

EENS 3050	Natural Disasters
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Tsunami	

This page last updated on 02-Jul-2012

Up until December of 2004, the phenomena of tsunami was not on the minds of most of the world's population. That changed on the morning of December 24, 2004 when an earthquake of moment magnitude 9.1 occurred along the oceanic trench off the coast of Sumatra in Indonesia. This large earthquake resulted in vertical displacement of the sea floor and generated a tsunami that eventually killed about 230,000 people and affected the lives of several million people. Although people living on the coastline near the epicenter of the earthquake had little time or warning of the approaching tsunami, those living farther away along the coasts of Thailand, Sri Lanka, India, and East Africa had plenty of time to move higher ground to escape. But, there was no tsunami warning system in place in the Indian Ocean, and although other tsunami warning centers attempted to provide a warning, there was no effective communication system in place. Unfortunately, it has taken a disaster of great magnitude to point out the failings of the world's scientific community and to educate almost every person on the planet about tsunami.

Even with heightened world awareness of tsunami, disasters still occur. On September 29, 2009, earthquakes in the Samoa region of the southwest Pacific Ocean killed nearly 200 people, and as a result of the Chilean earthquake of February, 2010, at least 50 casualties resulted from a tsunami triggered by a moment magnitude 8.8 earthquake.

On March 11, 2011 a Moment Magnitude 9.0 earthquake struck off the northern Coast of Japan. The Earthquake generated a tsunami that rose up to 135 feet above sea level and killed over 20,000 people. Because of Japan's familiarity with earthquakes and enforcement of earthquake resistant building codes, there was only minor destruction from the earthquake itself. But, despite that fact that a tsunami warning system was in place, the earthquake was so close to the coast, that little time was available for people to react.

Besides that high death toll, the tsunami caused one of the worst nuclear disasters in history. The Fukushima nuclear power plant, located on the coast was hit by a 49 ft. tsunami wave that overtopped the tsunami protection walls that were only 19 feet high, and flooded the backup generators for the plant that were somehow placed on the first floor in a known tsunami zone!

We will first exam videos of the Japanese tsunami, (see also - <http://www.pbs.org/wgbh/nova/earth/japan-killer-quake.html>) then discuss some important points about tsunami, followed by a PBS video concerning the 2004 Indonesian Tsunami which killed over 230,000 people (see <http://www.pbs.org/wgbh/nova/tsunami/>).

The lecture notes below cover the essential points discussed in class and provide more details.

What is a Tsunami

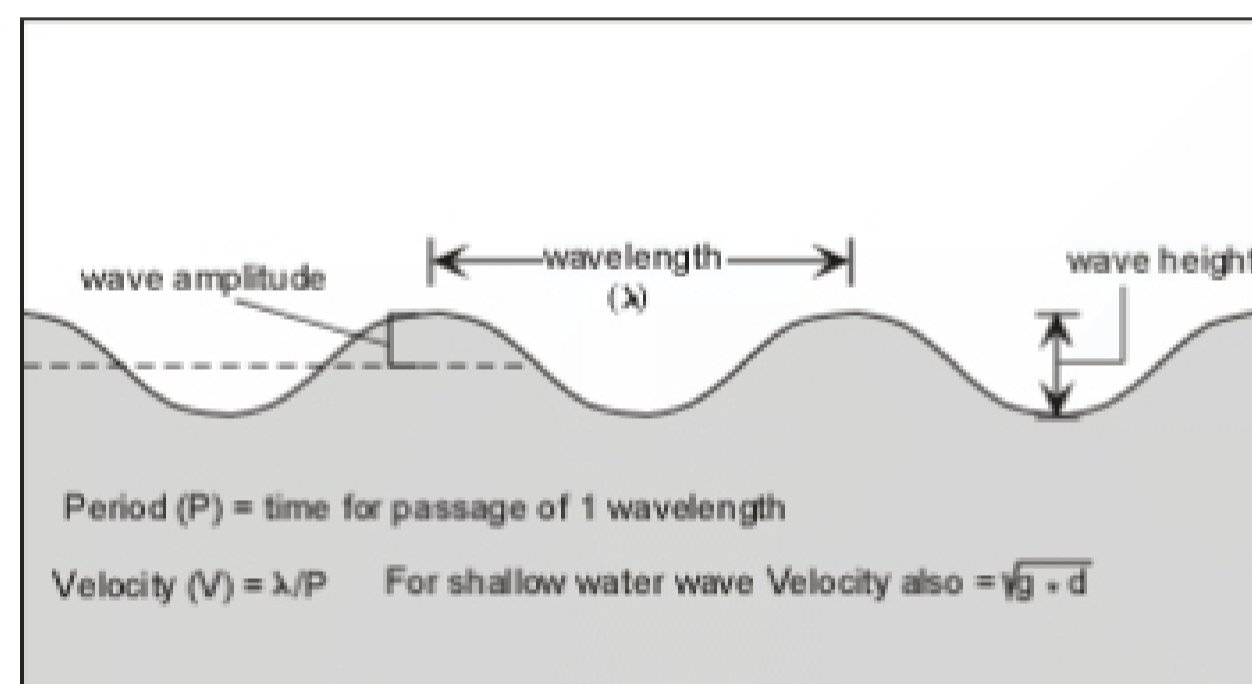
A tsunami is a very long-wavelength wave of water that is generated by sudden displacement

of the seafloor or disruption of any body of standing water. Tsunami are sometimes called "seismic sea waves", although they can be generated by mechanisms other than earthquakes. Tsunami have also been called "tidal waves", but this term should not be used because they are not in any way related to the tides of the Earth. Because tsunami occur suddenly, often without warning, they are extremely dangerous to coastal communities.

Physical Characteristics of Tsunami

All types of waves, including tsunami, have a wavelength, a wave height, an amplitude, a frequency or period, and a velocity.

- **Wavelength** is defined as the distance between two identical points on a wave (i.e. between wave crests or wave troughs). Normal ocean waves have wavelengths of about 100 meters. Tsunami have much longer wavelengths, usually measured in kilometers and up to 500 kilometers.



- **Wave height** refers to the distance between the trough of the wave and the crest or peak of the wave.
- **Wave amplitude** - refers to the height of the wave above the still water line, usually this is equal to 1/2 the wave height. Tsunami can have variable wave height and amplitude that depends on water depth as we shall see in a moment
- **Wave frequency or period** - is the amount of time it takes for one full wavelength to pass a stationary point.
- **Wave velocity** is the speed of the wave. Velocities of normal ocean waves are about 90 km/hr while tsunami have velocities up to 950 km/hr (about as fast as jet airplanes), and thus move much more rapidly across ocean basins. The velocity of any wave is equal to the wavelength divided by the wave period.

$$V = \lambda/P$$

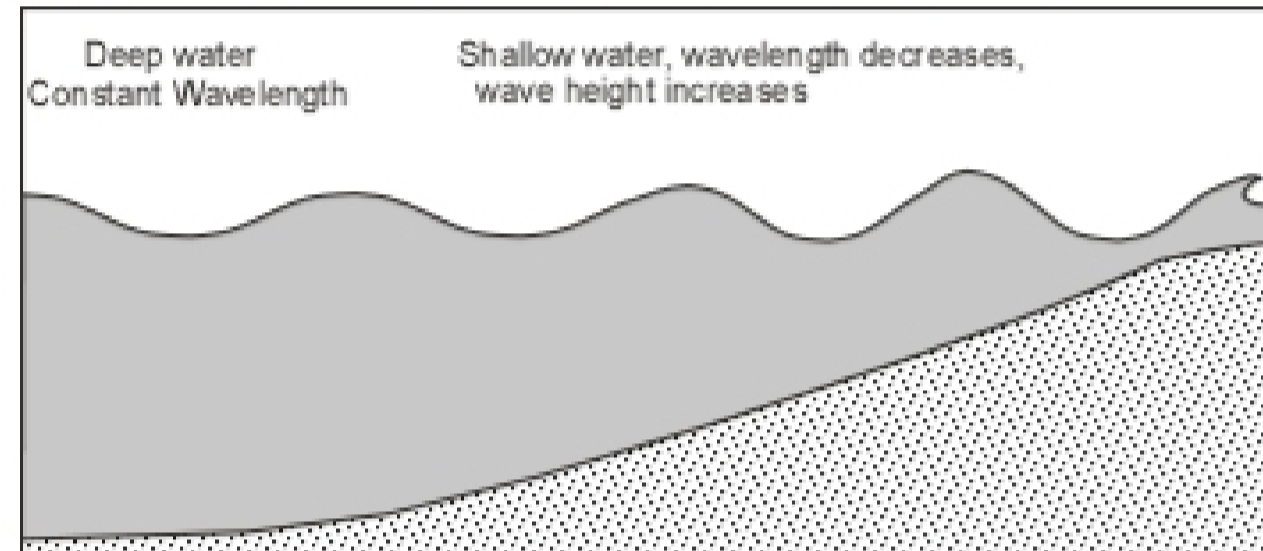
Tsunami are characterized as shallow-water waves. These are different from the waves most of us have observed on a the beach, which are caused by the wind blowing across the ocean's surface. Wind-generated waves usually have period (time between two successive waves) of five to twenty seconds and a wavelength of 100 to 200 meters. A tsunami can have a period in

the range of ten minutes to two hours and wavelengths greater than 500 km. A wave is characterized as a shallow-water wave when the ratio of the water depth and wavelength is very small. The velocity of a shallow-water wave is also equal to the square root of the product of the acceleration of gravity, g , (10m/sec^2) and the depth of the water, d .

$$V = \sqrt{g \cdot d}$$

The rate at which a wave loses its energy is inversely related to its wavelength. Since a tsunami has a very large wavelength, it will lose little energy as it propagates. Thus, in very deep water, a tsunami will travel at high speeds with little loss of energy. For example, when the ocean is 6100 m deep, a tsunami will travel about 890 km/hr, and thus can travel across the Pacific Ocean in less than one day.

As a tsunami leaves the deep water of the open sea and arrives at the shallow waters near the coast, it undergoes a transformation. Since the velocity of the tsunami is also related to the water depth, as the depth of the water decreases, the velocity of the tsunami decreases. The change of total energy of the tsunami, however, remains constant.



Furthermore, the period of the wave remains the same, and thus more water is forced between the wave crests causing the height of the wave to increase. Because of this "shoaling" effect, a tsunami that was imperceptible in deep water may grow to have wave heights of several meters or more.

If the trough of the tsunami wave reaches the coast first, this causes a phenomenon called *drawdown*, where it appears that sea level has dropped considerably. Drawdown is followed immediately by the crest of the wave which can catch people observing the drawdown off guard. When the crest of the wave hits, sea level rises (called *run-up*). Run-up is usually expressed in meters above normal high tide. Run-ups from the same tsunami can be variable because of the influence of the shapes of coastlines. One coastal area may see no damaging wave activity while in another area destructive waves can be large and violent. The flooding of an area can extend inland by 300 m or more, covering large areas of land with water and debris. Flooding tsunami waves tend to carry loose objects and people out to sea when they retreat. Tsunami may reach a maximum vertical height onshore above sea level, called a run-up height, of 30 meters. A notable exception is the landslide generated tsunami in Lituya Bay, Alaska in 1958 which produced a 60 meter high wave.

Because the wavelengths and velocities of tsunami are so large, the period of such waves is also large, and larger than normal ocean waves. Thus it may take several hours for successive crests to reach the shore. (For a tsunami with a wavelength of 200 km traveling at 750 km/hr, the wave period is about 16 minutes). Thus people are not safe after the passage of the first large wave, but must wait several hours for all waves to pass. The first wave may not be the largest in the series of waves. For example, in several different recent tsunami the first, third,