Original Article

International Journal of Ocean and Climate Systems

Environmental management and emergency preparedness plan for Tsunami disaster along Indian coast

The International Journal of Ocean and Climate Systems
2017, Vol. 8(3) 144–152
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DOI: 10.1177/1759313117708253
journals.sagepub.com/home/ocs
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Abstract

The 26 December 2004 Tsunami generated by the submarine earthquake in Andaman Sea with the magnitude of 9.2 Richter scale triggered the worst destruction, widespread inundation and extensive damage in terms of life and property along the Tamil Nadu coast and Andaman Nicobar Group of Islands. The shoreline features like dunes, vegetation and steepness of beaches played vital role in attenuating the impact of Tsunami from destruction. While the low-level Marina beach experienced minimum inundation, the coast between Adyar and Cooum was inundated heavily. As the present generation of India was not aware of Tsunami, the emergency plan and preparedness were zero and so the loss of human life was huge. In this article, the authors describe the Tsunami occurred in India on 26 December 2004 and its impacts on morphology. The appropriate Emergency Preparedness plan and the Disaster Management Plan in case of reoccurrence of such natural disaster are discussed.

Keywords

Tsunami, Indian coast, Andaman plate, early warning system, disaster management

Date received: 30 January 2017; accepted: 12 April 2017

Introduction

Tsunami is a series of long period gravity waves generated by undersea earthquakes, landslides, volcanic eruptions or meteorite impacts. The history shows that at an average two Tsunamis occur every year in the globe causing huge damage to the people and properties along the coast. Among them the most destructive Tsunamis occur once in 15 years causing colossal damage to the coasts. While most of the Tsunamis keep frequently occurring in the Pacific Ocean, their occurrence in the Indian Ocean is found to be less. The statistical estimate indicates that an average of eight Tsunamis occur every year in the Pacific Ocean, whereas one Tsunami occurs every 3 years in the Indian Ocean (Loughlin and Lander, 2003). The Tsunamis generated in Indian Ocean are mostly getting directed to the coasts of Indonesia, Malaysia, Thailand, Myanmar, Sri Lanka and India. Although there is no record available on Tsunami, the indication is that the frequency of Tsunami in Bay of Bengal reaching Indian coast is close to once in 500 years. The legendary Tamil Epics *Silapathigaram* cites the total devastation of sea side citadels at Poompuhar along the southeastern part of the Indian coast during 2nd century. The earliest Tsunami first recorded along the Indian coast was on 31 December 1881 due to an earthquake measuring Mw = 7.9 near Car Nicobar Island (Murthy and Bapat, 1999). The latest Tsunami which made visually experienced by the present generation had occurred on 26 December 2004, Sunday at 00:58:53 GMT (7:58:53 a.m. Indian Time) at the epicenter latitude 3.32°N, longitude 95.85°E with Mw = 9.2 (Murty et al., 2007). Ioualalen et al. (2007) described it as the third largest earthquake ever recorded. Car Nicobar Islands and the Tamil Nadu coast were severely affected in the Indian Ocean region

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Table 1. History of Tsunamis along the coastal regions bordering the Indian Ocean.

Year	Epicenter of earthquake	Magnitude	Coastline affected
1797	Western Sumatra	8.4	Padang
1833	Western Sumatra	8.7	Southern part of Sumatra
1861	Western Sumatra	8.5	Coastal regions of Sumatra
1881	Andaman Island	7.9	East coast of India
1883	Krakatau volcano	–	2 m Tsunami at Chennai
1941	Andaman Islands	7.7	Anecdotal accounts exist
1945	South of Karachi	8.5	12 m Tsunami at Kandla
2004	Northern coast of Sumatra	9.2	Coastal regions of Southeast Asian countries
2005	East of Andaman Islands	8.7	Andaman Islands

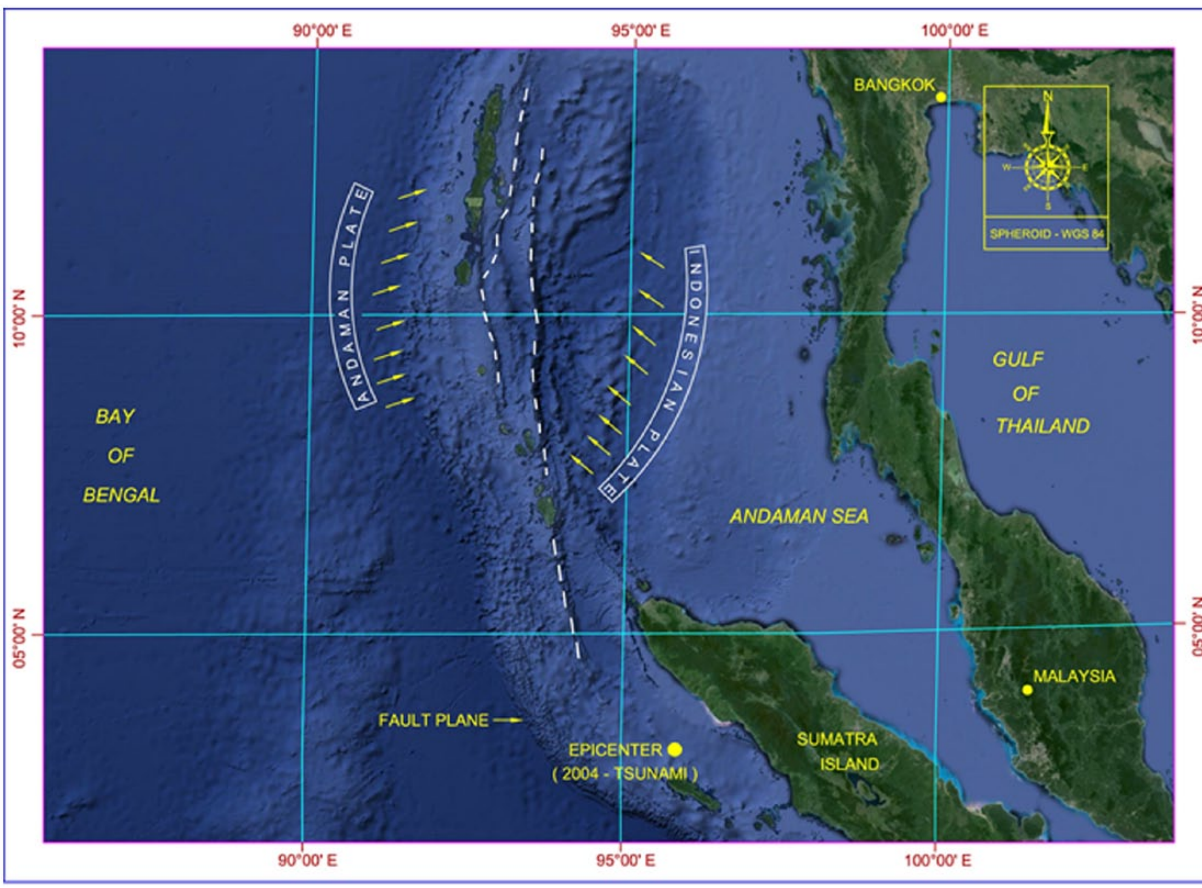

Figure 1. Movement of tectonic plates.

(Chadha et al., 2005; Jayakumar et al., 2005; Ramana Murthy et al., 2005; Yeh et al., 2005, 2006).

Tsunami occurred in the year 2004

Major Tsunami occurred in the past 200 years along the coastal regions of various countries bordering the Indian Ocean, which are given in Table 1.

The earthquake of 26 December 2004 had occurred at the interface between the Indian and Burma Plates. The Burma plate is characterized by significant strain partitioning due to oblique convergence of the India and Australia plates to the west and the Sunda and Eurasian plates to the east (Figure 1). It is a typical oceanic-oceanic convergent plate boundary where the Indian plate moving relative to the Burma plate came together, collided and sunk under the Burma plate. This subsidence of the large plate leads to a giant earthquake with a magnitude of 9.2 Richter scale which ruptured the greatest fault length of other recorded earthquake. The Tsunami was then generated by a sudden vertical displacement of seawater near the subduction zone of Andaman–Sumatra trench.

While the Tsunami wave approaches from the deep water to the shallow water, the velocity of propagation would reduce, say from 700 km/h at 4000 m depth to 25 km/h at 5 m depth. Also, the wave-induced water particle velocity would increase rapidly from 0.02 m/s at 4000 m depth to 3.5 m/s at 5 m depth. The Tsunami wave height will increase manifold and finally surge on the coast with devastating power. Witham (1974) has presented in detail the hydrodynamics of the Tsunami waves and Hammack and Segur (1978) addressed the applicability of long Tsunami waves in different water depths.

Impact on Andaman and Nicobar Islands

Tsunami waves first hit the Car Nicobar group of islands at 07:25 a.m. of Indian Standard Time on 26 December 2004. The southeastern part of the islands faced more fury of the Tsunami waves and the magnitude of Tsunami runup varied at different locations depending upon the local coastal morphology. The Nicobar group of islands, namely, Great Nicobar, Katchall, Teressa, Nancowry, Trinkat, Car Nicobar and so on, were severely affected as they are closer to the subduction zone and also smaller in size surrounded by the seas all around. Since the settlements in South Andaman Island are largely confined within sheltered areas like bays of on the elevated hilly regions, there were minimal loss of life, but damage to properties especially to fishing vessels was considerable.

Impact on Tamil Nadu coast

The elevation of beaches and presence of sand dunes are the major controlling factors for the extent of Tsunami intrusion and damage caused by the waves.

Between Ennore and Pulicat. Observations made along the north Chennai coast indicated that the water level at Ennore creek raised by a maximum of 5 m and water excursed upto 300 m at the adjoining coast. Tsunami in one way benefited the Pulicat Lake by widening its mouth, and except a beach hamlet, it was least affected due to the presence of sand dunes. This stretch is marked by open coastline present with sandy beaches. Buckingham canal and Kosasthalaiyar River are running parallel to shoreline at 1 km inside inland. The presence of fishing hamlets and inhabitation are relatively less. The appropriate method to protect this stretch against Tsunami devastation is constructing a soft form of the Tsunami mounds (TM) using sand at 200 m distance behind high tide line and planting rows of Casuarinas immediately after the TM.

Chennai coast. Marina beach, a few centimeters above mean sea level, experienced maximum inundation.

Figure 2. Chennai Marina beach – Tsunami runup.

About 1.8 km^2 of coastal area between Adyar and Cooum rivers along Chennai coast was totally inundated. The seawater intruded upto 590 m at Foreshore estate (Adyar river side) and 480 m at MGR memorial (Cooum River side) with a narrow excursion of 290 m at mid stretch. The series of Tsunami waves had a positive effect on Adyar and Cooum rivers, which are sewage carriers, whose mouths are closed for most part of the year due to sand accretion, got opened temporarily, due to which these heavily polluted waters with sludge were flushed out to a great extent which might be having significant impact on the water quality and biota of adjoining coastal environment. This segment of the coastal stretch is highly developed and forms as the nucleus of urban development. The huge buildings and roads border the coastline in 100–300 m inward from the high tide line. In order to protect this urbanized coastal stretch from Tsunami impact, some stretches are having enough width to build TM, but major stretch needs to be built with hard intervention of construction of concrete sea wall (Figure 3).

Chennai to Mahabalipuram. The preliminary results indicated that the southern Chennai upto Mahabalipuram along the east coast road has not been affected much due to wide and elevated dunes and the maximum inundation is seen upto 250 m. The presence of sand dunes and plantations at most of the locations played a vital role in protection of coastal villages in this area. However, the Kalpakkam stretch where the nuclear plant is located experienced larger inundation as the terrain remains flat and narrow with Buckingham canal running close to coastline. In order to protect from future Tsunami impact, the existing dunes can be further strengthened by building up high with available sand at backshore.

The recovery process from the impact of Tsunami started after 1 month and it took about an year for the beach to gain 90% of the original profile. The deposition of sediments at nearshore remained for about 5 years and the seafloor attained a different stable profile thereafter. The excess siltation and scouring in different river mouths remained as it is forever.

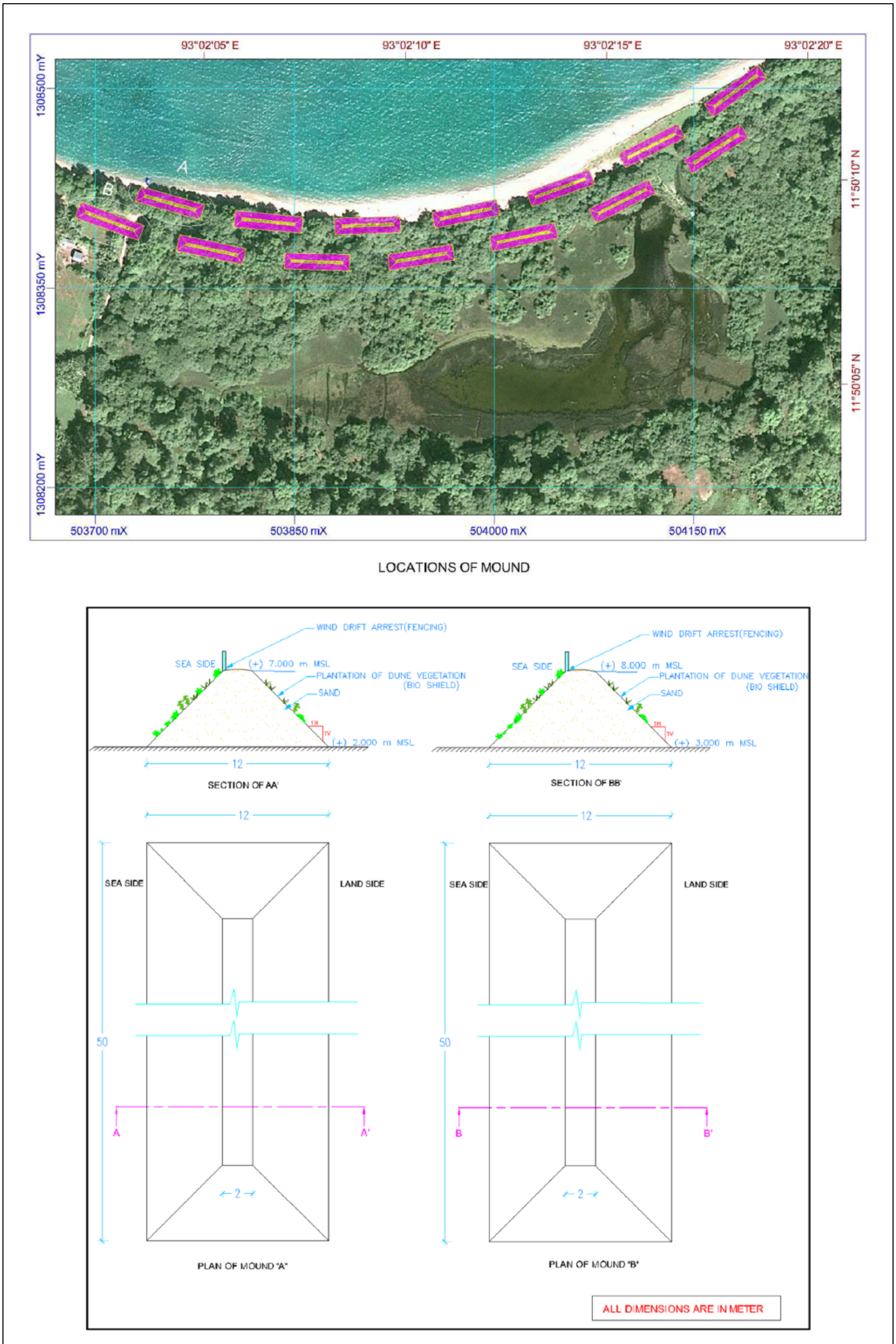

Figure 3. Design of Tsunami Mound.

Table 2. Inundation and runup during 2004 Tsunami.

S. no	Station	Position		Inundation (m)	Runup (m)
		Latitude (°N)	Longitude (°E)		
1	Arukattuthurai	10°23′30.51″	79°52′07.14″	390	3.8
2	Velankanni	10°40′48.68″	79°51′02.22″	320	4.0
3	Nagore	10°48′47.52″	79°51′04.38″	880	3.3
4	Karaikal	10°54′50.03″	79°51′08.04″	200	2.8
5	Velangirayan	11°32′15.04″	79°45′44.07″	080	4.2
6	Reddiar Pettai	11°34′34.00″	79°45′28.06″	170	4.4
7	Nanjalingampettai	11°36′45.03″	79°45′34.08″	380	3.8
8	Thevanampattinam	11°44′40.00″	79°47′18.09″	380	4.0
9	Pudu Kuppam	11°52′03.00″	79°49′09.36″	120	4.0
10	Periyakalapet	12°01′40.08″	79°52′02.52″	370	6.0
11	Nochi Kuppam	12°05′08.46″	79°53′55.01″	250	6.7
12	Ekkiar Kuppam	12°10′49.00″	79°57′37.03″	300	3.9
13	Kottai Kadu Kuppam	12°14′42.00″	79°58′59.04″	060	4.7
14	Alambarai Kuppam	12°16′04.92″	80°00′55.02″	230	2.5
15	Sadarangapattinam	12°31′22.09″	80°09′56.28″	270	6.0
16	Mahabalipuram	12°36′55.05″	80°11′56.08″	385	5.5
17	Kovalam	12°47′19.09″	80°15′16.02″	120	5.5
18	Urur Alcott Kuppam	13°00′35.28″	80°16′34.05″	510	5.2
19	Krishnapatnam	14°15′00.00″	80°08′16.56″	200	2.5

Source: Jayakumar et al. (2005).

The extent of Tsunami runup elsewhere in Tamil Nadu coast has been reported by Jayakumar et al. (2005). The runup heights with inundations are presented in Table 2.

Environmental management plan

The post-Tsunami survey made between Chennai and Nagapattinam was found to have variable results in terms of marine water quality, microbiology, plankton and benthos. Impact of Tsunami had altered the mouth of all storm drains, estuaries and backwaters. The sudden entry of Tsunami waters into mouth of the rivers resulted in the release of more total nitrogen.

Although the impact of Tsunami is disastrous, the impact is seen getting minimized by adopting the key components of environmental management plans. It was noticed that the places located behind the highly elevated dunes, casuarinas, dense vegetation, mangrove forests, offshore coral reefs and salt pan heaps were considerably protected. Such areas experienced low damage and people remained safe. The kinetic energy of the Tsunami waves get dissipated while riding into such natural barriers. Thus in a way the nature gives the scientific understanding of preparing the energy dissipation plan needed on the shore leading to better environmental management plan to protect the people and properties against Tsunami.

While the action on environmental management plan varies according to the local condition, in general, the following measures are quite applicable:

- Provision of Bio Shield (BS);
- Construction of Tsunami Mound (TM);
- Emergency Tsunami Rescue Shelter (ETRS).

Provision of BS

It is witnessed that the natural formations like coral reefs (Gulf of Mannar), offshore sandbars (Manappad), submerged reefs (Thiruchendur), sea grass beds (Palk Bay), coastal vegetation such as mangroves (Pichavaram), estuaries and deltas of river mouths and flood plains play an important role in dissipating the forces of Tsunami waves. A ‘bio-shield’ formed by planting a vegetation belt along coastlines would protect the region against coastal storms, cyclones and Tsunamis. It could also act as a *carbon sink* by absorbing emissions of the greenhouse gas. The coastal vegetation also has a very important role in stabilizing and trapping marine sediments and forming a protective buffer between the land and the sea. Although various options are available in the form of construction of TM and Tsunami Shelters, the development of BSs is extremely effective and environmental friendly for offering protection. During the 2004 Tsunami, a 12-km-long coastal stretch between Killai and Pazhayar in Tamil Nadu remained totally protected due to the presence of Pichavaram Mangrove forest. All people of the fishing villages lived in this region remained totally safe amid the colossal loss of life took place on either side of the stretch.

Artificial plantation of corals. Zoological Survey of India (ZSI) has carried out project on artificial implantation of corals in the sea. The growth of corals will act as a good offshore barrier against Tsunami waves.

Mangroves. Mangroves are often recognized as the best defences against wind and wave-induced erosion by deflecting and absorbing much of the energy. The State Forest Departments encourage afforestation of Mangroves. Because of the massive mangrove plantation programme initiated by the State, the fishing hamlets located on the leeward side of the Pichavaram were totally safe without any traces of Tsunami.

Planting of Casuarinas. Casuarina equisetifolia is the most popular farm forestry trees along the coastal stretches in India. The Casuarinas planted in places like Bhitarkanika in Odisha State had totally offered protection against the devasting Cyclone in October 1999. Planting Casuarinas along the coastal front would provide significant protection to the project region from the impacts of Tsunami as well as storm surge.

Planting other vegetation. Transplanting of vegetation may not totally prevent the impact, but it will accelerate the natural recovery after damage. Thatching and beach recycling will assist in the accretion of sand and will provide considerable protection from Tsunami waves.

TM

One of the natural methods of protecting the shore from the natural disasters like Tsunami and also from storm surge is to construct TM which will effectively help to dissipate the energy of Tsunami surge and protect the leeward side. A typical construction can consist of sand Mounds built in two rows: first row beyond the monsoon High Tide Line and the second row at about 100 m behind the first row in zigzag manner. The typical design showing its height, width, spacing between mounds, orientation and layout is shown in Figure 3. The top crest level of the mound can be raised to (+) 5 m to (+) 8 m above the prevailing ground level according to the locations. The spacing between the first row and second row of mounds can be 100 m. Each mound shall be 50 m long and 12 m wide at base. The spacing between the mounds along the row can be 25 m.

The mounds can be constructed with beach sand or any inland native sediments/rocks. The mounds should be erected without felling trees if they exist in this region. It is very important that the TM are constructed in a way that will not affect the existing trees along the coastal front. The faces of the TM can be planted with dune creeper like *Ipomea pes-caprae, Avicennia* sp. Also, Casuarina trees can be planted in between and within the mounds. Coconut trees can also be planted which will add protection against Tsunami. Planting the dune creeper is very essential to minimize the wind drift of the sand from the mounds. The presence of such mounds will not hamper the movement of people between inland and sea. It also adds beauty to the beach. Normally, construction of TM is attempted globally with soft form using natural sand and boulders. But at some places hard form using rubble mound seawalls and artificial concrete seawalls are implemented. While the soft measures are more suitable without causing any damage to the environment, the hard measures are expected to cause problem by affecting the adjacent coastline in the event of waterline reaching the structures.

ETRS

The warning and disaster evacuation system is the most important element in ensuring the public safety. Suitable shelter must be constructed similar to Cyclone Shelters constructed in main land in order to evacuate the people in case of Tsunami warning. The arrival of Tsunami after receiving warning provides only a limited time for people to move safely to ETRS. Evacuation time is calculated using the distance to the safety zone and the speed of the evacuees. Great care must be taken in the selection of evacuation sites and routes. The location of the shelter must be chosen such that it is easily accessible. The ETRS should also have access for the public living in the vicinity. The location of the shelter should be such that it can be reached within 5 minutes after the alarm/warning. They must be located at the vantage points and the number of ETRS should be planned according to the location and number of people. Maintenance of these ETRS and the access roads and keeping them in good condition throughout the year to its functional requirements is very important. Narrow or dangerous points along routes that could present obstacles during an evacuation must be avoided. The time required to evacuate is set at human walking speed. For the sake of safety, this speed can be adjusted to the pace of the elderly or physically challenged. Necessary mobilizing tools and equipments should be kept ready in order to evacuate aged people, children, physically challenged and pregnant women.

The ETRS should be equipped with water supply, toilets, first aid centre, generators, ration storing rooms and minimum cooking facility. A typical layout of ETRS is shown in Figure 4. The ETRS should be designed to bear the load of minimum 200 people. The stairway should be wide enough (>3 m) for the rushing people to climb the top without confusion and struggle. It should have an elevated handrail with proper light and ventilation. There should not be any windows on the seaward side to avoid the entry of water due to rising Tsunami wave. But enough windows and other ventilation measures must be provided on the leeward side of ETRS. The availability of safety

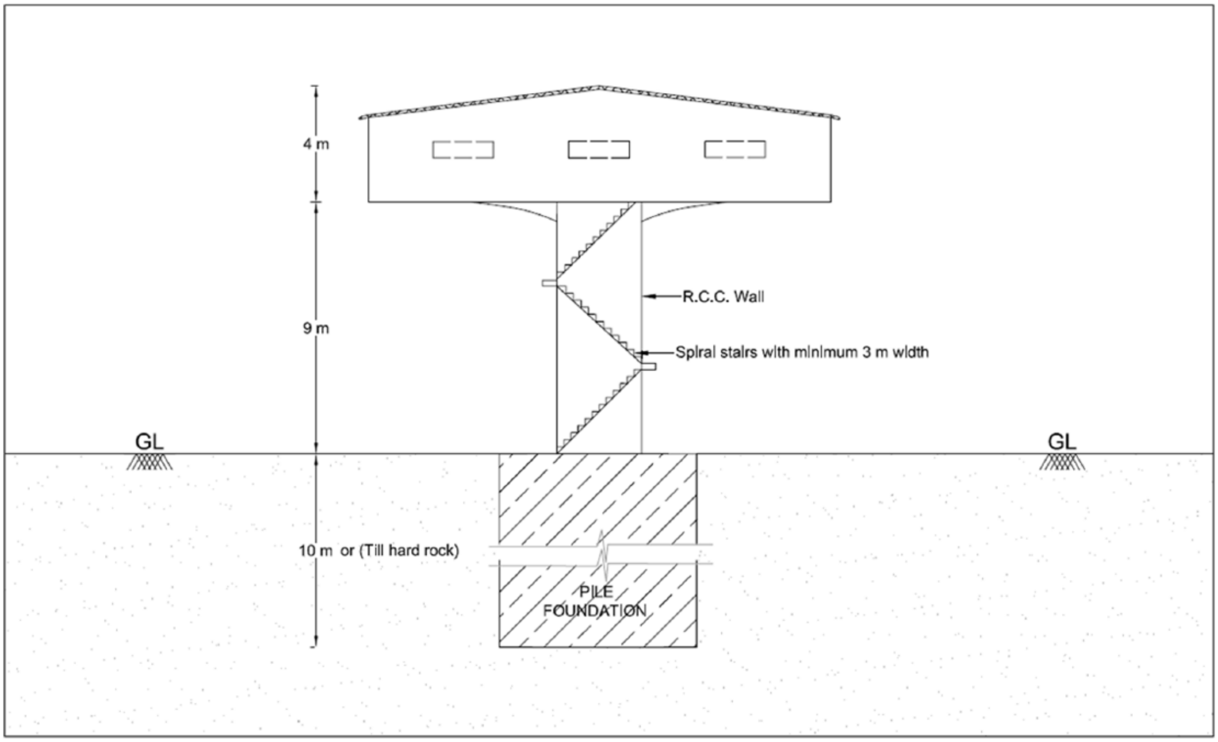

Figure 4. Conceptual layout of Emergency Tsunami Rescue Shelter (ETRS).

zones that can be used as evacuation sites within walking distance must be inspected. People can be evacuated to hills over 10 m in elevation or the deep inland (>1000 m) out of coastal inundation. Roads can be laid along the escape route to the safer place.

Strenthening of existing cyclone shelter

Large numbers of cyclone shelters are built along the Indian coast and their numbers are more along the east coast of India. Tamil Nadu has added recently 29 cyclone shelters along nine coastal districts (Nandakumar, 2015). They are being used as community centre during non-cyclonic periods. These cyclone shelters can be strengthened and expanded to use as Tsunami shelter.

Emergency alarm from Government Institutions

An understanding has to be made with National Institute of Ocean Technology/Indian National Centre for Ocean Information Service/National Disaster Management Authority (NIOT/INCOIS/NDMA) and a communication link should be established between region to be protected and the national institutions through satellite or GPRS. In case of emergency if warning is given at the above-mentioned institutions, they can instantly activate the alarm and give caution to the vigilant team through satellite/GPRS so that they can immediately start the rescue operation. Also, the Government has to make arrangements with mobile operators to send warning SMS instantly to all users about the foreseen Tsunami prediction.

Emergency preparedness plan

The damages and loss due to Tsunami can be minimized if appropriate preparedness plan is formulated. The following statutory guidelines are recommended by NDMA to minimize the impact due to Tsunami:

- Developing sand dunes along the coast with sea weeds or shrubs or casuarinas for stabilization of the sand dunes (Tsunami Mound);
- Raising the ground level (above the design water level) with natural beach sand so as to rehabilitate the coastal region;
- Development of coastal forest (green belt) by planting casuarinas and coconut trees along the coastline to cover minimum of about 500 m width of the beach;
- Adopting natural beach nourishment to create steep beach face;
- Creation of sandy ramps at close intervals along the coast.

The emergency preparedness plan shall contain details about: (a) warning that should be given, (b) protective measures to contain the effect the Tsunami and (c) precautionary measures to be taken. The key aspects in preparedness plan are as follows:

- Coordination with international and national agencies;
- Vigilant on Tsunami warning;
- Emergency evacuation.

Coordination with international and national agencies

International. Following a series of Tsunamis that hit Japan and North America, an international Tsunami warning network was put in place in 1960s in regions around the Pacific Ocean. This network is administered by National Oceanic and Atmospheric Administration (NOAA), USA. NOAA comprises hundreds of seismic stations worldwide, which can detect earthquakes that are precursors to Tsunami. This network also includes coastal tide gauges that detect local changes in sea level and sophisticated DART buoys (Deep Sea Assessment and Reporting of Tsunamis buoys) in the Pacific basin. DART was introduced in 2003 and this system consists of a pressure sensor anchored to the seafloor and a surface transmitter. When potentially dangerous seismic activity is detected, the network of DART buoys will detect the small change in the sea level and the data are transmitted acoustically to the surface buoys and relayed by satellites to the warning stations. Computer modelling converts the data into a prediction of potential damages for the use of the members of the network.

National. In India, after the 2004 Tsunami, the following organizations are involved on watch and cautioning the government and public in the event of possibility of occurrence of Tsunami. As a part of Tsunami hazard mitigation, warning systems have been established in India by the coordination of the following organizations:

- INCOIS, Hyderabad (www.incois.gov.in);
- NDMA, New Delhi (www.ndma.gov.in);
- Indian Meteorological Department (IMD), New Delhi (www.imd.gov.in);
- NIOT, Chennai (www.niot.res.in);
- Andaman Nicobar Administration (webmaster.and&nic.in).

Conclusion

Studies on Tsunami received special attention during International Decade for Natural Disaster Reduction (IDNDR) and revealed many interesting results. The studies also resolved many unsolved problems as regards to the track and use of synthetic data. The genesis, structure, physics and dynamics of Tsunami are now well understood. Numerical models are now predicating accurately the intensity and tracks of the Tsunami in the Indian Ocean. Liu (2013) and Denys Dutykh (2007) have presented more details on the numerical methods and approaches to modelling of Tsunami. However, it is felt essential that a further improvement in the warning system, monitoring system, satellite and observations network and a well-planned preparedness programme would help mitigate the disaster and reduce the loss of life and property in the region. The use of local language while disseminating weather information and awareness generation among the affected community should also be an integral part of the preparedness programme. Detailed studies on the 2004 Tsunami on Tamil Nadu coast are reported by Jayakumar et al. (2005) and Ramana Murthy et al. (2005).

An exclusive safety team has to be present on 24×7 basis with the live contact with NIOT/INCOIS/NDMA through net and mobile services. They should also have continuous contact with Indian Navy, Island administration, Coast Guards, Fishermen Associations, Marine polices/State Secretariats in different coastal states. In the way of keeping a vigil on the warning and the organized evacuation can help to avoid loss of life and also protect the coastal properties to a considerable extent.

Acknowledgements

The authors sincerely thank IMD, INCOIS, NDMA, NIO, NIOT, ICMAM and NCSCM who had drawn various environmental management plan and emergency preparedness plan.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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