NEES LANDSLIDE TSUNAMI GENERATOR:
MODELING A LANDSLIDE GENERATED TSUNAMI OFF OF A CONICAL ISLAND AND IMAGE PROCESSING OF A LANDSLIDE GENERATED TSUNAMI OFF OF A FJORD AND HEADLAND CONFIGURATION

Stephanie López
Civil Engineering
University of Puerto Rico at Mayagüez

NEES Site: Oregon State University
Project PI: Dr. Hermann M. Fritz
Mentor: Brian McFall, P.E.
Abstract

Landslide generated tsunamis are some of the most destructive impulse waves because of their locally high amplitudes and runup. This project presents the author's participation in a three dimensional multipart study on landslide generated tsunamis, specifically on a conical island, and the fjord and curved headland configurations. For all the configurations, a pneumatic landslide tsunami generator was used to produce the landslide by launching granular material. Instrumentation such as a particle image velocimetry (PIV) camera, a hi-speed camera, various cameras above and under water, multiple acoustic transducer array (MTA), wave gauges and runup gauges were used to collect data. For the conical island configuration a steel cone modeled the island. The landslide occurred on the side of the cone. This study focused on understanding and visualizing the landslide generated tsunami’s wave runup, propagation and behavior as it moved around and away from the cone. During the author’s participation no results or conclusions were generated, only raw data was collected. In the future these data will be used to form empirical equations and calibrate numerical models. For the fjord and headland configuration the author's participation was limited to image processing.
1 Introduction

1.1 Background

In the past few years we have witnessed the destructive nature of tsunamis, most recently at the beginning of this year in Japan. The Japan tsunami was generated by tectonic action, but landslides, either submarine or subaerial, can also generate tsunamis. From previous studies we have learned that these types of tsunamis are less common, but have more dispersive and highly directional wave propagation than tectonic tsunamis (Glimsdal et al. 2006). Because of this, depending on the wave amplitude, they can be very destructive locally but will quickly decay the farther away it propagates. These waves have been the most destructive impulse waves in history. In July 1958 the highest wave runup in recorded history occurred at the head of Lituya Bay on the south coast of Alaska. This wave, which was caused by a major rockslide, ran up to an altitude of 524 m and caused forest destruction and major erosion (Fritz et al. 2001). It is important to understand properties of a potential tsunami in the regions prone to landslides so realistic computer models can be made and used to prevent the loss of life and property.

![Fig. 1 People flee a landslide on a speed boat as a result of aftershocks in Yingxiu, Sichuan Province, China. Picture by Getty.](image)

1.2 Literature Review

Many studies have been done on tsunamis and their behavior in the past, but there is still much more to learn. Using numerical methods is one of the strategies that has always been used to study wave characteristics and behavior. An example of this is the work done by Hall and Watts (1953). They did some early experimental work on wave runup using the vertical rise of solitary waves.
on impermeable slopes. From this, they created an empirical formula for solitary wave runup on an impermeable slope with a 45° angle.

\[ \frac{R}{d} = 3.1 \left( \frac{H}{d} \right)^{1.15} \]

This equation is still used to verify analytical results and the accuracy of numerical models. Another study done by Slingerland and Voight (1979) formed predictive models of landslide generated impulse waves. The results found by studies done using numerical methods are used to create predictive models, which use the resulting empirical formulas to calculate a wave’s characteristics, however these formulas need to be calibrated using physical models. Most physical models have been two dimensional (Fritz et al. 2001, 2003a, 2003b, 2004), but three dimensional models have also been used in some studies (Di Risio et al. 2009; Mohammed and Fritz 2010).

In 2001 Fritz et al. made a two dimensional reproduction of Lituya Bay and successfully recreated the 1958 tsunami wave. In this study they used a pneumatic landslide generator, also known as a landslide tsunami generator (LTG), to launch the granular material that was used to model the 1958 landslide. They were able to produce an experimental wave runup that perfectly matched the trimline of the destructed forest in the inlet (Fritz et al. 2001). The results produced by this experiment give us a good idea about how accurate the use of the LTG and granular material can be when trying to recreate a realistic landslide generated tsunami.

A three dimensional experiment was also conducted using granular material by Mohammed and Fritz in 2010. This experiment modeled a linear coastline in which both the landslide and wave characteristics were studied. From this study researchers concluded that tsunami wave characteristics are dependant on both the slide impact velocity and the shape of the slide upon impact. The amplitude of the wave also depends on the Froude number and the thickness of the landslide (Mohammed and Fritz 2010).

Di Risio et al. (2009) modeled a tsunami produced by generating a landslide down the side of a conical island. Plastic material covered by fiberglass, with a flat bottom, was used to model the landslide. From this experiment Di Risio et al. concluded that near the tsunami generation zone the wave runup grows until a distance two times the landslide width. After this critical distance, the runup starts to decrease. Near the generation zone the first wave is responsible for the maximum runup, but at angles higher than 90° the third wave produces the maximum runup (Di Risio et al. 2009). In addition to this Di Risio et al. also noted that the bigger the shoreline radius the higher the runup.

By using three dimensional models instead of two dimensional models, radial wave spreading can be more rigorously studied. Including the radial movement of the wave provides more accurate and realistic results in modeling experiments. To many different types of materials can be used to generate a modeled landslide. Results are more accurate when using granular material instead of solid block because it deforms realistically due to the slide motion and the interaction with the water body (Mohammed and Fritz 2010).
1.3 Project Overview

This study, conducted in O. H. Hinsdale Wave Research Laboratory at Oregon State University, is part of a larger project on landslide generated tsunamis. The experiment modeled a three dimensional landslide occurring off the side of a conical island. Granular material and the landslide tsunami generator were used to create the landslide. The study focused on understanding and visualizing the landslide generated tsunami’s wave runup, propagation and behavior as it moved around and away from the cone. This paper presents the author's participation in the setup and experimentation stages of the study. It also explains what will be done with the collected data after the experiment trials are done.

2 Experiment Descriptions

2.1 Experiment Setup

A truncated steel cone served as our model of a conical island. The cone has a base diameter of 10 m, a slope angle of 27° and a height of 1.83 m. On top of the cone sat the landslide tsunami generator (LTG), which consists of an open rectangular box connected to four parallel pneumatic pistons.

![Image of LTG mounted on top of the truncated steel cone. Picture by author.](image)

The open rectangular box was filled with naturally rounded river gravel, the granular material chosen to model the landslide, by using a funnel shaped bucket. The pistons connected to the box, which were previously pressurized, were then released causing the box to accelerate down the slope of the cone. When the box reached the desired launch velocity the pistons retracted and the front wall of the box fell open due to the impact of the moving gravel. The gravel
slid down the side of the cone, simulating the landslide, and then impacted the water making the waves that propagated both offshore and around the cone. The gravel deposit at the base of the cone was then shoveled on to the center of the recovery plate and then transported back into the funnel shaped bucket so the process could start again.

Fig. 3  Diagram of the gravel loading, launching and recovery process described previously. Image by Mohammed and Fritz.

A diverse group of instrumentation was used to collect data from each experiment trial. Wave gauges were located off shore towards the front left side of the cone (the front of the cone refers to the centerline of the landslide, which will also be the 0˚ line) and directly behind the cone. Runup gauges were setup along the slope of the cone every 15˚, starting at 30˚, on the left half of the cone. Two more runup gauges were placed on the right half of the cone for redundancy. In total 40 wave and runup gauges were used. A variety of cameras were also used to gather information. Particle image velocimetry (PIV) cameras and the Hi-speed camera were placed on top of the bridge directly in front of the slide. These cameras recorded the cavity that formed when the gravel hit the water, the formation of the first wave and in some cases the landslide before it hit the water (this was not possible in the deepest water depth because the gravel would immediately hit the water after it was launched). An underwater camera was placed on the basin floor in front of where the slide formed its deposit. Other cameras were also placed on every side so that each section could be viewed. The last instrument used to retrieve data from this experiment was the multiple acoustic transducer arrays (MTA), which was used to scan the underwater landslide deposit at the base of the cone.
Fig. 4  Top and side view of the wave and runup gauge setup around and on the slope of the cone. The red dots connected by one or two lines are the wave and runup gauges, respectively. Image provided by Brian McFall.

Fig. 5  Runup gauge (left), hi-speed and PIV cameras (second to left at top), underwater camera (second to right at top), wave gauge (right) and the MTA (bottom center). Pictures by author.
2.2 Experiment Trial Conditions

The experiment was run numerous times so conditions like water depth, gravel amount and gravel launch velocity, which depends on the air pressure in the pneumatic pistons, could be varied. Four different water depths were done: 30, 60, 90 and 120 cm. Two different amounts of gravel were also used. Full gravel loads consisted of approximately 3000 pounds of gravel and half loads were approximately 1500 pounds. Lastly, the pneumatic pistons were pressurized to four different pressures: 58, 87, 116 and 145 psi. This permitted a variety of launch velocities. In total 32 different scenarios were possible, but many more runs were done for redundancy, to retrieve more information in certain cases and to make sure all the instrumentation was running correctly.

3 Testing Outcome

Each experiment run produced a large and diverse group of data due to the varied instrumentation that was used. The wave and runup gauges produced voltage vs time graphs, which can be easily converted to water depth vs time graphs by multiplying by a coefficient. This is possible because of the linear relationship between voltage and distance.

![Wave gauges off shore](image1)

![Runup gauges northeast](image2)

Fig. 6  Example of the voltage readings from wave gauges off shore (top) and runup gauges on the northeast side of the cone (bottom). Images provided by Brian McFall.

The particle image velocimetry (PIV) camera produced two and three dimensional views of the landslide as it moved down the side of the cone. These views show the thickness of the landslide as it slides down the slope of the cone. The PIV also created velocity vector fields of the slide, which give the average velocity and direction of the gravel in a specific point and time.
Fig. 7  Example of a two dimensional view of the landslide produced by the PIV camera during an experiment run using a full load of gravel. The warmer the color, the thicker the slide is at that point. White spots are places where the PIV was not able to determine the surface height, probably because in these areas the surface is the highest.

Fig. 8  Example of a three dimensional view of the landslide produced by the PIV camera during an experiment run using a full load of gravel. The warmer the color, the thicker the slide is at that point. White spots are places where the PIV was not able to determine the surface height, probably because in these areas the surface is the highest.
The hi-speed camera took videos of the landslide at a rate of 100 frames per second. Because of its constant frame rate this footage is used to determine the velocity of the front of the slide (the part of the slide that hits the water first) by determining how much it moved each one hundredth of a second. The underwater camera placed in front of the slide recorded the underwater deformation of the landslide. The rest of the cameras, which were positioned all around the cone, recorded the landslide and the wave propagation around the cone. The multiple acoustic transducer arrays (MTA) produced tree dimensional views of the underwater landslide deposit.

Fig. 9 Example of a velocity vector field of the landslide produced by the PIV camera. This image is one of the 2010 experiment (Landslide generated tsunami off of a fjord and headland configuration) results, but the velocity vector field produced by this experiment should be very similar. Image provided by Brian McFall.

Fig. 10 Example of a three dimensional view of the underwater landslide deposit made with the data collected by the MTA. Image provided by Brian McFall.
4 Future Work

Now that all the experiment runs have been completed the data collected will be processed and analyzed. The images, vector fields and graphs produced by the PIV camera and the MTA do not need to be modified and are ready for analysis. The wave and runup gauge data has to be converted from voltage to distance. All the videos produced by the hi-speed camera, the underwater camera and the cameras around the cone will be calibrated and then processed to retrieve the information required from each. The procedure used to process these videos will be very similar to the one used for the two previous landslide generated tsunami experiments. Some of the image processing from the 2010 experiment, which consisted of a landslide generated tsunami off of a fjord and headland configuration, was done during the setup stage of this project, using Matlab. The videos from the last experiment were converted into pictures and then calibrated. After this the wave surface was outlined in each calibrated picture. The calibrated outline produced a water height vs time graph, which would later be nondimensionalized and analyzed. When all the data from the current project has been processed it will also be nondimensionalized, so it may be applied to any size landslide and water depth, and analyzed.

4.1 Future Applications

The nondimensionalized data will be combined to form empirical equations, which describe and link the landslide and wave characteristics with the resulting runup. All the processed data and empirical equations will also be used to calibrate existing computer models to be used when a landslide generated tsunami occurs.

5 References


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7 Further Information

For further information on the author’s participation in this project contact Stephanie López at stephanie.lopez4@upr.edu. For further information on the completed project and its results contact Brian McFall at bmcfall4@gatech.edu.