Chapter 5

Tsunamis

Introduction: ‘Tsunami’ is a Japanese word, ‘tsu’ means ‘harbor’ and ‘nami’ means ‘wave’. In the Tamil language in India, the word is ‘aazhiperalai’; in the Acehnese language, it is ‘ie beuna or alon buluek’. On Simeulue island of Sumatra in Indonesia in the Defayan language, the word is ‘Smong’, while in the Siqulai language it is ‘emong’. The Greek historian Thucydides suggested in 426 BC that tsunamis were related to submarine earthquakes, but the real research started in the 20th century. As a matter of historical interest, see Fig. 5.1 and 5.2. In the Fig. 5.1 is seen the turmoil of the 1755 Lisbon, Portugal earthquake and tsunamis. In the other figure is seen the Russians of Pavel Lebedev-Lastochkin meeting the Japanese after their ships being tossed inland by a tsunami in the year 1779.

Fig. 5.1 The turmoil of Lisbon earthquake and tsunami in 1755

Fig. 5.2 The distressed Russians meeting the Japanese after a tsunami in 1779

Among the many physical processes such as Earthquakes and volcanoes, Tsunamis also rank the same level as that of earthquakes from the point of view of damage created by it. Looking at the ‘cause and effect formalism’, the effect tsunami is due to the earthquake as the cause. Some authors call tsunami as ‘tidal waves’ even though tides have nothing to do with it and that usage has been discarded by geologists and oceanographers. Different authors give different meanings for tsunamis and I
found, after going through various research papers, a concise meaning for it from an elementary college book titled, “Handy Science Answer Book”.5.1 Tsunami is a giant wave set to motion by a large earthquake occurring in the sea bed and lifting a large volume of water in the vertical direction thus creating a tsunami. The upward lifting of water creates the highest crest of the tsunami wave measuring as high as 50 meter and travels with a speed of about 800 km/hr. The wavelength range from 100 to 300 km. When the wave reaches shallow waters near the shore, the wavelength gets reduced considerably. Earthquakes of magnitude below 6.5 and those that shift the ocean floor horizontally do not produce any dangerous tsunami. A One of the highest recorded tsunami was that along Lituya Bay in Alaska, US on July 9 1958 and had a speed of over 150 km/hr. Another tsunami of recent origin is the one on 26 December 2004 caused by an earthquake (M 9.3) erupted off the western coast of Sumatra. The sea level at the source was lifted to over 10 meter and killed over 200,000 people in 14 countries bordering the Indian Ocean worldwide. Earthquakes, volcanic eruptions, any underwater explosions (including nuclear explosions), landslides, glacier calvings, meteorite impacts and other disturbances above or below water all have the potential to generate a tsunami.

Thus, it is of interest to make some literature review of this dangerous phenomenon which purely geological and natural.

**REVIEW OF LITERATURE**

Derek K. Miller has extensively discussed the tsunami of December 2004 that shook the entire world by surprise. According to the author, tsunamis are more dangerous than earthquakes that generate them. The number of deaths were more as tsunamis do not have a reliable warning system. Tsunami waves have larger wavelengths of the order of about 100 km whereas ordinary sea waves have lengths about 100 meter or sometimes less. The maximum speed of a tsunami is about, say 800 km/hr so that the frequency is about 8 per hour thus making a period of 0.125 hour which is equal to 7.5 minutes. That is to say that in 7.5 minutes each wave will be repeated. Taking a worst case of a wavelength 100 km, a crest of water of sizeable height will appear for a distance of 50 km which is half the wavelength and damaging property and killing people on its way. It takes less than 4 minutes (approximately half the period of 7.5) for a trough to appear.
and will create a no water region on the shore for few seconds or less than a minute before the water of the crest which has gone earlier starts flowing back into the sea to make one feel that the tsunami has gone back. But, this consolation is a short-lived one because after 3 or 4 minutes will appear the monster crest again to repeat the same process. Thus the tsunami oscillates in this manner. I have illustrated the formation of tsunami in Fig. 5.3 a, b and c. The extent of damage will depend on factors such as location of epicenter whether far away from the shore or near the shore and the magnitude of the earthquake.

Ms. Petula Brown, who was enjoying her vacation in Phuket, Thailand when the tsunami hit and she was the first to witness the action of tsunami and she said:

“I am still confused about the water retreating as where we were the water disappeared for 5 or nearly 10 minutes allowing people to wander out to investigate more. Why should this water remain for so long? The first wave was more like a fast rising tide, but the waves to follow were crashing monsters destroying everything on its way. Fortunately, the sleeping rooms in our resort were 105 steps up from the beach. So people were only injured, but no one died.”

A technical page from Tulane University by Dr. Stephen Nelson’s gives the answer for this.

A phenomenon called “Drawback” occurs when the trough of the tsunami first reaches the coast and will make one feel that there is a considerable drop of sea level in that region of the coast. The drawdown is immediately followed by the crest and takes people by surprise and this phenomenon is called “Run-up”. All the three parameters, velocity, period and wavelength of these waves are so large

![Diagram of tsunami formation](image)

(a) A tsunami crest first approaching the shore (Run-up)
(b) The trough following the crest cannot be properly formed because of the land. There is a retreat of initial thrust (Drawback) dragging debris and sucking people into the sea.

(c) The monster crest again appears and the process gets repeated.

Fig. 5.3 Tsunami formation (Picture illustration by author of thesis)

that it may take a long time, sometimes hours for the successive crests to reach the shore. As explained earlier, the first wave may not be the largest, but the following ones may be. One has to wait till all the waves pass and it may take hours for it. Recent studies on tsunamis have indicated that the 1\textsuperscript{st}, 3\textsuperscript{rd} and 5\textsuperscript{th} waves were the largest.

Let us now see the situation when a trough first approaches the shore. This is shown in Fig. 5.4. There is a sudden decrease in water level at the shore. The water starts flowing fast from the shore to the interior something like a major low tide. This is an indication of trough of the tsunami being formed at the shore. This is a good warning sign, but the available time is less. The time will be more for a severe earthquake. It should be noted that the time will be only in terms of minutes and not hours. Local population can prepare themselves to get saved from the hazard and get themselves prepared to face the following monster crest. The low water level observed is a local
phenomenon confined only to the region where tsunami is struck. It is just the trough of the tsunami being formed. It can very well drag debris and suck people into the sea.

For a tsunami to occur, the type of earthquake, its magnitude, the topography of the sea along with the marine geology of the sea are all important. A tsunami wave train moves as ocean swells do, by raising and lowering the water level as it passes by. In the tsunami of 2004, the water that drowned people in Somalia was African water and that in Thailand was Thailand water. The water is carried on and on due to the tremendous energy of the wave comparable to some nuclear explosions. The energy is hardly dissipated but gets decreased when it meets with obstruction on land. Any after-quake tremor adds to the energy. A tsunami in the mid ocean will take a long time for the water level to rise. Many of the tsunamis occur in Japan because of its seismic vulnerability and the entire country consisting of islands surrounded by water. Mild earthquakes of magnitude 4 or less are common in Japan and the resulting tsunamis from them are not severe. Such tsunamis are called local or regional tsunamis. Those tsunamis which are ferocious in their behavior of damaging property and deaths have been rightly called as mega tsunamis. Sometimes due to low atmospheric pressure and depressions that cause tropical cyclones, create a storm surge create tides much higher than the usual high tides and resemble tsunamis. Such tsunamis are called Meteotsunamis.

George Pararas-Carayannis has given a historical summary of early tsunami research in the United States. The research started in the University of Hawaii as early as 1946 after the end of Second World War. What prompted the Americans to open a
research center was the damage and deaths occurred in the tsunami that struck Hawaii on 1 April 1946. They have established a Pacific tsunami Warning Center (PTWC) at Honolulu, Hawaii.

The author has dealt with some formula to find out the intensity and magnitude for a tsunami. The intensity, I is expressed as the sum of a pure number $\frac{1}{2}$ and another term with the logarithm to the base 2 of the average wave height, $H_{av}$. That is,

$$ I = \frac{1}{2} + \log_2 H_{av} $$

This scale is known as the Soloviev-mamura Tsunami intensity scale.

Now, coming to magnitudes, there is a scale proposed by Murty and Loomis known as the ML Scale and based on the potential energy. As there were difficulties in calculating the potential energy of a tsunami, this scale is discarded. Abe took into consideration the maximum tsunami amplitude, $h$ expressed in meters and measured by a tide gauge at a distance $R$ from the epicenter. If $M_t$ is the magnitude scale, then

$$ M_t = a \log h + b \log R = D $$

where $a$, $b$ and $D$ are constants.

In the research paper by Hock Lye Koh, et al. have mentioned that an active research has been initiated in the Universiti Sains Malaysia (USM) immediately after the infamous and deadly earthquake of the 2004 Banda Aceh and the ensuing Andaman mega tsunami that killed over 200,000 people. The authors have developed Disaster Research Nexus (DRN) in their School of Civil Engineering of the University in order to conduct active collaborative research in the subject including landslides. A tsunami simulation model called TUNA is applied to the 2004 tsunami. They have also discussed the role of mangroves in the control of disaster. The main aim of DRN is to create awareness and implementation both nationally and internationally regarding hazards, prediction, preparedness and mitigation leading to effective emergency management programs pertaining to all disasters in general and earthquakes and tsunamis in particular. The details arrived at by the authors regarding the deadly tsunami of 2004 is given below:

Date: 26 December 2004
Time: 00:58:53 UTC (08:58:53 Malaysian time)
Location: Western coast of Banda Aceh, North Sumatra
Water lifted at the source by: 12 meters
Quantity of water lifted upwards: 200 trillion tons
Magnitude: 9.3
Direction: Initial tsunami wave split in two fronts; one moving eastwards towards
Malaysia and Thailand while the second towards Sri Lanka and India.

A mathematical treatment (Credit: 5.4) for tsunami is based on Shallow Water
Equations (SWE) which are depth averaged and subject to conservation of mass and
momentum. They are:

\[
\frac{\partial \eta}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0 \quad \ldots (1)
\]

\[
\frac{\partial M}{\partial x} + \frac{\partial}{\partial x} \left( \frac{M^2}{D} \right) + \frac{\partial}{\partial y} \left( \frac{MN}{D} \right) + gD \left( \frac{\partial \eta}{\partial x} \right) + \left( \frac{gn^2}{D^{7/3}} \right) M \left[ (M^2 + N^2) \right]^{1/2} = 0 \quad \ldots (2)
\]

*Spelling used by authors in more than one place.*
\[
\frac{\partial N}{\partial t} + \frac{\partial}{\partial x} \left( MN \frac{D}{D} \right) + \frac{\partial}{\partial y} \left( \frac{N^2}{D} \right) + gD \left( \frac{\partial \eta}{\partial x} \right) + \left( \frac{gn^2}{D^{7/3}} \right) N \left[ \left( M^2 + N^2 \right)^{1/2} \right] = 0 \quad \ldots (3)
\]

where M and N are the volume flux per unit length in the x and y directions respectively; They are related to the depth averaged velocities by the relations, 

\[M = u (h + \eta) = uD\]

and \[N = v (h + \eta) = vD\], where h is the mean sea depth and \(\eta\) is the water elevation, D is the total water depth and g the acceleration due to gravity.

**Mitigation:** What protective measures are to be taken from earthquakes, almost the same measures are to be taken for the tsunamis. In the case of tsunamis, it is the danger of water and people facing death suddenly by sinking. In earthquake prone countries which are islands like Japan, walls of height about 5 meter are built along the coast. In some localities, they have built floodgates and channels to redirect the water from the incoming tsunamis.

Authors have discussed the mitigation and protective measures from the tsunamis by planting mangroves and other vegetation throughout the coast. A numerical simulation model developed within the framework of TUNA, the continuity and momentum equations in flux forms in the x-direction are expressed by the following equations:

\[
\frac{\partial \eta}{\partial t} + \frac{\partial M}{\partial x} = 0 \quad \ldots (4)
\]

\[
\frac{\partial M}{\partial t} + \frac{\partial}{\partial x} \left( \frac{M^2}{D} \right) + gD \left( \frac{\partial \eta}{\partial x} \right) + \frac{gn^2 \left| M \right|}{D^{7/3}} + \frac{C_D}{2} A_0 \left( \frac{M|M|}{D^2} \right) + C_M \left( \frac{V_0}{V} \right) \left( \frac{\partial M}{\partial t} \right) = 0 \quad \ldots (5)
\]

and the drag coefficient is,

\[
C_D = 8.4 \left( \frac{V_0}{V} \right) + 0.66 \left[ 0.01 \leq \left( \frac{V_0}{V} \right) \leq 0.07 \right] \quad \ldots (6)
\]

The various quantities in the above equations are:

- \(M\) → Flow flux in m\(^2\)/s,
- \(D\) → Total water depth = (h + \(\eta\)) in m
- \(h\) → Still water depth in m
- \(n\) → Manning coefficient
- \(g\) → Acceleration due to gravity in m/s\(^2\)
- \(C_D\) → Drag coefficient
- \(A_0\) → Area of trees under water surface per 100 m\(^2\)
\[ V_0 \rightarrow \text{Total volume of tree under water surface in } m^3 \]
\[ V \rightarrow \text{Control volume in } m^3 \]
\[ C_M \rightarrow \text{Inertia coefficient} \]

The last term in equation (5) is the mangrove friction term. The inertia coefficient \( C_M \) is worked out and found to be 1.7 and the non-linear shallow water equations (4) and (5) are solved by method of finite differences.

The situations when the wave approaches a mangrove obstacle are shown in Fig. 5.5. As the wave approaches initially at the mangrove, there is a slight increase in amplitude (Fig. a). The flow from back gets added and the amplitude further increases to larger heights (Fig. b). The flow then retards with almost horizontal wavelets (Fig. c).

![Direction of wave →](image)

(a) Wave just approaching a forest of mangroves  
(b) Amplitude increases  
(c) Water starts receding

**Fig. 5.5 Situations when a tsunami wave approaches a forest of mangroves**

**Warnings and Predictions:**
Looking upon the damage and deaths created by tsunamis, it becomes necessary for the government and rulers of the land by issuing warnings and predictions at appropriate times. The extent of damage can be seen from the Fig. 5.6 which shows the devastation done by Tsunamis from the 1964 Alaskan earthquake. The picture shows the bay at Seward with an overturned ship, a demolished truck and torn-up dock strewn with logs and scrap metal attest to the power.

![Fig. 5.6 The extent of damage done by the 1964 tsunami of the Alaskan earthquake](image)
of wave. A section of the waterfront slid into the bay. Waves spread in all directions destroying rail road docks washing out rail, road and highway bridges.

The flaming petroleum spread over water igniting homes and an electrical generation plant. In Fig. 5.7 is shown a fraction of the extent of damage done by the earthquake and ensuing Tsunami of 11 March 2011. One can see a large number of vehicles mutually toppled over each other.

A tsunami cannot be precisely predicted, even if the magnitude and location of the earthquake is known. Geologists, oceanographers and seismologists analyze each earthquake and based on their findings may issue or may not issue a warning. In most of the earthquake and tsunami-prone countries there are warning signs of an approaching tsunami. In a country like Japan, the people are so accustomed that even if an earthquake erupts on land, the people living in coastal areas start looking at the sea thinking that some tsunami might follow. In Fig. 5.9 is shown a deep water buoy used in the tsunami warning system. The principle is that bottom pressure sensors attached to the buoys, constantly monitor the pressure of the overlying water column.

To put things in a nutshell, Times of India, Mumbai (Date unrecorded) has given a comprehensive illustration which is self explanatory regarding the March 2011 Japanese tsunami under the title, "Makings of a Tsunami" and the same is shown in Fig. 5.8.

In Fig. 5.10 a, b, c, d, e and f (All picture Credits: 5.3) are shown some of the tsunami warning signs along with some monuments. The pictures being small, some of the
writings are not very clear. In some are mentioned the escape routes. Sirens are also fitted on hill tops.

**Use of Computers:** The arrival of an incoming tsunami can be predicted with the help of computers. Bottom pressure sensors relay information in real time. Based on the pressure readings, the seismic information, the shape of the sea shore and the coastal topography, the computer models can estimate the amplitude and surge height of an approaching tsunami. The prediction can be done within minutes.
MAKINGS OF A TSUNAMI

Tsunamis and earthquakes happen after centuries of energy build up within the earth. Here is a look at the forces behind the destruction.

Pieces of Puzzle
The earth has four major layers. The brittle, breakable crust is where most earthquakes originate. Some also occur in upper mantle.

Lithosphere: Includes crust and part of the upper mantle. Broken into pieces, called tectonic plates, that constantly move.

Asthenosphere: Semi-liquid layer of the mantle that tectonic plates rest on, allowing them to move around.

Ring of Fire: Where about 90% of the world's earthquakes occur.

How Tsunamis Occur
1. As one plate subducts below another, pressure builds after many years, resulting in a section of the megathrust giving way.
2. This section gives way, it ruptures the ocean floor, resulting in a massive displacement.
3. Tsunamis are barely felt as a ripple on the ocean surface but as the wave reaches land, they increase in size as the water becomes shallower.

Earthquake Deformation
1. Earthquake occurs as plates snap...
2. ...resulting in tsunami.
3. High stress.

Shocking Waves
During earthquake, energy goes in all directions as seismic waves cause earth to shake.

P waves: A sound wave that travels through inner layers shaking things in same direction.

S waves: More damaging than P waves move through inner layers thrusting up.

Wave crest grows as it reaches land due to shallowing water.

Wakasa
Subayu
Pacific
Ocean
Waves in ocean

Rupture displaces water

JAPAN

North American Plate
Pacific Plate
Pacific Ocean
Direction of Force
As I am writing this part of the thesis, I just happened to put a glance over today’s (Monday, 2 April 2012) Times of India, Mumbai and on page 16 I found a small news item titled “Japan warns of future risk of 112 feet high Tsunami” and the same
reported from Tokyo. As an end to this chapter, this news item is of importance and hence, I am producing the same in italics below:

“Tokyo:- “A 34 metre (112 feet) tsunami could hit the Japanese coast in the wake of a massive earthquake, an expert panel has said after revising its worst case scenario projections following last year’s disaster.

If a 9.0 magnitude quake struck in the Nankai Trough off central to western Japan huge swathes of Pacific coastline could be inundated, with over 20 metre waves hitting areas from Tokyo to the south-western island of Kyushu.

At the town of Kuroshio in south-western Kochi prefecture the tsunami could reach 34.4 metres - the highest level projected under the scenario, the cabinet office panel said late on Saturday (31 March 2012).

And at the now offline Hamaoka nuclear plant in central Shizuoka prefecture, the tsunami could be as high as 21 metres, breaching the 18-metre breakwater that operators are currently constructing, the panel said. In its previous projection in 2003 the panel gave a worst case scenario in which no areas would be hit by a tsunami of more than 20 metres. But the panel has upgraded its predictions in the wake of the 9.0 magnitude earthquake on March 11 last year (2011) that sent a tsunami barreling into the north-east, killing some 19,000 people and devastating the coastline.

The panel said that it will continue studying the extent of areas that could be hit by a tsunami, while the government will examine the emergency disaster measures based on the latest estimation.” AFP.

Conclusion:- Oh! What a great physical process the almighty has created. Danger to property and death to millions! Being a process beyond control and no existing prevention, it is the work of mankind to prepare themselves not to get affected by the fury of the process. The implied meaning being that one has to fight against nature. A Herculian task indeed!

In what way an earthquake is disastrous, in the same manner a tsunami is equally disastrous. In fact, the latter is little more as the energy is carried by water waves affecting the coastal areas of other countries. The disaster from an earthquake may be confined to areas in the land surrounding the epicenter. Prediction of a tsunami can be almost the same as that of an earthquake in a restricted sense because the epicenter being under the sea bed, special instruments are required for detection of signals.
Hence mitigation is the only solution. Only try to reduce the damage caused by it. In Japan at many places in the coastal areas are built walls of height about 5 meters in order to protect populated coastal areas. In some places flood gates have been built and channels to redirect the water from the incoming tsunami. But, such things are of not much use. For example, the 12 July 1993 earthquake that struck Okushiri of Hokkaido in Japan generated a tsunami of height about 30 meters almost the height of a 10 storey building.

Planting mangroves as mentioned in the literature review of this chapter throughout the coastal areas is a good proposition. What is needed is to weaken the initial thrust of the tsunami. The danger will be more if the crest of the tsunami first reaches the shore. On the contrary, when a trough approaches first, it gives sufficient time for preparation for the people to protect themselves. The protection can be done by not only planting mangroves but even by thick forestation of the coastal areas. People want to enjoy the good breeze of the beach and stay in hotels and resorts facing the sea. Why not to build them few kms, away from the shore? Start a good town planning right now or earliest the better. As there is no prevention, the cure has to be highly effective. One can think of some rock structures of sufficient height which are of just monumental value and not any residential put up throughout the coastal areas. Let the tsunami come and clean those structures. The population should be few kms. away from the shore. The farthest the better. If we start now, the success will be at least after a quarter century and beneficial for the future generation. How many people will agree with my proposition has to be seen only after going through this chapter of my thesis.

Let us be blessed with methods to control this deadly divine weapon.

REFERENCES:


[7] 5.7 The Times of India, Mumbai (Date unrecorded).

[8] 5.8 The Times of India, Mumbai dated 2 April 2012.