Report on the 2004 Sumatra Earthquake and Tsunami Disaster

Edited by

Kimiro MEGURO

International Center for Urban Safety Engineering
Institute of Industrial Science
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Preface

Triggered by a M9.0 earthquake that occurred along the Sunda Trench, Off-Sumatra, at 07:58 (local time), on December 26, 2004, a huge and devastating tsunami hit the Indian Ocean Rim countries, causing unprecedented disaster with over 300,000 dead and missing persons. The International Center for Urban Safety (ICUS) would like to extend our deepest sympathies and condolences to the victims of this terrible disaster. This event reminded us that in spite of our efforts to make our societies disaster resilient, there are still more works to be done and lessons to be learnt.

Aware of this situation, the ICUS compiled this report which discusses topics related to the December 26, 2004 earthquake and tsunami, such as infrastructure damage, disaster response, relief and recovery efforts, economic effects, etc. in different countries along the Indian Ocean Rim. The preparation of this volume was possible thanks to the contributions of four experts in the field of disaster mitigation: Mr. Teddy Boen (Indonesia), Dr. Pennung Warnitchai (Thailand), Dr. Srikantha Herath (Sri Lanka), and Dr. Fumihiko Imamura (Japan). The ICUS would like to express its grateful recognition to their efforts.

The December 26, 2004 tsunami showed us that natural disasters do not distinguish country boundaries and can cause devastation over vast areas. Therefore, we need to work together, establish common systems and share experiences in order to minimize future losses. With these ideas in mind, I propose a new concept on tsunami disaster mitigation system suitable for Indian Ocean rim countries in the last article of this volume. We hereby commit ourselves to continue investigating and assisting on the recovery and reconstruction processes of the devastated regions.

International Center for Urban Safety Engineering

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K. MEGURO and M. TAKASHIMA

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LESSONS LEARNT FROM THE 2004 SUMATRA TSUNAMI DISASTER AND FUTURE RESEARCH DIRECTIONS

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ABSTRACT

The Sumatra Earthquake and following Tsunami has left a great challenging task for us; and Japan, as a disaster experienced country, could take responsibility on scientific and technical support like: Tsunami Warning System from JMA, Community-based Disaster Mapping, Disaster Education and Disaster Facilities Technology, etc.

From the site survey by the International Tsunami Survey Team it was recorded that the tidal surge had reached 40 m height and 5 km inland in the northern Sumatra. The East and South Coast in Sri Lanka had been totally damaged; and roads of the capital city Male of Maldives were totally flooded. People observed some phenomena when the tsunami was coming, like: various sounds, blast, etc. Seawater configured with a long horizontal tidal wave and showed its "abnormality"; but people could not understand. If this "abnormality" could have been evaluated and classified as a tsunami, warning information could have been circulated, the danger recognized, and the people evacuated. Considering the facts and findings, this paper focuses on the direction of research, its system and the respective solutions necessary for Japan to actively contribute to the world tsunami disaster reduction.

1. INTRODUCTION

The damage caused by the 2004 Sumatra Earthquake and Tsunami was extended to all over the coastal areas of the Indian Ocean Rim countries; it was so severe that, it became the ever-largest disaster taking more then 300,000 human lives. It is for the first time that an earthquake of such a large scale M9 happened in this region, though the earthquakes of M8 magnitude, which also caused tsunamis, occurred in the past. Another earthquake of magnitude M8.7 occurred on March 28, 2005, (local time: 11: 09: 36 PM) with its hypocenter in the south, causing a lot of damages. So, it is necessary to clarify: why these two earthquakes of such large magnitudes happened and when the following earthquake will take place.

This tsunami disaster raised many problems that should be examined thoroughly over a long period of time. The strong ground motion due to earthquake of magnitude M9 and tsunami caused huge damage over the whole area of the Indian Ocean. It struck local residents and other visitors like tourists. In fact, the international rescue operation teams had to reach to the victims of millions of people. This catastrophe has also left numerous lessons for countries, such as Japan, where the tsunami disaster is being forgotten.

2. CURRENT STATUS

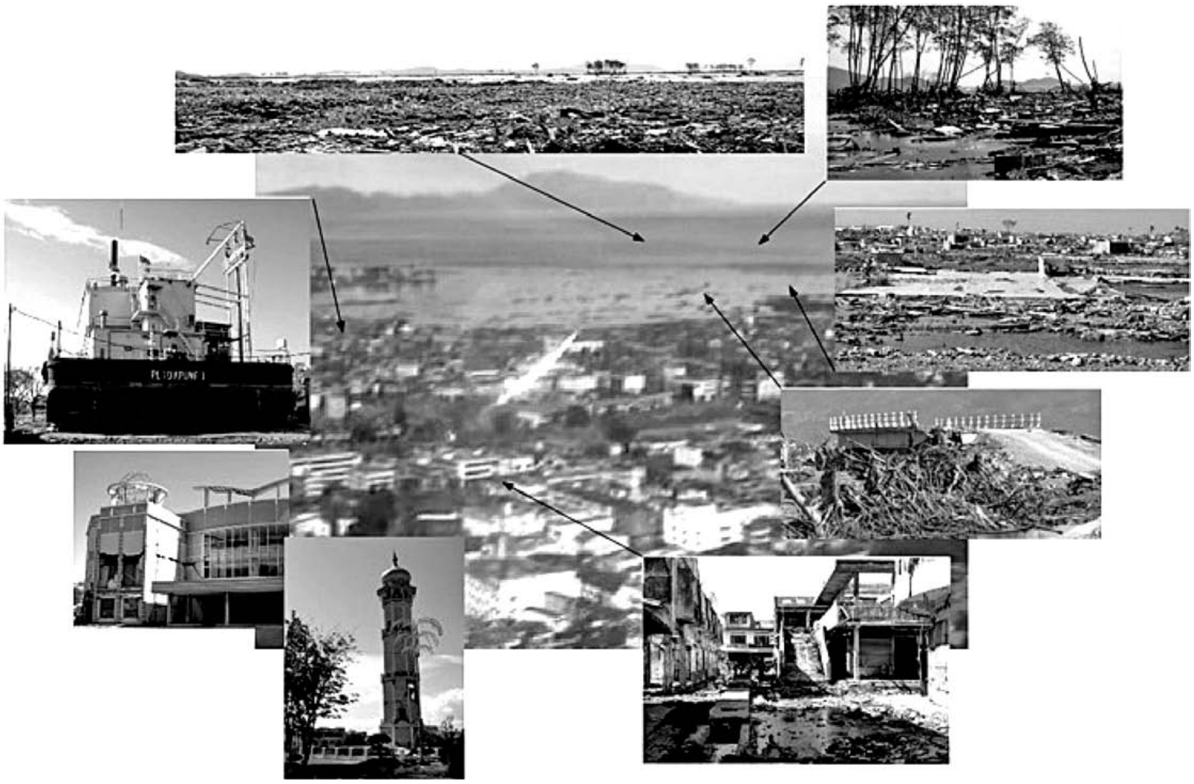
There are various organizations and groups from many countries of the world who have been executing field investigations aggressively and a lot of results are being achieved. However, there are still many remaining problems because the surveys have been conducted over a wide area within very limited time. Furthermore, the experts and specialists in the conventionally existing fields of research, such as science, engineering, sociology, etc., are investigating independently over their respective matter in their own manner. Therefore, the investigations on the overall aspects are few. Moreover, with the passing of time, rescue and recovery activities at the stricken areas will shift to restoration; therefore, continuous surveillance studies are needed.

3 FEATURES OF THIS DISASTER

3.1 Damage description

The severest affected area of Indonesia is the northern part of Sumatra, and it is reported that the coastal areas are completely destroyed by the strong shake and sudden large tsunami attack. Inland inundation marks were found up to 5 kilometers from the coast, and there were a lot of debris carried out by the tsunami wave into the center of the city, which increases the destructive power of the tsunami. It was observed that the tidal surge reached over 40 meters-height on the hilly area where the tsunami run over the top of the peninsula with a saddle shaped hill. The nature of damages by this earthquake is similar to that of the great earthquakes with magnitude over 8 which will occur within 30 to 50 years in Japan along the Nankai Trough Trench with epicenters very close to the land. They will generate strong ground motion and great tsunami.

In Thailand and Malaysia, many sightseeing spots were damaged seriously and a large number of foreign visitors became victims of the tsunami disaster. This is a serious issue to mitigate tsunami damage in the coastal area because each nation has its knowledge, and response to a natural disaster.



Damage in Banda Aceh, Indonesia

In addition, India and Sri Lanka were seriously damaged. Especially, in Sri Lanka, the death toll raised to nearly 40,000. The east and south coast in Sri Lanka were totally damaged. Besides Colombo, the south-west of Sri Lanka was damaged too, even though the coast is not located directly on the tsunami propagation path from the source. In the coastal areas, the community villages were totally destroyed. A stopped train was used by people to observe the tsunami passage. Unfortunately, it was toppled by the tsunami wave and more than one thousand people inside it drowned.

In the Republic of Maldives, the tsunami attacked at 9:00 AM on 26th December. Maldives is a group of about 1,200 coral islands, and its maximum height is only 1.8m. Almost all the roads in the capital city Male were flooded. There were no vacancies in hotels because it was Christmas season. Therefore, the tsunami caused severe damage. There was no tsunami warning system in the Indian Ocean. In some coastal areas, people could not feel the ground motion, so, the inhabitants were suddenly attacked.


The damage in the area of Kahawa, Sri Lanka

3.2 Tsunami predecessors went unnoticed

The video images recorded at resorts in Thailand have shocked us. Not only did the tsunami attack, but also the tourists and local people recorded it on video. They did not evacuate or did not take any other action because they did not recognize that a tsunami was approaching to the beach. It is understandable that people did not evacuate because they did not know about tsunamis, and there was no tsunami warning system. It should be investigated why they did not notice the tsunami attack and if it was very hard to circulate.

According to a victim, the tsunami at offshore, initially, had the following features:

- Roar like a jet engine, or sound like rumbling of the earth
- Rumble of the ground
- Strong wind/blast

There are some phenomena that precede a tsunami, and the sound intensity is different for different =tsunami types. There is a research on the tsunami generated sound by Shuto (1993). The sound type has several variations which are caused by the wave breaking offshore, current of the strong waves, wave breaking at seashore, wave which collides at other beach, etc. Sometimes, ground shake and sound occur simulteneously. Besides, when a tsunami like a stair figure occurs, it is almost the same as a wide wall of a tidal wave coming with high speed. So the atmosphere or wind which is in front of the wave is pushed forward, and a strong blast occurs. This blast can be felt by hearing and feeling with the help of human five senses.

In addition, man has the sight and sense of smell. In case of Papua New Guinea Earthquake in 1998; a strong smell came when the tsunami occurred. It is not similar for the other cases; it is thought that this is not a usual case. On the other hand, everyone should be able to recognize the situation in which an abnormal water level raised and white-crested waves raid straight. However, in the video, people saw the tsunami coming, but people did not run away because they could not understand this "abnormality".

There is a possibility that this observations have changed greatly by the position of the person who see the coast. Many people who saw from hotels and higher places, acknowledged the mass of huge seawater in the horizontal scale and its configuration with a long tidal wave, and felt the abnormality. On the other hand, people on the coast and at the beach did not see the back side of the tsunami wave. In addition, a distant object looks smaller in the coast region by the scenery of the panorama character, and the height of a perpendicular direction object looks smaller with respect to its real scale. People could not realize the height because there was no object for comparison of the wave-height. (In Kao Lack, a patrol boat served as reference.) In such a situation, it is difficult for people to obtain enough sight information.

Views which were taken at the Indian Ocean Tsunami could be considered as important basis for tsunami prediction. If we can evaluate and classify “anything unusual, or abnormal” in case of a tsunami attack, we can release tsunami warning information, or we can recognize a danger; and people could manage to escape. It is meaningful to research relationships between tsunami types and the character of pre-tsunami phenomena from now on.

An episode from the video footage in Kao Lack, Thailand
(Source: THAI NATIONS)

4. ISSUES

The real images of the total earthquake and tsunami disaster are not clear yet. Also, reliability of the enormous data is not confirmed; and it is neither compiled in a database, nor shared with others fact-findings data. Because of co-existence of different related organizations and foreign aid groups in the disaster areas, the on going recovery activities are not unified and defined. Especially, the drafting and promotion of comprehensive disaster countermeasures -which should be implemented by combining the hardware and the software-, drafting of the town plan for disaster reduction by matching the environment with a long term basis plan and making use of vegetation such as mangrove, have not yet been done. Because of slow recovery of educational functions and facilities like schools, there is a delay in mental recovery and other important recovery activities such as training of responsible persons.

In Japan, we have a world-leading performance on research of subduction-zone earthquakes on the Pacific coast and the Japan Sea. Japan also leads the world in knowledge sharing about subduction-zone earthquakes predicted to occur in seas close to Japan. It has also good prediction technology on earthquake probability, for example the Tokai, Tonankai and Nankai Earthquakes. And Japan is leading the research on tsunami and establishing tsunami warning systems. It has advanced performance in research on earthquake prediction and source process, and community-based tsunami research and countermeasures. Japan is leading the world in this area therefore the affected countries may have demand on scientific and technical support like tsunami warning system from the Japan Meteorological Agency (JMA), Community-based disaster mapping, Disaster education and other Technologies for disaster reduction.

5. DIRECTIONS OF THE RESEARCH

Under this situation, we give the directions of research and its environment which we think are necessary from now on.

- We need to establish a new system which will support recovery and reconstruction of affected areas systematically and constantly. The Japan International Cooperation Agency (JICA); which provides a lot of international support, should play an important role in this new system. We also need to develop an organization which will adjust and cooperate with international development divisions in domestic ministries, government offices, expert groups and academicians.

- We consider the output of these activities to be the core of diplomatic strategy and international support, and technological cooperation of Japan.

- Internationally, the UNESCO meeting on tsunami warning system was conducted. The “Natural Disaster Mitigation” group of Inter-Academy Panel (IAP) and the International Council for Science are planning “Ad-hoc Scoping Group for an International Program on Natural and Human-Induced Environmental Hazards”. We need to organize the system by which Japan can participate there.

- Japanese researchers in earthquake, tsunami and disaster reduction should cooperate and propose countermeasures for future disaster reduction due to great earthquakes in Sunda fault.

First, we need to analyze the nature of this tsunami and earthquake at the Sumatra trench, and then give technical advice for disaster reduction to the affected countries. And, through an international symposium, we should propose and appeal the tsunami warning and disaster reduction system, and a new city planning for proper reconstruction in order to minimize the damage due to future earthquakes and tsunamis by securing the leadership in the field of earthquake, and tsunami disaster prevention in Asia.

6. NECESSARY POINTS AND THEMES OF THE RESEARCH

6.1. Necessary points for future researches

The followings are the necessary points that we should consider when we do earthquake and tsunami disaster researches.

- Partnership with the Asian countries.
- Strong cooperation with institutes in Asian countries, such as: Indonesia, Thailand, Sri Lanka, etc., which suffered a great damage by Sumatra Earthquake.
- Strong cooperation between many related institutes in various field, like: Science (hazard mechanism), Engineering (countermeasures), Social science (recovery and reconstruction), etc.

6.2 Essential research theme

Followings are the themes that we should take from now.

- Mechanism of huge earthquake and tsunami like Sumatra type.
- Mechanism of damage and disaster due to huge earthquake and tsunami.
- Technology development for disaster reduction.
- Effective uses of Tsunami Warning System and Information Recognition, and Evacuation system as well.
- Effective uses of Tsunami Warning System and Information Recognition, and Evacuation system as well.
- Recovery and reconstruction policy and plan; and a new city plan improving built environment for disaster reduction.

- Collection of basic data from wider areas and establishment of its archives.
- Training and education system for the capacity building against earthquake and tsunami disaster.

THE 26 DECEMBER 2004 SUMATRA EARTHQUAKE AND TSUNAMI DISASTER IN INDONESIA

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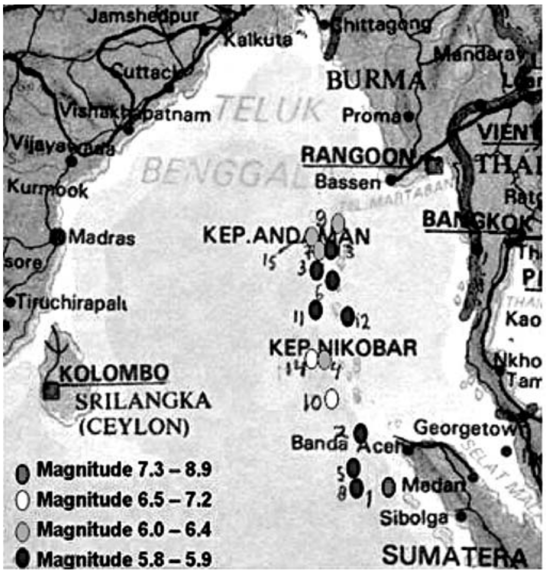
ABSTRACT

On December 26, 2004, an earthquake of M 9.0 occurred and was followed by a devastating tsunami that hit Indian Ocean countries, such as Indonesia, India, Malaysia, Maldives, Myanmar, Sri Lanka, Thailand, etc. Among these countries, damage in Indonesia was the worst. Due to both strong ground motion and killer tsunami induced by the great earthquake, many infrastructure, buildings and houses, were destroyed and washed away in North Sumatra. The World Bank has reported that 128,000 were killed in Banda Aceh only and at least another 37,000 people became missing. The total reported death toll is likely to exceed 165,000. Over 550,000 of the survivors became homeless. This was the worst natural disaster experienced in their history. Hereinafter, a quick survey report giving the overall information on damages to the engineered and non-engineered buildings with references to infrastructure damages in Indonesia is presented.

1. INTRODUCTION

On Sunday morning Dec 26, 2004 Banda Aceh was holding a 10 K marathon and approximately 1000 residents were doing their daily exercise at Blang Padang square, where the Suelawah plane monument is located. The city was crowded by the 10 K participants in their sports gears and some participants had reached the finish line, when at that time 07:58:50 WIT (Western Indonesia Time) the earth was shaken by a strong earthquake. Almost everybody was panic and lay down on the ground. Some could watch the most popular hotel in Banda Aceh, the Kuala Tripa hotel shook and settled and subsequently the lobby story collapsed. People at Blang Padang did not run because it was an open field. After the earthquake shaking stopped, people start wandering in the city watching some collapsed buildings. A TV reporter even toured the city to check damaged and collapsed buildings. At around 08:42 WIT, the first tsunami wave reached the coastlines of Banda Aceh and according to eye witnesses, the first wave was not so powerful and caused flood from the coastal area to the “center” part of Banda Aceh and some people start shouting: “water, water from the sea” and many people start running towards the center of the city. However, at around 08:53 WIT, the second more powerful wave swept the coastal area and caused significant destruction and many people still running on their way to higher ground were swept and cascaded by debris of collapsed



EQ 26 December 2004			
No	Time	Depth (km)	Magnitude
1	00:58:50	10.0	8.9
2	01:48:46	10.0	5.9
3	02:15:57	10.0	5.8
4	02:22:01	10.0	6.0
5	02:34:50	10.0	5.8
6	02:36:06	10.0	5.8
7	02:51:59	10.0	6.0
8	02:59:12	10.0	5.9
9	03:08:42	10.0	6.1
10	04:21:26	10.0	7.3
11	06:21:58	10.0	5.7
12	07:07:09	10.0	5.7
13	07:38:24	10.0	5.8
14	09:20:01	10.0	6.5
15	10:19:29	10.0	6.2

Figure 1: Main Shock and After Shocks within one day of the Sumatra Earthquake, December 26, 2004, USGS

buildings and died instantly. Some made it to higher ground; many were dragged by the flood several km.

At around 09:15 WIT, the third and most powerful wave swept through the coastal area up to a distance of approximately 4 km inland and brought destruction along their path. Most of the buildings that collapsed were non-engineered buildings and were subjected to the tsunami forces such as battering, scouring, impact and buoyancy. Many fishermen boats and cars were dragged from coastal areas to the city by buoyancy of the tsunami flooding and ramped buildings in its way. Almost all buildings along the coastal areas were literally disintegrated by this tsunami and the debris was dumped into the city up to approximately 4 km from the coastal area. The total destruction by the tsunami was within an area of approximately 15 sq.km from the East to the West of Banda Aceh and along a distance of 2 km inland. After the third wave, Banda Aceh was inundated up to a height of approximately 2 m for approximately 30-40 minutes within an area up to 4 km inland and subsequently water start flowing back to the sea and at around 11:00 WIT the water level was approx 30-40 cm (note: the timing of the arrival of the tsunami waves was obtained from an amateur video, but the video camera was not available for verification).

2. "WATER, WATER FROM THE SEA"... AN EARLY WARNING.

As mentioned earlier, the first tsunami wave came approximately 40 minutes after the M 9.0 earthquake and people on the coastal areas saw that the sea level subsided from the beach and also saw a huge wave was approaching the coast. Subsequently some people started shouting and issued warning that a flood was coming and started running towards the center of the city. However, most of the coastal areas occupants were not "trained" to immediately evacuate upon hearing the "early warning". Most of them do not have the idea what a tsunami wave could do to them until it was too late. Due to this “early warning”, approximately 30 % of the coastal area population survived the tsunami and some 70 % of them were literally wiped out together with their houses.The coastal area is a highly populated area and approximately 100 thousand were living in that area. Therefore, the estimated casualties from that area only are approximately 70 thousand. The rest are from the “inland” areas that were inundated by the tsunami “flood”. Similar “early warning” procedure was also practiced in Meulaboh.

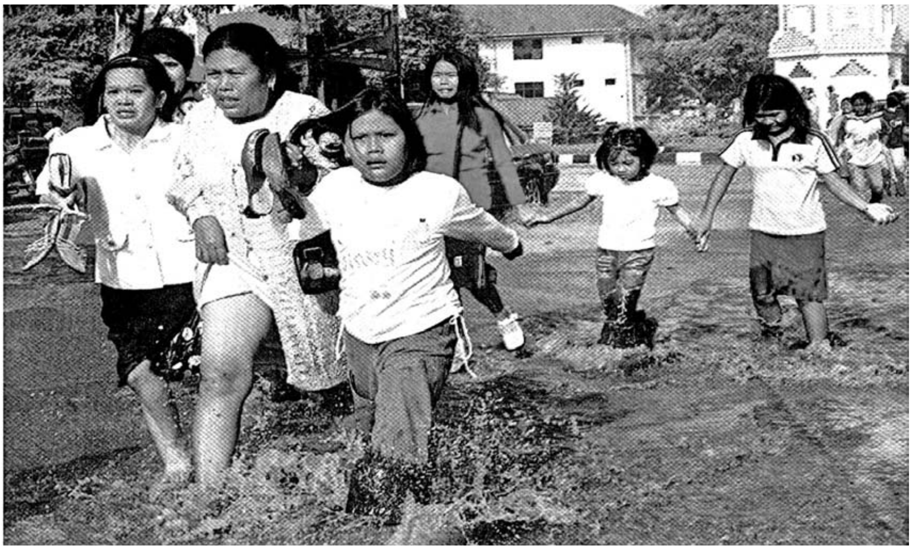
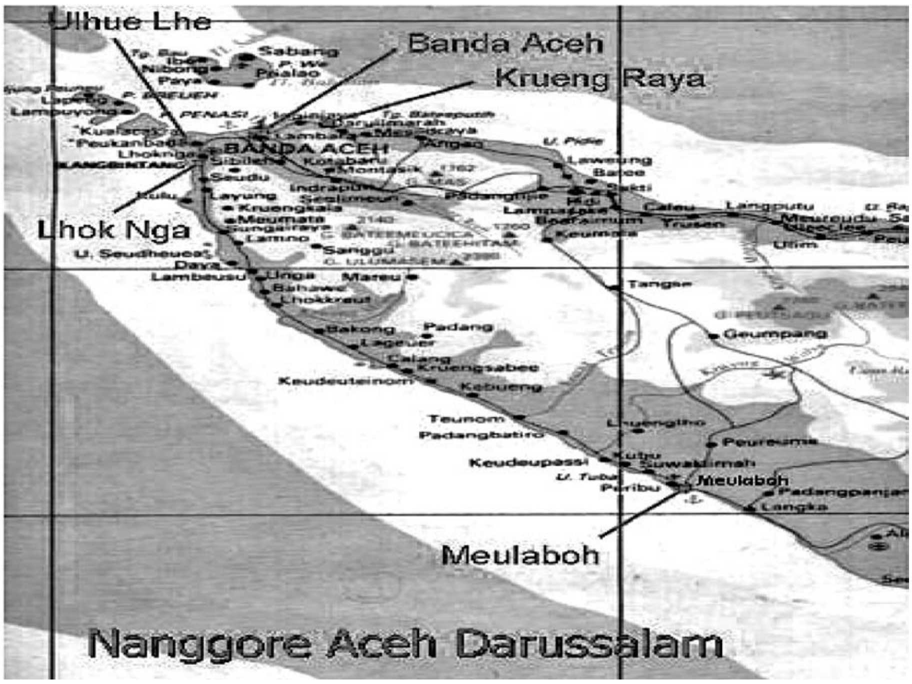


Figure 2: Banda Aceh, People were running to higher grounds after the first wave.

Figure 3a: Meulaboh, People were running to higher grounds after the first wave.

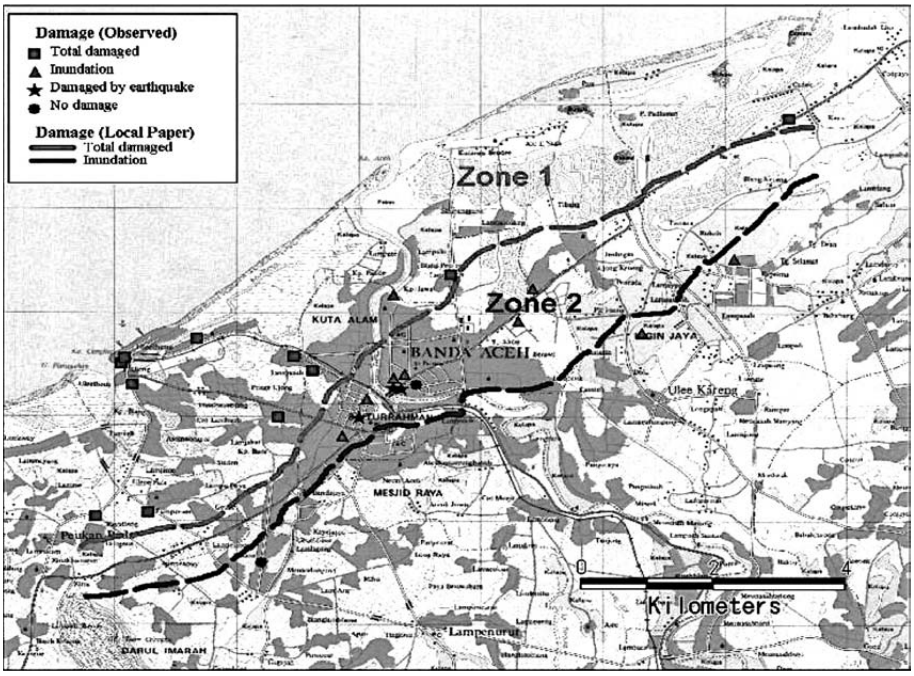
Figure 3b: Meulaboh, People were running to higher grounds after the first wave.



Sites surveyed

3. THE TSUNAMI CURSE THROUGHOUT THE COAST

In general there are two zones affected by the tsunami, Zone 1 is the coastal areas which were destructed by the tsunami forces such as battering, scouring, impact and buoyancy. In Banda Aceh this zone goes up to 3 km inland. Zone 2 was only inundated, where the tsunami force is already reduced and only caused flooding, dumping mud and debris. This area is approximately 0.5 to 1.5 km further inland.



Damaged & Inundation Zones in Banda Aceh
(Source of map: OYO International)

4. DISASTER EPISODES

In areas where the beach is gently sloped, the tsunami waves were very powerful and this is evident in places like Lhok Nga, Ulhue Lhe, Krueng Raya and Meulaboh. The destruction by the tsunami in those areas was very severe. The damage was mostly caused by the battering and scouring forces of the tsunami. This is evident from the timber debris originating from frames of timber houses which were practically disintegrated into building components. For masonry construction, walls were shattered into pieces of almost equal size and RC columns ripped off from the foundations and beam column connections severely damaged.

In places where there is a harbor with deep water, the tsunami wave strength was reduced and the dominant force is buoyancy. This could be observed at Lhok Nga cement factory jetty, Malahayati harbor and Ulhue Lhe harbor. In the case of Ulhue Lhe harbor, the tsunami waves came from the North and its buoyancy effect cause damage to the Harbor buildings. The jetty was protected by breakwater walls.

In areas close to the center of the city of Banda Aceh, the damage caused by impact force could be observed. The impact force was caused by floating of fishermen's boats and also by cascading debris in mud. The impact force was exaggerated by the density of mud which is larger than water. It was observed that the tsunami traveled through rivers upstream and lagoons and subsequently spilled over into landward areas. It was also observed that, in hilly areas, tsunami waves were able to run up much higher elevation along hill slopes and valleys than those in plain areas but the strength was reduced.

Various reports define the tsunami heights and are not exactly the same. The tsunami heights observed were from measurements of water level traces on walls from the ground level is approximately as follows:

- Meulaboh (Western Coast) about 4 m
- Lhok Nga (West of Banda Aceh) about 15 m (run-up height against hillside)
- Banda Aceh about 8 m in coastal areas (zone 1) and 2-3 m in zone 2
- Krueng Raya (North Coast) about 6 m (watermark on coastal side wall of the Mosque)

The different tsunami heights in different locations have almost the same destructive powers as can be seen in the pictures. Another observation is that trees, buildings, roads, hills, valleys and deep water seemed to reduce the tsunami force, apparently because those "obstacles" break up the tsunami energy.

Inundation Height in Banda Aceh

Inundation height observed in walls of a one story building in Banda Aceh

Inundation height observed in walls and buildings in Banda Aceh

Inundation height observed in walls of buildings and trees in Banda Aceh

Tsunami Run-Up Height in Lhok Nga

Tsunami wave run-up to higher land in Lhok Nga

Inundation Height in Meulaboh

Inundation height inside the house (above) and flood affect at surrounding areas of Meulaboh(bottom)

5. THE FATE OF THE RUIN CITY

Two types of buildings affected:

a. Engineered Buildings

b. Non-Engineered Buildings

5.1 a. Engineered Buildings consist mostly of Reinforced Concrete Structures

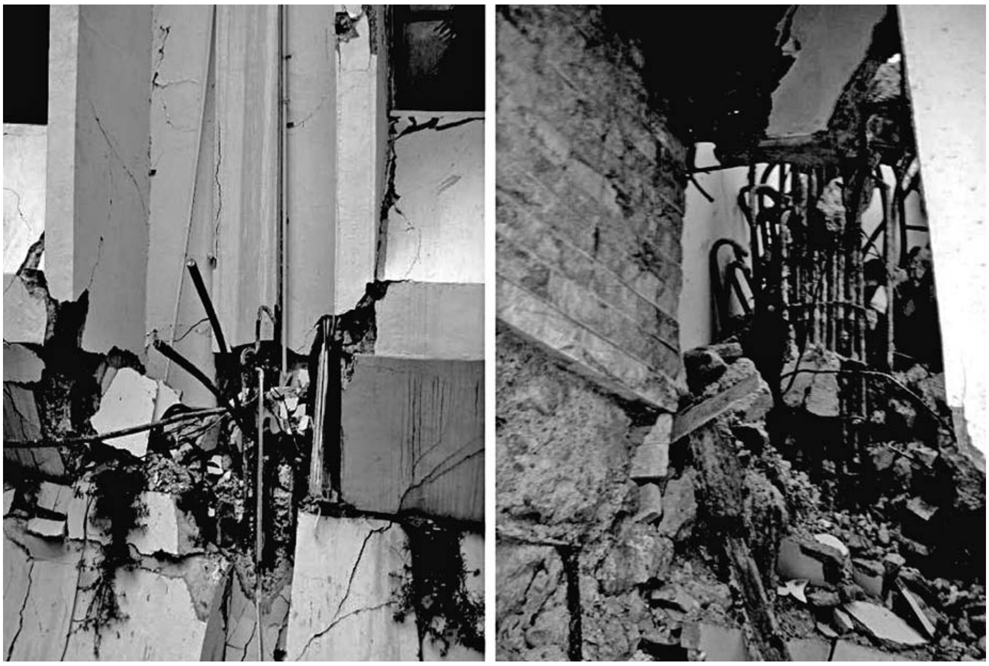
Almost all "engineered" buildings in Banda Aceh were unaffected by tsunami but some collapsed by the shaking of the Dec 26, 2004 earthquake

The causes of typical damage of reinforced concrete engineered buildings during the Sumatra earthquake in Banda Aceh were mostly due to vertical irregularities in certain RC buildings creating abrupt changes in stiffness and strength that may concentrate forces in an undesirable way.

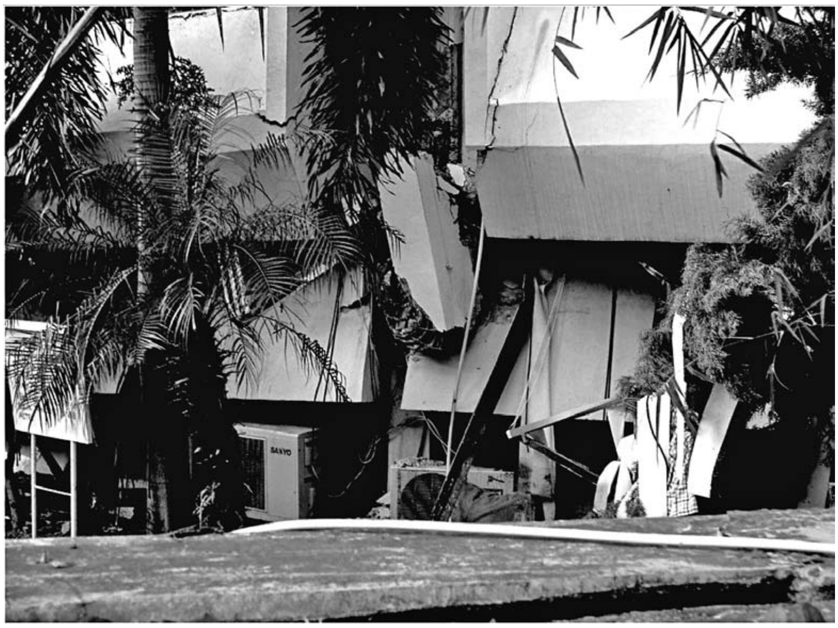
Also poor quality of concrete and detailing contributed to the collapse of those engineered buildings.

Right after the M 9.0 occurred, some high-rise buildings were damaged and a couple collapsed. The most obvious damage occurred to Kuala Tripa hotel, a 5 story RC building. It suffered a “first soft story” collapse. The second and third floor was severely damaged because of the impact but the building as a whole did not collapse. The collapse was caused by poor detailing and most probably it was analyzed as 2-D structures, therefore overlooking the first soft story effect. Another visible collapse was a three story supermarket, the Pante Pirak. The collapse was due to poor quality of construction. Another building that partially collapsed was the office of the department of finance. One of the wings suffered a pancake type of collapse. From the damaged columns it can be seen that the detailing was poor. This building suffered partial damage when shaken by a moderate earthquake in 1983. One other engineered building that collapsed was the extension of the Governor’s office, which collapsed while under construction. From the damage it was evident that the concrete quality was low and the detailing was not in accordance with requirements for earthquake resistant construction. There were few other buildings such as two stories shop house buildings that were damaged by the earthquake shaking, however, most of those buildings were poorly designed as well as poorly constructed. In general, it can be said that very few buildings collapsed or were damaged by the Dec 26 2004 earthquake shaking because the epicenter was some 240 km away from Banda Aceh. Even the subsequent aftershocks with an epicenter distance of approximately 100 km, did not cause any further damage to those buildings as well as other buildings.

Damage of Kuala Tripa Hotel: entry side



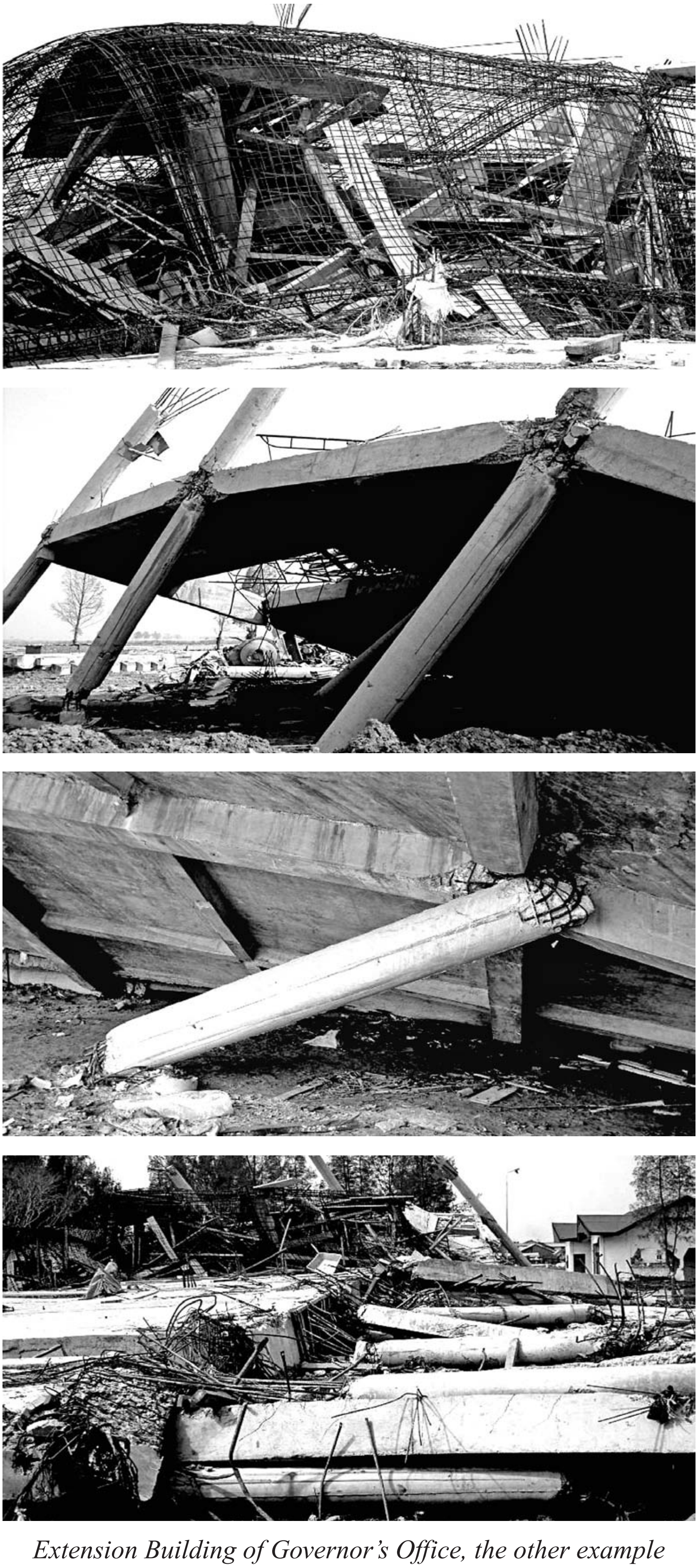
Exposed reinforcement after structural damage of Kuala Tripa Hotel



The other view: Ill faith of Kuala Tripa Hotel

The Pante Pirak Supermarket crushed down to the ground

The gigantic Department of Finance office faced falling down



Extension Building of Governor's Office, the other example

5.1 b. Non Engineered Buildings consist of:

i. Burnt Brick Masonry with sand and cement mortar.

ii. Timber buildings

The majority of the buildings that collapsed in Banda Aceh city, and villages in Lhok Nga, Krueng Raya, and Meulaboh city, are non engineered buildings consisting of two types. The first type is a one or two stories buildings made of burnt brick confined masonry using sand and Portland cement mortar. The roof mostly consists of galvanized iron sheets. All those buildings used RC "practical" columns and beams as confinement. The second type is timber construction consisting of a timber frame and also timber planks walls and usually use galvanized iron sheets as roof.

Almost none of the people's housing, one to two story masonry buildings collapsed by the shaking, even though some had cracks in the walls. The destruction was caused by the tsunami forces.

Buildings damage by battering and impact in Banda Aceh at Zone 1

Banda Aceh: Zone 1; Building damaged by battering and impact

Banda Aceh: Zone 1; buildings damaged by battering and impact

Banda Aceh: Zone 1; Buildings damaged by battering and impact

Most of the buildings in the coastal areas consist of non-engineered timber structures and confined masonry structures. The ratio of those two types of structures is estimated to be 30 % to 70 %. The epicenter of the M9.0 earthquake is approximately 240 km SW of Banda Aceh, therefore the shaking was not too significant and timber structures are reasonably built and could withstand the M9.0 earthquake shaking. Masonry structures were also reasonably built. In Indonesia, in almost all rural as well as urban areas , a good earthquake resistant design feature can be identified, namely almost all masonry buildings were built with reinforced concrete framing, consisting of the so called “practical columns and beams”. They did not collapse by the M9.0 earthquake shaking. Such type of masonry construction has become a new culture in Indonesia and, from past earthquakes, it is evident that provided they were built with good quality materials and good workmanship, they survived the most probable strongest earthquake in accordance with the Indonesian seismic hazard map. In Indonesia, the damage and collapse of the new culture "non-engineered" masonry buildings are mostly caused by the poor quality of materials and poor workmanship, resulting in, among others poor detailing, poor concrete quality, and poor brick lying.

The reconstruction period is a good momentum to start making quality control a culture to improve the performance of such buildings when shaken by earthquakes.

The damage along the road from Banda Aceh to Krueng Raya

Banda Aceh: Zone 1; Building foundation scoured by tsunami

Banda Aceh: Zone 1; Building moved from original location by translation

Banda Aceh: Zone 1; Overturning

Banda Aceh: Zone 2; Debris and mud dumped up to 4 km inland

Banda Aceh: Zone 2; Debris and mud dumped up to 4 km inland

Banda Aceh: Zone 2; Debris and mud dumped up to 4 km inland

Banda Aceh: Zone 2; Debris and mud dumped up to 4 km inland

Banda Aceh: Zone 2; Boats dragged by floating / buoyancy

Banda Ache: Zone 2; Building damaged by impact

Banda Ache: Zone 2; Building damaged by impact

Banda Aceh: Zone 2; Building collapsed due to earthquake shaking

Building Damage by Battering Impact in Ulhue Lhe at Zone 1

Tower in the photo(right)is the same structure shown in the circle in a satellite image(bottom).

Source: Digital Globe

In Ulhue Lhe: Zone 1; Building damaged by battering/ impact

In Ulhue Lhe: Zone 1; Building damage by battering/ impact






In Ulhue Lhe: Zone 1; Building damage by battering/ impact

In Ulhue Lhe: Zone 1; Building damage by battering/ impact

In Ulhue Lhe: Zone 1; Building damage by battering/ impact

Foundation Scoured by Tsunami in Ulhue Lhe at Zone 1

In Ulhue Lhe: Zone 1; Foundation scoured by tsunami

Lhok Nga: Zone 1; Boats, piece of rock and concrete wave protection walls dragged by floating / buoyancy

Damaged by Battering / Impact in Lhok Nga at Zone 1

In Lhok Nga: Zone 1; Damaged by battering / impact

In Lhok Nga: Zone 1; Damaged by battering / impact

In Lhok Nga: Zone 1; Damaged by battering / impact

In Lhok Nga: Zone 1; Damaged by battering / impact

Lhok Nga Coastal Areas Damaged by Scouring in Lhok Nga at Zone 1

In Lhok Nga: Zone 1; Coastal damage by scouring

In Lhok Nga: Zone 1; Coastal damage by scouring

In Lhok Nga: Zone 1; Coastal damage by scouring

In Lhok Nga: Zone 1; Coastal damage by scouring

Oil Depot Tanks Dragged by Floating / Buoyancy in Krueng Raya at Zone1

Krueng Raya: Zone1; Oil depot tanks dragged by floating / buoyancy

Damaged by Battering / Impact in Krueng Raya at Zone 1

In Krueng Raya: Zone 1; Damaged by battering / impact

Damaged by Battering / Impact in Meulaboh at Zone 1

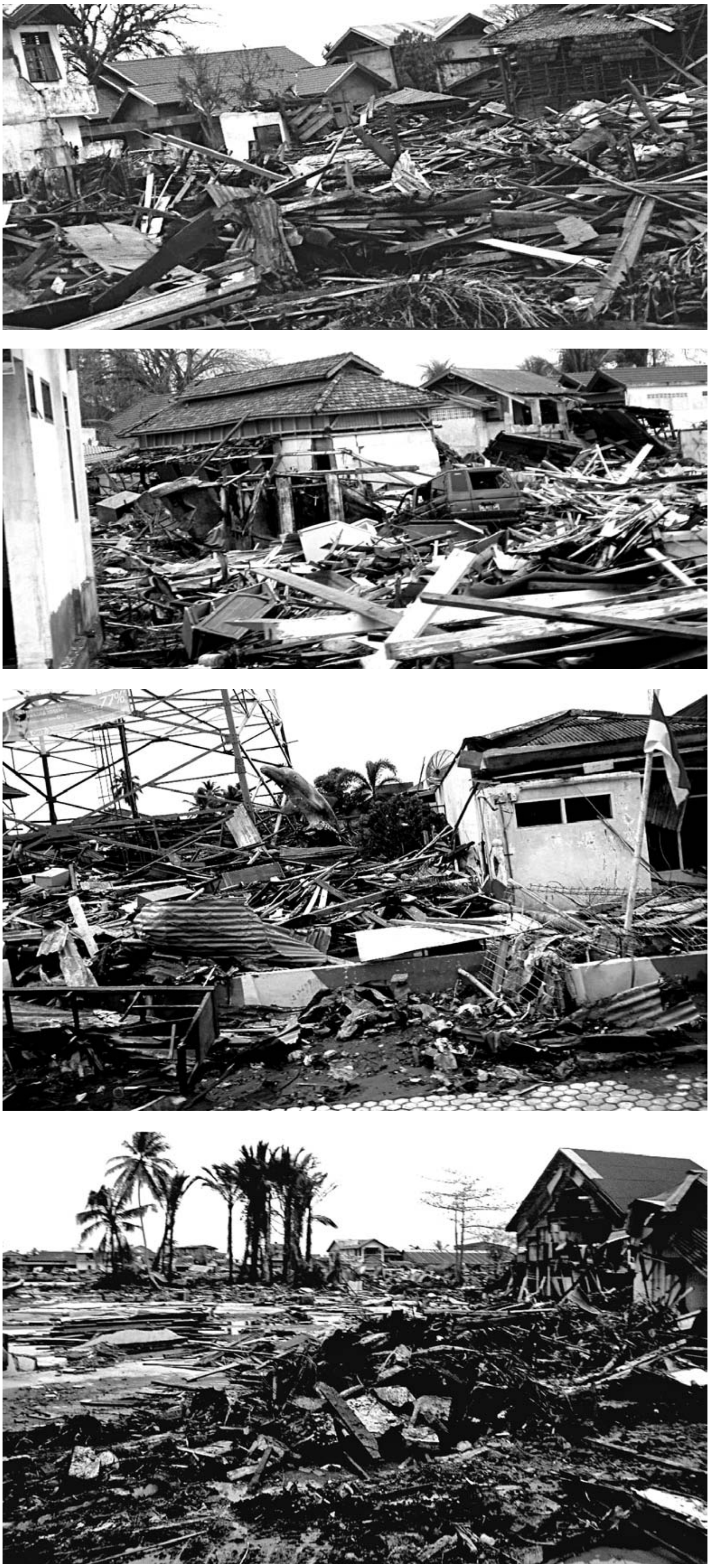
In Meulaboh: Zone 1; Damaged by battering / impact

In Meulaboh: Zone 1; Damaged by battering / impact

Debris and Mud in Meulaboh at Zone 2

In Meulaboh: Zone 2; Flooding water with debris and mud

In Meulaboh: Zone 2; Flooding water with debris and mud



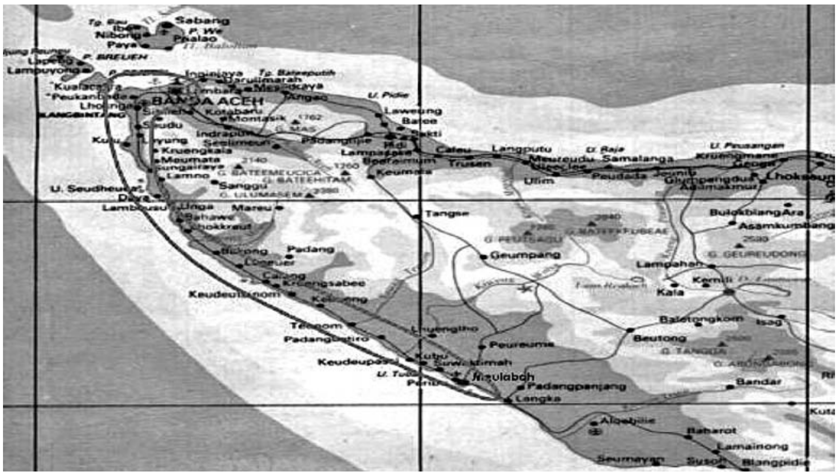
In Meulaboh: Zone 2; Flooding water with debris and mud

6. THE RUINED INFRASTUCTURE FACILITIES.

As was the case with buildings, most of the damage of infrastructures was caused by the strong force of tsunami and not by shaking.

6.1 Roads

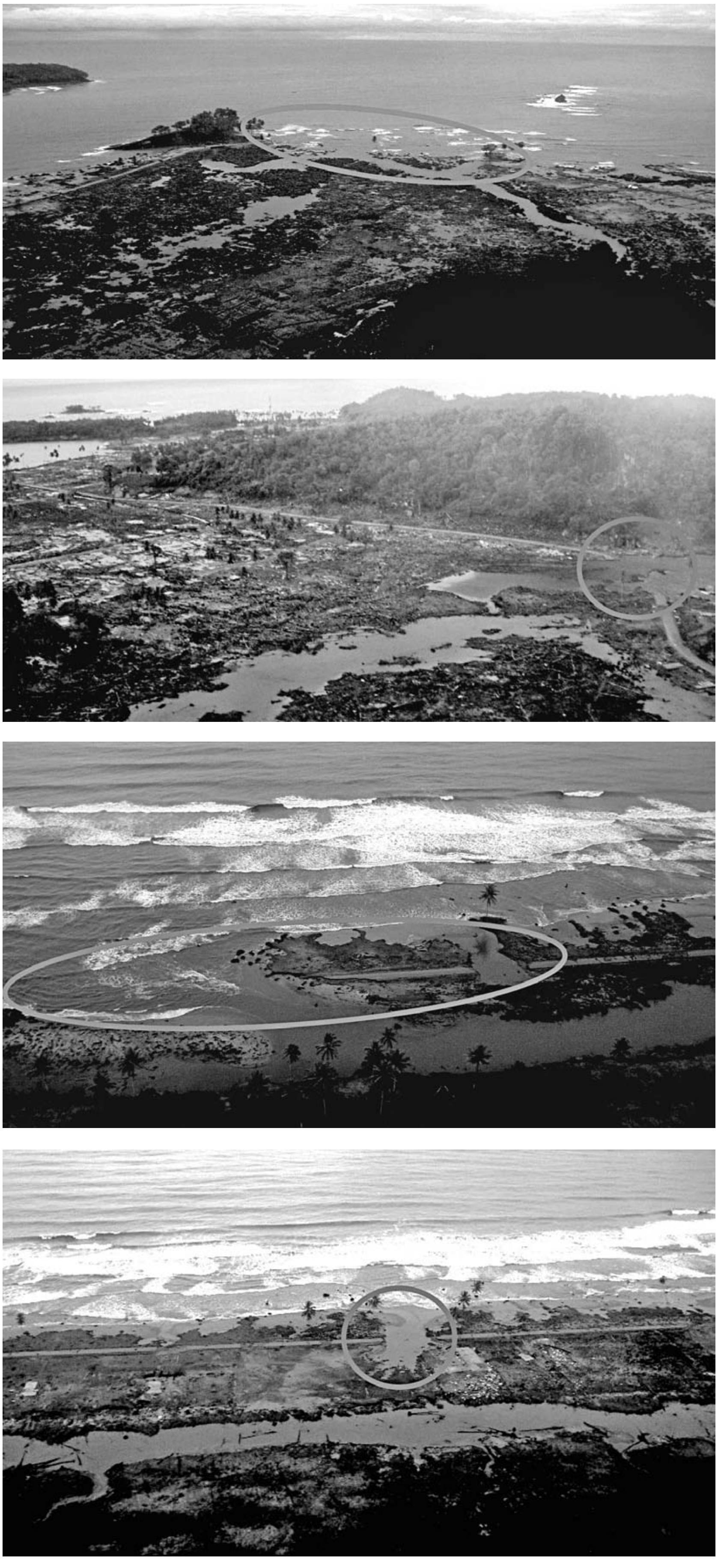
Some roads in Banda Aceh were scoured by tsunami but the majority was still in tact. Most of the main roads in zone 1 were covered by huge amount of tsunami debris. Several parts of the road from Banda Aceh to Meulaboh were washed away by tsunami.



Map showing the road from Banda Aceh

Damage to Roads and Bridges from Banda Aceh to Meulaboh

Unbelievable damage to roads and bridges



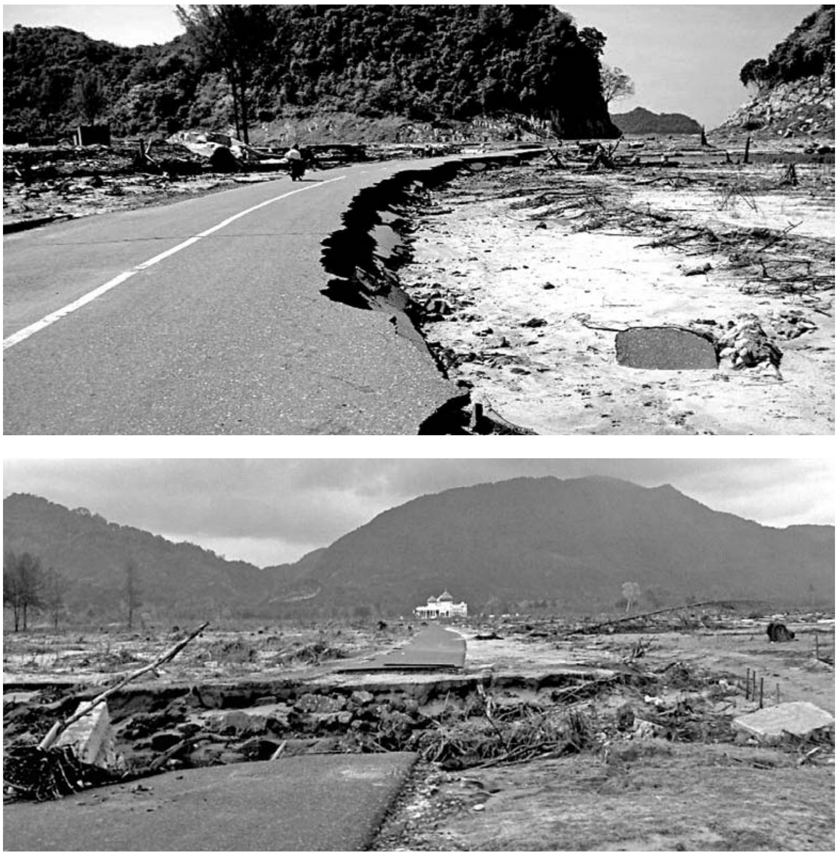
Washed out Roads and Bridges: An account from Banda Aceh to Meulaboh

Another damaged Road with its Bridge along Banda Aceh to Meulaboh

Roads Scouring in Banda Aceh

Banda Aceh – Scouring

Ulhue Lhe – Scouring



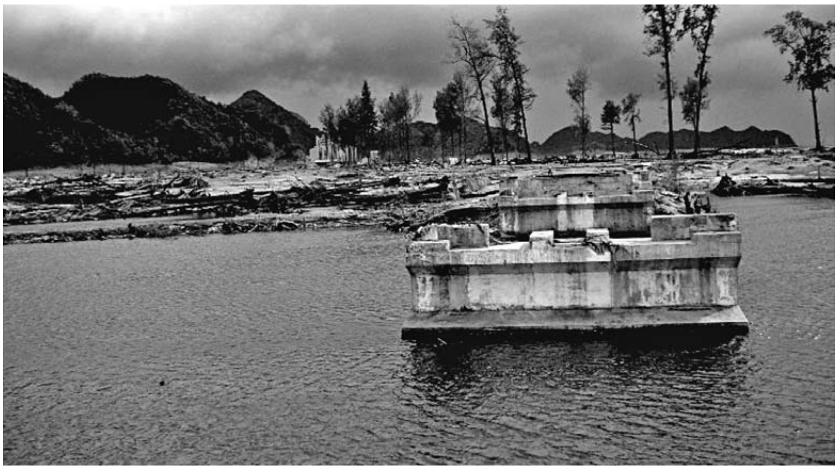
Lhok Nga Road - Scouring

Meulaboh – Roads along the Coast damaged by Scouring

6.2 Bridges

In Banda Aceh, several bridges were destroyed, one at Jl Iskandar Muda and another leading to Lhok Nga. The Lhok Nga Bridge has a main span of 20 m and secondary span of 10 m made of galvanized steel frames. Both were dumped into the river. Along the road from Banda Aceh to Meulaboh (distance approx 270 km), several bridges were washed away by tsunami.

Bridges washed away by tsunami battering and impact forces

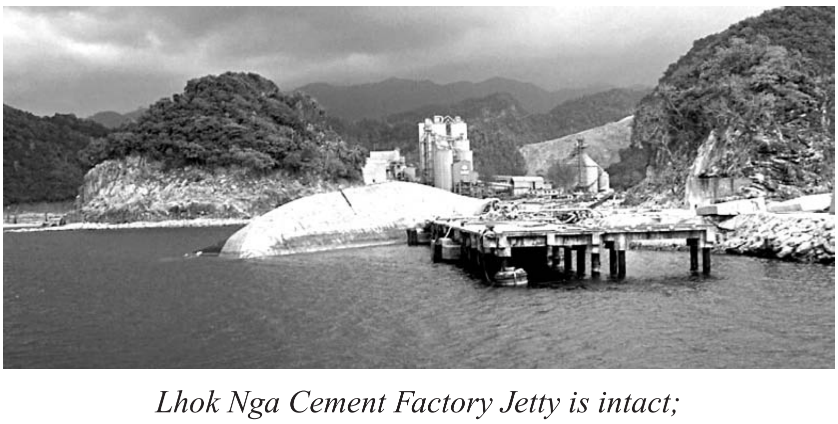


Bridge-span washed away by tsunami battering and impact forces

6.3 Ports

Generally, jetties and wharf of ports in Banda Aceh and in Kreung Raya as well as the jetty of the cement factory Lhok Nga were slightly damaged but could still function. Part of the platform of the jetty in Meulaboh was washed away by tsunami, but the supports were still in tact. The main building of the Ulhue Lhe harbor in Banda Aceh was damaged and only the frame remained.

Fishermen Jetty in Ulhue Lhe is not damaged



Lhok Nga Cement Factory Jetty is intact;
slightly damaged by impact of boat

Lhok Nga Cement Factory Jetty is Intact; Slightly damaged by impact of boat

Part of Jetty: Meulaboh Harbor

Jetty: Malahayati Harbor

6.4 Power supply

Main Power generating plant in Banda Aceh was not affected by the shaking or tsunami. However, many distribution poles and wires in devastated areas collapsed.

Electric cables poles toppled by battering, underground cables damaged by scouring and substation inundated

Electric cables poles toppled by battering, underground cables damaged by scouring and substation inundated

6.5 Telecommunication

Some mobile phone antennas towers were dismantled by the tsunami and dragged up to 500m from its foundations. Many telephone junction boxes were practically destroyed.

Telecommunication antennas swept by battering and dragged as far as 500 m

Telecommunication antennas swept by battering and dragged as far as 500 m

6.6 Water supply

Water Treatment plant in Banda Aceh was not affected by neither the shaking nor the tsunami, however, the underground piping systems were damaged by scouring and above ground piping damaged by battering and impact of the tsunami.

Water pipes unearthed and severed

Water pipes unearthed and severed

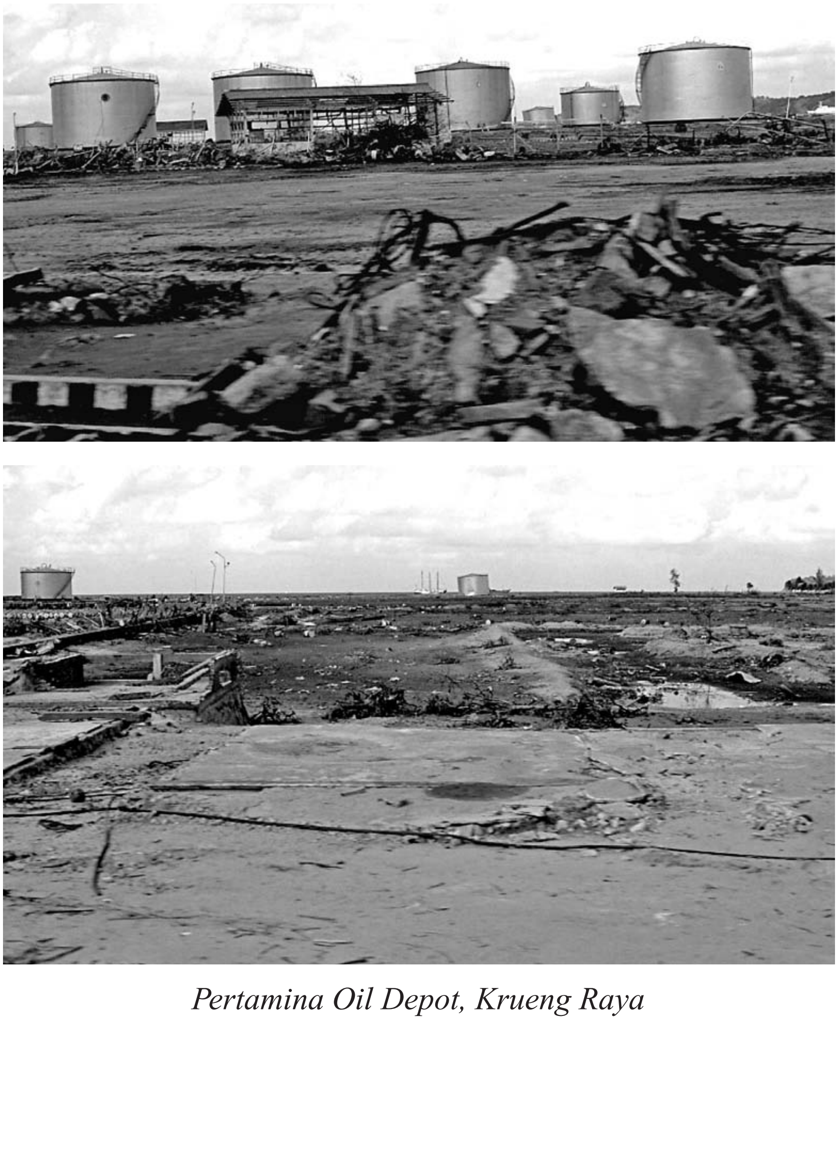
6.7 Industrial

- A cement factory located at beach side in Lhok Nga district was severely damaged.
- Oil depot in Kreung Raya (East of Banda Aceh) was damaged and several storage tanks were dragged up to 1 km. The tanks were submerged by about one-third of its height.

Cement Factory, Lhok Nga, damaged by battering, impact and buoyancy

Cement Factory, Lhok Nga, damaged by battering, impact and buoyancy

Cement Factory, Lhok Nga, damaged by battering, impact and buoyancy

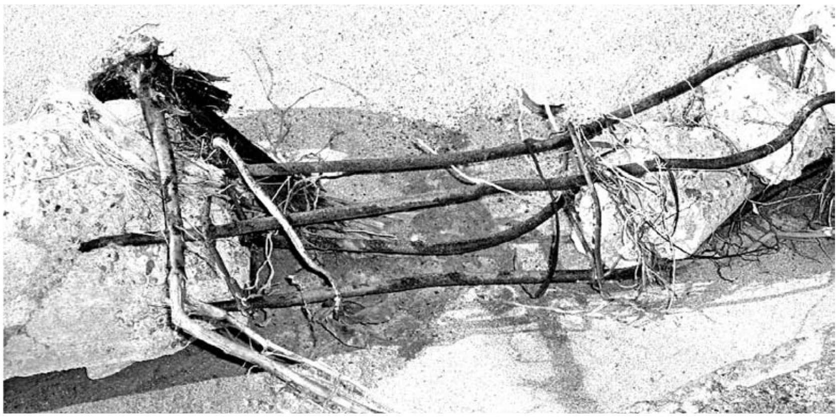


Pertamina Oil Depot, Krueng Raya

Pertamina Oil Depot, Krueng Raya

Poor Detailing

Poor detailing of buildings caused its structural damages into pieces



The poor detailing: a major cause of damage

Unbelievable damage mainly due to poor detailing

Damage due to poor detailing

Damage due to poor detailing

The Importance of Restraints (Vegetation or Buildings)

Vegetation: An ecological balance with building protection

With vegetations, buildings, at least have some protection against direct hit, but without it, face a direct blow

The self explanatory images with and without vegetations

The importance of restraints (vegetation or buildings)

The painful stories with the images

The importance of restraints (vegetation or buildings)

The importance of restraints (vegetation or buildings)

The importance of restraints (vegetation or buildings)

Mosque

The surrounding of Mosque at Ulhue Lhe

Mosque in Lhok Nga

Mosques along the road between Banda Aceh and Krueng Raya

Mosques along the road between Banda Aceh and Krueng Raya

Meulaboh

Mosques in Meulaboh

7. EMERGENCY RESPONSE AND NEEDS AFTER DISASTER

The mega tsunami that devastated Aceh was extraordinary and almost half of the 4 million population of Aceh were directly as well as indirectly affected. One or several of their family members are missing or died during the tsunami, therefore, since the second day, almost no local people were participating in the search and rescue because they must take care of their own family first. This resulted in the management of the deceased is very slow and until 7 days after the M 9.0 earthquake, many dead bodies were still scattered in streets and under debris. Only the Red Cross and the army were taking care of the deceased. Also, telecommunication broke down totally, making communication and coordination between the local and the central government very slow and difficult, resulting in the late management of logistics, such as food, medical supplies, gas etc. Electric power was also switched off inspite of the fact that the power generating plant was not affected by the earthquake or tsunami. Electric poles and wires in certain areas were damaged by the tsunami. The telecommunication was only partially restored after almost two weeks and this created panic for survivors in trying to contact their relatives and also in updating the central government about the facts on the ground. Electric power was also partially restored after two weeks.

The management of debris and rubble created by the tsunami was also late and resulted in the late start of the “recovery” process. Subsequently, after assessing the situation, the central government brought in additional army battalions from outside Aceh and also volunteers from various provinces started pouring in to take care of the complex problems arising from the tsunami. The “outside” people were not affected by the tsunami and could therefore concentrate on the assignments given to them. The Emergency Response Medical volunteers that came from a various provinces did a very good job in managing the tsunami victims and subsequently with the foreign armies’ medical teams managed to control the outbreak of various communicable deceases.

Right after any disaster, it is essential to RESTORE TELECOMUNICATION immediately. This will make emergency response easier and faster and reduce panic among the community.

In general, multinational armies and volunteers arrived in Aceh one week after the earthquake and tsunami and they were immediately involved in the emergency response, however, many foreign armies started to build field hospitals which in a tsunami case might be needed but not that much since the urgency was not there. As is known, a tsunami caused more dead victims than injured ones. Also, as a common case, many foreign countries sent medical supplies labeled in their own language and these are useful when used by their medical staff who really understands what is written in the labels, but not so for the local staff except those written in English.

The challenges in the recovery is not to repeat mistakes from past disasters , among others on how to prevent NGOs, local as well as foreign from bringing in all sorts of “alien” materials and products such as knockdown houses which are not compatible with the local culture. All Government officers and community leaders and donors are discussing about the recommendation to relocate the destructed villages and almost all of them are relying on NGOs/donors who have shown willingness to “adopt” certain villages. Appropriate planning and analysis shall be made prior to recommending implementing post earthquake disaster relocation.

Efforts must be emphasized on how to make such masonry houses earthquake resistant and information dissemination on how to appropriately build masonry houses, meaning the enhancement of the current practice to produce good quality buildings as a culture. Earthquake resistant should be interpreted as resistant if shaken by an earthquake and not if subjected to tsunami, particularly to cater mega tsunamis such as the Dec 26, 2004 one. It is considered impractical to design buildings having adequate strength for resisting extreme tsunami loads, such as: hydrostatic pressure, buoyancy, battering, impact, and pulsating water, translation, scouring, and overturning. Extreme pressures were exerted on all surfaces of structures during the Aceh tsunami. Such pressures resulted in cracking, displacement, and collapse of walls, floors and framing of structures. In some areas, timber as well as masonry houses were totally disintegrated by the tsunami.

Coordination by the Indonesian government during the first weeks of the disaster was not well managed resulting in the uncoordinated locations of foreign armies' activities and facilities. Also the flow and storage of so many food as well as medical supplies was not well organized.

During the multi national presence, everything seemed to be relatively easy to get, free of charge, particularly healthcare and some medical supply as well as food. If the free medical care and particularly free food supply is provided for too long, it can create an over expectation on the displaced people and cause envy among the people unaffected by the tsunami.

8. RISK TO THE INDONESIAN ECONOMY

It is predicted that the Aceh tsunami of Dec 26, 2004 will not have a significant effect towards the Indonesia economy and the 2005 national growth is still predicted as 5-6%. It is also predicted that the tsunami will not cause negative effects towards the expectation and risk perception on the Indonesian economy and will not disrupt investment plans as well as the performance of the exchange rate.

That statement was issued by the Bank of Indonesia, Directorate of Economic Research and Monetary policy. In addition the report also stated that if the flow of emergency supplies can be handled smoothly, the possibility of inflation could be minimized.

The effect of tsunami towards the Banking sector will also not be too significant because the role of banks in Aceh is small, below 1% of the national banking.

The role of Aceh economy towards the GNP is relative small, approximately 2%. It is predicted that the main Aceh economy activity in 2005 will be in the construction sector due to the reconstruction of the devastated areas. The effect of the tsunami towards export/import is also relatively small. The main export of Aceh is dominated by oil and gas products and the facilities for that purpose is not affected by the tsunami. The main import is chemical products and raw materials for both industry and this also will not be disrupted because the tsunami did not affect industries. However, the overall annual growth will be lower than the previously predicted 3.5%.

9. LAST DROP: THE LOCAL IMPACTS

In spite of the fact that the tsunami most probably will not disrupt the Indonesian economy, the loss of jobs could be crippling at the local level. Even though the damage of agricultural land is only 10%, it will take many years to recover. Farmers lost their livestock and equipments. The aquaculture losses were quite substantial.

Apart from all those, as mentioned earlier, the tsunami also swept and destroyed many roads, bridges, drainage systems, water piping, electrical lines, and telecommunication towers.

The repair and rebuilding of those all and the resettlement of displaced people will take many years and will need a substantial amount of fund, maybe a substantial percentage of the gross domestic product of the country.

LESSONS LEARNED FROM THE 26 DECEMBER 2004 TSUNAMI DISASTER IN THAILAND

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ABSTRACT

Triggered by a massive earthquake (M_w = 9.3) in the area off the Western Coast of Northern Sumatra, a series of destructive tsunami waves propagated throughout the Indian Ocean and devastated communities along thousands of kilometers of exposed coastline. In Thailand, all provinces facing Andaman Sea were seriously damaged by tsunami waves, where the total reported death toll including the missing people exceeded 8000 including the missing. An international survey team, comprising members from Thailand, Japan, and USA, has spent four days from 8 to 11 January 2005 in several hard-hit areas to collect information on tsunami inundation, building damage characteristics, ground and foundation failures, and associated data from eyewitnesses and survivors. The areas investigated include Khao Lak (Phang-Nga), Phi Phi Island, and Phuket Island. Many lessons have been learned from this post-tsunami reconnaissance survey, and they are briefly summarized in this paper.

1. A CHAOTIC MOMENT BEFORE THE ARRIVAL OF TSUNAMI WAVES

In the morning of 26 December 2004, at around 8:15 am while I was having my breakfast at home in Bangkok, I got several phone calls from friends and colleagues, reporting that many tall (30 to 50-storied) residential buildings in Bangkok had been shaken so violently, causing panic among the building occupants. Many of them said that the level of shaking was the highest compared to what they had experienced in the past, and the duration of shaking was very long-about 5 minutes or even longer. The water in swimming pools in several buildings was also sloshed and splashed out of the pools. Recognizing these as signs of a very large scale earthquake occurring somewhere far away from Bangkok (Reference 1), I then turned on the Radio and TV and learned that the earthquake epicenter was located around the Northern Sumatra, and the earthquake magnitude initially estimated by different agencies ranged from 6.4 mb to 8.0 M_s (a more accurate magnitude M_w of 9.3 was reported about one week after the event). At that time no one mentioned or even thought about a possibility of destructive tsunami triggered by the earthquake.

Hearing about a chaotic situation in a 24-storied hospital building, where about 400-500 patients and medical staffs went into panic by the building's vibration and were evacuating from the building, I then rushed out to join a team of experts including the Bangkok Governor to conduct a quick safety inspection of the buildings. The building was found to be safe without observing any significant damage; so, the evacuation was cancelled. At about 10:15 am, while I was still at the building, a friend phoned me and told that “gigantic sea waves” had hit Patong beach in Phuket Island and killed about 10-20 people. and about 100 cars were either overturned or destroyed. At first, I thought it was a rather exaggerated story, but shortly afterward similar stories about gigantic sea waves in various other sites in Phuket, Krabi, and Phang-Nga Provinces were also reported on Radio. The total death toll reported in these southern provinces increased rapidly to about 60 at noon, 120 in the late afternoon, and continued to increase. I then realized that we were experiencing a great tsunami disaster for the first time in the history of Thailand.

2. OVERALL IMPACT OF TSUNAMI WAVES

Triggered by the massive earthquake (M_w = 9.3) in the area off the Western Coast of Northern Sumatra, these series of destructive tsunami waves propagated throughout the Indian Ocean and devastated communities along thousands of kilometers of exposed coastline. Along with Thailand, deaths by this ocean-wide tsunami have been reported in 10 other countries: Indonesia, Sri Lanka, India, Malaysia, Myanmar, Maldives, Bangladesh, Somalia, Tanzania and Kenya. The total death toll including the missing people is more than 280,000. It can be ranked as one of the world's most catastrophic events in recent times.

In Thailand, all provinces facing the Andaman Sea were attacked by tsunami waves. The death tolls including missing in Phang-Nga, Phuket, Krabi, Ranong, Trang, and Stool provinces are 6026, 921, 1384, 171, 6, and 6; the numbers of severely damaged buildings are, 4615, 1235, 632, 349, 165, and 57 respectively. These statistics are provided by Department of Disaster Mitigation and Prevention, Ministry of Interior, Royal Thai Government, on 24 January 2005. Nearly half of the confirmed dead and half of those missing were foreign tourists, who were spending their holidays in the resort areas.

3. POST-TSUNAMI RECONNAISSANCE SURVEY

An international survey team, comprising members from Asian Institute of Technology, Chiba University (Japan), EDM/NIED (Japan), JICA, MCEER (USA), GISTDA (Thailand) and Thai Meteorological Department, was formed to collect information on tsunami inundation, building damage characteristics, ground as well as foundation failures, and associated data from eyewitnesses and survivors. The team, coordinated by myself, spent four days from 8 to 11 January 2005, in several hard-hit areas, such as Khao Lak (Phang-Nga), Phi Phi Island, and Phuket Island. Many lessons have learned from this post-tsunami reconnaissance survey, are briefly summarized in the following sections. In addition, 11 hours of geo-referenced digital video footage were recorded along the survey route, and about 1,500 GPS-located digital photos were also collected by the team, and were linked to satellite images (IKONOS, Quickbird). It is envisioned that these geo-referenced data will be invaluable for future research in evaluating damages from tsunami waves. Further details about these geo-referenced data and their possible applications could be found in References 2 and 3.

4. LESSONS LEARNED

Among several beaches in Phuket Island, the impact of tsunami was reported to be the highest in Kamala and Patong Beaches. The maximum height of tsunami waves above the tidal level at that time was about 4 to 5 meters, while the inundation depth was about 2 meters. The first sign of tsunami attack was the withdrawal of the sea the pushing backward of the sea water. Many people were surprised and went to see the exposed seabed. Many of them were killed or seriously injured as the sea withdrawal was shortly returned with a high tsunami wave. At Kamala Beach, three tsunami waves struck the shore at 9.54, 10.14 and 10.57 am respectively; and the 2nd and 3rd waves were higher than the 1st wave.

A series of photos-Fig. 1(a) to (c)-taken by an eyewitness from the 3rd floor of a beach-front reinforced concrete building in Kamala beach, shows clearly that the tsunami wave swept inland at high velocity as a sheet of water. The depth of the flow in Kamala beach area was about 2 meters or less, so only the first story was flooded as shown in Fig. 2. But the flow-velocity was roughly estimated to be about 3 to 4 m/s or higher. Hence, a lateral hydrodynamic pressure greater than 5.0-8.0 kN/m^2 was exerted on buildings and obstacles by the high-velocity water.

After the water had receded, a great amount of debris floating during the tsunami flooding, finally deposited on ground (Fig. 3), also water marks could be observed on building walls. The damage seemed disproportionately severe compared with that would be expected from a normal flooding of similar height. The high hydrodynamic pressure due to high velocity water and the collisions of floating debris appeared to be the main causes of the severe damage.

Tsunami wave heights at various sites shown in Fig. 4 were measured by a Japanese team led by Professor Matsutomi (Reference 4) and a Thai team led by Dr. Nakhorn Poovarodom of Thammasart University.

(a)

(b)

(c)

Figure 1 (a) to (c): A series of photos taken during the tsunami impact in Kamala Beach.

Figure 2: Tsunami flooding in Kamala Beach

Figure 3: A scene in Kamala Beach after the water has receded

The heights vary considerably from site to site, and the maximum height occurred at Khao Lak in Phang-Nga Province. This area has many luxurious hotels and was quite popular for foreign tourists, especially those from Europe.

Water marks in the form of stripped roof tiles on the 2-storied building in Fig. 5 indicates that the flow depth in Khao Lak area was as high as 7 to 8 meters. The flow velocity in this area was estimated to be about 6 to 8 m/s, and hence a very high hydrodynamic pressure of about 20 to 30 kN/m^2 was exerted on buildings and obstacles by tsunami waves. Due to these extremely high flow depth and pressure, Khao Lak was the hardest-hit area with the largest death toll. Most of the resorts surveyed sustained heavy to complete damage.

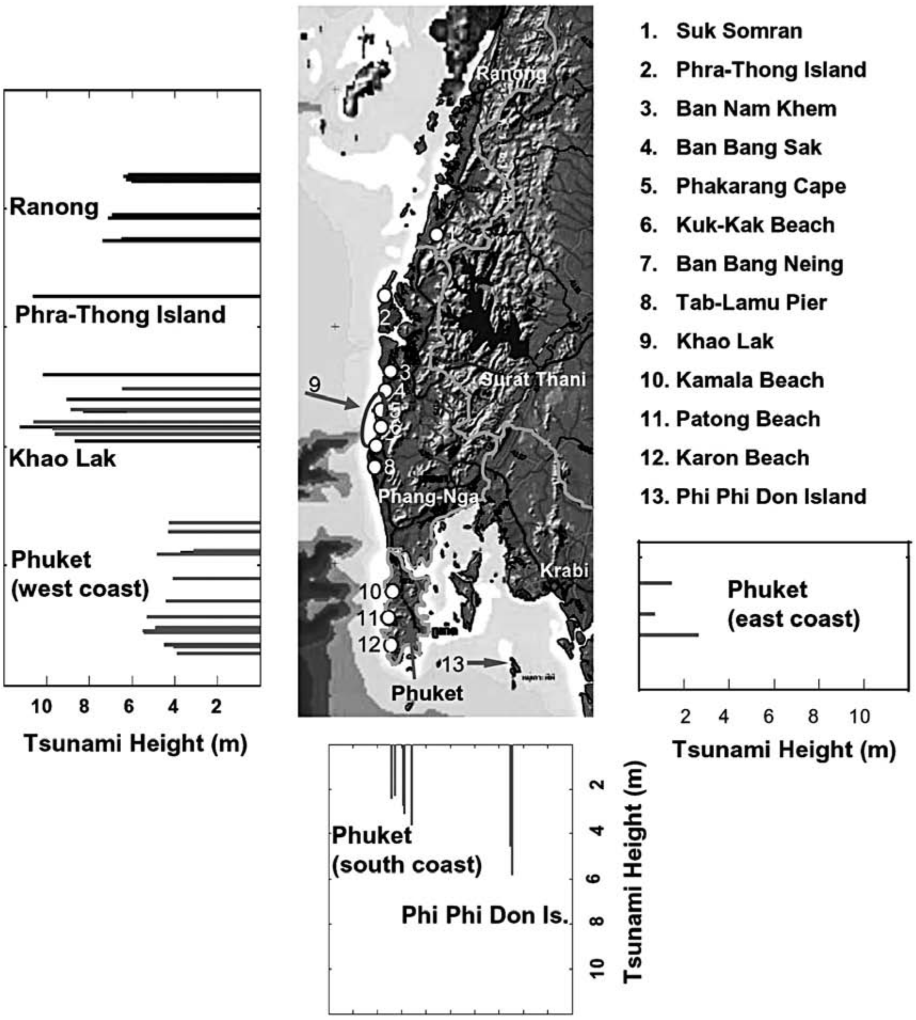

Figure 4: Tsunami wave height distribution

Figure 5: Maximum flow depth of about 7 to 8 meters in Khao Lak

(a) Kuk-kak Beach

(b) Khao Lak Princess Resort

Figure 6: Examples of completely destroyed buildings in (a) Kuk-kak Beach and (b) Khao Lak Princess Resort

As shown in Fig. 6, a reinforced concrete building facing Kuk-kak Beach in Khao Lak was completely destroyed by tsunami impact (Fig. 6(a)), while another concrete building in Khao Lak Princess Resort (Ban Bang Sak) was overturned (Fig. 6(b)). These are few examples out of many completely damaged buildings in this area.

(a) Khao Lak

(b) Phi Phi Don Island

Figure 7: Breaking of masonry infill walls by wave impact in (a) Khao Lak and (b) Phi Phi Don Island

One damage pattern commonly found in RC frame buildings is the breaking of frame-infill masonry walls: Fig. 7(a) and 7(b). These walls are generally 100 mm thick. They are much weaker than RC frame members, and they could not withstand high hydrodynamic pressure or impact of major floating debris carried by the strong current. Breaking of infill masonry walls, particularly in the first story, could be found in many sites where the flow depth was about 2 m. or higher. As shown in Fig. 7(b), the flow height did not reach the second story of a two-storied building, but it was able to demolish all infill masonry walls at the first story.

We observed that in general RC frames, in which infill walls had been completely ripped away were still in good condition-no damage or major cracks found in RC columns, beams, and beam-column joints. The breaking of infill walls seemed to help saving the RC frame structures by reducing the lateral pressure load on the structures. Therefore, to improve the safety of RC frame buildings in the tsunami affected areas, the infill masonry walls in the first story (and the second story in some areas) might be replaced by weaker (and lighter) panels that could be easily ripped away by the water. These observations and concept of design improvement are well in line with those made by the several investigators of past tsunami disasters (Reference 5).

Figure 8: Floating foundations of a building in Phuket

Another type of damage frequently observed to buildings in tsunami affected areas is the severe scouring of supporting sand underneath of spread footings of the buildings, leading to foundation failure as shown in Fig. 8. This severe scouring was caused by highly turbulent and strong tsunami-induced currents.

We have also found severe scouring of roads (see Fig. 9) and wall foundations in many sites, particularly in beach front areas. Another type of failure associated with shallow spread footings is shown in Fig. 10. Here, several buildings at Ton Sai Bay were floated and displaced from their original positions.

Figure 9: Severe scouring of road in Kuk-kak Beach

Figure 10: Displaced buildings at Ton Sai Bay in Phi Phi Don Island

As spread footings were commonly used for low-rise buildings in Phuket and many Southern provinces of Thailand, this issue was widely discussed among design engineers in several forums. Many engineers suggested that the use of spread footings for buildings in tsunami hazard prone areas should be forbidden, and that pile foundations should be used to improve the resistance to scouring, undercutting, and flotation effects.

Figure 11: Debris deposited on the beach in front of Khao Lak Princes Resort

One important feature of tsunami flooding, we have learned from this survey is that strong-current tsunami waves carried with them a great amount of debris including cars and boats. Figure 11 gives us a clear idea about the extent of debris carried by tsunami waves during the tsunami flooding. We found pieces of wood, furniture parts, refrigerators, trees, metal (zinc) roof sheets, sand and mud in the debris. High-density debris in tsunami waves is certainly one of the key factors that are responsible for a large number of tsunami victims.

Figure 12: A car on the roof of a building in Phakarang Cape

Many cars were rolled, pushed around, hit by floating debris, or thrown against buildings (Fig. 12) and obstacles. Many fishing boats were pushed from the shore toward the land and crashed into buildings. One patrol boat was forcefully transported into as far as 1.2 km. inland at Ban Bang Neing in Khao Lak area. The largest object that was displaced by tsunami waves is a battleship of Royal Thai Navy as shown in Fig. 13. The ship was tossed on to the shore in front of a naval base at Tab-lamu pier in Phang-Nga.

Figure 13: A battleship was tossed on to the shore at Tab-lamu Pier

While the Southern and central parts of Phang-Nga have several resort hotels, the Northern part is still a rural area with fishing and agricultural villages. In a populated fishing village named Ban Nam Khem, more than a thousand of residents were killed, and most RC residential buildings and masonry structures for shrimp farming suffered heavy damage. The survey team also visited one fishing village named Ban Pak Jok in Phra-thong Island?a small island, located just off the Northern coast of Phang-Nga (see Fig. 4). In this village, all wooden fisherman houses and small light-frame concrete buildings were completely wiped out as shown in Fig. 14. All survivors were evacuated from the island and resettled in the Northern coast of Phang-Nga.

(a) Devastated fisherman houses

(b) School buildings

Figure 14: (a) Devastated fisherman houses, and (b)school buildings in Phra-thong Island

We saw evidences in this village and in many other sites (such as Phakarang Cape) that wooden houses, compared with normal RC frame buildings, are much more vulnerable to tsunami impact. At sites where RC buildings were lightly or moderately damaged, the wooden houses had been severely damaged or completely destroyed. The findings suggest that wood construction should be as much as possible avoided in tsunami prone areas.

In Ban Pak Jok village, only one structure was left intact: an RC water tank tower. It reminded us of a tsunami tower in Japan, in which people can easily evacuate from low-lying ground to its high-level platform during the tsunami flooding (Fig. 15).

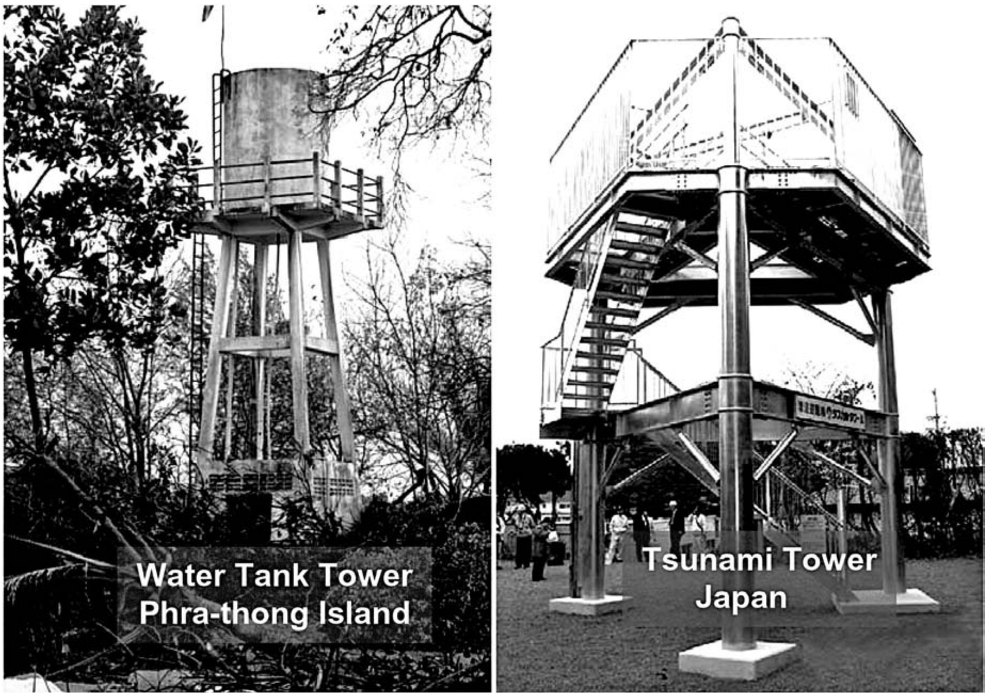

Figure 15: Water tank tower & Tsunami tower

Since the whole area of Phra-thong Island is very flat and surrounded by sea, it would be very difficult to find a safe (high-level) ground for the evacuation in considering the next tsunami event. Hence, RC tsunami towers seem to be a practical solution in this case.

Figure 16: Sand belt area in Phi Phi Don Island was attacked by tsunami waves from both sides

By interviewing several eyewitnesses and survivors, the survey team learned that tsunami waves at some sites were quite complex. These sites include Phi Phi Don Island, which was among the worst affected areas. Looking from the tsunami source area, this island is located outside the shadow of Phuket Island, and thus was hit by large tsunami waves of about 5 to 6 m maximum height (see Fig. 4). The number of casualties in this island was 691 and that of missing was 951. Most of them were tourists and residents in a highly populated sand belt between two bays as shown in Fig. 16. The elevation of this sand belt area is only 2 to 3 m above the sea level. When the first tsunami wave attacked from Loh Dalum Bay, people were in panic and they tried to escape by running to Ton Sai Bay on the other side. However, by the time they reached Ton Sai Bay, a much larger tsunami wave was also arriving in this bay, and then swept across the whole sand belt area killing a large number of people.

5. CONCLUDING REMARKS

Prior to this event, a tsunami disaster of this scale was considered by the Thai public to be impossible. This general belief was simply based on the fact that such a disaster had never happened before in the history of Thailand. They also believed that the risks from other natural disasters (such as earthquakes) were also very low, and limited to a small scale. Most decision makers in the government did not pay much attention to planning and preparation in mitigating the risks, or supporting more scientific researches to understand the risks. The emphasis was only placed on emergency response measures.

After the event, the attitude of the general public and government officials towards natural disasters has changed significantly. They are now much more interested to learn about these natural disasters and their potential impacts. Also, they are more ready to invest their money in making and ensuring a safe environment. Of course, it was an unwanted blow, but it is true that the Thai public has learned a very important lesson from this tsunami disaster.

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THE 26 DECEMBER 2004 TSUNAMI DISASTER AND RECOVERY CHALLENGES IN SRILANKA

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ABSTRACT

With over 31,000 lives lost, which translates to more than 1800 persons killed per every 1 million inhabitants, and an economic loss estimated to be between 6-8% of GNP, the Indian Ocean Tsunami Disaster in 2004 December is the worst natural disaster experienced in Sri Lanka. In relative terms it is among the most damaging natural disasters faced by a country. While early warning and evacuation systems would be the most effective responses for mitigating future Tsunami disaster losses, the present tragedy highlighted the lack of an adequate disaster management structure to respond to the diverse extreme events the country has faced in the recent past. The immediate concern is to rebuild the coastal areas addressing not only the future safety but also alleviating the widespread poverty. The report describes the impact and the immediate damages to various sectors of the economy and infrastructure by the Tsunami and the challenges that lie ahead for 'Preparing for the Unforeseen'.

1. INTRODUCTION

The 26th of December 2004 goes down in history as the day Sri Lanka experienced its worst natural disaster. The massive earthquake registering 9.0 on the Richter scale that struck off the coast of Sumatra, Indonesia at 00 59 GMT was followed by a series of more than 67 aftershocks, the largest of which occurred approximately three hours after the first earthquake and registered 7.1 on the Richter scale. A series of tsunami waves triggered by the earthquake radiated through the Bay of Bengal at a rate of more than 500 kilometers per hour, reaching coastal areas of Bangladesh, India, Indonesia, Kenya, Malaysia, the Maldives, Mauritius, Myanmar, Reunion, Seychelles, Somalia, Sri Lanka, Tanzania, and Thailand from about 15 min in Indonesia, 2 hours in Sri Lanka and 14 hours in Cape Town, South Africa.

Sri Lanka was one of the hardest hit countries in terms of loss of life, infrastructure and assets. Between two to three hours after the first earthquake, waves reached more than two thirds of the coastal area of Sri Lanka. Current estimates stand at more than 35000 lives lost, over 5000

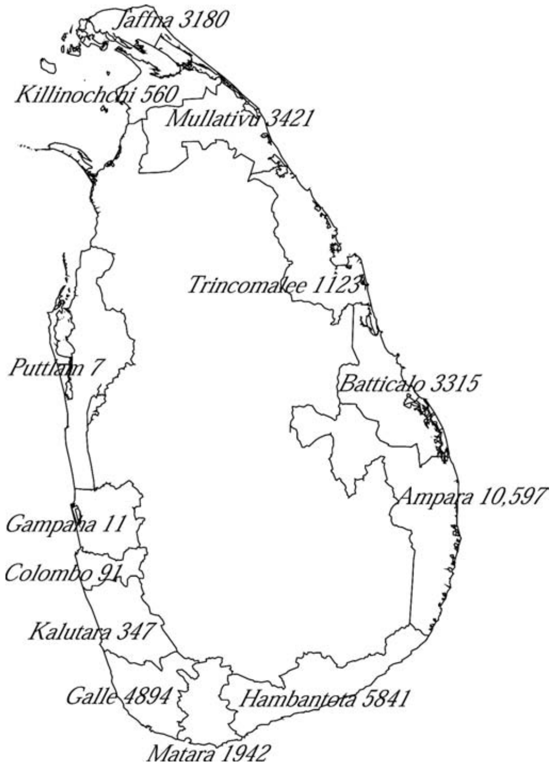


Figure 1: Distribution of dead and missing persons
(source: Department of statistics and census, Sri Lanka)

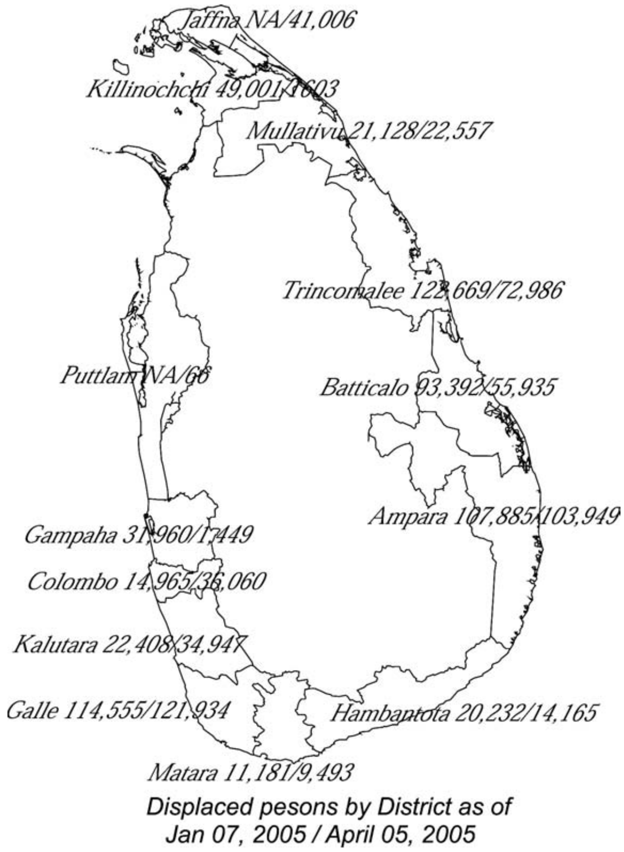


Figure 2: Distribution of displaced persons on Jan 07 and April 05
(source: Department of statistics and census, Sri Lanka)

missing and 1 million affected. Almost half of the affected lost their livelihoods. According to the CRED database, Sri Lanka with 1809 persons killed per 1 million inhabitants had the highest number of per capita casualties from all natural disasters in the world in 2004. Indonesia, the worst affected from the Tsunami had 759 people killed per million. Figure 1 shows the distribution of the deaths and Figure 2 shows the distribution of displaced people. The estimated economic losses varies from around 6.0% of the national GDP (by ADB/JBIC/World Bank) to 8% (by TAFREN) These are staggering numbers for any country, but especially so in Sri Lanka when they are compared in relative terms and the capacity to recover.

This article provides an overview of the event, impacts and reconstruction challenges in the aftermath of the Tsunami tragedy.

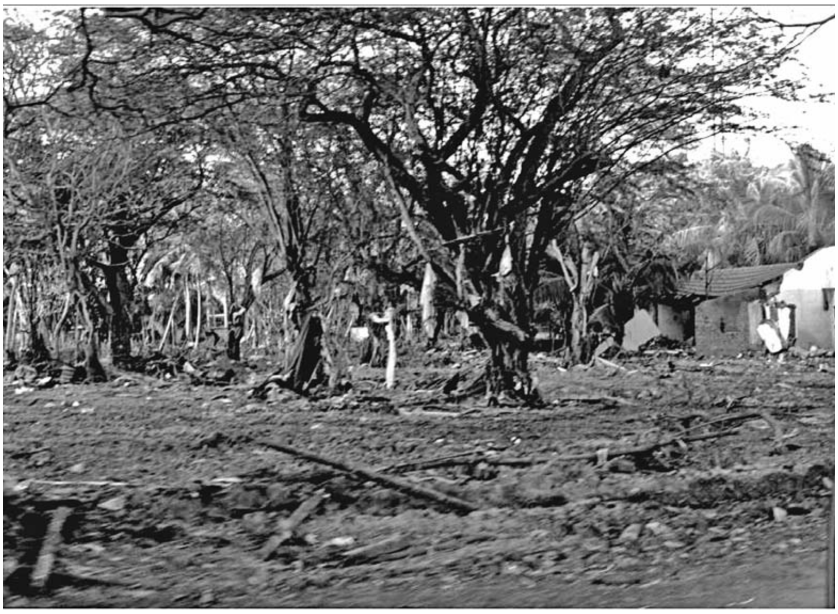
2. EVENT AND THE IMMEDIATE RESPONSE

2.1 Experience

The tsunami tragedy could not have happened at a worst time. The year-end school holidays generally start at the beginning of December and lasts till the end of the month. In 2004, December 25, 26 and 27 also happened to be public holidays commemorating both Christian and Buddhist events. Not only all the government organizations were closed, almost all the beach resorts were full of local and foreign tourists who flocked to sunny beaches for the holiday season.

From eyewitness accounts, the Tsunami experience was varied from place to place. The only common factor was that it appeared without any warning claiming the biggest casualties from coastal cities, mostly from Sunday market gatherings. In Galle, located in southwest of Sri Lanka, a towering wave hit the coastal area. In Hambantota, located in the southern Sri Lanka, a first wave came about half a meter high and while it was receding, before the water was completely drained, second wave rushed in. In some areas, as in Galle, a high wave, composed by the duel funnelling effects of the bay and sea coast rise, rushed ashore whereas in Hambantota, the first wave was reported about 0.5 m high but the second wave has kept on rising up, steadily going over rooftops in the beach area. In Kalutara, near Colombo, seawater kept on rising slowly but steadily with each ordinary wave. While one could walk away from the incoming wave, nothing would stop it as it bore down sweeping and pushing away beach benches, boats and what ever that stood in its way.

The run-up had been as high as 8-9 meters in some places, but mostly the range was 4-5 m. Inundation length from the coast varies according to the elevation, but was observed up to about 1 km length. The penetration of water had been greatest along the watercourses and in many areas retreating seawaters took people and dragged buildings down. Up to 5 waves were experienced at different parts of the country at varying intervals. In many areas of East and South, the two waves came very close to each other. Tsunami heights have been measured by various teams, USGS,



The Tsunami strength has been altered very much by the local conditions. Pockets of complete devastation adjoining partial damage as well as unaffected stretches as in this village, was common along the South West Coast line between Colombo and Galle.

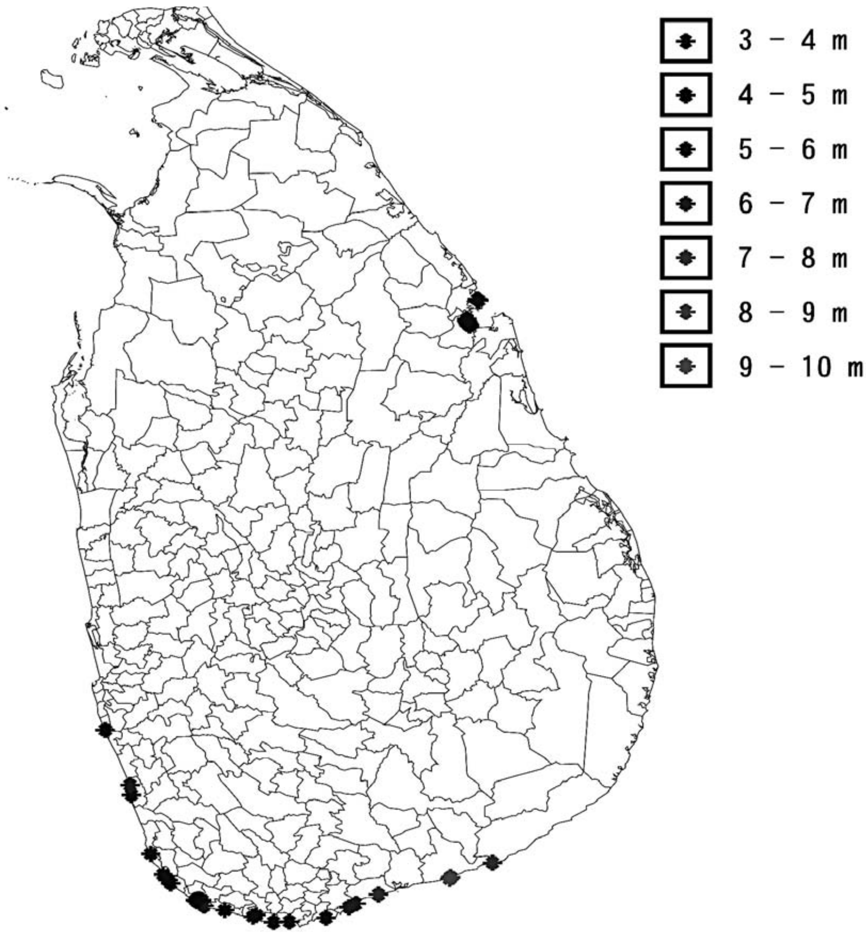


Figure 3: Run-up heights measured in the field

Japanese, Korean and UNU in collaboration with partners from Sri Lanka. A composite map of wave heights from most of these observations is shown in Figure 3.

Boats taken ashore was a common site along the road from Colombo to Galle

Yala sanctuary, in the Eastern coast, a popular destination for both local and foreign tourists had full of holiday makers when the Tsunami struck at its peak force. It had completely demolished the holiday homes and carried vehicles hundred of meters inland.(Source: CNO)

A colleague was driving his car towards the central bus stand away from the old fort in the coastal town of Galle. His only recollection was a black wall of water suddenly appearing and tossing his car inland. He managed to leave the car and escape unhurt. A lady from the further south town of Matara recounted the horror of the day. She lived about 100 m from the coastal line and was alerted by the commotion on that Sunday morning. As she came out she could hear the voice of her sister who lived closer to the sea shouting them to run as the sea is coming. The head started helping her escape without injury although they lost all of their property and she was grateful to the fact that she lived at least some distanse away from the coastal line.

Further down south, in Hambantota city, where many lives were lost in the thin strip or land between the sea and the lagoon, the survivors were still dazed, unable to come in to terms with the experiences of the day. A man in his later forties recounted how his family started moving towards the high grounds after the first wave came in, which was around 0.5 m high. Half way, his wife decided to come back to lock the door. She would have arrived at their house just as the second wave came in. Later her body was discovered on the other side of the lagoon. Further down the road, I talked to a man who was standing in front of a new two-story house carrying a small child. The kitchen, toilet and the storage rooms at the back of the house facing the sea were damaged, but the main building was not damaged. I assumed the family could escape the tsunami impacts as the water level came to only about 50 cm. on the second floor. Unfortunately, this was not so. The family had some small business next to the house, and on the day of the Tsunami, they were on the ground, by the house. Until the waves struck them, they had no idea of the incoming wave. The husband, wife and the farther of the husband were swept away, and the baby was left on a mattress inside the house. The husband could mange to cling to a tree, but he other members of the family were not so lucky. Inside the house, the mattress rose with the rising water level with baby on the mattress. Although the water level rose above the first floor level of the house, an air pocket formed between the first floor roof and the rising water just leaving enough breathing area for the baby to survive. Tsunami had caught them all by surprise, as the high density of buildings along the narrow coastal strip completely covered the sea and they had no idea of the incoming wave. He believes that in the future we need to give more space to the sea, and keep the coastal belt as open as possible, so that that communities would be less vulnerable to variation of sea level and it would be easy to notice changes to sea waves or wind patterns.

2.2 Response

When Tsunami arrived, most of the responsible government organizations were closed for the holiday. Whenever information reached responsible personnel, it has been fragmentary. One of the major difficulties had been to piece together reports arriving from different parts of the country to form a coherent picture. It was not until the information of the massive earthquake and the Tsunami was broadcasted on international TV, that it was realized high waves observed in different parts of the country was part of a single phenomena.

The Tsunami impact in the East Coast, Yala Sanctuary (source: CNO)

The immediate response to the Tsunami tragedy was magnificent. It was a spontaneous solidarity provided by ordinary citizens, volunteer organizations, armed forces, government and private organizations from all corners of the country. Refugee camps were set up immediately, and major NGO's have prepared extremely detailed needs assessments at each refugee camps that were passed to government authorities and volunteer organizations.

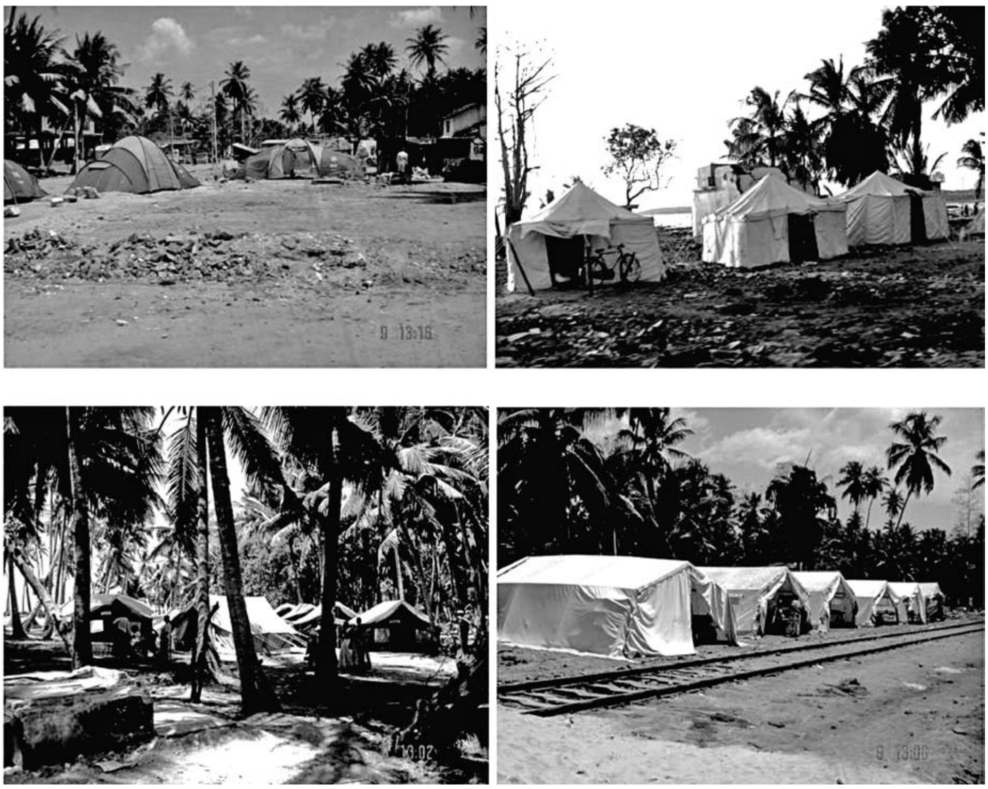
Sri Lanka has a National Disaster Management Centre, under the ministry of welfare and women empowerment, which was primarily involved in relief operations in the past. NDMC has been involved in the development of a disaster plan for Sri Lanka to establish a larger disaster management unit with a broad mandate. The proposed action plan had not been ratified in the parliament at the time of Tsunami. In the aftermath of the Tsunami disaster, the government immediately appointed a commissioner general in charge of essential services. Soon after, on December 28 the president has appointed 3 Task Forces to be in charge of different aspects of relief and reconstruction.

The first Task Force was for Rescue and Relief operations (TAFRER) also known as Center for National Operations (CNO), which had the mandate to coordinate all initiatives taken by government ministries, agencies and other institutions relating to relief efforts. The highest priority was given by CNO to assess relief needs and direct resources to maximise the effectiveness of relief efforts. It played an extremely valuable and visible role in collecting analyzing and tabulating data related to affected population as well as needs assessments in all sectors. It also had the task of coordinating all international donor assistance, voluntary services and NGO support.

The second Task Force was empowered to coordinate logistics of relief work. Its main task was to ensure the availability of essential goods and services to victims. The task force also was responsible for law, order and security in the affected areas.

After the initial phase of the rescue and relief work which largely depended on the voluntary support, responsibilities of TAFRER and TAFLOL were transferred to one body termed TAFOR, which was mainly manned by government servants. The relief packages for victims were introduced under TAFOR.

The third task force TAFREN that stands for Task Force for Rebuilding the Nation, was established to coordinate and assist government agencies and institutions in their efforts at reconstruction and rehabilitation. Its main functions are to carry out damage assessment, development of a comprehensive plan for reconstruction and the coordination and implementation of the plan. The task force also coordinate all donor assistance; fund raising and other financial aspects related the reconstruction plan. The task force is required to draft a parliament bill to setup an Authority to carry out the reconstruction tasks as a successor to TAFREN over a period of 3-5 years.



Camps for displaced persons were set up by various local and foreign NGO's. They came in different sizes, colors and forms. In the first week of January 2005, there were 608 camps providing shelter to over 330,000 persons.

Volunteers, armed forces, police government officials and clergy carried out most of the initial relief and rescue operations. From the government the Ministry of Social Welfare has been involved in the

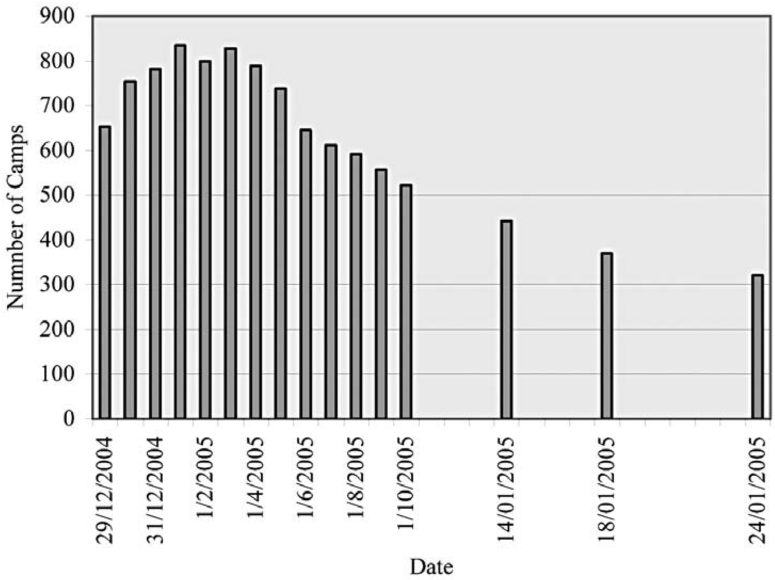


Figure 4: The variation of number of camps set up for the affected people (source: National Disaster Management Center, Sri Lanka)

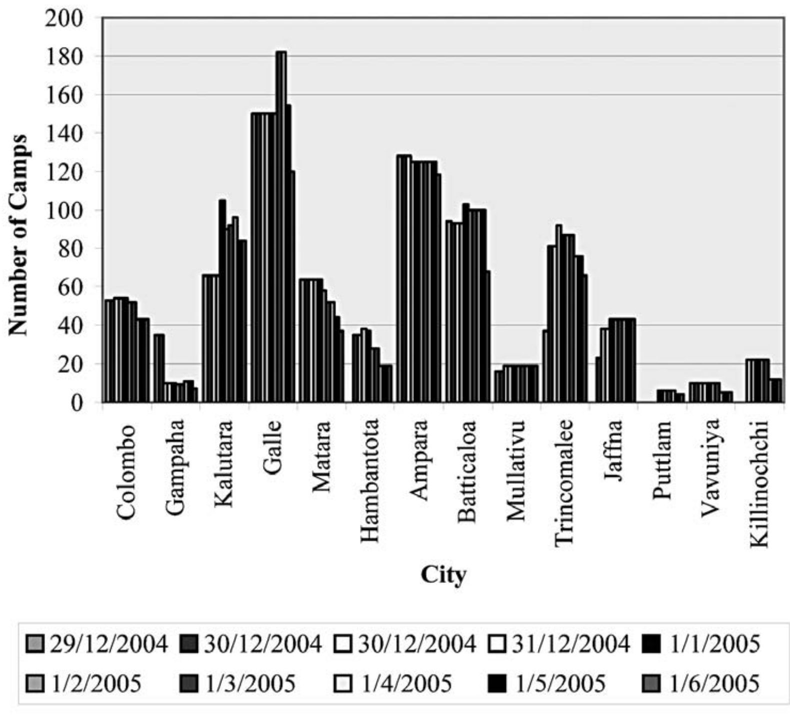


Figure 5: Number of camps in each city during the period from December 29 2004 to January 6 2005

distribution of food and other essential items to affected areas. Private individuals and organizations during the initial period distributed most of the relief supplies. For the displaced persons 53 camps were setup on the day of the disaster, which peaked to 835 on the 1st of January and has gradually reduced and reached the number of 273 by April. Figure 4 shows the variation of camps with time.

The majority of the refugee camps were set up in Galle which had the highest population of severely affected cities. Figure 5 shows the number of camps for each city during the first few days after the Tsunami.

Soon after the initial relief and rescue phase, the government announced a relief package consisting of (a) Rs. 15,000 per person for funeral expenses, (b) Rs. 2500 per person to purchase kitchen utensils, (c) a cast grant of Rs. 200 and (d) ration coupons worth Rs. 175 that can be used to purchase food, per person per week for a period of six months and a (e) Rs. 5,000 settlement allowance per family. The total value of this relief package amounts to about USD 108 million. For a family of 4 the above package excluding the support for funeral amounts to about USD 84 or about Rs. 8400 per month. This figure is considered sufficient to provide adequate nutrition. In fact the reason to make the aid package a combination of food and cash is to guarantee an adequate nutrition intake. Further, women usually prefer food aid rather than cash as the effectiveness of cash aid has proven to be less than that of in kind because of high incidence of alcoholism that also contribute to the poverty in the coastal areas.

Table 1: Shift of displaced persons from camps to live with friends and relatives

Province	District	07/01/2005 Displaced Persons In Welfare Centers	With Relatives and Friends	Total	No. of Camps	05/04/2005 Displaced Persons In Welfare Centers	With Relatives And Friends	Total	No. of Camps
Northern	Jaffna	n.a	n.a	n.a	43	7,625	33,381	41,006	12 **
	Killinochchi	11,985	37,016	49,001	11	0	1,603	1,603	0
	Mullaitivu	11,872	9,256	21,128	23	11,993	10,564	22,557	23
Eastern	Trincomalee	61,709	61,661	122,669	65	13,778	59,208	72,986	33
	Batticaloa	61,848	31,544	93,392	66	20,888	35,047	55,935	36
	Ampara	107,885	n.a	107,885	105	26,382	77,567	103,949	70
Southern	Hambantota	3,067	17,168	20,235	17	1,803	12,362	14,165	11
	Matara	11,181	n.a	11,181	37	3,087	6,406	9,493	22
	Galle	28,937	85,618	114,555	106	1,687	120,247	121,934	17
Western	Kalutara	17,160	5,248	22,408	79	2,306	32,641	34,947	10
	Colombo	14,965	n.a	14,965	43	5,446	30,614	36,060	26
	Gampaha	n.a	n.a	31,960	7	876	573	1,449	2
North Western	Puttlam	n.a	n.a	n.a	6	66		66	1
Total		330,609	247,511	578,120	608	95,937	420,213	516,150	263

The government also introduced a scheme of financial assistance to relatives or friends who would accommodate those displaced by the Tsunami until temporary and permanent housing are prepared. This was an effective measure as many displaced persons have found the cramped life in the tents to be difficult. Table 1 shows the distribution of displaced people who are staying with families and relatives, and those who are staying at the camps on the 07th of January and 05th of April. As can be seen, although the total number of displaced persons have not changed much during those four months, there is a marked shift in the distribution of them from the camps to among friends and relatives.

3. DISASTER LOSSES

3.1 Loss of life

The greatest damage from the December Tsunami was the immense loss of life along the coastal cities. The latest figures from the National Center for Disaster Management put the death toll at 31,229 with 4,600 people missing. The detailed distribution of deaths by province and cities are given in Table 2.

It is difficult to get a complete picture of the number of injured. The situation report for the of January 7 2005 by the NDMC, listed the number of injured persons as 16,760 according to the figures submitted by the provincial officials. The actual figure could very well be much above that number.

Table 2: Loss of life from the Tsunami (source: National Disaster Management Centre)

Province	District	Deaths	Missing
Northern	Jaffna	2,640	540
	Killinochchi	560	0
	Mullaitivu	3,000	421
Eastern	Trincomalee	1,078	45
	Batticaloa	2,975	340
	Ampara	10,436	161
Southern	Hambantota	4,500	1,341
	Matara	1,342	600
	Galle	4,330	564
Western	Kalutara	279	68
	Colombo	79	12
	Gampaha	6	5
North Western	Puttlam	4	3
Total		31,229	4,100

3.2 Affected

The Center for National Operations (CNO) statistics on the 20th of January 2005 has put the affected number of people as 1,095,880 which stands at 42% of the population of the affected administrative units. Nearly all the affected population (95%) is distributed in 56 administrative divisions in 12 districts along the coastal belt. Out of the affected areas, Western region, where the Capital Colombo is located, is relatively rich followed by south-west region which is a popular tourist destination. Southern, Eastern and Northern regions are poorer by comparison. East and North are especially vulnerable after prolonged ethnic conflicts that had 65,000 killed and over 800,000 displaced during the past two decades. Soon after the Tsunami, the World Food Programme (WFP) had carried out an immediate needs assessment survey with ILO supported by UNICEF and FAO. The survey covered 1863 households and 42 community key persons and has focused on livelihoods, food consumption, needs perception and others. The survey has reported the following findings. A large number of affected people, 35% of the total, depended on fishing as the primary occupation. In mid-January, this has dropped to 2%. Agriculture provided income for 9%, which dropped to 4%. About 35% of the population was engaged in the service sector which mainly comprised of tourism and retail trade. More than half of this group still had an income. Table 3 shows the summary of major livelihood distribution in the affected areas.

Table 3: Major livelihood changes after Tsunami

Sector	% Before Tsunami	% After Tsunami
Fishing	35	2
Services, tourism and retail	35	18
Agriculture	9	4
Charity/Govt. welfare	6	45

4. ECONOMIC LOSSES

4.1 Total damage

Soon after the Tsunami, a joint team of Asian Development Bank, Japan Bank for International Cooperation and the World Bank made a preliminary damage and needs assessment for the country during the period from January 10-28. Similarly, CNO has made damage estimates of the various sectors through direct consultations with officials in charge. The following is a summary of damage estimated through these studies and accessible sources.

The overall damage estimated varies from 1 billion direct asset losses and 0.33 billion in output losses (ADB/JBIC/World Bank) to around 1.8 billion USD (TAFREN). The total investment needs for reconstruction is estimated similarly between 1.6 billion (ADB/JBIC/World Bank) to 2.2 billion (TAFREN) USD. In terms of national GDP the economic losses translate to between 6-8%. The figures show that human suffering as well as economic damage inflicted by 2004 December Tsunami disaster is one of the highest in the world and the worst in the history of Sri Lanka.

4.2 Sectoral damage

4.2.1 Housing

Damage to buildings at Kinniya, Trincomalee was mainly due to foundation failure as the sands were washed away by the receding water. The water height varied here from about 3 m to less than a meter at the coast. However, extensive damage to houses could be seen due to foundation failure.

The statistical department of the government of Sri Lanka has recently completed a survey on the residential and non-residential structures. According to the survey made available on May 2005, 5900 non-residential buildings were completely or severely damaged while 5125 non-residential buildings are considered as partially damaged. Of the residential buildings about 50,000 are either completely damaged for heavily damaged and needs to be replaced. Around 38,500 houses are partially damaged and may be repaired and used. Table 4 outlines the damage to residential buildings in the affected areas. Considering the current sub-standard housing and the damage caused to the existing housing the government has announced the intention to construct construction of 100,000 permanent houses for affected population. While the permanent housing construction is expected to take about 1.5 - 2 years, 20,000 temporary housing units will be constructed to supplement the existing camps and other temporary shelters. The annual new housing construction in Sri Lanka is between 4000 - 5000 units. The construction target of more than 20 times of that amount requires careful planning to avoid scarcity of raw materials and skilled labour.

Table 4: Damage to residential buildings

District	Completely damaged	Partially damaged	Total damaged houses	Damaged but can be used
Galle	4,482	1,687	6,169	6,040
Matara	1,667	734	2,401	3,837
Hambantota	1,076	275	1,351	1,094
Southern Province (total of above)	**7,225**	**2,696**	**9,921**	**10,971**
Colombo	2,824	573	3,397	2,948
Gampaha	227	97	324	530
Kalutara	2,056	615	2,671	3,070
Western Province (total of above)	**5,107**	**1,285**	**6,392**	**6,548**
Puttalam	11	16	27	27
NorthWestern Province(total of above)	**11**	**16**	**27**	**27**
Ampara	8,139	2,427	10,566	8,244
Batticaloa	7,445	2,460	9,905	7,500
Trincomalee	3,893	750	4,643	2,888
Eastern province (total of above)	**19,477**	**5,637**	**25,114**	**18,632**
Jaffna	3,369	317	3,686	1,829
Mullaitivu	4,428	709	5,137	554
Northern Province (total of above)	**7,797**	**1,026**	**8,823**	**2,383**
Total	**39,617**	**10,660**	**50,277**	**38,561**

Nothing remains in this once dense residence area of Hambantota, now occupied by camps for displaced persons.

For the reconstruction, the government has adopted the following policy guidelines.

- All families within 100m and 200m Coastal Zone whose houses have been completely damaged will be provided with safe houses outside the Conservation Zone by the Government.

- Those who are willing to construct their own houses outside 100m and 200m zone on their lands will be paid Rs 250,000 financial assistance and if necessary concessionary loans by state banks.

- Those who are willing to construct their own houses outside 100m and 200m zone will be provided with lands (04 to 10 perches depending on the availability of land), financial assistances and if necessary concessionary loans by State Banks.

- Minimum size of a house will be 500sq.ft. which will cost about Rs.400,000. These houses will be provided with all the basic infrastructure facilities such as access road, water, electricity, sewerage etc.

- All housing will be planned as Settlements. Play grounds, Recreation Areas, Commercial facilities and other basic services will be provided.

The following types of houses are recommended:

- Single story detached houses on individual land plots.
- Single story attached houses with individual gardens.
- Two storied attached terraced houses with individual gardens - Town Houses.
- Multi story (Ground + 02 or 03) Walk-up Apartments

The construction density guide lines for each type of houses are shown in Table 5.

Table 5: Recommended housing types and density

3 Type of Houses Recommended	Maximum Density Per Acre
Single story detached houses on Individual land plots	4P Land Lot – 28 6P Land Lot – 18 8P Land Lot – 14 10P Land Lot - 11
Single Story attached house with individual gardens	28
Two story attached terraced Houses with individual gardens –Town houses	37
Multy story Walk-up Apartments	
Ground + 02	50
Ground + 03	60

4.2.2 Fishery

Nearly 60% of the country's fishing boats and gear were destroyed in the Tsunami

Approximately 200,000 fishermen and 50,000 people employed in the sector make their livelihood from fishing in Sri Lanka. The fishing fleet is approximately estimated at 29,500 boats. Due to the Tsunami, about 7500 fishermen have lost their lives and around 18,100 boats have been destroyed and a further 4,200 damaged. In addition to the boats fishing gear such as nets, out board motors, ice storages were heavily damaged. Marine structures including equipment at harbours were destroyed. The total damage to the sector is estimated at around USD 100 million.

A Boat repair facility set up by a Norweigian group had their hands full.

4.2.3 Agriculture

The agriculture sector has not suffered as heavily as the other sectors. Mainly the paddy and other crop fields along the coastal belt were destroyed. A total of about 2300 ha of paddy land, 590 ha of other crops 470 ha of vegetable cultivation and 200 ha of fruit crops were reported as destroyed. No large scale livestock farming was carried out along the coastal area, but the small number of animals owned by many of the poor families along the coastal belt constituted a significant asset of each family. The heavy salinity caused by the tsunami was a significant concern as it was not clear how long it would take to naturally flush away the salinity by the rain. However, recent heavy rains have indicated that this would not be a major problem. Considerable amount of salinity has been already flushed away. The damage to the sector is estimated to be around USD 3 million.

4.2.4 Water Supplies and sanitation

A large number of wells had to be abandoned either due to damage from the Tsunami waves or from salt-water intrusion. More than 50,000 wells were estimated as abandoned. In addition, salt water intrusion into coastal aquifers, through wells, or from inland pond, flushing by rainwater, etc., has made long term impacts on the water supplies to the coastal region. Of the water supply systems, the major damage was to the coastal pipe lines for central water supply systems. Almost all damaged houses have lost individual latrines. Of major infrastructure, a pump house at a sewerage plant near Colombo sustained damage. Government is planning immediate rehabilitation of pipe borne water supply to all Tsunami hit areas and comprehensive water and sanitation development plan for the coastal belt affected by Tsunami.

4.2.5 Roads Sector

Roads adjacent to water courses have sustained heavy damage. (Source: CNO)

Roads in Sri Lanka are classified as National (Class A and B), Provincial (Class C, D and E) and Local Government roads. Approximately 690 km, 700 km and 1100 km of roads of each class have been damaged. This represents 5% of national roads, and 2% of provincial and local government roads. Major damages were inflicted on coastal bridges(Figure 6). The total damage has been estimated as about USD210 million for the road sector, that includes an estimate of 120 million USD for the road reconstruction.

Figure 6: Almost all the bridges along the coast line water course have been damaged by the Tsunami. Temporary works have been done and the bridges made passable within a few days by the government organizations. (Source: CNO)

4.2.6 Health

Health sector in the Tsunami affected area was under severe pressure to provide support for this unprecedented disaster with its facilities damaged and many of the sector personnel killed by the Tsunami. A total of 72 hospitals 149 peripheral units and 363 other units such as Dental, Child Clinics and Central dispensaries, were damaged. The estimated damage to the sector was USD100 million. With the support of donor agencies and countries more than 80% of the rehabilitation work has commenced.

4.2.7 Education

Table 6: Summary of Damage to Schools by Tsunami (Source: CNO)

No	District & Zone	Total No of		Number of Schools			Estimated Cost (Rs.Mn.)	No of Students In Affected Schools	No of Teachers in Affected Schools
		Schools	Students	Totally Destroyed	Partially Damaged	Total			
1	**Hambantota**	311	129,874	1	5	6	34	5,510	224
2	**Matara**	375	165,411	5	6	11	118	7,843	448
3	**Galle**	435	217,136	10	13	23	175	13,898	611
4	**Kalutara**	415	192,052	2	4	6	24.25	6,987	260
5	**Gampaha**	537	319,485	-	2	2	5	2,987	103
6	**Batticaloa**	314	117,197	15	18	33	202	11,514	462
	Batticaloa Zone			4	9	13	-		
	Paddirippu Zone			7	4	11	-		
	Kalkuda Zone			4	5	9	-		
7	**Ampara**	388	153,408	14	24	38	211	17,927	680
	Kalmunai Zone			4	11	15	-		
	Akkaraipattu Zone			10	13	23	-		
8	**Trincomalee**	259	94,236	5	14	19	106	4,089	167
	Trincomalee Zone			-	4	4	-		
	Muthur Zone			3	10	13	-		
	Kantalai Zone			2	0	2	-		
9	**Mullaitivu**	102	26,965	0	11	11		3,249	109
	Mullaitivu Zone			-	11	11	90.5		
10	**Jaffna**	411	134,960	7	5	12	-	2,907	109
	Vadamarchchi Zone			7	5	12	165.5		
Total		**3,547**	**1,551,324**	**59**	**102**	**161**	**1131.25**	**76,911**	**3,172**

The Tsunami has damaged 161 schools, affecting 80,000 students and over 3,000 teachers. Additionally, 4 universities and 18 vocational training and industrial training centers were affected. The details of damage to schools is given in Table 6 which shows the biggest impact was on the East coast with Amparai (38 schools) district suffering the most followed by the Batticalo (33 schools) and Trincomalee (27 schools). About 91 schools, which are located too close to the sea will be relocated to inland high ground. The damage to the sector is estimated as about US$ 26 million.

4.2.8 Environment

Most of the significant environment impacts are expected to be marine related such as for the Coral reefs and the marine eco systems. Inland, the major hazard is the salt-water contamination of shallow aquifers that would take quire some time to recover, rendering most of the dug wells unusable. There are number of methodologies that can be used to flush out the saline water from the shallow aquifers. However, as the government has already adopted a plan for pipe borne water supply in the coastal area, it may not be required to embark on such schemes.

The areas protected by sand dunes and vegetation had little impact from the Tsunami. Based on that, a number of programs have been proposed to establish such protection through out the coastal belt. However, several breaches of such protection works were also witnessed, especially around weakened points such as openings for drainage, leading to extensive damage around those areas. Therefore, maintenance of these works must be taken into consideration prior to embarking on constructing them.

4.2.9 Railway

Table 7: Damage to railway sector (Source: CNO)

Damaged Railway Facilities	Amount
Railwaystation	34
Sub-station	34
Reinforced concrete Railway bridge	2
Steel Railway bridge	8
Rail track (km)	160
Employee Houses & relay houses	32
Locomotives	4
Caterpillar engines	2
MTU (canadian) Engines	2
Power stes	3
Coaches	50

The southern bound railway line, which transfers 78,000 passengers daily, and transfer cargo from Colombo to Galle and Matara had been severely affected. The reconstruction is being carried out locally and the line is expected to resume operations within the year. The Eastern railway belt has not been affected severely and has resumed operations. The total damage to the railways estimated by TAFREN is USD 497 million.

4.2.10 Power

The power sector sustained damages around USD 67 million, mainly to transmission lines and distribution systems. All power lines have now been restored. The main damages were due to loss of supply wires and meters, which stood at 62,540 units at the initial estimate. This was followed by significant losses in LT lines amounting to 390 km and HT lines of 42 km.

4.2.11 Telecommunication

The total damage to this sector is estimated at USD 18 million. The bulk of the losses were to the main career, Sri Lanka Telecom which suffered about 84.6% of the total lost, followed by the operators, Suntel (7.2%), Mobitel (4.2%) and MTN (3.98%). The main damage to the Sri Lanka Telecom was from the damage to exchange facilities located in Southern, Eastern and North - Eastern coastal cities.

5. PHYSICAL CHARACTERISTICS OF TSUNAMI INUNDATION

5.1 Inundation and Run-up at Galle

Soon after the Tsunami, United Nations University has coordinated a field survey in Sri Lanka carried out by 3 international and 15 Sri Lankan teams to map the building damage, inundation and the run up in three coastal areas. The objectives of the survey was to

- To carry out a rapid reconnaissance survey to prepared a basic hazard map to assist the medium and long term reconstruction process
- Understand the Tsunami mechanism and impacts

The survey was carried out in the towns of Galle, Hambantota and Trincomalee located in South and North Eastern provinces of Sri Lanka as shown in Figure 7. Primary data collected were the elevation data prepared by compilation of existing elevation information improved with Kinematic GPS improvements, followed by building damage estimation and the wave run-up and inundation information. Following data were collected during the field survey.

Elevation Data: Kinematic GPS were used to collect high resolution data points to generate DEMs for the three cities. Additionally Total Station surveys were performed to improve coastal area data improvement. Existing 1:5000 Survey Department digital data were assimilated to the new data.

Other existing elevation maps were digitized and converted to elevation data points to enhance the existing datasets.

Land use data: sets were created from existing digital data of 1:5000 maps and additional information obtained from Satellite Images.

Wave Load: Structural damages were analyzed for over 80 buildings or wave heights structural components to derive relationship between wave impacts and Building Damage.

Building Damage: Kinematic GPS surveys were conducted to record the degree of damage to buildings. The information consisted of location, level of damage (completely destroyed, heavy damage, moderate damage, slight damage), construction material (buildings were classified up to 10 types) orientation, foundation failure, number of floors.

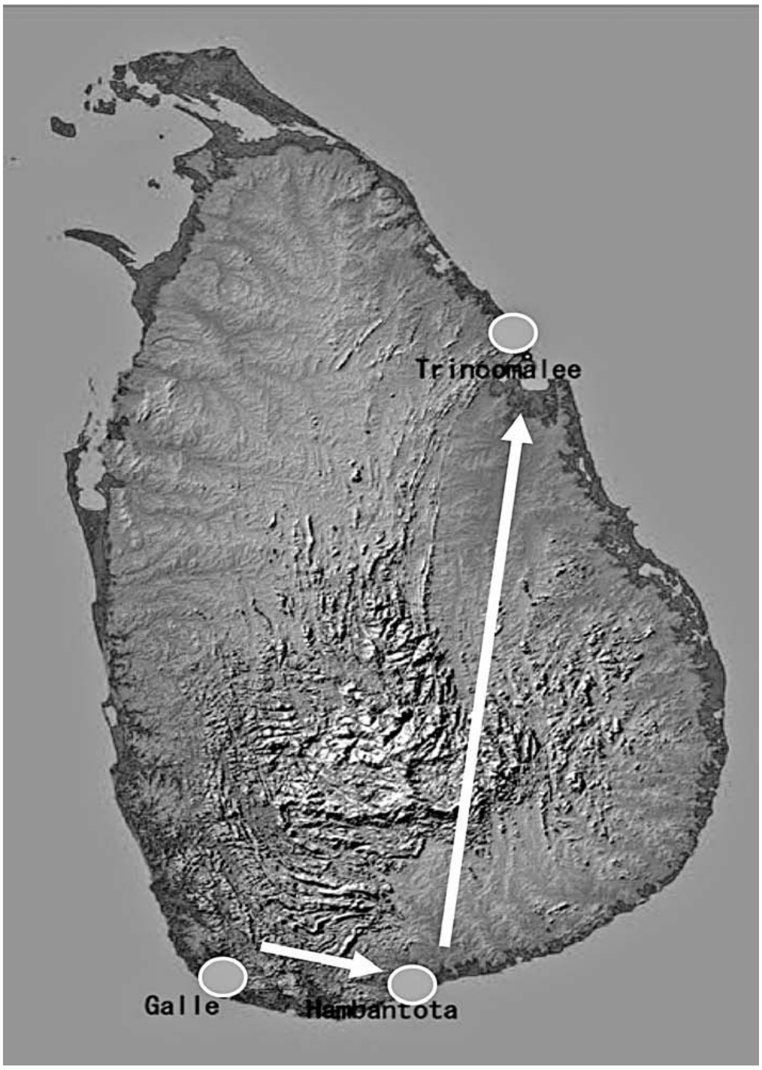


Figure 7: The cities where field surveys had been conducted

Figure 8: The Land use map of GALLE at 5 m grid resolution with inundation distance shown in blue circle

Figure 8 shows the land use map of Galle City overlain by the inundation map measured on field. The Blue circles show locations Tsunami has reached. The maximum distances in Galle were about 800m.

The Figure 9 shows the 3-D view of the Galle city with inundated area draped in blue colour. The effect of topography on the inundation distance is clearly shown in the figure.

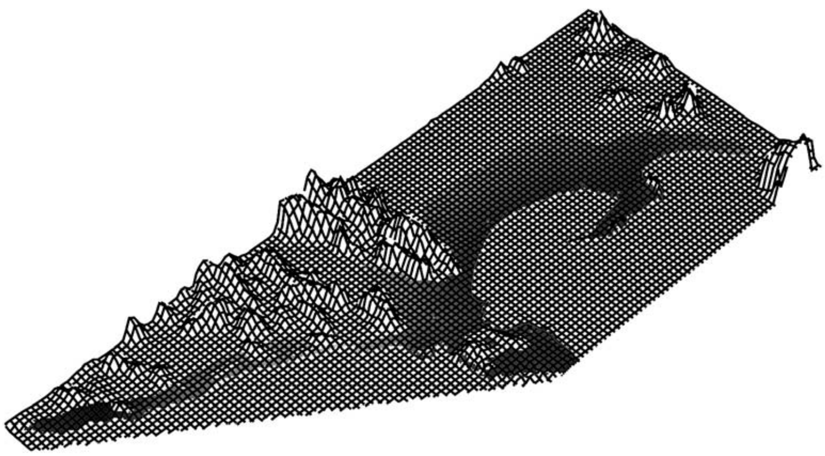


Figure 9 Inundation map of Galle City, overlaid on DEM with land use features.

5.2 Inundation at Hambantota

Figure 10 shows the 3D view of the Hambantota City with the distribution of buildings. As can be seen from the figure part of the city is located on the high ground to the west side and extends to the low lying area between the lagoon and the sea to the salt mines. Sand dunes around 4-5 m height and a thick vegetation belt on it provide a natural protection to the

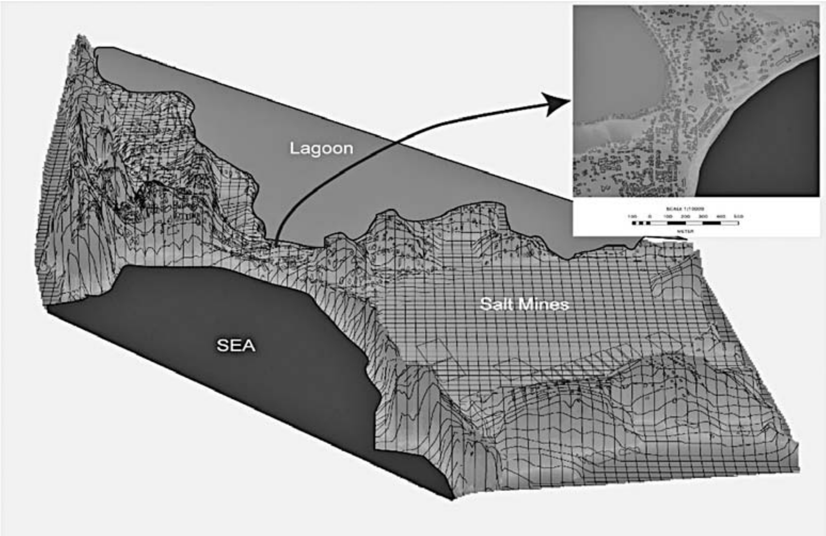


Figure 10: Both left and right side of Hambantota city is protected by sand dunes and a vegetation belt. The most vulnerable location, strip of land between the sea and the lagoon was the worst affected.

area except for the narrow strip between the sea and the lagoon which had been highly populated. The survivors explained the experiences on that fateful day and many in general agreed on the sequence of events. The first wave had taken all by surprise, and many were in the Sunday market on the high ground towards the western side. The water height was about 0.5 m in the lower valley portion of the city. As it was receding, the second wave started to come in. Unlike the first wave, the second wave had kept on rising,

A sand dune and thick vegetation protected much of the area along the coast of Hambantota city. However, it had breached in some locations as in the next photo.

The protective sand dune was breached here. A cutting to pump out water from the lagoon seen behind the vehicles gave way and a large stretch of sand dune and the protective vegetation was washed away.

soon surpassing the height of the buildings. It is most likely that the first wave has provided a smooth surface for the second wave to ride and connect to the lagoon on the other side of the landmass. The funnelling effect of the Tsunami according to the shape of the location, coupled with the restraining effect of the sand dune and vegetation layer must have concentrated the wave to the opening at the valley where it grew to a giant wave that demolished every thing that stood in its way. The sand dune and vegetation has provided protection to most parts of the coastal area in Hambantota but had been breaching of the sand dunes where it was weakened due to drainage lines.

6. RECOVERY AND RECONSTRUCTION

The Tsunami disaster in Sri Lanka is not only unprecedented in the history of Sri Lanka, it is also one of the biggest disaster to affect a country. As mentioned before the economic damage estimated to be between 6-8% of GNP put this disaster among the worst disasters in the world. In addition, the death toll of over 1800 per 1 million of population puts the human losses at the very high impact category. About 1 million of the population has been affected and an estimated 450,000 have lost their livelihoods.

Figure 11 shows the household income distribution obtained by the WFP-ILO survey mentioned in the opening section. According to these data about 80% of the population spends less than Rs. 100,000.00 (USD 100) a month, which is less than a dollar per day per person for a family of 5 members. The official poverty line is about Rs. 1500 per person / month, which is required to ensure required nutritional intake, which would translate to a Rs. 7500 /month for a family of four. Most of the

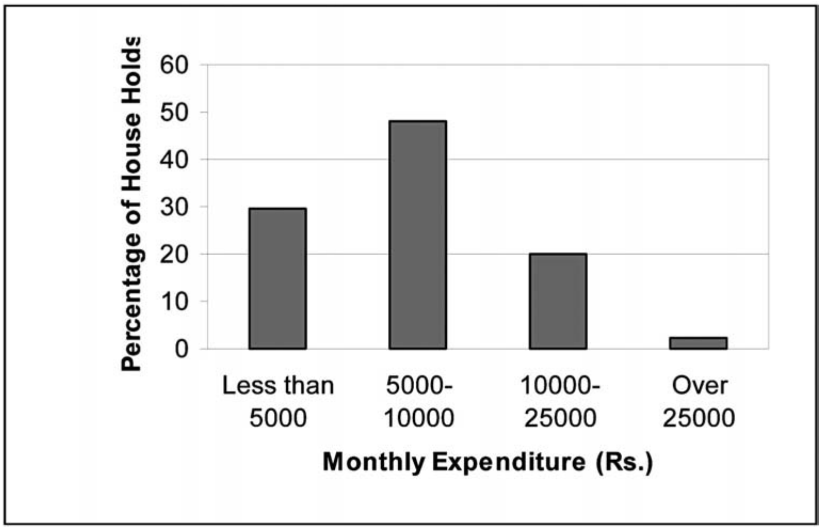


Figure 11: Income of affected people (source: Survey of WFP)

coastal areas were poor even before the Tsunami. 30% of the population spent only Rs. 5000 / month which put the family members below poverty line. The cost of food is relatively high in Sri Lanka, and people spent a large fraction of their income on food. The survey also found that about 30% of the population spent more than 75% of their income on food. The low earning and high food costs can easily lead to under nourishment and to safeguard against such situations, current support package of the government for the displace persons include cash support as well as food stamps which can only be used to purchase food items. Due to the general poverty of the region, there is very little resilience and economic surplus in the region and government support and leadership is essential for the recovery of the affected communities.

There are several issues the government has to respond immediately and effectively. Providing houses has the priority among the issues as it bring back the families together and provide opportunity for them to start their livelihoods. There are two basic problems in building new houses for those who lost their houses. On the average 4000-5000 new housing units are built annually in Sri Lanka. The need to build 100,000 new houses within a span of 1-2 years puts heavy pressure on construction materials and technicians required for the job. Acquisition of land has become a major problem. After the Tsunami the government has declared a 100m no construction zone in the West and Southern regions and a 200 m free zone in the East. However, there had been severe opposition to this zoning by many fishermen as well as the main opposition party. To implement the zoning, it was necessary for the government to obtain land from inland areas to move the current residents who had their houses very close to the sea falling within the no-construction zones. This has proved to be a slow process where available land and people's requirements have to be matched.

However, the major challenge for the government is to reduce poverty in the affected areas through the reconstruction process. Given the very high percentage of population living close to or below poverty line, the reconstruction strategies should be geared towards poverty alleviation. For example, multi-purpose safety centres which can be used as evacuation centres in a future tsunami or other disasters can act as community and social development centres during the normal times providing training and education to enhance income generating capacity to the residents. Similarly redevelopment of roads and other infrastructure should be geared for the economic development of the poor.

7. TOWARDS A SAFER FUTURE

The Tsunami disaster has shown the need to overhaul Sri Lanka's institutional structure for preparedness against natural disasters. Currently Sri Lanka has a National Disaster Management Center, under the Ministry of Social Welfare and Women Empowerment. NDMC has drafted a national act, which had not been ratified in the parliament until the Tsunami. After the Tsunami the national disaster mitigation plan has been adopted and it is expected the necessary institutional framework could be established soon. At present it is difficult for Sri Lanka to have a strong program for disaster reduction due to several reasons. On one hand the relevant organization having the expertise and capacity to deal with natural disasters are distributed across several ministries and the absence of a framework make it difficult to develop a unified approach against natural disasters. Secondly, the natural disasters faced by Sri Lanka makes it necessary to have a multi-disciplinary team with very high technical capability to make dedicated efforts to strengthen the preventive capacity, especially early warning capacity, against natural disasters. The reason for this becomes clear if an analysis is made of recent major natural disasters in Sri Lanka. In 1992, there had been an exceptionally high rain (estimated as 1:1000 yr return period) that caused flooding in Colombo, which lasted for more than 10 days due to inadequate drainage. The extraordinary rainfall has been confined to Colombo city, but if it had extended over to the Kelani River catchment area, and a breach of the River embankment could have made catastrophic losses in the capital. Recently, in 2003, May 11-19, a tropical storm caused 247 deaths, the displacement of 200,000 persons, and heavy damage to the infrastructure, economy and livelihoods of the South-Western Sri Lanka. The main cause of the deaths was the landslides in the central and southern parts of the country Sri Lanka, triggered by the heavy rainfall. In the past, there had not been a historical record of a cyclone in May in Sri Lanka. It was also rare that a cyclonic storm whose centre was 700-1500 km away and which was relatively weak could cause such damage.

Sri Lanka faces few regular recurrent disasters. Its major losses are from extreme events for which people are not prepared and hence "Preparing for the Unforeseen" is the challenge for disaster management in Sri Lanka. The developments in Science and Technology in disaster management should be fully utilized for this task. A high level coordinating organization where officers from various departments can come and work together for a few years on disaster related themes to develop national monitoring, forecasting and warning capacities should be established. A sustained effort in these technologies would be beneficial not only for preparing for the extreme cases but also for the day to day management of environment and natural resources.

PROPOSAL OF A SUSTAINABLE TSUNAMI DISASTER MITIGATION SYSTEM FOR THE INDIAN OCEAN REGION

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ABSTRACT

Triggered by a M9.0 earthquake that occurred along the Sunda Trench, Off-Sumatra, at 07:58 (local time), on December 26, 2004, a huge and devastating tsunami hit the Indian Ocean Rim countries, causing unprecedented disaster with over 300,000 dead and missing persons. The analysis of other potential tsunami scenarios in the region has revealed that 1.3 million dead and missing people may be expected, at worst. Therefore, an effective and sustainable framework against tsunami disaster is indispensable in this region.

Land use control, i.e. preventing people from residing next to the shore, is one way to mitigate tsunami disaster if people follow it. However, this is not always a proper option in the Indian Ocean Rim region where the economic activities, e.g. fishing, tourism, take place directly next to the seaside. For this case, a New Tsunami Disaster Mitigation System by combining a reliable warning system and proper evacuation facilities is proposed. Important characteristics of this system are its simplicity, economical efficiency and daily-usability.

This paper introduces the New Tsunami Disaster Mitigation System, highlighting its strengths and the works necessary for its implementation.

1. INTRODUCTION

Triggered by the M9.0 Earthquake that occurred along the Sunda Trench, Off-Sumatra, at 07:58 (local time), on December 26, 2004, a huge and devastating tsunami hit the Indian Ocean Rim countries, causing unprecedented disaster with over 300,000 dead and missing persons. The tsunami was triggered by one of the possible earthquake scenarios along the Sunda Trench. Four other potential earthquake events along the trench have been identified and the expected number of casualties in case they occur has been estimated. As a result, it was revealed that 1.3 million dead and missing people are expected, at worst, as shown in Figure 1. This number is several times larger than the observed in the December 26, 2004 event, showing that an effective and sustainable framework against tsunami disaster is indispensable in this region.

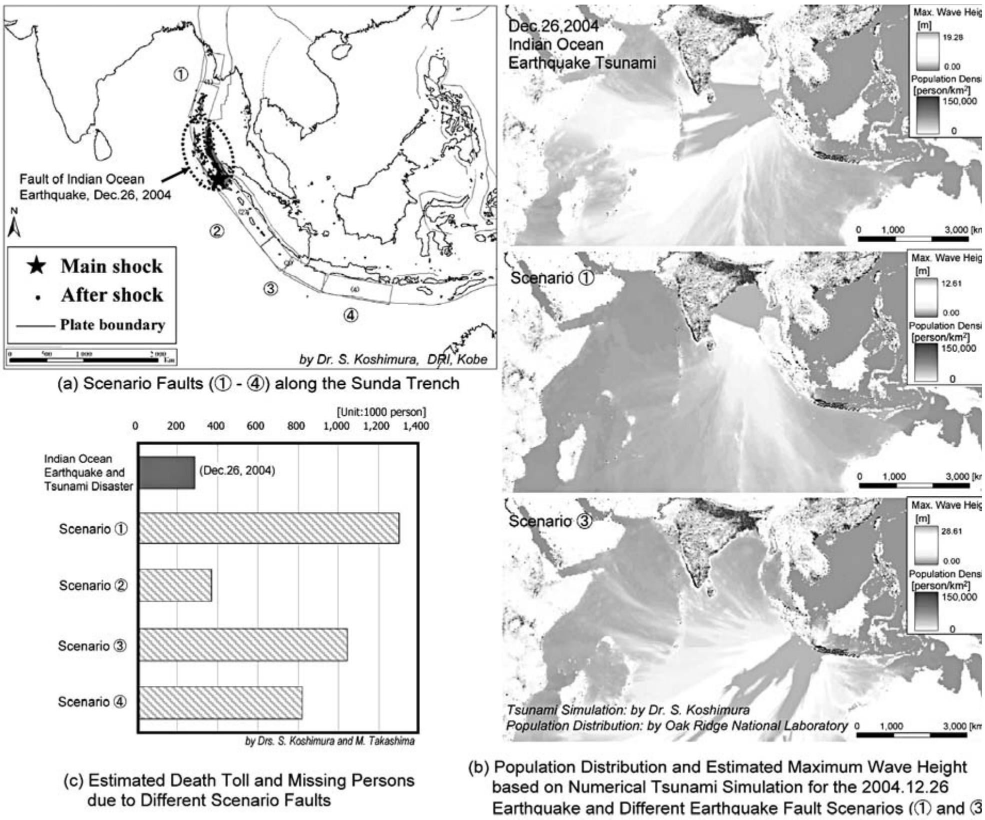

Figure 1: Estimated damage based on numerical tsunami simulation with possible fault scenarios along the Sunda Trench

Some countries along the Indian Ocean Rim have established a tsunami disaster mitigation system based on land use, i.e. prohibiting people inhabiting next to the seaside. Others are planning to adopt similar measures. Land use control is an efficient measure if people follow it. However, this is not always a proper option in case activities such as fishing and tourism, which are the pillars of the region economy, take place directly next to the shore. Under these conditions, it is inapplicable to implement land use control policies.

In the Pacific Ocean Rim region, tsunami disaster mitigation relies on a sophisticated warning system, which is used not only for disaster mitigation but also for earth science research. This system is costly in terms of both installation and maintenance. Furthermore, it requires a great deal of knowledge to operate it. Although it is very useful and appropriate for this area, where countries with financial and technological resources such as US and Japan are located, it is not applicable for the Indian Ocean region (Figure 2).

Taking the above mentioned points into consideration, a New Tsunami Disaster Mitigation System which combines a warning system suitable for the Indian Ocean region and proper evacuation facilities in terms of location, strength and sheltering capacity is proposed. With this system there is no need to relocate the people living along the seashore; therefore, there is no impact on the local economies. The proposed system is simple, economically efficient and daily-usable.

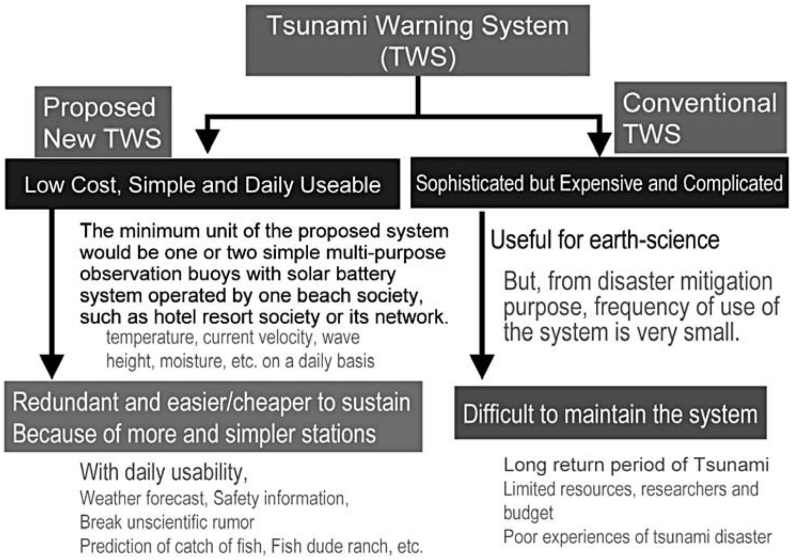

Figure 2: Comparison between conventional and newly proposed tsunami warning systems

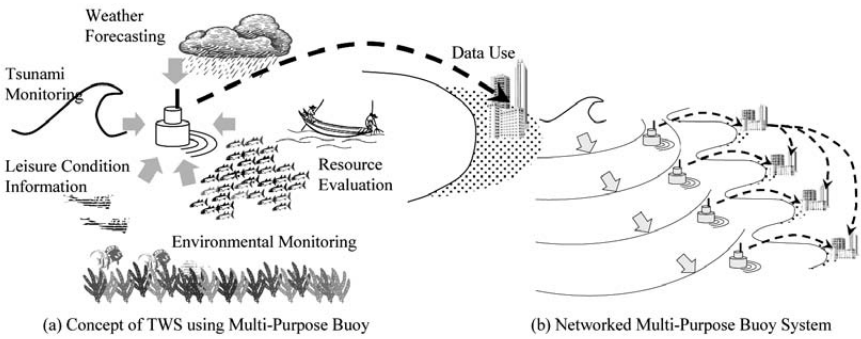

Figure 3: Concept of proposed tsunami warning system composed of networked simple multi-purposes observation buoys installed locally and internationally

2. PROPOSAL OF THE NEW TSUNAMI DISASTER MITIGATION SYSTEM

Our proposed New Tsunami Disaster Mitigation System combines a reliable warning system and proper evacuation facilities. As mentioned earlier, a warning system such as the one available in the Pacific Ocean Rim region is not suitable for the Indian Ocean region which has fewer technological resources, researchers and experiences of tsunami disasters. For this reason, We are proposing to use simple multi-purpose observation buoys, which in addition to serve as a tsunami warning system, would record temperature, current velocity, wave height, moisture, etc. on a daily basis. This information can be used for weather forecasting, safety assessment, fish catch prediction, etc. which are useful for the local businesses (Figure 3(a)). Our proposal is to use numerous and simple stations so that the system is redundant and easier/cheaper to sustain. The minimum unit of the proposed system would be one or two multi-purpose observation buoys operated and maintained by hotels/resorts or beach societies in the area. These businesses will benefit from the daily collected information.

It is expected that many beach societies install the system and join the multi-purpose observation buoy network beyond the administrative or international boundaries (Figure 3(b)). In this way, it may be possible to gather daily maritime information over a wider area and eventually forecast a transoceanic tsunami. A system for transferring this information between associations, domestic and foreign, already exists.

The installation of the proposed buoy system could have additional advantages. After the December 26, 2004 tsunami, the tourism industry has suffered greatly not only due to direct impact of the tsunami in the infrastructure but also due to the unscientific rumors. Visitors that used to come to resort facilities in the region started avoiding these destinations for fear that a new disaster may occur. In order to recover the tourists' trust, the information collected by the buoy system can be very useful. It is also known that buoys may become the center of marine ecosystems which could be an attraction for scuba divers.

Proper evacuation facilities in terms of location, strength and sheltering capacity are also part of the proposed system. In the region, it is common to observe temples, churches and shrines located along the coastal line. Therefore, We are proposing to use similar community centers as evacuation facilities. This scheme has two main advantages. Because worship centers are permanently used by the people, their location is well known so that in case an evacuation notice is released, everybody can easily access them. Additionally, because the people feel strong commitment with these facilities, they take active participation in their building and maintenance.

3. ESTABLISHMENT OF THE PROPOSED TSUNAMI DISASTER MITIGATION SYSTEM

In order to establish the proposed system, several works are needed as shown in Figure 4 and the reconnaissance team, which One the authors, Prof. Meguro, headed, carried out them.

1) Structural damage survey
2) Tsunami numerical simulation
3) Topographical survey
4) Questionnaire/Interview survey
5) Evacuation numerical simulation

The first three activities are closely interrelated and their main objective is to design the configuration and location of evacuation centers. The structural damage survey is intended to evaluate the tsunami load and corresponding damage. With this information, the relationship between tsunami wave load and wave height/velocity can be obtained. With tsunami numerical simulations using potential earthquake scenarios, it is possible to estimate the wave height and velocity and the tsunami inundation area due to future tsunami hazards. These data enable us to properly determine location and structural design criteria for evacuation facilities.

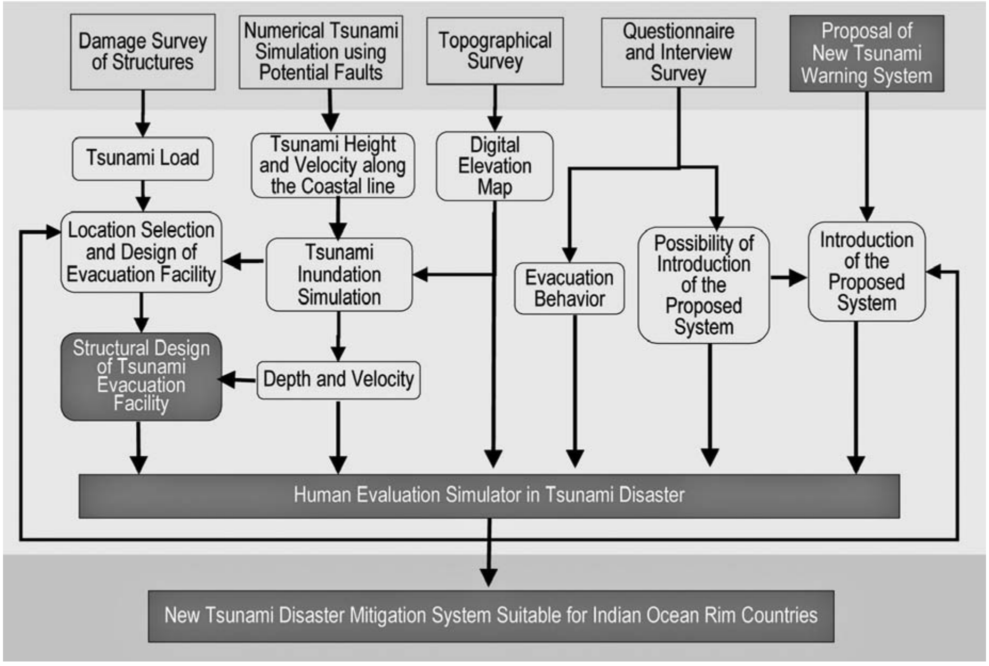

Figure 4: Establishment of the proposed tsunami disaster mitigation system

In order to guaranty that the evacuation centers are fully functional, their location should be selected so that when the expected tsunami occurs they will not be washed away. For this purpose, it is indispensable to carry out a topographical survey. Real-time kinematic GPS and laser total stations are powerful tools for this purpose.

Questionnaire and interview surveys are useful to gather data necessary for the evacuation behavior simulation. Relationships between human evacuation velocity and water depth, which are needed for this study, have already been proposed. The simulation will confirm whether the escape routes and proposed evacuation centers are suitable. Because the proposed tsunami disaster mitigation system heavily relies on the participation of regional organizations, the interviews are also helpful to assess the level of acceptance of the system among the people involved.

4. CONCLUDING REMARKS

This paper presents a New Tsunami Disaster Mitigation System for the Indian Ocean Rim region, which combines a reliable warning system and proper evacuation facilities. The warning system consists of multi-purpose observation buoys operated by local organizations such as hotels and beach associations. The system is not only used for tsunami warning but also to monitor temperature, current velocity, wave height, moisture, etc., information which can be used on a daily basis for the economic activities of the region.

The proposed evacuation facilities are designed taking into consideration: sheltering capacity, location, and structural strength. Location is especially important to prevent that the structures are washed away by the tsunami and to guaranty an easy access for the evacuees.

In order to verify the suitability of the proposed system, tsunami and evacuation simulations are recommended. Actually, the research team headed by one of the authors, Prof. Meguro, has already perform this type of study with some selected areas in Japan and Sri Lanka and proved the system effectiveness. The strong points of the proposed system are its simplicity, economy and daily usability, which makes it a sustainable option for the region.