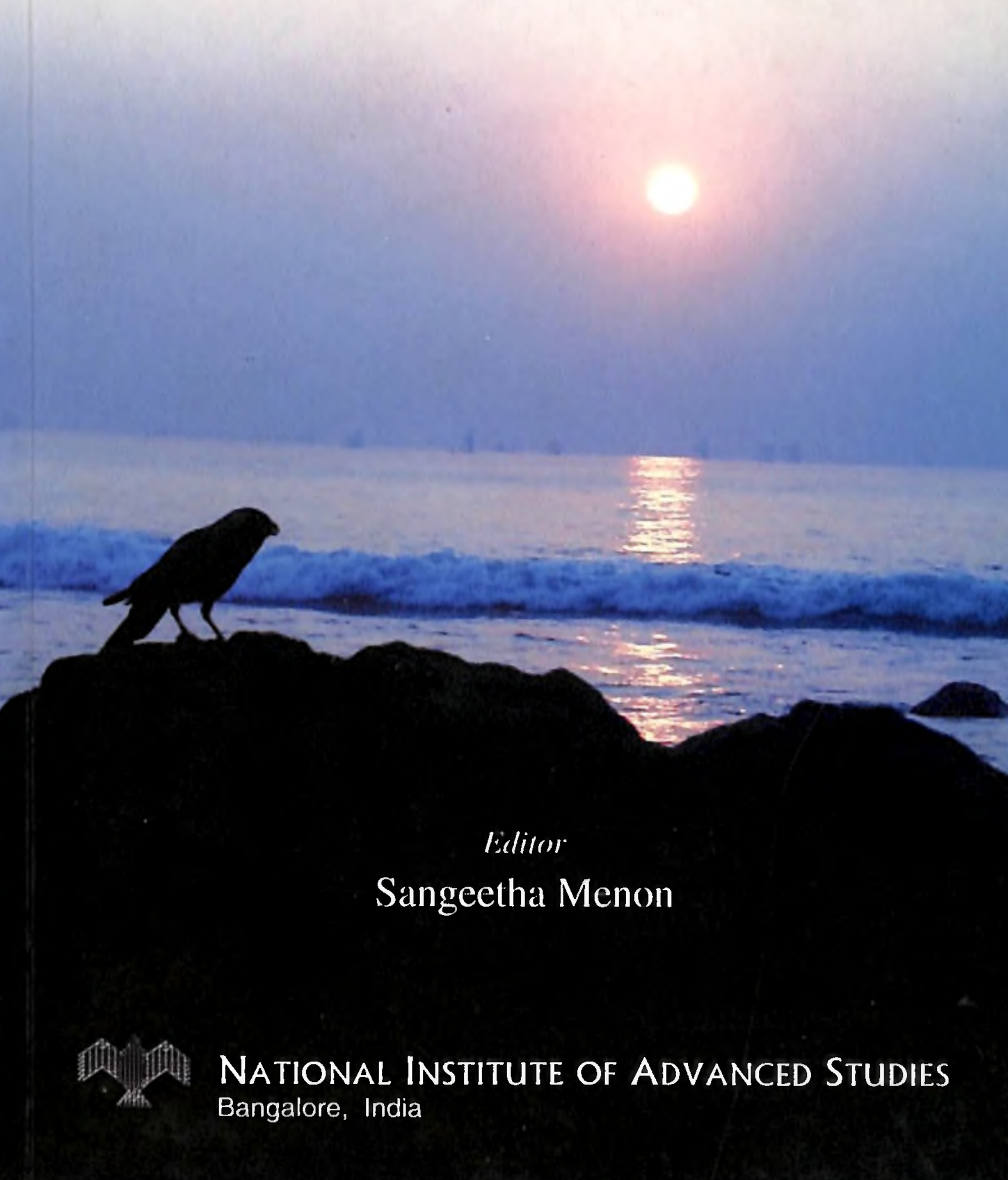
The Great Indian Ocean Tsunami of 2004

An Overview of a National Disaster



Editor

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NATIONAL INSTITUTE OF ADVANCED STUDIES
Bangalore, India

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Editor's Note

A meeting entitled "Six months after Tsunami" was held at the National Institute of Advanced Studies on 16 June 2005. The goal of the meeting was to place on table a multiperspectival assessment of the disaster. The presentations included an experiential account by Prof C. N. R. Rao who was a witness to the event; a keynote address by Dr V. S. Ramamurthy; a historical view by Prof S. Settar; an account by Prof S. Sukumar from the perspective of animal behaviour; on Sumatra Tsunami by Prof Vinod Gaur; futuristic measures by Dr Satish Shetye, Space based observations by V. S. Hegde; status of earthquake monitoring in India by Dr R. S. Dattatreyam; relief and rehabilitation accounts by Sri V. V. Bhat, Dr Sanjiv Lewin, Dr Rama Govindarajan, Prof S. S. Meenakshisundaram; and many other issues. It is now 12 months since we organized this meeting. Due to many reasons we got delayed in bringing out the proceedings of this meeting. But we believe that inspite of this delay the importance of this volume is still relevant and has not diminished. We thank all contributors to this volume. Many thanks to Prof R. Narasimha who conceptualized and designed the meeting. This book was possible because of his many meaningful interventions for its structure and content. Thanks to Ms. V. B. Mariyammal, as ever, for her sophisticated skills in not just assisting me in organizing this meeting but also for bringing the book to this final shape.

19 July 2006

Sangeetha Menon
Editor

Opening Remarks

K KASTURIRANGAN

Good-morning, Professor C.N.R. Rao, Professor Ramamurthy, Professor Narasimha, our distinguished participants, speakers, invitees, and ladies and gentlemen. It is my pleasure to welcome all of you this morning to this one-day discussion meeting on the tsunami.

Tsunami is no longer an unfamiliar word as it was for many a few months back. December 26, 2004 brought to us a revelation. Its exact meaning manifested in several dimensions. The phenomenon is very rare in the Indian Ocean region. The December 26 event sent us a reminder that this region is also not immune to one such natural calamity. Showing 8.9 on the Richter scale, a massive submarine earthquake at 6:28 a.m. IST near the Sumatran island of Indonesia triggered in a large part of the globe a massive disturbance in the ocean. This affected several regions particularly in the Indian Ocean area impacting on millions of people, affecting 11 countries, extending from the eastern part of the world, Indonesia and beyond to Thailand, to Malaysia, to the eastern coast of India, going into the western coast, Sri Lanka and, of course, the down range islands and reaching as far as the Somali coast.

India itself has been affected in a massive way. The total population that is affected is 2.7 million: 10,000 were killed, 615,000 were displaced. These statistics speak for themselves, the massive scale on which the tsunami affected this region.

Several discussions took place immediately following this not only to understand what happened, what went wrong and what is to be done. There were discussions in the Indian National Science Academy, there were DST-sponsored meetings, all to address the questions related to the scientific genesis of this event, the implications, the physics, the geosciences and also the type of observations that we need to make to provide meaningful prediction, warning, and preemptive steps that one could take. There have been discussions on this front by several agencies and several groups in this country, through discussion sessions, workshops, brainstorming sessions with experts in this are.

When Professor Narasimha agreed to organize a meeting of this kind and that too at NIAS, it was quite obvious that we didn't want to repeat exactly what has gone in, in the last few months, in understanding this phenomenon. Professor Narasimha felt that we could bring in, keeping in mind the interdisciplinary character of this Institute, people who have been associated with and very familiar with the science and physics of it; people who are involved in rescue operations, and other dimensions of tsunami; studying types of animal behaviour that were reported; the problems related to understanding this particular phenomenon in the context of the common man, the coastal processes and ultimately, the questions of actual field relief operations that were conducted by people and the psychology of the people who have been affected; the fishermen and many others in the coastal domain. The idea behind the meeting was to put together a set of specialists who have been directly associated with this area and also who have been participants of the activities of the most recent tsunami, and to bring them together to exchange their own experiences, share their own experiences and exchange their views.

My pleasant task is to welcome all of you. First of all I would like to thank Professor C. N. R. Rao who has agreed to come today. Professor C. N. R. Rao's presence, in a way, is very important to me for two reasons. He is, of course, currently the Chairman of the Advisory Committee, the Cabinet Committee for Science and Technology to the Prime Minister and, of course one of the outstanding scientists in this country. And, he is visiting NIAS for the first time after he has been recognized by the world with the Dan David prize, which he won recently, Instituted by the Israelis and considered very close to the Nobel prize. We are indeed very thankful to Professor Rao for being with us today morning and gracing this function. The other reason which I want to tell you is that whereas we all of us discussed the post-tsunami scenario and participated in the relief, he was right amidst the tsunami in Sri Lanka, being caught that morning when he was taking a walk. I am sure that he will share that very exciting experience with all of us. We would like to congratulate you, Professor C. N. R. Rao again for the very important recognition that you won based on your lifelong contributions to the cause of science, and particularly areas like Solid State Structural Chemistry, Nano Science and Technology and so on.

Professor Ramamurthy has been one of the very key figures of the post-tsunami period to discuss the strategies for the future, understanding the basis and also organizing brainstorming sessions which have led to identification of the type of configuration that we need to monitor this system. I would like to thank Professor Ramamurthy for being with us today morning.

My special thanks to Professor Narasimha because he is really the key person who has organized this particular meet. With his very broad understanding has been able to conceptualise the type of content and the scope of this meeting at NIAS. The varied type of participants that we have today morning is an ample reflection of the way he has conceptualized this programme. He was ably assisted by Dr. Sangeetha Menon of NIAS in this work.

I am also happy to see Professor Vinod Gaur, another very important person who helped us to formulate what should be the scope of this event. He really advised us what not to do in this particular meeting and also what has been left out, which needs more discussion.

I do see, of course many others: Professor Ramachandran, Professor Meenakshisundaram, Professor Shetty, Professor Baldev Raj, and also my own erstwhile colleagues like Mr Sisir Das, Mr. V. V. Bhat, the then Chief Secretary of the Andaman and Nicobar, who was a very key figure of the relief operations at that island when the problems were at their peak. They have graced this occasion today to participate in these deliberations.

We do look forward to a very intense deliberation for each of the presentations. I am sure that it is going to be not only an informative and educative exercise but also a very enjoyable day discussing something that has several dimensions, which makes itself amenable to a multidisciplinary approach of understanding.

Meeting Report: Six Months after the Tsunami*

R NARASIMHA, SANGEETHA MENON,
PAPIYA BHATTACHARYA AND M B RAJANI

A meeting was held recently to discuss the unexpected tsunami that struck the shores of South India and other neighbouring countries on 26 December 2004. An under-sea earthquake that occurred at 07 : 58 : 53 local time in Sumatra caused the tsunami. The tsunami was among the deadliest disasters in modern history, and killed more than 240,000 people. The epicentre of the earthquake was in the Indian Ocean, north of Simeulue island, off the western coast of northern Sumatra, Indonesia. The resulting tsunami devastated the shores of Indonesia, Sri Lanka, South India, Thailand and other countries, with waves of tens of metres height. It caused serious damage and loss of life as far as the east coast of Africa, with the farthest recorded death due to the tsunami occurring at Port Elizabeth in South Africa, 8000 km away from the epicentre.

The objective of the meeting was to discuss different aspects of the tsunami, including our scientific knowledge of the phenomenon, its environmental, historical, sociological, psychological and behavioural dimensions, and the most appropriate action that the country might take so that the large losses in human life and property that accompanied the December 2004 tsunami will

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not be repeated. The meeting brought together scientists, representatives from the government, historians and social groups that have been involved in tackling the consequences of the disaster. There were about fifty participants: twenty of them speakers (including six from out-side Bangalore) and the rest invitees.

The meeting began with a welcome speech by K. Kasturirangan, Director, National Institute of Advanced Studies (NIAS), Bangalore, who stressed the need for attention to the problem from a variety of different viewpoints. This was followed by an introduction by R. Narasimha, who highlighted the need for better understanding and monitoring of tsunamis; they do not give long warnings like cyclones, but on the other hand, once it is known that a tsunami has been triggered, the rest of its course can be predicted sufficiently accurately to take action to prevent loss of life, provided an efficient method of issuing warnings along the coastlines can be institutionalized.

C. N. R. Rao was one among the few Indian scientists who were actually witnesses of the event; he and his family were in Sri Lanka, right on a beach where the tsunami struck. Fortunately, he was not a victim of its fury, as a last minute decision to go away from the beach saved him and his family. He shared his first-hand experience of encountering this unexpected natural disaster, and stressed that what struck him most was how helpless he and others felt because of the difficulty in communication. The usual systems had all failed. (One mobile, which could reach Colombo, turned out to be a boon.) However, the entire ground floor of the hotel where they were staying was washed away along with furniture and many unfortunate people were taken unaware. As he was in a canal close by at the time of the disaster, the first thing that he noticed was that the water level in the canal rose abruptly, and all of a sudden many crocodiles appeared. He mentioned several questions that were raised by the devastation caused by the tsunami, including proper regulation of construction near the shoreline, measures that might be taken to have well-understood warning systems (frequently checked), and the setting up of an effective disaster management system which could respond immediately. He noted that this disaster was among the deadliest in modern history.

V. S. Ramamurthy (Department of Science and Technology, Government of India) delivered the keynote address, which began with details of the earthquake. He said that earthquakes are a major source of tsunamis, especially if the magnitude of the quake is more than 8 on the Richter scale. There is limited time to prepare for it. He proposed an earthquake monitoring system that works non-stop; ocean-based earthquake and tsunami detection systems; an on-line tide gauge network which will run round the clock, and a tsunami alert system where appropriate software will issue warnings to all cell-phone users. Ramamurthy pointed out that communicating in times of emergency is not easy (even if the system is working): one may not know what and how to communicate and how to respond. Referring to the false alarm on 31 December, a few days after the 26 December tsunami, he said there is nothing unprofessional in raising an alarm and withdrawing it; people should be trained to respond to such warnings. A tsunami in the South-east Asian area is uniquely characterized by low probability, long recurrence intervals and high-consequence hazard. Despite large aftershocks in the Andaman region since 26 December 2004, there have not been any tsunamigenic events till date. Therefore, he pointed out that a tsunami early warning system tailored to the specific characteristics of the Indian Ocean region has to be designed. Ramamurthy also suggested a National Emergency Response System, where a bulletin is issued if an earthquake is detected. The magnitude of the earthquake, sea-level data and ocean bottom sensors would give inputs for issuing tsunami warnings. It could be decided on the basis of such data whether the earthquake or the observed tidal wave activity would be enough to cause a tsunami. If the results are positive, a confirmatory warning could be given. He stressed that future efforts should be directed towards enhancing public awareness, improving disaster communication and modernization of existing technical systems.

The science of the tsunami was discussed by Vinod Gaur (Indian Institute of Astrophysics, Bangalore). He stressed the importance of creating quantitative hazard maps. He explained at length how a tsunami results from a rupture in the sea crust only if the earthquake results in an upward displacement of the sea-floor, and how we could use existing data on tsunamis and earthquakes to determine if conditions are changing. Based on the chronology of tsunamis and the topography, Gaur said that there would probably not be another tsunami from the same Sumatra source for another 100 years or so. He said that programmed science involving preparation of hazard maps, collection of relevant data, advanced warning systems, education and awareness, communication with appropriate software and construction of tsunami barriers may help in future tsunami disaster management. A tsunami may only be a metre or so high over the deep oceans, but can increase to tens of metres in height in shallow coastal waters. Close to land it begins to feel the ground, the wavelength decreases and the wave overturns. Considering that Indonesia is along plate boundaries, the earthquake itself was not unexpected, but what was astonishing was that it would travel thousands of kilometres. It is a lesson that rupture zones can link up, considering the quakes of 1881 and 1941 in the Andaman Islands.

In the session on 'Modelling and observational approaches', S. R. Shetye (National Institute of Oceanography, Goa) presented an analysis of the events of 26 December 2004, using the wealth of information provided by tide gauges in the Indian Ocean and elsewhere. As we plan for the future, sea-level data need to be carefully analysed to understand better the physics associated with such events. He said historical data that exist in the country concerning extreme events along the coastline should be carefully analysed, as it would help in taking a holistic view of many coastal hazards when we develop warning systems for some.

K. Radhakrishnan (Indian National Centre for Ocean Information Services, Hyderabad) said that his institute was a member of the government initiative to have operational tsunami and storm-surge warning system models by September 2007, the estimated total cost of which was Rs 125 crore.

S. Hegde (ISRO Headquarters, Bangalore) discussed the steps recently taken by ISRO, like the development and installation of automatic weather stations, which would be continuously operational and provide key parameters for atmospheric studies. He stressed the urgent need to expand India's radar network to cover all the coastal areas, and ISRO's proposal to develop optical or photonic sensors that can be placed at the ocean bottom to sense changes in tidal activity. Hegde also outlined the work undertaken using space-based platforms in inundation mapping, detailed scale damage assessment, identification of safer places for rehabilitation, integrated coastal management for reducing the impact of tsunamis using remote sensing data, providing communication links for relief, telemedicine and counselling via satellite.

The present status in India, of earthquake monitoring systems and plans for the future was explained by R. S. Dattatrayam (India Meteorological Department). He said the idea is to install a system called DART (Deep Ocean Assessment and Report) that would provide early warning of tsunami arrival on Indian coasts. It is expected to be fully functional in two-and-a-half years.

S. Settar (NIAS) and Sukumar (Indian Institute of Science, Bangalore) provided two unusual dimensions to the discussions at the meeting. Settar took us back to the 7th century Tamil poet, Nilakantan, whose work records that out of three Sangams, two were lost due to what presumably were tsunamis. During the first Sangam, the south of Sri Lanka was 'grabbed' by the ocean (*kadalkol*); and literature surviving today refers to the rivers Pehruli and Kumari and the land lost by them. Settar also discussed the legend of a sunken continent around South India called Lemuria.

Sukumar spoke on animal behaviour before and after the tsunami. Strangely, very few animals perished in it. Could it be because animals have a hidden sixth sense that tells them of such threats beforehand? Or could it be because animals like elephants, which communicate by sound waves around 10 Hz, can sense seismic signals, and can hear the approaching waves of the ocean? He cited an instance of eight tame elephants in Thailand that bolted away from the coast. There were reports of flocks of birds that left the Tamil Nadu coast, and wild animals which moved inland before the tsunami. One may ask if animal behaviour can be used to warn about quakes. In 1985, Chinese scientists predicted an earthquake based on their observations of rats coming out of their burrows everywhere, although the method was later discontinued.

The session on the 26 December tsunami event brought in reports of some firsthand experiences of people who were either in the affected areas at the time or reached there soon after the disaster. From the Andaman Islands there was a vivid account by V. V. Bhat, who was in charge at Port Blair. There were many practical problems during relief operations, e.g. the huge number of bodies of victims along the coastlines, difficulties in extracting and disposing of dead bodies, and delays in arrival of relief and help at Port Blair because of damaged runways, and bodies lying on the airstrip.

Sanjiv Lewin (St. John's Medical College, Bangalore) spoke of how his disaster relief teams participated in tsunami relief in the Andaman Islands. He shared the challenges faced by the teams and highlighted the need for being prepared to face a large-scale emergency situation, training people to provide relief in a productive way, prioritizing medical needs for providing essential drugs, and the need for disease surveillance, preventive measures, vaccinations, curative care, psychological counselling and local field assessments.

The kind of investments being made in sensor systems and other technologies seemed in direct contrast to the lack of funding support for the rehabilitated tsunami victims at Chennai. A film clipping projected by Thelma Narayan, an epidemiologist with Community Health Cell, Bangalore showed how miserable living conditions were in the relief camps. The material used for the dwellings became so hot that the residents were forced to go out, where squalor, trash and disease coexist. Women and children were not safe, and men did not earn enough to eat. The day before the meeting, she said, these dwellings had caught fire and many had died. These tsunami victims only prove the fact that to be poor in India is a sin.

Rama Govindarajan (JNCASR, Bangalore) presented an observer's viewpoint on the relief operations. She said that there were many volunteers but manpower was not properly used. There was desperate need for equipment like earthmovers, trained volunteers, and proper allotment and distribution of work. There was shortage of skin ointments, bandage kits, scissors, and local anaesthetics that are basic needs in a situation like this. Abundance of unwanted old clothes was the biggest hindrance in relief operations.

The last session was a panel discussion chaired by Arcot Ramachandran. Baldev Raj (IGCAR, Kalpakkam) dwelt on measures taken in the township and surrounding areas; S. S. Meenakshisundaram (NIAS) on rehabilitation and reconstruction strategies in general; D. Sengupta (IISc) on the need for research on disaster management and appointing right people for it; and Thelma Narayan on post-tsunami public health response to meet community needs. The meeting came to an end with Kasturirangan summarizing the proceedings of the day and with closing remarks by R. Narasimha.

It was clear from the workshop that we have tsunami relief teams all over the country, numerous NGOs girding their loins to outdo each other in helping the victims, a 'tsunami response watch' etc., but the question remains when we will be in a position we are better equipped to deal with another such multi-dimensional disaster, if one were to occur in the near future.

Myths, Legends and Traditions Associated with Tsunami

S SETTAR

In the 70's of the 19th century, a British zoologist Philip Lutley Scaltor and an Austrian botanist Eduard Suaess surprised the world by declaring that in the remote past there existed a large single continent stretching from the Indian Ocean to the Pacific. It was the homeland of a primitive primate called Lemur, according to Scaltor and of a botanic species called Gondwana, according to Suaess. Scaltor named it Lamurian Continent. Suess called it Gondwanaland. Between 1870 and 1890, these theories stimulated heated discussion among scientists. Though several agreed on the existence of this continent, not all of them agreed on the names given by the British and Austrian scientists. This led to the renaming of this continent. *'African Indian Continent', 'Indo-Oceania', 'Indo-Madagascar Peninsula'* were some among them. It was also argued that this was not only the home of a unique zoological or botanic species but the very birth place of the humans species. Earnest Haeckel of Germany was probably the most vocal advocate of the latter theory.

These scientists argued that Lemur and the Gondwana had spread across this land mass during the Mesozoaic era when it bridged South India with South Africa, Australia and even South America. At the close of the Cretaceous and beginning of the Eocene epochs, it was fragmented by a massive tsunami and, with the exception of small and a couple of large units such as Madagascar and Australia, the rest was appropriated by the Indian ocean.

This dialogue on the sunken continent was continued through out the late 19th and the whole of 20th century, now and then changing its course. It gradually passed from the hands of scientists to those of Theosophists and linguistic zealots.

Among the scientists of the 19th century who had broadly agreed on the extinct continent, same had remained unconvinced of its submergence in the ocean. In the 1870s, naturalist A. R. Wallace stated that the continents are static, they could be subjected to some amount of coastal erosions but they do not collapse into the sea and settle on its bed. A German meteorologist A. L. Wegener and some others of the 20th century also argued that when a continent breaks up, the splinter units would drift to some distances but do not drown into the ocean. Not withstanding these, believers on the sunken continent firmly held to their ground and aspired to know what was on the oceanic bed. This led to under-water expeditions such as *Anglo-Egyptian John Murray Exploration* of 1833-34, *HMS Challenger* of 1872-76, *British Admiralty Sealark Exploration* of 1904, *International Indian Ocean Exploration* of 1959-65, *Kerguelen Exploration* of 1998-99, etc. The ridges, peaks, granite masses and such other geographical formations noticed during these explorations enabled some not only to strengthen their conviction in the sunken continent but also encouraged them to establish their claims on the lost land. Two such claimants deserve special mention here - one of Pacific-Atlantic Ocean and another of Indian Ocean. The former argued that the Lemuria-Atlantic continent was submerged in the Pacific and the only fragment which survived this deluge was the California coast; the latter argued that it submerged in Indian Ocean, leaving behind some small islands and a couple of large units such as Madagascar and Australia.

The advocates of the Pacific-Atlantic school fell back on Plato, who in his two *Dialogues (Timus and Creteas)* had suggested that the continent which lay beyond Gibraltar was once as large as the

Asia Minor and Lybia put together, and that after enjoying a long period of high culture, it had sunk into the sea on account of a massive explosion. As early as 1500 B.C., the Egyptians had also made allusion to a massive volcanic explosion in the island of Thera which had resulted in the destruction of Crete.

These theories - especially of Plato's - made deep impact on medieval Europeans and enthused them to explore the oceanic bed surrounding America, Scandinavian, Kaneri Islands during the post-Renaissance period. Among such explorers, the name of Ignatius Donnelly stands out. In 1882, he declared that the Atlantic continent had been appropriated by the Pacific (not by the Indian) Ocean. This pro-Pacific argument was continued almost into the 1990s, though the most enthusiastic engagers in this debate were not scientists but Theosophists led by Helen Blavatsky, Annie Besant, Leadbeater, Scot-Elliot and others. The Theosophists held that the Garden of Edan was not a figment of imagination but it was a reality till the Eocene era. During this era, 12 to 15 feet tall humans with dark and sagging skin (like that of rhinoceros) had walked the continent, standing erect. They had three eyes and very prominent heals. Hit by massive tsunami, the land habited by them had collapsed into the sea. Those who managed to survive this calamity were later identified as 'Shalmalis' and the rare descendants of this lost community are supposed to be the natives of Australia, Tasmania, Malaya, Papua, Hotante and South India.

The Theosophists asserted that they were able to unravel the secrets of the remote past because of their clairvoyant power, which was beyond the reach of both scientists and historians. They gave this secret knowledge names such as the *'Stanzas of Dzyan'* (Blavatsky), *Akashiac Records* (Steiner), *Naacal Tablets* (Churchward), *Lemurian Scrolls* (an American who named himself Siddhayogi Gurudeva Sivaya Subramani Swamy). They declared that this secret was discovered by them in some remote chambers that lay in Burma, Asia Minor, Tibet, Hawaian Islands. They also identified Mt. Shasta in California as the home of modern day Lemurian descendants. The advocates of this philosophy established institutions and organisations to spread their beliefs. The *Rosicrucian Fellowship* (established in 1903 by Max Haindels), *Arcane Society* (established in 1923 by Alice Baily), *Mighty I am* (established in 1931 by Gai Ballard), *Ramtha Society* (established 1949 by Mrs. J.Z. Nite) are notable among them. A web-site called *Come to Lemuria* created by Sivaya Subramani Swamy is accessible on line even now.

Decades before the Theosophists established themselves in Adyar (Chennai), a section of Tamils had made claims on the Indian Ocean on the ground that what had been lost was once an extension of the coast of Kanyakumari. Infact, the seeds of this belief were first sown by Western scholars, including some scientists. As early as 1873, Henry F. Blanford had declared that Indian and African continents were separated after a great explosion had occurred in the Cretaceous era. H. B. Medlicott and W. T. Blanford, attached to the Geological Survey of India, supported this view and accorded it an official status by publishing this thesis in the *Survey Manual* in 1875. Professor Wadia of this department went a step further to declare that this was an undisputable fact, hardly meriting any further discussion. In 1885, Charles D. Maclean, an ICS Officer in the service of Madras Government, went even further and stated that South India was the birth place of human species and that Dravidians were not immigrants but natives of this land.

All this set into motion speculations on the original homeland of the ancient Dravidians, involving eminent scholars of the time such as Edgar Thurston, Herbert H. Risley and E. M. Forster. E. M. Forster epitomized this belief in his *A Passage to India* published in 1924 in the following words:

> 'The Ganges, though flowing from the foot of Vishnu
> through Siva's hair, is not an ancient stream. Geology,

> looking further than religion, knows of a time when neither the river nor the Himalayas that nourished it existed, and an ocean flowed over the holy places of Hindustan. The mountains rose, their debris silted up the ocean, the gods took their seats on them and contrived the river, and the India we call immemorial came into being. But India is really a older. In the days of the prehistoric ocean the southern part of the peninsula already existed, and the high places of Dravidia have been land since land began, and have seen on the one side the sinking of a continent that joined them to Africa, and on the other the upheaval of the Himalayas from a sea. They are older than anything on the world' (1984, NY, Pp. 135-136).

If the land beyond the southern tip of Peninsular India had sunk into the ocean, the Tamils argued that could have been of none other's than of their own as they were still living on a part of it. The Tamils modified the term 'Lemuria' to suit their phonetic requirement and called it *'Ilemuriyakkantam'* (Ilemaria Continent). Little later they replaced it with a Tamil term *'Kumari-kkantam'* (Kumari Continent). When the issue of the drowned land was warming up, the most ancient body of the Tamil literature, the 'Sangam Corpus', was also discovered. As important as this was the discovery of the term *'Katalkol'* (appropriation by sea) in a commentary written by Nakkirar on Sangam literature.

The Sangam corpus as well as later commentaries made on it brought in a new wave of awareness about their 'antiquity' among Tamils of the late 19th and early 20th century. According to ancient commentators there were three Sangams or Academies of poets and of them, the first two had lasted for 4,446 and 3,200 years respectively. The seats of these two Academies - Ten-Mathurai and Kapatapuram - were drowned in great tsunamis or *Katalkol.* The Third Sangam was established at Mathurai on the banks of Vaigai river some time after Kapatapuram had slipped into the sea. It lasted for 1,850 years. According to a tradition, the seat of the third Sangam was destroyed by an epidemic, but according to the Mathuri *Sthalapuranam,* it was swallowed by Vaigai river, swelled up by the sea. According to *Madurai Mahatmya,* when the Pandyan ruler completed ninetysix Asvamedhas at Madhurai, Indra became jealous of his achievements and hatched a plan to humble him. He bade the lord of the sea to inundate the city of Madurai and swallow it. According to another myth, it was a dispute between Varuna, (the lord of Rains and Seas) and Siva (the lord of Madurai) that destroyed this city. When Varuna covered the city with mighty dark rain-clouds, the lord of Madurai, Alavay or Siva, released four mammoth clouds to devour Varuna's creations. Enraged by this, Varuna bade his clouds to open up and release torrential rain. Siva situated his mammoth clouds in the four corners of the city like the *Matam* or mandirs and made this city gain the name *Nan Matakutal* (the confluence of four temples). Poets Perumparrapuliyurnampi and Paranjutimanivar have recorded and preserved these 'events'.

The *Silappadikaram*, one of the two early Tamil epics, refers to an encounter between Tennavan Pandyan and the Lord of the Ocean. When the Pandyan king hurled his long lance over the sea to declare his authority on it, the insulted Lord of Ocean stepped out in great fury and swallowed not only the rivers Pahruli and Kumari but also the entire hilly track adjoining them. How much of land was lost on account of this became the concern of Adiyar Kunallar while preparing a commentary on this epic. According to his estimate it constituted fortynine *nattus* or *nadus*, measuring seven hundred *Kavatam* of land. This estimate of ancient commentator was attempted to be converted to modern scales by the Tamils of the 20th century. Though they could not reach any conclusion, they did not stop making guesses. Their conjectural calculus brought them somewhere near 6000-7000 and 1400-2000 sq. mile area. More realistic among them felt that it may not have been far larger than two *Kurrams*.

While this probe was in progress, a school teachers named K. Annapoorni stole the hearts of Tamils by publishing a paper in 1935. She argued that the lost land was as large as *700 Kavatams*, almost equivalent to the Lemurian Continent suggested by scientists. By then, a series of attempts had been made by Tamil scholars to visualize the last land through cartographic representation. It seems to have begun in the year 1894 with the publication of a map in the *Geographical Journal* by Richard D. Oldham of the Geological Survey of India. He drew hypothetical boundaries of the land and the sea at the close of the Jurassic period and contrasted them with what had remained of them. He did not forget to accommodate Lemuria in this map. The first Tamilian to give a Tamil orientation to this map was S. Subramani Sastri, who published a paper titled 'Tamil Natukkal' (The Nads of Tamils) in 1915-16. He was modest enough to believe that the lost land was about the size of a modern taluka, not as large as Lemuria. Thereafter, several attempts were made to redraw the maps of ancient Tamilaham. Mere reading of captions of these maps should help us understand the end goals of the map-makers. *"Puranic India before the Deluge", "Puranic India after the Deluge", "Palaira Tamilaham"* (Ancient Homeland of Tamils), *"B.C. 30,000 India : Tamilnadu", "Katalkonta Kumarikkatam,* or *"Katalkonta Kumarinatu"* (Kumarikkantam or Kumari-nadu appropriated the sea) *"Vanished Lemuria Continent", "The Lemuria Continent which was Destroyed by the Sea", "Kumarikantu allatu Katalkonta Tennatu"* (Kumari Continent or the Southern Nadu appropriated by the Sea) were some among them. During this period, terms like *"Ilemuria Nilai"* (Lemuria: An Ancient Land), *"Ilemuria Kurkuya Nilai"* (Lemuria : A Sunkan Land), etc. entered into Tamil vocabulary.

Attempts were also made to strengthen the theory of the lost land from historical sources, especially from centres which were known to have been hit by the sea. The ancient port towns like Korkkai (of Pandayas), Puhar (of Cholas), Muciri (of Cheras), Nirpeyar (of

Tondaimans) were subjected to fresh studies and reinterpretations bearing this hypothesis. Korkkai (Skt. Kapatapura) which figures in the Sangam corpus such as *Agananura, Narrinai* and the epic *Manimekhalai* had been identified by historians with a village of the same name located at a distance of seven km. from the sea in Tinnavelly Dt. This was taken as evidence to show that Korkkai was rebuilt after the historic port town Kapatapuram, the seat of the second Sangam, was appropriated by a tsunami.

Apart from the Sangam references, any other evidence that surfaced from time to time was also made use for this purpose. For example, the exploration of the sea bed, conducted first in the late 19th century for laying submarine cables and continued subsequently with various other end-goals had bared several interesting secrets sheltered by the ocean. A long series of ridges, small and large mounds, deep valleys, extensive stretches of flat land, zigzag edged mountain peaks, great many falls etc., found during these explorations were counted as evidence to prove the extent of the land that once surrounded Kanyakumari. The Tamils identified this as '*Kumarikkantattota*r' or Mountain ranges of the Kumari Continent.

The idea of the lost land was so deeply and firmly embedded in the hearts of the Tamil of the time, (thanks to stray references found for it in the Sangam corpus), it began to manifest itself in a variety of local legends. These were called *Kshattitapuranam* or local chronicles, *Mahatmyas* or divine accounts, *Puranas* or mythical histories. In the majority of the *sthala puranas,* the divinity that causes the tsunami or flood is either Varuna (rain god) or Indra (lord of the Heaven). Apart from the encounter between Siva and Varuna at Madurai noted earlier there are also several others associated with other centres. In the majority of these, it is either Siva or Sakti who comes to the rescue of the flood victims. They contain the flood, abate its furry, succor the suffering and secure it a safe haven.

We have referred earlier to the port-city of Nirpeyarr of Tondaimanar. The literal meaning of this term is a town 'sprayed by water'; in other words, a port-city which was continuously refreshed by sea drops. On account of this, it was also called *'Katanmalli'*. This port-town was none other than the present Mahabalipuram (Mamallapuram), established by Mamalla, a Pallava king. Not only myths but also historical traces have proven that this famous city was flooded by the sea more than once. We may refer to one such myth associated with this place, as an example: in this Indra becomes jealous of the beauty and prosperity of this city and fearing that it may over-shadow the Indraloka, bids the lord of the Sea to swell, surge and swallow it. History lends some support to the periodical flooding of this port-city, the tsunami that occurred on the 24th December 2004 being the latest among them. When the giant waves retreated, the shore bared several monuments buried under the sand-bed around the famous Shore Temple, probably sucked in by earlier tsunamis.

Similar myths are also preserved in the *Periyapuranam, Kanchipuranam,* Sikailittalapuranam, *Kamakshivilasa, Kanyakumari-mahatmya,* etc., The relevance of these myths to historical reality can not be made out, but they cannot be summarily dismissed either by scientists or by historians.

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Shulman while writing on this subject on an earlier occasion - see *Sankalana*, a literary bi-monthly, (Dharwad), No. 22, (July-Aug. 2005), Pp. 31-44), No. 23 (Sept-Oct. 2005), Pp. 45-50, where a comprehensive bibliography on this subject is also provided). Material relating to the Sangam Literature, original corpus and later commentaries made on it, is too vast to be listed here. For Lemur, Gondwana, Plato, etc., I have depended on the *Encyclopaedia*, especially *EB*. For reference to Mamallapuram see, *The Hindu* (29.04.2005) Bangalore ed., and *Frontline*, (Chennai), 25.03.2005.

How Animals Behaved during the Tsunami: Are there any Lessons to be Learnt?

R SUKUMAR

In the aftermath of the devastating tsunami that hit the coast lines of South and Southeast Asia on 26th December 2005, there have been several stories about how various animals from elephants to ants seem to have sensed the impending disaster and escaped the giant waves. This gave rise to speculations about the "sixth sense" of animals and their potential use as advance warning systems for earthquakes and tsunamis. These stories are obviously anecdotal and it is not easy to place these within a strict scientific framework, but I believe that some useful insights can be had from examining such stories and our knowledge of animal behaviour.

Nearly two thousand years ago, the naturalist/writer Pliny the Elder stated that animal response was one of the four signs of an impending earthquake. The author of a "Natural History", however, himself perished in the eruption of Vesuvius. An even earlier observation dating from 373 BC in Greece relates to the violent earthquake that sank Helice, in Achaia, bordering the Gulf of Corinth. Five days prior to the earthquake, swarms of rats, weasels, snakes, worms, centipedes and beetles, migrated across a connection toward the city of Koria and were saved.

Among the widely reported stories of unusual animal behaviour prior to or during the tsunami of December 2004 are the following:

At Point Calimere along the coast of Tamilnadu, the large flock of flamingoes that feed in shallow waters left the area before the tsunami struck. At the same time, a number of other animals such as black buck apparently moved further inland before the tsunami. Wildlife officials thus found no dead animals after the tsunami.

In Yala National Park, in southeastern Sri Lanka, the giant waves came inland by as much as 3 km. There were many human casualties but hardly any of the animals of the park was found dead (with the exception of two buffaloes). Apparently all or most of the animals moved inland some time before the tsunami rolled inland. Actually, it is not unusual that a large animal such as the elephant escaped even if it had been caught up in the waves because the elephant is an excellent swimmer; in fact elephants are known to cross large water bodies such as shallow seas in the Andaman islands, reservoirs, and large rivers such as the Brahmaputra. However, the same would not be true of smaller animals in the park such as deer.

One widely reported story is about tame elephants in Thailand that behaved unusually hours before the tsunami hit the coast. A report in the Denver Post gave the following account:

Eight elephants live in a camp at Khao Lak about 500 metres from the coastline. Usak Jongkrit, the elephant keeper told this story. Around 4 AM in the morning, about six hours before the tsunami hit, the elephants started making an unusual sound, a loud scream he had never heard before. About 5 minutes before the tsunami hit, the elephants screamed again and one elephant broke its chains and ran uphill. Another elephant carrying tourists likewise bolted. Jongkrit believes that elephants have a sense of the sea.

Two stories about the behaviour of insects can be told:

A tourist family at a resort in Thailand complained to the management about the menace of cockroaches and ants on 25th December, and moved to a different resort.

I heard that a Sri Lankan veterinarian (who was at Galle) noticed millions of ants swarming out of the ground and moving away before the tsunami struck. He sensed that something unusual was happening and himself left the area.

A skeptic may explain this behaviour as follows. Cockroaches and ants are pests of buildings at several places and it may be just a coincidence that this tourist family complained about it at one resort. There are thousands of tourists in resorts along the coast and it is not unusual for one family to make such a complaint.

Elephants are known to behave oddly and disobey their mahouts.They often tend to break their chains and run away, especially if a bull elephant is in musth. Mahouts often have difficulty in controlling their elephants. There are thousands of captive elephants across Asia and many of these are kept along the coastline. It may be just by chance that the elephants of Khao Lak happened to behave in this manner on 26th December 2004.

Even the story of the escape of animals in Yala National Park is possibly exaggerated. Sri Lankan scientist Prithviraj Fernando who has been studying elephants in Yala tells me that few animals are actually found in the area that was inundated by the tsunami. Thus, it is not unusual that hardly any animals died as a result of the tsunami.

To an elephant behaviourist other explanations come to one's mind. During the 1980s it was discovered that elephants communicate through sound frequencies that are below the threshold of human hearing (Payne et al. 1986). This infrasound range of elephant hearing extends down to about 10 hertz. In fact, elephants have an elaborate language of communication based largely on infrasound. Could the approaching tsunami or the earthquake itself have generated low frequency sounds that were picked up by the elephants? If so, the natural reaction of the elephants to this completely unusual sound would have been to run away from the direction it came from – in this case away from the coastline.

There is another more plausible explanation to be considered. Recent research has shown that elephants can sense ground vibrations and the direction of such signals (O'Connell-Rodwell 2000). These seismic signals originate through "foot stomping" (as when an elephant is angry) and general locomotion, as well as through acoustic signals that transmit through the ground as "seismic-evoking" sounds. Seismic signals have the potential for long distance transmission. Large animals that produce high amplitude vocalizations are the most likely to produce seismic vibrations.

Seismic waves that originate from infrasound rumbles and foot-stomps both had a velocity of 248-264 m/sec that is lower than the speed of sound in air. These travel as Rayleigh waves in shallow almost 2-dimensional, cylindrical concentric shells along the surface of the earth, with predominant frequencies around 20 Hertz that is also within the ideal frequency range for long distance transmission in the air.

Detection of seismic signals may occur through receptors on the feet of elephants; such receptors – tiny hairs – have been found on the tip of the elephant's trunk. Localization of seismic signals may be facilitated by the fact that there is a greater phase difference between the front and the hind feet of the elephant relative to the phase difference between its two ears. Distance to a sound source could also perhaps be determined if elephants were able to use the difference in time of arrival between seismic and acoustic signals. Is it thus possible that the captive elephants at Khao Lak sensed the earthquake and the direction of the tremors?

Rayleigh waves have been well documented in communication signals made by many arthropods, crustaceans, amphibians and even large mammals such as elephant seals. Indeed, seismic signals can be a powerful component of an animal's communication system, serving as a tool for finding mates, detecting prey, intraspecific spacing and warning. Seismic signaling is well-known in burrowing animals such as rodents. For instance, the Cape mole-rat apparently communicates with others by drumming its hind legs on the burrow floor. The Namib desert golden mole is a functionally blind, nocturnal insectivore. This animal is able to detect termite colonies and other prey solely through seismic cues. Other modes of energy transfer in solid media, such as the P (Primary) and S (secondary) waves could play a role in such communication.

Can animal behaviour be used to predict earthquakes? The US Geological Survey states officially that animal behaviour cannot be used to warn about earthquakes. Such behaviours are not subject to analysis by the scientific method as they are not quantifiable and reproducible.

There is one unverified story that Chinese scientists used animal behaviour – such as rats coming out of burrows in large numbers – to successfully predict the Haicheng earthquake of 1975.

However, at least one scientist has tried to explain such animal behaviour prior to an earthquake as the outcome of the evolutionary process of natural selection (Kirschvink 1998). As seismic Primary (P) waves travel faster through the earth crust than the associated Secondary (S) waves, if animals are sensitive enough to detect vibrations accompanying the arrival of P waves, that sense could provide enough of a warning to trigger a death-avoiding response immediately prior to the arrival of deadly S waves. He thus concludes that an understanding of possible seismic precursors that are presently outside the realm of seismology could be gleaned from a study of animal behaviour, sensory physiology and genetics.

What about the responses of aboriginal human societies to the earthquake and tsunami of 26th December 2004? It is now well documented that the aboriginal peoples of the Andaman & Nicobar islands escaped virtually unscathed from the tsunami. Only 9 persons from the Shompen tribe who were on the coast fishing seem to have died in the tsunami, a very low death toll as compared to the thousands of other people (recent immigrants) who perished, especially in the Nicobars. It is not clear if other aboriginal people who survived did so because they moved into higher ground after sensing the earthquake (relying on folklore) or whether they just happened to be in deeper jungle in the first place.

Folklore and traditional knowledge would, however, be very important for tribes living along coastlines and isolated for thousands of years. There is evidence from a study of folklore among tribes along the Pacific coast that they possess such knowledge about earthquakes and impending tsunamis (McMillan 2002). Such folklore would undoubtedly have had adaptive value to tribes highly vulnerable to natural disasters that occur infrequently.

In conclusion, there is a scientific basis for detection of seismic events by various animals. This needs more detailed investigation. Our present knowledge of animal behaviour is insufficient for use as an "early warning system" for earthquakes and tsunamis but, undoubtedly, this is a subject we must pursue.

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Six Months after the Sumatra Tsunami

VINOD K GAUR

1. The Sumatra Tsunami and Measures to Mitigate future Adverse Impacts

The immediate cause of the giant Tsunami waves which wrought widespread havoc on Indian ocean shores on December 26, 2004, was the almost sudden ~50 feet uplift of a 600 km long and ~80 km wide strip of the ocean floor off the western coast of northern Sumatra in Indonesia (Figure 1). The concomitant vertical displacement of the deep water column above (Figure 2), subsequently counteracted by gravity, set off an ocean scale wave motion that radiated energy outwards of the initial pulse with a velocity of nearly 700 km/hr, across the world oceans. While the waves spread inconspicuously over the deep ocean, and virtually unattenuated because of the low viscosity of water, they were rapidly slowed down to a mere tenth of their original velocity on approaching the shore. Here, impeded by the complex shallowing floor of the coastal ocean, they shortened in wavelength thereby gaining height and tripping over their even slower fronts, steepened like the familiar surfs to turn into a flood of inundation that severely ravaged the Indian ocean coasts taking a heavy toll of life and subsistence habitats.

The catastrophic up-thrusting of the offshore Sumatra shelf against the Indian ocean floor to the west-southwest, occurred along a brittle contact surface (Figure 3) between the Islands' shelves and the Indian ocean floor that had remained locked by friction for more than a century but gave way to the steadily mounting stresses created

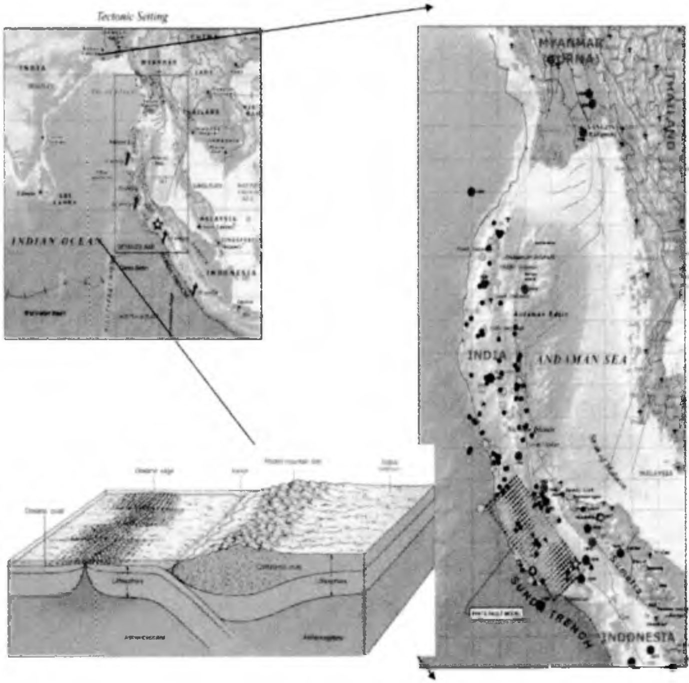

Figure 1. *Left upper:* Shows the Indian ocean-Andamans Indonesian plate boundary, arrows mark the relative motion of the denser Indian oceanic plate with respect to the islands; *Right:* Geographical location of the initial rapid motion Sumatra rupture with earthquake epicentres as circles denoting their sizes; *Lower Left:* A schematic of the subduction of a denser oceanic plate beneath a lighter island arc and the upper parts of their brittle interface.

by the continuing descent of the denser ocean floor slab on exceeding the frictional bond. Physical theory allows one to compute the evolution of a tsunami from its source to a target shore, given (i) its shallow bathymetry and coastal topography, (ii) bathymetry of the intervening ocean, (iii) morphology of the rupture plane - usually a deep ocean trench interface between the shelf and the subducting ocean floor - and (iv) its coordinates, dimensions and slip. Given this computational possibility, one can create a host of tsunami run-up scenarios (Figure 4) along vulnerable coasts for a suite of anticipated ocean floor ruptures capable of generating a damaging

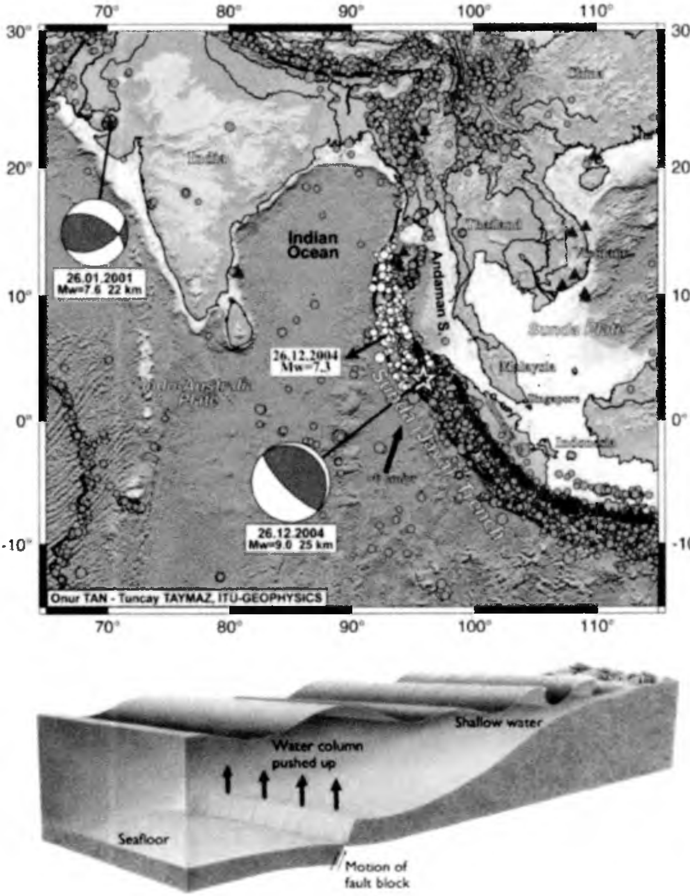

Figure 2. *Upper:* Geographical location of the Sumatra rupture and its failure mechanism; *Lower:* Schematic of the rupture causing a sudden vertical displacement of a deep water column.

tsunami impact, to furnish a probabilistic framework for Risk mapping of shore lines and rational approaches to space planning as well as design of coastal habitats and protective structures. Fortunately, global digital bathymetry maps continually updated by incorporating new depth sounding and marine gravity data, are available to enable one initiate this endeavour straightaway.

Technologies for generating the first three of the above mentioned prerequisite data sets for Risk Evaluation are at hand today and, albeit nontrivial, can be pressed into execution if purposefully pursued. Educated specification of probable rupture zones and parameters on the basis of our current understanding, although less precise, can then enable us to construct first order hazard maps. Meanwhile, a crucial task would be to refine our approaches to more realistic specifications of possible rupture parameters in a region in the perspective of our current understanding of the Underlying Causes of instability in the earth's brittle rind on which we live, in turn, stemming from the workings of planet earth's thermodynamic engine: Plate Tectonics and more specifically, its regional characteristics.

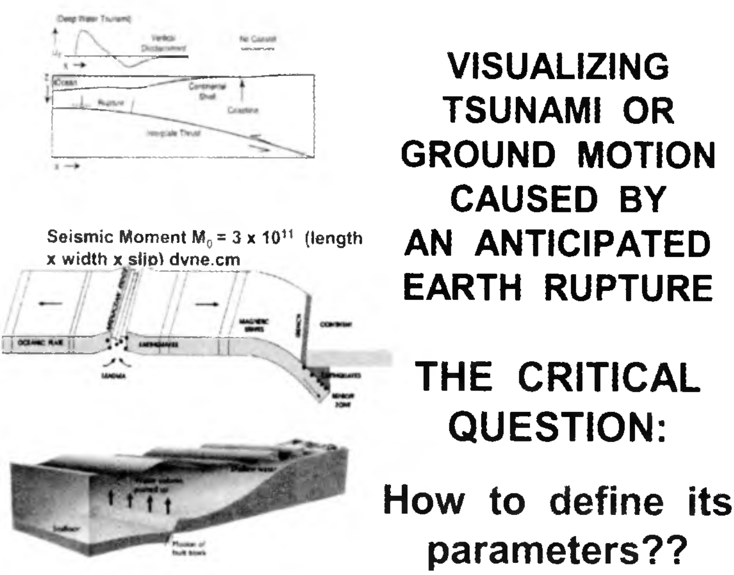

Figure 3. Schematic diagrams showing the brittle interface of a subducting oceanic plate, seismic moment of the rupture plane that is the amount of energy released by the rupture process also denoted by the magnitude of the shock and creation of an ocean scale tsunami wave.

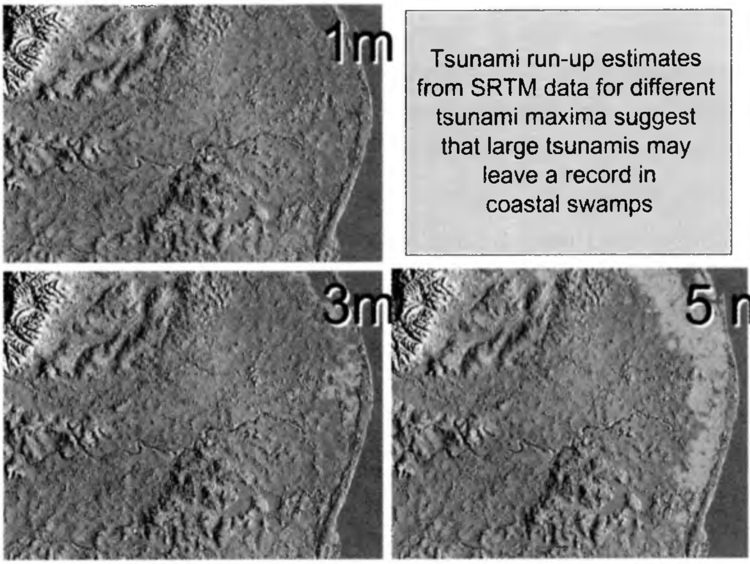

Figure 4. Computer simulated images showing the extent of inundation that would be caused by tsunami run-ups of 1, 3 and 5 metres over the Chennai coast, as an example of advance knowledge product for generating hazard scenarios as an aid to rational planning.

2. Three Critical Steps

I believe that a first order space-time evaluation of hazard and risk in terms of exceedance probabilities of maximal hazard intensities during selected future time windows, constitutes the first attainable and effective step toward catalyzing individual, community and State initiatives that would help sustain the resilience of coastal ocean communities as well as safeguarding critical infra-structure and lifeline supports. The second vital step of immense potential for engendering resilience against natural hazards, is the creation of wider awareness of their space-time characteristics and anticipated intensities, ingrained in the public psyche through well designed educational initiatives at various levels.

Imaginative R&D investigations designed to better delineate the regional plate tectonic regime, as well as a deeper understanding of the as yet dimly appreciated details of possible rupture processes, in my opinion, constitute the third important task towards fashioning a more resilient Post-Sumatra world well prepared to resolutely countenance future earthquake and tsunami hazards. A major challenge posed by this task is rooted in the fact that hazard distribution that is the spatial distribution of ocean bottom or land surface motions in the wake of an earthquake rupture is strongly determined by the mechanical properties of the inter-plate boundary: its location, disposition and roughness. Specifically, therefore carefully designed investigations are called for to better define the Andaman-Burma plate boundary through a detailed mapping of the 3-D structure of the ocean floor-shelf interface beneath offshore trenches and the regional strain field, as well as characteristic process rates covering several cycles of strain accumulation and release by establishing past earthquake and tsunami chronologies through investigative studies of the wealth of information left in the earth archives by such unusually energetic events: uplifted or tilted terraces, isotope branded corals, relicts of distinctive tsunami sediments shoved into mangroves, and the surveyed and/or tell tale evidences of geomorphic changes.

3. A Digression in the Underlying Causes - Perspective for Identifying Necessary Knowledge Products for Sustained Mitigation Measures - the Plate Tectonic Process

The outer ~70–150 km thick colder brittle lid of the earth is fragmented in about a dozen large relatively rigid spherical caps by planet earth's globe girdling fracture systems (Figure 5) eloquently marked by the narrow belt of earthquake epicentres. These caps or lithospheric (rocky) plates, so called because of their larger lateral extent of thousands of kilometres compared to their thickness, may

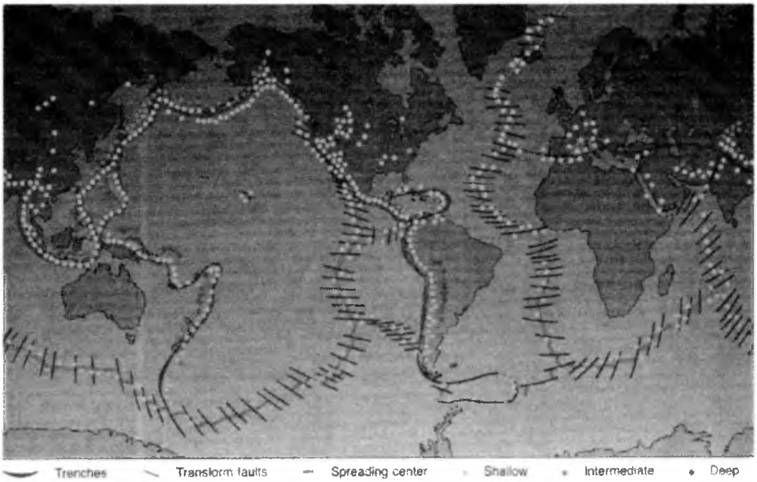

Figure 5. Geographical location of globe girdling fracture systems that divide the earth's outer brittle rind (~100 km thick) into a dozen brittle spherical caps and the sense of relative motions across these fracture boundaries.

be surfaced entirely by the lighter continental crust (Eurasia), a denser oceanic crust (the Pacific) or a welded composite of both such as the Indian plate. Pushed or pulled by forces related to thermal convection in the underlying mantle, through mechanisms as yet only dimly understood, these plates glide ponderously over the warmer, more yielding asthenosphere, inexorably reconfiguring the continents and oceans over aeons, into a new geography. What appears certain however, is that every few hundred million years after long wanderings and continual rearrangements, the continental lithospheres are re-assembled and fused into a single large one that may for long thereafter (~few hundred Ma) remain stationary over some part of the globe, blanketing the continuously accumulating heat underneath and creating, thereby, conditions for the next cycle of magma ascent, plate fragmentation, dispersal and a new assembly. This happens as the overheated underlying material expands and upwarps some favourably disposed region, eventually to split the continent astride an intervening chasm. Decompression melting then causes the already hot material to well up and fill the chasm thus created and, upon quenching, form a strip of new oceanic crust richer in iron and magnesium and therefore denser than the older, skimmed silica rich continents at whose rifted edges the new ocean floor is welded.

Apparently, either by the persistent pushing of the rifted continental plates from the axial chasm or by their being pulled at the far ends, this process progresses apace spreading the new oceanic lithosphere astride the rift axis (Figures 6 and 7) even as it gives up

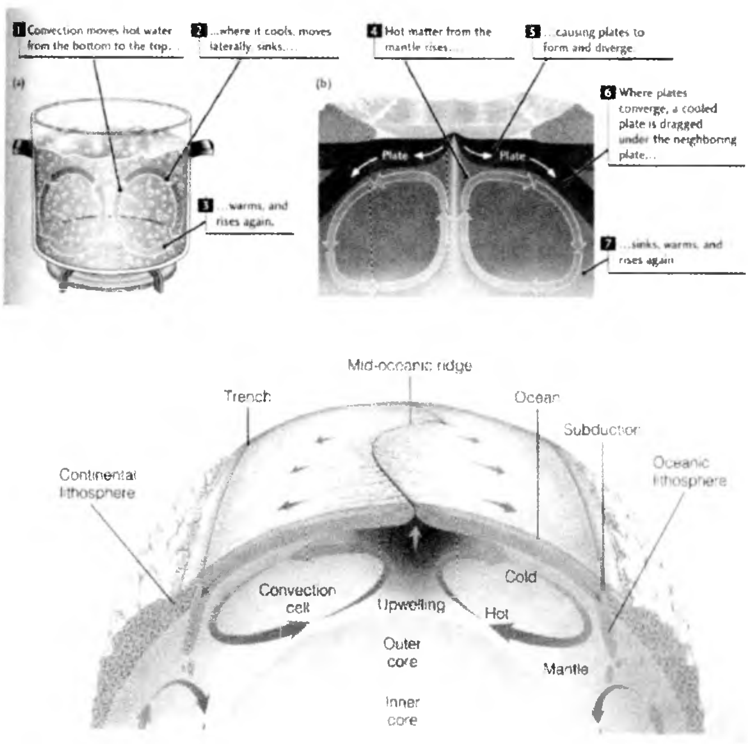

Figure 6. *Lower:* Schematic of heat transport from the earth's interior Analogous to convection cells in a beaker of water heated from below, and generation of an upper boundary layer that is the oceanic plate: the plate tectonic mechanism.

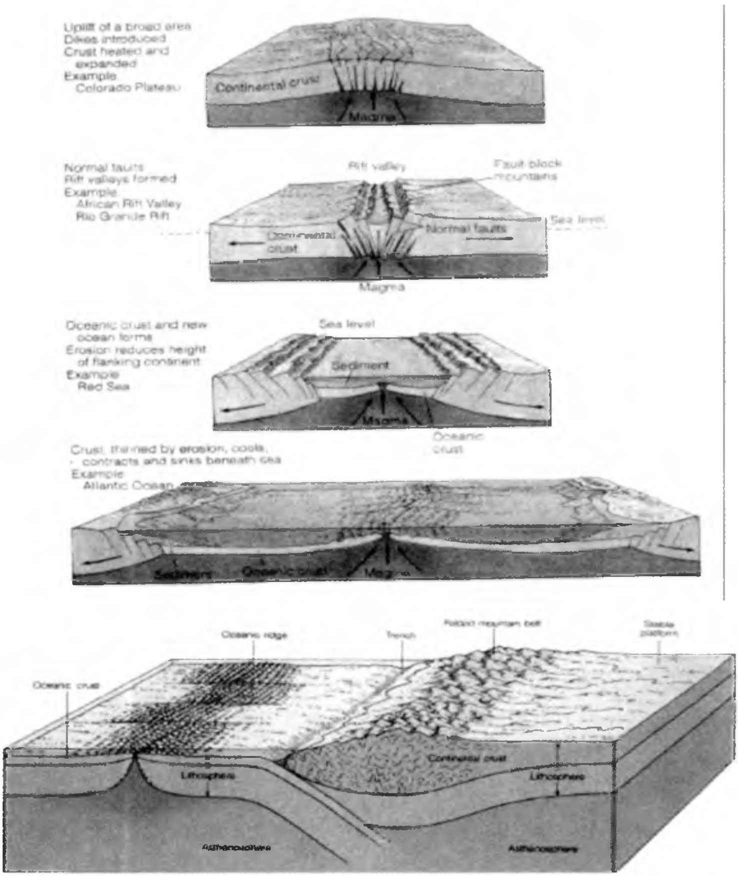

Figure 7. Sequential expansion of the oceanic boundary layer by accretion of quenched strips of successively welled up magma through the initial chasm, causing compression in the earth's outer rocky spherical caps and forced subduction of older, colder and denser plates

its heat and densifies at its farther ends, eventually to dive beneath one, the other or both of the lighter continental margins, its original site of creation, into the earth's mantle thereby closing the convection loop. Oceanic lithospheres, thus constitute the surface limb of mantle convection - transient lids of the earth no older than 200 million years compared with 4000 million years of the continents - that are forever being born, and die young. Their inexorable expansions, whilst still active, inevitably abridge the earth's surface space occupied by the extant lithospheres which are, in consequence, compressed and pushed one against the other. Plate boundaries are thus under constant stress, whether extensional where they diverge astride mid-ocean ridges creating new strips of oceanic crust, or compressional where a denser oceanic lithosphere dives beneath the lighter continental one, or where equally light continental plates are pushed together to crumple themselves into mountain ranges as in the Himalaya. Despite this steady appllcation of stresses, however, the upper ~15-20 km thick upper, colder and more brittle part of the plates are prevented from sliding steadily because of friction. Instead, they keep accumulating strain up to the limit of their strength before breaking down in a mechanical failure. Thus, oceanic plates in their gradual descent into the earth's deep, as happens all along the western Pacific or southwest and south of the Indonesian archipelago, persistently grind against the adjoining islands or continents episodically rupturing a shared interface by a sudden leap of a few metres of accumulated slip . Earthquakes caused by this stick-slip process in brittle materials thus broadly identify the plate boundaries of planet earth (Figure 8), even as some segments such as that between northern Andamans and western Burma remain tentative for want of precise enough seismic and geodetic record.

Long un-ruptured segments of these boundaries wherever clearly identified such as the circum-Pacific, in turn, call attention to the most probable sites of future earthquakes (Figure 9). Past time-history of Plate boundary ruptures thus provides a first order knowledge about future earthquake threats. Fortunately, this can be further detailed by investigations of the rate of strain accumulation across these boundaries, made possible by the steadily evolving millimetre precision GPS Geodesy, and estimates of the current strain budget reckoned from the previous great rupture assumed to have set the strain level to zero. Whilst we do not as yet have a detailed

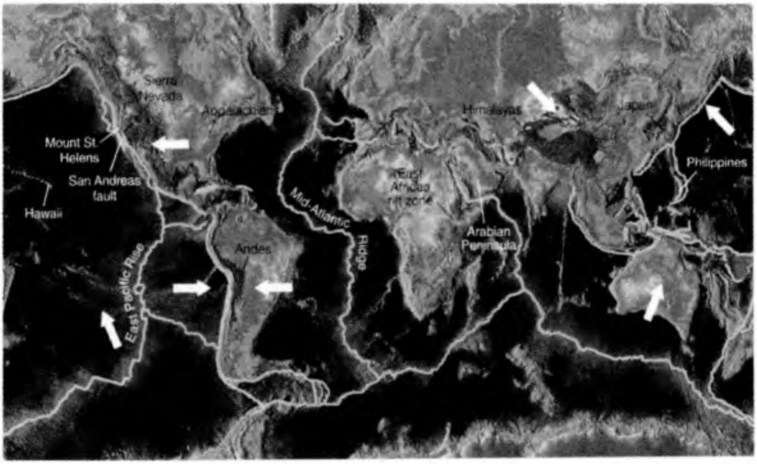

Figure 8. Showing plate boundaries of planet earth, their relative motions and corresponding stress regimes.

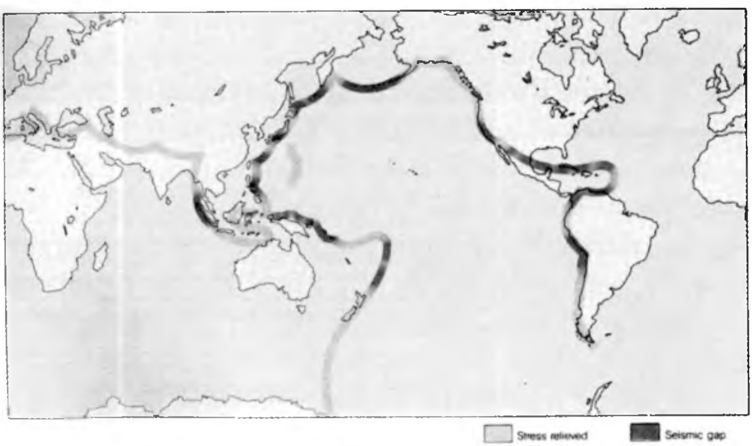

Figure 9. Showing segments of the Circum-Pacific Ocean plate boundary and their relative closeness to future rupture, based on recent strain release by historical and instrumentally recorded earthquake ruptures, those marked red being potentially the most imminent. This figure was generated over two decades ago and shows the imminent threat along the Sumatra plate boundary.

understanding of the rupture process and the variety of possible ways in which it could occur at a given interface, the closeness of the ambient strain budget to the now fairly well constrained failure strain level of ~1 in 10,000, provides valuable guidance to generate and periodically update probabilistic Bayesian estimates of future earthquake rupture scenarios, and thereby of maximum hazard intensities (ground motion, tsunami run-up figures). Meanwhile, careful investigations of the large scale and wide ranging evidences left in the wake of unusually energetic events such as the Sumatra rupture, have considerable potential of creating insightful new ideas about the still somewhat obscure mechanisms of plate boundary ruptures. And, these must constitute the third agenda of our post-Sumatra Tsunami endeavours.

4. Identifying Knowledge Gaps for Meaningful R&D

As is now well known, the rupture source of the Sumatra Tsunami lay on the eastern and southeastern margin of the Indian ocean plate subduction boundary with the Andamans–Sumatra Islands (Figure 9), ironically reminding us of the long standing recognition of this potential tsunami source in the Indian ocean. Indeed, smaller segments of this boundary along the Andaman and Nicobars had already ruptured in 1881 and 1941 (Figure 10), generating sub-metre tsunamis that had been recorded at Chennai and other coastal sites. However, even though the site of the latest Sumatra tsunami was well charted and the accumulated slip of ~10 metres since the last rupture in 1833 fairly well constrained, its severity was unexpected in that several segments of this long subduction boundary from northern Sumatra to Nicobar, linked up to create a single ~600 km long rupture almost instantaneously (~4.5 minutes), and then a little haltingly up to northern Andamans which, in consequence lurched south-west wards by as much as 4 metres (Figure 11). This amazingly complex rupture process involving an average slip of >5 metres (Figure 12) could fortunately be imaged from an analysis of ground

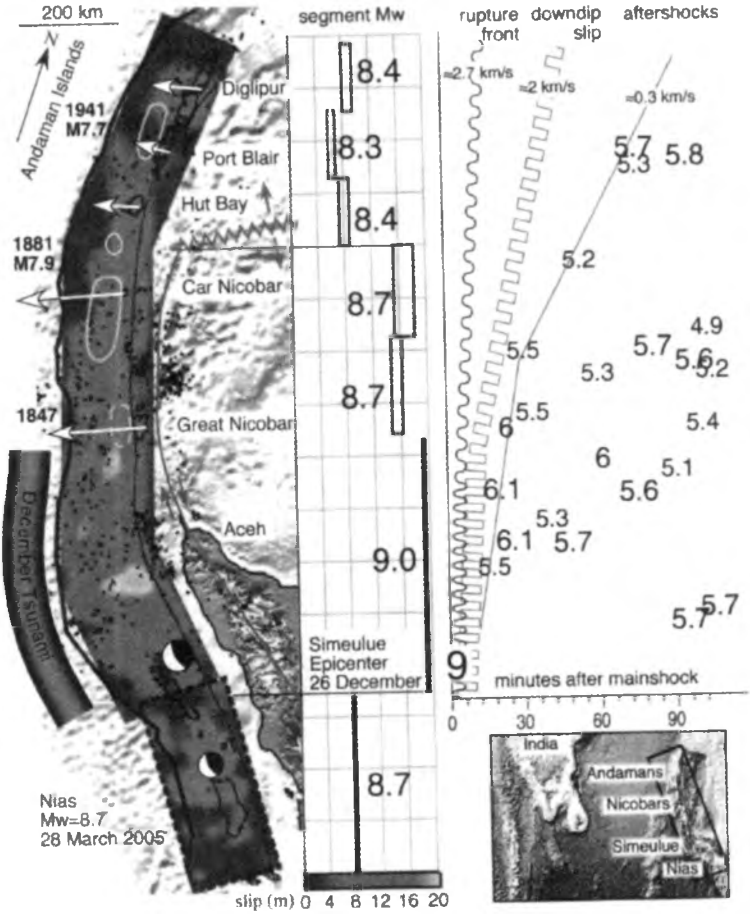

Figure 10. Shows past and the December 2004 rupture along the Andamans-Sumatra as well as the March 2005 rupture that followed the great Sumatra rupture, their extents and equivalent earthquake magnitudes. Arrows denote the actual westward displacements of the Islands. Details of the rupture slip were generated from analysis of seismic wave forms recorded at world wide seismic stations.

motion records generated at a number of sites by seismic waves that radiated outwards of the Sumatra rupture through the body of the earth (Figure 13). Travelling at velocities ~50 times greater than the

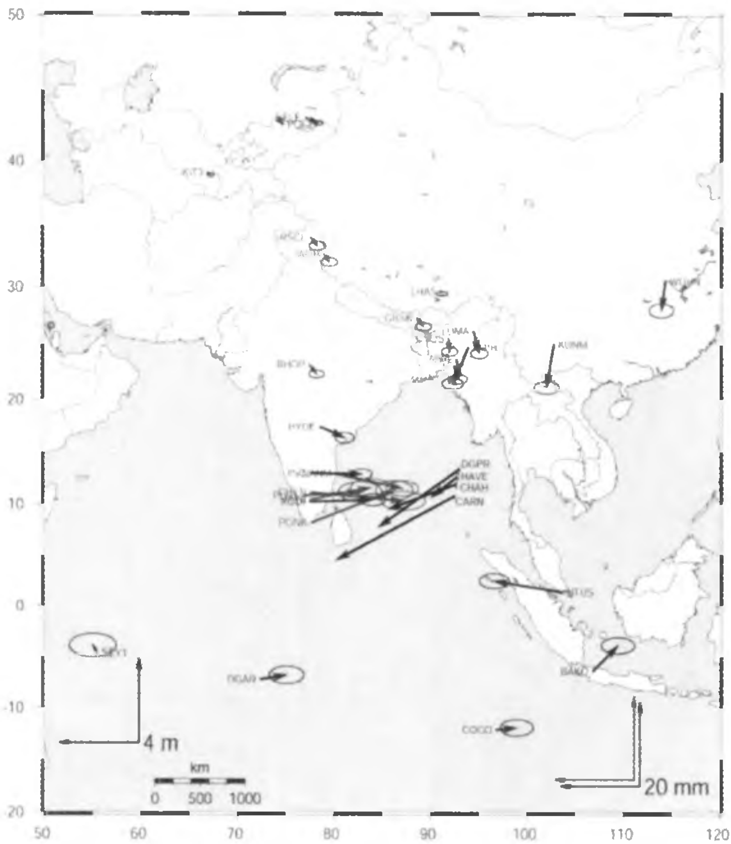

Figure 11. Shows the displacement vectors at various sites in India and the A&N islands calculated from GPS (Global Positioning System) measurements made before and after the Sumatra rupture by scientists at the CSIR Centre for Mathematical Modelling and Computer Simulation (C-MMACS) at Bangalore.

Tsunami, they had reached the farthest seismic stations around the globe within less than 15 minutes with evocative information about the mechanics of their rupture source and also about the path of their reconnoitering journey that scientists in Japan and the United States were able to piece together to create detailed images of the rupture process within an hour of the event, over an hour before the killer

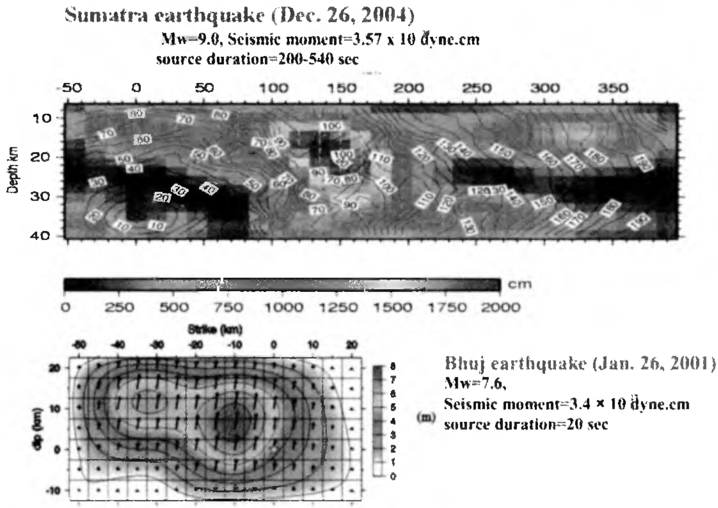

Figure 12. A plan view showing the distribution of slip on the main Sumtra rupture plane compared with that of the 2001 Bhuj earthquake (below), both calculated from analysis of seismic wave forms recorded at world wide seismic stations.

tsunami waves reached the shores of Sri Lanka and India. The enormous possibilities that available computational technologies thus offer for fashioning Advance Warning and Hazard Mitigation Systems can be well imagined. Hopefully, these would be creatively exploited to reduce our vulnerabilities to future visitations of natural hazards.

The seismic records also reveal that the latter half of the 1200 km long rupture from Nicobars to northern Andamans proceeded more slowly because of its passage through a lesser strained plate boundary already partly relaxed by the 1881 and 1941 events. Accordingly, it unleashed only ~30% of the total energy and did not contribute significantly to the main tsunami event. This was fortunate in reducing the effective impact of the earthquake rupture and the resulting tsunami which could have otherwise devastated the entire eastern seaboard of India, and of Burma and Thailand. On the other hand, the surprisingly long stride of the initial Sumatra rupture (~600

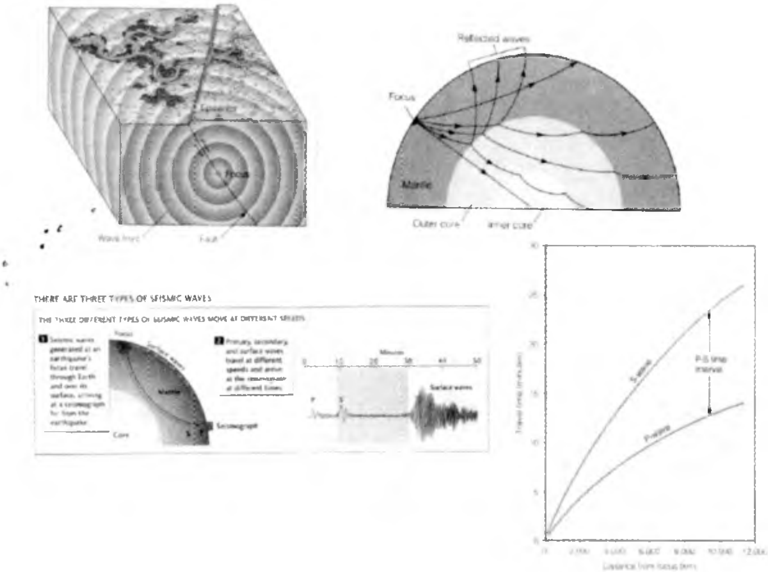

Figure 13. A schematic showing how waves spread through the earth's body following a rupture and reach the surface through direct and multiply reflected and refracted paths bearing critical information in their waveforms of the material properties along their reconnoitring path. These waves travel ~50 times faster than the tsunami waves and reach the farthest part of the globe within less than half an hour.

km) also draws attention to the horrendous possibility, no longer prudent to discount, that earthquake ruptures elsewhere along plate boundaries such as the Himalaya could similarly link up to generate massive shocks against which safeguards must be designed and put in place during the current quiescent period. Whilst these findings are the result of new insights that could not have been imagined before the occurrence of this tragic event, they can be wisely exploited with support from carefully designed research investigations to gain deeper insights into planet earth's inscrutable workings, to further refine and evolve more reliable scientific approaches to future hazard quantification.

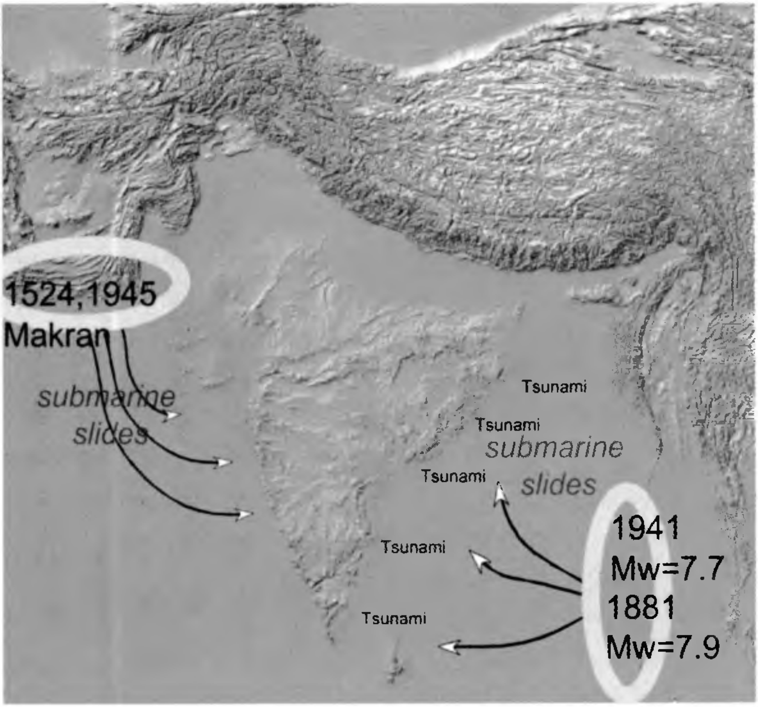

Figure 14. Showing tsunamigenetic subduction zones around the Indian shores as well potential tsunamigenetic mud slides from the gigantic submarine fans created by the Ganga-Brahmaputra and Indus river systems.

5. Future Potential Tsunami Hazards to Indian Ocean Shores

Although near- source ground and sea floor accelerations caused by seismic waves radiated from a massive fault rupture can exceed that due to the earth's gravity and displacements may be as high as a few centimetres, enough to cause devasatation of designed habitats, these are too feeble to rock the ocean water column into a tsunami wave. Because, Tsunamis which are the result of ocean-scale wave motion can only be generated by a sudden and substantial vertical displacement of a deep water column, by a few metres. Tectonic environments capable of producing such vertical motions are known to be associated with shearing of the upper brittle layer of an oceanic plate against an adjoining continental or island plate of lighter material. Since the Andaman-Sumatra rupture zone is expected to take another 100 years or so to accumulate significant recoverable strains, near future Tsunami threats to Indian ocean shores may be identified with other subduction boundaries in the region that may have accumulated sufficient slip for an impending rupture, notably (i) that of the oceanic Indian plate with the Burman platelet along the northern and northeast and (ii) the Makaran coast between the Indo-Arabian and the Eurasian plate in south-western Pakistan. Historical earthquakes have been known to occur along both these boundaries (Figure 14). The 1945 Makaran coast rupture had wiped out the important trading centre of Pasni (Pendse 1948) and caused widespread devastation around the port town of Karachi. Tsunami waves ~2 metres high were reported at Bombay and were quite significant even at Karavar over 1600 km away. Having identified these possible sites of a future tsunami, one must then ask as to what is the likelihood of any one or both of these recurring over the next 50 or 100 years. We now have a fairly good estimate of the rate (~4 cm/yr) at which the oceanic Indian plate grinds against the Burman plate by its continuing descent into the earth's mantle, thereby furnishing the persistent source of a growing strain budget preparatory to the next breakdown. Since the ultimate strain failure level is reasonably well constrained to be ~1 in 10,000, and the recent Sumatra rupture can be safely assumed to have completely drained the previous strain budget setting it to zero, it is highly unlikely that sufficient strain would have accumulated within the next 100 years to cause a significant tsunami-genetic rupture of this zone. However, the probability of the Makaran coast rupturing over the next 50 years is significant considering some estimates that the 1945 rupture was only partial, requiring less time for strain replenishment, and therefore capable of creating a future subduction zone earthquake.

6. Pointers for Action

Against the foregoing perspective, one can well identify both research and development initiatives that would deepen our insights into the earth processes preparatory to, during and after an earthquake rupture and create extensive capabilities for their evocative computer simulation, modeling and visualizations as well as robust management systems to synergistically interface knowledge, technology and a constructive social response. The former are in some sense more tractable because the goals are better definable even as a certain gestation period may be unavoidable for assembling and developing the requisite ingredients: technologies, skills and expertise. These include (i) elucidation of the kinematics of the diffuse northern Andamans - Burma plate boundary by detailed investigation of the contemporary strain field in the region and its tectono-chronology using potentially revealing tell tale evidences archived in sudden topographic (Figure 15) changes and past inundations that are datable: terraces, submergence and uplift of shorelines, characteristic tsunami sediments shoved in mangroves, (ii) advanced level computational skills for modeling and simulation for generating near real-time images of changing land surface, habitats and oceanic areas in the wake of a natural hazard, towards minimizing Risk as well as advance visualization of probable scenarios to sensitize individuals, communities as well as State agencies to potential hazards, (iii) generation of knowledge products: Hazard and Vulnerability maps of high Risk areas to guide rational planning and mitigation measures, (iv) acquisition of high resolution data characterizing shoreline topography and near shore and deep ocean bathymetry as well as three dimensional images of currently locked plate boundary interfaces, and (v) an evocative Educational-Awareness programme to empower people by knowledge of the nature and characteristics of natural hazards as well as issues of mitigating their possible adverse impacts which current scientific understanding and technologies make it entirely possible to address so that even as natural hazards being

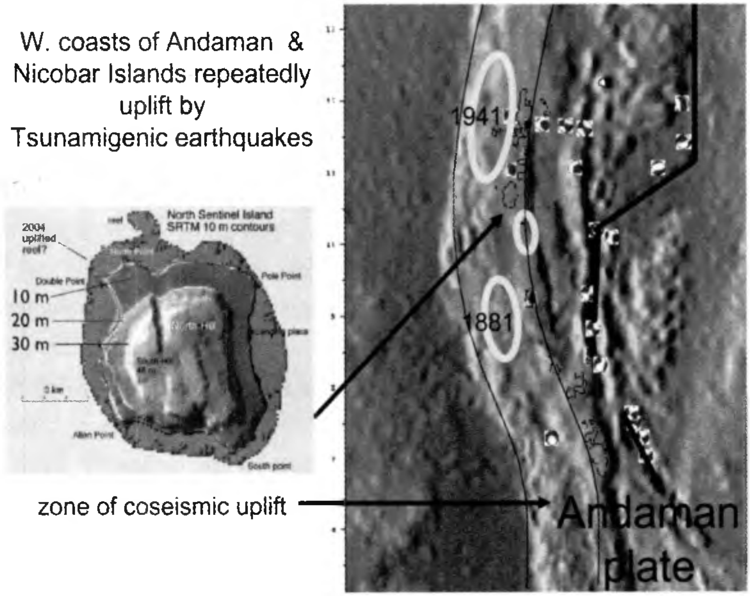

Figure 15. Showing SRTM (Shuttle Radar Topographic Mission) images of the western coasts of the Andamans and Nicobar islands and clearly visible terraces uplifted by past earthquake ruptures/tsunamis as well as the zone of recent co-seismic uplift, pointing to the scientific potential of dating past events and evolving a tsunami chronology for the region for insightful estimation of strain building and release proceses and their rates.

just the other face of a vibrant energetic planet may be inevitable, they are prevented from turning into disaster.

7. Epilogue

Since the dawn of civilization, humans have profitably used hypothesis testing through an inductive-deductive process, and applied the understanding thereby gained to safeguard their lives and support systems and in the process increased their tribe. Until the runaway success of our industrial civilization, however, a deeply intuited covenant with nature remained a powerful guiding force. Today, our increasingly designed world exposes itself to unsuspected risks by unwittingly breaching this nexus with Nature because of failure to grasp the larger reality with which we now engage without a commensurate deepening of our sensibilities despite a vastly more rapid expansion of observation systems, computational strategies and knowledge. Clearly, the greater challenge is to internalize the progressively improved understanding of the anatomy and physiology of natural hazards and their implications for a wholesome sustenance of our increasingly designed world into our life and work to create a wider culture of Design in the Mind both for structuring our operational and management strategies as well as for crafting creative solutions: fiscal, technological and others to accomplish desired societal goals such as minimized vulnerabilities, preparedness, resilience, equity, wider social sharing of losses, to name a few. Finally, it may be instructive to recognize that the full power of scientific and technological possibilities currently available can be more enduringly exploited by shifting our focus of hazard mitigation strategies from the currently limited one of Rescue and Relief to implementation of advance planning and preventive mitigation measures, creation of regularly updated user friendly Knowledge Products, education and awareness of constructive hazard consciousness and simulated visualizations of possible risk scenarios to animate that consciousness, as well as near real-time information and visualization systems for effective Rescue and Relief operations in the wake of a natural hazard.

An Analysis of the Events of 26 December 2004 to Plan for the Future

SATISH R SHETYE

An analysis of the data collected on 26 December, 2004, should help us understand the series of events that followed the great earthquake that occurred on that day. One of the most important amongst these data is the sea level variation. The tsunami triggered by the Sumatra earthquake left a distinct footprint in the records of tide gauges maintained by the Survey of India, Dehra Dun, in some of the Indian ports. These records provided critically important information to estimate the length of the tsunami source region. The length has now been estimated to be ~900 km, a figure at least 30% larger than that arrived at earlier without full use of the Indian tide gauge data. Exercises such a these should help us to develop an effective warning system in the future.

1. Introduction

An earthquake with a magnitude of 9.3 occurred at (3.307.N, 95.947.E) (255 km south-southeast of Banda Aceh, Sumatra, Indonesia) at 0629 IST on 26 December 2004 (Figure 1). This earthquake, which ruptured 1300 km of the eastern boundary of the Indian plate and is the second largest (after the Chile earthquake of 1960) instrumentally recorded (Lay *et al.*, 2005), triggered a tsunami that devastated South and Southeast Asia. The death toll has exceeded 300,000, making this the biggest "killer" tsunami in recorded history (Nagarajan *et al.*, 2006; Bryant, 2001).

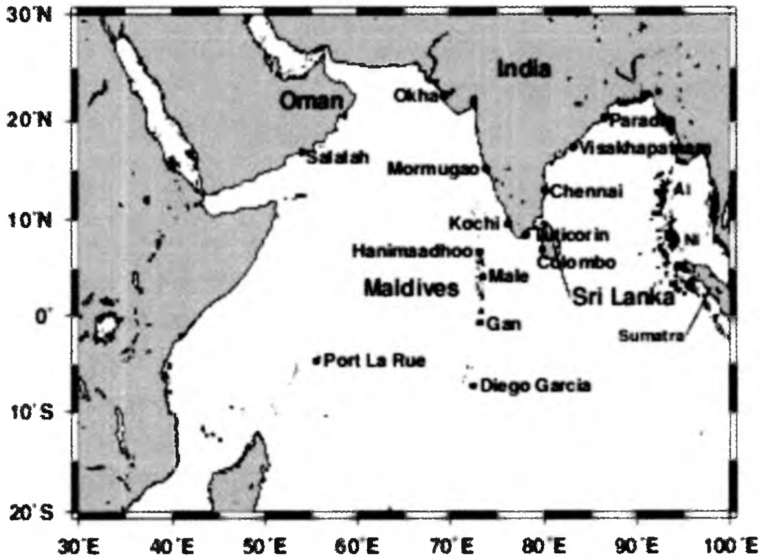

Figure 1. Map of the Indian Ocean showing the epicentre of the 26 December earthquake (asterisk) and the locations of the aftershocks (grey circles) till 10 February 2005. The locations of the tide-gauge stations operated by the Survey of India are marked by filled circles; Other stations are marked by filled squares. Data are not available for Nagapattinam, where the SOI tide gauge was destroyed by the tsunami. AI: Andaman Islands; NI: Nicobar Islands. (Source: Nagarajan *et al.*, 2006).

This article examines the above episode from a special angle: if we know how a tsunami behaved at a few locations far away from the region where it was triggered, can we reconstruct the initial perturbation of the ocean floor that triggered the tsunami? Tidal records tell us about how a tsunami behaved, and analysis of the records can provide an estimate of the initial perturbation, i.e. the tsunami source region. The article is divided in three main parts. The first provides an overview of characteristics of ocean surface waves that we call tsunamis. The next describes sea level fluctuations in tidal records, particularly those along the Indian coastline, during the tsunami of 26 December 2004. The third part uses the information derived from the tidal records to reconstruct the tsunami source region, and comments on how such exercises will help us develop an effective warning system.

2. Tsunamis

Tsunamis are a special class of surface gravity waves that occur in the ocean. They are called surface gravity waves because the gravitational pull of the Earth plays an important role in their dynamics. In a motionless water body, the surface remains flat and in stable configuration. The action of an external force – stress exerted by wind, gravitational pull of the Moon, disturbance on the ocean floor, etc.- can perturb the surface from the equilibrium by introducing kinetic energy into the water body, and particles start moving. Earth's gravity pulls the water particles back towards equilibrium. In the resulting motion, the sum of the kinetic energy and potential energy due to gravitational pull of the Earth is conserved.

The tsunamis are *shallow-water* surface gravity waves (See Shetye, 2005, for a brief introduction to tsunamis). They are called so because they occur in waters that are shallower than half of the wavelength associated with the waves. The ocean, on average, is 4,000 m deep. Hence, wavelengths associated with shallow-water waves are at least 8 km, but they can be much longer. The phase velocity of these waves is $\sqrt{gh}$, where g is the acceleration due to gravity (9.81 m/s^2) and h is the depth of water. As the phase velocity is independent of wavelength, these waves are non-dispersive. In the open sea, their phase velocity is about 200 m/s, i.e. about 750 km/hr. This is roughly the speed at which a jet aircraft normally cruises. The speed of particle motion associated with shallow water waves observed over the open sea is much weaker. The particle motions associated with shallow-water waves are along ellipses (Figure 2). The major axis of the ellipses associated with shallow-water water waves does not change with depth, and neither does the speed of the particles. In technical jargon, this kind of motion, in

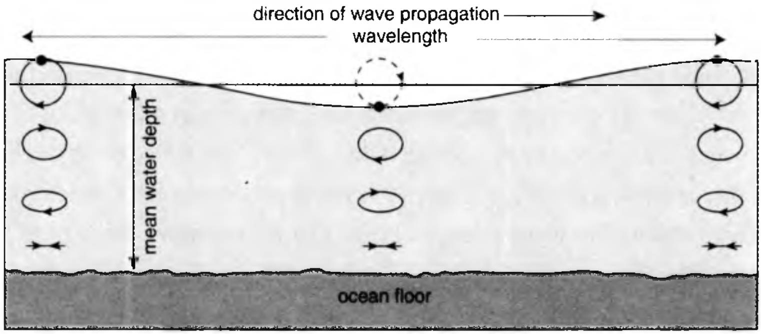

Figure 2. Particle motion in shallow-water waves, showing progressive flattening of orbits near the sea-bed (based on Figure 1.8(c) in "Waves, Tides and Shallow-Water Processes" by The Oceanography Course Team", The Open University, UK, 1994.

which the speed of the particle (the current) does not change with depth, called *barotropic.*

The most common example of shallow-water waves observed in nature are the waves due to tidal motion. They are generated by the gravitational pull of the Moon and the Sun. These motions have periods of about 12.5 hours and 24 hours. In the open sea, their wavelengths are in the range of 100-10,000 km. Tsunamis over the open sea, i.e. in waters about 4,000 m deep, propagate as shallow-water surface gravity waves with typical periods of 100-3,000 seconds and wavelengths of 10-500 km. The surface perturbation due to these waves over the open sea is typically less than about half a metre, and particle velocities only a few centimetres per second. Such particle velocities and surface perturbations are much too insignificant for a passing ship to notice. Hence, tsunamis remain unreported while travelling in the open sea, unless special instrumentation specifically designed to look for them is in place.

As the waves propagate towards a coast, two changes take place: the depth decreases and so does the wavelength. Due to the decrease in depth, the energy in the water column has to be accommodated over a smaller height. The shelf break in the Indian coastal region occurs at a depth of about 200 m. At this depth the wave energy that was earlier distributed over about 4,000 m of the water column has to be squeezed into 200 m. The decrease in depth also leads to a decrease in phase velocity and hence in wavelength. This means the wave energy also has to be accommodated over a smaller distance horizontally. The two effects, decrease in depth and in wavelength, lead to a rapid increase in available mechanical energy per unit volume of water as it propagates towards shallow areas. In other words, the energy density of the tsunami wave increases.

The increase in energy density leads to a transition of the wave from its linear version to a non-linear state. This transition is marked by a decrease in phase velocity and in wavelength, and by an increase in wave height and in particle velocity. According to Bryant (2001), about 60% of the increase in wave height takes place in the last 20 m depth change near the coast. Particle velocities near the coast reach a value of about 7 m/s (~25 km/hr). It is with such velocities that the waters associated with a tsunami move towards a beach. To an observer on the beach, the wave appears as a wall of water (in contrast to the spatially undulating surface seen in wind waves). As pointed out earlier, tsunamis have periods ~1-100 minutes. The periods of the incoming waves determine how rapidly the waters on a beach will rise, peak, and recede, but only to rise again. This goes on generally for about 2-3 days (the largest amplitudes being on the first day) until the energy contained in the packet of tsunami waves is exhausted.

Tsunamis are generated whenever there is a large-scale perturbation (over tens to hundreds of kilometers) of the ocean floor. There are three mechanisms that can lead to such a perturbation:

(a) earthquakes with epicenters located below the ocean floor can make the floor vibrate;

(b) mudslides on the ocean floor, particularly on the continental slope, can suddenly change shape of the ocean floor; and

(c) volcanic explosions, either on the ocean floor or on the nearby continent, can lead to shaking of the floor, or huge quantities of ash that accompanies an explosion can flow rapidly on the ocean floor.

Each of above perturbations of the ocean floor can lead to a perturbation of the ocean surface, which then propagates as a shallow-water wave.

Tsunamis are rare along the coast of India. No account about their presence seems to be available in historical literature from India. In fact, a word equivalent to "tsunami" does not seem to occur in any of the Indian languages. Of all the tsunamis that have been recorded in the Indian Ocean in the recent past, about 80% have been triggered by earthquakes. Earthquakes on the ocean floor occur most often when an oceanic plate subducts under a continental plate. One such "subduction zone" occurs along the eastern rim of the Indian Ocean.

3. The Event of 26 December 2004 as seen in Indian Tide Gauge Data

The earthquake that occurred on 26 December 2004 off the coast of Sumatra seems to have triggered some slumping of the ocean floor west of the Andaman and Nicobar chain of Islands. The earthquake and the slumping perturbed the ocean floor, which in turn perturbed the ocean surface, triggering a train of tsunamis that propagated outward from the region of their generation. Seven tide gauges maintained by the Survey of India, Dehra Dun, in Indian ports (Figure 1) recorded the arrival of the tsunamis. Nagarajan *et al.* (2006) provide an comprehensive description of the tide gauge data when the tsunami reached the Indian ports. The tide gauge at Nagapattinam (south of Chennai), which was the worst affected region on the Indian mainland, did not survive the tsunami. It was damaged along with the housing, and the records could not be retrieved. Data are available for Paradip, Visakhapatnam, Chennai, Tuticorin, Kochi, Mormugao, and Okha. Data are not available from the Andaman and Nicobar islands; the tide gauge at Car Nicobar was destroyed by the tsunami and that at Port Blair was under repair at the time of the tsunami. The SOI gauges are either mechanical float-type gauges or pressure-sensor gauges. The mechanical float-type gauges produce an analog record. Such records were digitised at an interval of 5 or 6 minutes to carry out the study reported here. The pressure-sensor gauges also record data at an interval of 5 or 6 minutes. The tsunami signal was obtained from these data by detiding the record; each record used for detiding was at least 30 days long.

The detided records for the tide-gauge stations along the Indian and Sri Lankan coast are shown in Figure 3. This figure also includes data from some other stations from the Indian Ocean (see Figure 1 for locations of all stations). The observed sea levels (including the tide) for some stations are shown in Figure 4. The stations on the Indian east coast were hit almost at the same time (around 0900 IST). Colombo, which lies on the west coast of Sri Lanka in the Gulf of Mannar, was hit at 0932 IST; Tuticorin, which lies on the other side of the gulf, was hit at 0953 IST. The first tsunami wave may have arrived earlier at the southeastern coast of India (in the neighbourhood of Nagapattinam) and the east coast of Sri Lanka, but no instrumental data exist to confirm this.

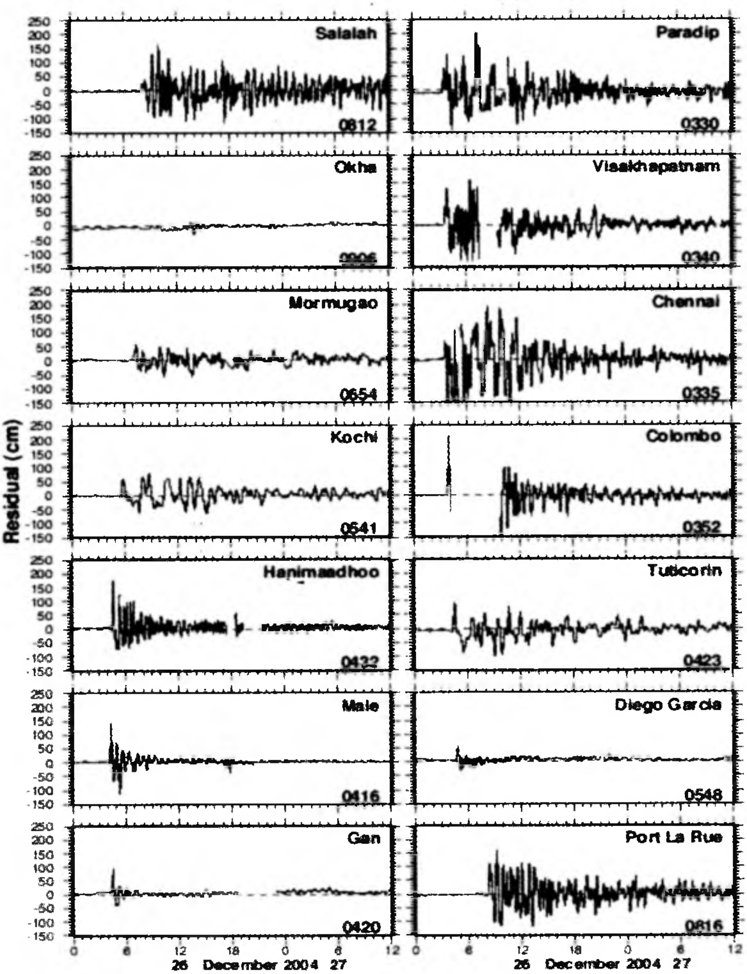

Figure 3. Detided water levels (cm) from the tide-gauge records. The tsunami arrival time (UTC) is given in the bottom right corner. Source: Nagarajan *et al.*, 2006.

Though hardly any damage was reported from Paradip (or from its vicinity), the data show that the tsunami wave was highest

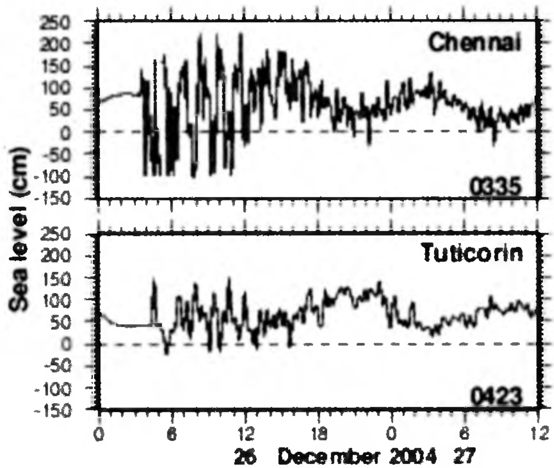

Figure 4. Water level (cm) measured by the tide gauges at Tuticorin and Chennai; the curve plotted includes both the tide and the tsunami. The tsunami arrival time (UTC) is given in the bottom right corner. Source: Nagarajan *et al.*, 2006.

there (note that data for Nagapattinam are not available); the maximum amplitude there was comparable to that at Colombo. At none of the three Indian east-coast stations was the first wave the highest (Figure 3), but the amplitude of the first wave as well as the maximum recorded amplitude were highest at Paradip. The first wave struck the Indian east coast around high tide; the maximum amplitude of the tsunami was, however, recorded around low tide, and this was also the maximum water level recorded at the three stations. At Tuticorin, the amplitude was less (~100 cm), but the first wave was the highest; this may have been so at Colombo too. There is a difference in the behaviour of the tsunami in the Gulf of Mannar and north of it. That the tsunami struck Tuticorin around low tide (Figure 4) also helps explain the lack of damage recorded in this region of the Indian coast.

Kochi, on the Indian west coast, was hit over an hour after the Maldive Islands.The amplitude here was less than half that at Hanimaadhoo (Figure 1), and the amplitude continued to decrease as the wave propagated north to Mormugao and Okha. As at most of the Indian stations, the first wave was not the highest: the maximum amplitude and maximum water level occurred much later than the first wave.

A Fast Fourier Transform (FFT) of the detided records shows that a dominant period is ~35–45 minutes at most stations (Figure 5), with another peak at ~20 minutes at some stations. The stations on the Indian east coast (Paradip, Visakhapatnam, Chennai, and Tuticorin) also show a broad peak between 1–2 hours. We need to understand the cause of this peak at high period. It may well give us clues on the character of the initial perturbation that was triggered by the earthquake, including length of the tsunami source region.

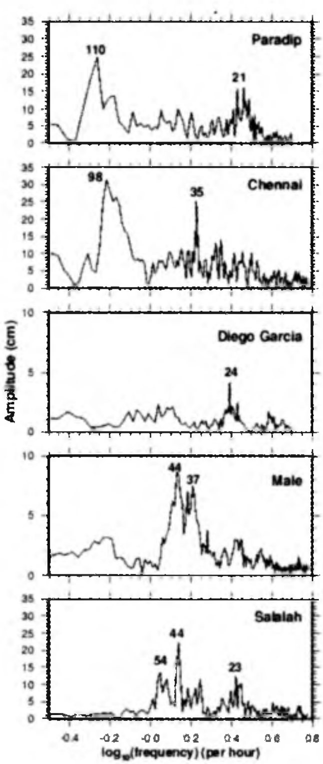

Figure 5. Spectral analysis (FFT) of the detided water level records. The abscissa is log10 (frequency) (per hour) and the ordinate is the amplitude (cm). The period corresponding to the prominent peaks is shown by the numbers (in minutes). Source: Nagarajan *et al.*, 2006.

4. Length of the Tsunami Source Region

Determining the length of the tsunami source region is one of the keys to understanding the complex nature of the 2004 Sumatra earthquake. Assuming an instantaneous rupture and total slip on the fault, Lay *et al.* (2005) used backward ray tracing to estimate a source region extending up to 600 km north-northwest of the epicenter, i.e. up to about 9 N. The extent increased to 10 N on considering the time delay due to finite rupture propagation and slip rise. Neetu *et al.* (2005) subsequently reexamined this issue by laying special emphasis on the Indian tide gauge data, particularly that from Paradip.

In the analysis of Lay *et al.*, the northern extent of the tsunami source region was constrained by the tsunami travel times reported from the Survey of India tide gauges at Chennai and Visakhapatnam, and from an acoustic tide gauge that was being tested by the National Institute of Ocean Technology, Chennai, at Port Blair. At the time of the tsunami, however, the clock of the Port Blair tide gauge was 46 min ahead of the actual time (G.A. Ramdass, personal communication, 2005). A data gap of 24 min (35 to 59 min after the earthquake) in this record added to the uncertainty about the tsunami arrival time at Port Blair. Hence, Neetu et al. excluded Port Blair from our analysis and reestimated the length of the tsunami source by including the tide gauge data from Paradip.

As pointed out earlier the tide gauges along the east coast of India show that the entire coast was struck by tsunami waves at almost the same time. That Paradip, the northernmost of the stations (86.70-E, 20.26-N), was hit at almost the same time as Chennai and Visakhapatnam, and that the tsunami amplitude here was comparable to that at these stations (Figure 2), motivated Neetu et al. to examine the compatibility of the tsunami source region reported by Lay et al. with the recorded tsunami travel time to Paradip (Paradip travel time was not included in their analysis). A forward ray tracing simulation showed that, although the rays starting from the estimated tsunami source region reached Chennai and Visakhapatnam in the recorded travel times, this was not the case with Paradip, implying that the estimated source region was not consistent with the travel times of all three stations. The tsunami source region must have extended farther north for Paradip to be hit at the recorded travel time.

Including the Paradip travel time as a constraint (in addition to Visakhapatnam and Chennai) and assuming instantaneous rupture propagation and total slip on the fault, Neetu *et al.* used backward ray tracing to reestimate the northern extent of the tsunami source region. The backward wavefront for Paradip was in the admissible regions of those of Visakhapatnam and Chennai, only ~11 N (Figure 6), implying a source region extending into the Andaman Islands and ~900 km long (from the epicenter). This is 200 km (~30%) longer than the estimate of Lay et al. Including the time delay due to tsunami excitation may extend the effective tsunami source region farther north.

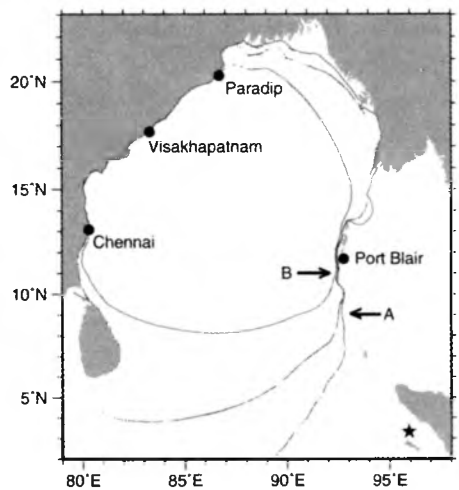

Figure 6. Backward wavefronts for Paradip (red), Visakhapatnam (green), and Chennai (blue) corresponding to their respective observed travel times. The asterisk marks the epicenter of the earthquake. The northern extent (~9 N) reported by Lay *et al.* (2005) is indicated by arrow A. Arrow B marks the new estimate (~11 N). (Source: Neetu *et al.*, 2005).

This new northern extent constrains the tsunami travel time to Port Blair to ~30 min, close to the data gap in the tidegauge record. The tsunami had already struck Port Blair by the time the tide gauge started recording again. Thus, an implication of the constraint imposed by the Paradip travel time is that tsunamigenic slip must have occurred over a longer arc than estimated earlier. The increase in length also indicates a much more destructive event than previously thought. Furthermore, the revised estimate has direct implications for slip distribution on the fault and should help constrain the set of possible geophysical solutions, leading to a better understanding of the processes involved in the 2004 Sumatra-Andaman mega-event.

5. Epilogue

The description of tide gauge data and their analysis that I presented in this lecture brings home two important points in the context of the Indian effort to study our region. First is that understanding a complex natural phenomenon, like the tsunami discussed here, requires us to go beyond the boundaries of classical disciplines. Here we find classical geophysicists finding useful inputs from classical oceanographers, who in turn need to know geophysics of the region to define the problem. Such interplay is necessary to make progress to understand the earth. We have to look at its study from the perspective of what is now often called the Earth System Science. Second, progress of this science needs access to field data from a variety of disciplines. Easier the access greater is the probability that someone will use it creatively. Sea level, i.e. tide gauge data, is one example. I can only speculate on what a wonderful "food for thought" it would be to all our young earth science researchers to have well over a century of hourly values of tide gauge data that the Survey of India possess. These records must be containing signals of innumerable phenomena that our coastline has witnessed, but have remained unnoticed. It is indeed a pleasure to know that serious efforts are now being made to digitize the data and make them easily accessible. Analyses of the kind that has been described in this article help to develop models with potential to predict evolution of a tsunami. Such models, and their verification by using historical data, form a critical part of the warning system that is now being assembled in the country.

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Space for Disaster Management Support (DMS): Emphasis on Enhancing National Response Mechanisms (including the Indian Ocean Tsunami)

V S HEGDE

India, characterized by the unique geodynamics, typical monsoon behaviour, flood prone river basins coexisting with semi-arid and arid regions and long coastlines, is amongst the nations most vulnerable to natural disasters. While the country has administrative response mechanisms in terms of a three-tier hierarchical organizational set-up connecting centre, state and district level functionaries, there are also networks of knowledge institutions mandated to provide the operational scientific and technological solutions towards disaster management. The natural disasters of rare severity, however, have brought into the focus the critical gaps and inadequacies in the operational systems. Non-availability of timely and reliable assessment of the damage to aid in response and recovery operations, absence of hazard zonation maps, vulnerability analysis, risk assessment of the potential population on desirable scale, inadequacy of appropriate tools and techniques (GIS, simulation models, decision support system, and lack of reliable and effective communication systems) have been the constraining factors to strengthen disaster management efforts.

In the above context, Department of Space (DOS) in the 10th Five Year Plan has launched a Disaster Management Support (DMS) programme. Using synergistically space (mainly INSAT and IRS satellites) and airborne systems in conjunction with the conventional technologies, the programme commits providing space-enabled products and services on a reliable and timely basis to strengthen the resolves of disaster management in the country. Based on GIS based comprehensive database, enabling technologies - including space modeling and networking systems, the programme has responded comprehensively to some of recent disasters the country has faced - including 26 December 2004 Tsunami, monitoring of artificial lake in Sutlej basins impending to flash floods in Himanchal Pradesh and the Floods of 2005 in different parts of the country.

Apart from integrating continuously the advances taking place in enabling technologies and services, the programme has also been drawing the lessons from each of the disaster it has responded to. Accordingly, the DMS activities get focused and draw priorities. The list of recent priorities, based on the requirements of the user communities at various levels, include:

- Satellite based emergency communications and Virtual Private Network (VPN) connecting the disaster management establishments;

- Enabling Hydro-meteorological Networks on land and in the ocean through INSAT based DRT systems, Automatic Weather Stations (AWS) and Ocean Data Buoys;

- Creation of Remote Sensing and GIS based Spatial Database and Hazard Zonation Maps for the priority areas in support of National Database for Emergency Management (NDEM);

- Critical R&D support to improve the scientific of understanding and quality forecasts, prediction and warning of natural disasters;
- Development of Actionable Products and Services, which could conveniently be put to use by end users;
- Setting up space enabled Emergency Resource Centre (ERC) in the perennially disaster prone regions of the country;
- Developing the constellation of Earth Observation (EO) Satellites to address the observational gaps and near/real time disaster event capture; and
- Joining Global Initiatives to learn from the experiences, best practices and information exchange.

To organize DMS programme, DOS has developed the critical mass in terms of institutional infrastructure, project management skill and domain expertise. In fact, DOS has placed all its technological and organizational strength in support of DMS programme. While DOS has created a single window delivery system – Decision Support Centre (DSC) to disseminate all space enabled products and services to the end users, it has also got a separate Disaster Management Support (DMS) programme office to develop the institutional interface with policy makers, international organizations and user agencies. DMS programme of DOS is therefore developed as a mission oriented and project based endeavour providing the critical technological and institutional support towards disaster management in the country.

Providing the free of cost access of remote sensing based products, capturing the impact of natural disasters, to the civil defense/ disaster management agencies in support of the emergency management has been considered as 'entry point activity' for international cooperation. International Charter for Space and Major Disasters, implemented in 2000 to ensure immediate access to remote sensing based products from participating space agencies [CNES (France), ESA (European Union), CSA (Canada), ISRO (India), NOAA (US), CONE (Argentina) and JAXA (Japan)] to the organisations dealing with major disasters, is a major step in this direction. The main features include an operational mechanism, which delivers remote sensing based products to civil protection agencies and to signatories during emergency situations. DMS programme, apart from an integral component of National systems, is also integrated well with other space agencies through International Charter.

Response to the Indian Ocean Tsunami

Disaster Management Support (DMS) programme of Department of Space (DOS) has been among the firsts to respond to the tsunami disaster event, which severely affected the Andaman and Nicobar Islands and parts of East and West Coasts. The response has been in terms of providing rapid deployment of satellite based emergency communication systems, and quick survey and damage assessment of the affected areas using satellite and aerial surveys.

As the Tsunami had caused heavy damage to the terrestrial communication infrastructure in the Andaman and Nicobar Islands, the immediate response of the DMS programme has been by way of providing emergency communication support in the worst affected parts of the Islands, viz.,

- Deployment of flyaway VSAT Terminal; and satellite mobile phones - both INMARSAT and the INSAT based MSS phones - for augmenting the telecommunications link within the Islands; and between the Islands and the mainland.

- VSAT based video conferencing facilities for relief and rehabilitation. Regular video-conferencing facility through dedicated transponder on INSAT-3E was enabled.

- Telemedicine facilities at 2 Hospitals in Port Blair (GB Pant Hospital and INS Dhanvantari), and Indira Gandhi Hospital at Car Nicobar.

- Videoconferencing for psychiatric counseling to those under trauma has been enabled at 3 tsunami relief camps in the East and West coasts.

Data from Indian and foreign satellites were acquired over the tsunami affected areas, and damage assessment was carried out on priority basis. The information was provided to Crisis Management Group at Ministry of Home Affairs and concerned State agencies. The support through the International Charter on Space and Major Disasters was also availed for obtaining data from foreign satellites such as SPOT, RADARSAT and ENVISAT. The data from Indian remote Sensing Satellites (IRS) were provided to all the tsunami affected neighbouring/Asia-Pacific countries.

Aerial survey was carried out for all the affected areas, and detailed damage assessment made. This has brought out the damage in terms of: exact extent of inundation; agriculture areas affected; damage to clusters of habitations, coastal vegetation, landforms, breaches, beach erosions, etc.

The IRS pictures of the tsunami affected Trinkat Island, in UT of Andaman & Nicobar, is shown below as an example:

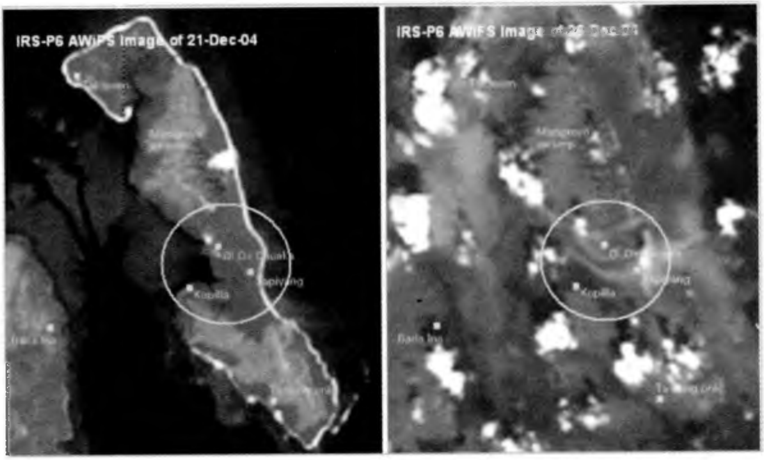


Figure. Tsunami-affected Trinkat Island as seen by IRS Images

ISRO/Department of Space is also a key associate in the National Tsunami Warning System being put set up by Government with Department of Ocean Development as the lead.

Earthquake Monitoring in India - Status and Future Plans

R S DATTATRAYAM

Abstract

An earthquake of great magnitude (Mw:9.3) occurred on 26th December, 2004 at 06 Hours 29 Minutes IST, off west coast of northern Sumatra. The earthquake, which is rated as the second largest in earthquake history and strongest since the 1964 Alaskan earthquake, has produced unprecedented Tsunamis along the coasts of the Indian ocean rim countries including Sri Lanka, India and Maldives, causing extensive damage to property and loss of lives. The earthquake was also felt widely in parts of southern India and was followed by an intense aftershock activity spreading over an area extending from 3 degree North latitude to about 14 degree North latitude along the Andaman–Nicobar–Sumatra island arc region. Presently, India does not have the required ocean-based instrumentation and a dedicated Tsunami Warning System as prevailing for Pacific Ocean region. The paper makes a brief description of the existing seismic monitoring capabilities in the country, the response to the Sumatra earthquake and future plans towards handling such disasters in future.

1. Seismic Monitoring in India

India Meteorological Department (IMD) is the nodal agency of Government of India with the mandate of monitoring the seismic activity, round-the-clock, in and along the borders of the country and to disseminate earthquake-related information immediately after the occurrence of the event to the concerned decision making authorities and other user agencies. Towards this objective, IMD is maintaining a countrywide network of 51 seismological observatories (Figure 1). IMD is also operating a 16-element V-SAT based digital seismic telemetry system for close monitoring of seismicity around Delhi region (Figure 2).

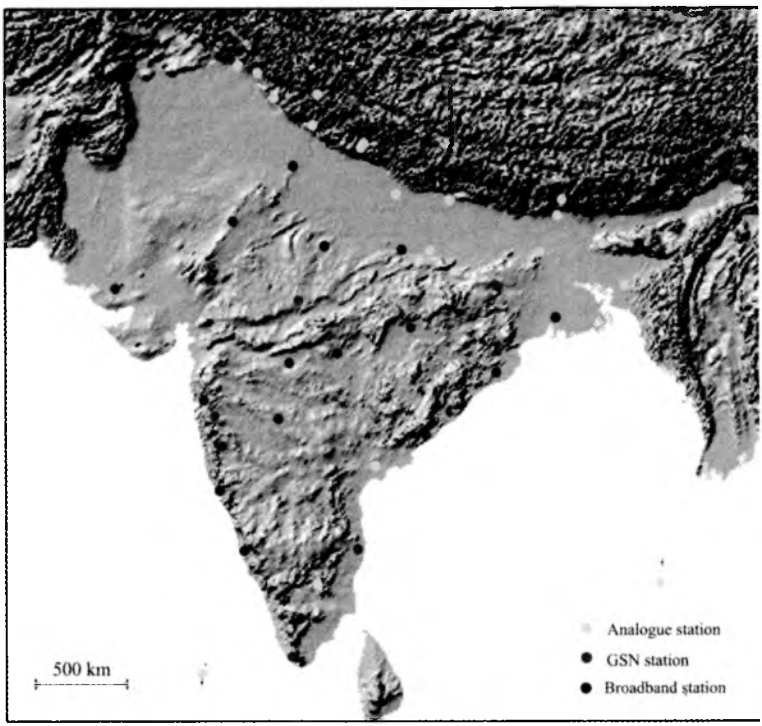


Figure 1. Seismic monitoring network of IMD.

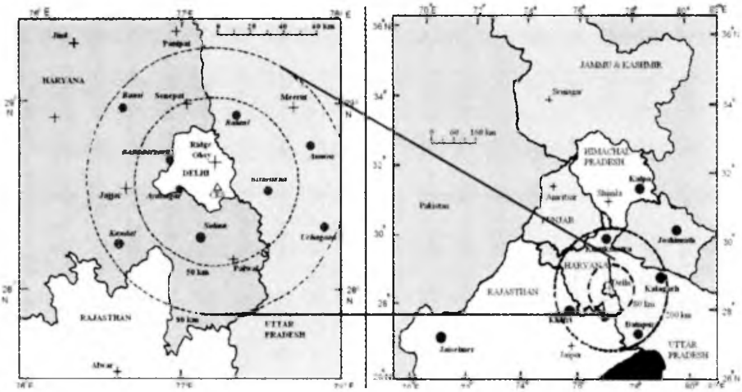


Figure 2. VSAT based seismic telemetry network around Delhi.3

In addition to the above, a number of seismic observatories and Strong Motion Accelerographs are also being maintained by different universities and research organizations in project mode as a part of their in-house activity or on-going R&D programs of the Department of Science and Technology (DST). The DST plays a very important role not only in promoting new areas of Science and Technology but also in organising, coordinating and promoting S&T and R&D related activities in the field of Seismology in the country.

On an operational basis, the Central Receiving Station (CRS) of IMD first ascertains the occurrence of an event from the trigger information received on line from the field observatories. The operator then downloads the waveform data through VSAT/telephone modem communication channels, from a few representative field stations. After computer processing of the data received, a Preliminary Earthquake Report (PER) is prepared giving details of the time of origin, location (latitude and longitude) and magnitude of the event. The PER is disseminated immediately to all the concerned agencies. Information pertaining to significant earthquakes is also posted on IMD's website (www.imd.ernet.in). The department is in the process of upgrading the seismological monitoring capabilities in the country.

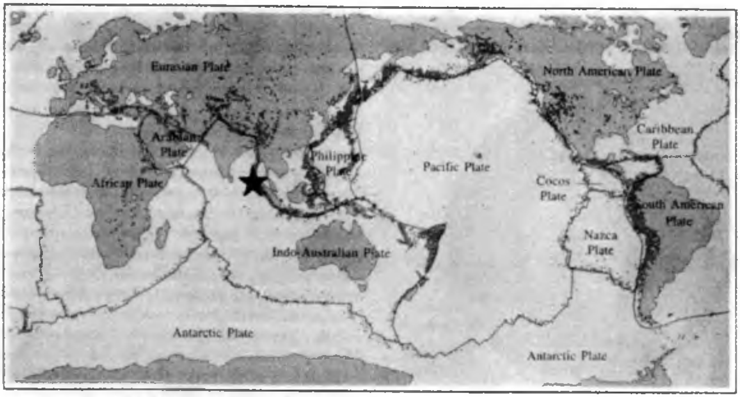
The disaster management related issues are mainly dealt by the Ministry of Home Affairs of Government of India.

2. Sumatra Earthquake of 2004

An earthquake of great magnitude (Mw:9.3) occurred on 26th December, 2004 at 06 hours 29 minutes IST off west coast of Sumatra island region (Latitude: 3.3 degree North Longitude: 96.1 degree East). It has generated destructive Tsunamis in the coastal zones of the countries fringing the Indian Ocean, causing extensive damage to property and loss of life. The Andaman & Nicobar islands, the states of Andhra Pradesh, Kerala and Tamil Nadu and Union Territory of Pondicherry are the worst affected in Indian territory. There are reports/anecdotal accounts of Tsunamis affecting the Indian coasts in the past. Few examples include earthquakes of 1833 (M:8.7); 1861 (M:8.5); 31st December, 1881; 26th June, 1941 (M:8.1); 27th November, 1945 (M:8.3) and 1883 Krakatoa volcanic eruption. However, the Tsunami that hit the countries fringing the Indian Ocean on 26th December, 2004 is rated as the most devastating in terms of its scale and reach.

3. Seismicity of the Region

The Alpine-Himalayan seismic belt which extends from south Pacific islands through Java, Sumatra, Andaman-Nicobar islands, Himalayan mountains, Greece, Italy and Spain is seismically one of the most active parts of the world and several great earthquakes have occurred in this region in the past. The 26th December, 2004 earthquake is the largest mega-thrust event since 1964 and the second largest to have ever been recorded in the history of the earth. The other significant earthquakes of the world are: 4th November, 1952 Kamchatka, Russia (M:9.0); 9th March, 1957 Andreanof islands, Alaska (M:9.1); 22nd May, 1960 Chile (M:9.5); and 28th March, 1964 Prince William Sound, Alaska (M:9.2).



Boundaries of major tectonic plates and distribution of earthquakes (Source: Judson and Richardson, 1995)

Figure 3. Global Seismicity and the location of Sumatra earthquake.

The devastating megathrust earthquake of 26th December 2004, occurred at the interface of the India and Burma plates and was caused by the release of stresses that develop as the Indian plate subducts beneath the overriding Burma plate (Figure 3).

The Indian plate moves in a northeast direction at a rate of about 6 cm/year relative to the Burma plate. This results in oblique convergence at the Sunda trench. The Indian plate begins its descent into the mantle at the Sunda trench, which lies to the west of the earthquake's epicenter.

4. Aftershock Activity

The main shock is followed by intense aftershock activity, which is normally the case after any major earthquake. India Meteorological Department is keeping a continuous watch on the aftershock activity in the region. Information pertaining to aftershocks of magnitude 5.0 and above is continuously being disseminated to the concerned administrative authorities including MHA. Aftershocks of larger magnitudes ($M \geq 5.0$) are being monitored using the regional network data. Till 09:00 Hours IST of 15th September, 2005. Three hundred and seventy three aftershocks of magnitude 5.0 and above have been recorded (Figure 4). The aftershock activity extends over an area of about 1200 km between 3.0–15.0 degree North latitude, which is a part of the seismically active Alpine–Himalayan belt. An array of five temporary field observatories at the following locations has also been setup in Andaman–Nicobar islands region for monitoring the low-level aftershock activity (Figure 5).

- Polytechnic college Port Blair (Lat. 11° 38.155' N; Long. 92° 43.019'E)
- Forest Guest house, Baratang (Lat. 12° 10.09'N; Long. 92° 45.78 E)
- Forest range Office, Havelok (Lat. 12° 01.87'N; Long. 92° 59.80 E)
- Polytechnic college, Hut Bay (Lat. 10° 36.762'N; Long. 92° 32.249' E)
- Campbell Bay, Circuit House, Great Nicobar (Lat. 07° N; Long. 93° 55.002')

The seismological observatory of IMD at Portblair has been upgraded by deploying a state-of-the-art seismograph system with facility for data transfer through telephone modem on 7th January, 2005.

The Sumatra arc region witnessed another great earthquake of magnitude 8.3 (Ms) on 28th March, 2005, which was also well recorded and monitored by the IMD's network. Information pertaining to the occurrence of this earthquake was transmitted immediately to MHA. Although no destructive Tsunami was generated by this earthquake on the Indian coasts, the follow-up action relating to this earthquake was very quick. Slip inversions have indicated that the main slip is fairly deep, like 30–40 km, which could be attributed for the absence of destructive Tsunamis. Other factors that may contribute

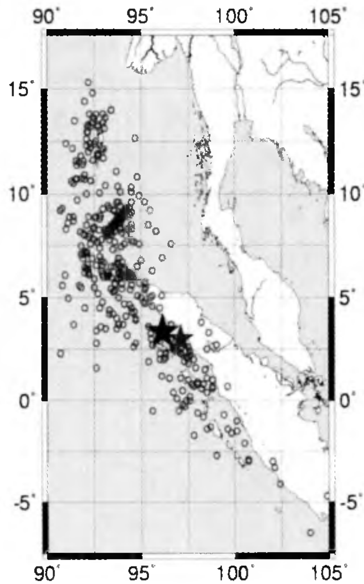


Figure 4. Aftershock activity.

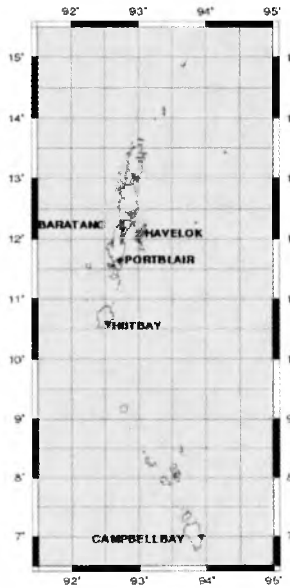


Figure 5. Temporary seismic Network.

in Tsunami generation include, whether or not the rupture reached the ocean floor, vertical motion/dip of the fault plane, presence or absence of sediments in the trench and possible slumping of the sedimentary wedge.

5. Future Plans

Government of India is working on setting up an Early Warning System for Tsunamis and Storm Surges in the Indian Ocean. The system is expected to be functional in about two years and will help in providing advance warnings of Tsunamis and Storm Surges in Indian Ocean region. The Department of Ocean Development (DOD), Department of Science and Technology (DST)/India Meteorological Department (IMD), Department of Space (DOS), CSIR laboratories and MHA are the major agencies involved in this endeavor.

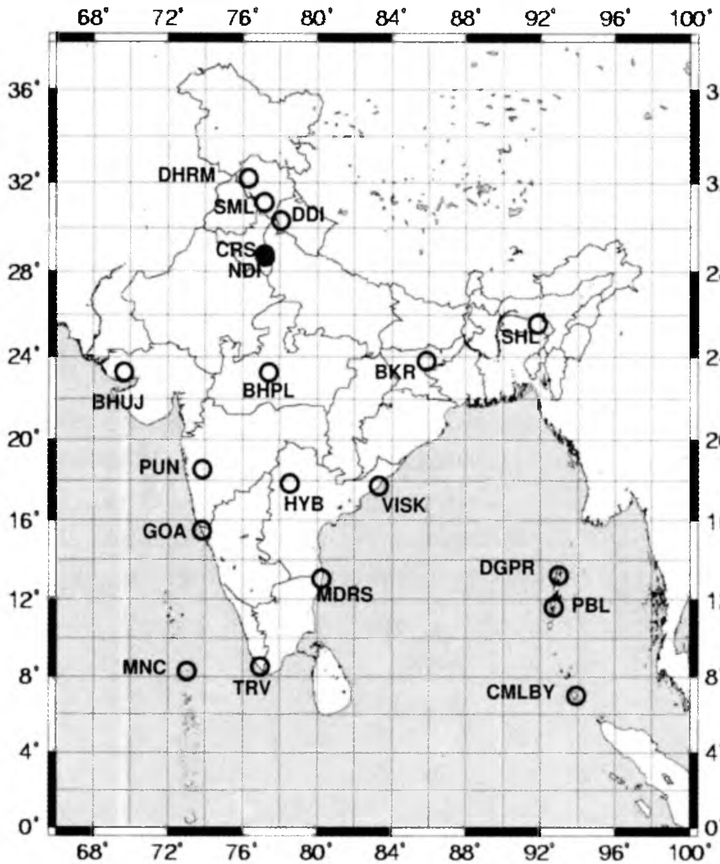


Figure 6. Real Time Seismic Monitoring Network for Tsunami Warning Centre.

As a part of this, DST/IMD is in the process of establishing a Real Time Seismic Monitoring Network in India for monitoring Tsunamigenic earthquakes (Figure 6). The system will have a real time seismic data transmission and analysis facilities to facilitate dissemination of information in real-time mode to the Tsunami Warning Centre. The other components of the work relating to ocean bottom sensors, tide gauges, modeling etc., will be taken up by DOD and other agencies.

6. Conclusions

India Meteorological Department monitored the great Sumatra earthquake of 2004 and its aftershock activity on a continual basis and information pertaining to aftershocks of magnitude 5.0 and above is being disseminated to the concerned administrative authorities including MHA. In the absence of a dedicated Tsunami Warning System, no advance information relating to the Tsunami of 26th December, 2004 could be issued. Government of India is now working on setting up an Early Warning System for Tsunamis and Storm Surges in the Indian Ocean. The Department of Ocean Development (DOD), Department of Science and Technology (DST)/India Meteorological Department (IMD), Department of Space (DOS), CSIR laboratories and MHA are the major agencies involved in this endeavor. As a part of this, DST/IMD is in the process of establishing a Real Time Seismic Monitoring Network in India for monitoring Tsunamigenic earthquakes.

The Great Tsunami of December 2004 - Lessons for Rescue, Relief and Rehabilitation

V V BHAT*

Abstract

The tsunami which followed the earthquake of 26th December 2004 (measuring 8.9 on Richter scale, with epicenter at 3.7 degree N and 95 degree E, at a depth of about 20 miles below ocean's surface, off the island of Sumatra in Indonesia) made 2004 the deadliest year in two decades since it killed an estimated number of 2,25,000 people in South East Asia. The impact of tsunami on Andaman and Nicobar islands, Sri Lanka and eastern coast of India was unprecedented. In the management of the consequences, valuable lessons have been learnt, which will be helpful for dealing with disasters of different kinds. This paper deals with impact analysis, rescue and relief, rehabilitation, and management issues with particular reference to the experience of Andaman and Nicobar islands.

1. Introduction

Earthquakes are a known phenomenon in Andaman and Nicobar islands but the tsunami which accompanied the massive earthquake of 26th December was unprecedented as well as unexpected. The epicenter of the quake was about 160 kilometers away from Great Nicobar, the southern most island. Later studies revealed that half of

* The author was Chief Secretary of Andaman and Nicobar Administration, when the Tsunami occurred. However, the views expressed are purely personal.

the 1600 miles of the entire faultline in Indian ocean ruptured. At 7:58 AM local time, the western side of the under sea mountain range, on the edge of the plate was thrusted up by as much as 40 feet. Consequently, the seabed is estimated to have lifted up, over a length of 750 miles.

At 6:30 AM (IST), when earthquake shook Port Blair, the impact on southern islands was not known. The first report of damage in Car Nicobar came at 11:30 AM (IST) from the sole satellite phone of Deputy Commissioner. The initial reaction at Port Blair was one of dealing with the matter as of an earthquake since there was no means of knowing the enormous impact of tsunami on southern islands; all the communication facilities had been totally wiped out. The earthquake brought the islands nearer to mainland by about a meter (!) and dipped the Nicobar islands and South Andamans by about 1-1/2 meters. This subsidence was not known when it happened; it was ascertained only after three weeks, when scientific assessment was made. Till that time, it was a puzzle as to why water had not receded from coastline especially in the Southern islands.

2. Impact Analysis

The impact on geology and land surface due to earthquake was seen in the cracking of the earth's surface, including the roads and runways at Port Blair, wider cracks on loose soil in Diglipur Tehsil in North Andaman, collapse and tilting of buildings etc. The experience of Bhuj earthquake in Gujarat was that if the hospital collapses in earthquake, rescue and treatment of the injured becomes much more complicated. The hospital at Port Blair, located near Cellular jail, (which had lost two of its wings in earthquake of 1941) was not affected. However, by 7:00 AM, two dozen injured persons and two dead bodies arrived in hospital. Therefore, the most immediate task was to alert the hospital staff and gear them up for trauma, care and crisis management. While this was done, the next most important action was to restore tele-communication system at Port Blair main exchange where the people had to come out since the building cracked; the dish antenna of satellite earth station was partially tilted. After immediate inspection of the building by the engineers, the staff restored tele-communication with mainland and locally in Port Blair within three hours. Since the telecast was not affected, by about 10:00 AM, people were able to get news of Tsunami hitting Tamil Nadu coast. As it happens, under such unexpected crisis, the local officials and others who were responding to the crisis were not knowing what kind of information and news was in the media.

The impact on human life and livestock as assessed subsequently is as follows:

Total dead and missing - 3513 (of which the details are: Adults – 2336, Children – 1177, Male – 1729, Female – 1784, Tribals – 2955 and Non Tribals – 558).

The loss of Livestock was estimated at 1,57,000 (of which Cattle – 3786, Pigs – 38446 and Goats – 16623). Paddy land affected was estimated at 1730 Hectares. Plantation land affected was about 9100 hectares. 938 boats were lost and 765 were partially damaged. About 10000 houses were fully damaged. 85 schools, 34 health centers. 37 mega watt power capacity located in different islands in 20 Power houses were washed away. 15 Jetties, which are the hub of activity in the islands, were fully damaged or sunk and 9 suffered damages. The loss of jetties incapacitated the communication by sea, rendering rescue and relief impossible.

Andaman and Nicobar islands constitute 0.25 percent of the total population and land mass of India. About 13635 persons had to be evacuated to Port Blair (mostly by air by Andaman and Nicobar Command) of whom 5661 were evacuated to mainland. 152 relief camps were organized for about 40000 affected people. 1514 injured persons were treated. Six smaller islands: (Bambooka, Trinket, Kondul, Pilomillo, Little Nicobar and Chowra) out of 33 inhabited islands were totally evacuated/abandoned. Large areas of coastal land in Great Nicobar and Katchal went under water. The island of Trinket appeared trifurcated since the low lying areas came under water.

The impact on population groups, especially on Nicobaris and settlers of Great Nicobar was traumatic. Out of the settlers in South and Little Andaman, about 11000 were displaced and 58 were dead. Out of 4000 settlers in Great Nicobar, all were displaced and 25 were dead. The primitive tribes, other than Shompens were not affected; (three Shompens could not be traced). Although, initially, it was estimated that about 8000 people might have gone dead and missing; subsequent estimates put the figure of dead and missing at 3513. Loss of 3000 members out of a Nicobari population stock of 32000 is dramatic. The tsunami left behind 210 orphans (191 tribals and 19 non tribals), 575 widows (439 in Car Nicobar only), 107 destitutes (in Car Nicobar only) and 150 disabled. 2400 tourists were air-lifted to mainland by about a dozen flights of Indian Airlines in two days. About 24000 fishermen and dependents had to be taken care of as special group since it was directly dependent on sea for its livelihood.

The impact on ecology of coastal villages was irreparable: (i) Loss of land due to subsidence (ii) loss of habitat in addition to life supporting infrastructure, supply godowns, communications, jetties etc. (iii) Uprooting and loss of trees, coconuts and other fruit bearing trees. (iv) Damage to corals, including sand and mud accumulation. (v) Widespread denudation. (vi) New locations for resettlement (with implications for dereservation of forestland).

Impact on infrastructure, estimated at Rs.300 crores, consisted of the following: (i) Total loss of Jetties in Katchal and Teressa which could be approached only by helicopter for relief and rehabilitation. (ii) Cracks in Runway in Port Blair and Car Nicobar rendering them unfit for Boeing and IL-76 operations. (iii) Loss of navigational aids for shipping/aircraft operations at Car Nicobar. (iv) Loss of aviation fuel rendering IAF helicopters unusable. (v) Washing out of IAF stations at Car Nicobar (110 air force personnel lost). (vi) Total damage to coastal road in Great Nicobar, Car Nicobar and Teressa, thereby increasing the dependence on helicopters for rescue and food supply.

3. Response

Since awareness about disaster management was of a high order in Port Blair, in administration as well as in the public, the response was immediate. Since the Government of India, (Ministry of Home Affairs) galvanized material and man power resources, local administration and defence services got an immense support in its rescue and relief operations. The following were important elements of action: (i) Direct airlifting of supplies (water, rice, dal, tents, tarpaulins and medicines) procured by Government of India to Port Blair and Car Nicobar from mainland (which avoided problem of local procurement, inflation and non availability). (ii) Para military forces (Central Reserve Police Force, Central Industrial Security Force, Border Security Force etc,) for dead body disposal, erection of tents and unloading of supplies. (iii) Full involvement of Andaman Nicobar Command including Coast Guard (iv) Creation of Integrated Relief Command. (v) Daily reviews of Disaster Management Committee. (vi) Single Control Room from where entire administration worked for two weeks. (vii) Daily interface with media, Non Governmental Organisations, political parties and visiting VIPs. (viii) Special Relief Officers for each affected island. (ix) Restoration of shipping services, inspite of damages to port facilities at Port Blair (x) Ten Satellite phones and restoration of VSAT terminals at Great Nicobar, Camorta and Little Andaman. (xi) Air lifting of dish antenna and phone exchange to Katchal (which could be done only on the 13th day!) (xii) Public health measures (xiii) Use of video conference between Port Blair and Car Nicobar for health personnel (xiv) Epidemic prevention (xv) Ensuring water quality and availability. (xvi) Establishment of new supply chain and channel for relief materials (xvii) 500 small generators distributed village/ camp wise for lighting (Port Blair had to manage with 20 percent short supply of power due to damage to power house).

4. Relief Administration

Management of relief work involved administration of 152 relief camps for 40000 persons in 7 islands. Individual camp officers who were in charge of looking after camps did extremely well in maintaining cleanliness, orderly visit of outsiders including VIPs, co-ordination of distribution of relief materials by NGOs and in arranging activities like counselling, yoga camps, entertainment etc. In spite of trauma of affected people, the camps were reasonably disciplined and free of any major health problems or communicable diseases.

5. Rehabilitation

For long term rehabilitation, a Secretary to Administration was nominated as Secretary (Rehabilitation) so that a perspective was brought to the efforts of planning for long term with regard to (a) ecological rehabilitation (b) agronomic rehabilitation (including soil reclamation, identification of plant varieties, land use plans etc,) and (c) livelihood rehabilitation. In addition to issues of construction of temporary and permanent housing, reconstruction of infrastructure facilities like jetties and roads and acquisition of vessels also needed to be taken up parallely. Planning for the following were taken up on priority: (i) Locations of rehabilitation moved to levels higher than 10 meters and 200 meters away from high tide line. (ii) Planning for shore protection belt consisting of different kinds of trees like coconut, pandanus and other quick yielding varieties like banana (iii) Habitat planning for resettlement villages. (iv) Restoration of tele communication (v) Tele medicine connectivity to 24 hospitals

(vi) Community information center network for 40 higher secondary schools (vii) Transportation of fowls, pigs, goats and cattle from mainland. (viii) Restoration of economic activities like fishing (ix) Generation of wage employment.

An important approach towards restoration of self reliance of civil administration in terms of facilities and redeployed staff, followed right from beginning, helped immensely when the facilities of helicopters and other involvement of defence forces under "Operation Madad" came to an end after about 9 days. Thereafter, the involvement of Andaman and Nicobar Command based on its local resources however continued. Island specific problems and handicaps had to be addressed each day. The administration had only one helicopter operated by Pawan Hans. A second helicopter from Pawan Hans could come only after a month. This is illustrative of difficulties of logistics; even when resources exist in mainland, to reach them to specific locations involve time, decision-making as well as transportation.

The tsunami rehabilitation package approved by Government of India after consideration by the Empowered Group of Ministers amounted to Rs.9870.25 crores for the country as a whole. This consisted of external assistance of Rs. 3344.13 crores (World Bank, ADB and IFAD), Rs.1607.01 crores under Rajiv Gandhi rehabilitation package and Rs.4641.11 crores as additional budgetary support. The major sectors comprising approximately 75 percent of the outlay included housing (30 percent), fishery (11 percent), port and jetties (13 percent), road and bridges (13 percent), environmental and coastal protection (8 percent).

The specific provision for Andaman and Nicobar islands was about Rs.800 crores out of the above. It included items like desalination facilities, rainwater harvesting, Mangrove plantation and scientific study for location specific mitigation measures.

6. Involvement of NGOs

About 50 NGOs – local, national and international, involved themselves in relief and rehabilitation; only 2 could not be given clearance in view of their insistence to go to tribal area only for making survey of losses. With regard to international NGOs, visit to islands involved visa and restricted area permit and tribal area permits. The guidelines regarding functioning of NGOs available from website of Ministry of Home Affairs (especially regarding foreign aid of NGOs) were distributed to representatives of NGOs. In spite of nominating Facilitators in local administration, multiplicity of NGOs involved following problems: (i) Multiple NGOs, competing to work in same area/camp. (ii) Image building and media interaction of NGOs (one NGO advertised for media relations officer with remuneration of Rs. 4 lakhs per year) (iii) Lack of local resources, knowledge and manpower (hastily hired personnel could not handle work in a local situation) (iv) Difference in assessment made by different NGOs regarding the needs of affected people in camps (v) Keenness to distribute relief with associated publicity, without informing the norms and quantity of assistance to local administration (vi) Political and religious bias.

The following measures helped in mitigating difficulties relating to involvement of NGOs: (i) Mapping of resources of each NGO helped in avoiding duplication (ii) A Coordination committee, helped by a Facilitator from government could lay down ground rules for, publicity, banners, norms of assistance, and periodic reports to government etc. (iii) An offer letter from NGO about their manpower, funds and specific proposals/commitments can be followed up by discussion with local officials and a Memorandum of Understanding will be desirable for long term commitment of NGOs. (iv) An exclusive senior Relationship Officer proved immensely useful for facilitating as well as collecting information about relief distributed.

7. Media Relations

The media, naturally, has a rightful interest and role in reporting on a disaster but the speed with which it wants to report and the pressure for "exclusive" and "first to report" by visiting the site, by air, created difficulties for officials engaged in relief. In addition to dilemma of officials at various levels – 'to speak or not to speak', there were risks of threats by journalists and risk of adverse publicity. Their nexus with political people, parties and visiting VIPs only increased the difficulties. However, the following lessons could be drawn: (i) A transparent approach is not only required but also reduces misunderstandings and suspicions. (ii) Authorised spokespersons conducting joint daily briefings to the entire media is helpful in avoiding contradictory inferences and stories. (iii) Issue of daily press note and updating it in website is useful. (iv) The morale of field officials needs to be protected, without any knee jerk reaction to the feedback received from questions in press meet and individual reporters. The feedback should be used internally for making verifications, corrections or improvements. (v) Exclusive officers are required to deal with the media who may come in teams which are altered or rotated once in three to four days since facilitating work of newcomers with sufficient local information and updating is in the interest of factual reporting. (vi) Contradictions and clarifications regarding false stories, if any, need to be given irrespective of the stature and the sensitivity of the reporters involved

8. Administrative Accountability

Constitution of the Integrated Relief Command (with Lieutenant Governor as Chairman, Commander-in-Chief of A N Command as Vice Chairman and spokesperson, Member of Parliament as member, Joint Secretary (MHA) as member and Chief Secretary as Member Secretary) reduced the need for written communications and created a single point of accountability to Government of India. However, it may be noted that this bypassed the prevalent practice of requesting for defence assistance by the District Magistrate to his counterpart in the defence set up. Consequently, the issue of payment to the defence forces for their assistance to civil administration was unclear. In addition, the following issues are to be noted as lessons for any disaster management exercise: (i) Emergency procurement of materials from the local market through Empowered Committee of officers. (ii) Collecting reports/information from sector officers by the designated counterparts in the Control Room. (iii) Coordination of reporting to multiple higher authorities by an exclusive officer in charge of reporting. (iv) Information sharing with political parties and their representatives. (v) Daily coordination meetings in the Control Room, not exceeding one hour. (vi) Coordination with political parties and leaders who come from outside the territory with their volunteers and relief materials. (vii) Replacement of exhausted field officials for necessary rest by having additional manpower in reserve/roster. (viii) An exclusive arrangement for facilitating volunteers and researchers is required for reducing their familiarization problems and to enable them to contribute positively. (ix) Pressures for quick decision regarding complex issues of adoption of children/orphans may be handled carefully because verification of bona fide and credibility of persons and institutions takes time and adoption can wait for a slightly longer time. In any case, if local community is interested in taking their care according to their own ethos and culture, adoption is an inferior option. (x) Mismatches in food items, medicines etc., may take place in spite of the best attempts because packages might have arrived in different sizes and in differing contents (in some cases, contents of package may not be exhibited outside the package in detail, including in the manifesto. (xi) Appropriate packages for hele-lifting and dropping needs no emphasis (xii) Issue of duplicate documents and certificates becomes necessary for normalizing the life of survivors. (xiii) Distribution of ex-gratia and compensation in time bound manner to the heirs after identification and through makeshift bank branches, with least formalities for opening of bank accounts has to be organized by the

Relief Officers. (xiv) Hand held electrically operated saw, satellite phones, portable generators, tents and shovels, sickles and knives and such other emergency tools, if not available in the stores or as per contingency plan, have to be mobilized at the earliest for improving the response

9. Role of Scientific Departments

Some scientific departments have a special role in mitigation of disasters. These can be summarized as follows:

(i) **Health:** (a) telemedicine (b) Disease prevention (c) Drinking water quality (d) Identification and stocking of medicines required (e) Trauma counselling

(ii) **Communication:** (a) Restoration of telephones including mobile and WILL (wireless in local loop) phones (b) Special user group of mobile phones for messaging and emergency communication (c) Restoration of towers of mobile phones, TV and AIR for broadcasting (d) Ham radio deployment (e) Quality improvement of satellite phones (like improving the battery storage capacity and charging systems) (f) Restoration of postal service, E-mail and internet (g) Use of digital cameras for enabling transfer of pictures and news on e mail

(iii) **Science and Technology:** (a) Reporting incidents of earthquakes – frequency and intensity, through digital systems soon after occurrence (Indian Meteorology Department) (b) Doppler weather radars for aviation and navigation safety (Navy and Indian Meteorology Department) (c) Tsunami information system (Department of Ocean Development) with lead time of at least 15 minutes (d) Radio transistor sets with winding arrangement for battery (e) Dish antenna based communication network, independent of the terrestrial telephone exchange between key locations. (f) Forecasting state of the sea and tidal conditions/behaviour (Department of Ocean Development) (g) Monitoring wave-heights from altimeter platforms in satellites on real time basis (Departments of Space and Ocean Development) (h) Speedy analysis of seismic data (i) Publishing almanac of tides (j) Bio fume for burning dead bodies and carcasses (k) Vulnerability mapping, indicating risk zones and areas of possible submergence (l) Techniques of water testing and purification at household level (m) Hospital-ship equipped with helipad for on-board emergency treatment (n) Monitoring and study of volcanoes (Barren, Baratang and Narcondum) through satellite (o) Use of Light houses as GPS stations and centers for monitoring wave heights at night through laser based detection system (p) Civil defence training to include survival techniques (sea swimming, tree climbing skills) (q) Appropriate technology for building coastal infrastructure and civil constructions (r) Navigational aids and signal facilities in ports and channels in the harbours.

10. Conclusion

Disaster management has, of late, been facilitated by a higher level of awareness and the systems created by Government of India for responding to the emergency at national, state and district levels. Some of the issues discussed above may have long-term implications for preparation as well as after-the-event management. One of the key issue thrown up in the present context is the inadequacies of civil defence – as a concept and as a system; a de-novo look at this is necessary so that mobilization of the community can be done in a better way in the aftermath of a disaster.

Miles to Go before We Sleep - *St. John's Disaster Relief Team in the Nicobars: 28th December 2004 - 10th January 2005*

SANJIV LEWIN

Introduction

When television news began to bring reports of the terrible tsunami disaster along the South Asian coastline into our own living rooms, it once again galvanized us into doing something once again. Not many know that the St. John's Medical College Hospital, Bangalore, has a tradition of responding to Disasters over the last 34 years. This response has included eight teams to the refugee camps post 1971 war in West Bengal, Bhopal Gas Tragedy, the 1977 Andhra Pradesh cyclone, the 1991 Bangladesh cyclone, 1993 Latur Khilari earthquake, 2000 Orissa super cyclone, 2001 Gujarat earthquake and now this tsunami disaster. Being the only medical college in India with over seven past experiences behind them and a Disaster Relief and Training Unit, they have been a lead health resource for the National Institute of Advanced Studies (NIAS) Bangalore's Disaster Management training courses for the Indian Administrative Service (IAS) officers.

This tsunami disaster was one of our fastest and deepest responses. We were the first and only voluntary non-governmental medical team south of the Andamans in the Nicobars.

Preparation

On arrival at hospital our Disaster Relief and Training Unit was activated and immediate clearance was sought from our Director and as usual there was no hesitation. The next step was deciding where we should move to be most effective in our work. The coastal area of Tamil Nadu was dropped from our list, as we knew that there were numerous health care institutions in the vicinity and they would surely respond. In addition, our expertise and ability to base us in extreme areas made the Andaman and Nicobars the place to help considering the relative more need for medical assistance. Sitting in a busy out patient, the first calls to 'old friends' (Ajit Chowdry – Care Today; Parveen Sikand – Child for Life; Rev Fr Dr Thomas Kalam – Director and administrator St. John's Disaster Relief Fund; Rear Adm Raja Menon – Delhi based strategic studies) got us commitments for sums of money so important to enable a rapid and effective response. Need I say return calls within an hour confirmed the commitment and set the ball rolling. Within four hours, we had 49 volunteers with contact numbers and skills classified and our Pharmacy had packed the list of WHO essential drugs needed for our use. Jet airways gave us our bookings to fly into Port Blair via Chennai and even flew our supplies and equipment free of charge. Dr. T. Venkatesh (St. John's-Spark Adventures) by the end of the day handed us our usual team shelter we always carry. Our team always travels into an affected area totally independent with food and water fro 48-72 hours, our own medical supplies and equipment, our own tents and sleeping bags, medical protocols and communications. This enables the team to begin work on arrival and to avoid becoming a burden on the local population we intended to help. Unfortunately, our HAM contact had just undergone cardiac surgery and we could not make contact, only carrying various cell phones as communication (Only BSNL existed on the island capital of Port Blair). Beyond Port Blair we lost routine means of communication till the Earth satellite station on Kamorta Island was repaired a few days later. The selection of the first team was based on a need for a general-purpose team considering anticipated medical needs with knowledge that a tsunami usually had some components of both earthquake and cyclone-flood related medical problems. The first team had a Surgeon (with Orthopedic and Paediatric experience), anesthesiologist, emergency physician and two multipurpose nurses (Emergency medicine, Neurosurgical-Paediatric experienced). In addition, we had an Ophthalmologist who was experienced having worked for two years in the same area as a part of St. John's mandatory rural-underserved area bond and the team leader, a Paediatrician. Gender issues and the ability to cater to the needs of vulnerable populations in disaster areas were also the basis of team selection by the leader. The number of available reservations limited the seven-member team and the team selection was based on the need for a team capable of handling most emergencies and other anticipated health needs specific for the disaster. In addition, local contacts were important to enhance effectiveness and the mix of youthful enthusiasm and motivation along with restrain, caution and experience made this team exceptionally effective, innovative and most importantly, a team. With a brief orientation of expectations, roles and responsibilities of team members, all were kept on standby till further notice. All members carried their own minimal baggage, stationary/photographic equipment to document activities, personal medicine kits, sleeping bags/tents, dry food and water. The team was started on malaria prophylaxis. The exit time/date was decided upon once the team leader was certain that no further information was forthcoming from the administration on the islands, travel plans were in place and the leader was satisfied that the team would be reasonably safe and able to travel as deep as necessary rather than getting stranded on Port Blair.

Arrival

Overnight at Chennai, the team stayed at the Andaman House where we began receiving much needed but minimal information and further contacts. On our arrival at Port Blair, we immediately based ourselves at the Bishop's house and the adjacent Pilar Health Center. A group of us then proceeded to the Developmental Commissioner (Health Secretary) Mr. Anshu Prakash and Director of Health Services Dr. Ms Namita Ali presenting ourselves at their disposal to be sent to places in most need for assistance. It is our rule that we always report to the local civilian authority to be directed to areas as needed locally and to ensure coordinated efforts in the field. They were most kind to then orient us to the existing situation and directed us to immediately leave on board the destroyer, I.N.S. Rajput proceeding to the Nancowry Block of Islands, south of Car Nicobar. The Commissioner on hearing of the nature of our team agreed that additional nurses are the potential need and immediately we got him on the phone to our Chief of Medical Services, Dr. Mary Ollapally, who within an hour had a team ready and they were flown into Port Blair the same day. This second team was composed of five nurses and an orthopedic doctor. The first team was assigned to Nancowry block and this second team was sent into Car Nicobar initially and later in the refugee camps of Port Blair.

The first team steamed at over 20-25 knots to their destination and was flown by helicopter along with their medical relief supplies to Kamorta, the headquarters of Nancowry block. The second team was also flown into Car Nicobar. On board the I.N.S Rajput, we were most fortunate to have a captain (Capt Aiyappa) and crew most supportive of our efforts. The Principal Medical Officer, Surg Lt Cdr Rath, had been posted on Kamorta Island, eight years ago and was a fantastic source of local information on whose whom on the island. It was his story about the "Queen and Prince" of Nancowry that was most useful in being able to develop rapidly a rapport to perform our duties on the island among the tribal population. Rashid's (the Prince of Nancowry) presence during our meetings made us even more acceptable to the community on the surrounding islands. Rajput airdropped us onto Kamorta where we reported to the Officer on Special Duty Mr. Uday Kumar and the DySP Sarvanana, both having arrived the previous day. They were sent in since the Assistant Commissioner at Kamorta had not returned to his island and his whereabouts were unclear. That evening Uday Kumar and Sarvanana had a meeting of all the Village Captains (elected leaders of the tribal villages on all islands were called 'Captains') along with the contractors, AE, Education Officers, PWD, Electricity, Telecommunication staff, Port Control, the Princess (Ayesha), Prince (Rashid) and everyone who was important for any sort of local coordinated effort. On islands such as these, everyone who is someone is so important that if even one is unhappy nothing gets done. It was sad to hear that as we left the islands Mr. Uday Kumar was replaced by a seemingly competent Jt Secry Mr. P.R. Meena from Delhi to oversee further affairs along with a fresh graduate on his first posting as the new Asst Commissioner. DySP Sarvanana, a Vice Principal of a Police training school at Port Blair along with his young recruits played a most vital role of disposing of carcasses on most islands, providing security to relief supplies on islands and to medical teams in the field. The day we left, we missed him as had left at first light and was involved in locating the last few 17 tribals marooned in the jungle swamps of West Bay, Katchal Island. Of course, as usual the local politicians (from both sides of the political spectrum) slowed down any attempt to progress with work decisions the group was trying so very hard to coordinate efforts. Need we say that many were happy when some politicians actually insisted on boarding some of the relief transport to neighbouring islands and therefore being out of the way for a good many days. The main limiting factors were the absence of appropriate smaller vessels (Out board boats) to transport supplies and personnel to the far-flung islands since most jetties were destroyed and available motor vessels too large to beach; inadequate communications between islands in spite of attempts to place police wireless on all islands (unable to sustain needs with low power in batteries in the absence of generators that began to arrive towards the later part of our tenure). There were three camps on the island of Kamorta where community cooking and makeshift shelter was being provided. Rainwater harvested provided drinking water for the refugees. These islands had Tribals and Mainlanders. Most mainlanders were government officials and their families apart from merchants. There were many of them who had not been paid for bureaucratic reasons of being from different islands hence different accounts. On Katchal were the unique population of 1970s Sri Lankan Tamilian refugees now settled on Rubber plantations unique to inland Katchal. Apparently they had not been paid for over three months and when the merchant shops opened on many islands credit was unusual. On all islands we served the Tribals (Nicobari) were non-demanding, simple people who had already begun reconstructing their lives and shelters using locally available material (thatched coconut leaves, bamboo and jungle trees). They knew where the sources of drinking water streams existed and most moved inland to settle on high points knowing they were relatively safe from the fury of the coastal sea. It was difficult to read the minds of these people but considering the stories of survivors of the tsunami 10-18 meters high and at 400 kmph chasing people inland through the villages and withdrawing at similar speed, it must have been a terrifying sight. The psychological impact must be tremendous on this docile, non-aggressive population and will have to be addressed at the earliest to enable any sort of true rehabilitation. The NIMHANS team that usually follows us into the field every disaster would be in the right position to assist in this aspect. What was unusual is that the team was on the ground towards the second week, which some would consider too early in the stage of relief and rehabilitation.

Work Begins

The estimated toll on Nancowry block of islands has been estimated at around 5500 missing or dead out of a total of over 12633 (2001 census) See Figure A. The lack of publicity and media coverage compared with Car Nicobar and poor accessibility are possible reasons for a slight delay in intervention. Our teams were based at three locations but served many other islands using all available transportation means, even trekking through the tropical jungles with backpacks of medicine, wading and swimming between island and ships anchored off destroyed jetties. Teams were based on Kamorta Island, Teresa Island, Car Nicobar and Port Blair. From these islands, teams would mobilize everyday to serve the basti populations on Katchal especially the dense jungles on Upper Katchal near Vyatapu, Daring, the Pilpilou-Kakana village camps, the jungles inland on Car Nicobar, the camps of Chowra Island's evacuated population on Teressa Island, bastis formed between the destroyed Bengali-Alorang villages and the bastis/camps of populations from destroyed Kapanga-Mildera villages on Teressa. Strikingly, the islands have a over 81% literacy rate and with the board examinations due in March 2005, most Education Officers were well aware of the need for additional classes at the earliest and also a postponement. Education has been badly damaged as most schools were in the coastal villages and on Katchal alone at last count over 70-80 teachers out of 130 were missing or dead. Till medical assistance arrived there were numerous heroes like the nurse Sr. Dora and the volunteer Shanmugan on Katchal Island who ran a clinic from a church premises treating the wounded till Dr. Naresh Lal arrived on Wednesday.

Kamorta was the Nancowry division's headquarters and had electricity restored with adequate water stored with most of its 2915 (2001 census) alive except for one person who decided to try and salvage his stored money for his wedding between tsunami waves lashing the fishing village near the coast. Islands on all sides that protected it from damage surround Kamorta. The island of Trinket is apparently torn into three and most mortality is on Katchal Island (>3500 out of 5000 plus population). The islands of Chowra (500 missing/dead/1385-2000 population); Teressa (300/2026-2200); Bambooka (4/40-55); Katchal (3500/5312-7000); Nancowry (300/927-1000); Car Nicobar (18000/25000) were other estimates. The jetty now gets water up to 1.6 meters slowing down loading during that period of time. The jetty is the main point for operations – relief, medical, and water, fuel and shelter distribution. The three vessels MV Ramakrishna, MV Bulbul and MV Long Island and their hard working captains and crew were to be our best friends throughout our work in the area. Later, MV Shompen and Capt Pillai carried us on our small missions. Capt Pillai actually risked his life getting us onto the Teressa Island in a rather dangerous outboard boat and once again by jumping into the water to assist us while we swam to his vessel anchored out at sea in an attempt to communicate and decide on plans for the team. The team on Teressa Island found that the tents and sleeping bags pitched on the helipad near the basti most comfortable for a starry night sleep to enable them to wake at dawn (5 am) and put in a full days work. Of course, our friend Bandana Aul ("Bat-girl" to us!) kept us going with her stories of the tribal division of Nancowry. Bandana is the daughter of a retired General in Chandigarh and is a frequent visitor to these islands during her quest at research on various aspects of bats unique to these islands. Her rapport and local knowledge with the island population assisted us in carrying out our duties. It was the naval landing craft L-34 with Lt Cdr Bellary in command that thankfully dropped our team to the island of Teressa after the previously failed attempt aboard MV Long Island.

Teams would base themselves in bastis or camps and some of us would trek through the islands till evening helping persons in need of medical assistance. When teams found seriously injured or ill patients we would innovate and with the assistance of the village tribals evacuate them to hospitals wherever possible. Dr. Naresh Lal was the Chief Medical Officer at the Community Health Center on Kamorta whom we shared our stored supplies and assisted. He was the first one on Katchal Island on Wednesday and was actually stranded for two – three days and reported back the sad state of affairs. His manpower on all islands mostly stuck to their posts in spite of many a PHC being washed away and destroyed. Dr. Michael (PHC Medical Officer, Teressa Island) was one we worked alongside with.

What we first saw was this young doctor short pants and vest, stethoscope hanging around his neck and a knee hammer in his pant loops. The team worked hard with Michael in their treks from basti to basti covering all in need of medical assistance. Dr. Felicetta (PHC Medical Officer) holding fort during the few days Dr. Lal was on Katchal helped us take care of the two patients we disembarked from Rajput while at sea. Both men in their early 20s had lost families in the tsunami and had received initiation of treatment on board I.N.S. Rajput under the care of Surg Lt Cdr Rath. On had a possible traumatic fracture dislocation elbow joint with a large hematoma and possible secondary infection. The other had a pneumonia and acute severe asthma. The team on their Upper Katchal visit had to do an Incision and Drainage and injected antibiotics for a patient in severe pain due to cellulites and large abscess formation on a foot of a person who refused to be evacuated. The team also identified two other patients evacuated onto Teressa Island with severe traumatic spinal paraplegia and was able to support and minimize damage before getting them evacuated to Car Nicobar. On Car Nicobar, a young boy child found inland on Car Nicobar needed a reduction of a hip joint, rather painful but needed to enable transportation to the nearest hospital.

In most medical clinics in the field, we noticed no epidemics (sea washing away most debris/carcasses; water sources inland and protected from the death and destruction) and most who were brought in were children (44.7-60.7%). Among morbidity patterns as expected were injuries 10-24% (few major as illustrated above but mostly minor soft tissue injuries); Respiratory problems 28-76.2% (upper and lower respiratory problems, hyperactive airways, occasional pneumonia – mainly due to exposure to natural elements in the present inadequacies of clothing and shelter); Skin problems 8-24.7% (an exaggeration of usual problems, predominately children, on exposed parts of the body, with no burrows/family histories, probably related to the slush and the presence of tall grass to be walked through to reach new basti sites). At present there is no need for any supplies beyond the Essential

Drug List made out by WHO and neither should nay other drugs be allowed into the area. Every evening teams would sit around their tents or at the dispensary set up (usually the only meal of the day!) and discuss the days events completing report and plan for the day. Morale was kept high and team responsibilities included Team doctors (to monitor team health, Doxy for malaria prophylaxis), Team Logistic officer (check and monitor supplies), Team Mascot (to bear the brunt of our jokes and jabs) and even Team entertainer (which invariably changed persons depending who felt the happiest!). Routine medical needs continue and even interventions for delivery and labour are usually not catered for in disaster relief. Our team on Teressa had to assist in such routine care and support. At other clinics, patients on AntiTB drugs, Diabetics, Hypertensives and even persons with poor eyesight needed their routine care. When these patients came to our notice we did inform in writing their contact details to enable restoration of their routine care. Apart from curative medicine and surgical interventions, Teams stressed on and taught through demonstrations-practice methods to chlorinate stored drinking water sources, encouraged trench latrines and personal hygiene. This regular medical status feedback was sent daily to the local administrator and the navy to enable needs assessment and thus the urgent requests for additional tents and tarpaulins to protect against the elements. The populations deep in the jungles of Upper Katchal were relatively well protected from the elements and therefore showed less respiratory problems. Those on the 110 mt elevation on northern Kamorta (Pilpilou and Kakana) with little tree cover certainly had to live exposed to wind and even rainfall which occurred on more than once. Teams initially on Car Nicobar assisted the lone 4 nurses in the performance of their duties and then began field trips into inland Car Nicobar to help people in need. On their return to Port Blair, they were engaged in specifically two refugee camps (Nirmala School – 2000 people; Haddo Public School – 800 people) running clinics including antenatal and postnatal care. They also assisted in all activities of camp life as a part of psychological support – involving victims in tasks needed in camp life, sitting, talking, counseling, pre and school related classes (Action songs, Mathematics, Science, Language), even meditation and play/diversion therapy with the children in the camps. Other camps covered partially were Chouldari (300), Chidia Tapu (250), New Wandoor (116) and Wandoor (75). As the camps began to close over the weekend it was decided that they could be withdrawn – a job well done in an hour of need!

Medical Surveillance

Documentation of morbidity patterns and regular feedback once again proved vital for determining appropriate needs of the affected population rather than accepting wrong inputs based on hearsay and rumours. The news of Sweden sending 200,000 Cholera vaccines and the presence of numerous health care providers (29 doctors in one hotel we spent the night) and their vaccination supplies at Port Blair while we awaited our flight out was totally uncalled for and a burden on limited resources in the field. Nowhere in the world is mass vaccination recommended for secondary epidemics are extremely rare after natural disasters. These decisions are probably taken far away from the ground reality for disease surveillance on the islands does not suggest any such need. It is also well known that vaccination needs refrigeration to the point of service, time, skilled personnel, adequate disposable needles and syringes – factors unrealistic in the present situation. In addition, any of these attempts would divert scarce resources away from more important tasks of sanitation, protecting drinking water supplies, provision of shelter/ clothing and disease surveillance. The numerous health care providers on the ground as we leave would be worth the effort to make them stay back as teams to begin disease surveillance on independent islands. Also obvious was unscientific choice of health care personal sent in with inadequate understanding of the epidemiology of the disaster and anticipated needs, unprepared to function outside the four walls of a hospital.

Debriefing and Team Withdrawal

The uncertainty of schedules and the poor communications makes it extremely difficult to plan and implement what we needed to do and when. Every 6–8 hours we would hear different news and the withdrawal of teams was another logistic nightmare with one group hailing down the passing I.N.S. Magar and the second group managing a most fortunate Pawan Hans Helicopter drop of to Port Blair via Car Nicobar and Hut Bay. As our teams withdrew and were replaced by Border Security Forces, Indo-Tibetan Police and the Gurkhas, we summarized (see table A) the status of relief from the grassroots level of problems and needs and presented the same to the decision making relief coordinators (Commander in chief Andaman and Nicobar CICAN – Lt Gen B.S. Thakur incidentally the next Vice Chief of Army and his inter-service team – Cmde Jallander CSO – Operations, Cmde Mampally NOIC A&N, Surg Capt Ravindran CO INHS Dhanwanthri) the day our first team left Port Blair on the 7th January 2004. Our last team of a total of 13 health care providers (6 doctors and 8 nurses) arrived in Bangalore this morning. In view of over 35 doctors based on Car Nicobar, 29 from Delhi in our hotel in Port Blair and at least 3-5 doctors on islands of the Nancowry block over the last two-three days, our timing and decision to withdraw seemed appropriate to avoid becoming a burden to resources much needed in the field.

Bangalore and Future Efforts – Beyond Relief ... Rehabilitation

On arrival, the Coordinating team at our base at St. John's Medical College Hospital, Bangalore, headed by the Director Rev Dr. Thomas Kalam, Dean Dr. Prem Pais, Chief of Medical Services Dr. Mary Ollapally and Team Coordinators Dr. Kanishka Das sat down with us and it is decided that we need to know plan long term assistance to enable rehabilitation. We have decided on the following potential areas of long-term service as a part of rehabilitation:

i. Acceptance of the WHO offer to set up a Six-month Disease Surveillance Cell for the Nicobars (our area of operation and rapport) under the efforts of Dr. Arvind Kasturi Community Health, St. John's

ii. Initiation of a felt need to provide tertiary care nearer home through the formation of a satellite hospital at Port Blair providing periodic tertiary level consults and even interventions at least once a month linked to areas of work.

iii. Discussions to consider the feasibility of posting interns every month for a year in rotation for duties on areas most affected.

iv. Discussions to rapidly raise resources through the Friends of St. John's and their children to assist in the equipment of schools destroyed especially on Katchal Island.

v. A potential dream to resurrect Teressa Island by adopting it through our sponsors – St. John's, Care Today, Friends of St. John's.

To enable this our third team is to return lead by Dr. Marian Kamath (Friends of St. John's) and with four of us to Port Blair on the 11th January 2005 to decide/finalize on the spot plans for long term interventions as discussed above. This team is already touring the affected areas of coastal Tamil Nadu to meet us at Chennai and fly out together.

We have all returned with a degree of satisfaction of a job well done, at the right time and at the right place an are forever grateful for all those who supported our work . . . there are so many numerous unsung heroes back home and on the islands that we just cannot always remember but will do so whenever possible. It is not important who did what or who did more . . . but that a team went in and performed as well as it could under circumstances no one else can even comprehend. Without each other not one team member could have assisted in this effort and fulfill a task set out for us. We cannot but thank all our families, our institution and all our supporters especially our sponsors for their prayers and unconditional support to enable us to achieve the degree of care and support we could extend to people in need. Let there be no illusions that this was purely altruistic for deep in our hearts and minds we have gained!

As on 6th January 2005	**Kamorta**	**Teressa**	**Katchal**
Food	Regular (Rice, dhal, oil, fuel – island coconuts, bananas)	Regular (Rice, dhal, oil, fuel – island coconuts, bananas)	Regular (Rice, dhal, oil, fuel – island coconuts, bananas)
Water	Regular (including island sources)	Regular (including island sources)	Regular (including island sources)
Shelter	Partially adequate (Tents, tarpaulins)	Partially adequate (Tents, tarpaulins)	Partially adequate (Tents, tarpaulins
Power	Restored	Partially restored (ingenious repairs of gen sets, drops of additional gen sets)	Partially restored (drops of additional gen sets)
Communications	Restored (Earth station, Satellite phones, police wireless, paramilitary-military)	Partially restored (Satellite phones, police wireless, paramilitary-military)	Partially restored (Satellite phones, police wireless, paramilitary-military)
Medical supplies	In excess	In excess	In excess
Medical manpower	Adequate	Adequate	Adequate

Epidemics	NIL	NIL	NIL
Carcass disposal	Completed	Partially completed	Partially completed
Inter-island Transportation	Urgently needed	Urgently needed	Urgently needed
Needs	Out board boats	Out board boats	Out board boats
	Tents/tarpaulins	Tents/tarpaulins	Tents/tarpaulins
	Clothes	Clothes	Clothes
	Psychological support	Psychological support	Psychological support
Medical Surveillance/ Feedback	Inadequate	Inadequate	Inadequate
Morbidity pattern	Children	Children	Children
	Respiratory illnesses	Respiratory illnesses	Respiratory illnesses
	Injuries – major and minor	Injuries – major and minor	Injuries – major and minor
	Skin infections	Skin infections	Skin infections

Needs	Specifics	Comments
Shelter	Tents/tarpaulins	Protection against rain and wind and other elements
	Building material for permanent dwellings	Tin/aluminum corrugated sheets, tools for work, wood
	Clothes	T-shirts for both men and women, preferably those with Soccer teams on them!,

		Blouses for women, Short pants for men, continuously stitched lungies – pretty designs, colours to be used like sarongs. Remember to have similar stuff for children.
Food	Milk powder	
Sanitation	Soap – lifebuoy	
	Bleaching powder	
Transportation	Outboard boats	Inter-island transport
	Scheduled north-south-north vessels	
Rehabilitation	Hindi, English, Nicobari speaking HCP/Counselors	NIMHANS trained
	Footballs with air pumps	They love football, sons named Ronaldo!
	Educational material and teachers	Schools
Medical	Disease surveillance and periodic reporting	To monitor and have a continued needs assessment
Local Monitoring	Monitor problems, needs and distribution	The tribals never demand and quietly go on with their lives. Distribution must be monitored locally with feedback direct to the military command in charge of relief.

Team members:

1. Ms Parveen Sikand, Friend of St. John's
2. Dr. Kanishka Das, Paediatric Surgeon
3. Mr. Ravi Shankar, Pharmacist

4. Ms Janaki, Pharmacist
5. Ms Suma Natarajan, Neurosurgery Nurse
6. Ms Sheela Shalini D'Souza, Emergency Medicine Nurse
7. Dr. Kiran Naik, Emergency Medicine Fellow
8. Dr. Aril Antony, Anesthesiology Fellow
9. Dr. Mallipatna C. Ashwin, Ophthalmology Fellow
10. Dr. Antony Robert, Paediatric Surgeon
11. Dr. Sanjiv Lewin, Paediatrician
12. Sr. Cini M. John, Paediatric Nurse
13. Ms Belveera D'Souza, Nurse
14. Ms Linimol Thomas, Nurse
15. Ms Asha Wilma Corda, Nurse
16. Ms N.S. Arogya Mary, Nurse
17. Dr. Vimal Raj, Orthopaedic Fellow
18. Dr. Marian Kamath, Internist, Friend of St. John's
19. Ms Kamath, Public Health, Friend of St. John's

Tour Report: Visit to Nancowry Division, Nicobar - 20th to 28th January 2005

AJIT CHAUDHURI

Background

A series of tsunami waves struck the eastern coast of India in the morning of 26th December 2004. As the extent of death and destruction became clearer, Care Today (CTF) decided to respond to the situation. Appeals for funds were issued in India Today, Aajtak and Red FM, and funds were immediately committed towards an emergency medical team from St. John's Hospital, Bangalore who went on to work in Nancowry division of Nicobar Islands.

The Nancowry division is the central part of the Nicobar group of islands, between Car Nicobar in the north and Little and Great Nicobar in the south, and is headquartered at Komorta. The other islands in the division include Bambooka, Chowra, Kachal, Nancowry, Teresa and Trinket, and were badly affected by the tsunami as can be seen from the attached table. I received a permit to visit this area on the 19th (entry here is restricted and requires permission from the administration) and was fortunate to find a helicopter flying to Komorta on the 20th itself.

Table I: Dead and Missing in the Nicobar Group

Source: Deputy Commissioner (Andamans) Office

Island	Population (2001)	No. Dead	No. Missing	No. Injured
Car Nicobar	20,292	768	370	264
Chowra	1,385	41	15	
Teressa	2,026	50	9	
Katchal	5,312'	345	4310	1
Nancowry	927	1	3	24
Kamorta	3,412	51	387	144
Trinket	432	3	234	192
Kondul	150	38		
Pilomillow	145	163		
Little Nicobar	353	43		
Great Nicobar	7566	336	220	826
Tillangchang	13			
Bambooka	55		17	
Total Nicobar	**42,068**	**1839**	**5565**	**1451**

Aims of the Visit

- Assess the damage caused by the tsunami in the islands of Nancowry.
- Identify the most affected communities and their major needs.

- Identify the agencies and institutions that are active on the ground.
- Assess the possibility of a role for CTF in the future – this includes understanding the government's rehabilitation policy (once it is formalized) and its gaps, identifying specific needs, and meeting local institutions that are likely to be there over the long term.
- And finally, build credibility for CTF within the area.

Activities

20th January	Port Blair to Komorta Meeting with Assistant Commissioner (Komorta) Meeting with Tribal Council Meeting with A&N Environment Team
21st January	Komorta to Kachal Meeting with Special Relief Officer (Kachal) Visit to relief camp at Mildera-2, meeting with captains
22nd January	Visit to Upper Kachal, meeting with 2nd Captain Visit to Jhoola village Meeting with TISS team and SRO
23rd January	Meeting with Lt. Col Sharma of 5 GR Day at Kapanga watching clearing of the jetty
24th January	Kachal to Komorta, meeting with AC Komorta Meeting with 1st Captain, Trinket
25th January	Meeting with Commander Mann, CO of INS Karadip

	Meeting with youth leader of Kakana Meeting with AC Komorta
26th January	Meeting with Aysha Majeed of Tribal Council Leave Komorta for Port Blair on MV Yerawa
28th January	Reach Port Blair

Impressions/Discussions – Komorta

Komorta is not badly affected by the tsunami – the main reasons for this are that the islands of Nancowry and Kachal provide it cover, and that there is high ground in the immediate vicinity of the coast. The rising of the sea level has resulted in access to the jetty being covered during high tide. Most of the infrastructure in the town is in place, and it has 24 hours electricity. The main market is functional and basic meals are available in the local eateries.

People from other islands have moved into Komorta. Some, such as those from Trinket, propose to resettle in Komorta and have identified land in Vikas Nagar (some 15 km away from Komorta town on a road that is yet to be completed) to do so. Others, such as those from Nancowry, plan to go back to their own islands.

A young Assistant Commissioner, Mr. Ashok Kumar Meena, who joined here in early January directly from his probation, heads the administration. He is grappling mainly with the problems of supplying relief material to far-flung corners of Komorta such as Kakana, and to the other islands in the vicinity. His main other concerns were the need for tools, implements and housing material to enable people to move out of the camps and back to their homes, boats with outboard motors to enable more frequent supply of relief material, and the need to get the schooling system functional again.

The main non-governmental institution in Komorta is the Tribal Development Council – the son of the Queen of Nancowry, Mr. Rasheed, controls this and much of the trade between Komorta and the rest of the world. He was away in Port Blair during my visit; we met briefly as he departed on the same helicopter that I arrived in. His sister, Ms. Aysha Majeed, is actively involved with the council and has a good reputation both with the administration and within the community. Another local organization is the Nicobary Youth Association – its relationship with Mr. Rasheed was unclear to me.

Each tribal village is led by a group of captains, who are elected to the post for a fixed term. They have the authority to act on behalf of the community in its interaction with the government and other outside agencies. This enables the process of relief distribution to be relatively efficient and egalitarian. Many of the captains in Trinket and Kamorta are young and in their first term – some of them are overwhelmed by the situation and others are discovering hidden capabilities. Mr. Rasheed's hold over the captains is debatable as some of them are well educated and do not see the need for a go-between.

The captains are busy with the distribution of relief, relocation of the communities and other immediate issues and see the need for a discussion on the long-term future of their communities once the immediate issues are under control, probably in two months time.

Impressions/Discussions – Kachal

Kachal had a distinctive settlement pattern before the tsunami – the government infrastructure was mainly on the east coast in Kapanga (completely wiped out by the tsunami, see table), the Nicobarese tribals were based in settlements along the shores around the island, and there was a settler population based in Mildera in the center of the island (on high ground). The settlers include Sri Lankan refugees brought here under an international agreement, labourers brought here under the tribal pass system and illegal immigrants brought in by labour contractors (of whom the numbers are unclear). The deaths have taken place mainly among the Nicobarese, the government servants and the illegal immigrants, and there is considerable dispute over the numbers because of the last category. The other settlers have not lost lives or property in the tsunami.

Infrastructure

All infrastructure, except in Mildera, has been destroyed. The jetty at Kapanga has ceased to exist, and all supplies to Kachal have to be transferred from ship to small boats in rough open sea to reach the island. Large items, and large volumes, are thus difficult to supply to Kachal. I had myself witnessed the efforts of two naval landing crafts trying to find a way to get a truck and a bulldozer on to the island – the mission had to be abandoned. The lack of a jetty has led to worries about supply of electricity in Kachal as the generator is run on diesel and this is difficult to transfer on to the island and will be impossible once the seas get rougher.

Government accommodation, offices and schools have also been destroyed. Staying here is extremely difficult, even for the senior government officers posted here, with the lack of basic accommodation facilities, poor communications and shortages of electricity, food and water. The Special Relief Officer (an IAS officer on posting from Delhi) spends much of his time refusing requests from government servants to be sent elsewhere.

Most of the teachers of Kachal died in the tsunami, leaving the schooling system in a mess and the prospects for the 79 students appearing for their class X and XII examinations bleak. In addition, those students who were studying outside the state (one person doing a Masters in MCC Chennai, another doing an MBBS in Maharashtra, etc.) are having difficulty reaching their institutions and, once there, meeting their general expenses as all money has been washed away. The situation is similar for those studying in Port Blair.

The banking system here is also in a shambles with the bank (Corporation Bank) having been washed away along with all records, those with the bank and those with the bank account holders (except for the settlers). There is therefore no way of knowing who has how much money in the bank.

Table II: Situation in Kachal villages

Source: Tribal Development Council, Komorta

Settlement	Population (2001)	Dead	Missing	Current Location
Jhansin	250	10	153	Mildera-1
Jhoola	372	9	76	Mildera-1 & Beachdera
Kapanga	3519	21	2858	Mildera-2
Kulatapangia (Ponda)	370		317	Mildera-1
Mildera	1825		7	Mildera
Vyatapu	551	50	223	East Bay
West Bay	1050	Only 4 are still alive		Mildera-1

The Relief Camps

There are four relief camps that are functional in Kachal. They are Upper Kachal (East Bay) with 275 occupants, Mildera-1 with 625, Mildera-2 with 520 and Beachdera with 403. The other main settlement in the island is unaffected Mildera, with 1255 occupants (all of whom are non-tribals). Food is not a problem at present, with about a month's supply currently in stock. The main need is for lungis, soap, sanitary napkins, mosquito repellant, toothpaste and toothbrushes. The Upper Kachal (East Bay) camp is relatively remote, about an hour away from Kapanga by boat, all other camps are in the vicinity of Mildera.

Livelihood

The traditional tribal way of life, of having coconut plantations and depending upon the income from copra, is shattered with the plantations being largely destroyed. These will require 7 to 10 years before they can recover. Until then, people will require other means of livelihood. The Nicobarese say that an option is that the government puts in money for the rebuilding of infrastructure on the island and does not allow labour to come in, thus enabling the Nicobarese to provide the necessary labour.

Other Issues

There are two other issues that would affect any long-term intervention here. The first is the leadership vacuum among the tribals – all the first captains died in the tsunami, as did most of the other leaders. There did not appear to be any functional institutions among the tribals, and the hold of intermediatories such as Mr. Rasheed was minimal. The second is an undercurrent of tension between settlers and tribals – apart from the Upper Kachal area, all the tribals want to settle in and around Mildera (where the settlers already are) and have identified some of the 614 hectares of land available with the Rubber Corporation, some of which has already been encroached upon by settlers. In addition, the settlers are upset about the relief and compensation packages being targeted at the tribals.

The Main Needs

For an NGO, these, in my opinion, are as follows:

The short term:

- *Trauma counseling:* The affected community will have difficulty in handling the large losses suffered, and the psychological effects are beginning to show. There was one suicide attempt while I was there (a young girl drank a bottle of dettol, she had just found out that her parents were no more). There is an urgent need for professional trauma counselors to enable the community to deal with their situation.

- *Finances for Students:* Students studying in Port Blair or the mainland should be provided with cash to enable them to join their institutions and some funds to enable them to meet expenses for the near future.

- *Coaching Classes:* Students giving their classes X and XII exams need tutors brought in with the sole aim of enabling them to pass.

- *Building material and implements:* There is already a move by the government to provide building material and implements to each family so that temporary shelters can be up before the monsoons. The pace of this needs to be stepped up.

- *Cash injunctions into the community:* The immediate relief of Rs. 2,000 provided by the government can be supplemented.

- *Resource persons in each village:* It would be useful to identify a group of educated youth, both men and women, in each village and train them to be resource persons for the longer term rehabilitation effort.

A long-term strategy is difficult to visualize until the government's rehabilitation package is clearer.

Should Care Today Intervene?

The Nancowry division is clearly among the worst affected parts of India from the tsunami of 26th December 2004. At the same time, this area provides some special difficulties to any organization planning an intervention in relief and rehabilitation. These are

- The area is extremely remote and difficult to reach.
- There are no local organizations through which to work.
- Basic communication and infrastructure facilities are unavailable.
- Government permission is required for any intervention.

At the same time, Care Today has collected its funds from Indian citizens for the use of the worst affected communities in India, especially those that other organizations are not able to reach for reasons such as the above.

I would therefore like to discuss the possibility of Care Today working in Nancowry division over the next year with its Directors and with the Andaman and Nicobar Administration.

Immediate action already taken includes setting up a daily boat service between Kapanga and Upper Kachal on Kachal Island, for which an advance has already been paid to the local boat owner. The service began on 24th January and will continue for a month. In addition, a list of Kachal students studying in the mainland has been obtained from the SRO and I will shortly ensure that a grant will be available for them at their institutions.

Tsunami Relief: An Observer's Viewpoint

RAMA GOVINDARAJAN

This article is about becoming phenomenally well-prepared for disaster relief. It is based on thoughts formed during two days (January 1 and 2, 2005) spent in tsunami-hit villages close to Thirukkadayur in Tamil Nadu, and from discussions with several students of the Nehru Centre, Bangalore, and of IIT Chennai, who served for longer periods as volunteers. The perspective is thus highly localised in both space and time, and very deficient in knowledge and experience. Nevertheless it is hoped that the suggestions made will be of some value.

We in India must strive during good times to attain an unprecedented level of nationwide preparedness. We have repeatedly seen that our response to a given natural disaster is immediate and as efficient as possible under the circumstances. However the wake of a tragedy is not an opportune time to start getting organised: there is usually too much confusion, and help does not always reach the right place at the right time.

The two aspects we focus on here are (i) getting volunteers organised and (ii) being prepared with supplies and equipment.

Before describing these in detail, I would like to give some background about the affected areas, and the work that was being done. This region is beautiful, green and must have been clean and relatively prosperous before the tsunami. The worst-hit were the fishermen's villages, since they are closest to the beach. The affected people are articulate, forthcoming and very dignified. Their main problem is that their boats, and that means their livelihood, has been washed away. Their hospitality was unbeatable. A woman made tea without sugar for us on a patch of mud that used to be her kitchen, with borrowed tea leaves and milk.

The villages we saw were completely submerged under a few feet of sand and other debris. Each village had lost people, between six and forty in the ones we went to. Most homes were severely damaged and the roads were gone.

Several aid agencies in Bangalore were coordinating with volunteers, organizing them into groups, and putting them in touch with local bodies close to tsunami-hit sites. These people were also organising the collection, sorting and transport of supplies. Before leaving, we were given a five-minute counselling session over the phone, which helped a lot in preparing ourselves mentally. We were told to get anti-tetanus shots, wear shoes, carry gloves and masks. We were advised not to worry about the politics and motivations of others. Everyone followed this advice, and was only interested in helping. Our local transport and food were organised by local political and voluntary organisations. Everyone, both in the government and outside, worked overtime and really did their best. The spirit and determination of so many people was incredibly touching and has given us an abiding optimism for the future of this country. However, there is no replacement for being ready.

Volunteers

Wasting manpower can prove costly in terms of saving lives and providing urgent aid.

The Situation

On the first of January, 2005, in the fisher villages close to Thirukkadayur, there was an abundance of short-term volunteers and also a great deal to be done. However, despite the best efforts of everyone concerned, a large number of man-days went un-utilised and a large amount of work remained un-tackled.

A majority of the volunteers that I encountered were in their twenties, many of them software engineers and other professionals working in Bangalore and other cities. Many of them said they were there because they could not stay away, and more so, could not think of celebrating the new year in customary grandeur. There were also faculty and students from various places, homemakers and others. They were all physically fit, willing and able to contribute physical labour, time and money. We are fortunate that our young people are so serious and good. We need these people.

The first problem the volunteers faced was in deciding what to do and who was to do it. There were no experienced people, nor well-defined leaders and followers. A lot of time was wasted since everybody tried to lead, and had completely varied opinions about what was priority. Work was assigned arbitrarily and sometimes unsuitably. Shortage of equipment and transport also resulted in wastage of man hours. Many volunteers, who would have stayed much longer, grew frustrated at being idle in the face of urgent work needing to be done, and returned home.

When we arrived, we found that many survivors had fled their homes, and were stationed in camps situated some distance away from the shore. The conditions in the camp were not too congenial, but the residents were too intimidated by the appalling condition of their villages to return. We distributed ourselves among the villages and spent the first day cleaning up the buildings and surroundings of the schools, temples and women's community centres. This involved digging to remove debris packed several feet deep. The idea was to induce villagers to return and to start rebuilding their lives, by giving them a roof over their heads in their village. At the end of a tiring day of clearing debris, which included carcasses of animals, it was most rewarding to discover the shining floor of the temple. Some of the villagers were buoyed up with enough enthusiasm by evening to join us. All of them told us that our presence and concern gave them the moral support to get back, and they were now eager to show us how much better they are than we, and how fast the debris can get cleared. The inactivity enforced by camps on victims is demoralising and slows down rehabilitation. An important duty of a volunteer is to get the affected people involved in physical activity, i.e., to make herself or himself redundant.

What We can Do?

The above was good, but volunteers, if well organised, can do much, much more to save lives and minimise losses. We saw some of this in the recent floods in Mumbai. The following are suggestions for making the best use of volunteer power. All this needs to be done in good times, so that disaster management is more efficient.

Make it possible for volunteers to register themselves online (or via mail) by filling out a simple form. This site should be well-advertised.

The volunteer list should be sorted apriori according to geographical location, amount of time they are willing to put in, level of physical fitness, preferred type of work etc.

The sorted lists should be available online to relevant officials in the government, aid agencies etc., so that mobilisation is immediate. The government, the NGOs and other relevant people must coordinate and have a good plan for using volunteers to save lives and property.

Volunteers need short term training, counselling and elementary knowledge of paramedical aid. They must know what they need to do, what they must expect, and where they are in the chain of command.

Volunteers who can contribute in the long term, to reconstruction, to educating the children, to medical aid including psychological help to trauma victims etc. are a precious resource. There are innumerable Indians who want to do something in this regard, but don't know where to begin. With some leadership, they can be organised into a formidable team.

Equipment and Supplies

A big waste of manpower was caused by an acute shortage of equipment. There were two dozen people ready to remove debris with three or four spades between them. In any case the work that all these people could do in weeks could have been done by an earthmover in a few hours. Transport to the site often arrived hours late due to some communication gap, resulting again in a large wastage of man hours.

It is crucial to have digging equipment and earthmovers stationed within an eight hour radius of likely disaster sites. This can save many lives in tsunamis and earthquakes. It will also help to bring life back to normalcy much earlier.

Two of us spent a day with a doctor, going from village to village trying to administer treatment. Everywhere, people formed long lines to meet the doctor, and many said they had not received any medical help in the five days since the tsunami. The medical supplies provided consisted primarily of anti-inflammatory tablets. There were also large amounts of antibiotics, antipyretics, vitamins and electral. While some of these were handy, the things that we desperately needed included skin ointments, bandage kits, scissors, local anaesthetics, bronchodilators and anti-tetanus shots. Many people had been wounded by falling objects. Many had severe skin problems, either long-term, or, in a majority of the cases, originating from being submerged for minutes to hours in sea water. Breathing trouble was a common ailment. We were most often reduced to administering vitamins as placebo. To the ones with possibly cracked bones, we had only advice to give, that they go to hospital. It is crucial that medical kits which include the most needed items be kept ready at all times.

There was mismatch between what was needed and what was contributed in other supplies as well. It is important to get the children involved in some activity, to help them forget the trauma. It is children who are also the most willing to bounce back quickly. Toys, books, colouring pens etc. are sorely needed. The people also desperately need hygiene aids, especially soap and sanitary napkins. Old clothes were found to be a huge hindrance. First, and many others have made this point, tattered or dirty clothes are an affront to the dignity of the victims. Second, man-weeks were sacrificed to exploring boxes which contained nothing of use, and deciding how to deal with mountains of old clothes. Third, this is a waste of transport. Donors should only give new or sparsely used clothes, clean and ironed, and which are appropriate for wearing in villages. There should be repeated appeals in the media to donors, listing what is needed and what is not. Donors also should be reassured that the money and supplies they contribute, for the most part, will reach the needy. This was at least what we witnessed. Incidentally, it was noticed that the supplies which arrived from Gujarat were quite appropriate, probably because the experience after the Bhuj earthquake had given people a better idea of what is needed.

The food trucks came once a day to some villages, and that too around 3 pm. Those who were last in the line got only plain rice, which they were unable to eat. In other villages, food came more frequently, and the only complaint that we heard that was that the food was vegetarian! We in India are good at making high-energy-content food which is long lasting, e.g. for the soldiers at Siachen. Packets of nutritious and non-perishable food of various kinds must be distributed very early, and in sufficient quantities, to everyone. Also needed are chemical toilets and camping equipment, for both victims and volunteers.

Distribution of supplies in a fair manner can be a big problem, and also a major time-sink. The fittest and richest in a place are also often those that are able to get hold of more. Dominantly "low-caste" villages reportedly faced much greater difficulty in getting aid. Apriori, we need to work out methods of helping the worst-hit first, and of making volunteers aware of these methods.

In summary, (i) a countrywide volunteer network must be organized apriori, (ii) donors everywhere should be reoriented away from giving old clothes and towards giving approriate medical and other supplies (iii) earthmoving equipment and emergency supplies including non-perishable food packets to be kept ready and within reach at all times. (iv) there should be a master plan for collection and distribution of supplies, use of manpower etc.

Rehabilitation and Reconstruction Strategies

S S MEENAKSHISUNDARAM

The tsunami disaster has caused untold damage to life and property in several countries of Asia. In India, it caused massive destruction and casualties in the coastal regions of Tamilnadu, Andhra Pradesh, Kerala, Union Territories of Andaman and Nicobar Islands and Pondicherry. Several thousand people lost their lives and many were injured. In addition, the tsunami caused destruction of infrastructure, housing and livelihoods. The environmental impacts were severe, including large amounts of coastal land being contaminated by seawater. Beyond the visible effects of the tsunami, lives and livelihoods of countless people and communities were severely damaged. No doubt, the tsunami was devastating. But, it also presents an opportunity to equip ourselves, to face with greater confidence and competence, similar challenges in the future. Several Non-government Organisations (NGOs) responded very quickly to the situation and provided emergency relief and supplies to help the affected people. The Government of India in addition to initiating several short-term relief measures had taken steps to establish the 'Tsunami Early Warning System'. A National Disaster Management Authority has been put in place.

On the basis of experience gained during the last ten months, several short and long-term measures can be identified to equip the coastal areas to face natural calamities such as the tsunami, cyclones, flooding, etc., with much more courage. What are the short-term needs to be addressed in a tsunami like disaster? What medium and long-term measures should be undertaken to ensure that the vulnerable groups are benefited from reconstruction efforts and also to minimize destruction and devastation caused by such natural disasters? In this paper, we attempt to briefly answer these questions.

Short-Term Needs

What relief is required immediately after the disaster hits the people? When affected communities, having lost everything, have to rebuild their lives and livelihoods, the straight answer to this question would be to say everything that is needed to make their life work for them. This is easier said than done. From a variety of field reports that emerged soon after the tsunami had struck, several immediate needs can be identified. The first and foremost is to establish relief camps by providing temporary shelters. Ideally these temporary shelters should be established in existing traditional structures such as school buildings, temples, churches, etc. Historically religious places have been used in India as shelter in the event of natural calamities. If kept in good shape, they would be of great use, while facing an emergency or disaster. In the absence of such traditional places, we need to establish temporary shelters making use of available resources, both human and financial. Local material and local talents would have to be put to best use in establishing such a temporary shelter.

Once a shelter is established, the next thing will be to provide clean water and necessary sanitary facilities. For instance, in Andaman and Nicobar Islands, water-purifying tablets were in great demand and the companies which manufactured them were specially requested to donate them in large consignments. Chemical and makeshift toilets need to be established quickly, keeping gender sensitivities in view. Next comes the need for clothing. It must be borne in mind that the disaster-affected communities do not lose their dignity and the least thing they would accept is rejected clothes. The organizations which collect clothes for distribution in the disaster affected areas should weed out useless material right at the time of receipt. This would save enormous costs in transport and subsequent dumping. Blankets, women's undergarments and children's cloths were generally in demand throughout the tsunami affected areas and despite the availability of sizable amounts of clothing, their distribution posed a serious challenge to the volunteers in-charge. Efficient management, coordination and transparency were the felt needs in this area.

Preparation and distribution of food comes next in the list. Immediately after the disaster, it may not be possible to prepare food in the affected areas. We need to have ready-to-eat foodstuffs which have a longer shelf life for distribution among the affected people. Sooner we start the kitchen in the relief camps the better, though this would depend on the nature of the disaster itself. Food grains have to be stocked up either in the affected areas or nearby, so as to last at least for a few weeks. Transportation and distribution of the stocked food grains and other materials among the poor, particularly weaker sections of the society, is of great importance in dealing with the disaster and restoring the morale of the people.

An equally important immediate concern is the disposal of the dead - both human and animal, and also the prevention of diseases which usually follow death and decay in the affected areas. A team of willing medical practitioners and para-medical staff would have to be assembled to suggest and take up preventive action to ensure that no major outbreak of epidemics erupts in the affected areas. The medical team should be fully equipped with basic medicines to deal with anticipated ailments, in the aftermath of the disaster.

Another identified short-term requirement is psychological rehabilitation of the affected persons. Teams must be set up of men and women psychiatrists and trauma counselors, to cover severely affected areas to help the bereaved. Fishermen need to be assisted in overcoming fear of the sea. Farmers would need technical help and moral support. Destitute women would have to be rehabilitated within their own community and should not be herded in destitute homes. In addition, affected people should also be educated to properly handle the compensation money which arrives in plenty, from several sources, including the State and Central Governments.

The shape of urban India presents some special problems. Apart from concentration of population, much of the urban growth has occurred in large cities and urban agglomerations. The breakdown of infrastructure in one part of the metropolitan area affects the economy of the whole metropolis. Repairing the damaged basic infrastructure and putting them back in position as soon as possible, will have to be given the highest priority in the urban areas affected by the disaster.

The key factor in dealing with the short-term requirements of a disaster is the capability of the man in charge of the relief operations on the spot. A competent leader with a dedicated team of workers can win the confidence of the people and provide required relief. If efficiently handled, the relief operations can end within a few weeks of the disaster and the rehabilitation process can then start.

Medium-Term Requirements

Medium term plans for rehabilitation should start with an open ended food for works programme which should be sanctioned for about an year at least, to create assets in the tsunami affected areas and also to provide employment to the ravaged families during that period. Since the self-dignity of the affected families would not permit them to be on dole for a long time, it would be necessary to put them on a regular wage employment programme which can help in creating the assets required for their long term rehabilitation. The precise priorities in selecting the works, can be developed for each village in consultation with the affected families and the local panchayats. The responsibility of the Government should be to allocate sufficient food grains for taking up these programmes and get it implemented through the local self-government institutions.

Organizing training programmes for masons and construction workers on safe reconstruction should be initiated as early as possible, as these skills will be required locally for large-scale construction work needed there. Repairs and retrofitting of the existing community centres; establishment of citizens resource centres to disseminate information regarding damage assessment, rehabilitation packages, compensation claim processing, relief and recovery status, tips for safe reconstruction, support agencies and trained masons etc.; planning of livelihood restoration and options village-wise; and research and planning for temporary and semi-permanent shelters and house reconstruction using locally appropriate materials and technology are other areas where action has to be initiated as soon as the relief phase is over.

Identifying volunteers who can work with the people in the medium term would also be necessary, as the evacuees will need support when they start going back to their villages. These volunteers have to be carefully identified to ensure that they stay with the communities until the local people gain the capacity to sustain by themselves. The volunteers must be advised to go with adequate preparation and should, to the maximum extent possible, be self-sustaining.

Long-Term Plans

Longer-term rehabilitation programmes should cover all families along the coast — both fishing and farming families including the families of those who have no assets like land, livestock or fishing pond. These programmes should include ecological rehabilitation, agronomic rehabilitation as well as livelihood rehabilitation.

Ecological Rehabilitation:

The ecological programmes must include:

(a) Establishment of a bio-shield along the coast involving ing raising plantations of mangroves and the preservation of estuaries, lagoons, backwaters, tidal creeks and development of a proper land use plan around the wetlands. Initiating a coastal bio-shield movement is essential, as the bio-shield will serve as a speed-breaker under conditions of coastal storms, cyclones and tsunami. In addition, they will serve as carbon sinks, since they will enhance carbon sequestration and thus contribute to reducing the growing imbalance between carbon emissions and absorption. Mangroves also promote sustainable fisheries by releasing nutrients in the water, which in turn will provide additional income to the coastal communities. Coastal bio-shield can also involve agro-forestry programmes like the intercropping of casuarinas with hybrid pigeon pea or red gram, to be undertaken by the farming families.

(b) Regenerating fisheries and fostering a sustainable fishery programme: The new fishing vessels and nets should be so designed that they do not disrupt the fish lifecycle by catching the young ones and also do not destroy sea grass beds that serve as habitats for dugongs. The tsunami calamity can thus provide an opportunity for achieving a paradigm shift from unsustainable to sustainable fisheries.

(c) Raising artificial coral reefs: Artificial reefs can stimulate breeding and revival. These can be laid and managed by the Self Help Groups among the fisher women, with credit facilities from the banking institutions.

(d) Construction of permanent sea walls and dykes: These can be taken up in places where there is sea erosion owing to heavy anthropogenic pressure. The locations for such non-living barriers should be determined on the basis of a carefully conducted erosion vulnerability analysis.

Agronomic Rehabilitation:

Reclamation of salinised soils is an important necessity in the coastal areas, as the sea-water ingression has led to soil salinisation in several areas. A scientific team consisting of representatives of agricultural universities, the Central Soil Salinity Research Institute and the Council of Scientific and Industrial Research should take up the survey of the affected areas, study the nature and severity of the problem and suggest remedial measures. This should be done as quickly as possible so that farmers can resume their normal farm operations without losing a crop season.

Identification and adoption of suitable plant varieties in the coastal areas should be taken up simultaneously by organizations like the Indian Agricultural Research Institute, as well as the research foundations in the private sector. A vulnerability mapping based on an analysis of 100-years data to identify the areas prone to cyclones and other natural disasters will be extremely useful. Priority must be given to such areas in erecting bio-shields and in undertaking eco-restoration and erosion prevention measures. Agricultural vulnerability to potential changes in sea level should also be mapped.

There must be scientific land and water use planning to prevent salinisation of ground water. Land and water use patterns based on principles of ecology, economics and social and gender equity must be prepared by the local panchayats with the help of the locally available scientists from the farm universities as well as the field staff of the forest, fisheries and agriculture departments of the State Government.

Livelihood rehabilitation:

A sustainable livelihood rehabilitation strategy should be based on the principles of social inclusion and gender equity. It must cover not only the fishermen but also the land based farming communities as well as the land-less labourers. The key components of a livelihood rehabilitation programme must include:

(a) Aquarian Reform: Fostering harmony in the use of living aquatic resources between the ordinary fishermen operating catamarans and the commercial families operating mechanised fishing boats and trawlers has to be the primary aim of any Aquarian reform. A broad based policy to conserve the living aquatic resources, their sustainable use, equitable sharing of benefits and formulating a cost effective commodity chain for fisheries management needs to be evolved in consultation with the fishing communities.

(b) Integrating fisheries with sea water farming: The Self Help Groups among the fishing women must be encouraged to take up the rearing of prawns and suitable salt-tolerant fish species in canals along the sea coast. Agro-aqua farms involving the concurrent cultivation of tree species and rearing of fish and prawns can be promoted to enhance income and employment opportunities. Establishing aquaculture estates that can help confer the power of scale to fishing families in the production, processing and marketing of fish can also be thought of wherever possible.

(c) Coastal bio-villages: The economy of coastal villages can be strengthened through the bio-village model of rural development. This includes the sustainable use of natural resources and the introduction of market-driven non-farm enterprises as well as value addition to primary products. It also involves a paradigm shift from unskilled to skilled work, resulting in the addition of economic value to time and labour. The coastal bio-village movement, to be fostered by pachayatiraj institutions, should be based on a pro-nature, pro-poor, and pro-women orientation to enterprise development and adoption.

(d) A coastal grid of farm schools and demonstration centres: Farm and fisher families practising the use of natural resources based on the principles of ecology and economics can be chosen for establishing farm schools. Lateral learning among farmers and fishing families will be much more effective than formal institutional learning, and they can go together. Demonstrations of environmentally sound sea farming techniques should also be organized.

(e) Need based education system in the coastal areas: Designing a demand driven education programme for the children of the coastal communities will help in empowering these communities to face natural calamities in a much more organized fashion over a period of time. The timings of the schools in these areas can also be adjusted to meet the requirements of the local communities. Management and financial skills among the members of the Self Help Groups need to be constantly updated so that they can handle their own finances much more efficiently.

(f) Adoption of suitable Government programmes: There has been a plethora of Government programmes already in operation in the coastal belts of the country providing for self-employment, wage employment, area development, etc. Each one of these programmes should be critically evaluated to decide their suitability to the coastal belt and thereafter adopted to suit the needs of the local people. Dovetailing these programmes with the relief works that are taken up as a part of the rehabilitation package will help in not only enhancing purchasing power of the people but also in generating suitable assets for their future safety.

(g) Housing: The new houses to be built under the rehabilitation programmes should respect the 500 metres restriction and should be ecologically designed. A group of architects can design suitable coastal habitations keeping in view the human security needs in the event of a sea level raise. A code of conduct for construction beyond 500 metres should also be finalized with a package of rewards for initiatives in the areas of sunward oriented buildings, energy efficient construction, rainwater harvesting, tidal and solar energy, use of wind, effluent treatment, use of bio-degradable materials, improved chulahs and sanitary latrines. A coastal ecological security literacy programme should also be organized to bring to the attention of the builders the opportunities now available for mainstreaming ecology in building design and construction.

Information Empowerment

Evolving early warning systems using bio-indicators as well as science and technology is still a research requirement in the field of information empowerment. Once these systems are in place, access must be available to this information through internet, mobile phones, ham radios, police net, satellite phones, etc. BSNL and other appropriate institutions can help in establishing broad-band connectivity. Both wired and wireless technologies can be used for dissemination of information. A consortium of content providers and data generators must establish a digital gateway for coastal ecological and livelihood security. At least one woman and one man should be trained in every village on various aspects of disaster preparedness and management as well as in trade and quality literacy. They must be used as master trainers to disseminate knowledge among the other members of the community periodically. It is worthwhile to locate rural knowledge centres in public places within the village like the school or panchayat or youth club building to ensure equity in access. These centres can be managed either by NGOs or by self help groups. Developing a network of capacity building centres along the coast with relevant training modules will be extremely useful, as they can convert themselves into information centres in times of emergency.

Conclusion

To sum up, the tsunami disaster must be made use of, for launching an integrated psychological, ecological, agronomic and livelihood rehabilitation programme through public-private partnership. However, it must be borne in mind that such programmes can succeed only if community participation is ensured. They have to be people centered and managed by local communities with appropriate guidance and support from Government as well as the panchayatiraj institutions. While developing integrated coastal-zone management plans with necessary inputs from the coastal communities should be left to the Government agencies, academics, scientists and other interested knowledgeable local individuals, the implementation should be with the local communities including the panchayats. The role of gramsabhas as well as the community based organizations in providing a feed back on the quality of implementation of the rehabilitation programmes must be understood and appropriately made use of. Only then we can succeed in converting the tsunami disaster into yet another opportunity for development.

Management of Tsunami at Kalpakkam: Current Status and Plan

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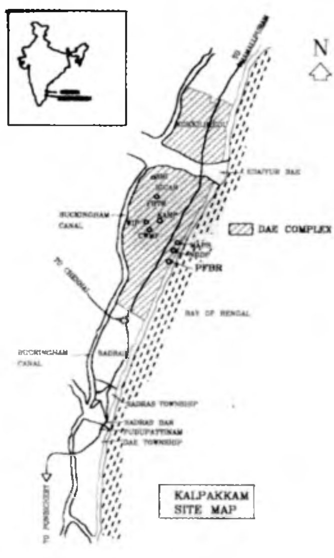
1. Introduction

Kalpakkam is situated 67 km south of Chennai, on the coast of Bay of Bengal. Major establishment of the DAE, namely Indira Gandhi Centre for Atomic Research (IGCAR), Madras Atomic Power Station (MAPS), 500 MWe Prototype Fast Breeder Reactor (PFBR) under construction and BARC Facilities are located at Kalpakkam. The township is located south of the plant site, againon the coast.



On 26th December 2004, when the Tsunami waves struck the east coast of southern India, both the plant site and the township at Kalpakkam suffered some damage. The damage is broadly classified into two categories, namely damage in township and damage in plant site.

2. Damage to Township

Due to entry of sea water, a large number of houses, hospital and other facilities at Kalpakkam Township (Pudupattinam and Sadras) were affected. Due to Tsunami tidal waves, 38 persons including 4 employees, family members and visitors to Township lost their lives. More than 400 houses out of 5010 houses got affected with sea water entry and the residents had to be shifted to other houses. The Anupuram Township of the Department with a small hospital and a community hall functioned as emergency center and provided relief to the affected persons. Electricity, water supply and telephone services were also affected. The whole area was filled with sand, slush and debris.

3. Damage to Plant Site

Impact on Madras Atomic Power Station (MAPS)

At the time of Tsunami, Unit I was under shutdown for carrying out coolant channel replacement and other life extension works, while Unit II was in operation with generation level of about 220 MWe. At 9.10 hours, due to high Tsunami tidal waves, sea water level in the forebay increased up to about 1.9 m above the operating floor in Pump House. The normal level with pumps drawing water is about 3 m below the operating floor. The condenser cooling water (CCW) pumps tripped due to submergence of the control switches. On noting the loss of CCW pumps, the control room operator had taken action to trip the turbine and the reactor. The reactor core cooling was maintained without any difficulty and the system was cooled down. There was no radiological or nuclear safety concern during the Tsunami.

During the Tsunami incident, the emergency process sea water pumps (EPSW pumps) which are normally fed by Class-III source of power supply (fed by diesel generator in case of loss of off-site power) became unavailable. Since the motors for these pumps are located in the Pump House at a lower elevation, they got submerged. However, the off-site power supply continued to be available during the incident and the normal process sea water pumps continued to be operable (in fact one of the process sea water pumps continued to operate throughout the incident) and hence the normal decay heat removal system could be utilized.

There was no other effect on any other main plant systems. A portion of the masonry wall at the outfall structure got damaged. On the sea water intake jetty, a portion of masonry enclosure to the liquid effluent line and a portion of the chlorination dosing line (HDPE pipe) got disturbed. The damage on the jetty was restricted to about 150 m from the shore line.

There is a natural sand dune with stone pitching on the southern side of MAPS, which withstood the impact of Tsunami and shielded the structures behind it. The sea water did not enter any other building during the Tsunami. Splashed water was seen on a small portion of the road in the vicinity of the pump house.

Impact at Prototype Fast Breeder Reactor (PFBR) site

The 500 MWe Fast Breeder Reactor Project (PFBR) site is situated towards the south of MAPS at a distance of 500 m. At the time of Tsunami, concreting work (Pour II) of the raft of the Nuclear Island Connected Buildings was in progress. The concreting was being carried out inside the pit, nearly 18 m below the existing ground level. The sea water entered the site by breaking the boundary walls (rubble masonry) on the east and north-eastern sides and inundated the pit to a depth of 6-8 m. All the 150 labourers working inside the pit could escape safely due to the timely alert given by the construction engineer. Further the excavated pits on the eastern side got filled initially and since the workers were engaged on the western side, adequate time was available for them to escape safely. The water did not enter the nearby Site Assembly Shop or did not cause any damage to the Batching Plant or the cement godown located further south of the pit. In addition to water, the incoming sea water had also brought in and deposited a large quantity of sand and other construction materials inside the pit. The peripheral dewatering system on the east and north eastern sides was dislocated. One lady worker engaged in the nearby Site Assembly Shop works got swept into the pit and died and this was the only causality at PFBR site.

4. Restoration Measures

Township

- A Control room was setup within half an hour under the Chairmanship of Director, IGCAR with participation of other unit Heads to provide Immediate relief and rehabilitation measures and take control over the situation.
- Emergency medical relief to the affected in and around the township was carried out.
- The Bridge between Sadras and Pudupattinam, water supply, Electricity, sewerage system and telecommunication were restored within 48 hours.
- Roads and other are as were cleared of sand, shrubs and debris.
- Entire Township was disinfected to avoid any spread of epidemic.
- Schools were re-opened within a week.
- Township could be brought back to life within 3 days.

Plant Site

- Unit II of MAPS was brought on line on 2nd January 2005, after taking necessary clearances from the Regulatory Authority.

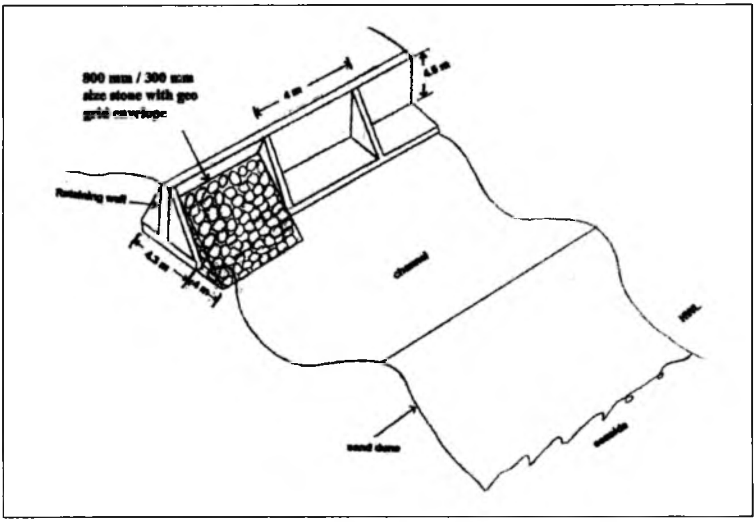
- After restoring the peripheral dewatering system, the water inside the pit at PFBR site was pumped out and the extraneous materials like sand and other construction materials was removed.

At the time of Tsunami, construction of second pour of concrete for NICB raft was on the verge of completion. Sea water came in contact with the green concrete. Considering the importance of the structure, it was thought that mixing of sea water with green concrete may cause serious problems and removal of this concrete was costly and time consuming. So, it was decided that the quality of the concrete be tested and if the quality comes out acceptable, further action will be taken. Various tests like chloride penetration test, compressive test, cement content and sulphate content were carried out for the sea water affected concrete. After qualifying the concrete, it was decided that the pour I and pour II can be considered as part of backfilling concrete below raft so that it need not be removed. Total thickness of the Pour I and Pour II was 1.25 m. New water proofing of around 50 mm and a plain cement concrete of 100 mm was placed over that to avoid diffusion of chloride ion to the new rafts. So, the total thickness is 1.4 m and the Finished Floor Level (F.F.L.) of Nuclear Island was increased by 1.4 m. The reconstruction work of the NI started on 26th April 2005.

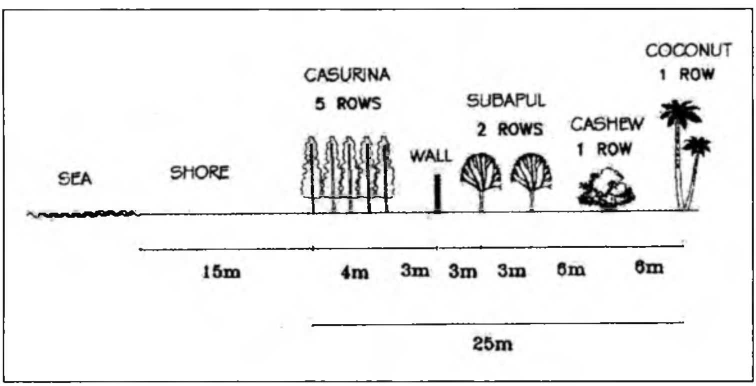
5. Constitution of Tsunami Related High Level Committee

A high level committee was constituted under the chairmanship of Director, IGCAR, to study the after effect of Tsunami and recommend remedial measures. Experts from CWPRS Pune, SERC

Chennai and IIT Chennai participated in the proceedings of the committee.



Proposed R. C. C. Barrier wall with sand dunes at Kalpakkam Coast.



Proposed Coastal Plantation for Kalpakkam as per the advice from M. S. Swaminathan Foundation.

Conclusion of the Committee

1. Adequate design margin against Tsunami exists at PFBR in view of the high finished grade levels (FGL) in both the Nuclear Island and Power Island. Hence, there is no need for any additional protective measures to the structures at PFBR site.

2. The design and safety features provided at MAPS enable safe shutdown of the reactor and its continued maintenance in a safe shutdown state after a Tsunami event.

3. The sand spit at MAPS and the naturally occurring sand dunes on the southern side of MAPS need to be protected and strengthened.

4. The proposed arrangement of integrated protection measure for outfall channel and coastline (MAPS and PFBR together), being worked out by CWPRS, Pune has been examined and is considered acceptable by the Committee. It is recommended for implementation after further detailing and examination by experts.

5. The proposed barrier wall along the township shore integrated with sand dunes and plantation is considered acceptable and may be implemented after further detailing by IIT, Chennai.

6. Considering the international practices, there is a need to define design basis. Tsunami at NPPs at Kalpakkam to start with. Since this exercise is complex and has uncertainties, it will require more time to arrive at logical conclusions and hence this needs to be treated as a long term project. The Committee recommends that the study can be carried out at Department of Ocean Engineering, IIT Chennai.

6. Additional Measures Taken in Township

The following additional remedial measures were taken up in the township

- 30,000 saplings are planted to bring back the natural greenery to the area.
- Action has been taken to construct an additional bridge connecting Sadras and Pudupattinam.
- Action is taken to construct an engineered RCC barrier wall with sand dunes and trees all along the Coast of Kalpakkam Township to withstand the impact of unlikely future Tsunamigenic threat and to act as a first line of defence.
- Action is taken to provide an additional emergency exit in school and emergency access to the first floor of the hospital which comprises a hall with essential medical facilities.
- Action is taken to advance the construction period of 150 numbers of houses.
- Series of Meditation Camps as well as Counseling classes are conducted for the Tsunami affected people to get rid of mental trauma.
- Interest free loan is arranged for each of the affected employee.
- The employees of other DAE Units contributed one day salary towards Tsunami.

Relief fund. BARC Officers Association (BARCOA) collected the contribution and Kalpakkam Management committee distributed the same to Tsunami affected employees of the Township.

7. Tsunami Warning System at Kalpakkam

The catastrophic Earthquake of Magnitude 9.0 which struck Northern Sumatra on 26th December took 2 hrs to reach the coast of Andaman and Nicobar Island and another 2½ hours to reach Tamilnadu Coast. In view of this it was felt that an early warning system regarding occurrence of earthquakes in our region is required along with suitable Sirens. The wireless Warning sirens (433.92 MHz) are installed at all strategic locations along the coast in the township. The systems are supplied by Ms Infotech Resources, Pune. The sirens can be triggered by hand-held trigger device. Each siren is provided with 12V rechargeable battery along with 5Watt solar panel.

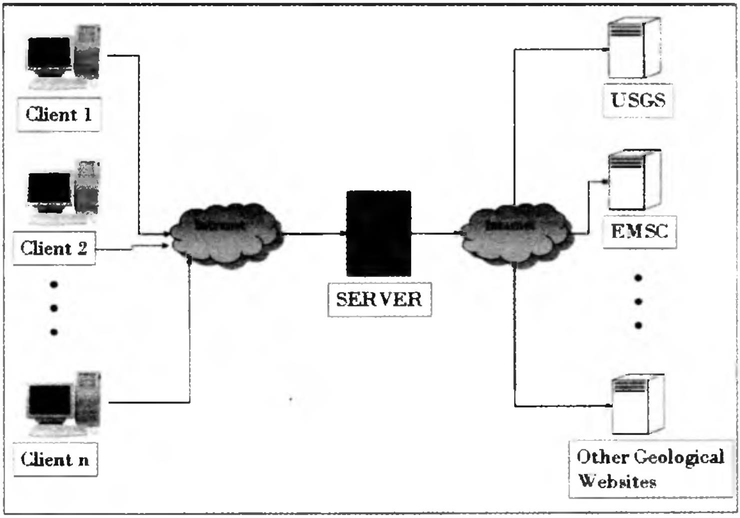
The Earthquake notification system needs the information regarding the earthquake events from any authentic source. The information is present on internet in the form of Web Pages, E-Mails from Geological Websites.

If there is an access to real time data from local seismic stations, then this warning system will be more effective.

The present Earthquake Notification System (ENS) is the software application program which scans the popular geological web sites periodically and checks if there are any new earthquakes occurred in our region, which may create a tsunami. The new earthquakes which are of our concern are shown as notification at the clients PC.

Architecture

Earthquake Notification System is based on Client/Server architecture. The server keeps scanning the geological sites at a regular interval and updates its database with new earthquakes in our region and having a magnitude more than some threshold. The client sits on the user computer and keeps querying the server at regular interval for new notifications. If there are any new notifications, the application



pop's up and shows the notification with an alarm. Overall architecture of Earthquake Notification System is shown below. The notification consists of earthquake details like magnitude, location, depth, region, and source of information. The user can click on individual notification and see the event location on an online map or news from news search engines like Google.

Server Application

The server scans the geological web sites at regular intervals and updates the database with relevant earthquakes.

Procedure

There are 2 important programs on the server:

- Earthquake Updater: This updates the server database with new information on new earthquakes of our concern.
- Earthquake Notifier: This sends notification of new earthquake to client when it contacts the server.

- Server Synchronizer: This synchronizes data between Main server and Standby server. This module is used for reliability purpose.

Earthquake Updater

The Server program periodically gets connected to the Geological website, Collects webpage having information about the recent earthquakes and then parses the webpage. The events in the webpage are filtered based on the event magnitude and location (If it is more than set threshold and if the location is in the region which effects Indian coast). Events which match condition are added to the database if that event is not seen before. It also updates the event counter. The flow of the updater program is shown below.

Server Application Configuration

The server scans the geological sites once in 5 minutes. The sites are scanned in an interlaced manner. For example Site-1 is scanned in 0th, 5th, 10th minute etc., and Site-2 is scanned on 2nd, 7th, 12th, 17th minute etc. This helps to reduce the burden on server with less processes in memory at anytime and also reducing the interval time as though it is 2 or 3 minutes. At present USGS (US Geological Survey) and EMSC (European Mediterranean Seismic Centre) are scanned.

Client Application

The client contacts earthquake notification server periodically. If there are any new notifications it pops up notification and makes an alarm. This alarm alerts the user in control room for further action.

Development Platform

Client application is developed using Visual Basic and Socket programming on x86 based processor with Windows Operating system.

Procedure

- The client has a Local Event ID which tells the Last Event ID notified on the Clients PC.
- The client connects to server and sends a GET request to a CGI program with a query string containing its local Event ID.
- It receives the list of Events with Event ID value more than the Local Event ID.
- If it receives any events it raises an alarm and shows the notification window on the client.

The client has other features of getting more information regarding the Earthquake event through news sites, seeing the location on a high resolution online Maps, clearing the alerts after action has taken place.

Client User Interface

On clicking on Start → Programs → Earthquake Notification System → Earthquake Notification System, the user interface comes up below.

The Plant Operator is also provided with Links to Popular Sites like Google News, BBC, NDTV etc to enable him to get further Tsunami related Information.

If there are any new alert notifications they are listed in the alert. There is a sound of a fire brigade when the alert window has notifications. You can temporarily switch of the sound by **Stop Sound** button but the sound repeats after a refresh if the widow is not empty. You can clear the alerts by clicking **Clear Alert** button which clears the notifications and even stops the sound. The alerts should be cleared only after confirming that the after effects of earthquake are not hazardous to Indian coast. The **old alerts** can be seen by clicking on the Old Alert button.

Every notification consists of information: about *Longitude and Latitude, Depth, Date and Time, Magnitude, Region and Source.*

Location on online map

To see the epicenter on a map, one can select the Event in the event windows and the Operator may click on Location on Online Map button.

For the above notification, the map similar to the one shown below will be displayed in web browser

8 Remedial Measures For Nearby Villages

As part of Social obligation, the following remedial measures are being carried out.

Awareness Programme

Awareness programes are conducted regarding the occurrence and severity of Tsunami as well as the necessary action and preparedness required for it. Tsunami warning Siren is being installed at nearby villages.

Knowledge Center

As part of the activity of M S Swaminathan Foundation, Knowledge center is commissioned at Sadras fishermen village. Relevant information for fishermen and farmers are continually displayed.

Self–Employment Scheme for Women

Women are trained in management of hatcheries and growing of mushroom. M/s. Venkateswara hatcheries has come forward to provide financial, technical and marketing support. The mushrooms are marketed by M S Swaminathan Foundation. The women of the village, are thus provided with regular income.

Health Care

Medical camps are being held periodically by DAB medical unit. Free counseling and distribution of medicine are carried out. A mobile desalination Plant was handed over to Meyur Kuppam residents from BARC which can supply 5000 litre/day potable water.

Human Resource Development through Skill Development

Jappiar Educational Trust, Chennai, has agreed to provide job oriented occupational training to young men and women of the nearby villages. Under this programme, courses will be organized at Kalpakkam for nine months. Practical training will be provided for three months at Chennai. Necessary support for job placement will also be provided.

9. International Workshop on External Flooding Hazards

An International Workshop on External Flooding Hazards at Nuclear Power Plant sites was held at Kalpakkam during 29th August to 2nd September 2005.

Experts from Japan, Italy, Netherlands, France, Spain, India, USA and IABA actively participated in the Workshop and discussed on the following items.

- Experiences and case studies on external flooding hazards
- Current methodologies and techniques for Tsunami flooding hazard assessment (analytical and experimental)
- Warning systems and emergency planning and preparedness in relation to operational aspects
- Regulatory requirements

Two panel discussions, one pertaining to 'Methodologies and Techniques for tsunami hazard assessment' and other pertaining to 'Tsunami Warning Systems and Nuclear Power Plant operational safety' were held.

During the technical tour to the PFBR, MAPS and township, the delegates, were quite appreciative of the fact that the construction of PFBR was restored within a very short time after the tsunami incident, and the fact that the rehabilitation of the township has been done very fast with practically no tell-tale sign in the area. As a goodwill gesture, the foreign participants collected more than Rs. 22,000/- and donated to a nearby local school.

The foreign delegates were impressed with the openness of the Indian participants and were also appreciative of the warning system developed/being developed by IGCAR and BARC respectively.

10. Conclusion

By God's grace mankind should never encounter another Tsunami. However with the commissioning of biological shield along the sea coast, the effect of Tsunami waves will not be felt by coastal residents. With the timely warning from Tsunami warning system, the residents will be moved to safer places, thus avoiding the human casualties and loss of precious properties. Teamwork and Synergy are important both in good times as well as bad times.

11. Acknowledgement

Immediately after Tsunami, Dr Anil Kakodkar, Chairman, AEC and Secretary, DAE cut short his vacation and arrived at Kalpakkam. With adequate interface with relevant ministerial authorities, he provided the necessary guidance in carrying out various relief measures. Mr S.K. Jain, CMD of NPCIL&BHA VINI and Dr S. Banerjee, Director, BARC visited the Tsunami affected areas and supervised the relief work. Engineering Services Group and General Services Organisation worked day and night in restoring the water supply, electricity and communication fecilities. With active participation from medical officers from other DAE units, Dr A. Vijaya Medical Supt and her team provided the much needed medical care to the residents of the township as well as nearby villages.

The office bearers and members of various associations worked shoulder to shoulder with Kalpakkam Management Committee in restoring normalcy in Township. Dr S. Ghosh, President, BARCOA mobilized the relief fund from various DAE units for distribution to the affected employees. Numerous individuals and various teams from within the department and Non-Government Organisations worked with dedication to enable us to meet the colossal challenge.

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Programme

Inaugural Session

0900-1000 **Welcome**
K Kasturirangan, NIAS, Bangalore

Introduction
R Narasimha, JNCASR, Bangalore

Inauguration
C N R Rao, JNCASR, Bangalore

Keynote address
V S Ramamurthy, DST, New Delhi

1000-1015 HIGH TEA

Session 1 : Overview (Chair: K Kasturirangan)

1015-1100 **Vinod Gaur**, CMMACS, Bangalore
What the science of tsunamis demands for a national action plan

Session 2 : Modelling and Observational Approaches
(Chair : V S Ramamurthy)

1100-1130 **S R Shetye**, NIO, Goa
An analysis of the events on 26 December 2004 to plan for the future

1130-1200 **K Radhakrishnan**, INCOIS, Hyderabad
The Indian initiative for putting in place early warning system for tsunami and storm surges

1200-1230 **V S Hegde**, ISRO, Bangalore
Space based observations

1300-1330 : Discussion (Moderator: R Narasimha)

1330-1430 LUNCH

Session 4 : Earthquake Monitoring (Chair: Vinod Gaur)

1430-1500 **R S Dattatrayam**, IMD, New Delhi
Earthquake Monitoring in India – Status and Future Plans

Session 5 : 26 December 2004 Tsunami Events
(Chair: Vinod Gaur)

1500-1520 **V V Bhatt**, IAS Officer, Delhi

1520-1540 **Sanjiv Lewin**, St. John's Medical College, Bangalore
Challenges faced by Disaster Relief Teams – Five Disasters, Five experiences

1540-1600 **Rama Govindarajan**, JNCASR, Bangalore
Tsunami relief: An observer's viewpoint

1600-1615 TEA

1615-1635 **R Sukumar**, CES, IISc, Bangalore
How animals responded to the tsunami

1635-1700 Discussion (Moderator: R Narasimha)

Session 6: Panel Discussion (Chair: Arcot Ramachandran)

1700-1830 **S S Meenakshisundaram**, NIAS, Bangalore
Rehabilitation and reconstruction strategies

Debashish Sengupta, CAOS, IISc, Bangalore

Baldev Raj, IGCAR, Kalpakkam

Thelma Narayan, Community Health Cell, Bangalore
Post tsunami public health response to community need

Radhakrishnan, Collector, Nagapatnam

1830 **Closing Remarks** R Narasimha

A meeting entitled "Six months after Tsunami" was held at the National Institute of Advanced Studies on 16 June 2005. The goal of the meeting was to place on table a multiperspectival assessment of the disaster. The presentations included an experiential account by Prof C. N. R. Rao who was a witness to the event; a keynote address by Dr V. S. Ramamurthy; a historical view by Prof S. Settar; an account by Prof S. Sukumar from the perspective of animal behaviour; on Sumatra Tsunami by Prof Vinod Gaur; futuristic measures by Dr Satish Shetye, Space based observations by V. S. Hegde; status of earthquake monitoring in India by Dr R. S. Dattatreyam; relief and rehabilitation accounts by Sri V.V. Bhat, Dr. Sanjiv Lewin, Dr. Rama Govindarajan, Prof S. S. Meenakshisundaram; and many other issues. This book presents the full-length papers of the presentations. We hope that this volume will be a significant addition to understanding and responding to the Great Indian Ocean Tsunami.

About NIAS

The National Institute of Advanced Studies was conceived and started by the late Sri J. R. D. Tata. Sri Tata was desirous of starting an Institute which would not only conduct high quality research in interdisciplinary areas but also serve as a medium which would bring together administrators in the government and private sector with members of the academic community. He believed that such an interaction could be of great help to executives in their decision making capabilities. NIAS is situated in the picturesque Indian Institute of Science Campus in Bangalore. Its faculty is drawn from different fields representing various disciplines in the natural and social sciences. The Institute carries out interdisciplinary research and is unique in its integrated approach to the study of the interfaces between science and technology and societal issues. Dr. M. S. Swaminathan is the Chairman of the Council of Management of the Institute. Dr. Raja Ramanna was the Director since its inception till his retirement on July 31, 1997. Prof. R. Narasimha was the Director from 1997 to March 2004. Dr. K. Kasturirangan, (Hon'ble Member of Parliament, Rajya Sabha), former Chairman, ISRO, is currently the Director of the Institute.

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