Effects of *M* 9 Sumatra earthquake and tsunami of 26 December 2004

The great mega thrust *M* 9 Sumatra earthquake on 26 December 2004 at 06:28:53 am IST created the most devastating tsunami in the known history. The deadly tsunami waves lashed low-lying towns adjoining the coastline of eleven countries, including Indonesia, Thailand, Malaysia, India and Sri Lanka, causing more than 150,000 deaths. Closest Indian landmasses to the epicentre are Andaman and Nicobar Islands over a narrow arc of about 800 km in the Bay of Bengal. The maximum intensity of shaking (on the MSK scale) along the Andaman–Nicobar Islands may be placed at VII and that along the mainland Indian coast at V. It resulted in the death of over 10,000 persons in India with over 5600 persons missing. Extensive devastation of the built environment occurred across the populated Andaman–Nicobar Islands and the coastal states of Andhra Pradesh, Tamil Nadu and Kerala along the mainland coastline of India.

This communication is based on a study organized by IIT Kanpur, in which a total of 13 investigators, divided into six groups carried out a reconnaissance investigation on the Indian Mainland coast and islands of Andaman and Nicobar during 1–13 January 2005.

The earthquake occurred along the plate boundary marked by subduction zone between the Indian plate and the Burmese micro-plate. The subduction zone is characterized by NNW–SSE arcuate trench running parallel to the western side of the Sumatra and the Andaman–Nicobar Islands. As a result of this movement of tectonic plates, the Andaman and Nicobar Islands have experienced uplift and subsidence at different places as seen from the field evidence. At Port Blair, the sea water level has risen by about one meter, suggesting a subsidence of the landmass, whereas in Middle Andaman Islands emergence of new shallow coral beaches suggests uplift (Figure 1). The implications of rise in water level by 1 m with respect to the land are rather severe: the buildings and roads at lower elevations and the dry docks are being flooded during high tide, making them non-functional and disrupting normal activities even weeks after the event. In Middle Andaman Islands, at Baratang an older mud volcano became active again after the earthquake and also several new small mud volcanoes erupted along with large ground deformation (Figure 2). Damages to buildings and other structures were primarily due to tsunami (as against due to ground shaking) on the mainland India, and in Little Andaman and other islands south of it (Figure 3); structural damage in islands north of Little Andaman was primarily due to ground shaking.

Tsunami created giant waves as high as 10–12 m; in several instances, objects were found on top of the trees after the tsunami. In the islands of Great Nicobar, Car Nicobar and Little Andaman, buildings constructed on the coast were washed away by the great waves, while those located on high grounds survived. When a number of rows of buildings existed on the coast, buildings in the first row from the sea suffered extensive damage, those in the rear rows did better due to the shielding provided by the front row. In general, constructions circular in plan (e.g., circular water tanks, light house) did better under the onslaught of tsunamis as the water could easily flow around such objects. At Car Nicobar about 100 personnel of air-force (including the family members) lost life or are missing. However, the operational area and the air-strip survived enabling rescue and relief operations by the air force after the event.

Due to the ground shaking, the wooden buildings suffered less damage compared to the more modern RC frame and concrete block masonry buildings. The latter sustained extensive damage when the seismic codes were not complied with. For instance, the Passenger Terminal Building at the Phoenix Bay in Port Blair was recently constructed but did not comply with the seismic codes. This rather expensive building has been irreparably damaged. A number of houses built by local people using reinforced concrete but without proper engineering supervision and seismic detailing collapsed. A three-storey apartment building in Port Blair on stilt columns, not complying with the codal requirements, collapsed (Figure 4). Similar damages were also observed in Rangat, and Mayabandar in northern islands as well.

A number of jetties collapsed or were severely damaged in a number of islands

Figure 1. ***a***, Up-throw of coral beds and rock strata due to uplift on the western coast of middle Andaman Island near Flat Island (Photo: Javed Malik). ***b***, Seawater flooded Andaman Trunk Road at Sipi Ghat area near Port Blair during high tide, suggesting subsidence of the landmass. (Photo: Goutam Mondal).

Figure 2. Eruption of a mud volcano near Jarawa Creek at Baratang Island in Middle Andaman, 105 km north of Port Blair (Photo: Durgesh C. Rai).

which severely affected the sea traffic and hence the relief operations (Figure 5). A new 268 m long bridge between North Andaman and Middle Andaman at Austen Strait had to be closed to even the light vehicles. The superstructure has moved on the substructure by a substantial amount and middle three spans fell off from the bearing (Figure 6 *a*). Two of the authors had visited this region two years back after a moderate *M* 6.5 earthquake on 14 September 2002 and in their published report[1] had expressed concerns about this very bridge as follows:

> Inadequate seating of bridge deck over piers and abutments is a serious concern for its safety during a stronger earthquake in future. The bearings are simple neoprene pads which are far from satisfactory for a bridge located in seismic zone V. Bridge deck restrainers are the minimum that need to be provided to ensure that the spans are not dislodged from the piers in future earthquakes. (available at http: //www.nicee.org/EQ_Reports/Andaman/Andaman_report.htm).

Further, a number of structures in and around Diglipur area which were damaged in the 2002 earthquake were again damaged in this earthquake as well. Many of these have been apparently 'retrofitted' without proper consideration of eliminating the underlying structural deficiencies that render them vulnerable to ground shaking.

Widespread lateral spreading in Andaman Islands led to significant damage of pavement and drainage structures of Andaman Trunk Road (ATR) and other link roads. Lateral spreading and other liquefaction-related phenomena were responsible for extensive damage to residential buildings and healthcare facilities in the low-lying areas, especially in the vicinity of water bodies, at several places in the northern Andaman Islands. The flexible airstrip at Diglipur developed on unconsolidated marshy land developed cracks.

Electric power supply was severely affected: the 20 MW fossil-fuel based power plant at Bamboo Flat near Port Blair was flooded by tsunami waves causing extensive damage to electrical and mechanical equipment requiring several weeks for restoration. The 5.25 MW Kalpong hydroelectric power plant near Diglipur, North Andaman Islands, also suffered damage to its turbines which could be restored only partially in a week's time. The collapse

Figure 3. RC frame building (MES Inspection Bungalow) now stands in waters at the Military Residential Colony south of Malacca on the east coast of Car Nicobar Island. (Photo: C. V. R. Murty).

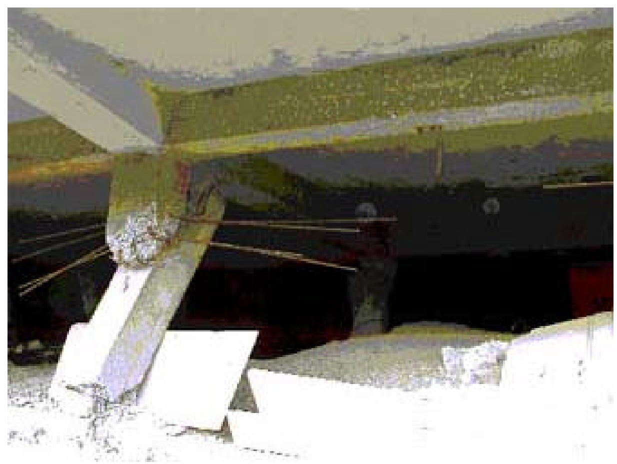

Figure 4. Collapse of a three-storey reinforced concrete frame building at Port Blair (Photo: Sudhir K. Jain).

Figure 5. Collapse of the 80 m segment of approach in Great Nicobar Island jetty at Campbell Bay. This has adversely affected the relief work. (Photo: C. V. R. Murty).

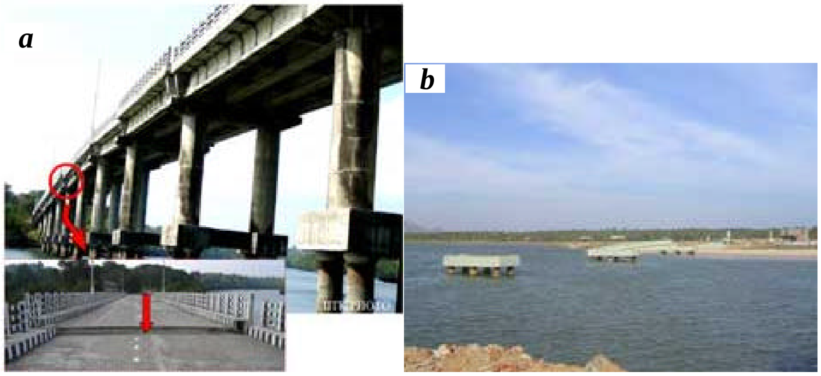

Figure 6. ***a***, Three middle spans of Chengappa Bridge over Austen Strait connecting Middle Andaman and North Andaman Islands, 230 km north of Port Blair fell off from the bearing due to ground shaking. (Photo: Durgesh C. Rai). ***b***, Complete loss of spans of the four-span RC bridge at Melmannakudi due to tsunami. (Photo: Alpa Sheth).

of the transmission tower at Middle Strait further restricted its power distribution to North Andaman Islands. Longitudinal cracks at the crest of its rockfill reservoir dam were also observed.

On the mainland India, the fishing community living along the shore suffered the maximum damage: to its housing, to its boats and fishing equipment, and in terms of loss of life. The other major sufferers were the tourists on some of the beaches. Most houses along the coast had been non-engineered. In general, quality of construction had a major influence on the level of damage sustained by the buildings. Buildings with low foundation depth, those with poor building materials, poor integrity and poor workmanship were worst sufferers. Several bridges suffered serious damages. Superstructure of all four spans of a bridge at Melmanakuddi came off the substructure and two of the spans were washed away to large distances (Figure 6 *b*). A good connection between the superstructure and the substructure and the additional provision of restraining upstands, recommended features for seismic design, would have helped the bridge. Infrastructure in Nagapattinam, Tamil Nadu was significantly affected: a railway line on the shore, telecommunication tower and control panel room were irreparably damaged. Compound walls up to 300 m inside the shoreline were extensively damaged.

In ports and harbours along the mainland coast, major disturbance was caused by vessels parting their ropes and becoming loose and hitting other vessels and causing damage. Small boats and ships were tossed astray onto the land by the incoming wave and thereby damaging them. Some boats were sunk to the basin due to the returning giant waves. Breakwaters generally did well, and helped reduce the impact of waves. Beaches shielded by landmass or by rocky cliff sustained less damage. Seawater intrusion was less in areas covered with thick vegetation compared to those with bare lands. Sand deposits due to tsunami in delta areas have damaged standing crops and affected fertility of the land.

To conclude the earthquake and tsunami of 26 December 2004 once again highlighted the vulnerability of civil infrastructure and population inhabiting the Indian territories which are well known to have significant seismic hazard. The lack of adequate preparedness against the probable ground shaking by way of not designing the structures for earthquake resistance, led to failure of many buildings and structures when they were needed most for the rescue and relief operation. Further, the hazard posed by tsunami to Indian coastal regions which has been conveniently ignored thus far, should become one of the major considerations while developing civil infrastructure in these areas. The repair and rehabilitation of structures should be carried out in a manner which addresses to remedy the underlying structural deficiencies that determine their performance in earthquakes.

1. Rai, D. C. and Murty, C. V. R., Reconnaissance Report on North Andaman (Diglipur) Earthquake of 14 September 2002, Department of Civil Engineering, Indian Institute of Technology Kanpur, Kanpur, 2003, p. 49. Available at www.nicee.org/EQ_Reports/Andaman/Andaman_report.htm).

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