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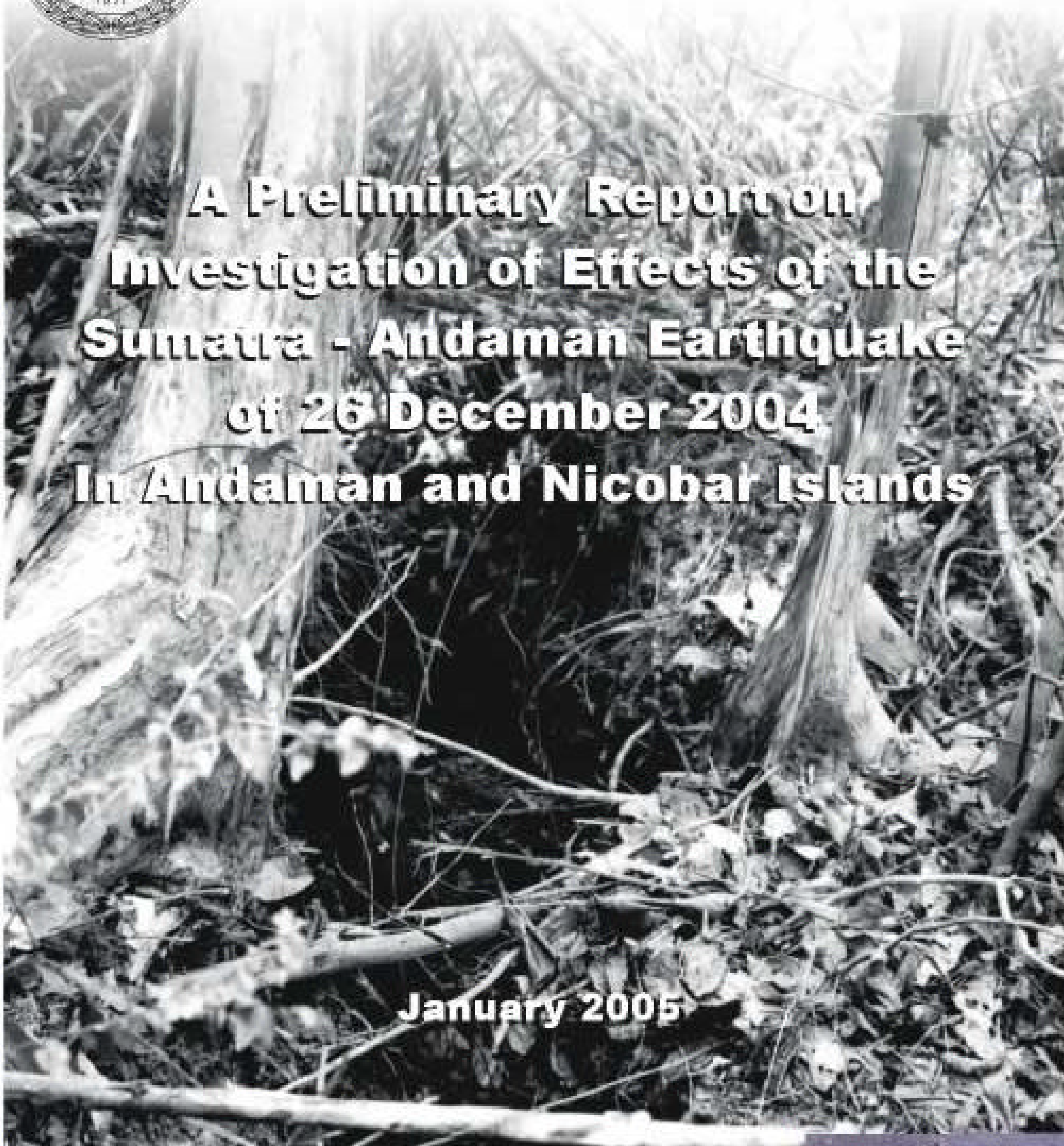
Geological Survey of India

A Preliminary Report on Investigation of Effects of the Sumatra - Andaman Earthquake of 26 December 2004 In Andaman and Nicobar Islands



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by

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Introduction

A Great earthquake measuring Ms 8.6 (IMD), Mw 9.0 (USGS) occurred off the West Coast of northern Sumatra (Indonesia) at 00:58:53 hrs. [06:28:51.1hrs. IST (IMD)]. This is one of the largest interplate shallow thrust earthquakes that occurred at the interface of the subducting Indian lithosphere and the overriding Burma plate. This mega seismic event from the Sumatra subduction zone in the Indian Ocean triggered giant tsunamis that devastated the coastal regions of Indonesia, Malaysia, Thailand, Sri Lanka, India and Maldives and affected even the coast of East Africa. The loss of human lives in the catastrophe has been put at 1.5 lakh. The impact of the tsunami was quite severe in the coasts of Andaman and Nicobar group of Islands, Tamil Nadu, Andhra Pradesh, Pondicherry and Kerala where over 10,000 people lost their lives, thousands injured and property worth several hundred of crores destroyed.

The Geological Survey of India has taken up the investigation of this earthquake and resultant tsunami in the Andaman - Nicobar region and other parts of the country. In this connection a team of senior scientists of the Department, headed by Dr. K.N.Mathur, Director General reached Port Blair on 7th January 2005. After discussions with the Officials of the Andaman & Nicobar Administration, the GSI team (Dr S.K. Ray, Dr S. Sengupta, S/Shri Prabhas Pande and Sujit Dasgupta) visited different parts of South Andaman and Baratang Islands to study the effects of the earthquake and tsunami. This team after initial surveys returned to Kolkata on 12.01.05. Another team of officers from Eastern Region, GSI also reached Port Blair on 07.01.05 and took up detailed investigations to document the effects of the earthquake and tsunami and install GPS in campaign mode. Another group of GSI scientists who reached Port Blair on 06.01.05 is installing an array of five digital short-period seismometers in different islands to record the aftershocks.

This report contains the observations from the studies carried out between 7th and 12th January 2005. A detailed report with analysis on the effects of the earthquake and tsunami and other related issues to be submitted on completion of the work.

Earthquake Parameters

Earthquake parameters for this great earthquake are continuously been revised and refined by USGS since the first estimate released on 26.12.2004. As on 13.01.2005 the parameters as per USGS are as follows:

Date: 26th December 2004
Origin Time: 00:58:53 (UTC) [local time at the epicenter 07:58:53]
Location: 3.316°N, 95. 854°E [± 5.6 km (3.5 miles) horizontally]
Region: Off west coast of North Sumatra
Magnitude: Mw 9.0
Depth: 30 km (18.6 miles)

Harvard Best Double Couple Solution:
NP1: Strike 329, Dip 08, slip 110
NP2: Strike 129, Dip 83, slip 87
Principal Axes: T: Val 4.01, Plg 52, Az 36; N: Val –0.12, Plg 3, Az 130, P: Val –3.98, Plg 38, Az 222

Tectonic Setting

The Andaman- Nicobar- Nias (off Sumatra) sedimentary arc in the northeastern Indian Ocean defines a nearly 2200 km long trench slope break and outer arc ridge between the Indian plate and the SE Asia/Burma plate. This convergent margin joins the Burmese arc to the north and the Sunda arc towards the south. The entire 3500 km long Burmese- Andaman arc constitutes an important transitional link between the Himalaya and the Western Pacific arc system (Figure 1) characterized by varying degree of seismic activity and volcanism. Active subduction of the Indian lithosphere below the Burma plate is documented by the presence of the Barren- Narcondam active volcanic arc that continues to the continental margin arc in Sumatra and an east dipping Benioff zone defined by earthquakes up to 250 km focal depth. The geologic and tectonic history of the region is complex due to the presence of active faults/tectonic features such as the West Andaman fault in the Andaman arc, the Semangko fault in Sumatra, the Sagaing fault in Burma and the Neogene Andaman back-arc spreading ridge.

Seismicity Pattern of the Region between 01.01.2004 and 25.12.2004

A total of 260 earthquake events occurred in the region during 2004 up to 25.12.2004 (USGS Catalogue). Out of these 241 events are of magnitude less than 5.0, 18 shocks between magnitudes 5.0 and 6.0 while there is only one event of magnitude 6.2. Majority (162) of these earthquakes are of shallow foci (≈ 20km) origin. There is an apparent seismic quiescence between 28th November and 25th December 2004 with the last event registered on 27th November 2004 (M= 5.3, depth 41 Km, 1.97N/97.89E).

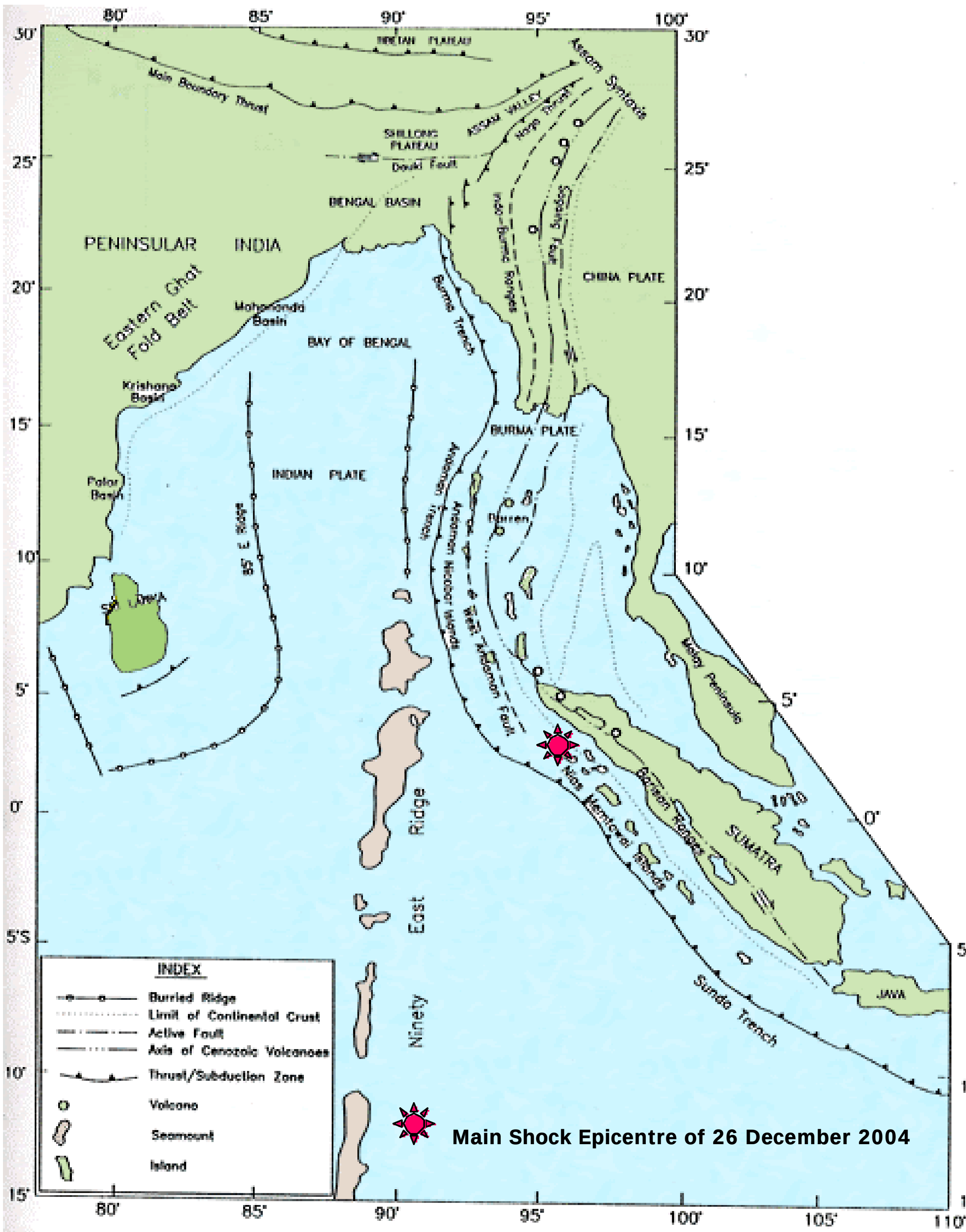

Fig 1: Tectonic Setting of Indo-Burma, Andaman and Sumatra-Java Islands (after Ghosh 1997; Verma et al., 1978)

Field Investigation

Immediately after reaching Port Blair on the morning of 07.01.05 the GSI team started investigating the effects of the earthquake and tsunami in and around Port Blair area (Photo 1). While the present report includes observations carried out by the team during 07.01.05 and 12.01.05, detail investigation in the area is in progress.

Macroseismic Survey

The 26 December 2004 earthquake was strongly felt in the entire Andaman group of Islands and the seismic intensity was enough to cause low order damage to many civil constructions. A cross section of people belonging to different parts of the Islands was interviewed to get first hand information on the nature of seismic shaking. The general human perceptions are as follows: At 06.35 AM (local time) feeble tremors were felt that made many feel giddy. This was followed by strong to and fro shaking which lasted for almost 40 seconds. The time gap between the 1st feeble shocks and the following strong shocks was reported to be sufficient for most of the people to come out of their buildings even from 2^{nd} floor. No sound, however, accompanied the tremors. People ran outdoors in great panic; most people lost balance, fell or sat down and crawled out of their buildings. Those riding bicycles or motorbikes felt strong wobbling effect and therefore immediately stopped. Parked cycles and a scooter fell down during strong shaking. A parked bus was visibly vibrating. Objects and utensils on racks were thrown. At few places even heavy objects like steel almirah and racks overturned. The total duration of shaking have been reported by many to be of the order of 3 minutes.

Different grades of damage to buildings have been recorded from different parts of South Andaman. In Port Blair area, places like, Marine Park, Aberdeen jetty, Chatam, Nayagaon, Bamboo Flat, etc. were visited. Buildings like the Secretariat, Haddo Circuit House, Blair Hotel, which are Type C structures suffered damage of grades 1 and 2. Most buildings of B/C type in and around Port Blair suffered similar damage. In a single case at Nayagaon a newly constructed 3-story building over stilt with RCC columns and beams suffered grade 5 damage. The entire soft-story ground floor caved in due to failure of load bearing base column (Photo 2 & 3). The upper two floors though tilted, were much less damaged. In the Bamboo Flat area many of the buildings showed grade 2 cracks. In a newly constructed house belonging to C. Mahammad Arif, which at the time of the earthquake was not even occupied, much higher damage was seen in comparison with rest of the area. This two-story structure with RCC columns, beams and RCC roof caved in such a manner that the ground floor got completely crushed and the first floor came to the ground floor level (Photo 4). This was also a stilted structure where the base columns were not tied with shear walls. It appears that under condition of prolonged lateral loading the base columns supporting a heavy load sheared off resulting in grade 5 damage.

In the Kanyapuram locality one newly constructed house belonging to Mr. Hamid, was reduced to a heap of rubble. The two-storied RCC structure with GI roof completely caved in and a car parked in the ground floor completely crushed (Photo 5).

In the Ograbraj locality, a godown of Malabir Society was heavily damaged. This was a structure with approximate dimensions of 8 m (w) x 15 m (l) x 6 m (h). The walls were of hollow concrete blocks with RCC columns at the corners and at the central parts of N-S aligned long walls. The slanting roof with GI sheets was supported by heavy wooden beams and rafters. The three walls and the roof suffered total collapse. The quality of construction was very poor, where steel used was found to be rusted and concrete of low strength (Photo 6). The area was subsequently inundated by the tsunami back flow (Photo 7). In the Collinpur locality, almost all the buildings suffered grade 2 or 3 damages. In a single case, a single story restaurant suffered damage of grade 5 in the form of total collapse of the structure. The long wall of the shack of GI sheet roofing seems to have thrusted in N45°E direction. In this area, the foundation comprised clayey soil with shallow groundwater table.

In the Baratang Island, similar seismic intensity was recorded. The Forest Range office suffered grade 2 or 3 damage in the form of shear cracks in walls and gapping settlement cracks in the floor. A number of steel almirah and racks containing office records and the hanging tube lights fell down during the earthquake.

Water Supply Schemes for Port Blair

Dhanikhari Dam

This water retention structure on Dhanikhari River was constructed during 1970-1973 for supply of water to Port Blair town. The dam is a 132 m long and 32.23 m high straight gravity –concrete structure with a central gated spillway having a capacity of 26,000 cusec. The reservoir extends to an area of 0.49 x 10 sq miles and the storage capacity is of the order of 9000 lakh litres. On 26 December 2004, the reservoir stood at R.L. 60.60 m. Inspection of the dam revealed some minor distress to the main structure due to the earthquake. Development of fine cracks and chipping off plaster along two of the right abutment block joints was visible (Photo 8). Inspection of foundation gallery showed cracking of the RCC along the fifth block joint, through which considerable amount of seepage was taking place. Some minor seepage was also coming from the right abutment slopes of the gallery. It was reported that prior to the earthquake, the water collecting in the foundation gallery used to be pumped after every six hours. After the earthquake and due to the increased seepage, it now requires hourly pumping. The reservoir water was also considerably agitated due to the passage of the shock waves as manifested by the seiche (standing water waves), which rose by as much as 3 to 4 m. After the earthquake, the main supply pipes were dislodged and therefore, in the initial days, the water supply to the town remained disrupted. It has later been restored.

Chouldari Dam

Chouldari water supply scheme is a 19 m high and 95 m long earthen dam structure with a 10 m wide and 80.58 m long left bank ungated RCC chute spillway. The earthen section has pitching of basalt blocks, both in the upstream and downstream sides. A concrete apron has been placed over the entire length of the crest. The distress to the dam on account of the earthquake is seen at the junction of the earthen section and spillway concrete. Here, the concrete apron has buckled by as much as 8 cm along the block joint (Photo 9). The profile of the earth section otherwise does not show any deformation or distress. It is reported that on 26th morning the reservoir level (reservoir area 15 ha) was quite low. But due to the tremors the waves in the reservoir rose so high that they splashed on to the crest portion that was about 5.6 m above the reservoir level.

Ground Fissures and Liquefaction

Ground fissures, slumping and subsidence were witnessed at several places in the coastal belt of Andaman Islands. At Collinpur locality, the fissures are arcuate in disposition, trends N-S and appeared to be a product of liquefaction and consequent lateral spreading (Photo 10). Here, the water table is barely a meter or less deep and the topsoil clayey silt. During the tremors, fissures were formed through which the ground water spouted. At a few places, cream-colored fine sand/silt also ejected out. As reported by the locals this zone of ground fissure continues intermittently for 6-7 km between Tirur in the north and Khurma beach in the south. A few buildings, which were founded over such a spreading zone suffered conspicuous damage. In a stray case, rolling down of a boulder from a hill has been reported at Collinpur. In the Baratang area the ground fissures are so pronounced that they damaged considerable stretches of the metalled road. These fissures are described below.

Mud Volcano Eruptions and Surface Rupture at Baratang

In the Island of Baratang, two major and some minor mud volcanoes among the chain of dormant ones erupted during the earthquake of 26 December 2004. Of the two major sites of eruption, the one in Jarwa Creek was examined in some detail. It is reported that soon after the major tremors, this volcano erupted with great violence. A series of explosions that lasted for several minutes accompanying the eruption could be heard from distances as far as 2-3 km from the site. A resident of Rajatgarh village narrated that he saw the mud splashing to above the forest tree height. At the eruption site on the following day he witnessed flames coming out of one vent. During the present study the site was visited after 17 days of the eruption. The mudflow of 26th December 2004, has spread in an area of around 10,000 sq m and had a very distinct bulged contact with the older mudflow (Photo-11). The shape of the mudflow can be described as that of a flattened bun. The main crater, located at the center of the mud deposits was no more active. Gases along with small quantity of sticky and viscous mud was still coming out in fits and rhythms through another newly formed vent located about 10m away from the previous one (Photo-12). Blowouts with an average frequency of 2 minutes accompanied by low blurring and hissing sound, was audible from a distance of 10 m or so. This crater is about 0.75 meter in diameter with a vent of about 20 cm at the center.

The erupted mud consisted of very fine clay particles containing small angular fragments of rocks. The wet spouted clay dried and hardened almost immediately after coming into contact with air and was getting deposited at the rim of the new crater. Gas and mud erupted are odorless, inflammable (probably methane) and were at ambient temperature. On the whole, a feeble sulphurous smell pervaded over the mud volcano. The maximum height of the recent deposits is estimated to be around 3 m. The total volume of the erupted mud is calculated as 1600 cu m. However, estimate by the Forest Authorities place this figure at 2400 cu m. It is quite certain that this entire mud was ejected out within a very short time span after the earthquake. The mudflow in the rim portion has partially flooded some of the tree plantations.

About 500-700m metalled road stretch from the mud volcano site towards Baratang Divisional forest office is highly fractured. These open fractures trend N25E, cut across the road (Photo 13) and continue on either side on ground as irregular fractures. Both right and left lateral slip of 5 to 10cm observed on the edge of the road. In this stretch at one place the black- topped road surface has buckled up to develop as an antiform with height at the axial region of 25-30cm. Almost parallel to the road a 90 cm to 1.5m wide surface fracture trending N55W continue for about 50m and join with one of the fracture that cut across the road. In this stretch a healthy long tree with its roots was found neatly split vertically into two parts and shifted horizontally (Photo 14). While the left hand portion of the tree remained almost insitu the right hand part was displaced about 1.20m diagonally towards north, thus showing left-lateral shear. The horizontal component of slip along the fault plane is about 85cm. Close to the intersection of this fault and the fractures cutting the road a newly formed small mud volcano with a distinct crater was seen. Through the pulsating vent small amount of odorless gas and wet clay with a film of black colored odorless substance were spouting at regular interval. In two nearby sites minor quantity of gas was continuously escaping from pool of water.

Effect of Tsunamis in Andaman Islands

The tsunamis or the sea waves generated by the main Sumatra Earthquake of 26th December 2004 was very profound in the low-lying coastal regions of Andaman & Nicobar group of Islands. The sea that rose as much as 2.5 m above the high tide line entered inhabited area with great velocity. The waves flattened a number of dwelling and constructions, breached the shore protection walls, certain sections of the low level roads, impaired some bridge and harbor structures and inundated vast stretches of shore land (Photos 15,16,17 & 18). Influence of the waves was greatly accentuated due to run-up and ingress of the seawater (Photo 19) into the low lying cultivated fields and human settlements through the various creeks. Many such areas are still inundated under the saline water and there is fear of the soil becoming unfit for cultivation in future. The tsunamis also flooded many of the dug wells thereby contaminating the fresh water sources.

A number of residents who witnessed the catastrophe were interviewed to reconstruct the scenario. The general observation was that after about 15 to 20 minutes of the main shock the first influx of sea waves approached the shores. The water level rose to above the high tide level. After some time the second influx came in which the water level increased still further and then receded. The recession in water level was so much that the seabed became visible for quite a distance. The residents never witnessed such phenomena earlier. The velocity of waves in the two influxes was slightly above normal. At around 8.30 AM the third influx came to the shore with such a velocity that everybody was caught unaware. The water level rose to the maximum, in some cases to over 2.5 m above the high tide level.

The velocity of the ingushing water was such that even those who were running away from the water front, were soon overtaken. After the 26 December, 2004, tsunami, the sea has remained at a higher level then normal and the difference between the high tide and low tide levels seems to have reduced. Now, during the high tide, some areas are still getting flooded and on an average the high tide level is about 1m higher than the pre-earthquake situation. This was never the situation before the tsunamis struck. However, it is observed that with the passage of time sea level is slowly tending to recede.

Aftershock Monitoring

An intense aftershock activity has been recorded following the Great Sumatra- Andaman earthquake (Figure 2). The IMD seismic observatories have recorded a total of 124 aftershocks in excess of M 5.0 from 26th December 2004, to 11th January 2005. The largest aftershock was of M 7.0 that occurred on 26.12.2004, 120 km west of Nicobar Island. 11 aftershocks are of magnitude ≥ 6.0 while the remaining 112 events are in the magnitude range 5.0- 6.0. USGS has recorded 223 aftershocks up to 09.01.05 of magnitude ≥ 4.4. While 52 events are of magnitude ≤ 5.0 remaining are above 50. Aftershock sequence from the IMD list gives a b-value of 1.08 while those from the USGS catalogue gives 1.20. Predicted Mmax is 7.1 from both the catalogue, which has already struck on 26th itself. p-value calculated from IMD list is 0.97 while that from USGS 1.27 suggesting that aftershocks of magnitude ≥ 5.0 will possibly decay within 40 days.

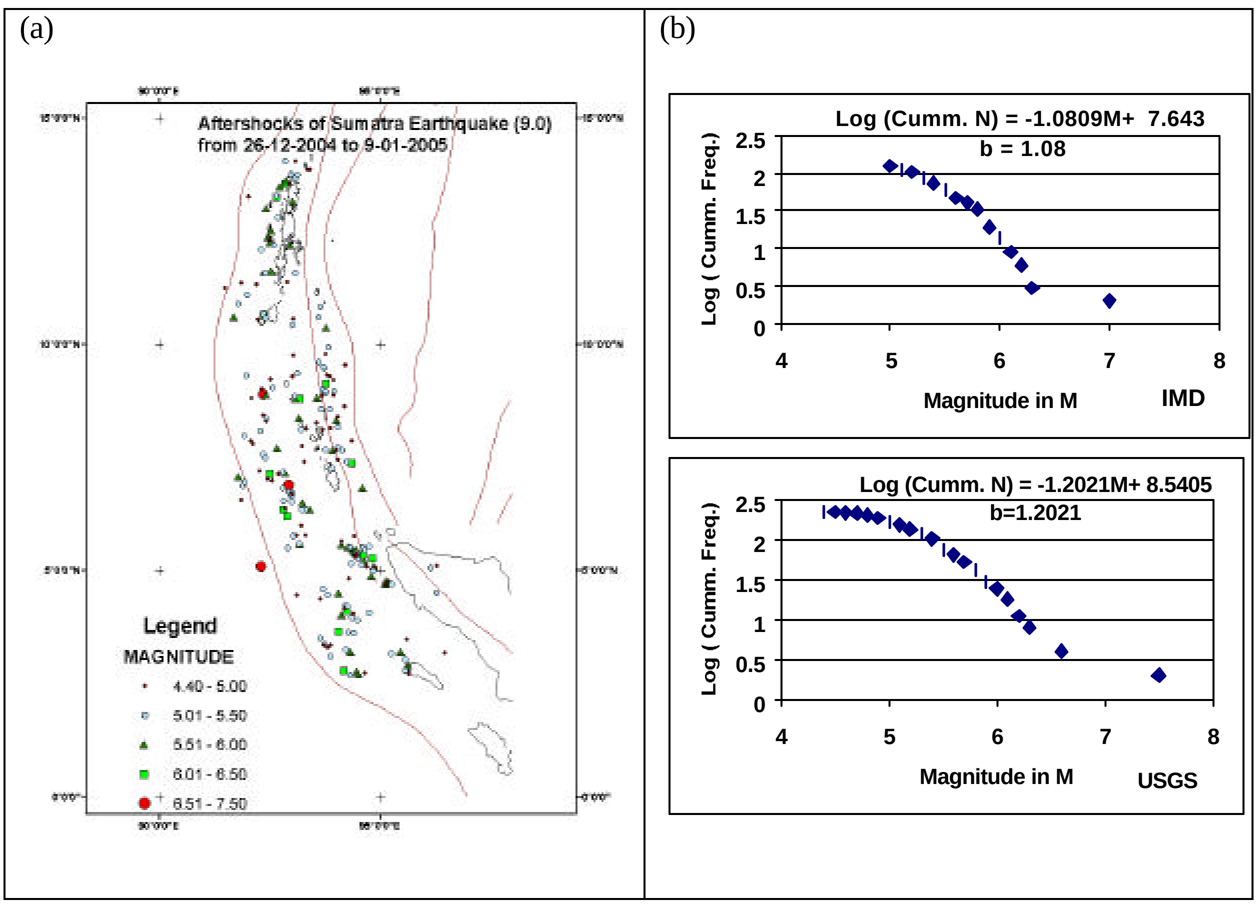

Figure 2. (a) Aftershock seismicity map up to 09.01.05 as recorded by USGS. (b) Frequency-magnitude plot of aftershocks as recorded by IMD (top) and USGS (bottom)

The Geological Survey of India has dispatched 5 short period digital seismometers to monitor the aftershocks. The first station was operational in the Naval Base Defense Colony, Vijaybagh, Port Blair from 6.1.2004. The second station was established in Car Nicobar Air Force Base on 8.1.2005. A third station was put in Little Andaman (Hut Bay) on 10.1.2005. Two more stations are planned to be deployed in Rangat and Diglipur, thus covering a length of 470 km between the northern parts of Andaman and Nicobar Islands. It is proposed to run the seismic network for about a month.

GPS Studies in Campaign Mode

GSI has planned to install several GPS and operate in campaign mode in different islands from Diglipur in North Andaman to Car Nicobar in the south covering a distance of about 470 km. The GPS stations are proposed to be re-occupied 2-3 times annually. The 1st station has been installed over rock exposure near GSI drilling campsite Beadonabad on 10.01.05. Another station will be at Chidyatapu Forest Rest House. Diglipur in North Andaman and Baratang islands will be occupied soon. Installation at other sites will depend on the availability of logistics for going to places like Little Andaman and Car Nicobar.

Summary

1. The Sumatra Earthquake of 26 December 2004 is the largest recorded seismic event along the Andaman-Sunda Subduction zone. The giant tsunamis generated by this offshore fault rupture have been unprecedented in the Indian Ocean and therefore call for inclusion of tsunami hazard in the disaster management plans of the country.
2. To locate earthquakes precisely from this highly seismic belt the 800 Km long Andaman- Nicobar Islands have to be covered by adequate seismograph stations.
3. The entire belt of Andaman & Nicobar group of Islands is an area of intense seismic activity and therefore has been included in the highest hazard class V of the Seismic Zoning Map of India. It is, therefore, of great importance that for any construction activity the BIS code on Earthquake Resistant Designs should be strictly followed. This applies more to any lifeline and structures of importance like schools, hospitals, water retention elevated structures and defense installations etc.
4. The recent earthquake has demonstrated in very clear terms that stilted structures without provision of any shear resistant walls behave very poorly under lateral seismic loading of even lower seismic Intensity of VII of MSK-64 scale. The results are similar to what was observed in case of Ahmedabad and Surat cities during the Kutch earthquake of 26 January 2001. It is, therefore, essential that design of RCC structures particularly G+2 and taller buildings, should be examined by competent structural engineer so that earthquake resistant elements are properly incorporated.
5. Prima facie, quality of RCC in case of the three collapsed structures in and around Port Blair was found to be inferior. It is therefore necessary to carry out proper geotechnical tests to determine the strength and durability of the concrete made out of locally available construction material.
6. Future development plans and activities in the tsunami run-up zones in coastal tracts, and in areas delineated by the High tide line and maximum possible tsunami run-up elevation needs to be regulated. Existing structures and human settlements are to be

relocated accordingly (ports, jetties, harbors, research stations, data collection centers etc. excluded). Regulatory measures and practices being followed in other countries which are frequently visited by tsunamis, may be consulted for this purpose and codal provisions made.

7. As earthquakes travel faster, the tsunami waves arrive later than the earthquake P-waves. The time lag depends on distance of the source area. So in islands and coastal areas of India, all felt earthquakes may be considered as natural tsunami alert signals and local residents as well as the administration should respond accordingly. As all earthquakes do not generate tsunami this response may be considered as a watch alert only and not a forecast or warning.

Acknowledgements

Support provided by the Andaman and Nicobar Administration during the investigation particularly by Mr Rishikesh and Mr Bhadra of the Department of Science & Technology, A & N Administration is gratefully acknowledged. Officers of Geodata and Database Division and Shri Anshuman Acharyya, Geologist, Monitoring Division, Kolkata are some among others without whose active support this document could not been released just in 3 days.

Photo 1: GSI team led by the Director General at Port Blair investigating the tsunami effects

Photo 2: Shearing of load bearing base columns leading to the caving in of G+2 storied RCC structure, Naya Gaon, Port Blair

Photo 3: Sheared base column and caved in stilt, Naya Gaon,Port Blair

Photo 4: Complete crushing of ground floor due to failure of basecolumn and first floor collapsing to the ground level of a newly constructed building in Bamboo Flat area

Photo 5: Complete caving in of the stilt and heavy damage of the first floor (now at ground floor level) of a newly constructed building in Kanyapuram. A car parked in the stilt got completely crushed

Photo 6: Failure of the three walls and roof of Malabar Society godown, Ograbraj due to strong tremors

Photo 7: Inundation of the structure in photo 6 and surrounding buildings by the tsunami

Photo 8: Fine cracks and chipping off plaster at theblock joints of Dhanikhari concrete dam

Photo 9: Buckling by 8 cm of the concrete apron at the interface of concrete spill way and earth section on the crest portion, Chouldari dam

Photo 10: A ground fissure cutting across the road through Anganbari Community Centre, Collinpur

Photo 11: Mud volcano that erupted after the 26th December 2004 earthquake in Jarwa Creek, Baratang. The recent mudflow has a distinct contact with an older flow

Photo 12: An active crater within the recent mud volcano

Photo 13: Fissure developed on the road at Baratang

Photo 14: A tree trunk with its roots separated into two halves along a wide open (90 cm) crack. The right side part of the trunk shows left lateral shear

Photo 15: Structures flattened by the tsunami in Wandoor

Photo 16: Breach in a section of the shore protection wall at Nazar, Port Blair

Photo 17: Washing away of a bridge by the tsunami at Corbyn's Cove, Port Blair

Photo 18: The tsunami water mark (brown – green interface) about 2m above the high tide level at Chidiyatapu

Photo 19: Inundation of a paddy field through the backwaters in Ograbraj

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