



Tsunamis: Generation and Propagation

An Online Continuing Education Course for Engineers

Course Number: G-3005

Credit: 3 Hours / 3 PDH / 3 CPD

Tsunamis: Generation and Propagation

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Course Overview

This course on “Tsunamis: Generation and Propagation” is presented as a complement to course C-3008 on “Earthquakes and Tsunamis: Fundamental Concepts” for the benefit of those students who want to learn more about this particularly devastating natural phenomenon. Whereas Course C-3008 addressed primarily the topic of earthquakes, this course addresses primarily the topic of tsunamis. This course is a stand-alone presentation and Course C-3008 is not a pre-requisite. For continuity, this course contains a few descriptive sections about tsunami effects that are included in course C-3008. However, the emphasis here is on explaining the mechanical principles of tsunami generation and propagation.

In this course you will learn that any number of large-scale, short duration disturbances of the ocean floor can generate tsunamis. Most frequently, however, it is the strong, shallow submarine earthquakes that are the most likely triggering mechanism of these monstrous sea waves.

Following a brief explanation of the origin of the word, you will learn how to describe the geometry and general behavior of water waves and what distinguishes wind-generated waves from tsunamis. The geologic concept of plate tectonics is then presented, which explains that the earth’s crust is divided into a number of rigid plates that interact with one another causing seismic activity along their boundaries. In fact, it is the interaction between the oceanic and continental plates that most frequently trigger the large seismic events that deform the ocean floor and spawn the most devastating tsunamis. A step by step illustration of this process is presented along with an explanation of how the initial tsunami wave splits into two waves that start traveling in opposite directions. The wave that travels out to the deep ocean is known as the distant tsunami, while the other wave that travels towards the nearby coast is referred to as the local tsunami. The wave transformations that occur at shallow oceanic depths are explained as they control the ensuing wave run-up that occurs all along the coastline. The equations used to compute the velocity of tsunamis are presented in an appendix at the end of the course.

The characteristics of the most notable tsunamis that occurred since 1900 are presented and discussed. Experiences gained from the study of these events led the US National Oceanic and Atmospheric Administration (NOAA) to develop and deploy several tsunami-warning stations in the Pacific Ocean in the mid-1990s. When data collected from these stations confirm the detection of a tsunami, scientists begin immediately to predict the propagation course and velocity of the waves. Warnings are then issued to the most susceptible areas likely to be affected. Following the devastating tsunami of December 26, 2004, several additional tsunami detection stations have been added to the existing network.

Finally, other mechanisms that could also trigger tsunamis are presented and explained. Examples from the historical and geological records are presented as evidence that tsunamis have occurred in the past and are therefore one of the recurring and potent geologic hazards of our planet.

A glossary of terms and acronyms used is provided at the end of this course as a reference to assist the student in following the concepts that are discussed throughout the text.

The information presented in this course is based on the professional experience gained by the author in dealing with various aspects of seismic issues he dealt with in association with the major engineering projects he managed around the world.

Specific Knowledge Gained

In this course you will learn that large earthquakes that affect the ocean floor are capable of generating immense sea waves called “tsunamis”, a Japanese word that means “harbor wave”. You will also understand why this is an appropriate descriptive term for this phenomenon. In the open ocean these waves have relatively low heights, but are of enormous longitudinal dimension (at right angle to the direction of propagation). As they approach the coast, these waves undergo significant transformations that determine the ensuing wave run-up above mean sea level along the coastline. Tsunamis can travel at great speed for very large distances such as across the entire widths of oceans, inflicting significant damage to far away coastal towns. You will specifically learn:

- 1) How the wavelength, wave height and period are used to describe the geometry and behavior of wind generated waves and tsunamis,
- 2) That wind generated waves and tsunamis are easily distinguishable,
- 3) That the earth’s crust is formed of interlocking rigid plates that interact with each other,
- 4) That the cycles of strain accumulation and slippage along these plate boundaries is the most common mechanism for the triggering of large earthquakes and tsunamis,
- 5) How the near shore transformations of tsunamis determine the ultimate run-up of the waves above the coastal mean sea level,
- 6) That the devastating effects of tsunamis led NOAA to develop an early tsunami warning system that was first deployed in the Pacific Ocean in the mid-1990s,
- 7) That the initiation of a tsunami can be readily detected by the monitoring stations of the warning system,
- 8) How to compute the propagation velocity of a tsunami in open water,
- 9) That tsunamis can also be generated by massive submarine landslides, the collapse of marine volcanoes, and even by the impact of large meteorites or asteroids, and
- 10) That tsunamis occurred periodically throughout the geologic record indicating that these events represent one of the most potent recurring natural hazards of our planet.

1.0 Introduction

A tsunami, also known as a seismic sea wave, seismic surge or earthquake sea wave, is produced by any large-scale, short duration disturbance of the ocean floor. As all of the alternate names imply, it is the strong, shallow submarine earthquakes that are by far the most prevalent causes for the generation of these potentially devastating sea waves. However, sudden submarine earth movements such as

massive landslides into oceans, submarine volcanic eruptions, the sudden collapse of volcanic structures, and even the impact of large cosmic bodies into oceans can also generate tsunamis.

In the past, tsunamis were often referred to as "tidal waves." The use of the term "tidal wave" in this context is incorrect because tides, which are the periodic rise and fall in sea level, result from the gravitational influences of the moon, sun, and planets. Although a tsunami is not a tidal event, a tsunami striking a coastal area can be influenced by the state of the tide at the time of impact.

1.1 Origin of the Word

Japanese fishermen upon returning to port and finding the area surrounding the harbor devastated first used the word tsunami to describe the scene. A few moments earlier, however, these same fishermen had not been aware of any wave passing under them in the open ocean.

Two characters represent the word: "tsu" and "nami." The character "tsu" means harbor, and the character "nami" means wave. These two Japanese characters are shown below.



Figure 1: The Japanese characters that represent the word Tsunami

The term "tsunami" was formally adopted for general use in 1963 by an international scientific conference to describe the devastating sea waves that are triggered by major oceanic earthquakes. In Japanese, the same characters are used for both the singular and the plural form of the word. In English, however, the plural form "tsunamis" is well established and is frequently used to refer to the waves from multiple events. Sometimes the descriptor "tsunami wave" is encountered in articles on the subject. The use of the word "wave" in this context is superfluous because it is a repetition of the word "nami" and would be equivalent to writing "harbor wave wave".

1.2 Wave Descriptors

Waves in water are periodic variations in the height of the water surface about its equilibrium position. A wave is generally described by three fundamental properties: 1) its height (the vertical distance between normal sea level and wave crest), 2) its wavelength (the horizontal distance between two successive wave crests in the direction of propagation), and 3) its velocity (the speed at which the wave travels). In addition, the period of a wave is defined as the interval between the passage of adjacent

crests by a reference mark. The period is equal to the wavelength divided by the velocity. The wave height and wavelength are shown on the following figure.

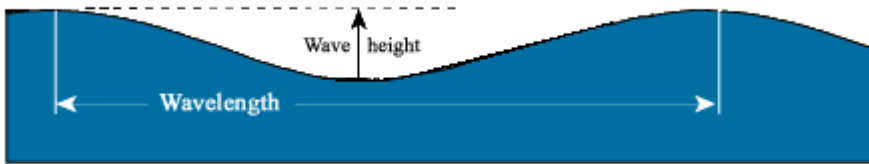


Figure 2: The Wave height and Wavelength of Sea Waves

Most waves in water bodies are generated by wind. Wind induced turbulence and random fluctuations of air pressure on the water surface, aided by wind shear, cause the formation of wind-generated waves. As these random pressure fluctuations cause the sea surface to rise and fall, forces that tend to restore the surface back to its original level come into play. The restoring forces are surface tension and gravity. Surface tension is effective only on very small waves, whose dimensions are measured in centimeters. This is the reason why most ocean waves are considered gravity waves.

1.3 Wind-Generated Waves v/s Tsunamis

Both wind-generated waves and tsunamis are described using the same geometrical properties of waves shown on Figure 2, above. However, although the two types of waves (tsunami- and wind-generated) have the same geometrical features and are measured in the same way, there are many differences between the two. The chart below presents some of these differences.

Wind-Generated Waves v/s Tsunamis		
Wave Feature	Wind-generated Waves	Tsunamis
Wave Speed (Velocity)	5-60 mph (8-100 km/h)	300-600 mph (500 - >1,000 km/h)
Wave Period (time required for two wave crests to pass a reference point in space)	5 to 20 seconds apart	10 minutes to 2 hours apart
Wave Length (horizontal distance between two successive wave crests)	300-600 feet (100-200 meters)	65-330miles (100-500 kms)

Offshore, the wave heights of tsunamis are usually small and their wavelengths are very long. This is why ships traveling in the high seas hardly feel the passage of tsunamis.

As shown on the table, the velocity of wind-generated waves and tsunamis differ greatly. Observations indicate that wind blowing at 50 Km/hr over open water produces waves that are about 7 meters high and have wavelengths of 75 meters. These waves travel at about 40 km/hr. With wind blowing at 110 km/hr the wind-generated waves are about 15 meters high, 375 meters in wavelength, and travel at about 85 km/hr. Larger waves can be generated by the wind when it blows over an extensive water surface. For example, in the open ocean hurricanes can produce waves in the order of 20 to 25 meters. Also, the velocity of tsunamis is independent of wavelength and depth. Particle velocity at the surface is about 1/10 of the velocity at the surface.

In the case of tsunamis, the wave height is only about one meter, but the wavelength is in the order of 100 kilometers.

The material in this Appendix is presented in an Appendix.

2.0 Triggers

As explained in the previous section, the ocean floor is not flat. The sudden changes in the ocean floor can cause tsunamis. These monsters travel along plate boundaries.

With the development of the earth is divided into plates. The boundaries between these plates are about 20 to 40 miles thick. The plates move beneath the ocean floor. The movement of the plates is called plate tectonics. The type of movement of the plates is of great interest to us here is that of one plate moving and sliding under another plate. This spatial relationship is illustrated in the following figure.

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