Experimental Set Up About Tsunami Impact Force on Standing Structures Generated by Submarine Slides

by

Farah Saliza binti Sallehuden

13797

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Civil)

JANUARY 2014

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CERTIFICATION OF APPROVAL

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Approved by,

____

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2014

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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FARAH SALIZA BINTI SALLEHUDEN

ABSTRACT

The study of this project is about the relationship between the generation of tsunami wave and the impact forces carried by the wave on structures. This study involves experimental work which takes place at Offshore Laboratory, Block J, Universiti Teknologi PETRONAS where the model of the landslide and tsunami waves were used. The height of waves generated from the slide and the impact forces applied to the structures were measured by using electronic devices attached along the tsunami model. Data were collected and analyzed on the same day as the experiment completes.

ACKNOWLEDGEMENT

In the name of Allah, The Most Gracious, The Most Merciful. First of all, I would like to thank Allah Subhanahu Wataala for granting me with well-being, serenity, and knowledge in completing this report after about 12 weeks of final year final semester study.

Acknowledgement is given to University Teknologi PETRONAS as they have created an opportunity for students to broaden up their mind and to have the involvement of issues related to the industry that is then studied by completing this research and project.

I acknowledge, with deep gratitude and appreciation for the inspiration, encouragement, valuable time, and guidance given to me by my supervisor, **Dr. Indra Sati Hamonangan Harahap,** I really appreciate the guidance given to me regarding this project. It was not an easy task, but through the guidance given to me by my supervisor, I manage to complete this report.

My deepest gratitude to Mr. Meor, Mr Zaid, Mr. Huan, Ms. Nur Zaidah, Ms. Nur Diyanah, and fellow members of offshore laboratory that have stayed with me until midnight and are willingly and patiently guide me through the working process of the project. Besides, I would also like to express my appreciation to all my colleagues for sharing their invaluable knowledge and expertise to help me in this project.

I would like to thank my family for their emotional and moral support throughout my internship and also for their love, patience, encouragement, and prayers. I am blessed to be surrounded with people that have always wanted me to learn as much as possible during my study here.

Last but not least, to everyone who have assisted me directly or indirectly in making sure my Final Year Project a successful one.

Thank you.

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CHAPTER 1

INTRODUCTION

1.1 Background

A tsunami or seismic sea wave is a series of waves with high energy and speed. It has always mistakenly called tidal wave, where tidal wave is caused by the gravitational forces of the moon on the sea while tsunami wave is caused by underwater interferences such as an earthquake, submarine landslides, submarine volcanic eruptions and meteorite impact. Tsunami has different wave characteristics depending on the depth of water where the event occurs. Meaning to say that, if the tsunami occurs in deep water, it will have a high speed of waves, long wavelength and low wave amplitude while for tsunami that occurs in shallow water, the wavelength is short, the speed and height of waves is inversed; speed decreases but its height will increase. Table 1 shows tsunamis generated by submarine landslides for the past 35 years.

TABLE 1. Summary of Tsunamis Generated by Submarine Landslides

Year	Location	Height of tsunami wave (m)	Volume of Landslide (m^3)
1979	Nice	3	1.5 x 10^8
1994	Skagway, Alaska	9-11	3-10 x 10^6
1998	Papua New Guinea	15	6.4 x 10^9
1999	Izmit Bay, Turkey	2.5	-

Everyone is aware that earthquakes can trigger tsunamis. However, besides earthquake, underwater landslide which also known as, submarine landslide, can also be said as one of the important factor of tsunami generation with high run-up which will bring damages to offshore structures, subsea infrastructures and endangering human lives along the shoreline. This type of landslide occurs when a slope fails to hold itself. It is a translational failure because it moves downward and outward on top of an inclined planar surface. Among the contributing factors for this landslide to happen are due to earthquakes and geotechnical characteristics of soils, e.g. weak layers, seepage and overpressure. Shaking, resulting from an earthquake will cause underwater rocks, soils and ice formation to fall down and the mentioned geological factors will make the downward driving stress to exceed the resisting stress on slope, causing movements along the surface. Submarine landslide was said to give serious impacts to surroundings and properties even though it only tilts about one degree.

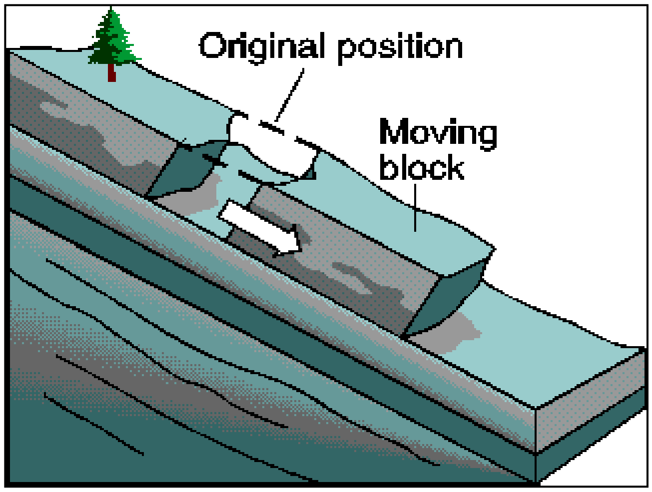


FIGURE 1. Landslide due to Translational Failure

Submarine landslide will produce tsunami with greater currents due to the long wavelength and also the time taken for the propagation of tsunami waves to reach lands. Tsunami waves that have great speeds are capable in covering huge distances in few hours. To understand on how submarine landslides can trigger tsunami waves, the author has decided to refer to the 1998 Papua New Guinea tsunami disaster. It started with an earthquake of 7.1 in the Richter scale which caused large volumes of underwater rocks to slide downhill. Water dragged in and collides in the middle, trying to displace the original location of those rocks and soils, and thus, sending a great wave radiating out.

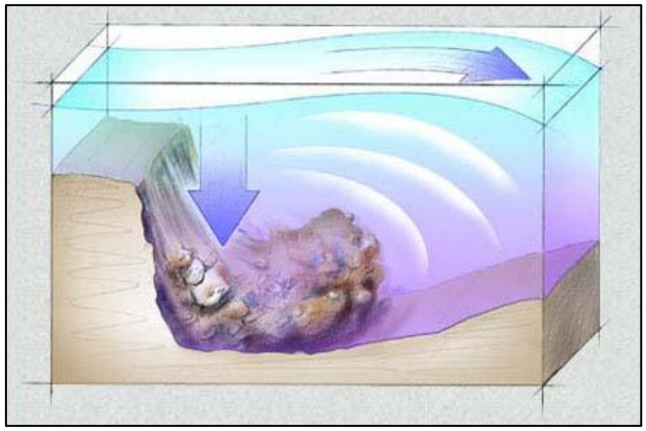


FIGURE 2. Illustration on Slide Triggered Tsunami

We can see that tsunami gives disastrous impacts to living things and buildings. The height and speed of tsunami waves are very high and can cause loss of lives for living things such as animals and human beings. Based on the Papua New Guinea tsunami, its speed in deep water is 400-800 km/h and its height as it reaches the beach is about 11 meters high. Since tsunami waves have long wavelengths, they gain more energy and can travel a long way inland. This strong wave energy is being compressed as the waves slow down, causing the tsunami waves becomes higher and steepen, leading to the monster waves that cause so much damages to surroundings.

Destruction caused by tsunami wave involved two mechanisms; the smashing force of wall of water and the destructive power of volume of water. It destroys everything in its way by the sheer weight of water. Although the impacts from tsunami waves are limited to coastal areas only, but, their strong currents and run-up can affect the entire ocean basins, human and environment. Escaping tsunami waves is almost impossible. People will have no time to save themselves, thus, causing them to lose their lives because of drowning and hitting by debris brought by waves. Moreover, under this condition, it is difficult for people to stay healthy as infections can be spread easily and all infrastructures like drinking water has been contaminated and destroyed. Other than death and diseases, tsunami waves caused property damages and changes on landscape. If dangerous chemicals are washed away into the sea, they will give serious threats to the marine habitats and species.

Tsunami waves caused by submarine landslides can be divided into three parts: triggering mechanism, tsunami generation, and propagation and run-up at the beach or offshore structure. We must first understand substance of tsunami clearly and how to find methods to reduce damage from tsunami wave. Hence, this paper will present a comprehensive review on the experimental test about waves generated due to sliding of solid blocks, which act as submarine slides, to obtain impact forces to structures located along the coast from these waves.

1.2 Problem Statement

Nowadays, lots of earthquakes and tsunamis news can be found either on the mass or social media. The occurrence of submarine landslides is one of the major factors that cause tsunami. These deformations affect structures and human lives along the shoreline. However, most of this type of landslide happened in deep water. Thus, they are difficult to be detected and determined in terms of their volumes, lengths and wave characteristics. The only means to study the tsunami behaviors caused by submarine landslides is by conducting laboratory experiments.

Other than that, the impact forces such as drag and hydrodynamic forces brought by tsunami waves were extremely large and exceeded the design wind loads for coastal structures. Measurement of these impact forces for various types of tsunami wave is necessary.

1.3 Objectives

- To investigate impact forces to structures caused by tsunami waves generated by submarine landslides

1.4 Scope of Study

A slide triggered tsunami can be generated by various parameters. However, for this project, the author will only covers on the volume of slides and the propagation of tsunami waves. These parameters will act as the manipulated variables. The focus of this project is to observe the impact forces to coastal structures due to tsunami waves.

This project involves laboratory works which will take place at Offshore Laboratory, Block J, Universiti Teknologi PETRONAS.

CHAPTER 2

LITERATURE REVIEW

Submarine landslide is an underwater slide that occurs when a slope fails to hold itself up. This has been supported by Hampton, Lee and Locat (1996) as they report that this type of landslide will take place when downward forces such as gravity and sea water exceed the resisting forces, which in this case, the shear strength of the slope material, leading to shifting along one or more concave to planar surfaces.

There are many factors contribute to submarine landslide. According to Masson, Harbitz, Wynn and Pedersen (2006), these factors can be categorized in two; geological properties of the landslide material and external phenomenon. An example of submarine landslide due to geological properties can be found in article "Submarine landslides: processes, triggers and hazard prediction", states that the slope where the location of landslide occurred was said to have weak layers of soil. Weak layer of soil can be defined as a soil with high amount of both clay and water content, causing it to have a more sensitive and brittle characteristics (Masson et al, 2006). Due to this problem, only a small shaking is needed to start a submarine landslide. Earthquake attack can be classified as an external phenomenon. Other than earthquake, climate changes also fall into the same category. In the opinion of Masson et al (2006), histories claimed that there are connection between landslides and earthquakes.

Tsunami waves can be controlled by several parameters such as angle of bed slope, volume of slides, dimensions of landslides, time, tsunami wavelength, length of slides, speed of waves, location of landslide and many more. In terms of slope, a slide with higher slope tends to produce a tsunami with high speed and elevations (Geist, 2000). However, Hurukawa, Tsuji and Waluyo (2003) believe that a low angle slope can also generate a huge tsunami waves as they have done a study on the 1929 Grand Banks event where a large landslide has occurred on a 2 to 6° slope. All findings with different parameters controlling tsunami waves are supported by an equation proposed by Satake and Tanioka (2003), where it clearly shows that in order to determine the maximum amplitude of the tsunami waves, it does not depend on one but various parameters are required.

$$|\eta_{max}| = 0.218T(\sin\theta)^{1.38}(\frac{L}{d})^{1.25} \qquad (1)$$

where T is the thickness of the slide, θ is the angle of slope, L is the length of the slide, and d is the depth from the water surface to the top of the slide.

For coastal communities within the wave run-up region, the tsunami flows around, through and over buildings since it will gain higher speed and height as it comes closer to the shoreline. This turbulent, fast-moving flow is capable in causing the structures along the area to damage, collapse or floating away. Other than that, people will be drowned because they will face difficulties of withstanding the wave forces, large turbulent eddies, and impact with debris brought by the tsunami wave. Linton, Gupta, Cox, van de Lindt, Oshnack and Clauson (2012) agree with these statements as they explain that there are three forms of tsunami impact force; overflow, bore and breaking. The Type 1 Overflow is a low flood velocity, Type 2 Bore is a quick flow and inundated tsunami carries out so lit on fission, and the Type 3 Breaking form is the type that will break in front of structures and only occurs when the buildings are too close to the shore. The Type 3 was said to bring the most critical hit despite that the potential of a tsunami depends on the location and situation (Linton et al, 2012). Watts (2000) states that all submarine landslides do not have same potentiality of causing tsunamis. But, on the other hand, Tappin (2010) explains that all forms of submarine landslides have the capability to produce tsunamis.

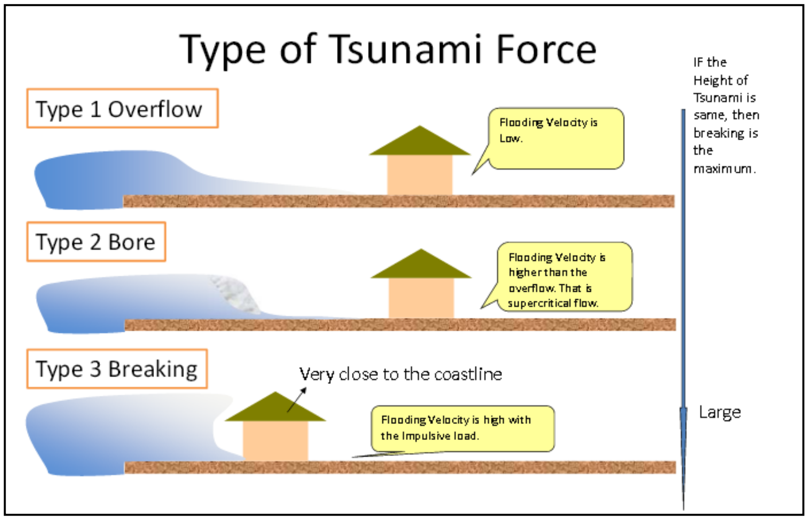


FIGURE 3. Types of Tsunami Force

Tsunami waves bring great amount of forces; hydrostatic, hydrodynamic, buoyant and debris impact force, that exceed the design loads for the coastal structures and can give damages to them. It is not practical and feasible to design structures that can withstand these forces. Figure 4 shows the force conditions in two scenarios; the initial impact and the post impact. F_i, F_s, F_b, F_{HS}, and F_d are the debris impact, surge, buoyant, hydrostatic and hydrodynamic (drag) force respectively.

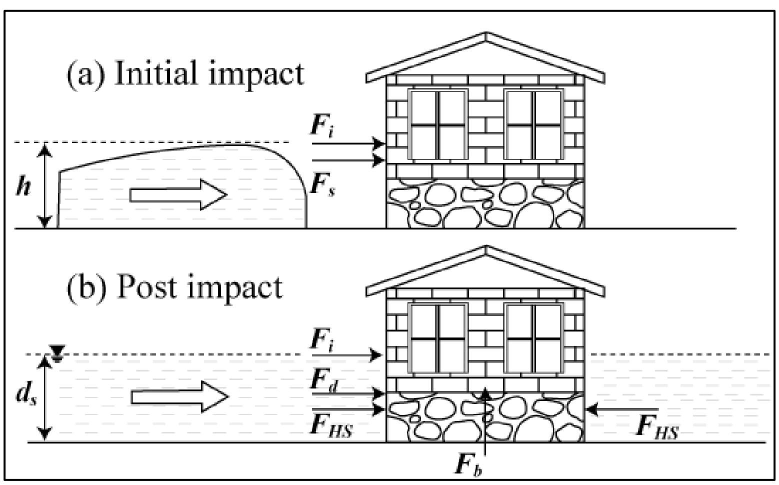


FIGURE 4. Loading Conditions

According to the Federal Emergency Management Agency (FEMA), these forces can be calculated by using the following equations:

a) Hydrostatic force

$$F_{hydrostatic} = \rho g \left(h_{max} - \frac{h_w}{2}\right) b h_w \qquad (2)$$

where ρ is the density of water, g is the gravitational force, h_{max} is the maximum water height above the base of wall of building, and h_w is the height of building wall.

b) Hydrodynamic force

$$F_{hydrodynamic} = \frac{1}{2} \rho_s C_d B (hu^2)_{max} \qquad (3)$$

where ρ_s is the density of water, C_d is the drag coefficient, B is the width of the coastal structure, h is the flow depth and u is the flow velocity. The combination between h and u represent the maximum momentum flux of the tsunami waves per unit mass.

c) Debris impact force

$$F_{impact} = C_m u_{max} \sqrt{Km} \qquad (4)$$

where C_m is the added mass coefficient, u_{max} is the maximum flow velocity carrying debris, K is the effective stiffness for debris and m is the mass of debris. This type of force depends solely on the debris and the material of the coastal structure. Since the debris brought by tsunami waves consist of various elements, thus, their stiffness will vary too, depending on their dimensions.

For tsunami waves' propagation and run-up, Watts (1998) claims that its amplitudes above a submarine landslide scale with characteristics of the solid block motion. The theoretical initial acceleration of a solid block is approximately:

$$a_0 = \frac{(m_b - m_o) g (\sin\theta - C_n \cos\theta)}{m_b + C_m m_o} \qquad (5)$$

where the added mass coefficient C_m is evaluated at the non-dimensional initial submergence *d/b* of the soild block for a given incline angle θ. The terminal velocity of a solid block is approximately:

$$u_t = \sqrt{\frac{2(m_b - m_o) g (\sin\theta - C_n \cos\theta)}{C_d \rho_o w b \sin\theta}} \qquad (6)$$

where the drag coefficient C_d depends on the solid block shape through the incline angle θ, and the Coulombic friction C_n is determined by the solid block and incline materials. Watts (1998) added that the equation below is a standard analytical solution of free bodies sliding down an incline subject to form drag at high Reynolds number. The solution of the approximate equation of motion is

$$s(t) = s_n \ln[\cosh\left(\frac{t}{t_o}\right)] \qquad (7)$$

which provides the solid block center of mass position along the incline as a function of time subject to the initial condition $s(0) = 0$. The first term in the Taylor series expansion of equation (3) about $t = 0^+$ is $s(t) \approx a_0\, t^2/2$. The characteristics distance s_o and characteristics time t_o of landslide motion

$$s_o = \frac{{u_t}^2}{a_o}, t_o = \frac{u_t}{a_o} \qquad (8)$$

are derived directly from the equation of solid block motion and are invertible functions of observable quantities, namely initial the acceleration and the terminal velocity.

CHAPTER 3

METHODOLOGY

3.1 Key Milestones

The target milestones for the project are shown in the Gantt Chart in Table 2 and 3.

TABLE 2. Gantt Chart of Project for FYP 1

PROJECT FLOW / TASK	WEEK													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Title Selection	■	■												
Preliminary Research Work		■	■	■	■									
Submission of Extended Proposal						■								
Proposal Defence								■	■					
Project Work Continue										■	■	■		
Submission of Interim Draft Report													■	
Submission of Interim Report														■

TABLE 3. Gantt Chart of Project for FYP 2

PROJECT FLOW / TASK	WEEK														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Project Work Continues	■	■	■	■	■	■	■	■	■	■	■	■			
Submission of Progress Report							■								
Pre-SEDEX										■					
Submission of Draft Report											■				
Submission of Dissertation (Soft Bound)												■			
Submission of Technical Paper												■			
Oral Presentation													■		
Submission of Project Dissertation (Hard Bound)															■

3.2 Procedure

Experimental test about tsunami wave will be carried out in a concrete flume of 20 meter length, 1.5 meter width and 1 meter depth at the Offshore Laboratory, Block J, Universiti Teknologi PETRONAS. The beach will be formed by using natural beach sand and a slope of 1 vertical to 3 horizontal (1V:3H). Tsunami waves will be generated by sliding down solid blocks along the inclined bed. The sliding surface will be lubricated so that the blocks can slide freely on it. Wave elevations will be measured by fixed wave gauges located along the wave propagation. Impact forces from tsunami waves will be assessed by pressure sensors placed on the steel structures.

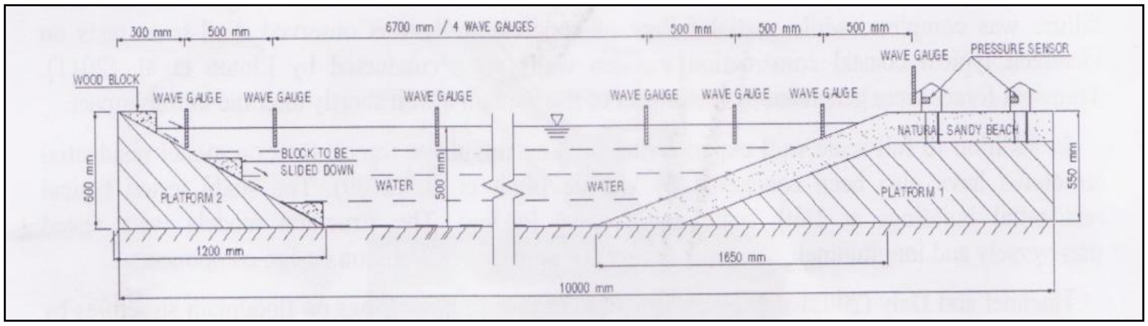


FIGURE 5. Main Section of the Experimental Test

3.3 Tools and Equipment

Tools and equipment required for this project are:

- Concrete flume of 20 meter length, 1.5 meter width and 1 meter depth
- Solid steel blocks
- Wave gauges
- Pressure sensor
- Steel structures of 100 mm height

3.4 Experimental Program

In order to study the tsunami behaviors and their impacts on the structures, the only means is by conducting laboratory experiments. As mentioned earlier, there are many parameters controlling the tsunami waves such as volume of landslides, height and speed of waves and angle of bed slope. However, this study only focuses on the volume of landslides.

For this project, the fixed variable is the shape of the steel block, which is, wedge. The author has proposed to have several thickness of the block to act as the manipulated variable during the experiment. The wedge will have two different thickness to create different volume of landslides; 100 and 200 mm.

The responding variable for this experiment are the reading of wave elevations on wave gauges located along the wave propagation and the reading of impact force on pressure sensors placed on the plastic structures.

3.4 Expected Results

Many studies have done the simulations and experimental works to study the tsunami behaviors with various parameters such as the dimensions of landslides, angle of slope, time, tsunami wavelength, length and volume of slides, speed of waves, location of landslide and so on. Thus, since this project only covers on the volume of slides and impact forces on the coastal structures, the author is expected to get a more or less results with those previous studies.

Figure 6 below shows the result of the experiment done by Grilli and Watts (2005) for different volume of landslides. The graphs of wave amplitudes against time were plotted at different locations; a) at the initial landslide position, b) 4 meter after the initial location, c) 7 meter after the initial location, and d) near the shoreline. The solid line indicates a rigid slide with no deformation, while the two dotted lines indicate the slides deformation with different volumes. These graphs explain that the bigger the volume of landslide, the higher the wave amplitudes.

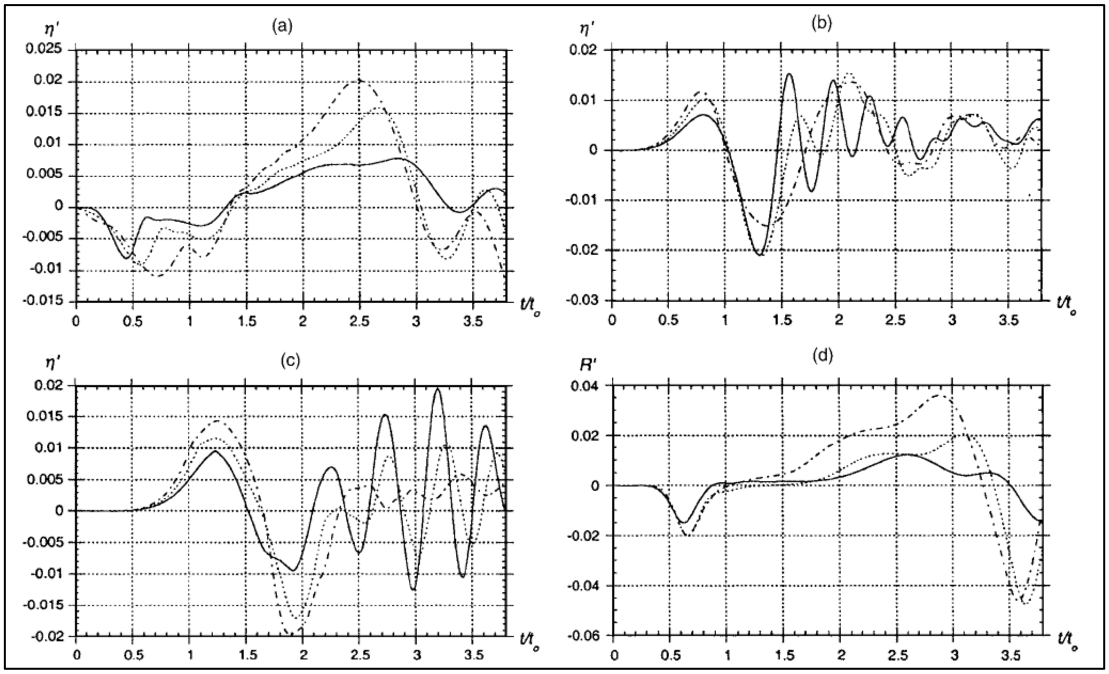
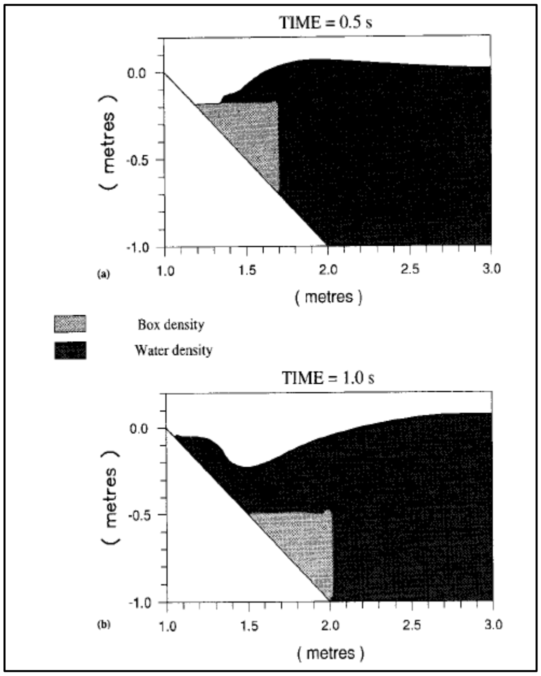


FIGURE 6. Graphs of Tsunami Wave Amplitudes at Different Locations with Different Volume of Landslides

To have a better understanding about the relationship between the length of landslide and the reading of wave elevations, experiments conducted by Rzadkiewicz, Mariotti and Heinrich (1997) by using a rigid solid box prove that the longer the length of slides, the higher the elevations. Figure 7 illustrates the movement of a rigid box at different length of slides; 1.5 meter and 2 meter, and the movement of water produced due to these slides. The results from these movements can be analyzed in Figure 8, where the wave produced by a longer slide will have a longer wavelength and higher in elevations.



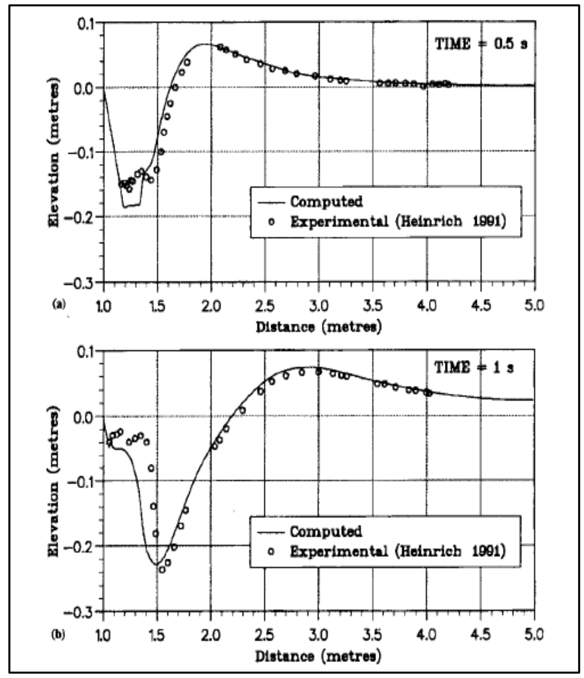


FIGURE 7. Graph of Computed Density Maps for Rigid Box Sliding Down Slope

FIGURE 8. Graph of Tsunami Wave Elevations against Length of Slide

In calculating the impact forces act on the building structures, there are two different equations used by Al-Faesly, Nistor, Palermo and Cornett (2013). They are from the FEMA P-646 [equation (3)] and FEMA P-55 equation:

$$F_{hydrodynamic} = \frac{1}{2} C_d \rho V^2 A \qquad (9)$$

where C_d is the drag coefficient, ρ is the density of water, V is the flow velocity and A is the surface area of the structure. When Al-Faesly et al (2013) carried out the experiment in determining the hydrodynamic impact force on the structures, it can be seen as in Table 4, that the experimental value are nearer to equation (9). However, when the momentum flux were calculated from the experiment, the output value are closer to equation (3).

TABLE 4. Results for Experimental and Estimated Impact Forces

Impound. depth (mm)	Water depth quasi-steady	Experimentally measured				FEMA P-55			FEMA P-646		
		u (m/s)	Max of (hu^2)	F_d (N) SQ*	F_d (N) CR*	u (m/s)	F_d (N) SQ*	F_d (N) CR*	Max of (hu^2)	F_d (N) SQ*	F_d (N) CR*
550	200	1.54	0.47	200	105	1.40	118.5	71.1	0.08	23.1	13.9
850	280	1.75	0.86	400	210	1.66	232.2	139.3	0.15	45.3	27.2
1150	330	2.36	1.84	600	305	1.80	322.5	193.5	0.25	75.0	45.0

*SQ and CR refers to the square and circular models respectively.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Experimental Apparatus

4.1.1 Steel Block

Since the manipulated variable for this laboratory experiment is the volume of landslide, the author has come out with two different sizes of steel block. These blocks will act as the submarine landslides. Figure 9 shows a steel block with dimension of 1000 mm length, 200 mm width, and 100 mm high. While Figure 10 shows a steel block with dimension of 1000 mm length, 400 mm width, and 200 mm high.

FIGURE 9. Steel Block 1

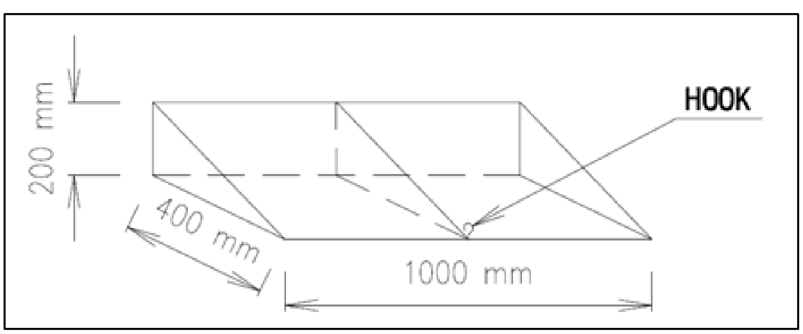


FIGURE 10. Steel Block 2

4.1.2 Flume Tank

The laboratory experiments were conducted in a concrete flume tank with dimension of 20 m length, 1.5 m width and 1 m depth, with transparent side installed with a rectangular glass.

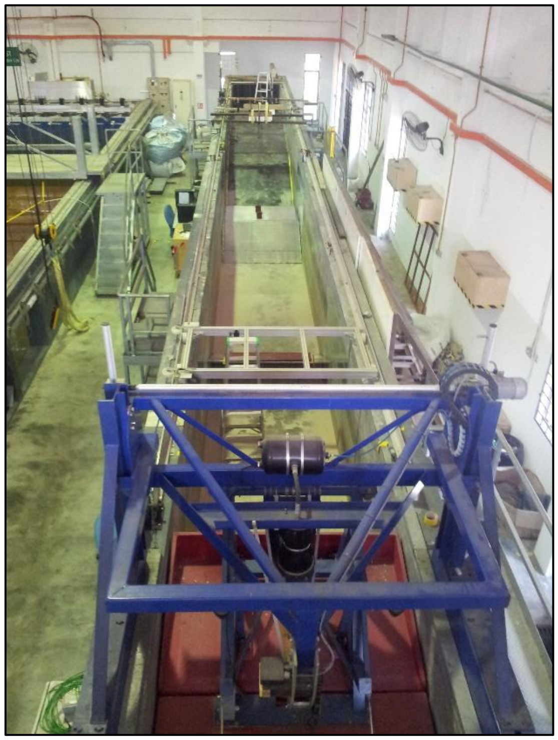


FIGURE 11. Flume Tank

4.1.3 Platform

Figure 12 shows the steel block used to act as a platform during the generation of tsunami waves. The platform is made constant with a slope of 1 vertical to 3 horizontal (1V:3H). Tsunami waves is generated by sliding down a solid steel block along the inclined bed.

FIGURE 12. Platform

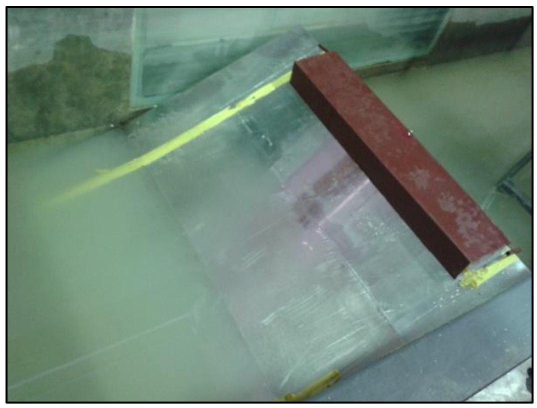


FIGURE 13. Generation of Tsunami Waves

4.1.4 Experimental Instrumentation

Upon the introduction of different landslides volumes, the wave propagation and its impact forces on the structures might be changed during the generation of tsunami waves. To monitor the changes of both wave propagation and impact forces throughout the experiment, the flume tank was equipped with fixed wave gauges located along the path of the generated waves and pressure sensors were placed on the plastic structures.

The using of several wave gauges at different locations can help to find the highest wave amplitudes with respect to its distance from the landslide source. The position of wave gauges and pressure sensors during the experimental work can be identified in Figure 5.

4.2 Observation of Wave Elevation and Impact Forces to Structures with respect to Landslide Volume

Wave tsunami was generated by sliding down the solid blocks along the inclined platform. The blocks have different volumes and thickness, and were made up of steel plate. The sliding platform was smooth and lubricated to provide a frictionless slope. Figure 14 below shows the simulation of pattern of wave propagation for Steel Block 1 produced after the solid block has been slide down the platform. Due to the small volume of landslide, the wave generated is not high and strong enough to give any impact forces to the structures. Hence, no reading of impact forces can be obtained on the pressure sensors.

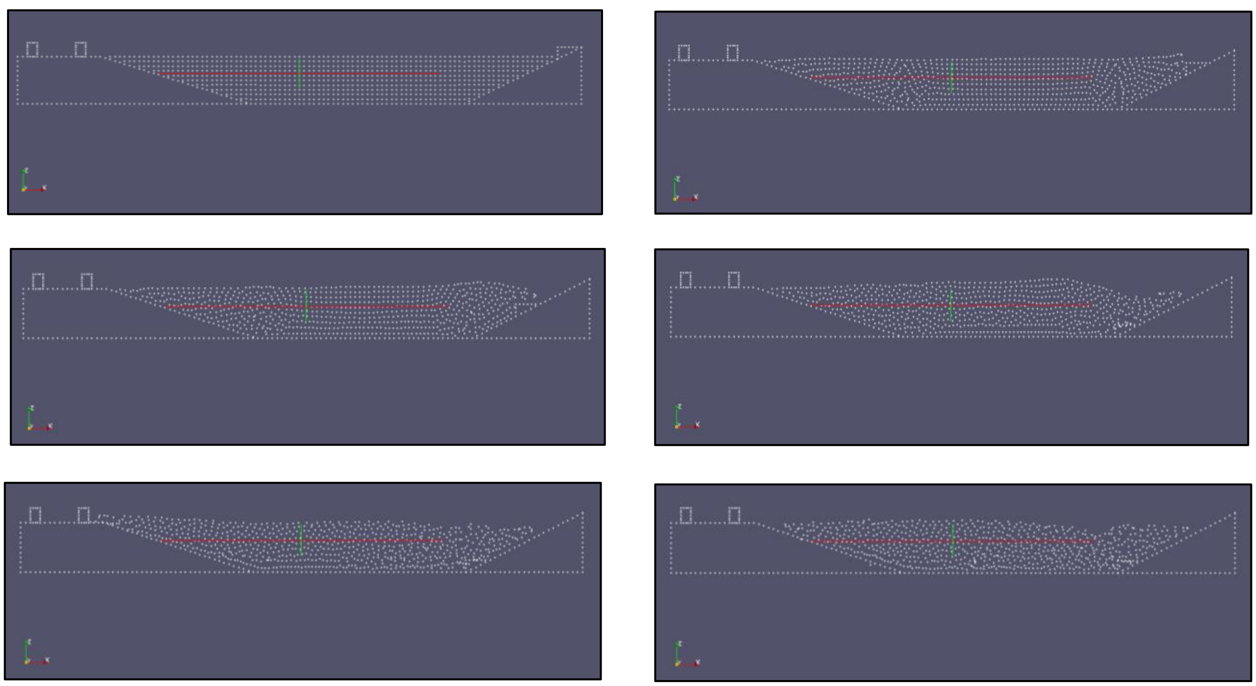


FIGURE 14. Wave Propagation for Steel Block 1

Since the objective of this project is to investigate impact forces to structures caused by tsunami waves generated by submarine landslides, and Steel Block 1 shows no impact forces effect on the structures, the laboratory experiment was continued by using the bigger steel block, Steel Block 2, with dimension of 1000 mm length, 400 mm width, and 200 mm high.

Understanding tsunami wave loading on coastal structures is important to improve their designs. Pressure sensors were attached to the model structures of 100 mm height. The results obtained from these sensors provide further insight into tsunami wave loading and can be analyzed in both Figure 15 and 16. In this figure, the maximum impact force carried by the tsunami wave is 1.46 N and the maximum pressure applied on the structures is 921.1 Pa. Therefore, for a full-sized structures of 2.5 m height, the maximum pressure that it can hold is approximately 921.1 x 25 = 23.028 kPa.

However, these maximum force and pressure did not occur at the moment the waves hit the structures. This is because the wave is longitudinal. When the wave reaches a shoreline, it will be reflected partially upwards and experiencing the effect of converting itself into a transverse mode. The pushing up action cause the wave to recede outwards and reaches back the shore with higher energy. Thus, it can be concluded that the first wave of a tsunami may not be the largest wave.

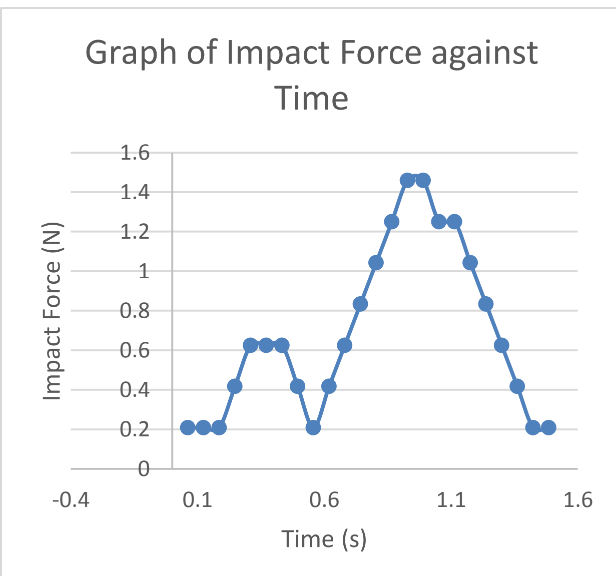


FIGURE 15. Graph of Tsunami Impact Force against Time

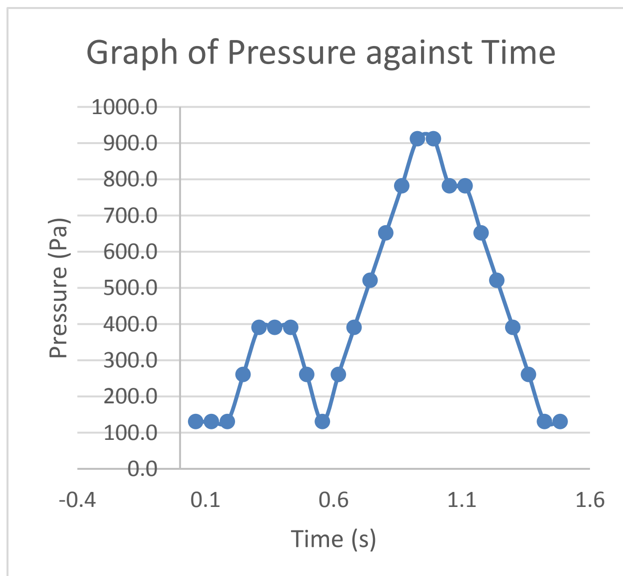


FIGURE 16. Graph of Tsunami Pressure on Structures against Time

Figure 17 to 19 illustrate the series of tsunami waves. In Figure 18, it can be seen that the behavior of the second wave is more furious and turbulent compared to the first wave of tsunami. This figure explains clearly on the high reading of the impact force and pressure from the interval time of 0.9 to 1 second in Figure 15 and 16.

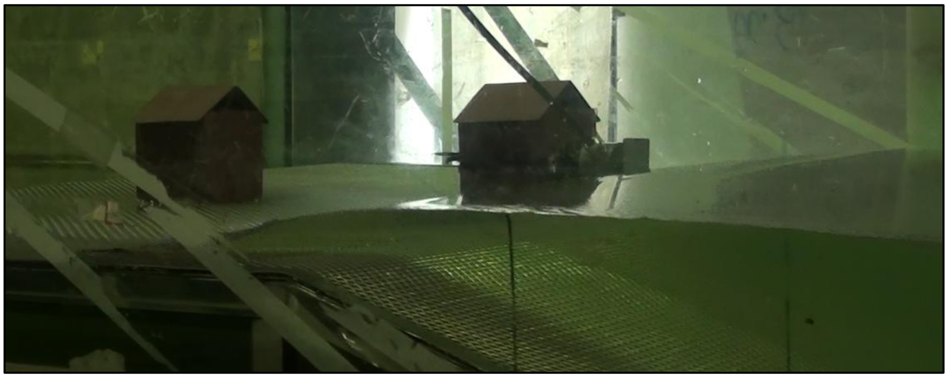


FIGURE 17. First Wave of Tsunami

FIGURE 18. Second Wave of Tsunami

FIGURE 19. Third Wave of Tsunami

To determine the wave elevations, wave gauges were used in this experimental set up. Elevation of the local water surface was recorded by them. With these gauges, maximum run-up height measurements can be compared to direct visual observation.

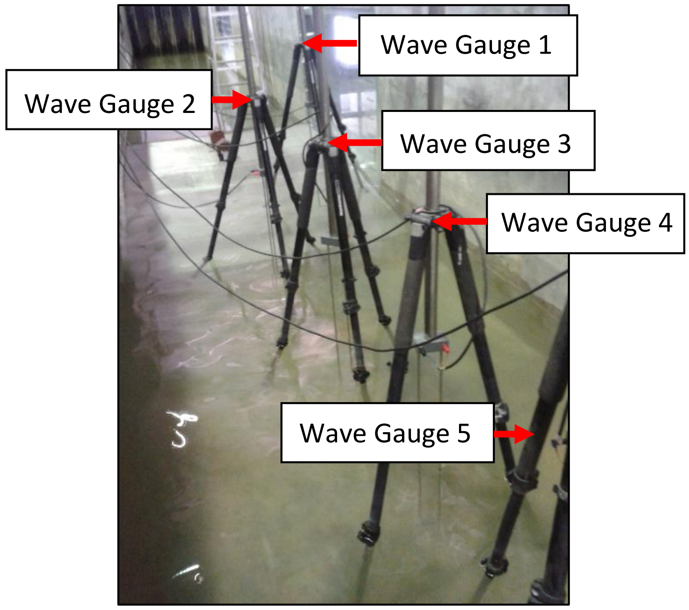


FIGURE 20. Position of Wave Gauges

A theoretical value has been calculated by referring to equation (1) to measure the maximum wave amplitude. The θ is taken to be at 45°, 200 mm thickness of solid block, d is 0.055 m and L is 13.416 mm.

$$|\eta_{max}| = 0.218T(\sin\theta)^{1.38}\left(\frac{L}{d}\right)^{1.25}$$

$$= 0.218(0.2)(\sin 45)^{1.38}\left(\frac{0.013416}{0.055}\right)^{1.25}$$

$$= 0.082\ m$$

$$= 82.39\ mm$$

From Figure 21 to 25, the maximum wave elevation generated from the landslide is 81.26 mm with wavelength of 2.15 m, at wave gauge number 5. While the minimum wave elevation generated is 49.32 mm with wavelength of 2.40 m, at wave gauge number 1. From these figures, it can be seen that the highest wave amplitude will occur near to the source of the landslide and that the theoretical and experimental results correspond to each other.

Other than that, they also have proven that the nearer the tsunami waves to the shoreline, its wavelength will decrease.

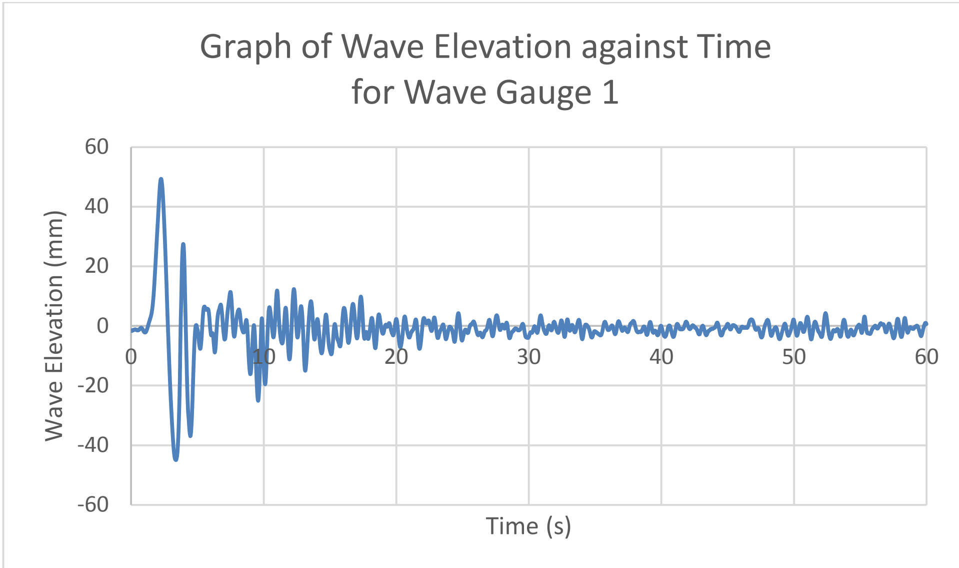


FIGURE 21. Graph of Wave Elevation against Time for Wave Gauge 1

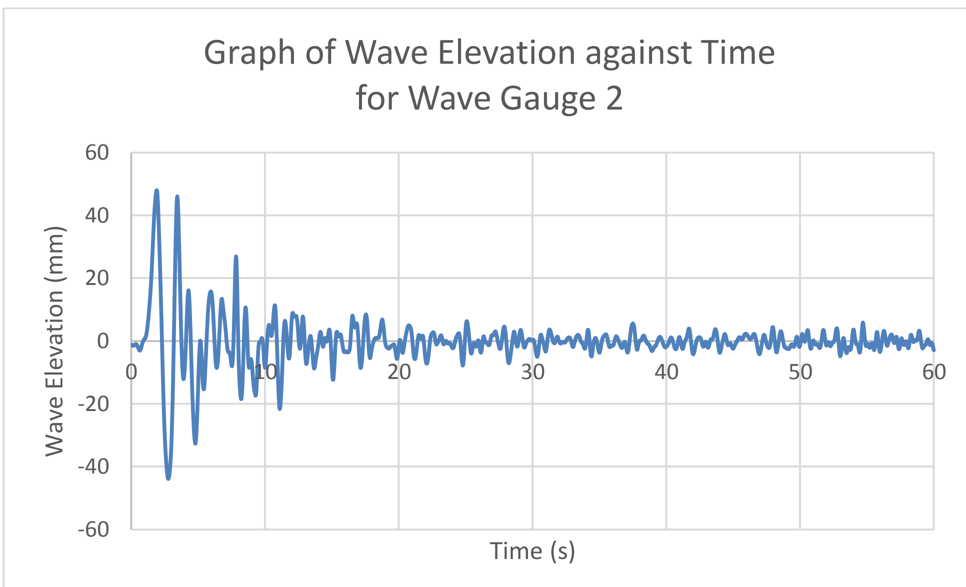


FIGURE 22. Graph of Wave Elevation against Time for Wave Gauge 2

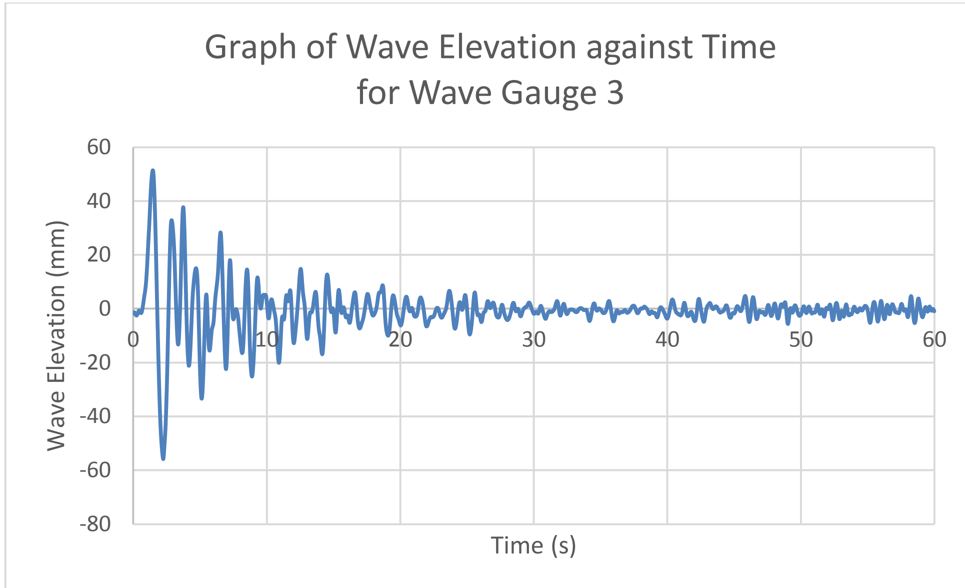


FIGURE 23. Graph of Wave Elevation against Time for Wave Gauge 3

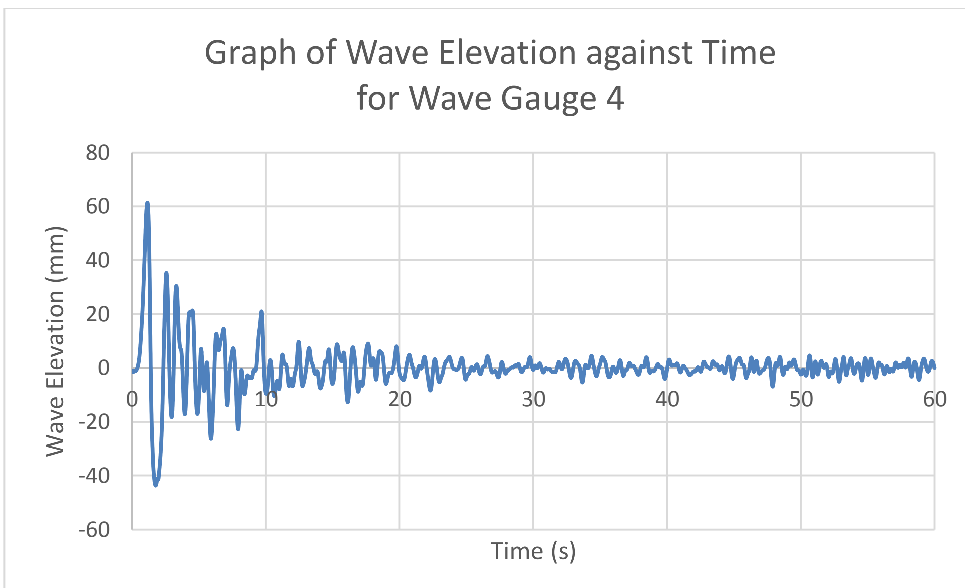


FIGURE 24. Graph of Wave Elevation against Time for Wave Gauge 4

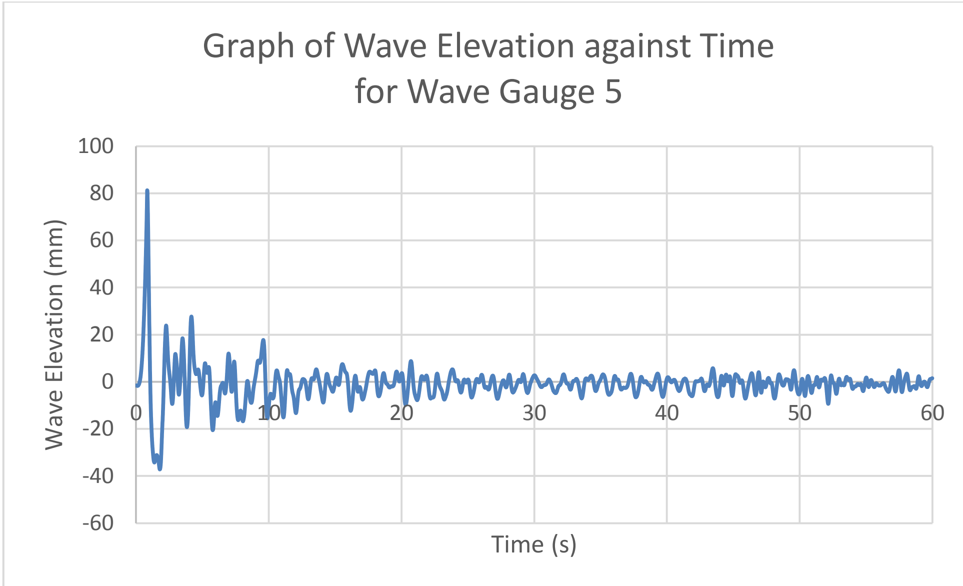


FIGURE 25. Graph of Wave Elevation against Time for Wave Gauge 5

CHAPTER 5

CONCLUSION AND RECOMMENDATION

It should be kept in mind that an earthquake can easily trigger a submarine landslide which resulting in presence of a tsunami wave. Factors for submarine landslide to occur and damages caused by tsunami generated by this type of landslide have been discussed in this paper. The dimension of a tsunami wave can be determined by the volume of submarine landslide. However, it is quite difficult to foresee the occurrence of this incident as it is usually happened in the deep water.

From the results of this study, it can be concluded that both generation of tsunami waves and impact forces to structures are influenced by the volume of landslides. Laboratory data analysis shows that the wave amplitude has a maximum increasing near to the source of landslide. Effects of slide size on wave feature were also investigated and it was concluded that the wave was affected strongly by the thickness of slide. By comparing the dimension of Steel Block 1 and 2, it clearly shows that the bigger the block, the higher the wave amplitude and the impact forces produced by the tsunami waves.

Physical understanding of tsunami caused by submarine landslide and its wave loading acts on structures near the shore are poor. It is crucial to upgrade the structures' designs as their locations have made them highly exposed to the type 3 (breaking) tsunami impact force. For this reason, experimental tests and simulations about submarine landslide and tsunami wave need to be done with some more modifications to get clear perspective about the topic.

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