

Tsunami

Tsunami [noun]: a great sea wave produced by under water earth movement or volcanic eruption, sometimes called a tidal wave. From the Japanese *tsu* meaning harbour and *nami* meaning wave.

What is a tsunami?

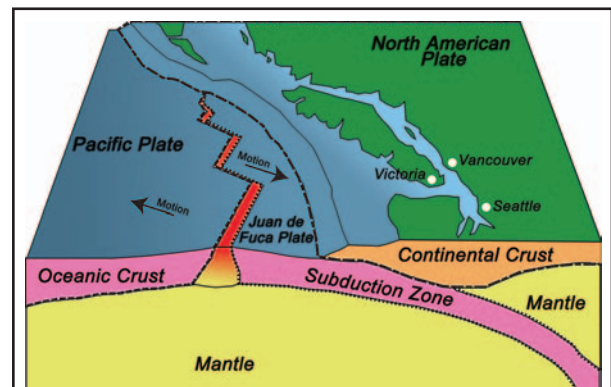
A tsunami is a wave – or series of waves – caused by a sudden disturbance which vertically displaces a body of water. While tsunamis are a water-based phenomenon, they are generally started by movements of the Earth - earthquakes, landslides and volcanic eruptions.

Could an ocean engineer help your community predict or survive a tsunami?

Where do tsunamis happen?

Most significant tsunamis occur near subduction zones – areas where oceanic tectonic plates meet and slip under continental plates. These quakes occur when years of stress built up by the relative movements of two (or more) tectonic plates is released in a sudden thrust. Due to the size of the tectonic plates, these earthquakes are among the world's largest, often exceeding 9.0 on the Richter scale. For the most part, they occur in the Pacific Ocean because it covers and borders one of the most geologically active regions on Earth.

Do you know what this region is sometimes called?



Based on an image from Natural Resources Canada, <http://www.pgc.nrcan.gc.ca/geodyn/cascadia.htm>

The entire west coast is subject to earthquakes, because it lies over a subduction zone, where the oceanic Juan de Fuca plate is slipping under the continental North American plate.

On December 26, 2004, however, the entire world learned just how powerful and devastating a tsunami in other oceans could be. A magnitude 9.3 earthquake occurred in the Indian Ocean west of Sumatra and Thailand and east of India. It generated a series of waves which killed more than 200,000 people in 12 southeast Asian countries.



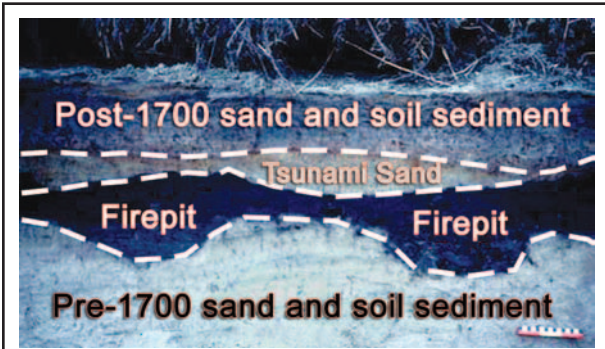
Courtesy Digital Globe, <http://www.digitalglobe.com>

Satellite images of Banda Aceh, Indonesia, before (L) and after (R) the December 26, 2004, tsunami.

At 9pm on the evening of January 26, 1700 the peace and quiet of the mid-winter was shattered all along the west coast of North America. From Alaska all the way down to California, people felt the Earth shudder as a huge quake ripped through the off shore Cascadia fault.

The Huu-Ay-Aht people were at their winter camp at the head of Pachena Bay on Vancouver Island. Today, from homes built in the same area, they still remember the evening through stories that tell of shaking so long and so violent it made people sick. What happened after the shaking stopped was worse; the ocean receded and then came back in a wave so huge that the entire village, except for one person, was swept out to sea. Up and down the coast, in different nations, Elders repeat the same story with slight variations depending on how hard and how high the water was when it hit their villages.

Do your Elders tell any stories of tsunamis?



Based on an image from the United States Geological Survey
USGS, <http://earthquake.usgs.gov/regional/pacnw/paleo/greateq/index.html>

Geological evidence of the 1700 tsunami can be found up and down the west coast. The photo was taken at an excavation at the mouth of the Salmon River along the central Oregon coast. The remains of two fire pits can be seen under a layer of sand washed up by the tsunami.

Tsunamis and earthquakes leave signs of their passing on the Earth. Drowned marsh lands get covered in silt and compacted into the ground; rocks and animals become misplaced and show up in places where they do not belong. By studying soil and the ocean floor, scientists can read these signs and the stories they tell. They call these stories geological evidence.

From the stories told by Elders and the Earth (and records of what happened when the tsunami made it all the way to Japan) scientists now believe the killer wave of 1700 was caused by a magnitude 9 earthquake. It occurred when years of stress built up by the relative movements of the Juan de Fuca and North American tectonic plates was released in a sudden downward thrust of the underwater Juan de Fuca.

Geological evidence indicates that 13 massive quakes and tsunamis have occurred on the west coast of North America in past 6000 years. The most recent one was in 1964. It caused massive damage along the north west coast from Alaska down to Port Alberni, BC.

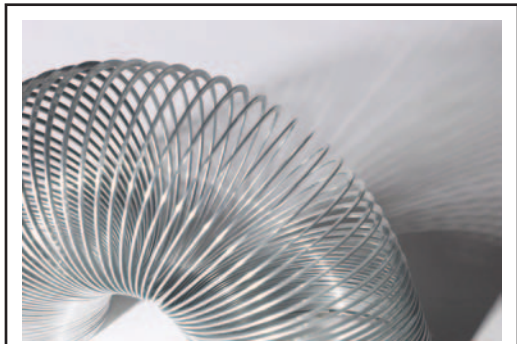
Waves are movements of energy

Waves are a topic of particular interest in physics because many natural phenomena – light, sound, and yes, water waves - occur as waves.

*Think about waves you seen on the water.
What do you know about waves?*

In physics, a wave is a disturbance which moves through a medium (water, air, a slinky) from one point to another. The key point is that it is the disturbance that moves, not the medium. The disturbance is caused by energy transferring from one particle to another, so waves are sometimes called energy transfer phenomenon.

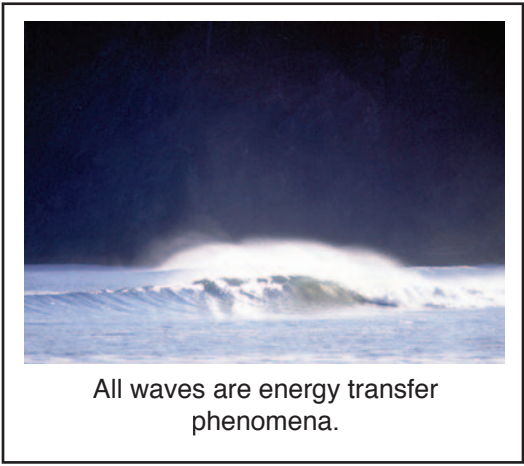
*Have you ever been in a boat?
What happens to the boat when the water is wavy?*



Waves of energy can pass back and forth through the metal coils of a Slinky while the Slinky as a whole never moves.

Waves on water are usually caused by the wind. Individual molecules of air traveling over the water's surface crash into individual molecules of water, and in doing so transfer energy to them. The water particles then transfer energy to other nearby particles of water and so on. We see this energy transfer as a ripple on the water, or in heavier winds (which transfer more energy), waves. This process keeps on going from one set of molecules to the next until the waves reaches the shore.

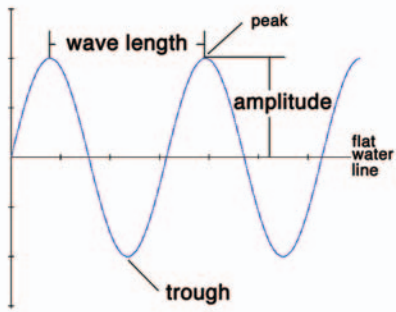
Have you ever seen waves anywhere other than in water?



All waves are energy transfer phenomena.

Amplitude, wavelength and period

To help measure the amount of energy in a wave, scientists make different measurements, which are shown in the diagram. If you think of the diagram as a picture of waves on the water, the straight horizontal line represents the water when it is perfectly still.



Peaks (or crests) are the highest points above the flat water line. Troughs are the lowest points below the flat water line.

The amplitude of the wave is how high it is above the flat water line (or how low it is below the flat water line).

The wavelength is the distance from peak to peak, or trough to trough.

The period of the wave is the length of time from when one peak passes a point to when another peak passes the same point.

Amplitude and energy: Why size matters

What happens to waves in a really strong wind or hurricane?

Every wave can be described by its amplitude, wavelength and period. So, as devastating as tsunamis are for both people and property, their formation and actions are governed by physics.

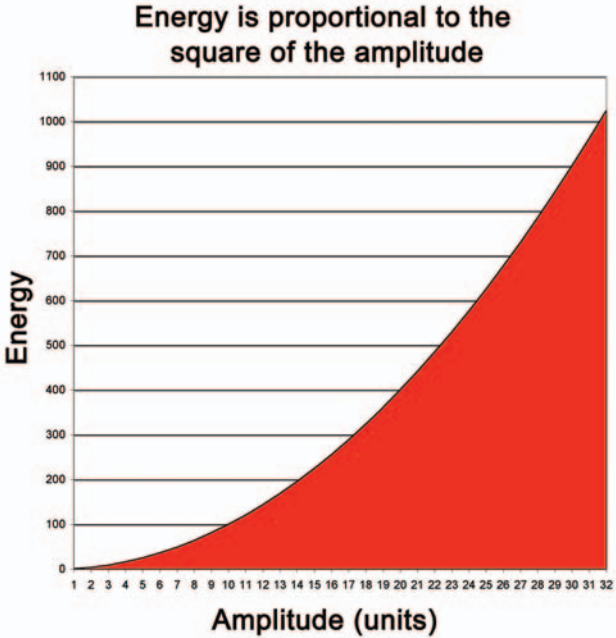
The amount of energy carried by a wave is related to its amplitude. High energy waves have large amplitudes and low energy waves have smaller amplitudes. In other words, bigger waves have way more energy than smaller waves – and tsunamis are BIG waves.

The energy (E) in a wave is actually proportional (\propto) to the square of its amplitude (A).

$$E \propto A^2$$

This means that every time the amplitude of a wave doubles, the energy it contains actually increases 4 times.

So while an every day 1m wave has 1 unit, a large tsunami of 32m has over 1000 times more energy. The largest tsunamis are about 30 meters high when they hit land.



Tsunami formation

Tsunami formation is quite complex. The size and energy of the wave are related to the earthquake's magnitude and depth, water depth where the quake occurs, the amount of vertical motion of the sea floor, the velocity of that motion, and the efficiency with which energy is transferred from the earth's crust to ocean water.

*What is the difference between velocity and speed?
Do you know what engineers mean by efficiency?*

When an earthquake happens under water, the ocean floor can drop (or rise) very suddenly. In a megathrust earthquake, the displacement can be extremely large and occur over the entire length (sometimes more than 1000km) and width of a fault. Energy is transferred to the water both from the shaking of the earth and the sudden rise or fall of the sea floor.

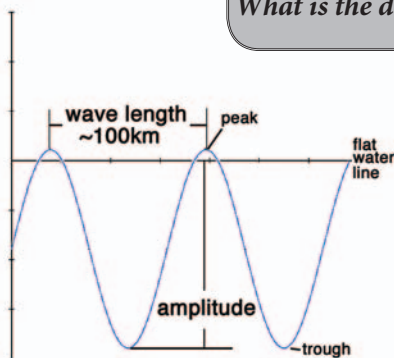
Why would a drop or rise in the sea floor transfer energy to water?

The December 26, 2004 earthquake in the Indian Ocean dropped millions, possibly billions, of cubic meters of water by about 15 m. In other words, in a very short period of time, the water went from having billions and billions of joules of potential energy, to having billions and billions of joules of kinetic energy. This energy is what spreads out from the source and across the ocean to form the tsunami wave.



A megathrust earthquake causes great waves of energy to move out from the source much like a dropped pebble causes ripples in a puddle.

What is the difference between potential and kinetic energy?



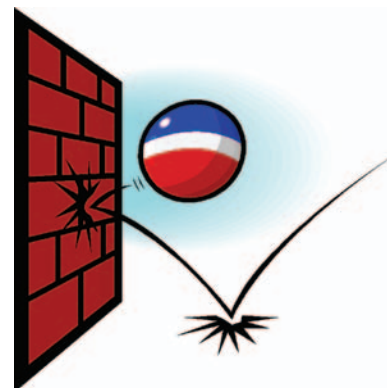
Most of the amplitude and energy of a tsunami wave is hidden in deep water.

Even though tsunamis are big waves, in deep water their size is hidden in the ocean depths. Crests may be a meter high or smaller and separated by 100 kilometers or more, but they are also moving extremely fast, sometimes more than 500 kilometers per hour, as fast as a transcontinental airplane. Tsunamis don't get large until they get close to shore.

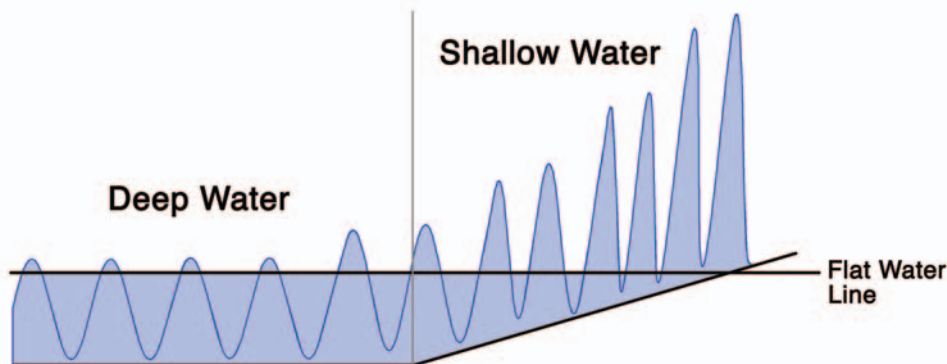
In shallow water

When a tsunami hits shallow water close to shore, it begins to interact with the land. Part of the wave is reflected back offshore, like a ball hitting a wall. Turbulence and friction slow down the part that is not reflected, but because the wave has so much energy to begin with none of these processes significantly decrease its overall energy.

When a tsunami slows down but doesn't lose a lot of energy, what do you think happens to the wave physically?



Physics tells us that when the energy in a system remains constant, but velocity decreases, the mass in the system must increase. A slower moving tsunami, is a physically higher tsunami; all the water in the wave “scrunches together like the ribs of an accordion and heaves upward” (Waves of destruction).



When a tsunami enters shallow water it loses velocity, but gains height.

In other words, when the front part of the wave starts to slow down, all the mass at the back of the wave catches up with it, and creates a MUCH bigger wave. As they reach land, very large tsunamis have been known to reach heights of 30 meters. This measure is known as the run up height.

Coming ashore

How a tsunami comes ashore really depends on how it begins and how the land is shaped. In some cases, water will actually withdraw from sheltered harbours, leaving boats stranded, shells exposed, and fish gasping for breath on the exposed ground. In other cases, the ocean just rises and rises without warning and a wall of water floods onto shore.

The force with which the waves hit lands is tremendous. It is enough to wipe away beaches, knock down trees and crush structures. The water will continue inland for hundreds of meters, pushed along by the huge mass of water behind it. To make matters worse, the wave can be just as destructive as it withdraws, smashing together objects caught in its wake, and dragging debris far out to sea.



Photo courtesy NOAA.
<http://www.photolib.noaa.gov/historic/c&gs/theb1341.htm>

In 1964, a magnitude 9.2 earthquake off the coast of Alaska spawned a tsunami which did extensive damage to many coastal towns including Kodiak, AK (above) and Port Alberni, BC.

Predicting tsunamis

Since most tsunamis are caused by earthquakes, being able to predict tsunamis means being able to predict earthquakes. Unfortunately, predicting earthquakes is extremely difficult. As much as we do know about the Earth, there are too many variables that contribute to earthquakes to know with any certainty when one will occur. The best scientists can do is provide probabilities that tell us how often, on average, earthquakes of various sizes will occur.

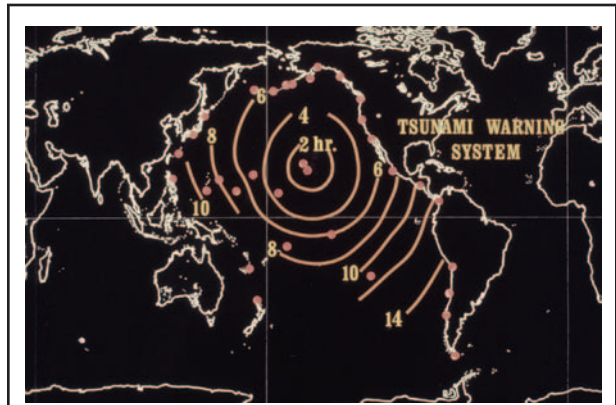
For instance, the most geologically active region of Canada (and the continental United States) lies along the west coast. In this region there are about 1000 small earthquakes each year, most so small that no one feels them. There have been about 100 earthquakes of magnitude 5 or more in the last 70 years. Once every 10 years or so, there is an earthquake of magnitude 7 or bigger – these are called crust damaging quakes. Big megathrust quakes (magnitude 9 or greater) occur only once every 300-500 years.

If we can't know for sure when an earthquake and tsunami will occur, how do probabilities help?

Tsunami protection

Since predicting earthquakes is so hard, tsunami protection relies on warning systems. These warning systems combine seismographs with water-based sea level gauges, sea floor pressure sensors and satellite communications, so that when a tsunami causing earthquake occurs warnings can be provided to coastal areas as quickly as possible.

How fast can a tsunami reach land?



Courtesy National Oceanic and Atmospheric Agency (NOAA)

This map, from the Pacific Tsunami Warning System, shows approximate travel times for a tsunami generated by an earthquake near Hawaii.

Not all countries are served by warning systems, and even those that are often have trouble getting warnings out to small or remote communities. In addition, while warnings help save lives, they do not protect land, buildings and vegetation from the power of massive waves. So, in some places people have taken actions to develop some protection from the force of the sea. Sea walls, are usually built to prevent coastal erosion, however they might in some instances help dissipate energy in tsunami waves so that less destruction occurs on land. Natural barriers to water also help. In the December 2004 tsunami, communities protected by mangrove forest suffered less damage than those completely exposed to the wave.

The Huu-Ay-Aht people remember the stories the Elders tell about the great wave that nearly wiped them out 300 years ago. They also remember the tsunami of 1964; their community wasn't built then, but the nearby town of Bamfield suffered a lot of damage. They are taking steps to protect both themselves and their homes. They have been negotiating with the Government of British Columbia to move their entire community further away from shore and onto higher ground. While an agreement hasn't been reached yet, the Boxing Day tragedy in Asia has reenergized their efforts.



Courtesy National Oceanic and Atmospheric Agency (NOAA)

On April 1, 1946, a magnitude 7.4 earthquake occurred off the southern coast of the Aleutian Islands (just west of Alaska). Although the earthquake was relatively small, it lifted a huge part of the sea bed and generated a massive tsunami. A 30m wave hit Scotch Gap on Unimak Island within 45 minutes of the quake, completely destroying a 30m, reinforced concrete lighthouse located well above sea level. Five hours later, the wave hit Hawaii killing 159 people. It was still over 15m high when it ran aground in Hilo on the Big Island (shown above). This tsunami was the impetus for what is now the Pacific Tsunami Warning System.

What to do in a tsunami or the value of traditional knowledge

While tsunamis usually occur in the Pacific Ocean, all low-lying coastal areas can be struck by tsunamis. In North America, higher risk areas have warning systems in place, and clearly marked evacuation routes.



The best advice for surviving a tsunami is to get as far away from its destructive force as possible.

- If you are caught on land near the coast during an earthquake, move as quickly as possible away from the water and, if possible, up higher ground.
- If you are on open water in a boat, move as quickly as possible to deeper water.

Most buildings will not provide a great deal of protection from tsunamis. Some may collapse, others may flood trapping you inside.



The best thing to do if you feel a coastal earthquake is head for the hills.

This basic knowledge passed down from generation to generation saved whole villages of the Moken people during the recent Indian Ocean tsunami. Moken Elders tell stories of the Laboon, the wave that eats people. They say that before the wave arrives, the earth shakes, birds and bugs fall silent, water animals move deep into the ocean and land animals move to higher ground, then the water recedes. As the story goes, when these signs occur all the people must abandon their homes and move to higher ground as quickly as possible, because the water will return quickly in quantities bigger than can be imagined. As far as any one can tell, only one Moken died in the recent tsunami.

What is lifesaving knowledge in your community?

Sources:

Ask the Surfing Scientist

<http://www.abc.net.au/science/surfingscientist/ask/tidalwaves.htm>

British Columbia, Provincial Emergency Program

<http://www.pep.bc.ca/>

Fisheries and Oceans Canada – Tsunami Physics

http://www-sci.pac.dfo-mpo.gc.ca/osap/projects/tsunami/tsunamiphysics_e.htm

Megathrust earthquake

http://en.wikipedia.org/wiki/Megathrust_earthquake

Ocean facts and Stastics

<http://www.ocean98.org/fact.htm>

Saved by Knowledge of the Sea

http://magma.nationalgeographic.com/ngm/0504/feature4/online_extra.html

Tsunamis: The Great Waves

<http://www.nws.noaa.gov/om/brochures/tsunami.htm>

USC Tsunami research group

<http://cwis.usc.edu/dept/tsunamis/alaska/1946/webpages/index.html>

Waves of destruction

<http://www.pbs.org/wnet/savageearth/tsunami/index.html>

Connecting to Math

1. You are the Emergency Services Coordinator for the Mi'kmaq Nations of Nova Scotia. You know that tsunamis don't happen very often in the Atlantic Ocean, but that they can occur. One of your key concerns is the Cumbre Vieja volcano on La Palma Island in the Canary Islands. Cumbre Vieja is very unstable and has the potential to slide into the ocean causing an Atlantic-wide tsunami that could seriously impact the east coast of North America.

a) The speed of a tsunami can be estimated using the formula
 $\text{speed} = \sqrt{g \times \text{depth}}$

where $g = 9.81 \text{ m/s}^2$. Knowing that the depth is approximately 4000m, can you estimate the speed of the tsunami in km/h?

b) The communities you serve are about 4300 km away from Cumbre Vieja. How long would you have to implement emergency measures if the volcano triggered a tsunami?

2. Your class holds a fundraiser to help in tsunami relief efforts in southeast Asia. You go to the UNICEF web site to see what your money can potentially contribute, and find the following information.

Amount (\$)	Can ...
0.07	...provide 1 packet of Oral Rehydration Therapy for one child to treat severe dehydration and diarrhea, a leading cause of death among young children
0.30	...support 1 person through the emergency health kit for three months.
1.00	...provide 1 dose of measles vaccine.
1.50	...immunize a mother and her child against maternal and neonatal tetanus
6.00	...provide 1 vial of penicillin to treat various illnesses.
12.00	...provide 1 family with a 14-piece, aluminum cooking set for use in emergency situations.
15.00	...provide 1 carton of high energy protein biscuits, specially developed for emergency supply.
20.00	...immunize a child for life against six major childhood diseases.
50.00	...provide blankets to protect 10 small children from the cold.
110.00	...provide enough clean water to meet the early needs of 10 families during the early stages of an emergency.
250.00	...provide 1 school-in-a-box kit to provide basic education to 80 children during times of crisis to allow them to continue their education.
290.00	...provide emergency health kits with essential drugs, medical supplies, and equipment to support 1,000 people for three months.
310.00	...provide one tent to be used for lodging during an emergency when homes are destroyed.
525.00	...provide one metric ton (40x25kg bags) of formulated supplementary food for children
615.00	...provide enough vitamin A capsules to boost 16,000 children's immune system and protect them from blindness.
1300.00	...provide one large tent to set up a clinic or hospital after a disaster.
1900.00	...provide emergency health kits to support 10,000 people for three months.

a) You realize that there are cost for emergency health kits varies depending on how many are purchased. What is the cost per person associated with the different totals? Why do you think the totals are different?

b) Your class decides it would like to raise enough money to let 3 classes continue with school during the emergency. It also decides that it would like to have enough money in total to provide each student in the classes with immunization against childhood diseases. How much money do you need to raise?

c) You manage to raise 1095.67\$. Once the school-in-a-box kits are purchased, how many immunizations against six major childhood diseases can your donation purchase? What could you do with any leftover money?