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Review

# The impact of tsunami in coastal areas: Coastal protection and disaster prevention measures—Experiences from Japanese coasts

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**Abstract**—The experience of the recent Indian Ocean Tsunami was new to the people of India. Various assumptions were made on the damages to property, environment and the follow up coastal protection measures, but it was very difficult to predict due to lack of previous data and experiences. The tsunamis are frequent in Japan and various coastal protection measures were implemented such as hard solutions (sea walls, breakwaters, water gates, high rise river dikes), soft approaches (education and awareness, forecasting, communication, evacuation, preparedness) and natural barriers (coastal forests, mangroves, coral reefs) throughout the Japanese coasts. The field visits in the tsunami affected coastal areas from north to south Japan, covering six Prefs. provided hand-on experience and knowledge with detailed historical information on damages, coastal protection measures, successes and failures. The Japanese experiences could be taken as a model for any coastal conservation practices, however it is recommended as an integrated approach in the case of Indian Ocean region, particularly to India because of differences in the socio-economic nature of the coastal areas. The integrated approach could be practiced, involving soft solutions as a major strategy with the natural barrier concepts and the hard solutions only for required specific areas.

**Key words:** Tsunami, coastal protection, hard solution, soft approach, natural barriers, integrated approach

## Introduction

Tsunamis are seismic sea waves caused mechanically by a sudden rise or fall in the earth's crust and subsequent displacement of water column above. Tibballs (2005) describes "tsunami as a chain of fast moving waves that are generated when water in the ocean or even a lake is rapidly displaced by a sudden trauma in the form of an earthquake, a volcanic eruption, a landslide or the impact of the meteorite. Tsunami waves race across the ocean at speeds of up to 960 km/h and are virtually undetectable out in the open sea. When the tsunami waves approach land, the shall water acts as a brake on the front of the wave, slowing it down to around 320 km/h, while the back of the wave continues at full speed. The name tsunami derives from the Japanese for 'harbour' ('tsu') and 'wave' ('nami').

The Pacific Ocean region has the high risk of tsunamis, but the last major tsunami in the Indian Ocean occurred in 1883 had very minimal threat. Tibballs (2005) stated that the 2004 Indian Ocean earthquake, which occurred deep under the oceanic basin between the Australian and Eurasian plates, was the fifth largest quake ever recorded and the biggest for four decades. The energy from the earthquake vertically jolted the seabed by several metres, displacing hundreds of cubic kilometers. The Indian Ocean tsunami, which struck the 11 nations bordering the Indian Ocean on 26th December 2004, brought much incalculable damage to both the humans and the environment.

In India, it was the first such tsunami disaster in the history and the impact was experienced in Andaman and Nicobar Isalnds, 3 states (Andhra Pradesh, Tamil Nadu and Kerala) and 1 union territory (Pondicherry) in the mainland. The damage in Andaman and Nicobar islands was due to both earthquake and tsunami waves, but in mainland, the impact was due to tsunami waves only. In Andamans, the earthquake was very severe with M 8.9 and it was reported 129 after shocks (118 aftershocks between M 5.0–6.0 and 11>M 6.0). Over 2,260 km coastline was affected in the mainland, which includes 25 districts (Andhra Pradesh—7, Tamil Nadu—13, Kerala—3 and Pondicherry—2). India had been affected by several natural disasters such as earthquakes and super cyclones, but the Indian Ocean Tsunami was unexpected and implicated heavy loss on human life, infrastructure, property,

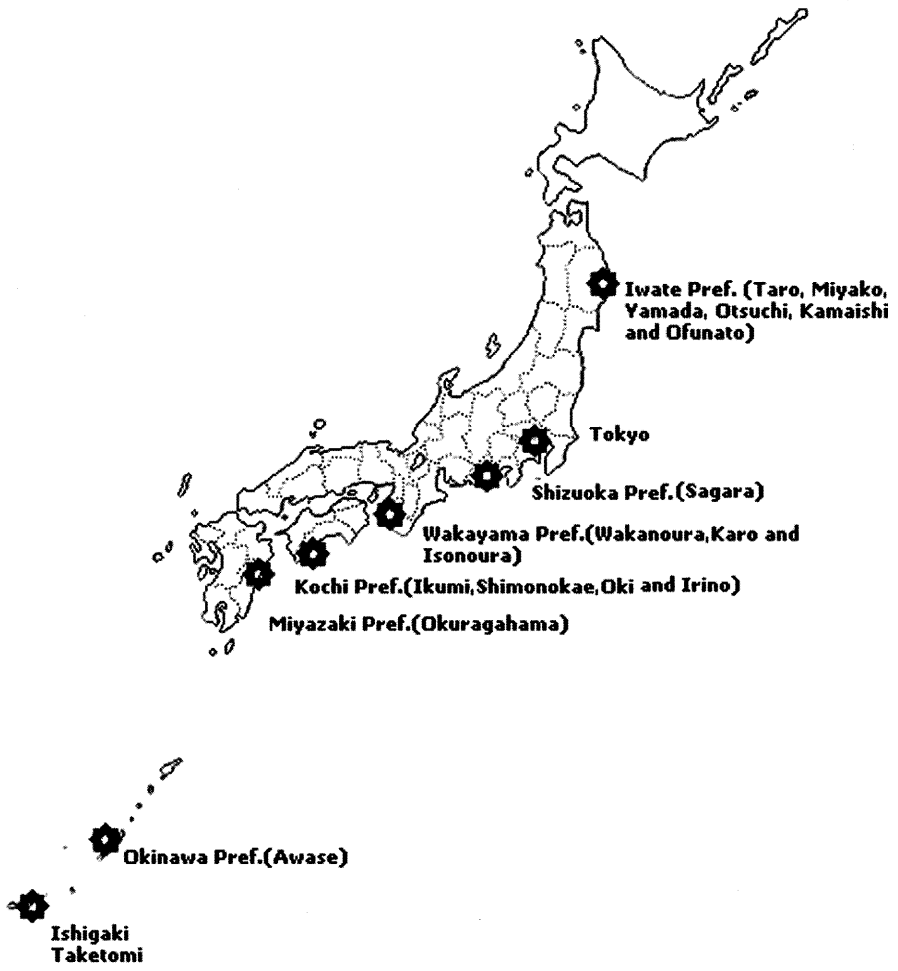


**Fig. 1.** Map of Japan, indicating the areas visited for the present study.

and socio-economics of coastal people. Initial rapid environmental impact assessment along Tamil Nadu coast revealed that the damages are at various levels (minimum to maximum) such as changes in the inter tidal and sub tidal faunal assemblages and sea floor topography; shoreline changes mostly transgression; unusual deposition of heavy minerals (garnet and ilimenite) along the coastal track (SDMRI report 2005b) and needs further assessment and attention. Interestingly, there was no significant impact on the coral reefs and mangroves except minor transitional damages (SDMRI report 2005a, 2005b). At the juncture, the first author had the interest to study the tsunami impacts and coastal protection measures in Japan, which has plenty of tsunami experiences and accordingly along with other authors of this report, a field study had been conducted from 1st August to 31st October 2005 on the tsunami affected coastal areas. The authors had visited many tsunami-affected areas from north to south Japan, covering coasts in Iwate (Taro, Miyako, Yamada, Otsuchi, Kamaishi, Ofunato), Shizuoka (Sagara beach), Wakayama (Wakanoura, Karo Bay, Isonoura beach), Kochi (Ikumi, Shimonokae, Oki and Irino beaches), Miyazaki (Okuragahama beach) and Okinawa (Awase, Ishigaki and Taketomi) Prefs (Fig. 1). Discussions were made with many scientists who work on tsunami related issues, local people and officials from local government.

## Tsunami impacts in Japanese coastal areas

The authors have made extensive field study in the above-mentioned coastal areas and the visits include coastal cities, towns, bays and villages. The impacts could be understood well in all areas by means of information boards, monuments, pamphlets from local administration etc. The museums in Ofunato and Kamaishi in Iwate Pref. explain the previous tsunami disaster events in a detailed manner. The Table 1 gives an overview of major tsunamis in Japan during the past 100 years (http://www.glocom.ac.jp/eco/esena/resource/isobe/index.e.html). It is evident from this report that tsunamis are one of the several major natural disasters for the loss of human lives, infrastructure and property in Japan. The Sanriku coast (include Iwate and Miyagi Prefs. and part of Aomori Pref.) in northern Japan is considered as most vulnerable to tsunamis. The *Meiji Sanriku Tsunami* in 1896 had completely devastated the whole village in Taro and killing 22,072 people. The great seawall in Taro with 10 m height

**Table 1.** Major tsunamis in Japan during the past 100 years (magnitude of 3 or higher).
Source: A formal paper by Masahiko Isobe, Department of Civil Engineering, The University of Tokyo (http://www.glocom.ac.jp/eco/esena/resource/isobe/index.e.html).

| Day (M/D/Y) | Name | Magnitude | | Maximum height of tide (T.Pm) | Deaths (missing) | Homes [Totally or partially destroyed/ washed away (units)] | Homes [Water seepage —flooding in homes (units)] |
|---|---|---|---|---|---|---|---|
| | | Earth-quake (M) | Tsunami (m) | | | | |
| 6/15/1896 | Meiji Sanriku Tsunami | 6.8 | 4 | 24.4 (Sanriku Cho, Iwate prefecture) | 22,072 | 10,393 | 3,964 |
| 3/3/1933 | Showa Sanriku Tsunami | 8.1 | 3 | 23.0 (Ryori Cho, Iwate prefecture) | 1,522 (1,542) | 5,851 | 4,018 |
| 12/7/1944 | Southeast Sea Earthquake Tsunami | 7.9 | 3 | 9.0 (Owase City, Mie prefecture) | 998 | 76,139 | — |
| 12/21/1946 | Southeast Sea Earthquake Tsunami | 8.0 | 3 | 6.5 (Shira-hama Cho, Waka-yama prefecture) | 1,330 (102) | 36,529 | 33,093 |
| 5/24/1960 | Chile Earthquake Tsunami | 8.5 | 4 | 8.1 (Noda Cho, Iwate prefecture) | 119 (20) | 5,013 | 37,195 |
| 5/26/1983 | Sea of Japan Chubu Earthquake Tsunami | 7.7 | 3 | 13.0 (Hachi-hama, Akita prefecture) | 104 | 5,099 | 1,040 |
| 7/12/1993 | Hokkaido Southwest Sea Earthquake Tsunami | 7.8 | — | 30.5 (Okushiri Cho, Hokkaido) | 202 (29) | 2,545 | 250 |

and 1.3 km length (Fig. 2) has been built as a reflection of the damage due to tsunami in that coastal town.

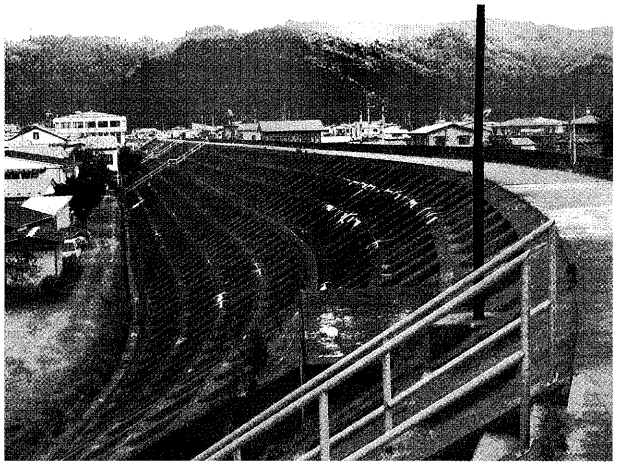

**Fig. 2.** Sea wall in Taro (Iwate Pref.).

## Tsunami Counter measures in Japan

The repeated tsunamis in Japan made the Government more cautious in protecting the people, coastal zones, and infrastructure. Having the narrow coastal zone, steep coastal slopes, and comparative lack of sediments, the hard coastal protection structures in Japan such as sea walls, breakwaters, water gates and high-rise river dikes formed the prime counter protection tools after 1933 *Showa Sanriku Tsunami*. The sea walls were highly effective during *Tokachioki Earthquake Tsunami* in 1968 and minimized the human loss, but the waves of *Hokkaido Southwest Sea Earthquake Tsunami* in 1993 overflowed the sea walls. Table 2 is the report on the tsunami disasters and the counter measures in Japan, during the 20th century that explains the counter measures taken by the government in detail (Source: http://www.tsunami.civil.tohoku.ac.jp/hokusai2/topics/counter.html).

Nowadays all tsunami affected coastal zones are protected by seawalls after the *Chilean Tsunami* in 1960 with varying heights and length based on the recent past tsunami wave height in the particular coast. Single and double layered wave breakers of concrete structure were erected near the shores in all bays which could not only reduce the power of tsunami, but also used for fishing harbour purposes because the typhoon and winter monsoon winds are very strong. On the other hand, in most of the occasion, the concrete sea walls and breakwaters reduce water circulation, which leads to eutrophication and causes various environmental problems. In order to prevent such situation, artificial reef modules are being used as breakwaters in different shapes and sizes which are highly efficient, but expensive and therefore, at present the modules are used mainly in marine park areas.

The tsunami impact is comparatively less in open bay than closed bay. Also, if the rivers join the bay, the possibilities of tsunami impact are greater because of its access to the upper reaches through the river. For example, Otsuchi Bay in Iwate Pref. is a closed bay and is 8 km long and 4 km width. The depth is about 80 m in the mouth and 40 m in the middle.

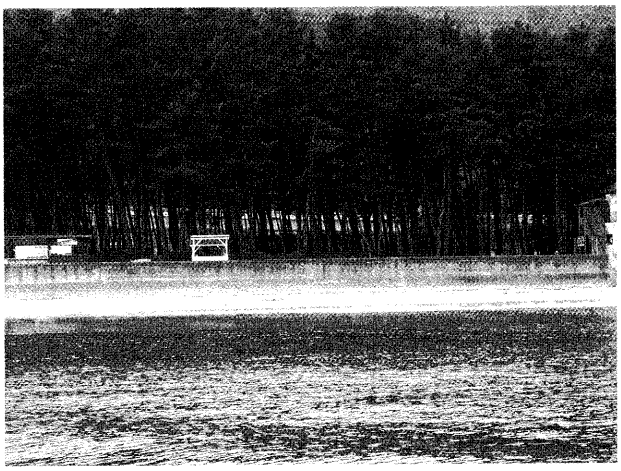

**Fig. 3.** Nami-ita Beach (Iwate Pref.).

There are 3 rivers join in this bay. During earlier tsunamis, because of its closed nature, the damage was high in this coastal area and also the waves traveled upwards the rivers to upstream and caused greater damages. After the Chilean tsunami in 1960, the coast is now protected with 6 m height sea wall, wave breakers and river gates, which are erected near the mouth to prevent the entry of tsunami waves through the river. The Otsuchi local government is also actively involved in the protection and enhancement of pine trees along the coastal areas. The Funakoshi Bay in Iwate Pref. is an open bay, located north of Otsuchi. The 1960 Chilean Tsunami damage is comparatively less in Funakoshi Bay than Otsuchi bay because of the shape and also there is no river flows into this bay.

The beautiful sandy beach, Nami-ita is located in Funakoshi Bay, which is a good example for the coastal protection measures against tsunami. The length of the beach is about 300 m and about 50 m width. Immediately after the sandy beach, there is a sea wall of about 4 m height and at that level, pine trees are planted densely for about 30 m width and at 6 m height from that level, the highways was constructed (Fig. 3). The breakwaters using concrete structure and artificial reef modules with regular intervals are also constructed to reduce the tsunami power. It was revealed during one of the discussions the first author had with the scientists from Iwate University that over 200 years back the elders planned the living areas with landscapes of much height for protection from unexpected natural disasters, but at that time no one really realized its importance, but now they are remembered.

## Natural Barriers

The plantation particularly pine trees have been raised as coastal protection measures in almost all tsunami affected areas in northern part of Japan after the 1933 *Showa Sanriku Tsunami*. The hard solutions such as sea walls coupled with plantation are also in existence in most areas, particularly in

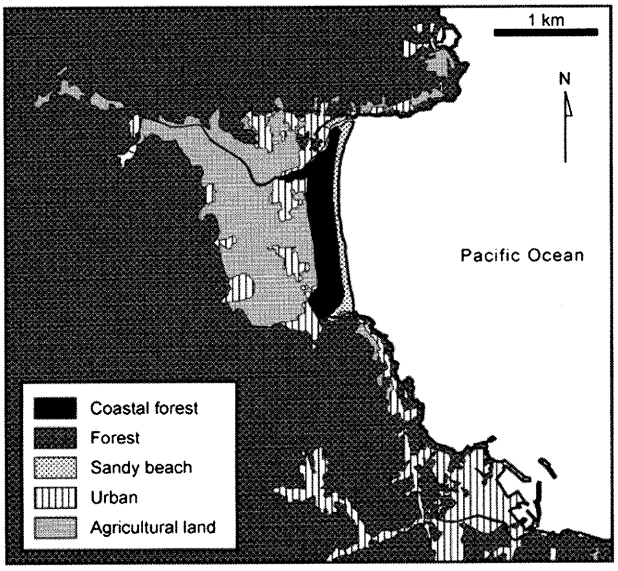


**Fig. 4.** Map of Oki (Kochi pref) showing land use and land cover, and position of the coastal forest. Drawn from an aerial photograph, purchased from the Japan Map Center, taken in May 2002.

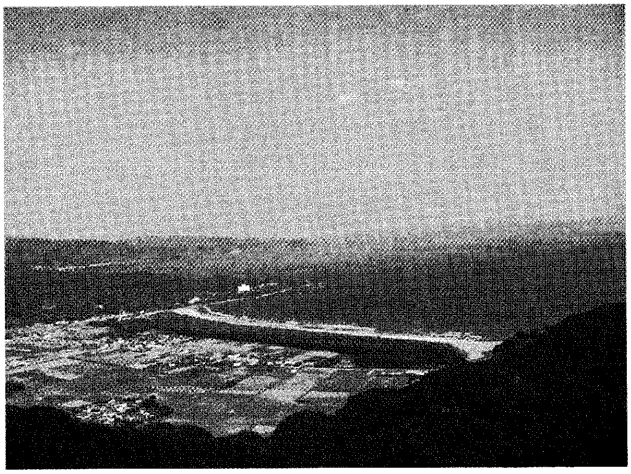

**Fig. 5.** Bird's eye view of Oki beach and its vicinity, including the coastal forest.

Sanriku coast. In addition, the coastal forests in various beaches in Kochi and Miyazaki Prefs., developed over 3–4 centuries ago by ancestors for protecting the agriculture lands from salt spray by strong winds, abnormal high tides, flying sand and also tsunami (Figs. 4 and 5). These forests are now acting as viable natural barrier against tsunami to protect human lives, property and agriculture fields and also in enhancing coastal fishery production. Yamaguchi (2005) observed decline of intertidal populations of bivalve mollusks, particularly *Meretrix lamarckii* in sandy beaches along southern Japan. He stated two factors for this decline, one is beach erosion and narrowing of intertidal flat zone where early juvenile clams aggregate and the other is the loss or absence of coastal forests that might supply nutrients to interstitial microalgae as food for the juvenile clams. The Kochi

**Table 2.** Tsunami disasters and the counter measures in Japan, 20th century (Source: http://www.tsunami.civil.tohoku.ac.jp/hokusai2/topics/counter.html).

| Date M/D/Y | Name | Human Loss/Problems | Counter Measures |
|---|---|---|---|
| 3/3/1933 | Showa-Sanriku Earthquake Tsunami | • Causalities 3,064 (missing 1,542 inclusive)<br>• Terrible damage in Sanriku Coastal Area<br>• Fires in Ofunato, Taro and Kamaishi | • Instructions for Tsunami Disaster Prevention made in1933<br>• Resettlement to higher locations (Yoshihama, Tanohama and Ryori in Iwate Prefecture, Aikawa in Miyagi Prefecture)successful.<br>• Construction of sea wall in Taro and Yoshihama<br>• Tsunami control forest, revetment and sea wall<br>• Design of tsunami prevention areas and evacuation roads<br>• Tsunami warnings, evacuation from tsunamis<br>• Commemorative activities |
| 4/ /1941 | | | • Establishment of Tsunami warning organization by Sendai District branch of Meteorological Agency for the Sanriku Coastal Areas |
| 12/7/1944 | To-Nankai Earthquake Tsunami | • Casualities 1,251 | |
| 12/21/1946 | Nankai Earthquake Tsunami | • Casualities 1,330<br>• Sea wall in Hiro, Wakayama Prefecture made after 1854 Ansei Eathquake Tsunami was effective for the first time in 90 years | |
| 3/4/1952 | Tokachioki Earthquake Tsunami | • Tsunami warning tentatively issued before the official use and it was effective | |
| 4/1/1952 | | | • Tsunami Forecasting System started by the Japan Meteorological Agency |
| 5/24/1960 | Chile Earthquake Tsunami | • Casualities 142<br>• Tsunami Warning not issued<br>• Affected area covers the Japanese Archipelago from Hokkaido to Okinawa | • Establishment of the Pacific Tsunami Warning Center (PTWC) in Hawaii<br>• Construction of Tsunami bay-mouth Break Water (Ofunato)<br>• Construction of Tsunami/High Tide sea wall (all coastal areas of Japan)<br>• Tsunami water gate was constructed for the first time |
| 6/16/1964 | Niigata Earthquake Tsunami | • Casualities 26<br>• Damage of oil tanks, spread of oil by tsunami and fires followed<br>• Large-scale damages from liquefaction also occurred | |
| 5/16/1968 | Tokachioki Earthquake Tsunami | • Causalities 52 (most deaths by the earthquake)<br>• Sea wall prevented tsunami attacks well | |
| 8/ /1976 | | | • Possibility of Tokai Earthquake was publicized<br>• Policy change was made from the counter measures against the past tsunamis to expected tsunamis in the future |
| 1977 | | | • Tsunami inundation map was made in Shizuoka Prefecture for the first time |

**Table 2.** (Continued.)

| | | | |
|---|---|---|---|
| 4/4/1979 | | | • The Deep-Ocean Tsunami Observation System was started to operate in Omaezakioki, Shizuoka and it was integrated into the national seismic observation |
| 3/ /1983 | | | • "Guidelines for Comprehensive disaster Prevention Counter measures in Tsunami-prone areas" was made.<br>• The largest tsunami in the past 200 years was adopted as the Design Tsunami.<br>• Integration of disaster prevention facilities, local plans and counter measures.<br>• The idea was accepted that design tsunamis may cross over disaster prevention facilities. |
| 5/26/1983 | Nihonkai-chubu (Japan sea) Earthquake Tsunami | • Casualities 104<br>• The first wave came after 7 minutes after earthquake<br>• Delay of Tsunami warning by 13–15 minutes<br>• Reconsideration of Tsunami education<br>• Soliton fission was confirmed in the nearby waters for the first time<br>• Tetrapods were displaced<br>• Problems of filtered data in tidal station for tsunamis<br>• Anglers lost their lives | • Lead time for tsunami warning was shortened by the introduction of new tsunami forecasting system |
| 7/ /1984 | | | • The Tsunami Museum was opened in Karakuwa town, Miyagi Prefecture |
| 7/12/1993 | Hokkaido-Nanseioki Earthquake Tsunami | • Casualities 202<br>• Delay of tsunami warning by 5 minutes<br>• Tsunami waves overflowed sea walls<br>• Fires occurred in residential area<br>• Delay in communication | • 4 Government Ministries / Agencies started joint meeting for tsunami disaster prevention |
| 3/ /1997 | | | • "Guidelines for Tsunami Counter measures in Disaster Prevention Local Plan" was made.<br>• Adoption of Design tsunami concept from the largest earthquake tsunami in the past and for tsunami-free areas (a tsunami caused by the largest scale earthquake imaginable to the best expert knowledge)<br>• Anti-earthquake / tsunami reinforcement and maintenance of Tsunami disaster prevention facilities<br>• Land use planning, zoning and betterment for safety<br>• Disaster prevention counter measures (organizations, forecasting, communication, evacuations, awareness, training and response)<br>• "Tsunami Disaster Forecasting Manual" was made for numerical analysis |
| 4/1/1999 | | | • JMA started Quantitative Tsunami Forecasting System |

prefectural government is taking much care in enhancing the coastal forest areas in Oki Beach (1.5 km long and 200 m width dense forest) and Irino Beach (4.5 km long and 160 m width dense forest) with native species and newly developed pine trees. Mangroves, casuarina and coconut trees withstood the tsunami impact as natural barriers and saved many lives and property in Tamil Nadu coast during the Indian Ocean tsunami (SDMRI report 2005b).

During 1771 Yaeyama earthquake tsunami, the wave height was about 30 m at eastern coast of Ishigaki Island in Okinawa Pref. and the village, Siraho in Ishigaki Island was completely devastated, but the nearby Taketomi Island received minimal impact and presence of well-developed coral reefs was cited as one of reasons by Nakamura (2005). Tibballs (2005) reported that geological features such as reefs might dissipate the energy of a tsunami. Coral reefs also played great role in protecting the coastal area in the mainland during Indian Ocean tsunami (SDMRI report 2005a).


**Fig. 6.** Mobile artificial earthquake facility for awareness creation.

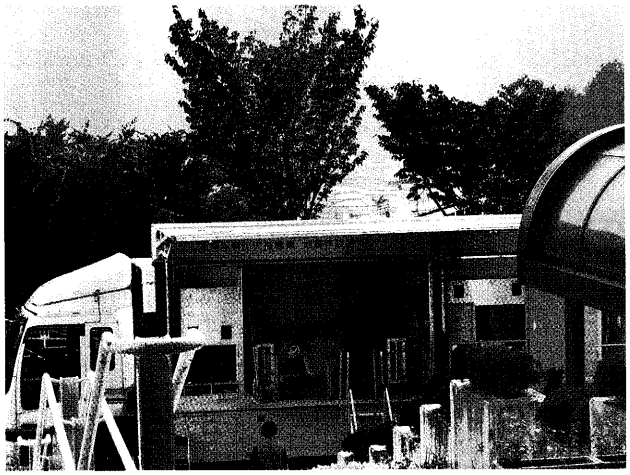

**Fig. 7.** Mobile artificial earthquake facility for awareness creation.

## Disaster prevention measures

Tsunami is an unpredictable natural disaster. Table 2 clearly explains how the Government of Japan is effective in dealing this live issue of tsunami with more reviews to its ideas and action plans after every tsunami event. Now it can be said that Japan is comparatively well prepared to deal with such situations. The administrators and scientists are busily engaged in dealing with the tsunami, but it is highly doubtful whether the public is responding positively or not? Apart from setting up the hard structures such as sea walls, breakwaters, water gates, and high river dikes, the government is also very keen on soft measures such as awareness and education, forecasting, training, communication, evacuation drills and preparedness etc. that are considered as most effective in protecting lives during the unpredictable situation.

Awareness and education on tsunami is one of the most important issues. Most of the people do not have basic idea about tsunami, however government wanted all people to know about the dangerous disasters and therefore they spread the message in various forms such as museum, television, schools and through demonstrations by local governments (Figs. 6 and 7). The local governments play a lead role in creating awareness and also coordinating the training and drills for disaster preparedness. The media plays an important role in disseminating the information on the danger of tsunami disasters very often as short programmes, so that the people could be able to understand and realize its danger.

Japan Meteorological Agency (JMA) has started the Quantitative Tsunami Forecasting System from 1st April 1999 with the state-of-the-art facilities and upgrading technology for accurate information. It serves as a great source of information to the public, not only for tsunami but also for other disasters like earthquakes, typhoons etc.

Training to deal with disaster situation has been in practice in the country, and in particular, conducted regularly for the people in the repeated tsunami affected coastal areas. Schools are also involved in these training schedules. The training module includes how one should act during earthquake and the follow up tsunami, quickness in action, follow up of instruction through communication etc. The local government and allied departments play a lead role in these training activities.

Communication is an integral part of the disaster prevention measures. Table 2 indicates the time-lag in disseminating tsunami warning in couple of occasions such as no warning in 1960 (*Chilean Earthquake Tsunami*), a delay of 13–15 minutes in 1983 (*Nihonkai Chubu Earthquake Tsunami*) and a delay of 5 minutes in 1993 (*Hokkaido Nanseioki Earthquake Tsunami*) in giving warning, which led to high human losses. Saito (1990) reported from his questionnaire survey that the inhabitants along the coast of Sanriku, Iwate Pref. complained about the delayed issuance of evacuation order and inaudible radio announcement during the 1989

*Sanriku-Oki earthquake Tsunami.*

The post tsunami evacuation and preparedness is a highly coordinated effort with various departments and volunteers. In such situation they should be professional and swift in discharging their duties. Training to such personnel is also given periodically in order to make them to get ready for any situation. The first author during his stay in International Coastal Research Center (ICRC), Ocean Research Institute (ORI), the University of Tokyo at Otsuchi experienced the *Miyagi Earthquake* (M 7.2) on 16th August 2005 and could witness the alarm through common public address system about the disaster and also through forecasting by JMA. Even though it was informed that the generated wave height of the tsunami as 10 cm, the seawall doors in Otsuchi Town was closed as a precautionary measure.

## Lessons Learned

Because of the narrow coastal area, the coastal protection practices in Japanese coasts were mainly with hard structures, which involves much investment and more than that the maintenance cost. However, if one raises the question whether these protection structures would be sufficient for protection against tsunami, the answer could be "no" because exact prediction of the power of tsunami waves could not be possible and also the seawalls are constructed based on the height of recent past tsunami wave height. It is to note that the waves of *Hokkaido Southwest Sea Earthquake Tsunami* in 1993 was up to 30 m, as high as ten storey building. Although the port town of Aonae was completely surrounded by seawall, the waves washed over the wall and destroyed all wooden framed structures in the area (Tibballs, 2005). The wall may slow down the power of tsunami, but it is expected that the damage and loss would be more in such situation. That is why the Japanese government nowadays concentrates more on soft protection measures, which is considered as the best escape method from this dangerous nature furry with comparatively less investment, but precise techniques. Several examples could be quoted for this strategy, however, the following are provided as it attracts much attention.

The Shizuoka Earthquake Education Center, which is mainly functioning as an awareness creation and education centre about the impacts of earthquake and tsunami among people and also involved in the preparation for the expected *Tokai Earthquake* and the follow up tsunami. This center is already in the process of creating several tall and earthquake resistant buildings for evacuation during the Tokai Earthquake tsunami, which is expected at any time. The "Disaster Prevention Station" in Sagara Town is one of the two (other station is in Hokkaido) state-of-the-art disaster prevention stations, and is taking care of 12 km long Sagara Beach. It is responsible for weather condition monitoring with centralized operation of tsunami protection systems such as seawall gates, water gates etc. It is also responsible for making the pubic and school children to be aware of the natural disasters through various means such as booklets, brochures etc. Besides, local governments are also taking various steps for propagating the messages through seminar and training programmes. The first author had attended a seminar on "Natural calamities and disaster protection counter measures of Iwate—Earthquakes and Tsunami", arranged at Shiroyama Park by Otsuchi Local Government. The lecture content (Saito 2005) given at the seminar was very informative with the details of previous earthquakes and tsunamis in Iwate Prefecture, steps to take measures when earthquake occurs, steps to reduce the damages, response to tsunami disaster, and efforts in Iwate Pref. to tackle the situation. The local government is also making efforts to give information about tsunami to tourists by providing details through pamphlets, which are kept in hotels, museums, and other tourist areas. The communication system is also well developed by the development of Information and Communication Technology and increased users and so, warnings and forecasting information are transmitted directly to individual mobile phones in order to avoid delays in evacuation.

The concept of protection and enhancement of natural barriers such as coastal forests, mangroves and coral reefs have also gained momentum. The local governments in Sanriku coast are strictly protecting the forests along the coasts and new forests areas are also developed with planting pine trees, which have been most widely used for a counter-tsunami grove during the past three hundred years. However, it is believed that the groove could not be effective enough unless planted densely with low-lying bushes as well as trees and in width of at least 200 m. Though a counter-tsunami grove must not be depended upon as a protection against inundation, it is expected to play an important role in ridding the tsunami of some of its energy, or in preventing infectious destruction of properties due to drifting materials. The usage of a counter-tsunami grove in combination with a seawall could be one of the most realistic devices for prevention of a worst tsunami disaster (Horikawa 1962).

The coastal forests along the Irino Beach are now well protected by the Prefectural Government. Similarly, the coastal forests in Oki Beach are well managed in Kochi Pref. During Second World War, Japanese Military Authority ordered to clear the forests, but a dedicated Forest Chief, Mr. Y. Horiuchi made stiff protest and saved this forest. Now, the National Forest Authority and Municipal Authority are providing funds for management by the Prefectural Community Centre, which is the local authority responsible for overall management of 4.5 km long and 160 m wide dense forest area. The responsibilities of removal of dead trees and disease control are vested with National Forest Authority. Coastal forests not only protect the shorelines from beach erosion, but also help to establish nursery environment for many fishery resources, because the shallow sandy beaches

**Fig. 8.** Boulders washed ashore along Ohama beach during 1771 Yaeyama tsunami.

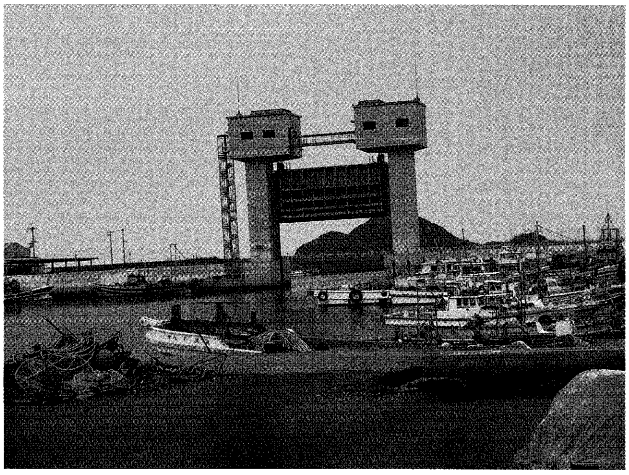

**Fig. 9.** Water gate in Karo bay (Wakayama Pref.).

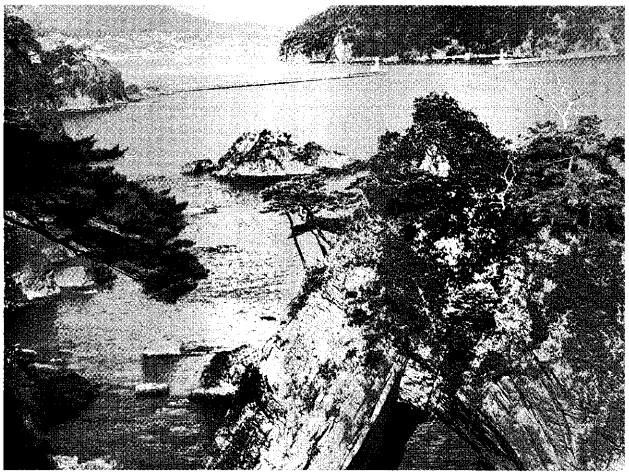

**Fig. 10.** Breakwater in Ofunato bay (Iwate Pref.).

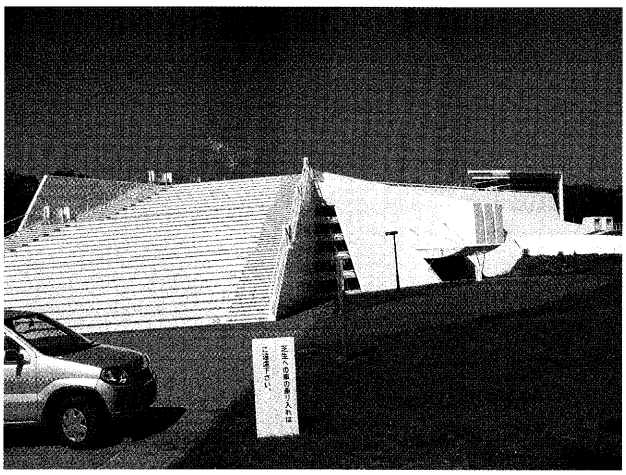

**Fig. 11.** Evacuation facility in Irino beach (Kochi Pref.).

are now recognized as a transit habitat for juveniles for many commercial species (Yamaguchi 2005).

However, there are several lacunae in the approach of certain local governments particularly Okinawa Pref. In most cases, developmental activities overlook environment and protection and people tend to see the immediate economic benefit only. The 1771 *Yaeyama Earthquake Tsunami* has completely devastated Siraho village in Ishigaki Island. Tsunami entered the Ohama beach and traveled up to the opposite Nagura Bay. Huge boulders were washed ashore along Ohama beach and are still existed. In one area, a boulder weighing many hundreds of tonnes was washed about 500 m away from the shore (Fig. 8) and remind us the danger and power of tsunami. But, many tidal and reef flats in Okinawa and Ishigaki islands are land filled for industrial and residential purposes without thinking of the impacts.

Another important developmental activity is creation of number of small fishing harbours. Each coastal village is having a fishing harbour with much protective mechanisms such as seawalls, breakwaters and water gates. For example, in Wakayama Prefecture, the Karo Bay is having not more than 40 boats, but it has a fully protected fishing harbour (Fig. 9). These kind of developmental activities increase the risk and also reduce the productivity of these areas. The Ofunato bay area is polluted because of lack of water circulation due to the construction of breakwaters (Fig. 10).

Though earthquake, tsunami and typhoon are frequent in Japan, the people enjoy the beauty of sea particularly during holidays. The Sagara, Kataonami, Isonoura, Ikumi, Shimonokae, Oki, and Irino beaches are famous for swimming and surfing and are flooded with tourists during vacation. All are open sea beaches and tsunami danger and risk are very high. Except for the Irino Beach (Fig. 11), the evacuation route, sign and facilities are not properly provided in these highly preferred areas. As the epicenter of the earthquake would be located very close, the follow up tsunami would reach within 20–30 minutes and in such case, the people in those crowded beaches could find it very difficult to escape from the danger.

It is also felt that the younger generations are not seriously taking the tsunami related messages. Even for the

meetings arranged by local governments, the participants are normally in the age group of over 60 because they wanted to know more as they witnessed the situation earlier. This is because major tsunamis would hit any coast in Japan once in several decades or longer. So, it is highly essential to educate and make awareness the people from their childhood about this disaster, cause, sign etc. that would give more fruitful results. Media and booklets with such information in local language would serve the purpose very well.

## Suggestions to improve Japanese coastal protection measures

- Earthquake and tsunami education and awareness among young people should be increased and intensified, so that human loss could be minimized.
- The Government should consider the past histories and experiences of tsunami when they plan the coastal developmental activities. Government should also adopt strict Coastal Regulation Zones in order to minimize the coastal developments in the tsunami risk prone areas.
- Increase of hard structures all along the coast in the names of protection and economic development would deplete the productivity of the coast and therefore should find alternate ways to reduce such destructive activities.
- Natural barriers such as coastal forests, mangroves and coral reefs should be preserved and enhanced systematically in order to protect the coastal environment, people and property from tsunami and also to increase the coastal fishery production, which is one of the major economic sources.
- The swimming and surfing beaches all along the coasts in Japan should be well planned in terms of communication and evacuation during tsunami. The proper evacuation route, sign, and facility should be in place in order to save thousands of lives.
- Local governments should form a well-trained volunteer groups for disaster management to involve in the rescue operations at any place during any kind of natural disaster situation.
- Each Prefectural government should encourage the local scientists with necessary funding to involve in tsunami related environmental research programmes so as to have the baseline information and remedial mechanism.

## Suggestions for coastal protection measures in India

The field study by the first author with other co-authors along the Japanese coasts is also helpful to make few concrete suggestions for Indian coasts. In Indian context, tsunami is new to people, however based on the experience from Japanese coast, it is wise to follow some methods, but not wise to adapt the same concept in India because the Indian coastal area is completely different from that of Japanese coasts. It is therefore suggested that India need to adopt an integrated approach in the case of coastal protection measures, by giving much importance to soft protection measures and natural barriers.

- In India, the Coastal Regulation Zone notification was made in 1991 and this was mainly implemented for regulating development activities, the coastal stretches within 500 m of High Tide Line on the landward side. The effective implementation of this notification could avoid most of the damages. However, the developments made before 1991 needs attention and necessary protection measures have to be taken.
- It is highly essential to concentrate more on soft approaches such as awareness and education, forecasting, communication, evacuation and preparedness.
- Tsunami could come once in 100 or 1000 years and therefore people will tend to forget its devastative impact. Proper education and awareness to people from their childhood about tsunami disaster, cause, sign etc. would give more fruitful results. Media and booklets with such information in local language would serve the purpose in an effective manner. Fully established communication network with proper infrastructure facilities in coastal areas would help to pass the warning to the people without delay. It is essential that people should not be panic, but they must act, for which awareness is the basic tool.
- Government should concentrate more on enhancing natural barriers such as coastal forests, mangroves and coral reefs. Those existing should be protected and, wherever possible, such resources should be enhanced. This would not only help to protect the coast, but also to enhance the fishery production, on which thousands of coastal folk are depending. The responsibility of managing these resources could be given to the local people through panchayats, so that they would involve in this process more actively. Nowadays government is involved in creating shelterbelts with casuarina trees and mangroves wherever the conditions are suitable. The plantation of native species would minimize disease problems and the density of the plantation (minimum of 200 m width) is highly important to reduce the impacts. During the recent tsunami, coconut trees also withstood the impact in several areas in Tamil Nadu coast and so, the coconut trees could also be considered for shelterbelts wherever possible, which would provide regular income to local people who involve in the management.
- In Gulf of Mannar and Andaman & Nicobar Islands, coral mining is in practice for more than three decades. Even though the enforcement authorities are active, the mining is going on illegally for various purposes. After the tsunami, the situation has changed and the people realized, particularly in Gulf of Mannar area that because of the is-

lands and reefs their coastal villages were saved and they came forward to completely stop this illegal practice. Enhancement of the coral cover in all degraded areas with native species through intensive reef restoration programmes would serve the purpose of coastal protection and also to enhance the fishery production.

- Hard solutions such as seawalls and breakwaters could also be considered only wherever it is essential such as the areas with severe sea erosion, low-lying areas and harbour establishments.
- District level disaster management volunteer group has to be formed with young trained people to help the authorities during any natural disaster situation.
- Hazard-mapping of disaster vulnerable areas should be done at district level, so that precautionary action could be taken swiftly ahead of any natural disaster situation. Low lying areas without proper protection should be avoided for human settlement.
- Government should encourage the scientists with necessary funding to involve in tsunami related '*Environmental Research and Disaster Management programmes*' so as to have the baseline information and remedial mechanism. "*Disaster Management Facility*" should be established in each district under the supervision of government or non-governmental organization to make aware and prepare the people to face any kind of natural disasters.

Man cannot stop nature's activity, but can wisely handle the situation and reduce the impact. It is therefore need of the hour to face and manage tsunami like disasters wisely with courage with the available resources and expertise. Government and people should start working on this line from now onwards without delay to face future natural disasters like tsunami.

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