

AC 2009-588: TSUNAMI WARNING SYSTEM

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Tsunami Warning System

Abstract

Tsunamis occur rarely on Earth but their impact is devastating. If successful, the project objectives provide a substantial first step to minimizing the material destruction and mortality caused by this immense force of nature. The goal of this project is to develop a system that can detect an incoming tsunami. The project will also explore possibilities to dampen the impact of the tsunami wave.

I. Tsunami Background

A. Creation

Tsunamis can be caused by meteors, underwater volcanoes, underwater landslides, and underwater earthquakes [1]. Underwater earthquakes are the most frequent cause of tsunamis. During an underwater earthquake, a large amount of water is displaced and an enormous amount of energy is added by the motion of the tectonic plates. The energy must dissipate, so it travels away from the epicenter in all directions. In the deep ocean, the presence of a tsunami is not apparent. The sea level rises on the order of inches. As the tsunami approaches land, the depth of water decreases. This fact causes the massive amount of energy to push the water upward into an enormous wall of water [1]. The speed of the tsunami decreases as it approaches land because some of the kinetic energy is transferred into potential energy. The speed of the tsunami is a function of gravity and the depth of the ocean: $S = \sqrt{g \cdot d}$ [1].

B. Comparison with Wind-Generated Waves

Tsunamis are orders of magnitude greater than wind-generated waves in terms of the lateral speed, the wave period and the size of the wave. Wind-generated waves are the transfer of energy across the ocean. The energy is usually provided by the wind. The water particles themselves are not making any voyage across ocean. Instead, the particles are traveling in small circles as the wave passes. This can be seen in the following diagram [4]

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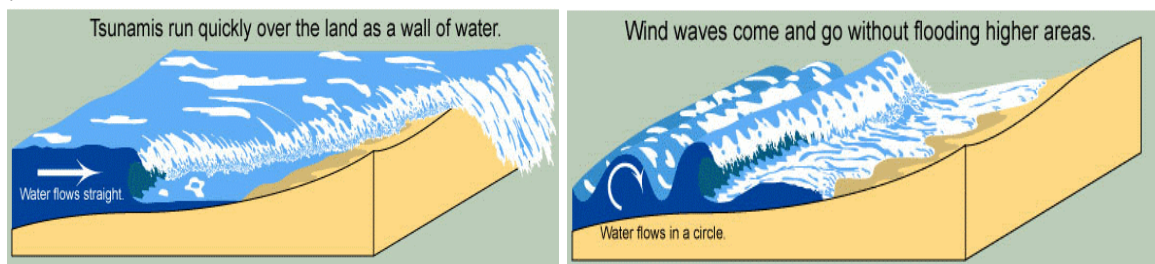


Figure 1 Shows the differences between the landfall of tsunami and wind waves

The top diagram demonstrates the movement of the water particles in a wind-generated wave. The bottom diagram shows how the tsunami differs from the wind-generated wave when it arrives on shore. Since the tsunami has so much more force, it is able to penetrate deep inland.

The speed of a wind-generated wave ranges from five to sixty miles per hour. The speed of a tsunami ranges from five hundred to six hundred miles per hour. The wave period, or the time for two waves to pass a specific point, for a regular wave is five to twenty seconds. The tsunami wave period is ten minutes to two hours. Common waves have a wavelength of three hundred to six hundred feet, while the wavelength of a tsunami is sixty to three hundred miles. These differences between a tsunami wave and a wind-generated wave are the major reasons why the tsunami is so deadly and so difficult to find a solution for.

II. Real-World Tsunami Detection System

The tsunami warning system has become the Pacific tsunami warning system and has never missed an event [9]. To detect a tsunami, one can use the fact that the presence of a tsunami can be felt on the sea floor. The energy of wind-generated waves can be felt at a depth of half the wavelength. Wavelengths for wind-generated waves are around three hundred feet, so these waves would be felt at a depth of around one hundred and fifty feet. With a wavelength of sixty to one hundred miles, a tsunami's energy will be felt at a depth of thirty to fifty miles. The average depth of the seafloor is around two miles [6]. The deepest point in the world is the Mariana Trench, which is almost seven miles deep. These ocean depths are all shallower than the maximum depth at which a tsunami will be felt. By placing a piece of equipment that can sense this energy on the seabed, one should be able to accurately sense the presence of a tsunami.

In the Pacific Ocean, the National Oceanic and Atmospheric Administration has in place Tsunami Warning Systems. An example of the system is [3]

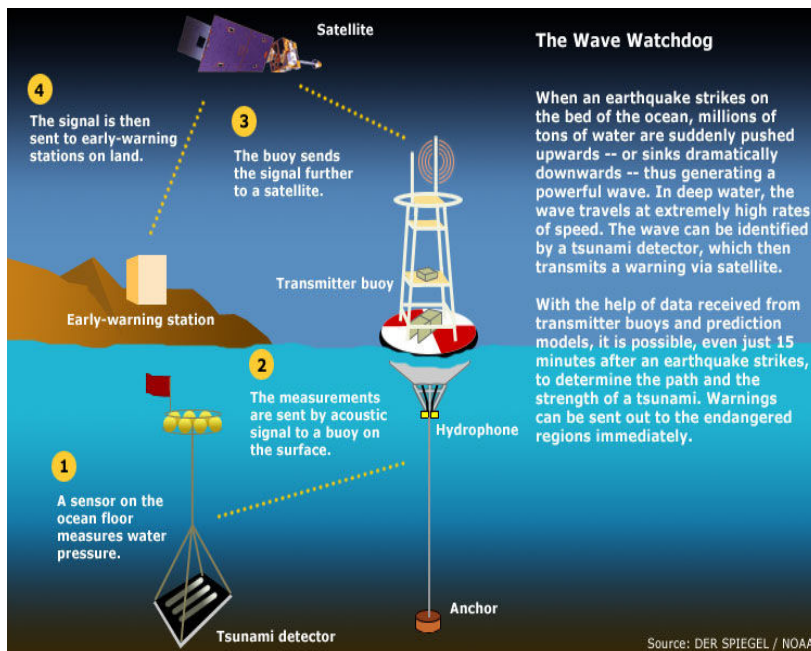


Figure 2 NOAA Tsunami Warning System

According to the diagram, the sensor will rest on the bottom of the ocean [3]. It will continuously measure the pressure [3]. A spike in the pressure on the ocean floor most likely means that a tsunami has just passed over the sensor [3]. Once the measured pressure spikes, the sensor will send a signal acoustically to a buoy with a hydrophone and transmitter [3]. The buoy would be resting on the surface of the water [3]. Once the buoy has received the signal from the pressure sensor, it will transmit via satellite to an Early-warning station the information it has [3]. The Early-warning station will be able to inform the endangered areas of incoming danger [3].

III. Model Tsunami Detection System

While this project is being researched theoretically on a real world scale, the actual system being built is a model. Instead of placing the device on the ocean seabed, it was placed in the bottom of a water tank in the Hydrolab at the United States Naval Academy. The equipment, including the pressure sensors were chosen to accomplish the goal of making a successful model. The water tank is one hundred and twenty feet long, five feet tall, and eight feet wide. The water tanks are able to generate waves of variable period and wavelength. The shortest wavelength of a wave that could be generated is 2.59 ft. The longest wavelength that could be created in the Hydro Lab is 31.83 ft. The goal is for the control system to have the ability to detect when the longest wave that the Hydro Lab can create has passed over the system. This long wave will simulate a tsunami. The principles of this detection are similar to the first two steps of the DART System.

IV. Tsunami Detection

A. Pressure Sensor

A pressure sensor can measure the pressure of a liquid or gas. An underwater pressure sensor works by measuring a mechanical deflection of a membrane to measure the change in pressure. To detect a tsunami, a pressure sensor would be placed at the bottom of the ocean floor. Once a certain pressure threshold is exceeded, the system will know that there is a strong likelihood of a presence of a tsunami.

The pressure sensor should have an acceptable range, sensitivity, accuracy, precision, and speed. The range refers to the minimum and maximum pressures that can be detected. A larger range is preferred because the waves that will model the tsunami waves will have significantly higher pressures than the waves that model the wind-generated waves. The sensitivity refers to the smallest difference in pressure that can be detected. A smaller sensitivity means that the sensor is more sensitive. It is important to note that there are many types of sensitivity: two of which are Temperature sensitivity and Pressure sensitivity. Temperature sensitivity refers to how much a change in temperature will affect the pressure reading. This characteristic may be important in the ocean, but it will not be significant in the Hydrolab tank. This project prefers a more sensitive pressure sensor. The accuracy parameter is defined as how close the detected pressure readings of the sensor are to the actual pressure in that location. This should not be confused with precision. Being precise simply means similar results are observed from a repeated number of executions. The fact that the results may be entirely wrong does not mean the device is imprecise. That situation means that the device is inaccurate. This project would prefer equipment that is as accurate and precise as possible. The pressure sensor must be

watertight. If it is not, the water could short circuit the sensor, putting it out of commission. The system used three Keller America Inc. pressure sensors. They can sense the range of pressures from 0 to 1.5 PSI. The pressure sensors can output between 0 and 10 volts.

B. Results

In the Hydro Lab, data was gathered of the short-wavelength wind-generated waves and the long-wavelength tsunami waves. The experiment was started by running the logging measurement program for each sensor. The data was recorded every 0.02 seconds. Immediately after the data started to be logged, the wave generator was started. The waves were placed around the middle of the tank. This meant that the waves would take some amount of time to reach the sensors. This data is shown below:

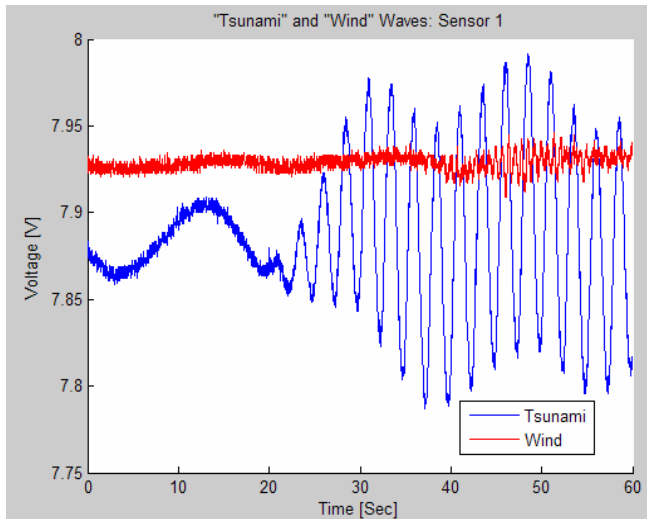


Figure 3 Plot of sensor 1 voltage output of tsunami and wind waves *Tsunami Amplitude: 1 inch* *Tsunami Period: 2.50 seconds* *Wind Amplitude: 5 inches* *Wind Period: 0.714 seconds*

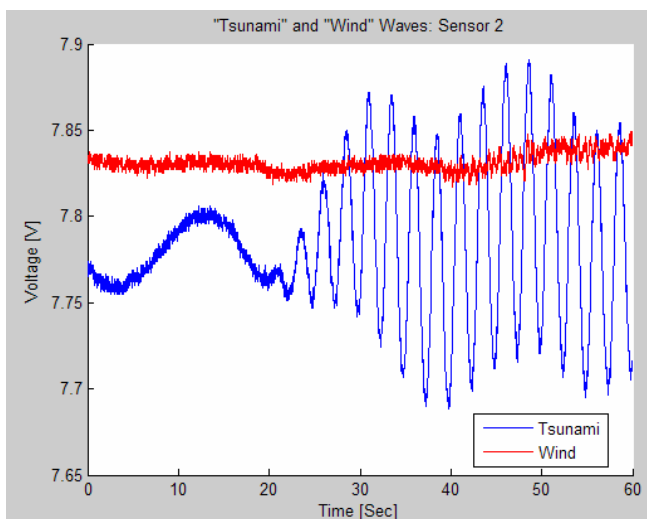


Figure 4 Plot of sensor 2 voltage output of tsunami and wind waves *Tsunami Amplitude: 1 inch* *Tsunami Period: 2.50 seconds* *Wind Amplitude: 5 inches* *Wind Period: 0.714 seconds*

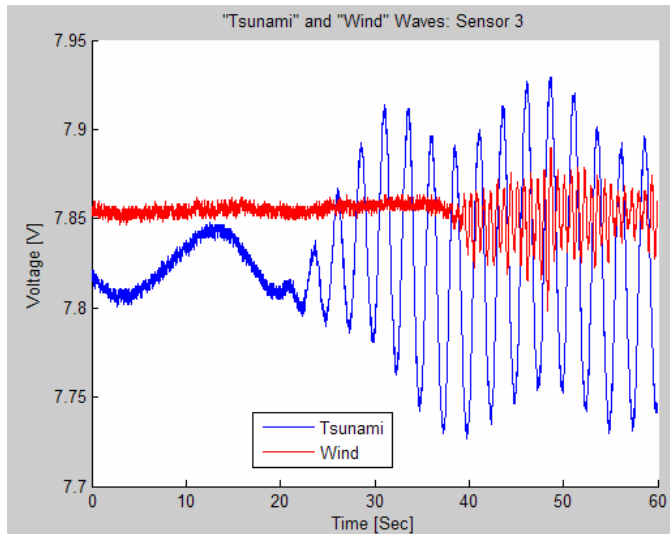


Figure 5 Plot of sensor 3 voltage output of tsunami and wind waves Tsunami Amplitude: 1 inch Tsunami Period: 2.50 seconds Wind Amplitude: 5 inches Wind Period: 0.714 seconds

This exercise was run with the amplitude of the tsunami wave at 1 inch, and the wind wave amplitude was 5 inches. The period of the tsunami wave was 2.50 seconds, and the wind wave period was 0.714 seconds. This plot shows that the tsunami waves and wind waves oscillated around 7.8V. Since the frequency of the wind wave is greater than the frequency of the tsunami wave, the lateral speed of the tsunami wave is faster. The wind wave has a slower lateral speed, so it arrived later than the tsunami waves did.

This plot shows that there is a significant difference between the pressures felt at the bottom of the Hydro Lab when waves of different wavelengths pass over it. The voltage peak to peak for the simulated tsunami-wave was 0.2V. The simulated wind-generated wave's peak to peak voltage was 0.05V. This voltage difference is roughly twenty-five percent of the simulated tsunami's wave. This fact shows that there is a significantly higher pressure increase as a longer wave passes over an area. The peak voltage of the wind-generated wave depends on which sensor is being used. Sensor 1 displayed a peak voltage of 7.94V, while sensor 2 and sensor 3 displayed a peak voltage of 7.84V. To use this data to detect a "tsunami", a cut-off voltage could be set at a voltage that is above the peak voltage of the wind-generated wave. A program could be written to send a warning out once this cut-off voltage is met or exceeded.

VI. Future Aspirations

The project was able to come up with a method for detecting tsunamis from the ocean floor. The device should also successfully detect the presence of a wave with a larger wavelength in the Hydrolab. Consideration should be given to exactly what happens after a positive signal is received from the pressure sensor. There should be some method of communication, either wired or wireless, to a piece of equipment on the surface. The Tsunami Warning System should also be able to sense environmental parameters, such as oxygen levels, pH levels, or marine activity.

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