**Tsunami Safety Rules**

In case you are ever in an area where there is a threat of tsunami, I have downloaded the following tsunami safety rules from the West Coast & Alaska Tsunami Warning Center Home Page: http://wcatwc.arh.noaa.gov/safety.htm

A strong earthquake felt in a low-lying coastal area is a natural warning of possible, immediate danger. Keep calm and quickly move to higher ground away from the coast.

All large earthquakes do not cause tsunami, but many do. If the quake is located near or directly under the ocean, the probability of a tsunami increases. When you hear that an earthquake has occurred in the ocean or coastline regions, prepare for a tsunami emergency.

Tsunami can occur at any time, day or night. They can travel up rivers and streams that lead to the ocean.

A tsunami is not a single wave, but a series of waves. Stay out of danger until an "ALL CLEAR" is issued by a competent authority.

Approaching tsunami are sometimes heralded by noticeable rise or fall of coastal waters. This is nature's tsunami warning and should be heeded.

A small tsunami at one beach can be a giant a few miles away. Do not let modest size of one make you lose respect for all.

Sooner or later, tsunami visit every coastline in the Pacific. All tsunami - like hurricanes - are potentially dangerous even though they may not damage every coastline they strike.

Never go down to the beach to watch for a tsunami! WHEN YOU CAN SEE THE WAVE YOU ARE TOO CLOSE TO ESCAPE. Tsunami can move faster than a person can run!

During a tsunami emergency, your local emergency management office, police, fire and other emergency organizations will try to save your life. Give them your fullest cooperation.

Homes and other buildings located in low lying coastal areas are not safe. Do NOT stay in such buildings if there is a tsunami warning.

The upper floors of high, multi-story, reinforced concrete hotels can provide refuge if there is no time to quickly move inland or to higher ground.

If you are on a boat or ship and there is time, move your vessel to deeper water (at least 100 fathoms). If it is the case that there is concurrent severe weather, it may safer to leave the boat at the pier and physically move to higher ground.

Damaging wave activity and unpredictable currents can affect harbor conditions for a period of time after the tsunami's initial impact. Be sure conditions are safe before you return your boat or ship to the harbor.

Stay tuned to your local radio, marine radio, NOAA Weather Radio, or television stations during a tsunami emergency - bulletins issued through your local emergency management office and National Weather Service offices can save your life.

**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 = λ/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/sec2) and the depth of the water, 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, and fifth waves were the largest.

**How Tsunami are Generated**

There is an average of two destructive tsunami per year in the Pacific basin. Pacific wide tsunami are a rare phenomenon, occurring every 10 - 12 years on the average. Most of these tsunami are generated by earthquakes that cause displacement of the seafloor, but, as we shall see, tsunami can be generated by volcanic eruptions, landslides, underwater explosions, and meteorite impacts.

**Mitigation of Risks and Hazards**

The main damage from tsunami comes from the destructive nature of the waves themselves. Secondary effects include the debris acting as projectiles which then run into other objects, erosion that can undermine the foundations of structures built along coastlines, and fires that result from disruption of gas and electrical lines. Tertiary effects include loss of crops and water and electrical systems which can lead to famine and disease.

Within the last century, up until the December 2004 tsunami, there were 94 destructive tsunami which resulted in 51,000 deaths. Despite the fact that tsunami warning systems have been in place in the Pacific Ocean basin since 1950, deaths still result from tsunami, especially when the source of the earthquake is so close to a coast that there is little time for a warning, or when people do not heed the warning or follow instructions associated with the warning. These factors point out the inadequacy of the world in not having a tsunami warning system in place in the Indian Ocean, where in one event, the death toll from tsunami was increased by a factor of 5 over all previous events.

**Questions on this material that could be asked on an exam**

Note that answers to some of these questions will come from the video

1. Discuss 5 ways that a tsunami can be generated.

2. Compare and contrast tsunami waves with normal wind-driven ocean waves in terms of their wavelength, period, velocity, and amplitude.

3. Is a tsunami a single wave or numerous waves? If a tsunami has multiple waves, is there any patterns as to which will be the highest and most destructive?

4. What are the best ways to mitigate against casualties and damage from tsunami?

5. If you are on the beach, what signs of an impending tsunami are observable, and what action(s) should you take to avoid death or injury?