Estimating the Recurrence Interval and Behavior of Tsunamis in the Indian Ocean via a Survey of Tsunami-related Sedimentation

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ISDR

NIED
National Research Institute for Earth Science and Disaster Prevention

Greetings

On behalf of the host organization, we are delighted to hold this symposium titled "Estimating the Recurrence Interval and Behavior of Tsunamis in the Indian Ocean via a Survey of Tsunami-related Sedimentation."

The project upon which this symposium is based was sponsored by the United Nations Secretariat of the International Strategy for Disaster Reduction (UN/ISDR).

In collaboration with many domestic and international institutions, we conducted a survey of tsunami-related sedimentation around the Indian Ocean and estimated the recurrence interval and characteristics of tsunami events in the region.

In addition to yielding valuable research results, the project has enabled the transfer to related researchers of the methodologies and techniques employed in sedimentation surveys.

This symposium focuses on historical and pre-historical tsunamis associated with earthquakes in the Indian Ocean, as well as mitigation strategies for tsunami disasters, and tsunami warning systems.

We hope that the outputs of this project will help to improve the effectiveness of mitigate strategies against future tsunami-related disasters in those countries bordering the Indian Ocean.

Finally, I must convey the sad news that Dr. Iwasaki, the head researcher of this project, passed away last November. We never imagined that this symposium would serve as a memorial for our dear friend and colleague. We would like you to join us in wishing him eternal peace.

Yoshimitsu Okada
President
Independent Administrative Institution
National Research Institute for Earth Science and Disaster Prevention (NIED)
Japan

In memory of Sin-iti Iwasaki

Sin-iti Iwasaki passed away on 6 November 2008 at the age of 55 years.

He was a leader of the project titled “Estimating Tsunami Periods and its Behavior in the Indian Ocean Through Tsunami Sedimentation Survey,” having established the project plan and assembled a team of experts. After agreement regarding the project had been reached between the United Nations Secretariat of the International Strategy for Disaster Reduction (UN/ISDR) and the National Research Institute for Earth Science and Disaster Prevention (NIED), he fell ill. We prayed for his health at this time; however, he passed away. This project remains his final work.

Wednesday 18 March

-Opening Remark

Yoshimitsu Okada (President, NIED)

-Keynote Speech

-Tsunami in Indonesia

Thursday 19 March

-Tsunami in Sri Lanka

-Tsunami in Thailand

-Tsunami Disaster Mitigation

18 March 2009

Forecasting Future Earthquakes from Tsunami Deposits and Simulation

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Abstract

Forecasting location, time and size of earthquakes requires information on recurrence history of past earthquakes, from which probably of future earthquakes can be calculated. For earthquakes with long recurrence intervals, geological data such as tsunami deposits are essential to estimate the earthquake history. Recent studies indicate gigantic earthquakes repeat at several hundred years interval in the subduction zones in the world, including the source region of the 2004 Sumatra-Andaman earthquake. Past earthquake source can be modeled by an inverse approach, such as a comparison of tsunami deposit distribution and simulated inundation area. Future tsunami hazard can be estimated by a probabilistic approach.

Key words : giant earthquake, tsunami deposit, tsunami numerical simulation, probabilistic forecast, paleoseismology.

1. Earthquake recurrence and forecast

Most tsunamis are generated by large submarine earthquakes, which repeatedly occur at plate boundaries and cause damage from ground shaking as well as tsunamis. Because they repeat, future occurrence can be forecasted from past records. When a cyclic nature of past earthquakes is known, it can be used to calculate the probability of future earthquake occurrence. The time interval between successive earthquakes can be treated as a variable for a probability density function. The Brownian passage-time (BPT) distribution has been recently used, because it models steady tectonic loading plus Brownian perturbation[1]. The probability of next earthquake in the specific time window can be computed if the average recurrence interval and the date of the most recent event, as well as aperiodicity parameter, or variation coefficient, are known.

Probabilistic earthquake forecast had some success in Japan. In March 2003, the Japanese government made a long-term forecast for great (M~8) earthquakes along the Kuril trench. They estimated that the probability in the next 30 years (starting March 2003) was 60 % in Tokachi-oki where the last earthquake occurred in 1952 and 20–30 % in Nemuro-oki where the last event was in 1973. Six months later, on September 26, 2003, great Tokachi-oki earthquake (M 8.0) actually occurred. In addition to the occurrence date, probabilistic estimate was made for ground shaking, which was also successful in forecasting locations of strong ground motion. In 2005, National Seismic Hazard Maps for Japan was published (http://www.jishin.go.jp/main/index-e.html).

2. Tsunami deposit and past earthquakes

Typical recurrence interval of large tsunamigenic interplate earthquakes is an order of hundred years. Because instrumental records of earthquakes or tsunamis usually exist for up to a hundred years or less, in order to study older events, we need to use non-instrumental data such as historical records or geological data. At some places like southwestern Japan, historical records exist for more than a thousand years[2)], but at other places geological data such as tsunami deposits are the only data of past earthquakes.

Study of tsunami deposits has been widely made in the last two decades around the Pacific Ocean[3)]. After the 2004 Indian Ocean tsunami, similar studies have been also conducted around the Indian Ocean.

The 1960 Chilean earthquake (M 9.5) was the largest earthquake in the 20th century, exceeding the 2004 Sumatra-Andaman earthquake, and caused tsunami damage in the Pacific Ocean. Historical data in South America show that similar earthquakes occurred in 1837, 1737 and 1575. Geological data (tsunami deposits) show that only the 1575 earthquake and similar events with ~ 300 year intervals produced tsunami comparable in size to the 1960 event[4)].

In North America, paleoseismological evidence such as tsunami deposit, coastal subsidence and deep-sea turbidites shows that interplate earthquake occurred at about 500 year interval and the most recent event was around 300 years ago[5)].

Tsunami deposits from the past 7,000 years in eastern Hokkaido, Japan, show that the southern Kuril trench repeatedly produced earthquakes and tsunamis larger than those recorded in the region's 200 years of written history[6)]. Deposits of prehistoric tsunamis underlie lowlands and lagoons along 200 km of eastern Hokkaido's Pacific coast. In Kiritappu, prehistoric sand sheets extend as much as 3 km inland across a beach-ridge plain, where the tsunami from the 1952 Tokachi-oki earthquake penetrated only about 1 km from the coast. The time intervals between the extensive sand sheets average about 500 years, as inferred from volcanic ash layers.

3. Tsunami simulation and earthquake model

Once the tsunami source, or seafloor deformation, is known, numerical simulation of tsunami propagation can be made on actual bathymetry to predict coastal behavior such as arrival times, costal amplitudes or inundation on land. This approach, starting from initial condition, is called forward modeling. The tsunami source is usually not known but can be studied from the observed data such as instrumental record, description in historical documents, or tsunami deposit, by comparing the results of numerical simulation. This approach is called inverse modeling and often used in geosciences.

The exact date and size of the Cascadia earthquake occurred around 300 years ago was estimated from Japanese historical documents, that recorded the tsunami damage from unknown origin in January 1700. Numerical computations show that a tsunami takes 10 hours to travel across the Pacific Ocean. From the earliest tsunami arrival time in Japanese documents, considering the time difference, the origin time of the Cascadia earthquake was estimated at around 9 PM of January 26, 1700[7)]. Furthermore, a comparison of tsunami heights estimated from damage description in Japan and computed coastal heights by numerical simulation from fault models in Cascadia indicates that the size of the 1700 earthquake was at around Mw~9, similar to the 2004 Sumatra-Andaman earthquake[8)].

For the 17th century Hokkaido tsunami, numerical simulation of tsunami on the Kiritappu marshland was made for several fault models, and the computed inundation areas were compared with the distribution of tsunami deposits. The comparison shows that the outsized tsunami, characterized by large inundation area and long recurrence interval, is best explained by an earthquake that ruptures multiple segments, including Tokachi-oki and Nemuro-oki, of the Kuril subduction zone[6, 9)].

4. Forecasting future tsunamis

Probabilistic models have been developed to estimate coastal tsunami heights from future earthquakes. Such methods have been widely used for seismic hazard (Probabilistic Seismic Hazard Analysis), but rarely applied to tsunamis until recently. For the Pacific coast of Hokkaido along the Kuril Trench, where the 2003 Tokachi-oki earthquake actually generated the tsunami, the probability of 2 m tsunami was estimated as 7–15 % and that of 5 m tsunami was 7 %[10)]. The actual tsunami heights in 2003 were up to 4 m.

A Probabilistic Tsunami Hazard Analysis using logic-tree was recently proposed[11)]. The end product is a hazard curve, a relationship between coastal tsunami heights and the probability of exceedance at a particular site. The hazard curve is obtained by integration over the aleatory uncertainties, whereas a large number of hazard curves are obtained for different branches of logic-trees representing epistemic uncertainty, such as tsunami sources, size and frequency of tsunamigenic earthquakes, standard errors of estimated tsunami heights.

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Hydraulic inferences from sediments of the December 2004 Indian Ocean tsunami along the Sumatra coast of Indonesia

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Abstract

The 2004 Sumatra-Andaman tsunami flooded coastal northern Sumatra to a depth of over 20 m, deposited a discontinuous sheet of sand up to 80 cm thick, and left mud up to 5 km inland. In most places the sand sheet is normally graded, and in some it contains complex internal stratigraphy. Structures within the sand sheet may record the passage of up to 3 individual waves. The Sumatra deposits also show the contribution of multiple sediment sources, each of which has its own composition and grain size. These contributions are separable using statistical techniques, and enable an understanding of the depositional history of the waves.

Key words : Sedimentation, tsunami deposit, inundation

1. Introduction

On December 26th, 2004, an earthquake estimated at between magnitude 9.0 and 9.3 resulted from rupture of over 1000 km of the Andaman Subduction Zone. The rupture also generated a tsunami that caused damage throughout the Indian Ocean, killing some 250,000 people and causing billions of dollars in damage. The tsunami was the most devastating in more than 40 years, and one of the largest such events on record.

As disastrous as the tsunami was, it presented an unparalleled opportunity for geoscientists to study a large tsunami. One aspect of this study was to study the sediments left in the passage of the waves. Although one previous trans-oceanic tsunami (1960 Chile) was among the first tsunamis to be studied by sedimentologists, the 2004 Indian Ocean tsunami represents the first time that sedimentary deposits have been studied systematically both near to and far from the tsunami's source.

Such studies are vital to understanding the hazard posed by low-frequency, high-risk events like tsunamis, because sediments left in the wake of tsunamis are often the only discernable record that a coastline has been struck. In locations with a relatively short written history (such as the west coast of the United States and Canada), tsunami deposits may be the only way of assessing the magnitude and frequency of large tsunamis. It is vital, then to understand how to recognize the deposits of tsunamis, and to use those deposits to attempt to determine how large the waves were from the deposits they left behind.

2. 2004 Indian Ocean tsunami deposition in Sumatra

The 2004 Indian Ocean tsunami was a global phenomenon, entering all oceans of the world. Damage, however, was restricted to the Indian Ocean, where the tsunami struck Indonesia within about 15

Fig. 1. Sediment deposited by the 2004 Indian Ocean tsunami near Lhok Nga, Sumatra, Indonesia. Beach in foreground was sandy before the tsunami; note the presence of a discontinuous sand "sheet" moved inland by the tsunami. Yellow labels show sample locations along a transect; black arrows show approximate direction of tsunami flow.

minutes of the earthquake, Sri Lanka and Thailand within about 2.5 hours, and India about 3 hours after the earthquake. The waves reached areas more than 35 m above sea level in Sumatra, Indonesia, and flooded coastal lowlands to a depth of more than 20 m. In Sri Lanka and Thailand, more than 700 km from the earthquake epicenter, waves reached more than 6 m above sea level and flooded coasts with more than 2.5 m of water.

The tsunami also deposited sediment virtually everywhere reached by water. This sediment ranges in size from individual coral boulders removed from offshore reefs to mud picked up from fields and deposited farther inland. Along most of the Sumatra coastline, however, the deposits consist of sheets of sand transported inland from beaches (Figure 1). The sheets are usually 10-30 cm thick along the coast of Sumatra and are commonly laminated and become finer upward, although local deposition exceeds 80 cm, and some deposits become coarser upward (Moore et al., 2006). Similar sand sheets have also been reported in Sri Lanka and Thailand (*e.g.*, Goto et al., 2005).

Deposits along the Sumatran coast consist of poorly sorted coarse sand that becomes progressively finer landward and upward. In some places the sand sheet contains complex internal stratigraphy, including structures (most commonly fining upward "pulses" within the sand sheet) that may record the passage of up to 3 individual waves. Within each pulse, the sediments are commonly laminated—a sedimentary structure caused when sediment rains down from the water column, rather than rolling and hopping along the bottom (in contrast, deposits of coastal storms commonly contain sedimentary structures consistent with sand rolling along the bottom). Although the deposit is thin or absent near the shoreline (where the soil has been eroded to bedrock), it maintains an average thickness of 10-15 cm starting about 50 m from the shore and extending nearly to the limit reached by the tsunami, suggesting that the tsunami was initially erosive, and became more depositional inland. The sand tends to selectively fill in low spots, most dramatically in pre-existing stream channels.

Most of the sand in the tsunami deposit is indistinguishable from material found on the beach shortly after the tsunami. However, the tsunami deposit also contains grain sizes and grain compositions not found on the present beach—these grains become more prominent landward and upward in the deposit (Figure 2), suggesting that some other source of sand became progressively exploited and intermixed with the beach sand by the tsunami. The deposit also contains fresh shells of subtidal marine organisms, suggesting that at least part of the deposit came from below the low tide line.

3. Discussion

Sedimentation from the 2004 Indian Ocean tsunami near Lhok Nga shows mixing from several sediment sources. Principal Component Analysis (PCA) of the sediment distributions reveals four main components; a coarse fraction corresponding to building debris, a

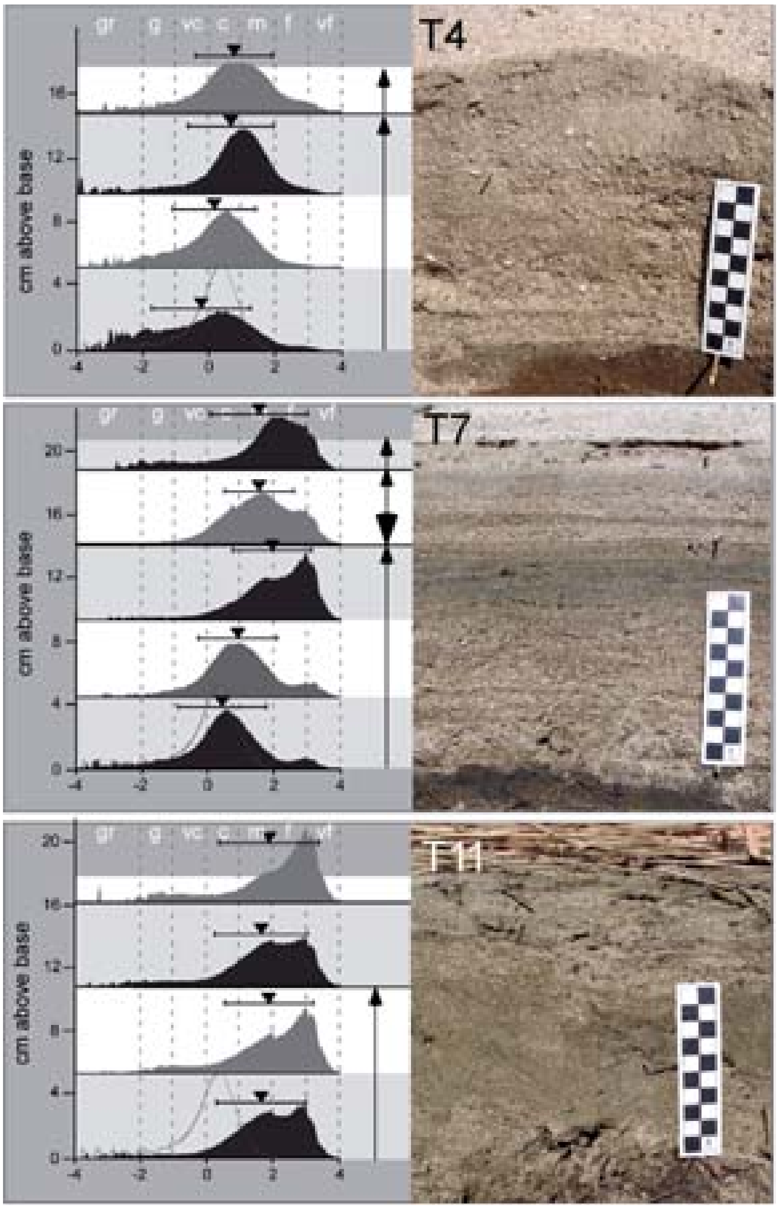

Fig. 2. Grain size distributions for sand along the transect shown in Figure 1. In each case, the horizontal axis is in phi units (coarse grains to the left, fine grains to the right). The gray line at the bottom of each transect shows the grain size distribution of beach sand after the tsunami. Overall, the deposit shows a shift from coarse particles (coarser than those commonly found on the beach) at the base of the most seaward deposits (T4), to much finer material than that found on the modern beach higher in the section, and landward (T11).

finer fraction (at about 0.25 φ) corresponding to beach sediments, a well-sorted 1.2 φ fraction of unknown origin, and a 3.5 φ fraction associated with offshore sands (Figure 3). Although landward and upward fining occurs within each of these populations, most of the fining seen in the deposit is caused by changing admixtures of these four components. In particular, vertical grading in T7 (Figure 2) occurs from the successive replacement of beach sand by the 1.2 φ and 3.5 φ peaks until about 13 cm have been deposited. Deposition then resumes with a mixture of all three peaks, then shifts toward finer peaks a second time. The sudden appearance of 1.2 φ material in the column (1.2 φ material is notably absent from T4, for example) midway up T7 suggests that some source of material between T4 and T7 was exploited during the tsunami, presumably sometime after the deposition of the lower parts of the deposit at T7.

Similarly, nearly all 0.25 φ (presumably beach sand) has been removed from the sediment before deposition occurs at T11. If the sediment is emplaced by advection, meaning that sediment is carried to nearly its final resting place in one movement, and then buried before much reworking can occur, then

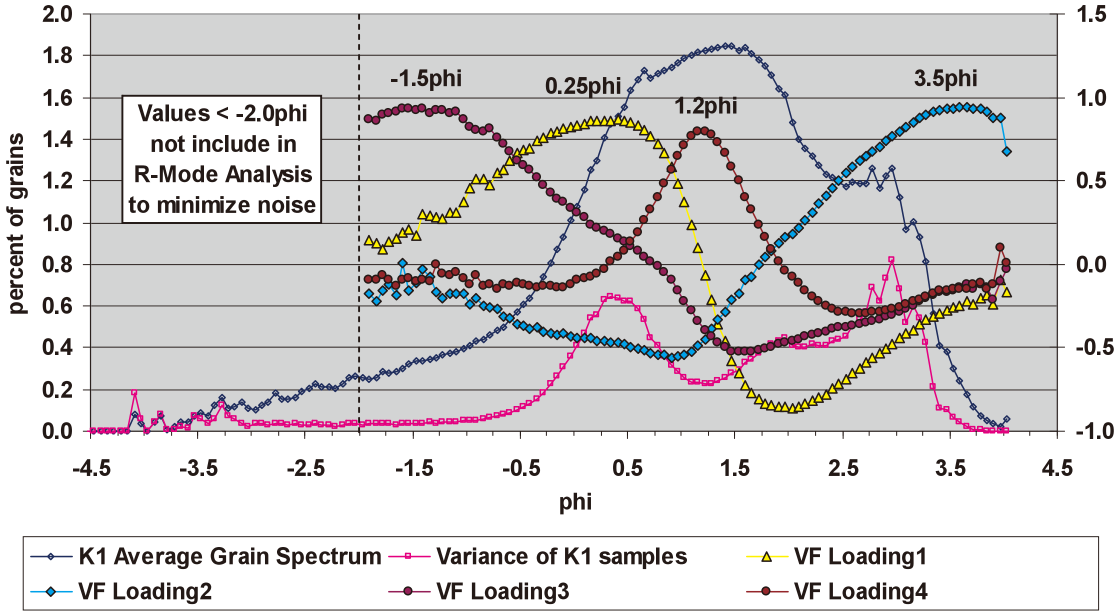

Fig. 3. Principal Component Analysis of sediment along transect shown in Figure 1. Tsunami sediment at Lhok Nga is primarily composed of four components (shown in yellow, aqua, purple, and brown, in order of importance to the deposit).

it should be possible to constrain the flow depth and velocity of the flow by measuring the distance from the sand source (the beach) to the farthest inland extent where 0.25 φ sand can be found.

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Predecessors of the 2006 South Java Tsunami

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Abstract

On July 17, 2006 Indonesia suffered another tsunami on the Sunda subduction zone in the south coast of western Java. In the 20th century, tsunami stroke the central part of south Java's coast in 1921, and the eastern part in 1994. Obviously the Java's tsunami threat needs to be better defined by extending the island's tsunami history into its recent geologic past.

In search of predecessors of the 2006 tsunami events, we dug exploratory pits into old beaches ridge, drilled at several points and cleaned the creek banks. We found four candidates for pre-2006 tsunami deposits. Storm deposition is unlikely to explain either of these deposits because Java, like Sumatra, is not subject to large cyclones as large as those farther north, in India or Bangladesh.

The younger of the two candidate tsunami deposits is a bed of dark gray sand less than 16 cm below the based of the 2006 tsunami sand sheet. In reconnaissance we found that this bed extends about 480 m parallel to shore. Like the 2006 sand sheet, it has an abrupt lower contact, and its upper contact is also sharp. The sand is about 1 cm and pinches out to the sides. Because of its shallow depth, we tentatively correlate the bed to the 1921 tsunami catalogued by *Newcomb and McCann*. The second candidate is almost identical in character with the first one. The third candidate shows a continuous undulated layer and little bit thicker than the first and the second ones. The older candidate lies about 1.0-1.5 m below the putative 1921 deposit. We found it exposed along approximately 500 m of the creek bank ranging from 430 to 510 meters from the modern shoreline. It consists of gray sand 15-20 cm thick. The sand rests on greenish gray and dark gray clay that may represent a lagoon, and it is capped by light brown silty sand that we interpret as fluvial or eolian. The clay resembles that of rip-up clasts in the middle of the sand bed. Tsunami eroded a lagoon floor around the time of a tectonic might be the possible scenario for this sand layers as the sharp contact with the clay layer below imply an abrupt changes of deposition flow. Minor storm may suggest other possibility, but it is unlikely as the sand layer is too thick to be settled by a minor storm. Nearby stream changes is also improbable as we found no lamination in the sand layers as usually left by stream deposition. Field and lab work is needed to test this speculation, because it suggests a combination of tsunami and coastal uplift that is unknown in Java's written history.

Key words : Sedimentation, tsunami deposit, inundation

1. Introduction

Last year, on July 17, Indonesia suffered another tsunami on the Sunda subduction zone in the south coast of western Java (Fig. 1a). The human toll reported by Indonesian Ministry of Health reached 668 dead and 65 missing.

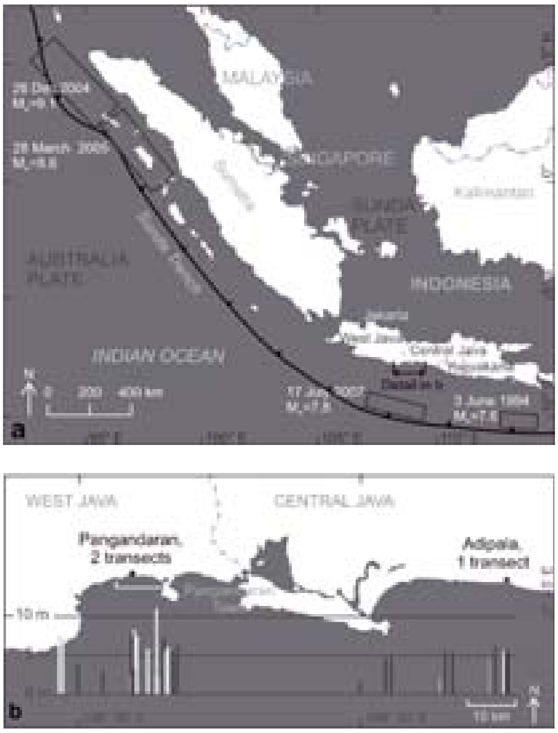

Fig. 1. Index maps. (a) Sunda subduction zone, with estimated rupture areas of recent earthquakes associated with tsunamis. The fault rupture plane locations of 26 December 2004 and 28 March 2005 earthquake after *USGS Website* [http://neic.usgs.gov/neis/eq_depot/2004/eq_041226/neic_slav_ff.html and http://neic.usgs.gov/neis/eq_depot/2005/eq_050328/neic_weax_ff.html], while the 3 June 1994's after *Nobuya Horiuchi* [http://www.ess.washington.edu/tsunami/specialized/events/eastjava/animation.html]
(b) Inundation heights: white, Cousins et al.(2006); light gray, *Kongko et al*. [2006]; dark gray, *Tsuji et al*. [2006]; and black, our data.

Reasons for these losses include surprise that was inherent in the tsunami and compounded by tsunami-hazard assessments. Indonesian tsunamis are commonly preceded by earthquakes strong enough to provide natural warnings, and recession of the sea [*Hidayati et al*., 2006]. By contrast, the parent earthquake of the 2006 Java tsunami produced weak shaking on the coast, and the tsunami arrived without a conspicuous leading recession. According to newspaper accounts, assessments beforehand had downplayed the tsunami hazard on Java's south coast relative to western Sumatra, where a history of repeated great earthquakes suggests a high probability of a tsunami near Padang [*Borrero et al*. 2006]. However, in the 20th century alone, tsunami stroke the central part of south Java's coast in 1921 [*Newcomb and McCann*, 1987], and the eastern part in 1994 [*Rynn*, 2002]. Obviously the Java's tsunami threat needs to be better defined by extending the island's tsunami history into its recent geologic past. The logical first step is to characterize the geologic signatures of modern tsunamis. Accordingly, we documented the 2006 sedimentary deposits' landward extent, thickness, and internal layering as guides to identifying the geologic traces of earlier Javanese tsunamis and estimating their relative sizes. In addition, we discovered two earlier sand beds that might aid in reconstructing Java's tsunami history.

2. The Earthquake and Tsunami of 17 July 2006

The July tsunami was generated during an offshore earthquake of moment magnitude 7.7 – 7.8. The shock has been called a tsunami earthquake for several reasons: the shaking felt onshore was slight compared with the size of the ensuing tsunami; the fault rupture, which lasted three minutes; propagated at just 1.0-1.5 km/sec; and the rupture area, approximately 200 km in length (Fig. 1a), was near the updip end of the subduction zone [*Ammon et al*., 2006; *Fujii and Satake*, 2006].

The tsunami reached heights of 5 m or more along 250 km of Javanese coast, from Ciandum in West Java to Gunung Kidul in the Central Java (Fig. 1b). Some of these measurements, by an Indonesian team, were posted July 28 [*Kongko et al*., 2006], and additional measurements, by researchers from Indonesia, Japan, Korea, and New Zealand, were made available on August 14 by *Tsuji et al*. [2006] and in a science report by *Cousins et al*. [2006].

2. 1 Survey of Recent Tsunami Deposits

Our sedimentological reconnaissance took place July 19-29. We focused on along three shore-normal transects across coastal plain undisturbed by disaster recovery activities and reconstruction. Two of these transects are near Pangandaran, in West Java Province; the third is to the east at Adipala, Central Java (Fig. 2). In both places eyewitnesses spoke of three waves, the second being the largest. We studied the tsunami deposits on the walls of 34 trenches. We found a tsunami-laid sand sheet as much as 18 cm thick that contains as many as three layers. In some places we found the sand normally graded (fining upward), while in others we noticed no internal structure.

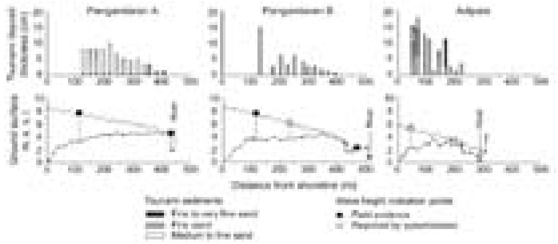

Fig. 2. Topography, inundation heights, and tsunami deposits along transects near Pangandaran and Adipala.

Near the two Pangandaran transects the tsunami crested about 8 m above mean sea level (a.m.s.l.), penetrated about 0.5 km inland and drained through a shore-parallel tidal creek (Fig. 2). We estimated the total height of 7.3 m and a flow depth of 3 m from damage to a house 100 m inland of the shoreline. Backwash was negligible on the plain, even as far inland as a paddy field close to the creek, as shown by grass knocked down landward. In addition, two eyewitnesses, who survived the tsunami by climbing the coconut trees on the plain, reported seeing inflow only.

Along both Pangandaran transects, the deposit, commonly less than 10 cm thick, consists of a dark brown fine to medium fine sand, spotted with white sand grains. We saw no layering or other structure in the deposit, except for normal grading on transect A. The sand sheet reaches its maximum thickness at 220 m from the shoreline in transect A, and at 130 m inland on transect B. Landward of its maximum on transect A, the sand thins steadily to near zero in about 400 m inland, 30 m short of the tsunami's horizontal limit (Fig. 2).

Along the Adipala transect, the tsunami crested less than 5.8 m high near the beach and the flow depth was 1 m deep at about 200 m inland. We obtained these estimates from accounts of eyewitnesses who held onto or climbed trees, and from the heights of palm-sap buckets that the tsunami left undisturbed. As at Pangandaran, eyewitnesses reported three waves, with the second being the largest. The first wave reportedly came from the south, the second from the southwest. Eyewitnesses reported no backwash across the plain or beach.

Tsunami sand, very fine to fine and grayish brown to brownish gray, covers the coastal plain along the Adipala transect with a maximum thickness of 18 cm. The deposits generally thin inland but locally thicken in depressions. In most trenches we found a single sand layer without obvious grading. In some trenches, however, we found two upward-fining layers or two layers without visible grading. These layers in some cases were seperated by a thin layer of very fine sand, and in others were distinct because the lower layer was coarser than the upper layer. (Fig. 2).

2. 2 Recconaisance for Paleotsunamis

In search of predecessors of the 2006 tsunami events, we dug exploratory pits into an old beach ridge and cleaned the creek bank at four locations between Pangandaran transects A and B, near the limit of 2006 inundation. We found two candidates for pre-2006 tsunami deposits. Storm deposition is unlikely to explain either of these deposits because Java, like Sumatra, is not subject to large cyclones as large as those farther north, in India or Bangladesh..

The younger of the two candidate tsunami deposits is a bed of dark gray sand less than 16 cm below the based of the 2006 tsunami sand sheet (Fig.3). In reconnaissance we found that this bed extends about 480 m parallel to shore. Like the 2006 sand sheet, it has an abrupt lower contact, and its upper contact is also sharp. Because of its shallow depth, we tentatively correlate the bed to the 1921 tsunami catalogued by *Newcomb and McCann* [1987].

The older candidate lies about 1.0-1.5 m below the putative 1921 deposit (Fig.3). We found it exposed along approximately 500 m of the creek bank ranging from 430 to 510 meters from the modern shoreline. It consists of gray sand 15-20 cm thick. The sand rests on greenish gray and dark gray clay that may represent a lagoon, and it is capped by light brown silty sand that we interpret as fluvial or eolian. The clay resembles that of rip-up clasts in the middle of the sand bed.

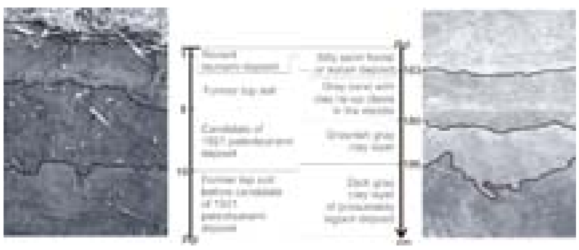

Fig. 3. Layered tsunami sand sheet with potential candidates of paleotsunami deposit discovered in a trench in Pangandaran.

Tsunami eroded a lagoon floor around the time of a tectonic might be the possible scenario for this sand layers as the sharp contact with the clay layer below imply an abrupt changes of deposition flow. Minor storm may suggest other possibility, but it is unlikely as the sand layer is too thick to be settled by a minor storm. Nearby stream changes is also improbable as we found no lamination in the sand layers as usually left by stream deposition.Field and lab work is needed to test this speculation, because it suggests a combination of tsunami and coastal uplift that is unknown in Java's written history.

Acknowledgements

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Preliminary results of paleo-tsunami study in Aceh Province

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Abstract

New geological evidences of historical and pre-historical tsunamis are discovered in Simeulue Island, Nanggröe Aceh Darussalam Province. Shallow coring and excavations in coastal lowlands exposed sand layers left by past tsunamis. Dating inferred that one paleo-tsunami deposit results from a tsunami caused by the 1861 or 1907 earthquake, and that the other chronologically corresponds with a pre-historical earthquake inferred from uplifted coral microatolls. Added to paleo-tsunami deposit hunting, we describe characteristic muddy tsunami deposit. This expands knowledge of facies variation in tsunami deposit and may be meaningful for more precise reconstruction of tsunami history.

Key words : tsunami, Indian Ocean, tsunami deposit, Aceh, Indonesia

1. Introduction

Tsunami histories inferred from geological evidence are beneficial to mitigation of future catastrophe. Recent pioneer work on paleo-tsunami after the 2004 Aceh-Andaman earthquake evidenced unrecorded past tsunamis in Indian Ocean regions(1)(2). To build more precise earthquake and tsunami history, comparison and mutual complement of results of multi-regional fieldworks are needed.

This paper presents our resent effort on paleo-tsunami hunting in Nanggröe Aceh Darussalam Province, Indonesia. Characteristic muddy deposit of the 2004 tsunami is also described to expand knowledge of facies variation in tsunami deposit. This would be meaningful not to overlook tsunami traces in sedimentary records and then to reconstruct more precise tsunami history.

2. Methods

Shallow coring and excavations exposed modern and past tsunami deposits at coastal lowlands in Nanggröe Aceh Darussalam Province, Indonesia. Tsunami deposits are sediments transported from seafloor and shore during tsunami inundation and left on ground surface to be tsunami records. Coral boulders and organic materials such as seeds and leafs are used for U/Th and carbon isotope dating to confine the ages of past tsunamis.

3. Paleo-tsunami deposits on Simeulue Island.

Simeulue Island locates off northern Sumatra Island and straddles the boundary of the 2004 and 2005 ruptures(3). As well as 2004 and 2005, tsunamis associated with historical earthquakes in 1861 and 1907 washed the island. Shallow excavations exposed paleo-tsunami deposits at two coastal lowland sites in southern Simeulue Island. The paleo-tsunami deposits at the Inor–Naibos and Busong Bay sites appear as laterally continuous sand layers in terrestrial sedimentary successions.

3.1. Busong

Two paleo-tsunami layers exist at Busong Bay; the younger one is bounded by peat layers and the older one separates peat and underlying muddy sediment that was probably deposited in an inter-tidal or sub-tidal environment. Both tsunami deposits are rich in coral clasts and show multiple-sublayers that is commonly observed in modern tsunami deposits. A fresh, uneroded coral boulder from the upper tsunami layer yielded a U/Th age that is consistent with emplacement in 1861, the year of an historical great (M~8.5) earthquake there. The lower tsunami layer may have been emplaced during an earlier uplift event around A.D. 1799, documented by an uplifted coral microatoll at the site. This interpretation is consistent with the sedimentary facies change from mud to peat across the lower tsunami layer, which probably represents an environmental change due to uplift.

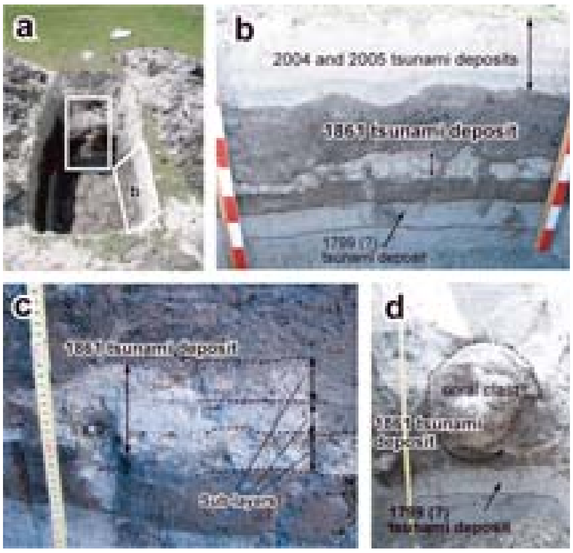

Fig. 1. (a) Full view of a pit at Busong. (b) Wall surface of the pit. A paleotsunami sand is in black peat. The upper most white sand is the 2004 and 2005 tsunami deposits. (c) Close view of the paleotsunami sand. Sublayers bounded by erosional surfaces are observed. White grains are calcareous algae fragments. (d) Coral boulder on the paleotsunami sand that provided an age consistent with the 1861 earthquake.

3.2. Inor-Naibos

Single paleo-tsunami layer was exposed at 8 of 15 pits at Inor site. The sand layer shows multiple sub-layers and contains shell fragments and rip-up clasts. Tsunami layer at Naibos, where is separated for 800 m from Inor, is accompanied by a coral boulder that provided an age consistent with the 1861 earthquake and tsunami.

4. The 2004 and possible paleo-tsunami deposits on Aceh mainland

In general, it is assumed that tsunami deposits are coarser than background sediments because of its sedimentation under higher energy condition. Hunting for paleotsunami deposit actually tends to focus on sand layers in muddy successions in coastal lowlands. The assumption is true as long as sand and gravels are available during tsunami sedimentation.

Fig. 2. The 2004 tsunami deposit at Meulaboh, Nanggröe Aceh Darussalam Province. Organic-rich mud of the 2004 tsunami covers sand and sandy silt of pre-2004 strand plain. The 2004 tsunami mud is partly accompanied by basal thin sand layer (left core).

Muddy tsunami deposit is out of the scope of the assumption. As is supported by local eyewitnesses, the 2004 tsunami deposit is dominantly muddy at Meulaboh, northwestern Sumatra. Although sandy 2004 tsunami deposit is also observed, it is confined to the coast.

The deposit is 13-30 cm thick, dark colored organic-rich mud that partly accompanied by thin basal sand layer. The deposit continues more than 600 m along shore-perpendicular traverse line. Basal sand disappears at the inland end of its distribution. Without basal sand, boundary between the muddy tsunami deposit and background peaty sand is obscure because of slight grain-size difference. It is suggested that the muddy tsunami deposit was supplied from the extensive marsh in front of the sedimentation site.

Discovery of indiscernible muddy tsunami deposit signify that many past tsunami records are overlooked. This may be a reason why paleotsunami deposits are absent in some areas facing subduction zone despite historical tsunami record.

Hunting for paleo-tsunami deposit is also conducted in Aceh mainland. Shallow coring at inter-ridge swamp exposed possible paleo-tsunami sand layers in thick peat successions.

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A rapidly prograding beach ridge plain as an archive for past tsunamis

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Abstract

The 2004 Sumatra-Andaman earthquake and following tsunami were unprecedented in Aceh, the northernmost province of Sumatra. In this study we use buried sand sheets on a coastal beach ridge plain to extend tsunami history 1000 years into Aceh's past. The 2004 tsunami deposited a sand sheet up to 1.8 km inland on a marshy beach ridge plain. Sediment cores from these coastal marshes revealed two older extensive sand sheets with similar sediment characteristics. These sheets, deposited soon after AD 1290-1400 and AD 780-990, probably represent earlier tsunamis. An additional sand sheet of limited extent might correlate with a documented smaller tsunami of AD 1907. These findings are a first step towards a paleotsunami record for northern Sumatra.

Key words : tsunami, Indian Ocean, tsunami deposit, Aceh, Indonesia

1. Geological setting

Aside from the 2004 tsunami and its successor in 2005, few tsunamis are documented in 400 years of Indonesian history to have reached Aceh (Hamzah et al. 2000). The largest of these, in 1907, is known to have devastated the west coast of Simeulue Island but run-up heights in Aceh are uncertain. However, as estimated from interviews with inhabitants, wave heights were probably far from reaching the extreme wave heights of the 2004 tsunami.

We sought geologic evidence for past tsunamis on a marshy plain along 4 km of coast north of Meulaboh, West Aceh. The marshy plain shows a characteristic ridge and swale topography that formed by rapid shoreline progradation (Fig. 1). Individual beach ridges, which mark former positions of the shoreline, run parallel to the coast for several kilometers. They are separated by swales where peaty marsh deposits accumulate.

The sequence of ridges builds progressively seaward at a rate that can be determined from the ages of deposits on the beach ridge plain: The oldest deposit in a swale in ~1800 m distance from the current coastline is dated at between 780-990 AD, or between 1230 and 1020 years ago. Assuming that at the time of its deposition the coastline was located at the foot of the beach ridge immediately before it, i.e. at a distance of ~1600 meters from the current coastline, the average coastal progradation rate can be estimated to lie between 1.3 to 1.6 m/y.

2. Methods

In swales between beach ridges we took more than 100 auger cores along 4 transects running perpendicular from the coast up to 2 km inland. The coring in the swales was limited to depths of 1-2 m by compact shoreface sand that extends beneath the beach ridge plain. Because swale age increases inland, however, coring progressively farther from the modern beach allowed us to extend the sedimentary record about 1,000 years into the past.

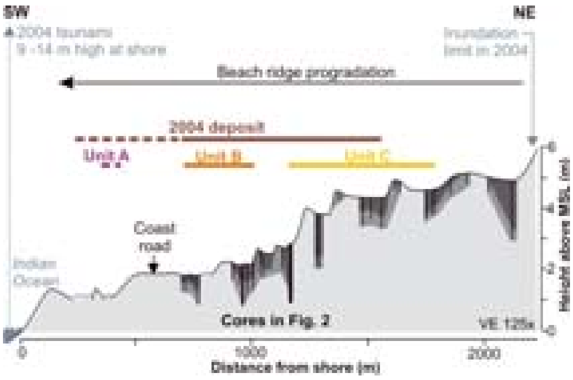

Fig. 1. modified after Monecke et al. 2008. Cross profile through beach ridge plain and extent of sand sheets.

3. Tsunami deposits

The 2004 tsunami deposited a sand sheet that can be followed up to 1.8 km inland and which shows overall landward thinning from ~ 50 cm near the shoreline to a few millimeters farther inland. Near the present shore the 2004 deposit consists of moderately to well-sorted medium sand dominated by silicate grains. Farther inland the sorting becomes poor; the mean grain size diminishes to fine sand, and the sand grains are mixed with soil fragments and plant debris.

Sediment cores from the swales revealed three older sand beds, a few millimeters to 25 cm thick, that are intercalated with peaty marsh deposits (units A, B, and C in Fig. 1, Fig. 2). We correlated them both between cores along shore-normal transects and between transects connected by shore-parallel beach ridges. Though nowhere encountered in vertical stratigraphic succession the three units are superposed geomorphically: In keeping with the progressive seaward shift in shoreline, the oldest of the three units (C) is the farthest inland, and the youngest unit (A) the closest to the modern shoreline. The three units can be distinguished not just by geomorphic position on the beach ridge plain but also by landward fining along transects and by radiocarbon ages.

We obtained AMS radiocarbon ages on pieces of wood and other plant debris, all probably detrital, from below and above sand beds. We interpret the lower dates as limiting-maximum ages and the upper ones as limiting-minimum ages for the times of sand-sheet deposition. The resulting age estimates, with ranges in years AD at two standard deviations, are younger than 1640-1950 for unit A, between 1290-1400 and 1510-1950 for unit B, and between 780-990 and 1000-1170 for unit C.

Units A, B and C are best explained by tsunamis that ran onto the beach ridge plain and deposited sand on top of peaty marshes. The three units architecturally resemble tsunami sand sheets described elsewhere (Morton et al. 2007): the sand extends hundreds of meters inland and rarely exceeds 25 cm in thickness. Massive or normally graded beds and the lack of bed-load transport structures further indicate settling from suspension, which is characteristic of tsunami deposition. Finer-grained and less well sorted deposits with increasing distance from the shoreline have been observed in other tsunami deposits and point towards waning flow velocities, and the incorporation of plant debris and soil into the flow during the landward passage of a tsunami.

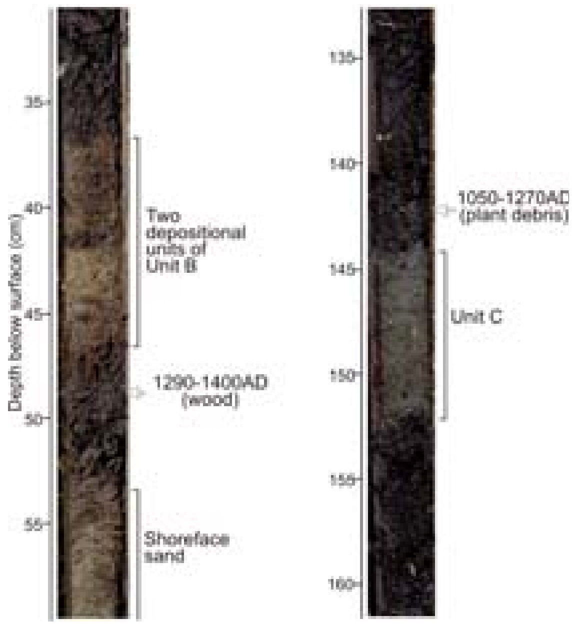

Fig. 2. modified after Monecke et al. 2008. Photographs of auger core samples from sand sheet units B and C.

4. Correlation of tsunami deposits in the Indian Ocean region

Unit A, being younger than AD 1640-1950 and limited to a narrow area might represent the documented smaller tsunami of AD 1907. Unit B, if deposited shortly after AD 1290- 1400, may correlate with the youngest pre-2004 tsunami deposit inferred from sand sheets of Phra Thong Island, Thailand, dated to soon after AD 1300- 1450 (Jankaew et al. 2008). Unit C, deposited after AD 780- 990, has no dated equivalent in Thailand. However, marine terraces in the Andaman Islands, the northern part of the 2004 rupture area, have been dated to AD 1170-1600 and AD 550-1330 and interpreted as evidence for subduction earthquakes (Rajendran et al. 2008). Acehnese units B and C might correlate with these terraces.

5. Future work

Future work will combine a thorough survey of the beach ridge plain, thermoluminescence dating of the beach ridges and a detailed study of spatial data like old and modern maps, satellite images and aerial photographs to understand long-term coastal progradation rates and short-term coastal recovery after the dramatic changes caused by the December 2004 earthquake and following tsunami. This data should help to determine coastal progradation and if beach ridge formation is linked to large earthquakes and associated ground movements.

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Source Model of the 2007 Bengkulu Earthquake Determined from Tsunami Waveforms and InSAR Data

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Abstract

On September 12, 2007 at 11:10:26 UTC, an earthquake with moment magnitude of 8.4 occurred off the west coast of Sumatra. The epicenter of the earthquake located at 4.52°S-101.374°E about 130 km southwest of Bengkulu. This earthquake located in Sumatra subduction zone where at least two previous major events of the 1833 (M8.5-9) and the 1797 have ruptured the same plate interface. In this study, we estimate the slip distribution of the 2007 earthquake using tsunami waveforms and InSAR (Synthetic Aperture Radar Interferometry) data. By comparing the result with the rupture area of the previous two large earthquakes, the recurrence pattern of large earthquakes in this area can be understood in order to identify the source area of future tsunamigenic earthquake.

The tsunami waves generated by the earthquake were recorded by tide gauge stations around Indian Ocean and two tsunami buoys deployed in the deep ocean northwest Sumatra and off the Sunda Strait. We select tsunami waveforms recorded in Padang, Cocos Islands, and on the tsunami buoys. Surface deformation on Pagai Islands was detected by "Daichi" (ALOS) satellite and the maximum crustal deformation located on the southern part of the island is approximately 1.8 m.

The synthetic tsunami waveforms at the four stations are calculated by solving the non linear shallow water equations. The synthetic dislocation in the line of sight direction is scaled from displacements calculated by the Okada (1985) formula. We estimate source model of the earthquake by performing joint inversion using recorded tsunami waveforms and crustal deformation on Pagai Islands detected by InSAR. In estimating the slip distribution we include smoothing factor (α2) in the calculation. On the ruptured area, we create a fault segment area of 150 km width by 300 km length and divide it into 72 subfaults. We use single focal mechanism (strike=327°, slip=12°, rake=114°) determined by Global CMT solution for each subfault.

The slip distribution inverted from tsunami waveforms and InSAR data shows that the major slip regions are located about 100 km north from the epicenter and on the southern part of the Pagai Islands. Assuming the rigidity of 4×10^{10} N/m^2, the total seismic moment obtain from the slip amount is 3.4×10^{21} Nm (Mw=8.3) which is consistent with the Global CMT solution on the seismic moment determination of 5.05×10^{21} Nm.

Key words : Slip distribution, tsunami waveform, InSAR data, smoothing factor

1. Introduction

On September 12, 2007, an earthquake occurred off the west coast of Sumatra, Indonesia. According to GCMT the moment magnitude is 8.4 (mo= 5.05 10^{21} Nm), the earthquake has Strike of 327°, dip of 12°, and slip of 114°. The epicenter was located at 4.52°S and101.374°E. The sea floor displacement generated tsunami that propagates through the Indian Ocean. Surface deformation on Pagai Islands was detected by "Daichi" (ALOS) satellite, the number of fringes from northern part to southern part of Pagai Islands indicates that the maximum crustal deformation in the line of sight direction located on the southern part of the island is approximately 1.8 m.

2. Data

We use tsunami waveforms recorded in 2 tide gauge stations (Cocos Islands and Padang) and 2 buoy stations (DART 23401 and Krakatau Tsunameter). The wave height recorded in Padang is about 1 meter. We use the first tsunami waves that recorded in tide gauges and use several waves that recorded in buoys for the tsunami inversion.

Surface deformation on Pagai Islands was detected by "Daichi" (ALOS) satellite. The surface deformation obtained by combining two satellite images from before and after the earthquake. We digitized the deformation fringe phase from figure that was done by the Geographical Survey Institute of Japan (GSI).

3. Method

The synthetic tsunami waveforms at the 4 stations are calculated by solving the non linear shallow water equations. Satake (1989) explains the method of tsunami inversion is considering the observed tsunami waveform as a superposition of synthetic tsunami waveforms. On the ruptured area, we create a fault segment area of 150 km width by 300 km length and divide it into 72 subfaults. We use single focal mechanism determined by Global CMT solution for each subfault and calculate the displacement using Okada (1985) formula.

The synthetic dislocation in the line of sight direction is scaled from displacements calculated by the Okada (1985) formula. The line of sight (LOS) which is perpendicular to the satellite track has an azimuth of 261.84° and the off-nadir angle is 34.3°. The relationship between LOS displacement and displacement components on the ground is expressed as follows

$$D_{LOS} = d_h \cos(\phi - \xi)\sin(\theta) + d_v \cos(\theta) \quad (1)$$

where D_{LOS} is LOS displacement, d_h is horizontal displacement, d_v is vertical displacement ξ is the azimuth of the perpendicular to the satellite track, φ is azimuth of the displacement, and θ is the off-nadir angle.

We estimate the slip distribution of the earthquake by performing inversion using recorded tsunami waveforms and crustal deformation on Pagai Islands detected by ALOS satellite.

The smooth variation of slip along the fault surface is required since the stress field in and around the faulting region is finite (Yabuki and Matsu'ura, 1992). In estimating the slip distribution we include smoothing factor (α^2) in the calculation. In this study the smoothing factor for the slip distribution is 0.075.

4. Results

The slip distribution inverted from tsunami waveforms and InSAR data shows that the major slip regions are located about 100 km north from the epicenter with maximum slip amount of 5.8 m and on the southern part of the Pagai Islands with maximum slip amount of 5.1 m. The maximum slip amount and the location of major slip region are similar to the estimation using seismic waves calculated by USGS.

The simulated tsunami using slip distribution obtained from the joint inversion is generally agreed to the observation at all stations.

Surface deformation on Pagai Islands is represented by fringe phases. The number of fringes calculated from the source model is the same with those from satellite data. The maximum residue of the dislocation toward the satellite between the satellite data and the calculation using slip distribution from the joint inversion is about 10 cm.

5. Conclusions

We have estimated the source model of the 2007 Bengkulu earthquake using recorded tsunami waveforms and crustal deformation detected by ALOS satellite.

The maximum detected uplift on Pagai Island is calculated to be about 1.2 m on the southern part of the island. Seismic moment calculated from the slip distribution using $\mu = 4\ 10^{10}\ N/m^2$ is $3.4\ 10^{21}$ Nm. The moment magnitude of the earthquake determined from this study is Mw 8.3 which is slightly smaller than the magnitude Mw 8.4 determined from seismic wave.

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19 March 2009

Sedimentary Records and the Environmental Impacts of the 2004 Indian Ocean Tsunami at Sri Lanka

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Abstract

Tsunamis preserve a layer of sediments that can be used to understand about the wave that deposited them. By examining the thickness and grain size distribution of tsunami deposits, we may also be able to evaluate the wave height and flow velocity of the wave. Tsunami sediments may also contain markers that illustrate different sources (deep sea, terrestrial, estuarine, etc.) of sediments. These records may be an important evidence to understand a particular region that may be at risk from a tsunami. By studying sediments from recent tsunami deposits in Sri Lanka, we may be able to identify and interpret tsunami sediments in a much better way in the geological record throughout the world.

Key words : tsunami sediments, Sri Lanka, 2004 tsunami, Yala, Recent sediments, texture.

1. Introduction

2004 tsunami in Sri Lanka has devastated most part of the Sri Lankan coasts. It is necessary to understand dynamics of the tsunami in order to prevent such human disasters in the future. One of the most effective tools is to study the wave character is to use the tsunami sediment texture and structure. In the present work, we have studied tsunami sediment thickness, run-up, heights, inundation distance, and topographic profiles for 8 transect along the tsunami affected south western coastal zones. Samples were collected (by open pit sampling) for laboratory analyses for grain size distribution, sedimentary structures, mineralogy, and chemistry. Sedimentary characteristics of the tsunami deposits and underlying material were logged and photographed. Box cores were taken at several sites to study the stratigraphy of the sediments. Erosion and flow-direction indicators were also documented. Residents were interviewed for their observations of the tsunami and local conditions before and after the tsunami.

2. Objectives

- To understand the structural, textural, chemical and mineralogical significance in tsunami sediments
- To understand tsunami wave energy (wave height and flow velocity) with respect to sediment thickness, grain size distribution, etc.
- To understand depositional characteristic with respect to the run up and back flow movement of tsunami waves
- To understand the topographic effects on tsunami

waves

•To understand the vegetation effect (including mangroves) on tsunami waves

3. Sampling

Tsunami sediment survey was carried out at south and south western coast of Sri Lanka as shown in Fig. 1. Transects perpendicular to the coastline was taken where there are extensive sediment sheets were deposited.

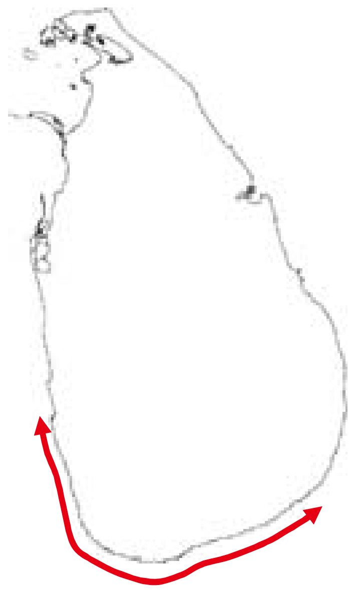

Fig. 1. Tsunami sediment Survey area

4. Results and Discussion

The Results shows, that tsunami waves are capable of eroding the coastal region, up to 100 m. For example, at Patanagala, about 75 m whereas in Mahasilawewa about 100 meters. The sediments transported to onshore form a recognizable tsunami sediment deposit. Tsunami sand deposits at Yala started about 75 meters inland, and decreased in thickness from about 20 centimeter total thickness to about 1 cm thickness at about 750 meters inland (Fig. 2). Tsunami deposits also show recognizable layering which may due to different tsunami waves, incoming and out going waves and also due to seiches. For example, layering indicates three main tsunami waves that affected Mahaseelawa and the second wave was the biggest (thick coarse and poorly sorted sediments) and the third wave came after a considerable time lag. In between the second and third waves, there were many laminations which may have occurred because of seiches that were common after tsunamis. In addition, results show that the mangrove forest has considerably decreased wave energy (e.g. Yakghagala area) and the heavy minerals content has defined some of the tsunami layers. Further Numerical modeling using ComMIT model shows wave energy or number of tsunami waves are related to the thickness and number of tsunami sediment layers.

5. Conclusions

•Structural and textural characteristics are useful to identify the tsunami sediments.

•Tsunami wave energy, wave height and flow velocity can be predicted by using results of

•grain size distribution, sediment thickness, sorting index and other local features.

•First seventy five meter from the mean sea level is dominated by erosion

•Mangrove forest reduces the wave speed and wave height at Iduruwa (Yakgahagala).

•Hambanthota and Dikwella area shows possible paleotsunami indication

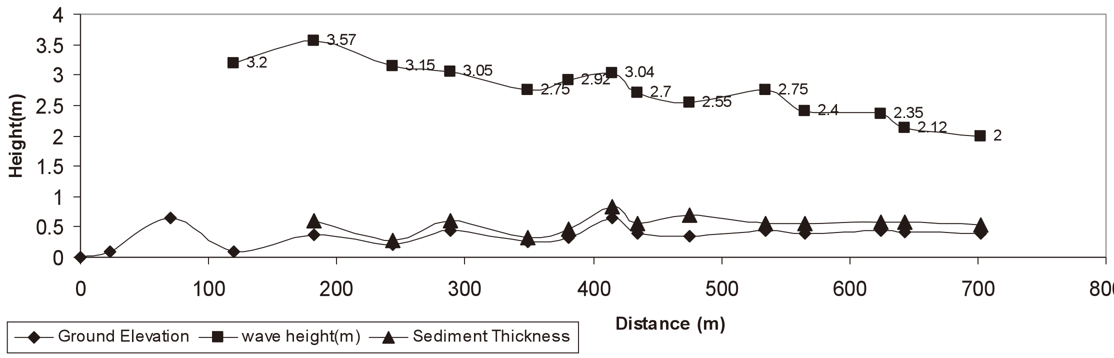

Fig. 2. Tsunami Profile at Yala

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The overview of the joint research project for the paleo-tsunami deposits in Sri Lanka

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Abstract

Tsunamis preserve a layer of sediments that can be used to understand about the wave that deposited them. By examining the thickness and grain size distribution of tsunami deposits, we may also be able to evaluate the wave height and flow velocity of the wave. Tsunami sediments may also contain markers that illustrate different sources (deep sea, terrestrial, estuarine, etc.) of sediments. These records may be an important evidence to understand a particular region that may be at risk from a tsunami. By studying sediments from recent tsunami deposits in Sri Lanka, we may be able to identify and interpret tsunami sediments in a much better way in the geological record throughout the world.

Key words : tsunami sediments, Sri Lanka, 2004 tsunami, Yala, Recent sediments, texture.

1. Introduction

Sri Lanka is an island nation situated in a geologically stable continental shelf. Therefore, natural disasters such as earthquakes and tsunamis are unheard events for the most of Sri Lankan society. However, since the 2004 Boxing Day tsunami, we realized, Sri Lanka does not have to be located in a continental margin to be subjected to natural disaster like tsunami. Aftermath of this disaster, attention has converted to a famous incident occurred during the period of King Kawanthissa (2100 -2300 yrs B.P), occurrence of a disastrous sea flooding in a town called Kelaniya situated the western coastal area of Sri Lanka, which; has resulted setting afloat his daughter, Princess Vihara Mahadevi into the sea to appease the gods. People has started to believe this event, this event as a tusnmi.

At this moment, no scientific evidence supports this historical account. This account is only one that described the possible paleo-tsunami event in the Indian Ocean countries. In order to find the geological evidence of this account, we organized Sri Lanka-Japan joint research team. Here, we report the preliminary results of the ongoing project.

Fig. 1. Preliminary drilling at the Yala National park.

2. Sampling and Methodology

In this study, we have conducted preliminary drilling at approximately 40 sites from west to southeast coast of Sri Lanka to determine the points for the full-scale drilling (Fig. 1). We also conducted sub-bottom acoustic profiling at Karagan Lagoon, Hambantota (Figs. 2 and 3) in order to find the drilling point. Based on these preliminary surveys, we decided the full-scale drilling sites at southern Sri Lankan coast of Dikwella Marsh (Fig. 4), Karagan Lagoon (Hambanthota), and Kirinda Lagoon.

Over 20 undisturbed core samples were collected using a mechanical vibro coring from Dikwella Marsh, Karagan Lagoon (Hambanthota), and Kirinda Lagoon. Samples were cut into 1 to 1.5 m sections and stored in poly vinyl pipes before transporting to the Moratuwa University, where samples were stored in the deep freezer. Later samples were cut into half for identifying sand layers (possible tsunami sediments), photographed, and suitable sediments were collected for the dating.

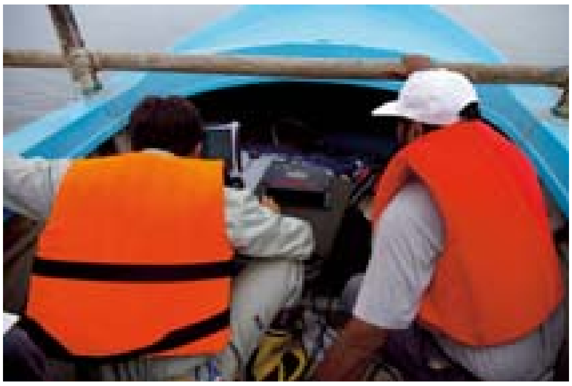

Fig. 2. Sub-bottom acoustic profiling survey at Karagan Lagoon, Hambantota.

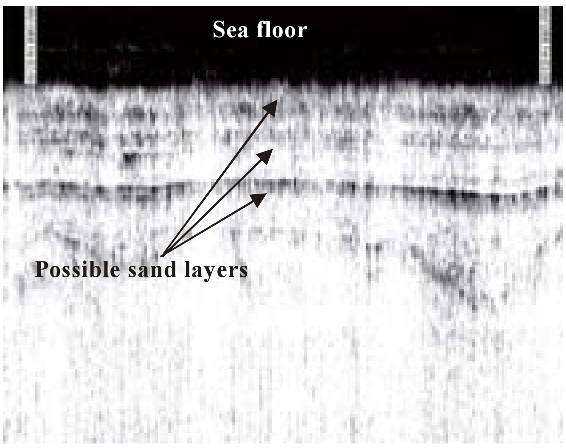

Fig. 3. Sub-bottom acoustic profiling results. Possible sand layers are visible.

3. Results and Discussion:

Goto et al. (2009, this volume) conducted radiocarbon age dating using drilling core samples at Dikwella, Hambantota, and Kirinda. According to their results, continuous sedimentary samples between approximately 3500 and 7300 year B. P. were recovered. Possible tsunami sediments were identified in these sediments (see also Goto et al. in this volume). On the other hand, the sediments younger than 3500 year B. P. were very rarely found in these cores.

Only one sample, which was recovered approx. 20 cm from the sea floor at Karagan lagoon, Hanbantota was 2130 year B.P. Approximately 10 cm below this sampling level, we found a several-centimeter-thick sand layer. It might be formed by the tsunami and correlate with the historical account, although we need to conduct more age dating to determine the precise timing of the formation of this sand layer.

Overall, the sediments younger than 3500 year B. P. were very rarely observed at our studied regions. The erosion of the surface sediments during the 2004 Indian Ocean tsunami event is one possible reason. However, the tsunami erosion seems insufficient to fully explain this observation. We tentatively interpreted that the sedimentation rate after 3500 year B. P. at southern Sri Lankan coast was remarkably slow.

Fig. 4. Full-scale drilling at Dikwella area.

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A Sedimentary Record of the Tsunami Recurrence in Sri Lanka

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Abstract

We investigated the sediment samples that were obtained from Dikwella and Hambantota sections at Sri Lanka in order to clarify the tsunami recurrence interval in Sri Lanka. We obtained the continuous sedimentary record between approx. 3500 and 7300 year B. P. We preliminary observed 4 to 5 distinct sand layers at each study area and some of these layers show clear upward fining feature. The radiocarbon ages suggested that the formation of sand layers both at Dikwella and Hambantota can be correlated well. Moreover, storm and flood events probably couldn't have been affected these sections. These results suggest that these sand layers would have been formed by the past tsunami events that were affected both at Dikwella and Hambantota sections.

Key words : tsunami, Sri Lanka, tsunami deposit, recurrence interval, Hambantota, Dikwella

1. Introduction

On 26 December 2004, huge earthquake (Mw 9.0-9.3) was generated at northwest Sumatra Island, Indonesia. Following this earthquake, one of the largest tsunami (the 2004 Indian Ocean tsunami) in human history struck coastal areas of more than 10 countries surrounding the Indian Ocean. The tsunami killed nearly 230,000 people, and caused severe property damage (e.g., Imamura et al., 2006).

In order to conduct a future tsunami risk assessment in the Indian Ocean, it is important to know the tsunami recurrence interval. However, there is no historical record that describes the earthquake (Mw>9.0) and tsunami events in the Indian Ocean in the past. There is a mythical account in Mahavansa, Sri Lanka's national Buddhist chronicle, which describes the sea flooding on land about 150 B.C. (e.g., Goff et al., 2006). However, no reliable scientific evidence supporting this mythical account has been available until now. In order to understand the tsunami recurrence interval in the Indian Ocean, scientific research is required instead of the historical accounts.

Large tsunamis remove sediments from the sea bottom and beaches and transport them landward or seaward. Sandy sediments transported by a tsunami and deposited on land or on the sea bottom become part of the geologic record, deposits that can be used to identify historical or prehistoric tsunami events (e.g., Atwater, 1987; Nanayama et al., 2003). In the Indian Ocean countries, Jankaew et al. (2008) recently reported the sedimentary evidence for the past tsunami event in the grassy beach-ridge plain at southern Thailand. They reported that the most recent full-size predecessor to the 2004 tsunami occurred about 550-700 years ago. Monecke et al. (2008) also reported similar results at Sumatra Island, Indonesia that the sand sheets were deposited soon after A.D. 1290-1400 and A.D. 780-990. These results are very important to understand the occurrence of the huge tsunamis in the Indian Ocean in the past. However, it is still unclear whether these past tsunami events were similar magnitude to the 2004 Indian Ocean tsunami, whether these past tsunamis also devastated to the other countries such as India or Sri Lanka, and whether such huge tsunami periodically occurred in the past.

In Sri Lanka, tsunamis rarely attacked in the past, because there is no subduction zone around the island and only transoceanic tsunamis such as the 2004 Indian Ocean tsunami would have reached there. In this context, Sri Lanka is one of the best countries to study the sedimentary record of the past tsunamis in the Indian Ocean. In this study, we conducted field survey at the southern coast of Sri Lanka to find the sedimentary records of the past tsunamis at this country.

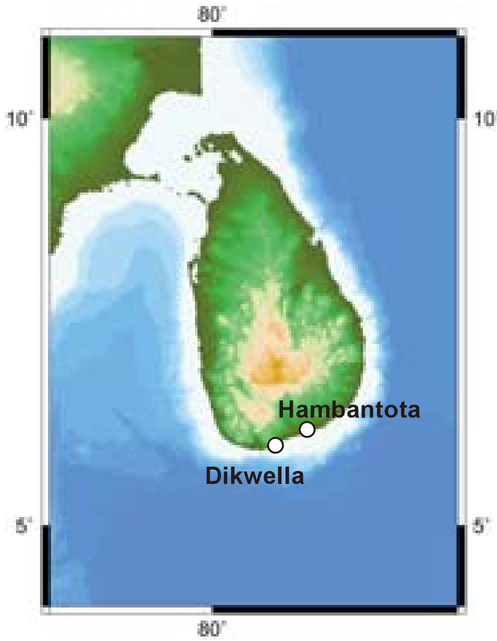

Fig. 1. Studied area (Dikwella and Hambantota) at Sri Lanka.

2. Study area and method

We conducted field surveys at Dikwella and Hambantota at the southern coast of Sri Lanka (Fig. 1). The Dikwella section locates the low ground and now it is used as the rice field. The Hambantota section locates in the Karagan Lagoon. At these sections, we took several drilling core samples. Each drilling place locates within the inundation area of the 2004 Indian Ocean tsunami according to Wijetunge (2006) and local residents. Using these core samples, we conducted sedimentological study and grain size analysis as well as radiocarbon age dating for the pieces of plant debris as well as shell fragments.

3. Preliminary Results

At Dikwella section, we obtained 9 cores that are less than 6.5 m in length. There are at least 4 obvious sand layers (Fig. 2), few centimeters in thickness, including the 2004 tsunami sand layer. The lower boundaries of the sand layers with the organic silt layers are very clear and the erosional contacts are sometimes observed. Grain size analysis revealed that some of these sand layers show clear upward fining feature. Our preliminary dating results show that the radiocarbon age of the sediments near the bottom of the core is approximately 5700 year B.P.

At Karagan Lagoon in Hambantota, we obtained 3 cores that are less than 8.5 m in length. There are 5-6 distinct sand layers including the 2004 tsunami sand layer. The radiocarbon age of the sample from approximately 30 cm subbottom depth is 3530 year B. P., whereas the age of the sediments at the bottom of

Fig. 2. A possible tsunami sand layer at Dikwella section. Grain size analysis revealed clear upward fining feature of this sand layer.

the core (8.3 m in subbottom depth) is approximately 7320 year B.P. (Fig. 3).

4. Discussion

Sand layers at Dikwella and Hambantota sections overlie the organic silt layers with clear (sometimes erosional) boundaries. Moreover, several sand layers show clear upward fining features. These observations suggest that they were formed by the extreme wave events. We preliminary interpreted that these sand layers were formed by the past tsunami events. This is because the studied sections couldn't have been affected by the strong storm surge or flood events. Moreover, the radiocarbon ages suggest that the formation of sand layers both at Dikwella and Hambantota can be correlated well, suggesting that these sand layers were formed by the same events that were affected both at Dikwella and Hambantota; the distance of these two sections are approximately 50 km.

Although the origin of the sand layers should be confirmed by the further detailed study, the possible tsunami sand layers were found to be formed about 600 to 1000 years interval at Hambantota (KR-3 core), which might suggests the tsunami recurrence at Sri Lanka.

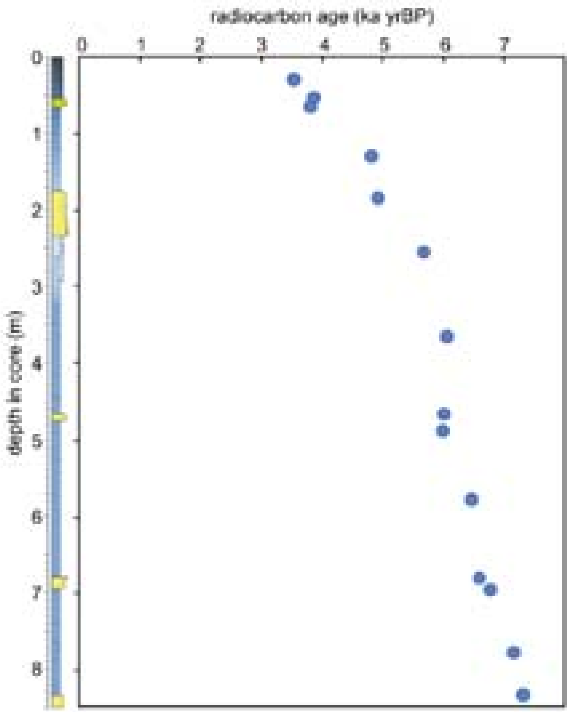

Fig. 3. A columnar section of the drilling core at Hambantota (KR-3) and the radiocarbon ages.

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Hunting for the paleotsunami deposits in Thailand

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Abstract

This presentation aims to show our attempt in searching for the paleotsunami deposits in Thailand leading to the Phra Thong Island's paleotsunami sand layers as published in Nature. The lack of co-seismic deformation, to give contrast in sediment stratigraphy, along the Thai coast caused distinguishing and identifying paleotsunami deposits difficult. High vegetation and human disturbance along the western coasts of Thailand further hindered the possibility of finding the historical tsunami deposits. The mangrove environment is found to be unfavourable for preserving tsunami records. It is a marshy swale in the ridges-swales system such as those on Phra Thong Island that can serve as a suitable recorder for tsunami events.

Key words : Pra Thong Island, paleotsunami deposit, Thailand, Indian Ocean, tropics

1. Introduction

The 2004 Indian Ocean tsunami was an unprecedented catastrophe for Thailand. Geologists and scientists from Thailand had never anticipated that such an event could occur and have an affect to the coast of Thailand. There was no written record of Indian Ocean wide tsunami occurring prior to the 2004 Sumatra tsunami. To improve our understanding of the risk from large Indian Ocean tsunami, it was evident that there is a need to study tsunami deposits in order to extend the tsunami record in this region. For the past two decades numerous publications reporting paleotsunami deposits were from the Pacific Ocean realm countries which are in the temperate latitudes (e.g. Atwater and Moore, 1992; Pinegina et al, 2003; Nanayama et al., 2003 and Cisternas et al, 2005). Most of the tsunami deposits are sand-sized, and few are of boulder-sized (e.g. Nott, 2000; Scicchitano, et al., 2007). The Indian Ocean tsunami emphasizes the need to search for paleotsunami in the tropics. This presentation documents our efforts in searching for paleotsunami deposits in Thailand. Some of the questions raised by Rhodes et al. (2006); What are the best depositional environments in the tropics for preserving a record of paleotsunamis? How well do mangrove forests preserve tsunami records? What post-burial changes occur over time in tsunami deposits that accumulate in a tropical environment?, will be answered here.

2. Searching along the Thai Coasts

Our team has been searching for evidence of past tsunamis in the Thai coastal areas inundated by the 2004 tsunami. Sites investigated include Kamala Beach and Le Pang Bay of Phuket Province, Thap Lamu, Pakarang Cape, Ban Nam Khem tidal inlet, Kho Khao Island and Phra Thong Island of Phangnga Province. The environments of these locations span from tidal flat, back beach lagoon and mangrove fringed tidal inlet. In these locations we learn that the 2004 tsunami deposits are not well preserved in mangrove environment because of their extensive root system and the great biodiversity they contain (crabs, mud lobsters etc). The 2004 tsunami sands are already being mixed up by these organisms causing low or no tendency of these sands being preserved as a paleotsunami deposit for future observation. Preservation potential of previous tsunamis along the Andaman Coast of Thailand is further jeopardized by the extensive placer tin mining, coastal developments and other human disturbance of the area.

After several field seasons spanning over two years, it was in marshy swales of Phra Thong Island that served as an excellent recorder for the tsunami sand layers. On a nearby ridge, on another hand, distinguishing the tsunami laid sand and the underlying ridge sand was at places difficult due to the lack of soil formation on top of the ridge sand. Jankaew et al., (2008) reported three sand layers which are likely to have been deposited by the predecessors of the 2004 tsunamis. The age of the youngest sand layer by mean of radio carbon dating was postdated AD 1300-1450. The OSL dating of the three paleotsunami sand layers from swale Y and two paleotsunami sand layers from swale X from Pra Thong Island, give ages of 350 ± 50, 990 ± 130, 1410 ± 190 and 2100 ± 260 years ago, representing four tsunami events (Prendergast et al., in prep).

Phra Thong Island is an excellent site to observe how the 2004 was preserved. Four years after the Indian Ocean tsunami, black organic rich soil as thick as 5 centimeters has already developed on top of the 2004 tsunami sand layer in the swales, which are submerged under water for most part of the year. High precipitation causes a high level of weathering of inorganic material and also aids in the decomposition of organic material that make up this black organic rich soil.

Because of its relatively flat terrain Phra Thong is also offers a suitable site to study velocity and depth of flow from properties of the deposits.

Apart from establishing evolution of Pra Thong Island (beach-swale series), our future studies plan include hydraulic interpretation of 2004 tsunami deposit on Phra Thong Island, establishing chronology of tsunami sand layers and correlation of sand layer across the island (^{14}C and OSL).

The reports of paleotsunami sand layers in swales of Phra Thong Island (Jankaew et al., 2008) and in Meulaboh, Indonesia (Monecke et al, 2008) have proven that the best depositional environments in the tropics for preserving a record of sand-sized sediments laid down by pre-historic tsunamis. It is an important step towards establishing tsunami history for countries that lacks long historical records such as Thailand. Through this and future study in paleotsunami deposits, we hope to improve our understanding of the risk of this region from tsunami, its frequency and magnitude.

3. Conclusion

Identification and distinguishing tsunami deposits in the tropical areas that lack co-seismic deformation such as Thailand is challenging as deposition and preservation potentials of these sediments are relatively low. The high vegetation and human disturbance along the western coasts of Thailand further hinder the possibility of finding the historical tsunami deposits. The mangrove environment proved to be unfavourable for preserving tsunami records. It is, however, shown that the swales in the ridges-swales system at Phra Thong Island can serve as a suitable recorder for tsunami events. Additionally, Phra Thong Island is also a good site to observe paleotsunami taphonomy in action.

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Hydraulic Approach to Tsunami Deposits

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Abstract

To mitigate the tsunami disaster damage, it is indispensable to understand historical tsunamis. Tsunami deposits include the precious information and the hydraulic approach such as physical experiments and numerical modeling are expected to improve analysis of them. Regretfully the present model of sediment transport due to tsunamis could not simulate tsunami deposits on land well, because a water depth becomes very small when tsunamis run-up and it is difficult to evaluate velocity and bottom shear stress preciously. The present model, however, expected to be upgraded and be adapted to the tsunami deposits in the near future. And a hydraulic experiment has been carried out for the tsunami deposit forming process. In the experiment, several types of tsunami run-ups were simulated and the distributions of tsunami deposits were measured. Then the present model and the experimental results are introduced.

Key words : bed load, suspended load, run-up, return flow, deposit distribution

1. Introduction

The main objective of tsunami disaster mitigation is to assess the impact and to mitigate the damage of future tsunamis. To predict the future disasters, we need to study past tsunami phenomena. Tsunamis are rare disaster compared with other disasters such as storm surges and river floods, and the modern tsunami observation system has been improved in recent years. Then the data of historical tsunamis is useful and important for the tsunami disaster mitigation plan. To obtain the information, however, is depending on ancient documents and traditions. The new method to understand the historical tsunamis is required. As one of the methods, many tsunami researchers have been focused on tsunami deposits. The tsunami deposits are formed on land or in shallow sea region by tsunamis, and they may include the information of the tsunami phenomena.

Many field investigations on tsunami deposits have been carried out and achieved success[1) 2)]. Further comprehension of tsunami deposits can be obtained by the hydraulic approach such as physical experiments and numerical modeling. The present model of sediment transport due to tsunamis[3)] could not simulate tsunami deposits on land well regretfully, because a water depth becomes very small when tsunamis run-up and it is difficult to evaluate velocity and bottom shear stress preciously. The present model is expected to be upgraded and be adapted to the tsunami deposits in the near future. On the other hand, a hydraulic experiment has been carried out for the tsunami deposit forming process on land[4)]. In the experiment, several types of tsunamis were simulated and the distributions of tsunami deposits were measured. In this presentation, the present model and the experimental results are introduced.

2. The present model of sediment transport due to tsunamis

The present model consists of a bed load layer and a suspended load layer. In each layer, their respective fluxes are conserved. A diagram of this model is shown in figure 1. ρ_s is a density of sand particle, $\overline{C}_S$ is mean concentration of suspended load layer, $\overline{C}_B$ is mean concentration of bed load layer, C is concentration at the boundary of both layers, ε_z is vertical diffusion coefficient, w_0 is settling velocity, q_B is bed load rate, h_S is depth of suspended load layer, h_B is depth of bed load layer, M is flow flux, λ is porosity and Z_B is bed level. To provide an interaction between these two layers, an exchange load is included. This exchange load is defined as a balance of rising load and settling load. It gives transition of suspended load without the equilibrium concentration distribution, the reference concentration and its height. According to this diagram, the governing equations of this model are developed as follows.

$$\frac{\partial Z_B}{\partial t} + \frac{1}{1-\lambda}\left(\frac{\partial q_B}{\partial x} + w_{ex}\right) = 0 \qquad (1)$$

$$\frac{\partial \bar{C} sM}{\partial x} - w_{ex} + \frac{\partial \bar{C} sh}{\partial t} = 0 \qquad (2)$$

Here, w_{ex} is exchange load rate and h is water depth. They are continuity equations in the bed load layer and the suspended load layer.

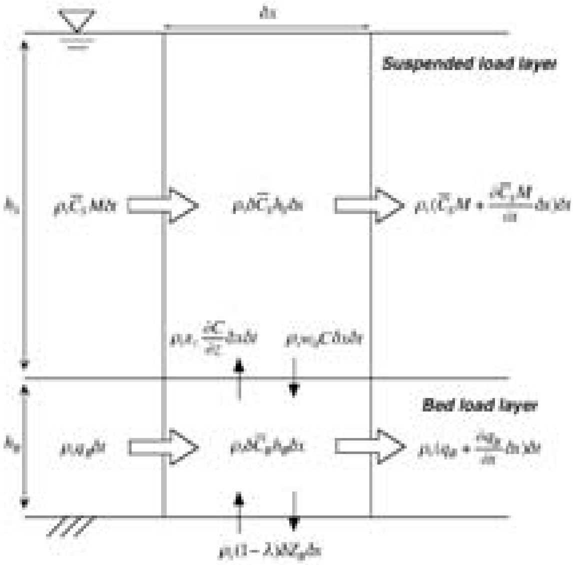

Figure 1 The diagram of the present model.

To solve the system, another momentum equations are necessary. They are the bed load formula and the exchange load formula to be applicable to tsunamis. To determine them, hydraulic experiments were carried out with the water tunnel and following formulae were obtained.

$$\Phi_B = 21\tau_*^{3/2} \qquad (3)$$

$$\Psi_{rise} = 0.012\tau_*^{2} \qquad (4)$$

Here, τ_* is Shields number, Φ_B is non-dimensional bed load rate and Ψ_{rise} is non-dimensional rise sand rate.

3. Hydraulic experiment on tsunami deposits on land

An open channel shown in figure 2 was used in this experiment. A wave maker at an end of the channel generated solitary waves assumed as tsunamis. The water level and velocity of the waves were measured by wave gauge and velocimeter. A slope at the other end consists of a movable bed and a fixed bed, and their boundary was assumed as shoreline. The waves transported sea sand in the movable bed to the fixed bed. Assuming several types of tsunami run-ups, following 5 cases were examined.

Case 1: Singular incident wave without return flow
Case 2: Singular incident wave with return flow
Case 3: Plural incident waves
(3, 5 and 10 waves of constant amplitude)
Case 4: Plural incident waves
(3 waves of decreasing amplitude)
Case 5: Plural incident waves with fluorescent sand
(3 waves of constant amplitude)

Here, the return flow means that ran-up water goes back to sea. In cases 3, 4 and 5, the return flow was assumed. In case 3, different colored sands were used for each waves.

As one of the examples, measured distribution of sand deposits along the run-up region in case 1 is shown in figure 3. A distinct wedge shaped deposit was formed. It is used as a proof of tsunami deposit in the field investigation.

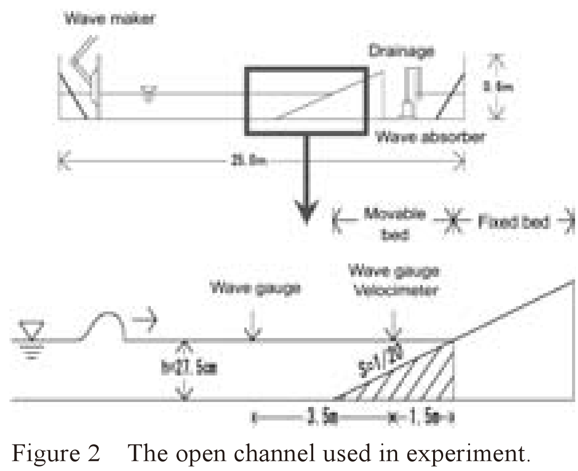

Figure 2 The open channel used in experiment.

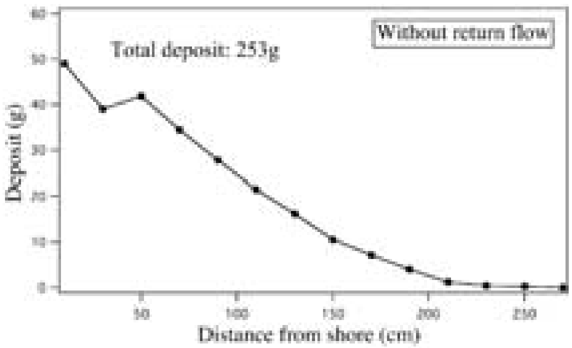

Figure 3 Sand deposit distribution of case 1.

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Probabilistic Tsunami Hazard Analysis Model

— For Input to Tsunami Disaster Mitigation Strategies in Banda Aceh City —

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Abstract

December 2004 earthquake (Mw=9.2) and tsunami has caused loss of more than two hundred thousand lives and many buildings, infrastructures, and lifelines have been completely destroyed. Coastal areas of City of Banda Aceh have experienced catastrophic damages due to the tsunami and earthquake. Almost all the residential houses in the coastal area were destroyed by the tsunami. Destruction of the building and infrastructures are due to extreme tsunami height, strong nature of the tsunami force and vulnerability of different buildings and infrastructures under different types and building construction qualities which are actually not designed to resist extremely high force such as due to the 2004 tsunami.

Rehabilitation and reconstruction is currently still undergoing, consisting of construction of thousands of residential houses and many infrastructures and lifelines as well as some critical facilities. Both seismic and tsunami hazard criteria is essential as a basis for rehabilitation, reconstruction, and long-term development, as well as for developing tsunami warning system for the city post great Sumatra 2004 earthquake.

Key words : PSHA, PTHA, Tsunami Mitigation, Banda Aceh city

1. Introduction

Rehabilitation, reconstruction, and long-term development require scientific and engineering input for formulation of disaster mitigation strategies. Therefore, probabilistic seismic and tsunami hazard assessment is conducted and presented herein, to provide recommendations on design criteria for long-term development of buildings and infrastructures along the coastline of city of Banda Aceh.

There are a lot of uncertainties related to tsunamigenic earthquake occurrences. This study presents analysis to treat uncertainties related to tsunamigenic earthquakes for input to tsunami disaster mitigation strategies. An established probabilistic seismic hazard analysis methodology is adopted for probabilistic tsunami hazard analysis combined with tsunami wave propagation analysis, to recommend various scenarios of tsunami occurrences. The essential input in the hazard analysis is the recurrence model of the potential tsunamigenic sources, maximum magnitude, total probability theorem, and wave propagation analysis to the site of interest.

Results of the analysis provide recommendations on the tsunami height and inundation map associated with its probability level due to earthquake of particular magnitude. Further inundation modeling to the area of interest provides inundation maps for different scenarios of interest. This methodology has been applied to the case study of Banda Aceh city.

Results of the study are a set of scenarios as an essential input in the tsunami design criteria as well as for disaster mitigation strategies for coastal area development planning such as criteria for infrastructures development. Various scenarios resulted from the analysis could be also adopted as input to the database of tsunami early warning system. The methodology could be adopted as a model for other tsunami disaster potential areas. Furthermore the recommendations resulted from the study also would be essential for developing tsunami disaster mitigation appropriate for the community and its infrastructures along the coastline affected by the 2004 tsunami both physically and non-physically.

2. Probabilistic Tsunami Hazard Analysis

Long-term development and related disaster mitigation strategies of the coastlines destroyed by the great Sumatra 2004 tsunami demand scientific, engineering input and criteria of future tsunami hazard potential. Tsunami hazard potential post the great 2004 Sumatra earthquake was evaluated herein to recommend tsunami hazard criteria. The earthquake generated tsunami potential to city of Banda Aceh is the subduction zones. This subduction zones are the same source that was used for the PSHA. Therefore, for tsunami hazard potential the subduction source zones and seismic parameters previously used for the PSHA were used for probabilistic tsunami hazard analysis (PTHA). The analysis was made by activating only the subduction seismic source zones (Aceh- Seumelue-Andaman segments). The analysis was done using EZ-FRISK computer program (Risk Eng. Inc., 2004) to provide hazard curve correlating earthquake return periods and the potential moment magnitudes considering the seismic parameters adopted in the recurrence models. The analysis was conducted by Sengara and Hendarto (2006) as shown in Figure 1. It is indicated that, the 2004 earthquake is approximately predicted to be of 520 years return period earthquake. Based on seismic hazard curve of Figure 1, several earthquake magnitude scenarios associated with its return periods were developed and these scenarios were adopted for earthquake generating tsunami wave propagation and inundation modeling.

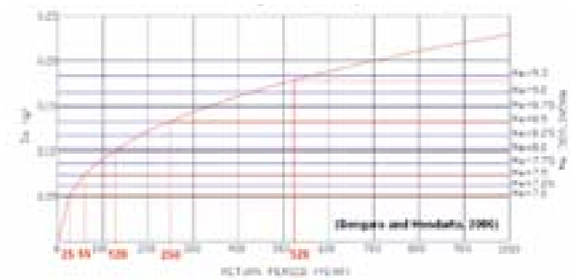

Fig. 1. Return period of PSHA at Banda Aceh city

3. Tsunami Wave Propagation and inundation Modeling

The result of PSHA was used as an input in tsunami wave propagation modeling to estimate the tsunami height at the shoreline of the site of interest. Each scenario with associated earthquake moment magnitude and return period will correspond to particular potential of sea-bed deformation as the tsunami generation input that could be calculated by using Masinha and Smylie method (1971) with the fault parameter which has been determined from focal earthquake mechanism results from Harvard-CMT solution. (www.seismology.harvard.edu/poject.cmt).

Simulation area for the Aceh tsunami is designed as shown in Figure 2. Banda Aceh tsunami is simulated using multi grid model (*nesting grid*), and is designed with 5 types of grid size.

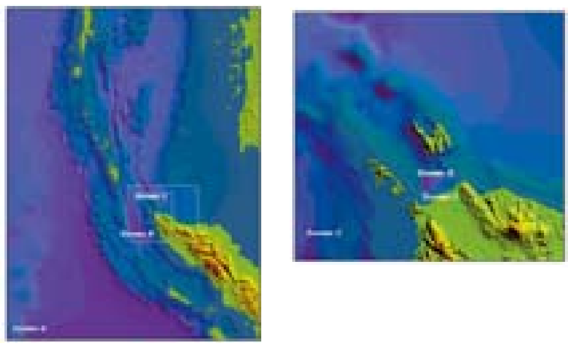

Fig. 2. Nested Model Design from Domain-A to –C (left) and Domain-C to –E (right)

The 2-dimensional depth-integrated continuity and momentum equations are used to simulate tsunami propagation and inundation, then solved by finite-difference method with the staggered leapfrog scheme are given by Goto and Ogawa, (1992). To validate the model we compare the tsunami heights of computation results and field survey measured (Figure 3) and gives a good agree as shown in Figure 4.

Fig. 3. Field survey points measured of The 2004 Tsunami in Banda Aceh city (Domain-E) by ITST (2005)

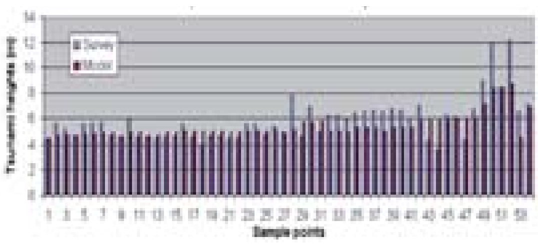

Fig. 4. Comparison of tsunami height between model and field survey.

Tsunami modeling for the city of Banda Aceh was then conducted adopting tsunami hazard curve resulted from PTHA taking into consideration various scenarios with several of moment magnitude (i.e. Mw= 9.2, 8.5, 8.0, 7.5 and 7.0). Results of the tsunami modeling for various scenarios correlating the return period or moment magnitude potential and maximum tsunami height at coastline of the case-study site is summarized in Table 1 and Figure 5

Table. 1. Return period of tsunami height with several moment magnitude

Moment Magnitude	Return Periods (year)	Tsunami height (m) at Banda Aceh
Mw= 9.2	520	9.50
Mw= 8.5	250	5.20
Mw=8.0	120	2.70
Mw=7.5	55	1.11
Mw=7.0	25	0.48

Inundation modeling for each scenario was run to obtain its corresponding inundation map. Each scenario with associated earthquake moment magnitude and return period will correspond to particular potential of sea-bed displacement as

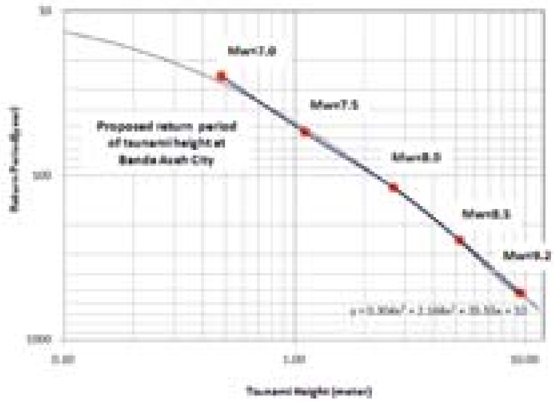

Fig. 5. Curve of return period of tsunami height with several magnitude

the tsunami generation input. Inundation maps for various scenario events (i.e. Mw= 9.2, 8.5, 8.0, 7.5 and 7.0) are shown in Figure 6 to Figure 10 respectively. These maps and graphic (Figure 5) could be used as tsunami criteria for formulating disaster mitigation strategies consisting of life safety, building and infrastructures tsunami design criteria, as well as developing appropriate tsunami warning system.

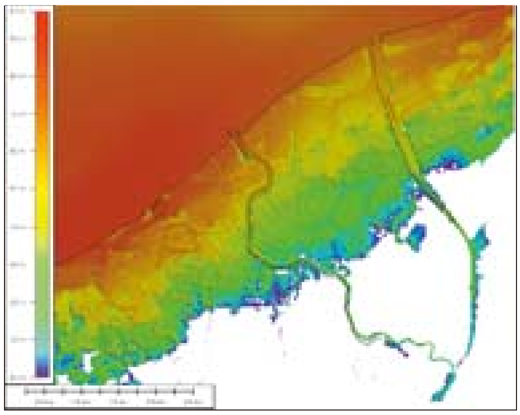

Fig. 6. Inundation map for the 2004 Aceh Tsunami at Banda Aceh City

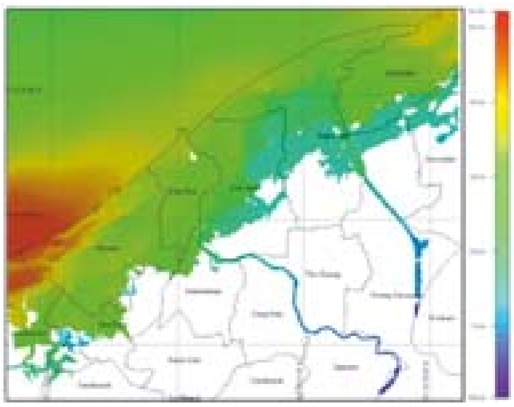

Fig. 7. Inundation map for Mw=8.5 at Banda Aceh City

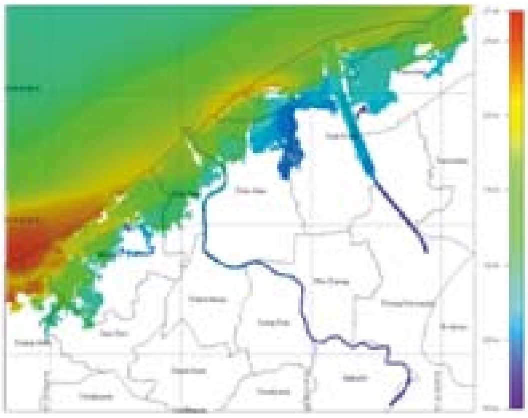

Fig. 8. Inundation map for Mw=8.0 at Banda Aceh City

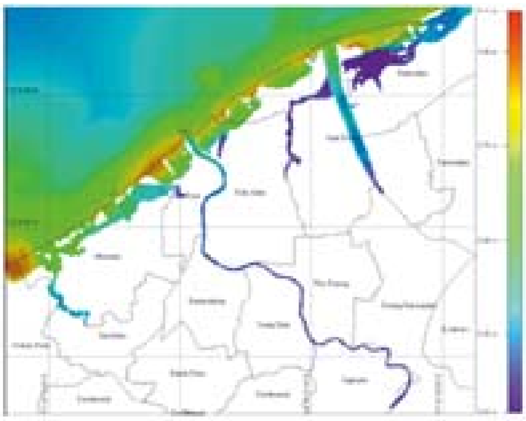

Fig. 9. Inundation map for Mw=7.5 at Banda Aceh City

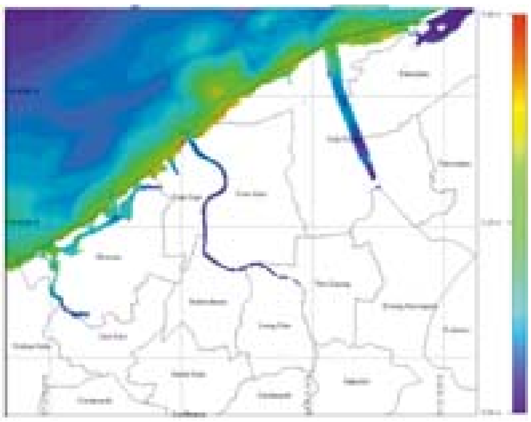

Fig. 10. Inundation map for Mw=7.0 at Banda Aceh City

4. Conclusions and Recommendations

Probabilistic tsunami hazard analysis, tsunami wave propagation and inundation modelling have resulted in useful maps for tsunami criteria for formulating disaster mitigation strategies consisting of life safety, building and infrastructures tsunami design criteria, as well as developing appropriate tsunami warning system. The methodology adopted in this paper could be used to develop seismic and tsunami criteria for other cities and areas.

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Changing Perception and Moving Towards Building a Safer Sri Lanka

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Key words : Road Map for Safer Sri Lanka, Comprehensive Disaster Risk Management.

1. Introduction

The Indian Ocean Tsunami of December 2004 raised the awareness worldwide of the potentially devastating impact of Tsunamis. Costal community in the region of Indian Ocean, big or small, are increasingly at risk from Tsunami and many other costal hazards including sever storms, floods and shoreline erosion. These chronic and episodic hazards include human caused action and natural events that are threaten the health and stability of coastal ecosystems and community. Although, mythological evidences and the 1883 volcanic activity at Sumatra region indicated that Sri Lanka is prone to tsunami. However until the Tsunami struck on the morning of December 26, 2004, it was not realized that Indian Ocean is Tsunami prone region.

The first tsunami wave began to impact the eastern coast of Sri Lanka about 100 minutes after the earthquake, at approximately 8:40 a.m. The wave surge was recorded at between 5 and 6.5 meters in most of the eastern and northeastern coast, and parts of the southern coast, doing most damage up to 3 meters above mean sea level. A secondary wave struck approximately 20 minutes later. The complex interaction between water-borne energy, sea-bed and terrestrial terrain meant that the affects of the tsunami were different from place to place, but in general the Eastern, North-eastern and South-eastern coast of Sri Lanka was particularly hard hit.

A veteran of examining tsunami effects, Liu was struck by the power of this killer wave. "The destruction was more severe than I anticipated and the magnitude of destruction was beyond any imagination," he said. "The 1992 tsunami in Indonesia was severe, but it was nothing like this one."

Liu spoke to many eyewitnesses. They explained they saw three waves, and this corroborates the general belief that three earthquakes over a 10-minute period caused the tsunami series. The waves traveled at jetliner speeds -- about 500 miles an hour -- through the Indian Ocean, and struck Sri Lanka about two hours later.

The waves measured between three and six meters (or 10 and 18 feet) high, he said. Because the coastal plain of Sri Lanka is relatively flat -- that is, with a very slight slope -- the ocean water poured inland between 500 meters (the length of five American football fields laid end-to-end) and two kilometers (about a mile and a half).

Professor Philip Liu- **January 27, 2005**A professor of civil and environmental engineering, Philip L. F. Liu, Cornell University

2. Devastating affect of the Indian Ocean Tsunami by 2004

Sri Lanka has been badly affected in terms of loss of life, infrastructure, and economic assets; the 2004 tsunami is widely acknowledged as the largest, most devastating natural catastrophe in the history of the country. Two hours after the first earthquake occurred, the tsunami waves struck an extremely long (more than 1,000 km, or two-thirds of the coastline) coastal area of Sri Lanka across thirteen districts, including Jaffna in the north, the eastern and southern coast, and parts of the west coast as far north as Chilaw of Puttalam District(.See figure 1: Map 01)

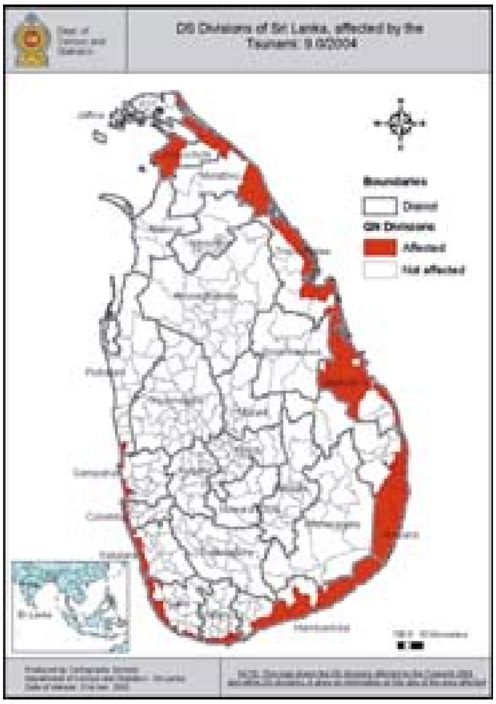


Fig. 1. Map 01

2.1 Overview of the Impact Assessment

The Seawater penetrated from tens to hundreds of meters inland (in places thousands of meters), and typically drained away within 30 minutes, leaving behind a trail of destructions. At the time of impact between 31,000 and 37,000 people were killed by drowning or debris impact and destroying government, and private properties. About 27,000 fatalities were fishermen, and two-thirds of the nation's fishing boats were wrecked, destroying many jobs. Farming was affected by the incursion of large amounts of salt water and marine sediment to fields and wells. Coastal infrastructure systems, including roads and railways, power, communications, water supply and sanitation facilities, and fishing ports have all been severely damaged. The tourism sector was also affected due to physical damage and cancellation of future bookings and additional jobs lost.

2.2 Sri Lanka's Fishing Industry

Sri Lanka's fishing industry contributed nearly 2.5 percent to the country's national income and there were 171,000 active fishermen engaged in fishing industry. The tsunami waves that hit Sri Lanka on the 26th December 2004 decimated coastal fishing communities. They were affected by loss or substantial damage to not only their shelter, but also boats and fishing gear. Some of the estimates of the scale of destruction indicate that:

1) Nearly 90% per cent of fishing people were seriously affected having lost their boats, fishing nets and homes.
2) Nearly 80% per cent of the 30,000 fishing vessels in the country were completely destroyed. The bulk of the boats destroyed or damaged are small non-motorized boats owned and operated by the poorest of the community. There are estimated 8000 small boats in Sri Lanka and all these boats had to be replaced. About 700 multi day boats need replacement.
3) Fishing ports, harbors and anchorage spaces were devastated with extensive loss of essential infrastructure such as ice plants, cold rooms, workshops, slipways and marine structures.
4) A large number of boat yards that produce boats for the fishing community were also very badly damaged

3. Recovery processes of the government of Sri Lanka

The Tsunami disaster presents a huge challenge to communities, civil society groups, charitable agencies and the governments. For the Tsunami emergency support operation government adopts an integrated/holistic approach to address the multiple needs of the affected communities by helping them to make a living and gain access to basic infrastructure and services like safe, clean water, transport, housing and electricity. Though the country was not geared for such emergency situation in 2004, government of Sri Lankan has managed to address critical issues by convene an agency know as Centre for National Operation (CNO) and three senior level task forces — the Task Force for Rescue and Relief (TAFRER), the Task Force to Rebuild the Nation (TAFREN), and the Task Force for Logistics, Law and Order (TAFLOL) to create a platform for the operational and coordination of all aid agencies to support all communities in both conflict and non conflict areas that have been affected. And also collaborate with National and International other aid agencies to ensure that additional needs (education, psychological, medical etc.) of the communities were addressed at the appropriate time of the recovery processes. In the recovery processes in 2005 mainly four components were focused initially to Build Back Better. At large, recovery processes main component focus at the following:

- Temporary shelter to permanent housing program
- Restoring of livelihoods
- Health and education
- Infrastructure Sector

As an agency not rooted in the existing state institutional framework, TAFREN experienced a sharp learning curve before instituting significant institutional reforms in the second half of 2005. Before these could be fully embedded, in January 2006, TAFREN was replaced with a new institution for the better result, knows as Reconstruction and Development Agency (RADA) in November 2005. RADA was placed under the Presidential Secretariat and given statutory authority by an Act of Parliament. This agency was created mainly to focus on reconstruction and development issues across all sectors and stakeholders in affected areas in the recovery processes. The Government of Sri Lanka has adopted the following guiding principles for recovery and reconstruction: equity, subsidiary, consultation, communication and transparency, analysis of individual interventions, management of debt relief and coordination, and monitoring and evaluation. Some of the developments are:

Equity. RADA is following district allocation of resources reported in DAD to ensure distributive equity. However the implementation and delivery of outputs in the North and East indicates that there is a slow down as a result of the deteriorating security situation. RADA and Ministry of Defense are working together to solve problems affecting the flow of goods to the affected areas.

Consultation (i) The Human Rights Commission (HRC) is deploying Help-Desks at the district level and will engage in people's consultation with selected focus groups; (ii) the revised housing policy includes "community participation" as an important objective, as well as wide consultations with Development Partners and District and Divisional Secretariats.

Subsidiary. In March 2006 the District Secretariats were authorized to assume overall responsibility for the implementation of all Tsunami Housing Projects in their districts, in partnership with affected parties, donor organizations, state agencies and relevant stakeholders.

Communication and transparency. Development Assistance Database (DAD) is fully operational and web based. A new communication strategy is being developed for communicating the revised Tsunami Housing Policy to the affected populations.

Monitoring, evaluation and accountability to beneficiaries. A monitoring and evaluation system is being finalized, which will enable RADA to produce a monthly progress report with input from the districts. This mechanism will be used to remove constraints and bottlenecks in the recovery process. A mechanism (survey and focus group discussions) to include the voice of beneficiaries in the monitoring and evaluation of the recovery process is being planned.

Disaster management and early warning. In February 2005, a multi-party Parliamentary Select Committee was created to investigate the lack of preparedness to meet future humanitarian emergencies and to recommend steps to mitigate future risks. In June, the committee recommended the formation of a new Disaster Management Centre (DMC) with a stronger mandate, allowing the DMC to work with multiple stakeholders at various levels of the administration, and also to actively engage in risk reduction. In may 2005, the Sri Lanka Disaster Management Act No: 13 of 2005 was enacted. By November 2005, the DMC was moved from the President's Office into a newly created Ministry of Disaster Management, under the Prime Minister's Office. (In early 2006, it was relocated again to form part of a new Ministry of Disaster Management and Human Rights. At the district level, the UN provided early skeletal support to District Secretaries through its UN Volunteer Programme).

Building partnerships for livelihoods recovery

Private sector: Federation of Chamber of Commerce and Industry Sri Lanka (FCCISL) to assist and facilitated loans to affected enterprises under their Back to Business project; This strengthen the coordination between affected enterprises and government banks. Federation of Chamber of Constructions to give technical guidance to community infrastructure projects and cash for work activities; Coir Council International is to support affected coir sector.

I/NGOs: Consortium for Humanitarian Affairs (CHA) as coordinating and facilitating agency for I/NGOs at national and district level. MOU with CHA & FCCISL has strengthened the coordination & facilitation among I/NGOs, private sector and government. Partnership with Relief Aid International (Canada) and Ceynor to set up 30ft boat manufacturing yard.

UN agencies: International Labor Organization with its Income Recovery Technical Assistance Program (IRTAP) to technically support "Income Recovery Program; United Nation Development Programme, especially with CADREP, to use their district staff for livelihood restoration activities in the districts; Food and Agriculture Organization to liaise with agencies supporting fisheries and agriculture sector restorations.

Government ministries: Ministries of Public Administration, Plan Implementation, Fishery, Labour, Agriculture & Livestock, Rural Livelihoods, Skills Development, Vocational Development, Tourism to coordinate their programs in line with RADA's activities.

Departments: Coordinating links with Fishery, Agriculture, livestock, Samurdhi.

Other agencies: Coconut Development Authority to establish national coordinating committee, University of Colombo and People's Planning Commission to represent community requirements in planning.

Banks: Central Bank of Sri Lanka to liaise with other registered banks.

3.1 Institutional framework For Disaster management in Sri Lanka

Aftermath of Tsunami 2004 the government of Sri Lanka, local and international organizations have recognized the urgent need for comprehensive risk management in terms of short terms and medium terms with the context of the post-tsunami recovery as well as over the long term with a view to integrating DRM with the development processes. . As a result of the above National Institutional Framework has been recommended by the parliamentary committee, to provide the legal basis for a DRM system in Sri Lanka. The DM Act established the National Council for Disaster Management (NCDM), Chaired by H.E. the president and Vice –Chaired by the Hon. Prime Minister with participation of the leader of the Opposition. This high –level oversight body provides direction to DRM efforts in the country. (Detail organization is shown in Figure:2)

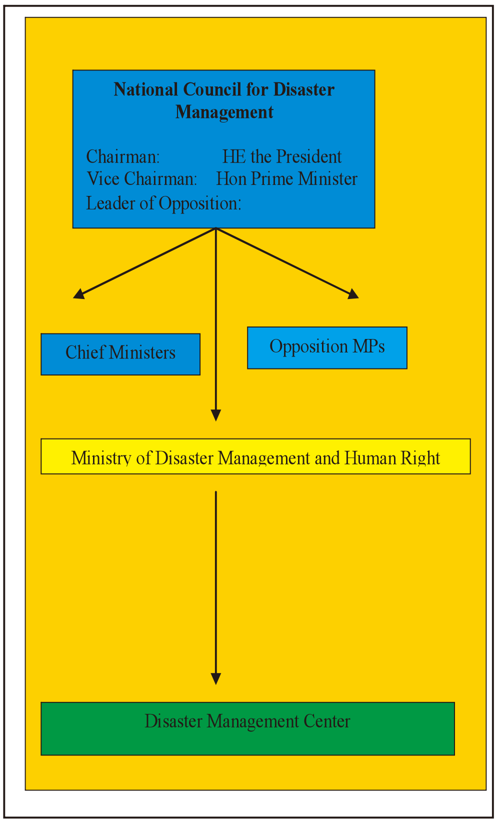
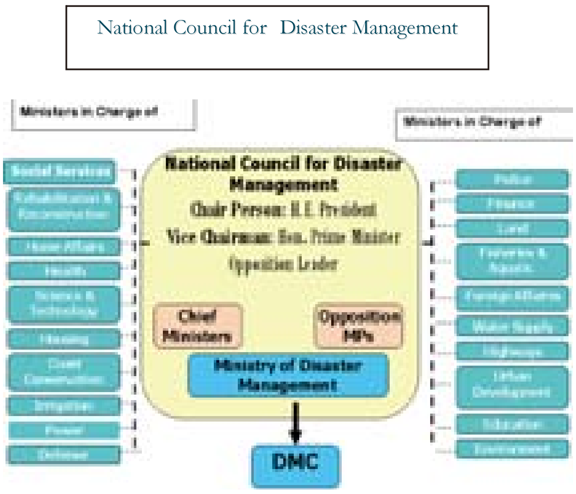


Fig. 2. Coordination Mechanism of Disaster Risk Management in Sri Lanka

Source: Road Map for DRM Sri Lanka

The Ministry of Disaster Management and Human Right is mandated of both the planning and implementation of policies on disaster mitigation and prevention. Under the preview of the ministry, DMC has focused primarily on pre- disaster event planning, mitigation and prepared activities to prevent or to limit adverse effects from all kind of hazards. The Ministry of Resettlement and Disaster Relief Services which oversees mitigation and emergency response was passed down the National Disaster Relief Service Center (NDRC) which was operational from early 1996 and aftermath of tsunami it was coordinate and reporting of Tsunami activities and it will concentrate on post disaster response and recovery activities. However, the need of coordinating effort of various government agencies and the offers of support by the international agencies has been widely recognized and yet to be fully harnessed. This need was reconfirmed against the demands of the UN- International Strategy for Disaster Reduction (UNISDR) Hyogo framework for Action 2005-2015 to coordinate which Sri Lanka is signatory. (Figure:3)



Source: Road Map for DRM Sri Lanka

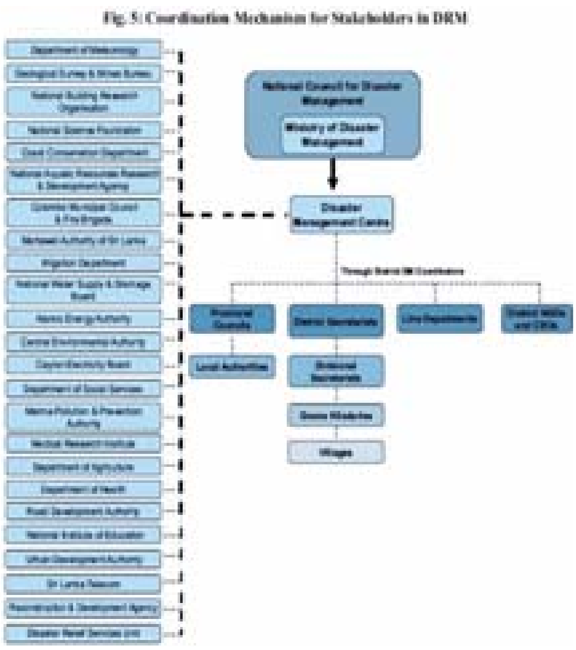


Fig. 4. Coordination Mechanism for Stakeholders in Disaster Risk Management in Sri Lanka
Source: Road Map for DRM Sri Lanka

4. Road Map toward Building a Safer Sri Lanka

A national disaster risk management frame work document titled as "Roadmap For Safer Sri Lanka "was launched in December 2005 in Colombo by the DMC of Sri Lanka and Ministry of Disaster Management and Human Right, in collaboration with UNDP Sri Lanka. This document proposes comprehensive framework which will identify and coordinate multiple stakeholder efforts in the next 10 years through a holistic strategy or Road Map towards building a safer Sri Lanka. This document focused on seven thematic components which are consistent with:

1) Policy, Institutional Mandate and Institutional Development
2) Hazard, Vulnerability and Risk Assessment
3) Multi-hazard Early Warning System
4) Planning for disaster Preparedness and Response
5) Disaster Mitigation Integration into Development
6) Community base DRM and,
7) Public Awareness, Education and Training

These components have been developed through consultative processes to identify the gaps, needs, priorities and strategies for implementation. The strategies and priorities for said project have been developed by working groups constituted from relevant stakeholder agencies. These groups comprised of multiple stakeholders, representing all sectors involved in DRM.

A supplementary to the Roadmap, with detailed project proposals and reference to the HFA was released (Volume 2 of the Roadmap) in March 2006.

5. Conclusion

The HFA call for a decentralization of disaster risk management to regional and local levels, which the National Disaster Management Plan (NDMP) attempts to do through numerous component of the Roadmap. The NDMP and Roadmap include component of capacity building, technology and knowledge transfer activities directly required by the HFA. The plans and policy of the Ministry of Disaster management and Human Right in strong belief

that it is the inclusion and resilience of communities- the first to affected by disaster and first to react – which will make DRM effective. To this end Sri Lanka's disaster management strategies are to be planned with all stakeholder ministries, national and provincial level administration, privet agencies, civil societies, non – government organization and community level.

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Tsunami Disaster Mitigation Consideration

— The Social Perspective of Tsunami Disasters —

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Abstract

This paper attempts to consider tsunami disaster mitigation from social perspective. The paper also tries to illustrate that this consideration relates to the importance of an integrated approach to disaster research and policy. To attain these aims, the paper tries to answer the following inquiries: “What is the meaning of tsunami disasters as natural disasters?”, “What is social system embedded in the context of tsunami disasters?”, “What is the relationship between disaster and recovery?”,and “How does research and policy help to mitigate the damage from a tsunami?”. In this paper, these are explained through a case study of the Indian Ocean Tsunami Disaster of December 26th, 2004.

Key words : Road Map for Safer Sri Lanka, Comprehensive Disaster Risk Management.

1. Introduction

On 26th December 2004, the Indian Ocean Tsunami Disaster provided many significant lessons and social perspectives on natural disasters. However, research on it has been disproportionately focused on the natural physical process, not its on social implications. This was due to in the main to a lack of available resources and local issues, for example, languages, accessibility, security, and unstable political climates. This paper identifies several aspects of social concern connected with tsunami disasters using a case of the Indian Ocean Tsunami Disaster, and proffers considerations for sustainable tsunami disasters mitigation.

To clear the above issues, the paper focuses on the following five points. First, it defines the ways in which a society is subject to the impacts of tsunami disasters. Second, it identifies the factors that determine the magnitude of socioeconomic impacts to tsunami disaster. Third, it identifies how and when a society can return to its pre-disaster level of social conditions in the disaster stricken communities and think about the necessity. Fourth, it describes how we can consider tsunami disaster mitigation for a sustainable future. Fifth, it identifies needs for an integrated approach to disaster research and policy to mitigate tsunami disasters.

This paper consists of three parts as follows: first, a theoretical framework; second, a discussion of the impact of the Indian Ocean Tsunami Disasters; and third, the better approach to mitigate tsunami disasters for a sustainable future.

2. Theoretical framework

2. 1 What are natural disasters?

This paper poses the question of“What are natural disasters?”. In addition, it addresses the issue of the “Risk Society” as a theoretical framework for understanding tsunami disaster mitigation.

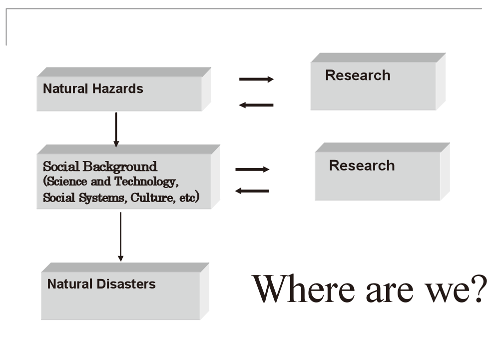

Fig. 1. Natural Hazards and Natural Disasters

Natural Hazards are defined by UNESCO as naturally-occurring physical phenomena. Moreover, natural disasters are the consequences or effects of natural hazards. Thus, we may say that disasters are the direct result of natural hazards whose effect can be classified as natural disasters. Since the effects of natural disasters on communities are widespread, we cannot omit the social context of natural disasters. We should understand that society makes disasters(Fig.1).

2. 2 Risk Society

The German sociologist, Ulrich Beck, stated that, "Risk reflects class pattern. Risk is inclined to exist in the lower class. In other words, poverty attracts risk. The wealthy classes can purchase safety and are free from risk because they have income, power, and education (Beck, 1992:35)."

From this perspective of risk, we have developed science and technologies, including information technology (IT), so as to reduce the risks of natural disasters. Despite these advances, a great number of people cannot yet obtain appreciable benefits from this knowledge because their low socioeconomic status means that they tend to lack awareness of natural disasters. As a result, they are more likely to become victims of natural disasters. This paper has focused on their position from sociological points of view.

2. 3 The Environmental Kuznets Curve

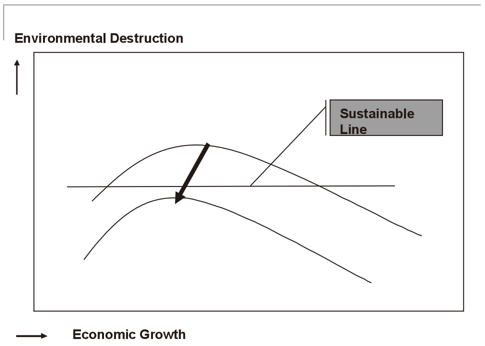

Fig. 2. The Concept of the Environmental Kuznets Curve (World Bank, 1992)

This paper outlines that we should focus on minimizing the Environmental Kuznets Curve for our common sustainable future (Fig.2). The curve, which is named after Nobel Prize winner Simon Kuznets, has been discussed and examined by many scholars and policy makers. However, almost all have focused only on the evaluation of the curve. The World Bank, for example, uses this curve to indicate that the amount of environmental destruction can be decreased by developing technology and increasing funds for environmental programs. This is exemplified by a Japanese case (World Bank, 1992). However, this paper focuses on how better to read and think about this curve because it covers a high number of victims. Furthermore, there are valuable lessons pertaining to environmental degradation and natural disasters. Finding a way to lower the curve under a sustainable line is a new perspective on the Environmental Kuznets Curve that will lessen the damage from future tsunami disasters.

2.4 Cycle of Development, Environment, and Disaster

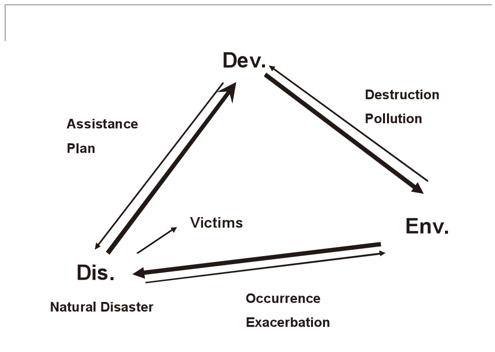

Fig. 3. Cycle of Development, Environment, and Disaster

This paper discusses the viewpoint that we should identify tsunami disasters as controllable natural disasters. The cycle of development, environment, and disasters (Fig.3) is presented. The cycle refers to how the process of economic development exacerbates the damage down to the environment. Disasters are followed by development planning and aid assistance, and vice versa; development planning and aid assistance may sometimes worsen the impact of a disaster. Disasters have an impact on environmental degradation, and environmental changes affect the development process. From this point of view, striving for economic development may increase the risk of tsunami disasters causing additional damage to local communities.

2. 5 Disaster recovery theory

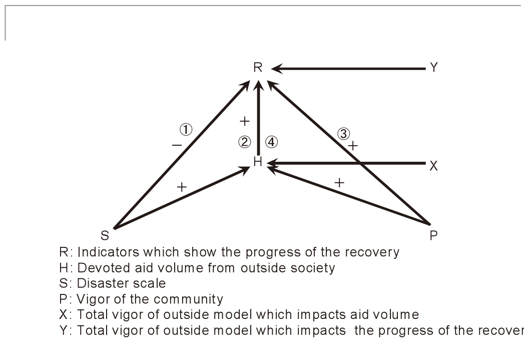

Fig. 4. Cause-Effect Diagram on Disaster Recovery Process (Hirose, 1982)

"Does recovery need to be complete?" "What is the meaning of disaster recovery?" Is Haas's assertion, "The recovery process follows the trend which the affected communities originally had before the disasters. The declining communities would decline after the events. The growing communities would catch up quickly and grow even if the communities had been completely devastated?"(E. J. Haas, et al., 1977) true? These are the pertinent queries regarding the disaster recovery process from this paper's point of view. A disaster recovery theory is shown in Fig.4. It shows that the progress of the recovery is derived from the vigor of the community, the scale of disaster, and the volume of aid devoted to it. In addition, Fig.5 shows the concept of vulnerability. Resilience is also an important facet to recognize in the field of disaster recovery.

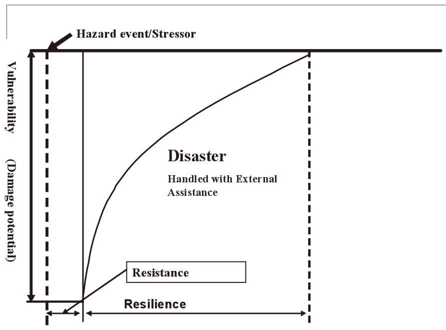

Fig. 5. Concept of Vulnerability (Bogardi, 2006)

This paper focuses that a disaster is induced by environmental degradation and caused by the development process. Areas that were devastated by tsunami disasters were already environmentally overloaded before the event. Therefore these points might give us the consideration of the inquiries above. We sometimes accept complete recovery on the surface without thinking about changes in the environment. A long perspective is needed in order to build a sustainable future. This means we should deeply reconsider the development processes of the affected areas after a catastrophic event.

3. The Impact of Indian Ocean Tsunami Disasters

3.1 Overview

Impact of Indian Ocean Tsunami of 2004 is shown in Fig.6. First, we can see that Asian countries are vulnerable to natural disasters. Second, we can understand the devastating impact of the tsunami

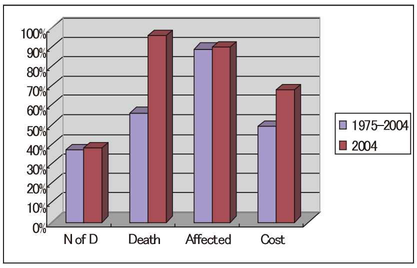

Fig. 6. Regional Vulnerability (Asia)

by the high number of deaths. The characteristics of the tsunami are that it was an international disaster and had a huge effect on developing countries in Asia (Fig.7). To find ways to reduce the damage from tsunamis, this paper has focused on these characteristics.

3.2 The Socioeconomic Status of Victims

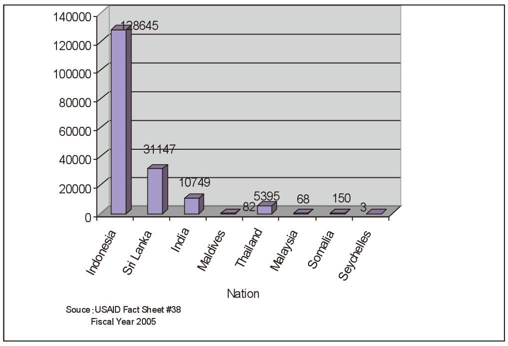

Fig. 7. Death Toll of the Indian Ocean Tsunami Disaster (USAID Fact Sheet)

The areas affected by the tsunami were mainly in developing countries in Asia. As seen from the death toll chart and the Human Development Index (HDI), deaths from the tsunami were concentrated among groups with a low socioeconomic status.

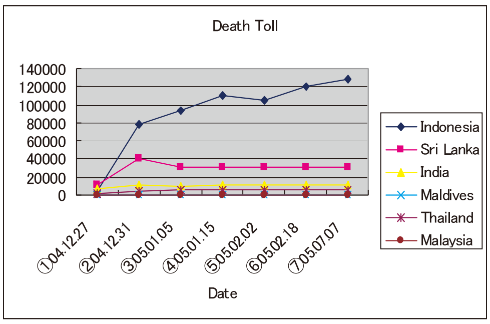

Fig. 8. Tsunami Death Toll by Country, December 27, 2004 - July7, 2005

The number of deaths changed day by day (Fig.8). For instance, the number of deaths reported in Indonesia from January 15 to January 30, 2005, decreased. By comparison, the situation in Yemen was quite different. The UN Food and Agriculture Organization (FAO), found more damage (five dead and over two thousands affected) than ever before recorded in Yemen. Staff from the FAO tried to list Yemen on the UN registry of countries eligible for international aid for tsunami victims. The delay in registering Yemen could be related to the fact that Yemen is one of the least developed countries in the world. A low level of development appears to hinder the ability of public officials to identify the number of victims and to receive broader acknowledgement from the international community of the impact of the disaster.

Table. 1. Tsunami Death and the HDI (Human Development Index) Rating by Country

Country	HDI Rank (1—177)	Death Toll from Indian Ocean's Tsunam (2005.2.)
Indonesia	111	128,645
Sri Lanka	96	31,147
India	127	10,749
Maldives	84	82
Thailand	76	5,395
Malaysia	59	68
Somalia	NA	150
Seychelles	35	3
Yemen	149	(5)

The HDI is derived not only from economic indicators, but also from levels of education, . Including these broader variables makes HDI useful as a social maturity indicator. Looking solely at GDP is not relevant because many Asian countries tend to seek economic growth by exploiting their natural resources without considering the effect upon the environment and society. As outlined in Table 1, most Asian countries affected by the Indian Ocean tsunami have a relatively low HDI.

3.3 Economic Development Increases the Number of Disaster Victims

Economic growth in Asian countries has been quite rapid. The policies of most Asian governments have served to stimulate economic development, often at the expense of the social and environmental development. The Asian countries most affected by the tsunami had exploited natural resources for the purposes of economic development. Natural resources continued to be depleted without considering the impact upon the environment and society. There is a correlation between the number of tsunami victims and an approach to development that ignores environmental issues.

For example, developing countries in Asia that export shrimp to Japan were seriously affected by the tsunami. They created shrimp farms by cutting down mangrove swamps in coastal areas. This intensive farming in turn reduced the quality of the land, so it became less productive over a relatively short period. To make matters worse, the damage to the land was exacerbated by expanding the shrimp farms further. The whole area became susceptible to natural disasters because of its exposed geographical location. The tsunami is an example of how the effects of the disaster in Thailand, Sri Lanka, and other countries in Asia were the direct result of environmental mismanagement. Japan, as the main buyer of shrimp from these areas, indirectly contributed to the destruction caused by the tsunami. The high scarce resources (UNU, 2006:8), experienced by many developing countries is evidence that the current development processes are not leading to sustainability. These processes are not only found in the current situation of developing countries', but also in Japan after the World War II.

4. An Approach to Mitigating the Damage from Tsunami Disasters for a Sustainable Future

4.1 Understanding and Responding to the Victims of Tsunami Disasters

This paper would like to emphasize the following three points: First, human beings have succeeded in mitigating the effects of natural disasters through the application of science and technology. This knowledge has played an important role in reducing the negative effects of natural disasters.

Second, despite this advance in technology, a great number of people in the world still do not benefit from this knowledge. Only the upper classes obtain the benefits. This is true in both developing and developed countries. Third, the developing Asian countries tend to seek economic growth by exploiting natural resources without considering the environmental and social impact. Developed countries through trade patterns exacerbate this process. Narrowly conceived economic development has increased the impact of tsunami disasters, causing widespread damage.

4.2 Interconnections

Finally, this paper focuses on interconnections, both historically and globally. We are here to connect with the past, the present, and the future. We are also here to connect with family, friends, co-workers, neighbors, and people in other countries on all kinds of levels, such as the web. Disaster and recovery, as it were, cut these interconnections in a moment and we then try to reconnect them again. The cycle of development, environment, and disaster that this paper has mentioned underlines the fact that they are connected with each other. Therefore, any development plan for a sustainable future must take into account how we can consider the environment and thus mitigate the damage from tsunami disasters. Moreover, this paper has shown how different countries are connected with each other through the example of shrimp farming. People are also deeply connected with each other through everyday interactions like the victims of the Kobe earthquake said “The most effective way of mitigating of the disaster was the usual conversation with neighbors about daily life”. We should recognize these interconnections, and how we connect with each other historically and globally of all kinds of levels we can estimate. This is one of the keys to start to consider in policy and research on mitigating the damage caused by tsunamis. As mentioned above, developing our countries by not only increasing economic growth but also by considering together with economic growth, the environment, disaster preparedness, and interactions with others, with special focus on the interconnections, is required for a sustainable future. More research and policy utilizing an integrated way of thinking, including social aspects such as focusing on interconnections mentioned above is needed so that we can better prepare for, respond to, mitigate against, and recover from tsunami disasters.

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Indian Ocean Tsunami Warning and Mitigation System: the role of tsunami risk assessment

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Abstract

The Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWS) was established following the devastating Indian Ocean tsunami of 26 December 2004. The ICG/IOTWS promotes the establishment of national and regional tsunami warning systems in the Indian Ocean through its six technical working groups. Working Group 3 provides guidance on tsunami risk assessment and also focuses on the links with the other parts of the tsunami warning system. Recent activities of WG3 include contributions to guidelines for tsunami risk assessment, collaboration with Geoscience Australia to produce a tsunami hazard map for the Indian Ocean, and palaeotsunami research in countries bordering the Makran subduction zone in the Arabian Sea.

Key words : Road Map for Safer Sri Lanka, Comprehensive Disaster Risk Management.

1. Introduction

The 26 December 2004 tsunami killed over 230,000 people, displaced more than 1 million people and left a trail of destruction around the coasts of the Indian Ocean. Although the tsunami took over 2 hours to cross the Bay of Bengal, more than 50,000 in India, Sri Lanka, Maldives and East Africa lost their lives. An early warning system would have saved many thousands of lives, but none was in place at the time.

Recognising the need for an early warning system, the coastal nations of the Indian Ocean responded quickly. Following two intergovernmental meetings in Paris and Mauritius, the Indian Ocean member states requested the Intergovernmental Oceanographic Commission (IOC) of UNESCO to form an Intergovernmental Coordination Group (ICG) to implement an Indian Ocean Tsunami Early Warning and Mitigation System (IOTWS), and this was formally established at the IOC Assembly in Paris, in June 2005.

2. Goals of the ICG/IOTWS

The terms of reference for the ICG/IOTWS, endorsed by the IOC Assembly under Resolution XXIII-12, are as follows:

1. To coordinate the activities of the IOTWS;
2. To organize and facilitate as appropriate the exchange of seismic, sea level and other data at or near real-time and information required for the interoperability of the IOTWS;
3. To promote the sharing of experience and expertise related to tsunami warning and mitigation for the Indian Ocean basin;
4. To promote tsunami research;
5. To promote the establishment and further development of national tsunami warning and mitigation capacities in accordance with standard protocols and methods;
6. To develop, adopt and monitor implementation of work plans of the IOTWS, and to identify required resources;
7. To promote implementation of relevant capacity-building;

8. To liaise and coordinate with other tsunami warning systems;
9. To liaise with other relevant organizations, programmes and projects;
10. To promote the implementation of the IOTWS within a multi-hazard framework;
11. To keep under constant scrutiny the status of the system and how it satisfies the needs.

The main objective of the IOTWS is to identify and mitigate the hazards posed by local and distant tsunamis. The goal is to create a fully integrated end-to-end warning system comprising three key components: hazard detection and forecasting; threat evaluation and alert dissemination; and community preparedness and response. The work of the IOTWS is conducted by six working groups specialising in seismology, water level measurement, risk assessment, numerical modelling, warning dissemination and community preparedness. The working groups are task teams who are experts in their fields, responsible for establishing standards and for developing work plans. They report their recommendations to the ICG for endorsement and implementation.

3. ICG/IOTWS Working Groups

The six working Groups of the ICG/IOTWS provide technical guidance and advice on all aspects of the end-to-end tsunami warning system.

WG1: Seismic Measurement, Data Collection and Exchange

WG2: Sea Level Measurement, Data Collection and Exchange

WG3: Risk Assessment

WG4: Modelling, Forecasting and Scenario Development

WG5: A System of Interoperable Advisory and Warning Centres

WG6: Mitigation, Preparedness and Response

4. Risk Assessment

Working Group 3 (Risk Assessment) is involved with the hazard detection and forecasting component of the system. The group works closely with Working Groups 4 and 6 to provide a link between the technical and community-oriented aspects of the end-to-end system.

The group's terms of reference are as follows:

- Develop guidelines for tsunami risk assessment as part of a multihazard risk management framework.
- Provide guidance to emergency response managers on the preparation of risk assessment products.
- Facilitate the application and use of model outputs for tsunami hazard and risk assessment.
- Facilitate data sharing, including access to and development of databases, incorporating exposure, tsunami hazard and vulnerability.
- Facilitate capacity building, including knowledge transfer, in the form of workshops, training programs and case studies for risk assessment in all Indian Ocean countries.
- Facilitate and promote the process of developing cost-effective and practical mitigation options and measures.
- Liaise with other modelling committees (including other ICG/IOTWS working groups) and organisations or professional groups that are developing models and data for their implementation.

Recent activities of WG3 include contributions to guidelines for tsunami risk assessment (to be published by IOC in April 2009), collaboration with Geoscience Australia to produce a tsunami hazard map for the Indian Ocean, and palaeotsunami research in Oman (see below), in preparation for a detailed field programme in Pakistan and Iran planned for 2009-2010 (pending funding).

5. Makran Palaeotsunami Studies

A group of 16 Earth scientists from 11 countries met in Oman for ten days in May 2008 for field work and intensive discussions on using coastal geology to assess earthquake and tsunami hazards of the northwestern Indian Ocean. The group focused on geologic clues to tsunami sources at the Makran subduction zone, which produced a tsunami that killed several thousand people in 1945 along what is now the coast of Pakistan. The entire subduction zone, 750 km long, poses a currently undefined threat to the coasts of southeastern Iran, northern Oman, and the Gulf shores farther west. The group accordingly planned a follow-up proposal, subsequently submitted through the IOC to the UNESCAP Multi Donor Trust Fund, to build capacity for using coastal geology and eyewitness accounts for tsunami risk assessment and risk awareness on the Makran coast of Iran and Pakistan.

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Jane Cunneen
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Aditya R. Gusman
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Associate professor
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Amarasingha Vidana Pathiranage Vijitha
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Kenji Satake
Professor
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Invited Speaker

Eko Yulianto
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Estimating the Recurrence Interval and Behavior of Tsunamis in the Indian Ocean via a Survey of Tsunami-related Sedimentation

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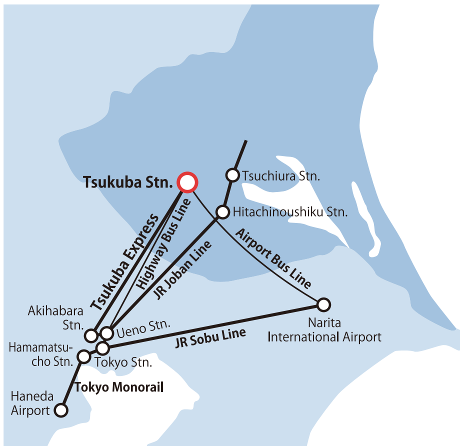

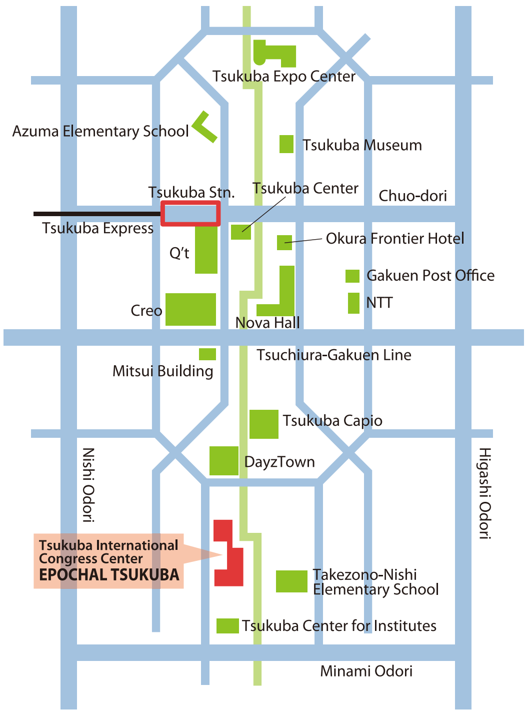

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