An introduction to tsunami in the Indian context

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Tsunami is a water wave caused due to tectonic activities under water and travels across oceans with very high speed and can inflict great damage to life and property at the shores. The recent Sumatra earthquake of magnitude 9.0 triggered the most devastating tsunami of the recorded history causing a death toll of more than 150,000. Many regions around the globe, especially the Pacific Ocean have witnessed many damaging tsunamis in the past. Countries around the Pacific Ocean have developed an early warning system that has been very effective for the last 50 years. Tsunamis have not been so frequent in the Indian Ocean, therefore lack of awareness has been a major cause for the great devastation caused by the tsunami of 26 December 2004. This feature gives a brief background about tsunamis.

What is a Tsunami?

Tsunami is a word of Japanese language meaning 'harbour wave', which is used to describe the large waves produced by an abrupt shifting of the sea floor which results in vertical displacement of the overlying water. When these waves reach the land by travelling large distances across the ocean, they cause devastation on the coasts.

These waves move at a speed, V, that is equal to the square root of the product of the acceleration of gravity, g, and the water depth, D, that is $V = \sqrt{D.g}$. With typical water depth in ocean at about 3000 to 4000 m, a tsunami travels at about 200 m/s, or over 700 km/h. Typically, in deep ocean tsunami has very large wave length (distance from crest to crest) running into 100-200 km and the wave height of less than 1 m. As the rate at which a wave loses its energy is inversely related to its

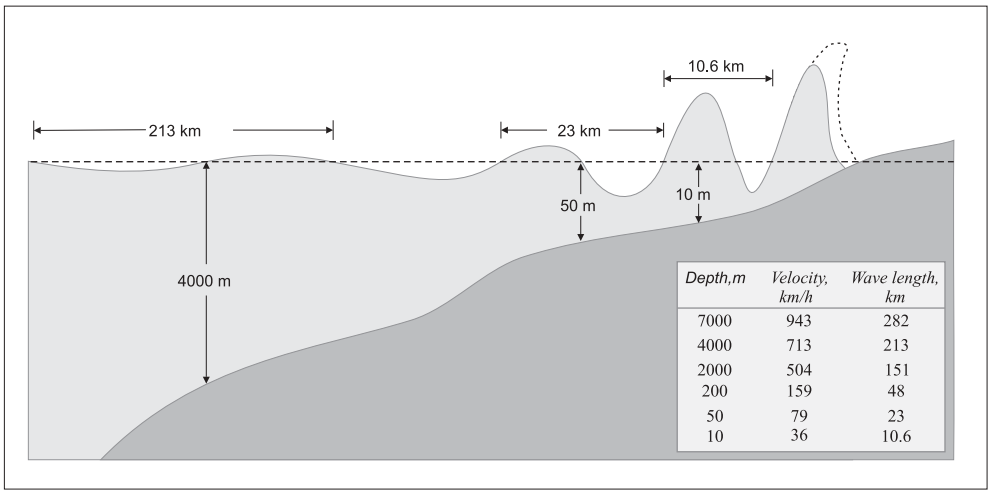

Fig 1 Shoaling effect of a tsunami[1]

wave length, tsunamis not only propagate at high speeds, they can also travel great trans-oceanic distances with very little energy losses.

As a tsunami approaches land and propagates into the shallow water near the coast, *Fig* 1, its speed reduces because of two reasons:

(i) the speed of a tsunami is directly related to the water depth and it reduces as water depth reduces

(ii) the friction of the continental floor slows down the front of the wave.

Thus, not only the waves slow down, they get closer to each other. Due to conservation of energy, decrease in distances between individual waves leads to increase in amplitude of the waves and therefore the waves rise up to 10 m or more near the coasts. This phenomenon is also known as "Shoaling Effect".

Sumatra earthquake and associated tsunami

The magnitude 9.0 earthquake of December 26, 2004 took place at the interface of India and Burma plates off the coast of northern Sumatra. It is a typical convergent plate boundary where the Indian plate is moving at a rate of about 5 mm per year relative to the Burma plate. The earthquake occurred when the stresses between the two plates built up so much that the Indian plate dived under the Burma plate!

Tsunami caused by the earthquake resulted in heavy death tolls in a large number of countries. As of January 13, 2005 (18 days after the event) the total number of deaths (approximate) as reported from various countries was: 159,484. The break-up is as follows:

- Indonesia : 113,306 (3,598 missing)
- Sri Lanka : 29,825 (5,806 missing)
- India : 10,672 (5,711 missing - 5625 on the Andaman and Nicobar islands)
- Thailand : 5,309 (3,396 missing)
- Somalia : 150
- Myanmar : 59
- Maldives : 82 (26 missing)
- Malaysia : 68 (6 missing)
- Tanzania : 10
- Bangladesh : 2
- Kenya : 1

Fig 2 Severe destruction caused by the tsunami waves in Cuddalore district in the state of Tamil Nadu
(Photo courtesy: Ms. Alpa Sheth)

Andaman and Nicobar islands, and a large part of the east coast and a small part of the west coast of the Indian mainland suffered extensive damage due to the tsunami, *Fig* 2. However, as we can see from the death toll above, the impact of the killer waves has not been restricted to the countries around the Indian ocean. The waves travelled thousands of kilometres through the Indian Ocean and have caused death toll even at African shores like Somalia and Tanzania.

One should note that some areas on the western coast of the Sri Lankan island have also been hit by the tsunami, while the tsunamis originated on the eastern side. This indicates that the waves refract on their route and therefore, can also hit the coasts which do not lie on the straight path.

Some past tsunamis

Though tsunamis have not been regular phenomena at Indian coasts, many other countries have been plagued by more frequent tsunamis for centuries.

- On November 1, 1755, a series of earthquakes destroyed Lisbon, Portugal, setting off fires and building collapses. An hour after the quake struck, a 15 m (50 ft) tsunami caused death of 60,000 people.
- On August 27, 1883, the Indonesian volcano, Krakatoa, erupted; causing tsunamis that killed 37,000 people on Java and Sumatra.
- A series of tsunamis in Japan in 1896 killed 27,000 people, and destroyed more than 10,000 houses.
- Tsunamis struck Hawaii and Alaska in April 1946 claiming 159 victims.
- In May 1960, a series of earthquakes in Chile caused tsunamis that killed nearly 1500 people. The same wave hit Hilo Hawaii later in the day and claimed 61 victims. The same tsunami hit Japan the next day and killed 150 more.

The first reported tsunami that hit the Indian coasts dates back to April 2, 1762. An earthquake at Bangladesh-Myanmar border triggered a tsunami in the Bay of Bengal. Water in Hoogly at Kolkata rose by 2 m; rise in water at Dhaka is reported to have capsized hundreds of boats and drowned many people. On December 31, 1881, an earthquake of magnitude 7.9 at Car Nicobar region generated tsunamis with maximum crest height of 0.8 m which were recorded around the Bay of Bengal. Ortiz and Bilham[2] have used the tide gauge records around the Bay of Bengal to estimate the parameters of this earthquake. The Krakatoa volcano eruption of 1883 mentioned earlier had caused a tsunami that was felt at Indian coasts also. In twentieth century also, Indian coasts have witnessed two major tsunamis. On June 26, 1941, an 8.1 magnitude earthquake at Andaman Islands generated a tsunami of about 1 m in height. The cellular jail in Port Blair was also damaged, and the earthquake was felt even in Madras and Colombo. Even the land of certain islands was reported to have sunk by about 60 cm. On November 28, 1945, Makran coast of Pakistan had an earthquake of magnitude 8.0. This earthquake was accompanied by generation of tsunamis and mud volcanoes. The tsunamis were as high as 12 m at some of the Makran ports, causing tremendous damage. The height of tsunami reached 11 m at Kachch coasts and about 2 m at Mumbai. About 15 persons were reported dead at Mumbai due to the tsunami. About 4,000 people died due to the earthquake and tsunami.

Tsunami warning system

Modern technology is capable of offering advance warnings of such events in many areas, giving people the chance to escape to higher ground. The best way to avoid such disastrous results is by better preparation for any such events in advance. In case of the recent Sumatra earthquake and subsequent tsunami, there was a lag of about 3 hours between the earthquake and the tsunami reaching the coasts of Indian main land. Unlike the direct damage due to earthquake, where the waves travel much faster and there is hardly any scope for warning, tsunamis may take hours to reach coasts and therefore offer sufficient time for issuing a warning if any such system is in place.

Currently, there are two tsunami warning centres in Hawaii and Alaska, respectively. Whenever a strong Pacific basin earthquake is detected, scientists at the Pacific Tsunami Warning Centre (PTWC), established in 1946, located at Ewa Beach near Honolulu, Hawaii and the West Coast/Alaska Tsunami Warning Centre (WC/ATWC), established in 1967, located in Palmer, Alaska, locate the earthquake and estimate its magnitude. If the earthquake is located beneath the sea floor and has a surface magnitude of 7.0 or larger, tsunami warnings, watches and information bulletins are issued. Warnings are issued for the communities which are within a three hour travel time from epicentre. A warning means that a damaging tsunami may be on its way. The interpretation of a warning, however, may vary from state to state, and decisions in evacuation of the coastal areas among other things are taken by local authorities. All communities within 3 to 6 hours travel time from the epicentre are put into a tsunami watch situation. A watch means that an earthquake that has a potential to create a tsunami has occurred and local bodies should be on the alert for further information. Tsunami information bulletin is issued to the communities farther than 6 hours travel time from the epicentre. This also works as an alert for the local authorities; however, tsunami information bulletin is also issued when there is no tsunami threat posed by a particular earthquake[3].

Recently, there have been efforts to detect the tsunamis as they travel through the ocean. As tsunamis may take a few hours to reach the coasts, if they are detected near the source, this time lag can be used to warn the people of a tsunami heading towards them. One such system is the "Deep Ocean Assessment and Reporting of Tsunamis" (DART), operated by the National Oceanic and Atmospheric Administration (NOAA) of the United States as part of the U.S. National Tsunami Hazard Mitigation Programme. DART systems consist of an anchored seafloor bottom pressure recorder (BPR) and a companion moored surface buoy for real-time communications[4]. The BPR can detect tsunamis with heights as small as 1 cm in water depths of 6,000 m. An acoustic link transmits data from the BPR on the seafloor to the surface buoy. The data are then relayed via a Geostationary Satellite Server (GOES) to ground stations, which demodulate the signals for immediate dissemination to NOAA's Tsunami Warning Centres[5]. Currently six such buoys are operating in the Pacific ocean.

The other techniques that can be used for real-time detection of a tsunami may involve sensitive radar altimeters

aboard satellites, which can detect subtle rises in the sea or to measure the rise of water surface through GPS sensors aboard ships or buoys.

Indian scenario

India needs to put in place a warning system to cover both its east and west coasts similar to the one operating in the Pacific ocean. However, a warning system may never be quick enough to alert those living near the earthquake source (for example, Andaman and Nicobar islands in case of Sumatra earthquake). In such situations, the earthquake shocks themselves work as a warning. The earthquake waves reach before tsunamis and can warn the inhabitants of a potential tsunami. Pacific warning centre in USA follows similar practice in Hawaii islands. In Hawaii, which is targeted by tsunamis from all directions, the maps of safe zones are printed in each island's telephone book. According to the Paul Whitmore, Assistant Director of the West Coast and Alaska Tsunami Warning Centre, "We try to drum in the fact that if you feel a strong earthquake, enough to make it hard to stand up, and it lasts more than 20 seconds, you should get at least 100 feet above sea level." (www.whyfiles.org/tsunami3.txt)

Thus, apart from the development of a unified tsunami warning system, the need of the hour is to train people to understand the hazard of tsunami, and the ways to minimise its devastating effects. People living along the coastlines need to be educated about some simple facts about tsunamis which can prove very helpful in preventing large number of casualties and damages. Some of these are[6]:

(i) a tsunami may consist of several waves with an interval of upto an hour. Therefore, one should stay away until all of them have passed

(ii) an earthquake near the coast is very likely to produce a tsunami and therefore, one should take such an earthquake as a warning of a potential tsunami and should move away from the coasts immediately

(iii) tsunamis are preceded by a noticeable rise or fall in water level, and this may also be considered as a subtle warning of a tsunami on its way

(iv) one should never go down to the beach to watch a tsunami as by the time one sees a wave coming it may be too late to escape.

Concluding remarks

The extent of unpreparedness in India to handle tsunami can be understood from the fact that IS1893 (Part 1[7]) does not even mention tsunamis among the other secondary effects of earthquakes. For instance, Foreword of the code states – "Earthquake can cause damage not only on account of the shaking which results from them but also due to other chain effects like landslides, floods, fires and disruption to communication. It is, therefore, important to take necessary precautions in the siting, planning and design of structures so that they are safe against such secondary effects also". Therefore, in Indian scenario, the solution is not only to develop a warning system, but also to launch a mass awareness campaign. Unless the local governments and the public can effectively react, the warning system may not be effective. Unlike an earthquake mitigation plan where we need to educate only a certain group of people who are directly related to the construction industry and enforce code compliance, in case of tsunamis, we need to educate everyone who is likely to be directly affected in case of any such calamity.

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