
Height (m)
Length (m)


Coral Height=0.25m, t=5s
X: 499
Y: 0.3933
Height (m)
Length (m)


Coral Height=0.25m, t=6s
X: 499
Y: 0.3936
Height (m)
Length (m)


Coral Height=0.25m, t=7s
X: 499
Y: 0.3941
Height (m)
Length (m)


Coral Height=0.25m, t=8s
X: 499
Y: 0.3933
Height (m)
Length (m)

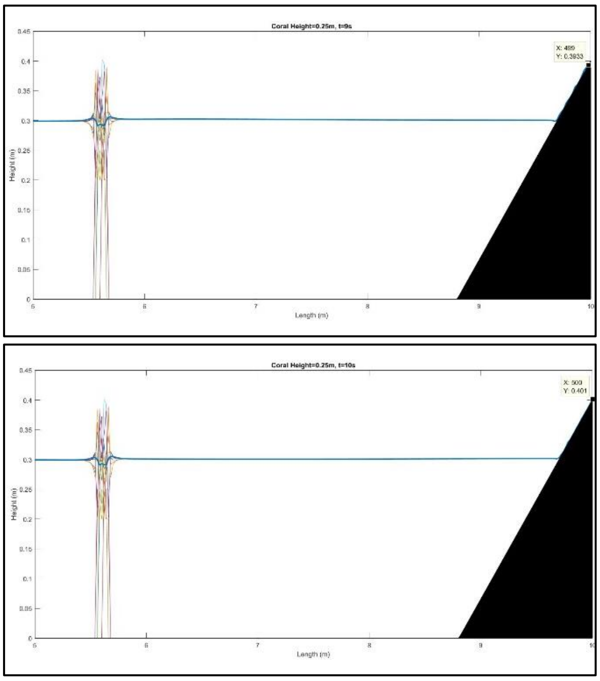


FIGURE 4.2.5 Water profiles for regular sine wave runup with height of coral = 0.25m at t = 0s until t = 10s.

TABLE 4.2: Runup heights for height of coral = 0.1m, 0.15m, 0.2m, 0.25m and no coral at time t = 0.

Time (s)	**Height of coral (m)**				
	No coral	**0.1**	**0.15**	**0.2**	**0.25**
0	0.3132	0.2798	0.2798	0.2869	0.3065
1	0.3936	0.3936	0.3936	0.3265	0.3934
2	0.3939	0.3935	0.3937	0.3935	0.3938
3	0.3933	0.3941	0.4001	0.3939	0.4003
4	0.4002	0.3933	0.3933	0.3933	0.4008
5	0.3933	0.4007	0.4007	0.4008	0.3933
6	0.3933	0.3946	0.4000	0.3941	0.3936
7	0.4010	0.3933	0.3933	0.3933	0.3941
8	0.4030	0.3933	0.4003	0.3933	0.3933
9	0.4048	0.3933	0.3866	0.3934	0.3933
10	0.4072	0.3933	0.4010	0.3934	0.4010

Table 4.2 records the runup heights of each simulation that has been carried out. The average runup for each height of coral is taken using the 3 first runups as shown in Table 4.3,

TABLE 4.3 Average runup heights for height of coral = 0.1m, 0.15m, 0.2m, 0.25m and no coral.

Runup, R	**Height of coral (m)**				
R_1	0.3939	0.3936	0.4001	0.3939	0.4008
R_2	0.4002	0.3941	0.4007	0.4008	0.3941
R_3	0.4072	0.4007	0.4003	0.3934	0.4010
R_{avg}	0.4004	0.3961	0.4003	0.3960	0.3986

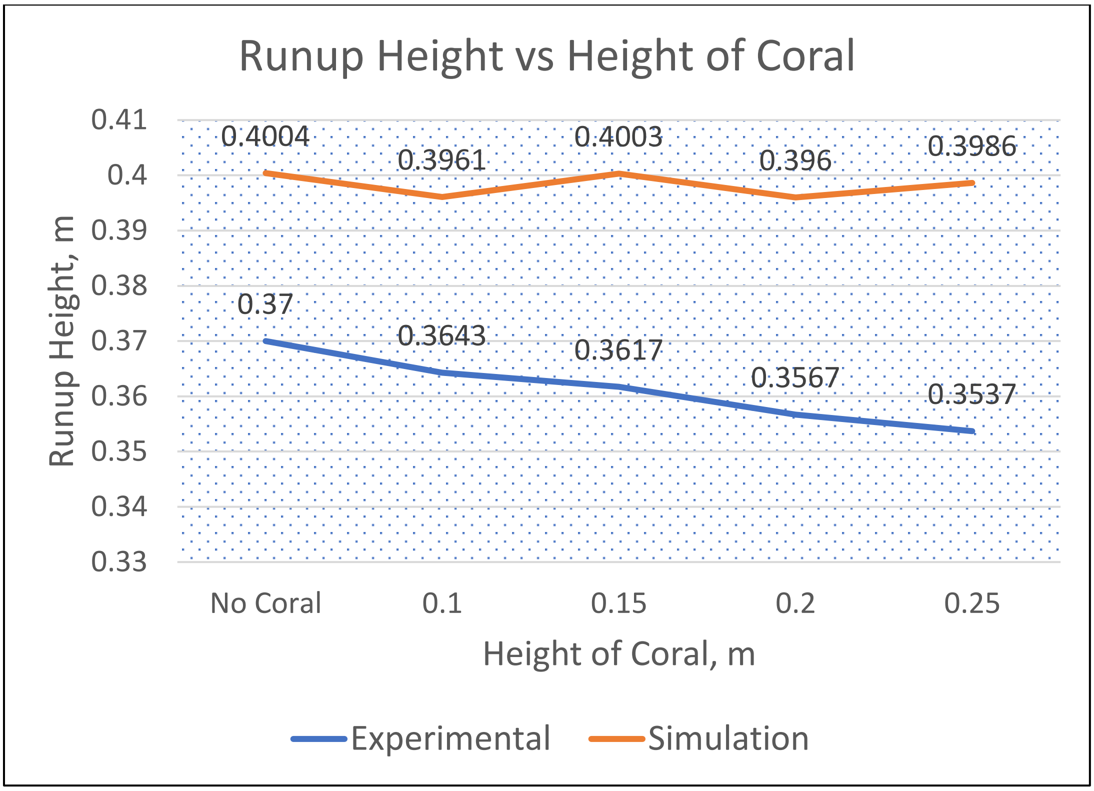


FIGURE 4.3 Comparison graph between experimental and simulation for runup heights with height of coral = 0.1m, 0.15m, 0.2m, 0.25m and no coral.

The graph in figure 4.3 shows a decreasing trend for the experimental values for runup height, but rather a fluctuating trend for the simulation runup height. However, in average, the runup height, when having coral of any heights in the system, is lower than when there is no coral present at all. Based on the graph, it is found that when using height of coral of 0.1m yields the lowest average wave runup height which is 0.3961m while having no coral at all resulted in the highest average wave runup which is 0.4004m.

4.3 Analysis for Percentage Difference:

The calculation for percentage differences is as follows:

$$\boldsymbol{Percentage\ Difference}\ (\%) = \frac{|\boldsymbol{Simulation - Experimental}|}{|\boldsymbol{Simulation + Experimental}|/2}\ \boldsymbol{X\ 100}$$

TABLE 4.4 Percentage differences for runup heights with height of coral = 0.1m, 0.15m, 0.2m, 0.25m and no coral.

Runup, R	**Height of Coral (m)**				
	No coral	**0.1**	**0.15**	**0.2**	**0.25**
Simulation	0.4004	0.3961	0.4003	0.3960	0.3986
Experimental	0.3700	0.3643	0.3617	0.3567	0.3537
Percentage Difference	7.89%	8.36	10.13%	10.44%	11.94%

Table 4.4 shows that the percentage difference when comparing between the results for simulation and experiment are all below 12% percent. These differences might be due to several factors which may come from both simulation and experimental stages. However, the difference may still be considered near to the allowable range of 10% and this shows that the LABSWE^{TM} is reliable for the numerical modelling of wave runup with presence of coral.

For the experimental stage, the inaccuracy might be due to inaccurate readings of the data taken or parallax error. This happens when the eye of the observer is not parallel to the scales. Another possible reason for the differences may be due to presence of other substances in the wave flume such as sediments from previous experiments or even small pieces of rubbish. This might also be caused by friction during the runup stage at the slope due to the material of the artificial slope (plywood), which is not specified in the simulation stage.

As for the simulation stage, the difference might occur due to the usage of relatively large lattice size. The error may reduce when using a bigger lattice size as the data readings can be taken in a more detailed and exact manner. One other factor that might have led to the difference between the results might be due to the value of time step, dt. More accurate data may be obtained when using smaller time step as we can cover a finer range of lattice grid as the simulation runs.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

Based on the results that have been obtained, it can be concluded that LABSWE^{TM} is a reliable numerical method to model the effects of coral reef towards wave runup as the highest percentage difference is 11.94%, which only slightly deviates from the allowable range. The average wave runup heights with presence of coral of all heights is lower than when no coral is present in the system. The results show that the optimal height for the coral is 0.1m as it gives the most reduction to the wave runup height. This shows that the presence of coral reefs affects the wave runup at which may aid in reducing coastal erosion as the runup height with presence of coral is lower. Hence, it is of utmost importance to conserve and preserve the coral reefs in our coastal area in order to provide a better protection and future for the shorelines.

5.2 Recommendation

A recommendation that may be done to further improve this study is by using different species of corals can be used and the optimal species in terms of wave runup reduction can be identified and be given more attention for further studies. Another suggestion is by having other parameters such as the distance of coral from the shoreline and the wave conditions.

REFERENCES

Darwin, C. R. (1842) The Structure and Distribution of Coral Reefs. Being the first part of the geology of the voyage of the Beagle, under the command of Capt. Fitzroy, R.N. during the years 1832 to 1836. London: Smith Elder and Co

Department of Irrigation and Drainage of Malaysia. (2013) Beach Erosion based on States. Retrieved from http://www.data.gov.my/data/en_US/dataset/hakisan-pantai-mengikut-negeri/resource/d6b07543-b697-4e81-8ac8-dd4bc803e088

Eliff, C. I., Silva, I. R. (2017) Coral Reefs as the First Line of Defense: Shoreline Protection in Face of Climate Change.

Ferrario, F., Beck, M. W., Storlazzi, C. D., Micheli, F., Shepard, C. C., & Airoldi, L. (2014) The effectiveness of coral reefs for coastal hazard risk reduction and adaptation. Nature Communications, 5, 3794. doi:10.1038/ncomms4794.

Ha, T., Shim, J., Lin, P., Cho, Y. (2014) Three-dimensional numerical simulation of solitary wave run-up using IB method.

Milanian, F., Niri, M. Z., Najafi-Jilani, A. (2017) Effect of hydraulic and structural parameters on the wave run-up over the berm breakwaters.

Principe, P., Bradley, P., Yee, S., Fisher, W., Johnson, E., Allen, P., Campbell, D. (2012) Quantifying Coral Reef Ecosystem Services. U.S. Environmental Protection Agency, Office of Research and Development.

Quataert, E., Storlazzi, C., Van Rooijen, A., Cheriton, O., Van Dongeren, A. (2015) The Influence of Coral Reefs and Climate Change on Wave-driven Flooding of Tropical Coastlines.

Reaka-Kudla, M. L. (1997) The Global Biodiversity of Coral Reefs: A Comparison with Rain Forests in Biodiversity.

Rodriguez, G. (n.d) Introduction to MATLAB. University of Salamanca.

Ruscio, D. D. (2009) An Introduction to MATrix LABoratory. Telemark University College.

Shafiai, S. H. (2011) Lattice Boltzmann Method for Simulating Shallow Free Surface Flows involving Wetting and Drying.

Sorensen, R. M. (1997) Basic Coastal Engineering, Chapman and Hall, New York.

United Nation Environment World Conservation Monitoring Centre, UNEP-WCMC. (2006) In the Front Line: Shoreline Protection and Other Ecosystem Services from Mangroves and Coral Reefs.

Williams, A., Rangel-Buitrago, N. G., Pranzini, E., Anfuso, G. (2017) The management of coastal erosion

Zhou, J. G. (2004). Lattice Boltzmann methods for shallow water flows. Berlin, Springer.