

Tsunami Hazard

Concepts and definitions

Tsunami is a Japanese word, meaning 'Harbour Waves'. The term was introduced by the fishermen who on return to the port (after fishing) found the area surrounding the harbour devastated by sea waves, a scenario which they had not encountered during voyage through the open sea / ocean.

The apparent paradox is because of the fact that the offshore Tsunami waves in the open sea have very small amplitudes (several metres) compared to the extremely large wavelengths (often hundreds of kilometre long). It is because of that the wave passes unnoticed forming only a fleeting bulge over the mid-sea/ocean. The Tsunami waves which appear quite innocuous in open sea move with high velocity. Using the mathematical formula illustrated in Figure 2, we find that for ocean depth of 5 km, the wave velocity would be about 220 m/sec, i.e. approximately 800 km /hr, which is comparable to the speed of a jet-propelled aircraft.



Figure 2. Cartoon diagram illustrating the mathematical relationship between depth-velocity relationship of Tsunami wave.

Dynamics of tsunami are essentially governed by the shallow water equations. The wavelength of a Tsunami wave (which is the product of velocity and time) is about 200 km having a period of 15-30 minutes in the open sea. In open sea thickness of water column could be as much as 3 to 4 km. As tsunami leaves the deep water of the open sea and arrives at the shallow waters near the coast, it undergoes a transformation, mainly due to a significant change in the water column thickness. Near the coast due to decrease in the water column thickness, the velocity of tsunami waves drop. However, the total energy and the period of the wave remains the same. Due to such a combination of energy and wavelength, more water is forced between the wave crests causing the height of the wave to increase. Because of this, the tsunami waves which are imperceptible in deep water undergo manifold increase in wave heights, as they reach the coast (Figure 3). A little before hitting the land, this slow moving wave is overridden by successive waves from the rear, and the composite wave after attaining a great height (at times over 70 m), and lashes the coastline like monstrous hydra-heads.

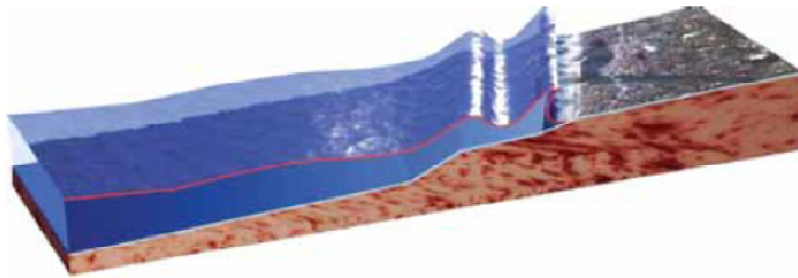


Figure 3. An artist's impression of buildup of Tsunami as the waves approach the shore line. (Courtesy: Wikipedia).

CAUSES OF TSUNAMI GENERATION:

Confusion prevails over the processes of Tsunami generation. Tsunamis are traditionally described as tidal waves. This is because, on approaching the land, the Tsunami waves take on the characteristics of violent onrushing tide rather than the sort of familiar cresting waves formed by wind action upon the ocean. The essential prerequisite for triggering a Tsunami is the sudden displacement of sea/ocean water on a massive scale. Tsunami is generated as the disturbed water level attempts to attain equilibrium. The disturbed ocean water moving under the influence of gravity radiates across the sea/ocean similar to ripples in a pond. Because there is very little energy loss during the propagation of the Tsunami waves over the ocean water, the harbour waves, which finally strike the coastal areas assume awesome ferocity. The process of Tsunami generation sets off with abrupt dislodgement of blocks of ocean floor rocks due to faulting with a strong vertical component of displacement. Two different situations are possible. Faulting can lift a part of the ocean floor vertically upward which in turn would push up the column of water above it creating a local bulge over the normal sea level (Figure 5A). On the other hand, if faulting causes down-sagging of the ocean floor relative to the adjacent part, a local depression in the sea water level is created causing ebbing tide. Such a situation may develop in Subduction Zones where the heavier Oceanic Lithosphere slides down below the lighter continental Crust (Figure 5B). In such a case, water is withdrawn from the coastal areas, resulting in a “ draw-down “ situation, a feature witnessed during 26 December, 2004, Indian Ocean Tsunami (Figure 6).

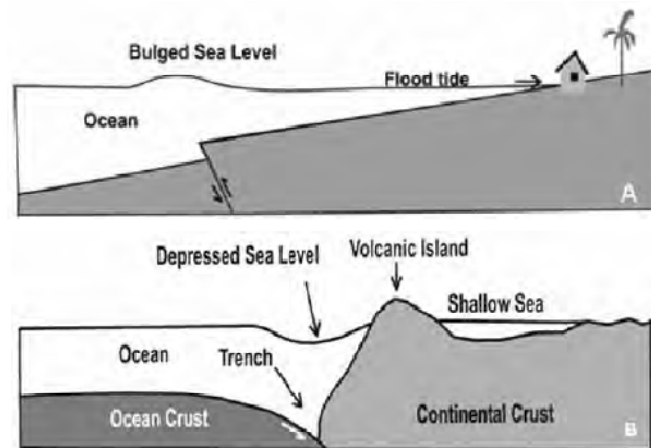


Figure 5 (A) Schematic diagram showing development of local bulge over the sea level because of uplifting of a block of Ocean Crust. This causes flood tide in coastal region. (B) Where fault causes down-sagging of a block as in Subduction Zone, a local depression in the sea level is created.

The Circum-Pacific belt is the most Tsunami-prone stretch in the world today which is characterised by the presence of deep Trenches over the Subduction Zones associated with an inclined zone of seismicity (Benioff Zones). Because of the down-sagging movement at regular intervals, a space is created virtually coinciding with the zone of Trenches. This in turn creates a sudden depression in the water column above the zone, leading to imbalance. The process that follows in attaining the equilibrium leads to generation of Tsunami waves. The tectonic situation of the 2004-Indian Ocean Tsunami is comparable to those that develop along the Circum-Pacific belt. The similarity is perceptible with regard to the source and nature of tsunami generation, due to massive down-sagging of the Indian Ocean Crust along the Java Trench. Sudden displacement of huge mass of water (enough to cause a Tsunami) could also be due to processes other than faulting. These include:

- Volcanic eruptions near sea or underwater. The most horrifying example recorded in history was the eruption of Krakatau in Indonesia on 26-27 August, 1883.
- Large meteorite impacts on ocean water (no known instance is recorded in human history). However, presence of some 'erratic' deposits along the Gulf coast of Mexico and the United States was presumed to have resulted during the apparent impact of a meteorite about 65 million years ago near the tip of the Yucatan Peninsula of Mexico
- Underwater testing of nuclear bombs (Nuclear testing by the United States in the Marshall Islands in the 1940s and 1950s generated Tsunamis).
- Massive landslides generated Tsunamis. The most famous example of a landslide induced Tsunami occurred at Lituya Bay in Alaska (USA) on 9 July, 1958, producing a giant water wave that reached 524 metres up the local mountains. However, there was virtually no effect outside the bay region (Figure 7). Besides these, a Tsunami could generate, if a landslide drops a huge mass of rock debris or an avalanche pours in huge chunks of ice mixed with rubbles of rocks and soils into sea or ocean. The Tsunamis generated by such processes generally have a localised influence. The waves

generated usually dissipate quickly, and rarely affect the coastlines distant from the source because of the small area of the affected sea.

TSUNAMI-EARTHQUAKE LINK

All the Tsunamis in the Circum-Pacific belt are invariably associated with earthquakes. So intimate is the association that these 'harbour waves' are conventionally described as 'earthquake generated Tsunami' or 'seismic sea waves' (Roy, 2008). Impressed by the close Tsunami-earthquake link, some enthusiastic earth scientists have even attributed the circum-Pacific earthquakes as 'Tsunamigenic'. Without refuting the Tsunami-earthquake link, the usage appears misleading because scientifically speaking both earthquake and Tsunami are manifestations of sudden dislodgement of rock masses during faulting, and the association does not bear any cause-and effect relationship (Roy, 2008). Earthquakes are vibrations in the Crust caused by moving energy waves released during the breaking (faulting) of 'strained rocks'. 'Elastic Rebound Theory' aptly explained how the energy released during disruption (or faulting) of strained rocks radiated from the source of origin as elastic waves along the San Andreas Fault (Reid, 1906). It would be wrong to say that the earthquake waves can provide energy for generating a Tsunami. A point to remember is that no Tsunami was generated during severe earthquakes along the San Andreas Fault, a considerable part of which runs through the ocean floor. The reason is that the movement along the fault causing earthquake was of translational or strike-slip type, and did not displace water in any significant way. And the fact is that unless there is massive displacement of water, no Tsunami would generate even though the faulting might cause a high intensity earthquake. In the ill-famed 'Troika of Catastrophe' that marked the 1 November, 1755, Lisbon event, an earthquake-induced massive landslide into the Atlantic water generated a mega- Tsunami that destroyed many settlements all along the coastlines. But, even in that case, it cannot be said that the Tsunami waves were generated directly by the earthquake. Earthquake can definitely be the cause of a type of 'enhanced' waves called 'Seiche' (also a Japanese term, pronounced 'saash'). The ground motion during an earthquake shakes the water back and forward at regular intervals setting off Seiche waves, which may at times and places be quite destructive. Such a Phenomenon, similar to Seiche waves, occurred in the southern Bengal coastal corridor on 26 December, 2004.

Tsunami Movement

A wave can be described by its wavelength, height, and period (p Figure 5-7). Tsunami wave heights in the open ocean are small. Tsunami generated by ocean earthquakes are often no more than a meter or two high far out in the ocean, with a maximum of about 15 meters near the earthquake epicenter. The average **wavelength** of a tsunami wave is 360 kilometers, so the slopes on the wave flanks are extremely gentle. The time between waves, or the **period**, may be half an hour. For example, for a wave with a 30- minute period, a ship would go from the wave trough to its crest and back to the trough in 30 minutes. A ship at sea would not even notice such a gentle wave.

The mechanisms that drive tsunami waves are different from those that drive typical waves, which are driven by wind. Water particles in waves travel in a circular motion that fades downward. The velocity of waves depends on their wavelengths. Waves touch bottom at depths less than approximately half their wavelengths. Tsunami waves with their long wavelengths drag bottom everywhere in the ocean, whereas wind-driven waves feel bottom only near shore. A tsunami feels bottom far from shore, so it becomes a fast-moving mass of water that continues to flow forward like a flash flood (p Figure 5-8). In the open ocean, tsunami waves can travel as fast as 870kilometers per hour, but as they reach shallower water, they slow because their circular motions at depth drag on the ocean bottom. Thus, water depth is related to wave velocity (p Figure 5-9 and **By the Numbers 5-1: "Velocity of Tsunami Waves"**). On the continental shelf, a 1-meter open-ocean tsunami wave may slow to 150 to 300 kilometers per hour. As the wave approaches shore, the front of the wave slows first and the rear keeps coming, causing the waves to become much shorter, perhaps one-sixth of their former wavelength. Because the volume of the wave remains the same, its height must rise dramatically, perhaps to six times its open-ocean height (p Figure 5-10). For example, a 3-meter-high wave in the open ocean could rise in shallow water to 18 meters!

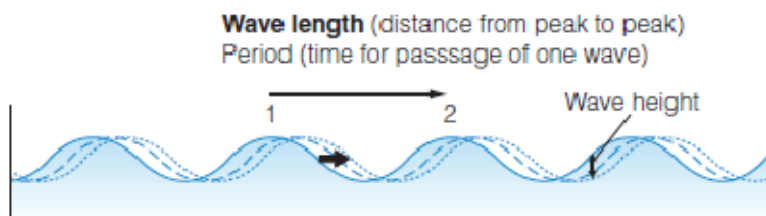


FIGURE 5-7. Although wind waves drag on the bottom in shallow water near shore, tsunami drag on the bottom across the entire ocean.

Tsunami Prediction and Possible Mitigation

We cannot prevent generation of a Tsunami, nor is it possible to make a precise prediction about it. There are, however, some warning signs of an impending tsunami. Mention has been made about the draw-down effect along beaches as an advance signature of incoming Tsunami waves (Fig.4). This happens when the displacement of water is linked with sudden down-sagging of the ocean floor (as it normally happens in case of Subduction related faulting). Under such a situation, there will be an unusual incidence of ebbing tide in the coastal regions; and the sea in such situations will recede from the coast, before the tsunami wave's arrival. If the continental slope is shallow, this recession can exceed many hundreds of metres. The time, for the return of water in form of giant 'harbour waves' might not be sufficient for the people to get prepared to face the impending disaster. Only those who have prior knowledge of tsunami resultant changes in the ocean wave dynamics saved themselves and others by rushing to

elevated zones of the area. Others perished due to lack of sufficient time to run for safety. One of the early warnings of an incoming Tsunami is sounded by the nearby animals, which have the ability to sense danger and flee to higher ground before the water arrives. This was first recorded in the event of Lisbon earthquake-Tsunami on 1 November, 1755, in Europe. The phenomenon was also noted in Sri Lanka during the recent Indian Ocean Tsunami. It is said that animals may have the ability to sense subsonic seismic waves from an earthquake minutes or hours before a tsunami strikes the shore. Some other views about the animal behaviour have also been expressed suggesting that certain large animals especially the elephants are able to sniff out danger. This instinct forces them to flee in the direction opposite to the approaching roars of Tsunami waves. In regions of high risk the 'Tsunami Warning Systems' are being used to detect approaching Tsunami to warn the general population before the wave reaches land. Since 1995, National Oceanic and Atmospheric Administration (NOAA) began developing the "Deep-Ocean Assessment and Reporting of Tsunamis (DART)" system. (Tsunami Information: www.ess.washington.edu/tsunami). Several stations have been deployed in the Pacific Ocean, which have 'pressure recorder' for detecting the passage of a Tsunami. The basic assumption is that the pressure of the water column is related to the height of the sea-surface. Any sudden change in the depth of the water column is indicated by a corresponding change in the water pressure. This in turn is an indication that a Tsunami is developing. The information is immediately sent to the 'Pacific Tsunami Warning Center' (PTWC) for dissemination to all concerned. The DART system rings out early warnings to all the Pacific coastal countries. We should however remember that the DART information from the Pacific would not be effective for the Indian Ocean region, because the Tsunamis developing in the Pacific would have no free passage to the Indian Ocean. Considering this, there is now an Indian Tsunami monitoring System working in the Indian Ocean. Tsunami is an exotic word for us without having any equivalent phrase in Indian languages, unlike the earthquake and the volcano (Shetye, 2005). This clearly implies that the Tsunami is not a regular visitor in the Indian coastal regions. Truly speaking, there is no information about any dreadful appearance of Tsunami 'monster' in the region in the known history barring one that had lashed the northern coastal belts of the Arabian Sea on 19 June, 1945.

The memory of the 2004 Indian Ocean Tsunami is so fresh in our mind that it is not possible to disbelieve that the 'waves' that devastated the region were anything other than a dreadful Tsunami. Even if it is assumed that 1737 Calcutta event was a Tsunami of a scale comparable with the most recent one, there is hardly any reason to be panicky. Tsunami of 2004 magnitude may not happen in the near future, as this tsunami was triggered by a very high magnitude earthquake that destabilised large chunks of the crust.

Japan has implemented an extensive programme of building Tsunami walls of up to 4.5 metres high in front of populated coastal areas. In some other parts of the world, floodgates and channels have been constructed to redirect the water from incoming tsunami. Without questioning the effectiveness of such Tsunami walls, it may be said that such a measure is economically unviable for the poor maritime countries in south Asia and Africa. One useful

suggestion, which might partly mitigate the effects of Tsunami is to plant trees like coconut, palms, and mangroves to cover the shoreline. The effectiveness of such a measure has been witnessed during the recent Indian Ocean Tsunami when some coastal areas covered by trees have escaped virtually unharmed, because much of the Tsunami energy was worn out considerably in the tree-covered belts (Figure 8).

The following precautionary measures to be observed:

1. *GIS*: Acquaint the geographical information of your house, street (height above mean sea level) and the distance from the coast.
2. *Education*: Be familiar with the Tsunami warning signals.
3. *Signs of Warning*: Coastal people should always be alert with the earthquakes. Earthquakes are the first warning signals of coming Tsunami particularly if they are violent shaking.
4. If the water in the Bay harbor or along the beach suddenly sucked or rushed out to sea, leaving fish, boats stranded, it is a sure sign of advancing Tsunami in a short time (within 5 to 30 minutes) that will hit the coast.
5. When Tsunami warning issued immediately rush to the safe top floor of the strong building 50-100 m above mean sea level (or very high elevated place) or cyclone shelter, but never venture to go towards the beach which will be inviting danger.
6. Take all precautionary measures that are recommended for storm surges.
7. Tsunami is a series of waves. First wave will be less dangerous, but subsequent waves will be progressively higher wave height and invade in a very short time. Do not leave the cyclone shelter or safe multi storied house where you have taken shelter till you hear the dewatering on Radio "All clear".
8. The hit (attack) of Tsunami will cause contamination of all food and water and cracks in structures/houses. Make sure that your house is safe before entering back into it. Be careful while wading through inundated water.
9. Monitor local Radio / DD announcements for evacuation orders when Tsunami warning issued. Do not return to low lying areas until the Tsunami threat has passed off and the "All clear" dewatering is announced.

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