Experimental Investigation on Tsunami Impact Force on Standing Structures Generated by Various Sizes of Submarine Slides.

By

Azizan Bin Ramly

14733

Dissertation Submitted in Partial Fulfillment of

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CERTIFICATION OF APPROVAL

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Approved by,

____

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2015

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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(AZIZAN BIN RAMLY)

ABSTRACT

Submarine landslide have a potential to generate tsunami wave. A different size of submarine landslide be able to generate a different type of run-up wave. The impact from this run-up wave be able to destroy coastal structure even bring fatality to human. Various sizes of submarine landslide used to model the generation of run-up wave and later the wave amplitude will be verified by using existing research. The study focus on submarine landslide parameter that will generate a different types of run-up wave. All the experimental work will be carried on the Offshore Laboratory and will be analysed using visual observation and using equation that have been derived by Watts (2005).

ACKNOWLEDGEMENT

In the name of Allah, The Most Gracious, The Most Merciful. First of all, I would like to thank to Allah Subhanahu Wataala for granting me with well being, serenity and knowledge in completing this final year project report after 2 semesters in final year studies.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Tsunami is a combination word of "tsu" meaning harbor and "name" meaning wave that taken from Japanese word. This tsunami will carry along a series of high energy waves mostly associated with earthquake, submarine landslide, submarine volcanic eruption or nearer to shoreline, meteoric impact or sudden movement of water column. These phenomenon usually were called tidal waves even it is not related to tidal and different with the waves created by wind on the surface of oceans.

The movement of tsunami covered movement of water from the seafloor until the surface area. These speeds of waves were controlled by the depth of water, which meaning, if tsunami waves were produced in deep water it will have a high speed of wave, long wavelength and low amplitude and as it reaches to shoreline, decreasing in depth, it were inversed. However, the wave speed in deep water column still move in high speed and after the wave bunching up, the wave height will increase.

Tsunami will occur in series of waves but the first one not necessarily the largest one. Tsunami need time to increase the wave height when it travels from long source or a gradual slope. Shoaling effect usually occurs in shallow water depth that less than 100 meter and the height of wave can achieve almost 30 meter from above sea level.

Tsunami wave synonyms triggered by earthquakes but there are also others factor can cause tsunami waves. For an example is, underwater movement of soil which is known as submarine landslide. This is one of major factors that triggered the tsunami, submarine mass failure (SMF) when the soil failed cause by earthquakes and geotechnical problems.This type of factor is believed be able to produce a high run-up wave that can bring a huge impact and damage toward coastal structure as well as damaging offshore structure and endanger human life.

This submarine landslide may happens in translational failure when the a mass of soil fail to hold itself and slide down moves downward. Factors that can cause this problem such as earthquakes and geotechnical properties of soil landslides. Example of geotechnical properties that able to cause this problem is weak layer underlain by a hard layer, seepage that can cause liquefaction and overpressure.

Mostly the areas that were have a steep slope and loaded with sediment have a higher probability for event to occur. When SMF occurred, the water will be dragged into and fill up the space created by displacement of volume of soil and the waves will be radiated out. Example of SMF that cause tsunami occurred at Papua New Guinea in 1998 that caused by submarine landslides. The volume of landslides is 6.4 Gm^3.

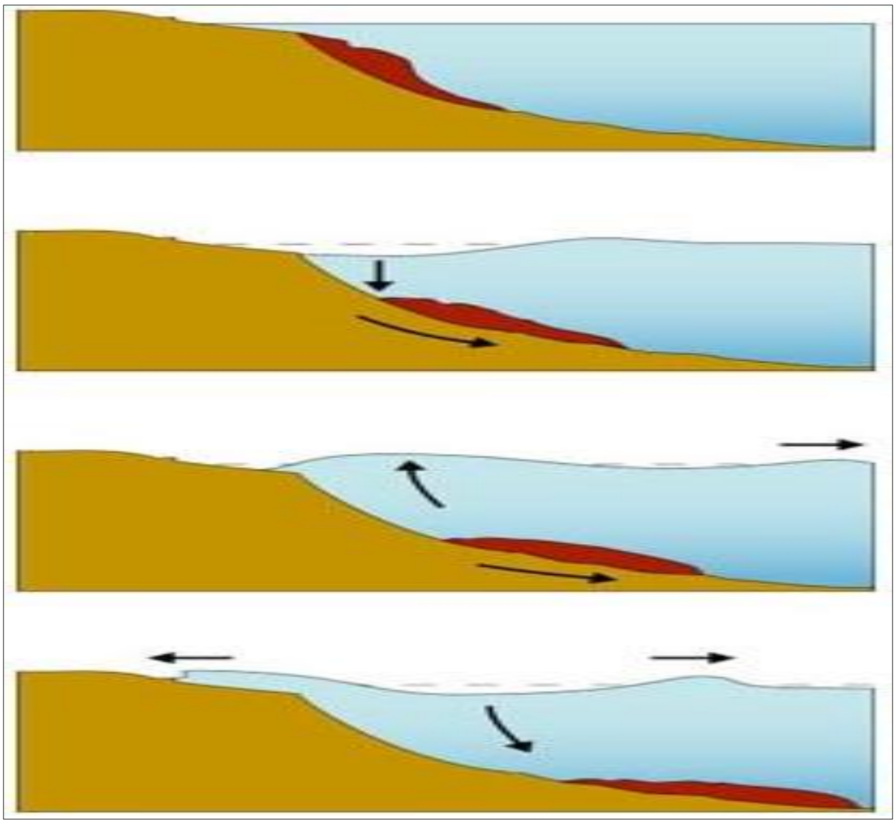


Figure 1.1: Submarine Landslide that can generate a high run-up wave

Presence of weak layer one of key factor that cause SMF because the load from above will cause the movement and the soil will failed. Besides, the major cause of submarine landslide is earthquake. Earthquake will caused a serious environmental stress and also will cause elevated pore water pressure and promote liquefaction that will ease for SMF to occured.

Year	Location	Height of Tsunami Wave(m)	Volume of Landslide (m^3)
1979	Nice	3	1.5E8
1994	Skagway,Alaska	9-11	3-10E6
1998	Papua New Guinea	15	6.4E9
1999	Izmit Bay, Turkey	2.5	-

Table 1.1: Tsunami Wave Generated by Submarine Landslide

The main hazard associated with submarine landslides are destruction of infrastructure, tsunami wave and even fatality to human life. Example of destruction towards infrastructure such as damage to subsea infrastructure, pipeline, cable network and coastal structure. These destruction have a high economy impact because cost to fix the problems. Submarine landslide that occured at Grand Banks in 1929 have caused damage to submarine cables up to nearly 600km away from the initial location of slide.

Besides the destruction, submarine landslide also can cause tsunami. These tsunami wave can be a catastrophic event when they hit coastal area. Eventhough, a different landslide can cause tsunami, all will causing the same features such as high run-up wave but quciker attenuation compared to tsunami caused by earthquakes. Example of tsunami generated by submarine landslide was in July 1998 at Papua New Guinea that cause wave up to 15 m. These tsunami had caused 2200 people died and impacted around 20km section. From study in this area, the tsunami wave also affected by coastal amplification.

From the recent studies done, tsunami wave is dependent on initial acceleration, thcikness, length volume, velocity, slope and specific density of slide. Its belive that, the volume and initial acceleration is key factor whether the submarine landslide be able to generate tsunami wave or not. Basically, all these submarine landslide almost undetected and not noticeable because mainly occured at deepwater. Hence, the correlation between submarine landslide size (parameter) and type of run-up wave generated is studied. All work will be carried out on the laboratory.

1.2 Problem Statement

Tsunami can bring a great harm to human or infrastructure nearer to the coastal area and also aquatics life will be damaged due to huge impact of tsunami. One of factor that will be highlighted in this study is submarine landslide that can trigger tsunami. This submarine landslide mostly occurred in deep water compared to shallow water. So, it is very difficult to detect when it occurrence, characteristic of landslide, volume length and thickness. Thus in this study, it shall be done in the laboratory to study the correlation between submarine landslides parameter and type of run-up wave.

1.3 Objective

The main objectives of this project is:

- to study the correlation between of submarine landslide sizes and type the run-up wave produced.

The wave generated will be analyzed whether the wave characteristic be able to produce tsunami waves. these submarine landslide models will be created and tested at Offshore Laboratory, simulation of submarine landslide shall be carried out to see the propagation of waves corresponding to sizes of landslide.

1.4 Scope of Study

In this study, the scope will be focused on the correlation between various size of landslide and type of run-up wave. These study will be conducted in Offshore Laboratory and the result will be in visual observation and graphical data. Then, the data collected from the experiment work will be verified by equation derived from related past research done. In *Figure 1.2* summarize the scope of study in this research.

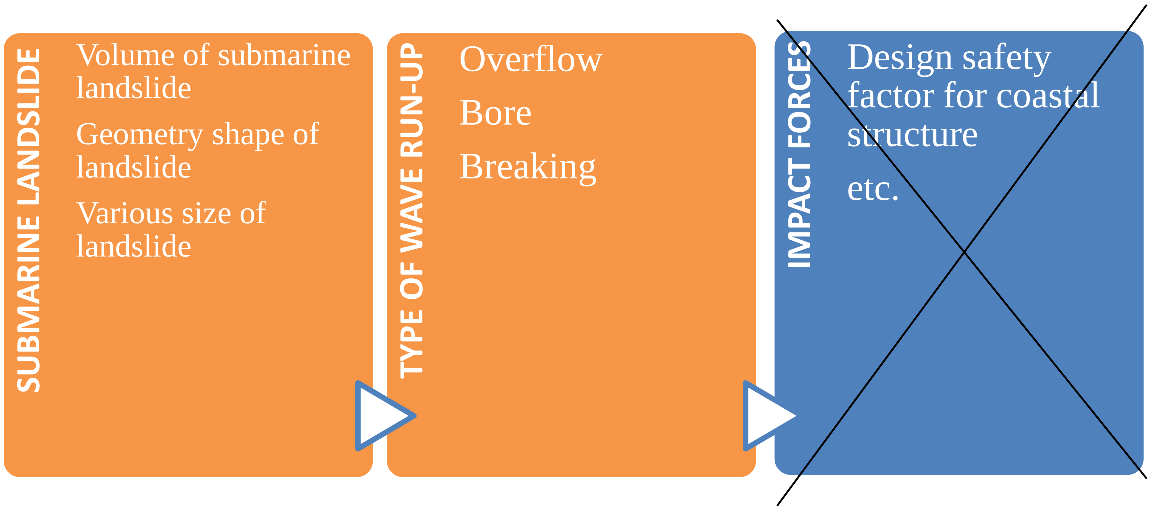


Figure 1.2: Scope of study in this project

CHAPTER 2
LITERATURE REVIEW

2.1 Factor of Submarine Landslide

Landslide is a phenomenon that happens on both land and underwater. This mass movement down the slope may due to the slope overstepening, increase in loading on the slope, increase in pore water pressure and etc. Landslides happens when the soil was failed due to shear stress exceed the shear strength of soil. According to Zydron and Zawisza (2011) the stability of slope depending on mechanical characteristic of soil which is the angle of internal friction and cohesion of soil. Submarine landslide failure have the same mechanism as landslide on land.

Sediments that deposited continental slope one of factor that can cause submarine landslide. This sediments were carried from land by rivers to continental shelf and then deposited at continental slope. The sediments may interbedded with pelagic sediments. These sediments often equate only to temporary storage, as instability in the slope deposits leads to periodic slope failure and landslide according to Mason et. all. (2006).

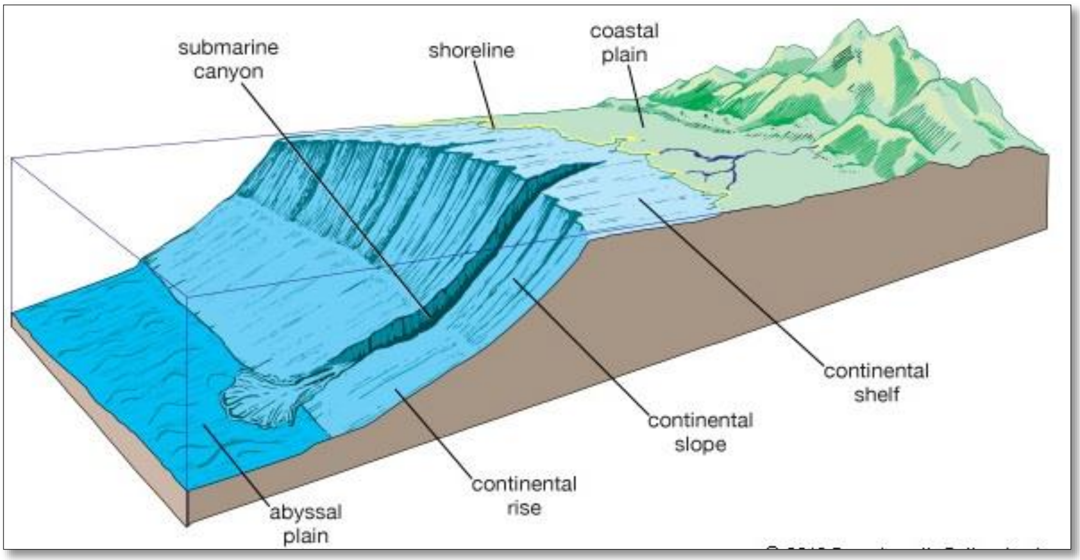


Figure 2.1: Diagram of continental slope may have capable landslide to happen

According to Hampton, Lee and Locat (1996) submarine landslide normally will occur at slope that have a weak geological materials and due to huge load from natural phenomenon like earthquake and storm waves. When these two factors contributed in submarine landslide, the resisting force will be sunken by downward forces and shear strength not able to withstand it, the slope will be shifted downward to planar surfaces.

There are a lot of factors that triggered submarine landslide. According to Masson, Harbitz, Wynn, Pederssen and Lovholt (2006) major factor influencing submarine landslide are elevated pore water pressure that reduce the frictional resistance toward sliding and also a weak soil at the below of soil layer that fail to hold itself. Elevated pore water pressure can be resulted from normal depositional process which sediments are carried from land to continental shelf to continental slope by erosion, ocean current, or storm and also from transient process like earthquake.

2.2 Impact of Submarine Landslide

Most of cases of submarine landslide occurred at the area that predominate by fine grained sediments (Masson et all. 2006). One of most of catastrophic event on earth which is lateral collapses of oceanic island volcanoes that can be a wave sources for tsunami to be created (Ward & Day 2001). Grand Bank Tsunami that happened in Atlantic Ocean resulted from submarine landslide and cause at least 27 peoples were killed and also damaged to subsea infrastructure (Fine et al. 2005). Tsunami force can be give a great impact toward the coastal structure, aquatic life, subsea facilities and etc if it happen nearer to the shoreline.

According to Masson, Harbitz, Wynn, Pederssen and Lovholt (2006), tsunami generated by small source wave cause by a submarine landslide will produce a shorter wavelength and high energy compared to tsunami generated by large earthquakes. Submarine landslide induced by submarine earthquakes are the principal cause of large tsunamis and earthquakes also play indirect role (Lovholt et al. 2005). Wave's energy produced by earthquakes will be decreasing as it far away from the point sources because the radial damping (distal effect).

If the tsunami generated by two dimension sources of earthquakes it will reduces the radial spreading. Tsunami character must be identified in order to study the tsunami genic potential. The main element that need to be known are landslide volume, initial acceleration, velocity, thickness of landslide and also the length. Lovholt et al. (2005) stated that there is a reasonable correlation between landslide volumes and landslide dynamics parameters.

Besides, the impact of tsunami generated by submarine landslide can be seen in 1996 Finneidjord slide, in Northern Norway. In this event, four people were killed with only $0.001km^3$ was mobilized.

2.3 Submarine Landslide Experiment

Several parameter has been identified to control the tsunami wave created by submarine landslide such as angle of slope, shape of landslide, volume, length, time, wavelength, initial acceleration and etc. In addition, Watts (2005) stated that submarine landslide in semi elliptical shape will generated most catastrophic tsunami wave. Watts and Grilli (2003) shows in their experiment, slide thickness, shape, length and density have the relationship with generation of tsunami wave and also the behavior of tsunamigenic have the relationship between the slide shape, motion and deformation at early time. Based on the experiment done by Watts and Grilli (2003), the size of landslide may not a major factor in tsunami generation.

According to Grilli and Watts (2005), landslide with a Gaussian shape will increase the amplitude of wave due to shape spreading decreased. So, semielliptical shape is used as the landslide shape block. Watts (2000) stated that not all submarine mass failure can induced tsunamis. If submarine landslide have triggered the tsunami wave it will affect the coastal structure, human life and etc. In this thesis, the main objective is to determine the impact design of coastal structure. Hence the coastal structure must have safety factor need to consider before it was constructed.

Generation tsunami wave have been studied more than half century but tsunami generated by submarine landslide has only widely studied last 15 years according to Mason et. all (2006). This after a few event happened but having a different wave propagation characteristic such as tsunami that happened in 1998 at Papua New Guinea.

Experiment the model of submarine landslide is very hard because submarine is hardly to detect and happen in deep sea. Hence, many researchers come out with their own model to simulate the generation of tsunami wave. The submarine model always been improved to have a better effects.

2.4 Numerical Simulation of Submarine Landslide-Tsunami

The numerical simulation is derived based on a large number of experiment conducted on the laboratory. From this work, a predictive equation can be formed. According to Watts et. all (2005) numerical simulation that have been derived can be used as predictive empirical equation describing tsunami generation submarine mass failure.

According to M.F Chai et al (2014), the process of potential Brunei submarine landslide failure is simplified as a solid block motion. The shape taken as semi elliptical shape same as proposed by Watts & Grilli (2005). The effect of lubrication force was neglected, the resulting force balance of a submerged solid block along the sliding path can be approximated by the following equation (Watts, 1998; M.F Chai et al 2014).

$$(\rho_b + C_m\rho_w)V_b\frac{d^2s}{dt^2} \approx (\rho_b - \rho_w)gV_b\sin\theta - 0.5C_d\rho_w A(\frac{ds}{dt})^2$$

Where, ρ_w is water density, ρ_b is bulk density of slide, C_m is mass added coefficient, C_d is drag coefficient, θ is angle slope, A is Tw.

CHAPTER 3
METHODOLOGY

3.1 Project Workflow

In this project, only experiment work shall be carried out to study effect of submarine landslide parameter toward run-up wave production. To enhance this result of experiment, comparison result between past researchers and this experimental shall be carried out. The research methodology was divided into three phase; design phase, implementation phase and analysis phase. The work flow for research methodology in this project can be seen in *Figure 3.1* below.

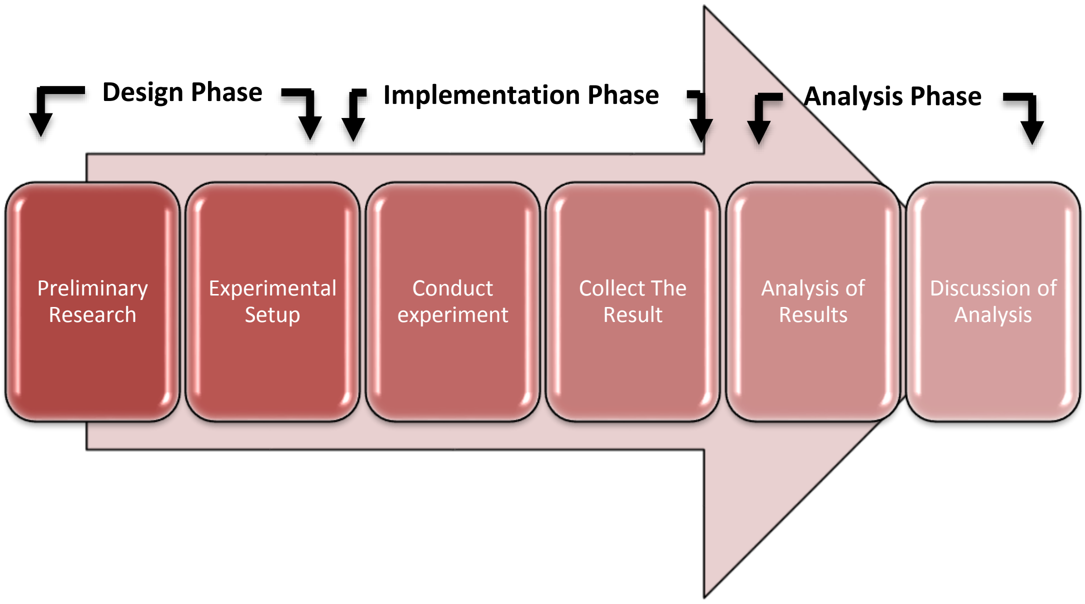


Figure 3.1: Work Flow for Research Methodology

The project work flow above present the overview of research methodology used throughout the study. Before proceed to design phase onwards, the study is developed from problem faced which is affects of tsunami waves triggered by submarine landslides towards coastal structure. Hence, the objectives was developed to limit the scope of study in this research. Literature study is conducted to obtain the idea and understand the mechanism of submarine landslide and tsunami generation. The literature review mainly focusing on:

- The mechanism of submarine landslide
- Affect submarine landslide towards tsunami wave generation
- Size and shape of submarine landslide used as model in experimental work
- Numerical simulation of previous study by pas researchers

After the objectives have been identified and scope of study is limited, the next step for design phase can be conducted.

3.1.1 Design Phase

In this phase, the initial stage of project done by doing preliminary research and experimental setup. Problem statement and objective(s) for this project need to be determined early in the preliminary research to ensure the study are within the scope of study as mentioned earlier. The scope of study for this research is correlation between submarine landslide and type of run-up wave generated. Hence, in this design phase, the design of solid block that act as submarine landslide is the main concern and crucial because it is expected to control the generation of run-up waves.

Before the designing work of solid blocks can be done, reading the literature review from past study is necessary to get an ideas. From the basic ideas from the literature review, a few design can be produced. What kind of shape that will give a huge impact wave production still unknown. In this project, three type of solid block were produced with a different volume and sizes.

Experimental setup shall be carried out after the preliminary research have completed. In this project, 16 wave gauges probes were proposed in this experiment. A large number of wave gauges probe will have an accurate reading of wave amplitude, energy and etc. but due to limitation of instruments, 8 numbers only will be used.

3.1.2 Implementation Phase

Implementation phase is the second stage in the methodology of this project. From the designing phase, the proposed solid blocks were fabricate before the experiment can be conducted in the laboratory. A several series of experiment shall be carried out at Offshore Laboratory located in Block J-A, Universiti Teknologi PETRONAS, Malaysia.

This experiment shall be done in 20 meter length concrete flume, 1.5 meter width and 1 meter depth and the concrete flume have transparent wall for ease for visual observation. Two platforms with 0.5m height and 1.5m length were placed approximately 5 meter in distance to each other. One platform for the solid block to slide down for generation of run-up wave and the other one is for structure model (single storey house).

The purpose of platform that have structure model on top of it is to observe what kind of run-up wave generated and also to determine the impact forces, measured by using force sensor (impact forces from run-up wave toward standing structure not in the scope of study). The slope shall be covered using a natural sand beach. The other one, which used for solid block slide down, an aluminum sheet shall be provided to reduce the friction between the platform and solid blocks.

In addition, at the bottom of these solid block a roller also shall be attached to reduce the friction. The both slope will have a fix slope of 1:3 (V: H). In between these two platforms, 8 wave gauge probes shall be placed in the middle of flume at different location to monitor wave propagation during the experiment. These wave gauges shall be attached to steel frame to have a fixed position. *Figure 3.2 shows how a complete experimental setup before the experiment can be started.*

Before the wave gauge probes were installed, a simulation shall be carried out first to observe run-up wave propagate or problems. The solid block will be placed on the inclined surface of platform and the initial submergence of solid block shall be fixed. Then, the solid blocks will be released down freely. If there are no problems with the solid block, wave gauge probes shall be installed and need to be calblirated first and checked wheter its functioning or not.

Then, the data of wave propagate from the source (solid block slide down) toward the house model can be collected. Furthermore, the wave run-up nearer to house model shall be observed and recorded using cam recorder because it also one of result for this experiment beside verification from past research.

Each block shall be run in this experiment a several time to reduce the error and to have a precise reading. Then, different type of solid block shall be used to run the experiment with the same parameter (initial submergence of solid block, slope of platform, depth of water and etc.). The result from each solid block shall be collected to be analyzed in the next stages.

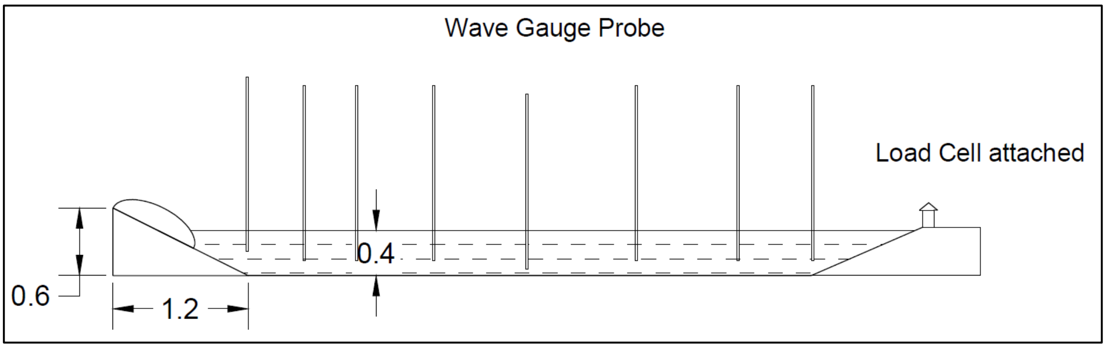


Figure 3.2 shows how a complete experimental setup before the experiment can be started.

3.1.3 Analysis Phase

In this analysis phase, it will take a longer time in order to examine the result from this study. There are two ways to analyze the result:

1. Data from experimental work including visual observation and reading from wave gauge probe.
2. Verification using past researchers' equation with same paramter used in laboratory experiment (numerical simulation).

The analysis will be done for both to ensure the data collected or experimented on laboratory are verified and to ensure this researched is validated. The result will be presented in grpahs of wave elevation against time while the equation will represent the maximum amplitude above the submarine landslide. The eqution used was develop by Watts (1998).

3.2 PROJECT TIMELINE

No.	Activities /Month (2014-2015)	9	10	11	12	1	2	3	4
1	*Preliminary Study & Literature Review*								
2	*Methodology Studies*								
3	*Collecting Information to Design Landslide block model and Other Parameter (water height, etc)*								
4	*Implementation of Design Block*								
5	*Conducting The Experiment*								
6	*Collecting and Analyze Result*								
7	*Compilation and Finishing Report*								

Table 3.1: Project Timeline for both FYP 1 amd FYP 2 for this reseacrh.

3.3 PROJECT KEY MILESTONE

This project key milestone that have been prepared need to be followed as a guideline in order to complete the Final Year Project (FYP) within the time frame given, 2 semester. This key milestone will keep on track the whole FYP project to ensure the objectives is achieved. For more details schedule, the author have develop the timeline for both FYP 1 and FYP 2. Below figure shown the project key milestone.

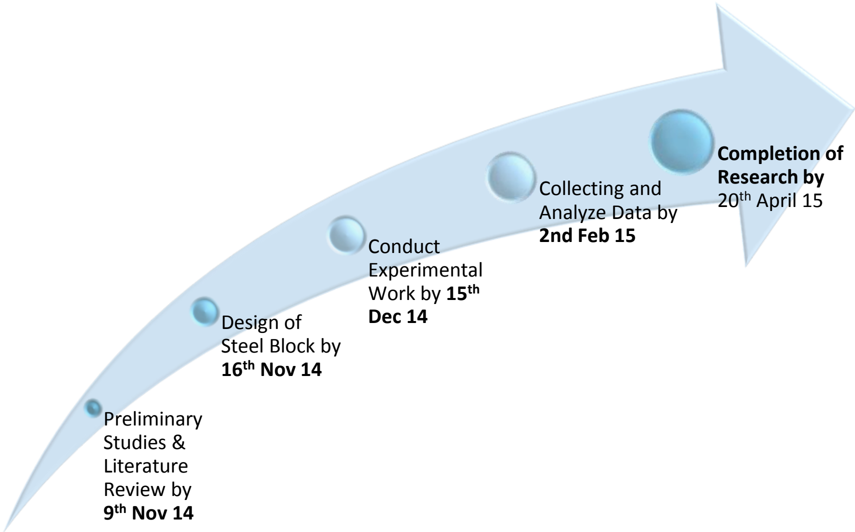


Figure 3.3: Project Key Milestone proposed for this study

CHAPTER 4
RESULT AND DISCUSSION

4.1 EXPERIMENTAL WORK

In this section, the finalized instruments used in the experimental work will be discussed further. Below in *Figure 4.1* shows the complete arrangement of experimental setup for the study.

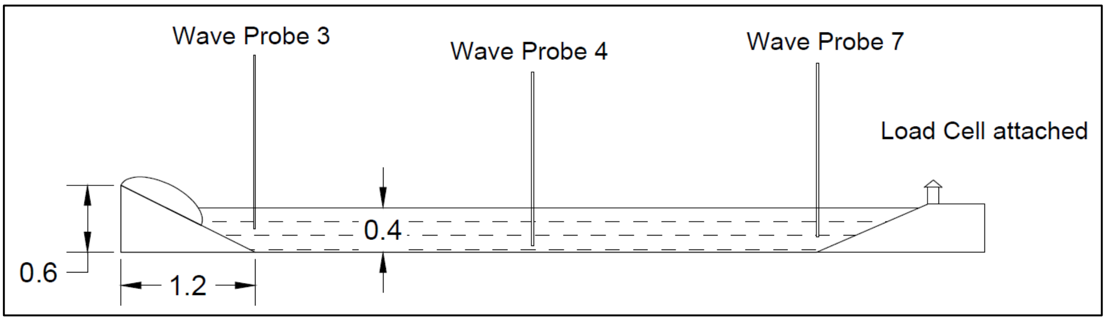


Figure 4.1: A complete experimental setup

4.1.1 Steel Block

Since the manipulated variable in this experiment only various size of submarine landslide and other parameter was fixed throughout this study. Solid blocks used in this study have a same density but differ in volume and size. The shape of solid blocks were made from steel plate and inside the block it was filled by sand. The sand used in all blocks has the same densities. Meaning in this study, the density of solid block does not changed in the experiment.

The main parameter of solid block that controlling run-up wave generation in this experiment is volume and size. Besides that, the relative thickness, T/b, will have an impact toward generation of tsunami waves. All solid blocks have the fixed volume and size. Experiment conducted by Watts (1998), a 25.4mm diameter hole was drilled through the center mass enabling a cylindrical (brass or lead) ballast to be inserted into the solid block. From this type of method, the densities of block can be altered without using a lot of number solid block that very costly.

Since the manipulated variable in this experiment is size of solid block that act as submarine landslides. In *Table 4.1,* shows a different type of solid blocks were proposed to use in this thesis and the picture of solid block shows in the APPENDIX. The first block is semi-ellipse shape and the last two is triangular shape. There are two shape of solid block in this experiment because what form of shape solid block that will generate a huge wave run-up wave still does not know for the time being.

The width of solid block is same, which is 1000mm. Eyelet was attached in front of triangular solid block. Then, a thin rope was used and attached it to eyelet to hold the solid block in position. While the semi-ellipse shape, two eyelets were used and attached at side of block because it very heavy to place in position. A small wheel also attached to the bottom of solid block to reduce friction and will increase the speed of block slide down the platform.

No	**Dimension(mm)**		**Volume(m3)**
	Height	Length	
1**	200	800	0.13
2*	200	400	0.08
3*	100	200	0.02

Table 4.1: Type of solid block used in this study

*=*triangular shape*

**=*semi-ellipse shape*

4.1.2 Platform

There are two platforms with the same size were used in this experimental work. One used for solid block to slide down and the other one for structural model to be placed. In-front of structural model that facing toward the other one platform, force sensor are be attached to read the impact force carried by run-up wave. These platforms have a slope of 1:3 (V: H). According to Geist (2000), submarine landslide that slide down with higher slope tend to produce a huge tsunami wave with high speed and elevation. At the same time, Hurukawa, Tsuji and Waluyo (2003) have a contradictory idea about the slope. In their study on 1929 Grand Banks, they believe that even angle slope around 2°-6° also tend to produce a huge tsunami waves.

In this study, the slope of platforms were fixed because the variable parameter is the size of solid block. The platforms for structural model have a layer of natural sandy beach to stimulate the same condition on site while the wave are hit the shoreline. While, a layer of aluminum sheet was cover the other one platform to reduce friction between solid block and platform.

4.1.3 Tank and Wave Gauge

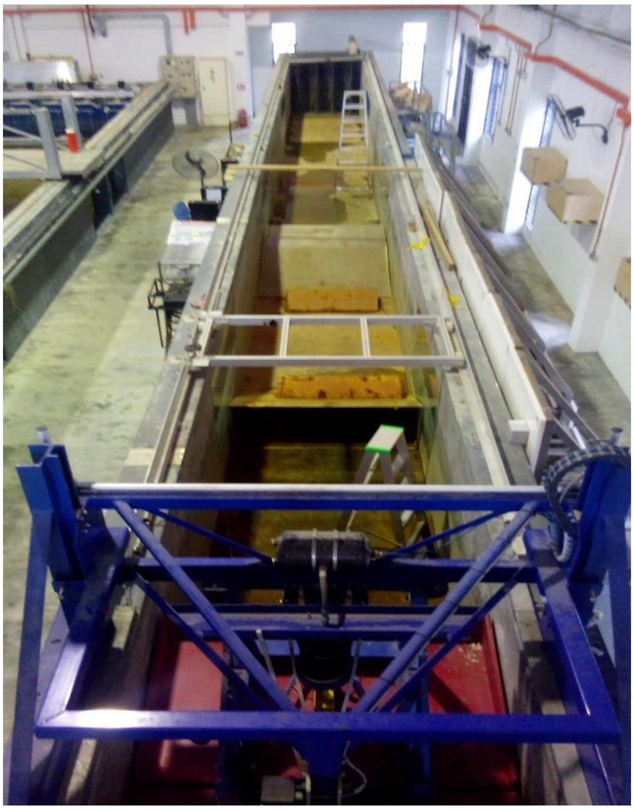


Figure 4.2: Flume Tank with Two Platforms

Run-up wave generation was conducted in the offshore laboratory, UTP. This experimental was done in 20 meter length, 1.5 meter width and 1 meter depth flume tank. Even though the flume is 20 meter, the distance between two platforms approximately 5 meter because the wave propagate too long will be dissipated and unable to study the run-up wave generated. Nearer to the platforms, window glass panel is provided to ease the monitoring work and observation for result. The height of water in this tank will be fixed throughout the experiment, which is 0.4 meter depth, 0.2 meter less than the platform. The water 0.4 meter depth was selected because the second platform for house model have height of 0.4 meter+-0.01meter. The house model placed need to be dried and not partially submerged. All blocks were partially submerged before the blocks slide down the slope and the initial submergence also fixed.

At first, eight wave gauge probes shall be used in this experiment to monitor the wave amplitude from the source of generation wave toward the structural model. But due to some of wave gauge probe unable to detect any wave amplitude, only three wave gauge probes were used. One of wave gauge probe was located near as posible to submarine landslide initial position, one located at the middle and the other one at the end of flume tank. The location of wave gauge probe shall be in the middle of initial solid block position according to Watts (1997, 1998) to construct wavemaker curve. He believed this position shall be able to study near field wave features. Other location of wave gauges shall be between these two platforms.

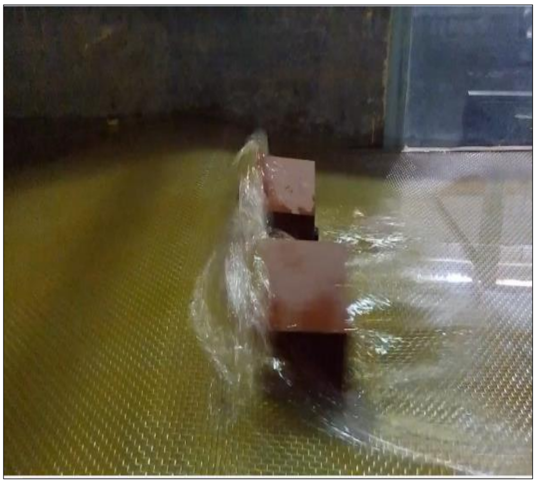
4.2 EXPERIMENTAL RESULT

This experimental result was divided into two categories which is observation of wave elevation with respect to landslide size and volume and also the reading taken using wave gauge probe. As from the observation, what size of landslide volume will give the huge impact toward coastal structure model and produce high wave elevation amplitude can be observed. While from reading wave gauge probe, the wave elevation at specific location can be determined.

4.2.1 Observation of Wave Elevation with respect to Landslide Size

Every block was run in three tests by sliding down along the inclined platform to take an average result. The observation was recorded using cam recorder, cause later the observation can be seen more clearer. Basically, the slope for inclined platform was coated with aluminium sheet to provide a smooth surface. Besides, the slope also was lubricated to reduce the friction between slope and steel block.

Figure 4.3 (a) shows the wave elevation captured by video that overtopped the structure model without the force sensor attached to it. While in *Figure 4.3 (b)*, the wave elevation reach top of structure but due to force sensor attached to, the wave was blocked. This result come from the solid block number 1, which has semi-eliptical shape and volume of $0.13m^3$. According to Watts (2005), using semielliptical shape or nearly semielliptical shape submarine landslide to produce the worst case tsunami scenario for characteristic amplitude.



(a)

(b)

Figure 4.3: Wave elevation observed that hit the structure model using submarine model 1. (a) without force sensor attached and (b) with force sensor.

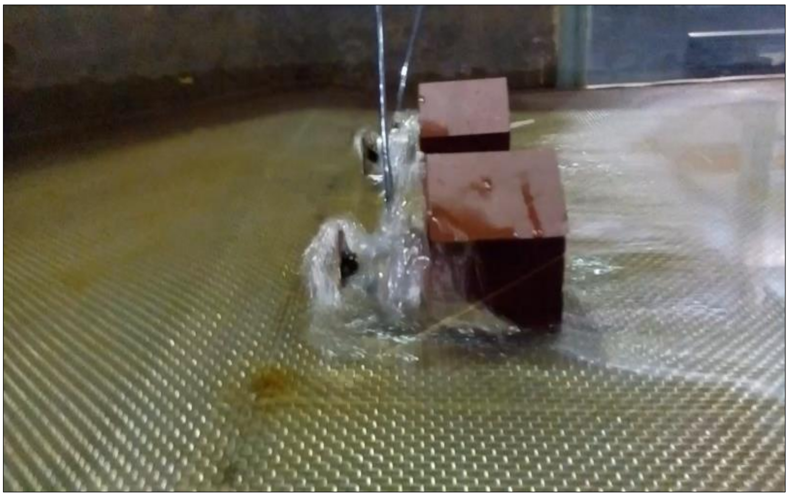


Figure 4.4: Wave Elevation produced by submarine landslide model 2

Figure 4.5: Wave Elevation produced by submarines landslide model 3

The wave elevation produced by each submarine landslide can be observed from *Figure* 4.3 to *Figure 4.5*. The wave elevation at the middle in the between two platform can be observed but the difference is queit difficult to differentiate. Hence, the observation focused at the end of flume, at the structure model to see how high the wave elavation can be produced. Basically, the first model, semielliptical shape produced the highest wave elevation that can overtopped the structure model. The test was run about three time and the result almost same to each other.

While the other two model which have triangular shape expected to have a lesser wave elavation height due their volume is lower. The second model produced wave elavation about half of the structure model as in the *Figure 4.4* and last model does not produced a significant wave elevation that can be observed. The wave elevation only can be observed at the middle of the flume but at structure model there only water flow through.These two model, still same as the first model went for three test to see the average result.

Hence, from this observation result, the first model using the semielptical shape with volume $0.13m^3$ have the capabality to produce tsunami wave. The volume of this model is about 60% more bigger compared to second model and 650% larger compared to last model. Meaning, as the submarine landslide become larger, the wave elevation will increase correspondingly.

Then, second solid block was experimented in this study. The trial of experiment done with a significant wave generated. Actual experiment was done and the high of wave generated almost reach half of the structural model. This volume of solid block is 400% larger than the solid block 1. It have 0.08m^3 with a double dimension, 400mm in length and 200 in height. This generation of run-up wave is very significant compared to third block because the volume is high.

However, the first wave that hit the structural model was not the larger one as an observation have been made. It's to be believed that the wave that hit structural model bouncing back and then bunching up with second upcoming wave and the height of wave will increase. This called shaoling effect as the water travel from deepwater column towards coastal line.

4.2.1 Wave Elevation from Wave Gauge Probe reading

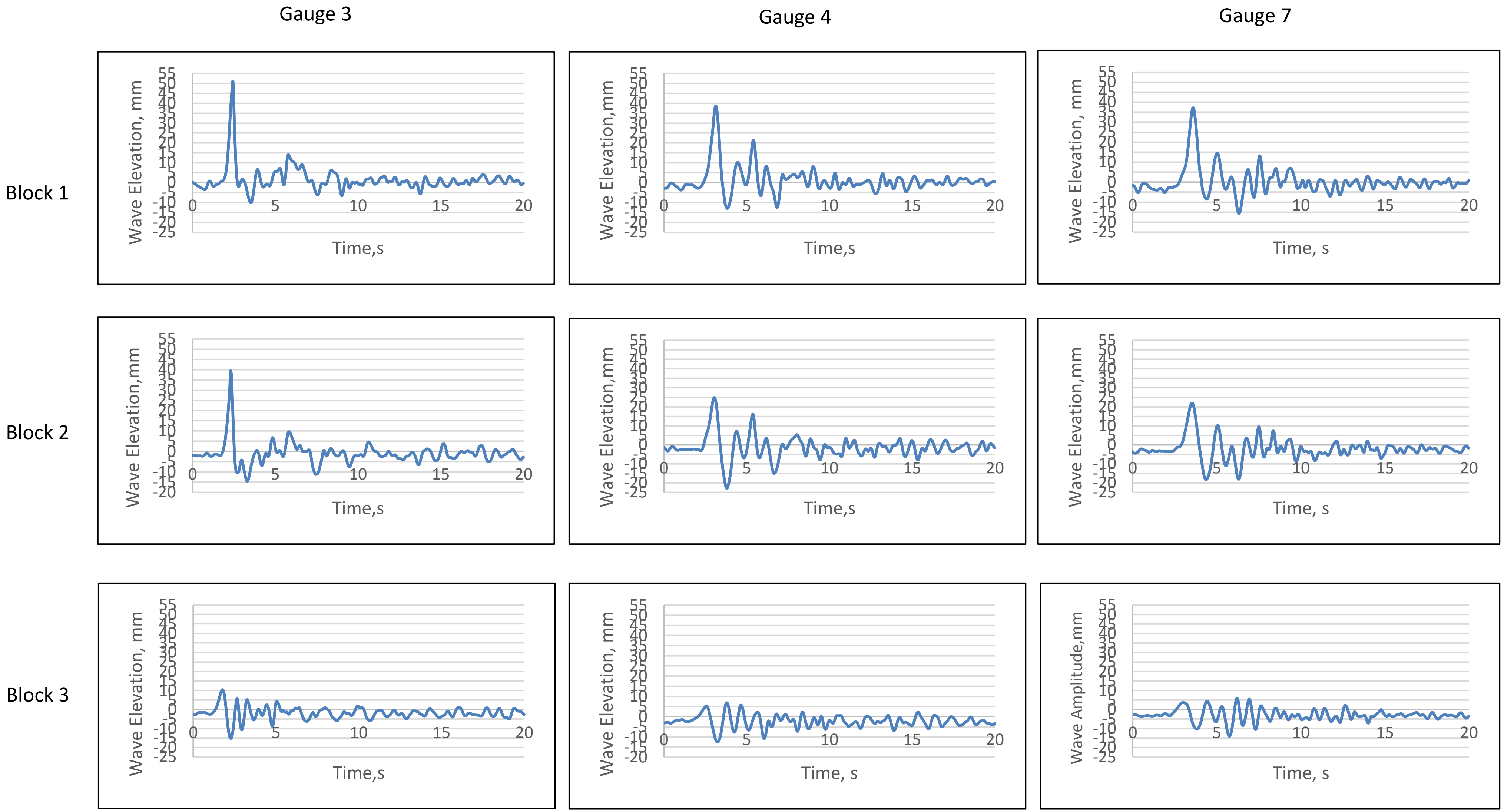


Figure 4.6: Graph of Wave Elevation against Time based on Type of Submarine Landslide and Location of Wave Gauge Probe

To determine the wave elevation at several location, wave gauges were installed at several location. As mentioned earlier, the proposed wave gauges used in the study is 8 but due equipment limitation, the number of wave gauge is 3. These wave gauges enable to record wave elevation maximum run-up height measurement can be be compared to direct visual observation.

Based on the *Figure 4.6*, the wave elevation highest for submarine landslide model 1 same as in the observation made the wave elevation can overtopped the structure model. The location of wave gauge probe can be identified as in *Figure 4.1* in the section 4.1 Experimental Work. As the wave propagate from the source of submarine landslide, the wave will decrease as it move away from the source.

From these result, it can be proven that nearer the source of generation of wave, submarine landslide will have the highest wave elevation and also from the visual observation made earlier. The wave elevation at wave gauge probe 4 and 7 almost similar for all submarine landslide due to having the same water depth which is 0.4 meter.

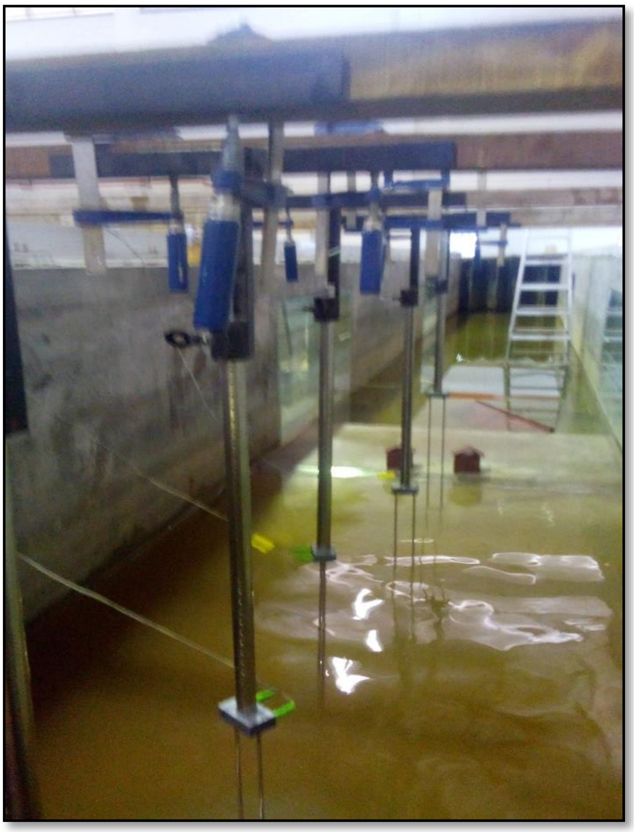


Figure 4.7 : Position of Wave Gauge Probe

4.3 NUMERICAL RESULT

Besides just only getting the result from the experimental data, in this study, the result will be verified using past research. The parameter from the experiment will be used as input for the equation that have been derived from empirical formulations. First equation used in this verification was devoleped by Watts et. all (2005) in their paper, “Tsunami Generation by Submarine Mass Failure. II: Predictive Equations and Case Studies”. There are no constraints stated for this equation to be used. The equation is as below:

$$\eta_{0,2d} = S_o(0.0574 - 0.0431 \sin\theta)(T/b)(b\, sin\theta/d)^{1.25}(1 - e^{-2.2(\gamma-1)}) \quad (1)$$

While for the second equation used in this numerical experiment come from the paper Chai et. all. (2014) in paper “Potential impacts of the Brunei Slide tsunami over East Malaysia and Brunei Darussalam”. The landslide generation model used in this paper was proposed by Watts (1998) to describe the characteristic motion parallel to inclined plane. Basically from the predicting tsunami amplitude, η_d (equation (6)) above the landslide that have been derived based on the curve fitting result of numerical simulation by (Enet abd Grilli, 2007; Grilli and Watts, 2005; Grilli et al., 2009; Watts et all., 2003; Watts et all., 2005). γ is a specific gravity that obtain from dividing density of submarine model over density of water.

$$initial\ acceleration, a_o = \frac{d^2s(0)}{dt^2} = \frac{\gamma-1}{\gamma+C_m} g \sin\theta \quad (2)$$

$$terminal\ velocity, u_t = \frac{ds(\infty)}{dt} = \sqrt{\frac{\pi g b}{2C_d}(\gamma-1)\sin\theta}\ , \quad (3)$$

whereas Cd=drag coefficient and b=length of submarine landslide.

$$characteristic\ distance, s_o = \frac{u_t^2}{a_o} \quad (4)$$

$$characteristic\ time, t_o = \frac{u_t}{a_o} \quad (5)$$

$$\eta_{2d} \approx s_o[0.04772 - 0.03559\sin\theta + 0.00813(\sin\theta)^2]\left(\frac{T}{b}\right)\left(\frac{b\sin\theta}{d}\right)^{1.25} \quad (6)$$
$$X\ 1.18(1 - e^{-2.2(\gamma-1)})$$

There are four independent parameter that controls tsunami amplitude based on this equation (6) . There are:

1. Slope angle, ∅
2. Specific density, γ
3. Relative SMF thickness, T/b
4. Relative depth of submergence, d/b

And there are also some constraints, for the equations to be used.

Type of Constraints	Based on Experiment
∅<30°	∅=26.56°
1.46<γ<2.93	γ=1.553
T/b<0.2	T/b=0.25
d/b>0.06	d/b=0.20

Table 4.2 : Type of constraints for the predicting tsunami amplitude

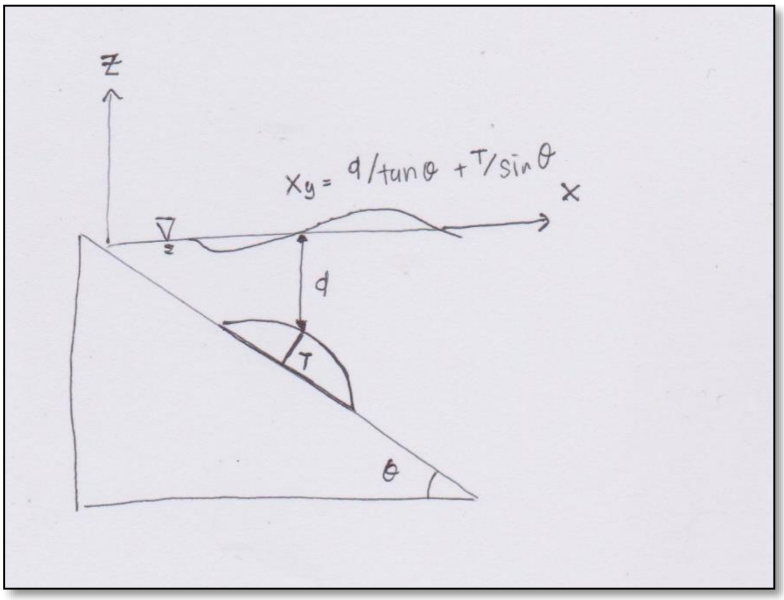


Figure 4.8: schematic diagram of numerical model. X_g is location of numerical wave gauge to record the characteristic tsunami elevation above the maximum initial landslide thickness

Even though this equation can predict the wave amplitude for tsunami wave generation, the location of prediction of submarine landslide is at above the center of submarine landslide. For the experimental setup, the wave gauge probe was installed above toe angle of platform. Meaning, the wave elevation from the equation should be higher than experimental result.

This experimental work not a fully submerged landslide and the initial submergence depth, d not same as in the *figure 4.8*. Hence, the initial submergence depth, d was taken 200mm based on vertical depth of partially submerged block, from edge to the surface of water as in *Figure 4.1*. The wave gauge also cannot be placed at Xg location (location for numerical wave gauge) but it was placed on top of end of slope. This location was chosen because it most nearer to X_g location without obstructing the submarine landslide.

r_w	:	1025	kg/m^2
r_b	:	1591.549	kg/m2
γ	:	1.552731	-
C_m	:	1	-
C_d	:	1	-
g	:	9.80665	ms^{-2}
Vb	:	0.125664	m^3
mass	:	200	kg
b	:	0.8	m
w	:	1	m
T	:	0.2	m
d	:	0.16	m
Θ	:	26.56	degree

Table 4.3 : Parameter for Submarine landslide Model 1

Based on experimental work done, the maximum wave amplitude recorded by wave gauge 3 is 51.11mm as in the Figure 4.6 for model 1. While from the numerical result is 46.65mm using equation (6). By using equation (1) the result is slightly higher than experimental result, which is 60mm. Below in Table 4.4 shows summary of numerical result and also the experimental result.

Model	Experimental Result	Equation 1	Equation 6
1	51.11mm	78.49mm	60.85mm
2	39.80mm	32.99mm	25.58mm
3	11.90mm	-	-

Table 4.4: Summary of Experimental and Numerical Result

4.4 DISCUSSION OF RESULT

Based on the experimental and numerical simulation, the data almost similar. But the location of wave gauge probe 3 and predictive wave gauge are at different locations. Somehow, the numerical simulation only can predict the wave amplitude above the mass submarine landslide not for the whole journey of wave toward coastal line.

There are equation for at several location but need to do more research on how the researchers derive it. This will help to understand and how to use it wisely to get an accurate result from it. In this study, the predictive wave amplitude equation only done for one location only. For the experimental result, the wave gauge was placed at several location to read the wave amplitude. As shown in figure 4.6 the wave amplitude increase as the submarine landslide increase. The wave amplitude will decrease from time to time as it propagate toward coastal line. However, the wave amplitude from these 3 wave gauge probe reading does not decrease rapidly.

The size of submarine landslide have a several control parameter which are thickness of slide, length, density and width. These parameter need to be studied more to get an accurate result. The actual submarine mass failure is very hard to be seen and analyse. Hence, from this study, its believed that thickness, angle slope, length and width will have significant impact toward run up wave height.

The size of submarine landslide will control the run-up wave based on several parameter. The first one is submarine relative thickness, as the submarine become thicker and long it will produce high run up wave. Besides, the higher density will give a high impact toward production of wave.Initial submergence and angle of slope also play important role in tsunami generation by submarine landslide.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

The aim of this paper is to study the correlation between of submarine landslide sizes and type the run-up wave will be produced. To enhance this study, it's highly recommended to do a numerical simulation to prove the experimental work were carried out correctly. From the result obtained from the experimental work and also from the numerical simulation, the relationship between these two will be analyses and discussed.

Submarine landslide motion is characterized by several parameter such as angle of slope, thickness, length along the incline plane, specific density and width. All these parameter control will control the run-up wave generation. These parameter can be estimated using bathymetry data through marine survey. By using the data obtained from the survey, run-up wave can be estimated and safety precaution can be taken.

From the result of this study, it can be concluded that the generation of tsunami wave influences by volume of submarine landslide. These volume also control by several parameter that can produce a high run-up wave. These parameters are length of slide, width and thickness of submarine landslide. It just like the same volume of submarine landslide but the stated paramter, that contribute to the volume is diferent. Example, two volume submarine landslide is same, but the length of both submarine landslide is different. Both submarine will produce diferent run-up wave and the longest landslide length will produce a higher run-up wave.

The width of submarine landslide model is constant at 1000mm. Beside, the initial submergence depth also will affect the generation, Even in this study, the initial submergence depth is constant at 160mm from surface of water.Besides from the experimental result, the input from experimental work tested in numerical simulation based on equation derived from the past study. The equation used also stated that the same parameter as the experimental data will control the run-up wave but there are limitation to use this equation.

Based on experimental work done, the maximum wave amplitude recorded by wave gauge 3 is 51.11mm and from the numerical result is 60.85mm and 78.49mm. From the equation as the initial submergence depth, d was reduced, the wave amplitude will increase and vice versa. The experimental work need to be carried out again with other different size that fulfill the constraint of relative SMF thickness, T/b. Moreover, the SMF should be done in fully submerged and see how the result either same or not. However, from both of result, the wave amplitudes were not far from each other. There should be a lot of number of experimental work need to be done as well as numerical simulation to derive the equation for wave amplitude based on experiment done.

Hence, it prove that there are correlation between submarine landslide size and run-up wave generated and the size also have several parameter control it. As a recomendation for this study, a further study should be carried out to derive own equation from the experimental work. This will helps to understand more the relationships betweem submarine landslide and run up wave. On top of that, the location of wave gauge experimental work and predictive equation gave slighlty different, hence its highly recomended for futher studies.

On top of that, the initial submergence depth of landslide also will affecting the run-up wave produced. The study on effect the initial submergence depth can be studied. Expected result from this type manipulated variable is the lower the initial submergence depth it will cause more impact toward the generation of run-up wave. At the same time, if the landslide is out of water and hit the surface of water it will produce more.

Furthermore, the angle slope of landslide also can affecting the generation of run-up wave. As in this paper, the angle slope is fixed at 26.56° and as the increment of slope angle the generation of tsunami expected to be increased. Its believed that, there are some limitation of slope angle lanslide can produce high tsunami wave. Besides increasing the landslide slope angle, the intersection between platform and datum of flume need some modification to ensure the landslide model will slide further. As the angle of platform increase the landslide model tend to stop without sliding further.

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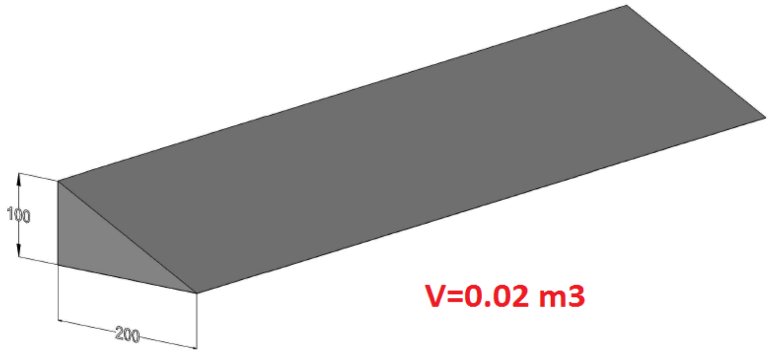
APPENDIX



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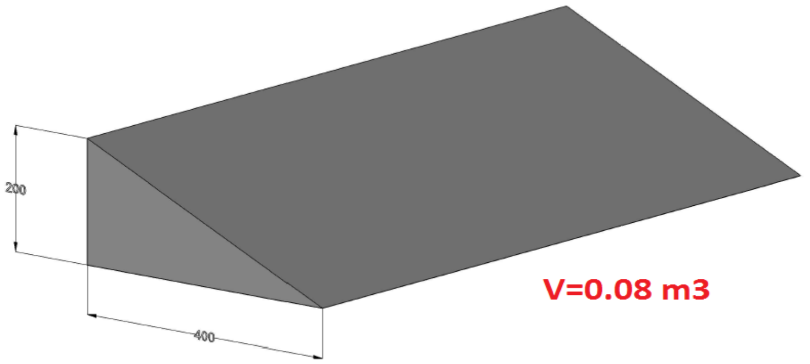

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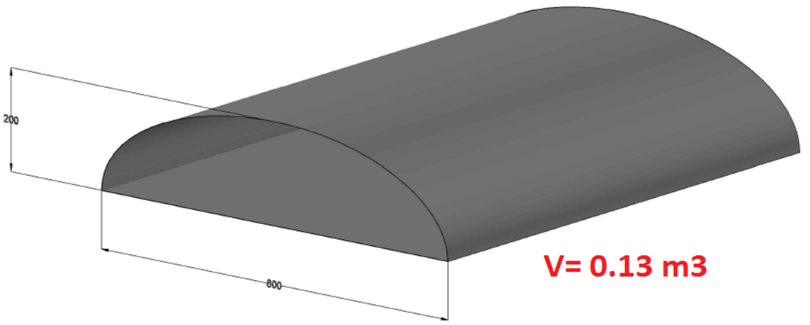
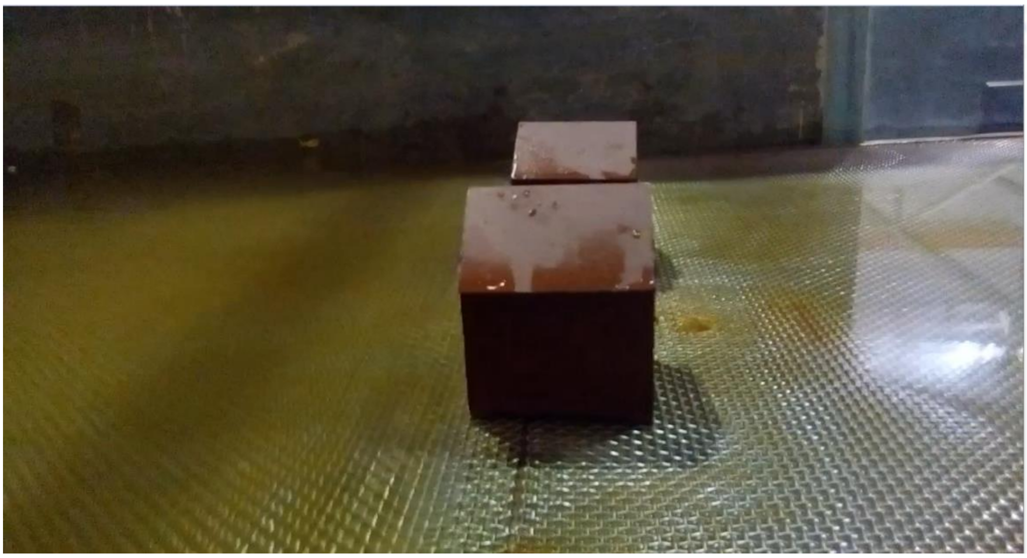


Solid block no 3

Solid block no 1

SIMULATION WORK



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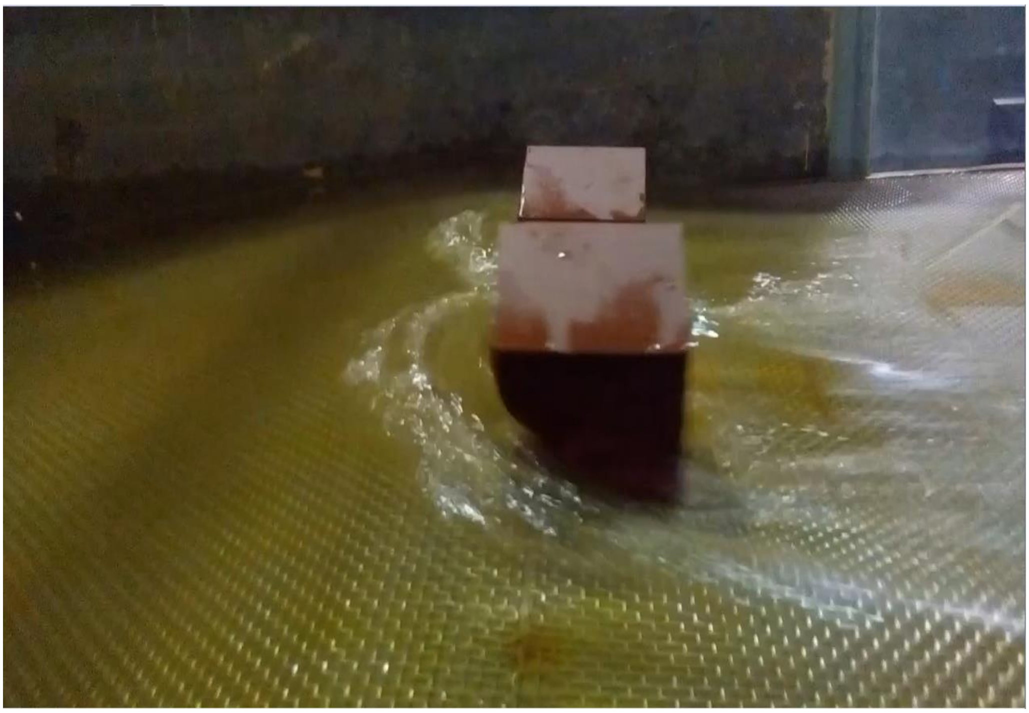

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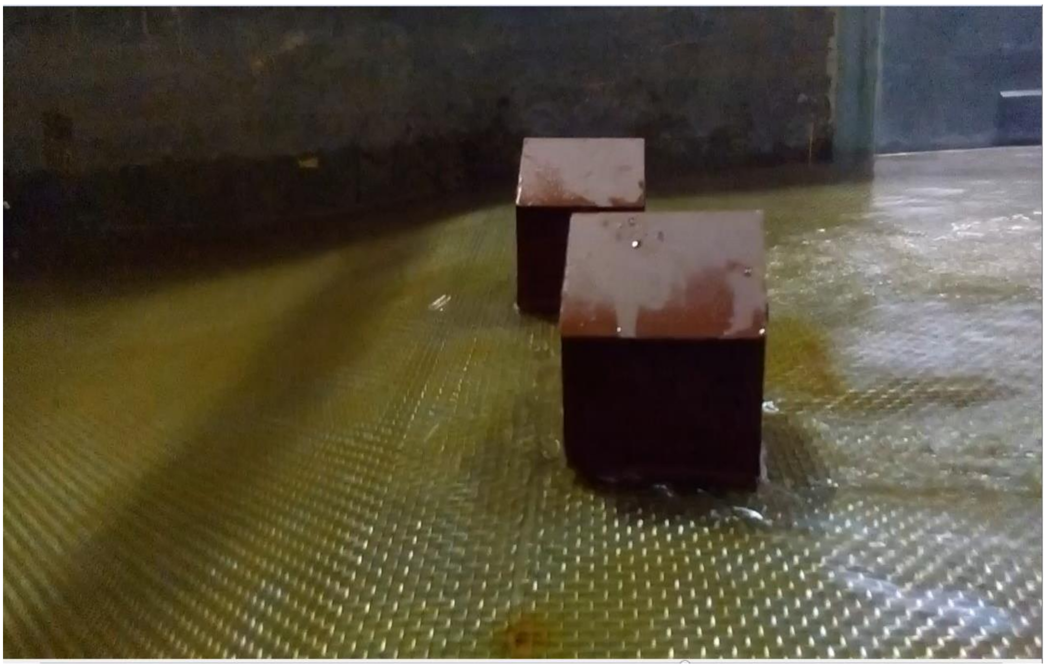
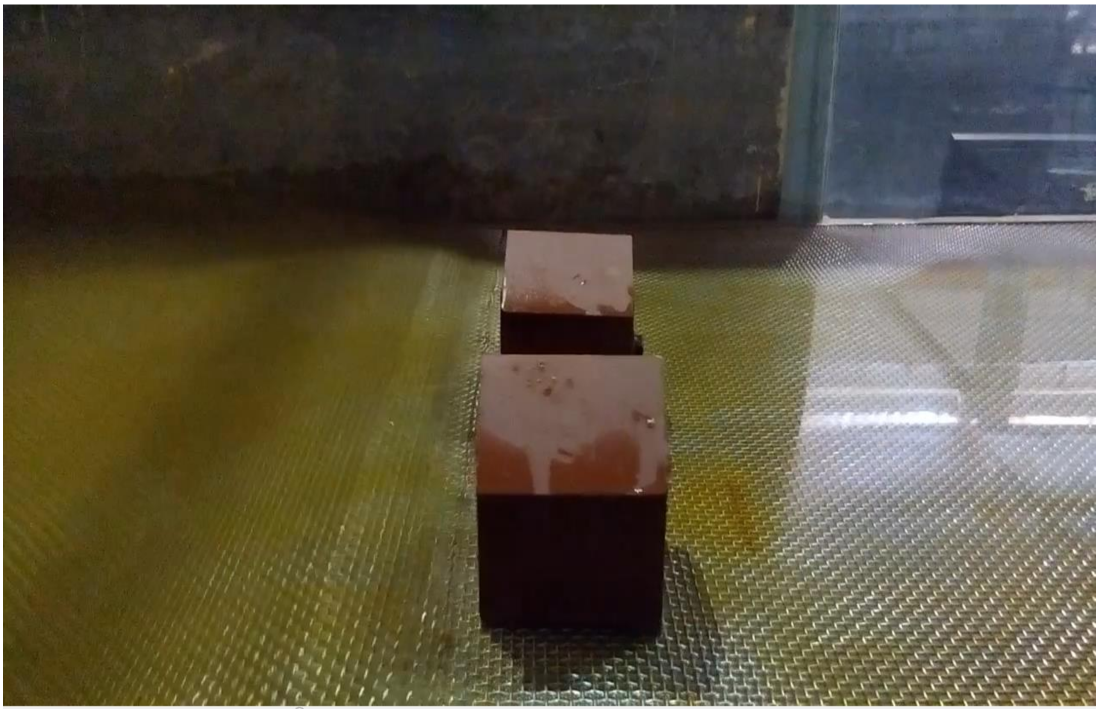


3

SIMULATION WORK 2



1

2

3