Landscape changes in Andaman and Nicobar Islands (India) due to *Mw* 9.3 tsunamigenic Sumatra earthquake of 26 December 2004

The Sumatra earthquake (*Mw* 9.3) of 26 December 2004 is one of the most important earthquakes from the point of view of plate tectonics. This event occurred along the plate boundary marked by the subduction zone between the Indian Plate and the Burmese Plate (a part of the Eurasian Plate). The subduction zone is characterized by N–S arcuate trench running parallel on the western side of the Sumatra and Andaman–Nicobar (A&N) Islands. Recent global tectonic plate reconstruction data suggest that the NE-moving Indian plate is obliquely converging with the Eurasian plate[1] at 54 mm/yr. Also, the GPS observations[2,3] between Bangalore and Port Blair (capital of A&N Islands) suggest that the Indian Plate is approaching the Burmese Plate at a rate of 15.3 mm/yr. Uplift and subsidence of A&N Islands along the western and eastern coast respectively, have been reported in literature during the *Mw* 7.9 1881 Car Nicobar earthquake[3].

The locations of the 26 December 2004 mainshock and its aftershocks suggest that the rupture extends over 1000 km length of the Sunda–Andaman arc. Large amount of energy released during this event caused ground shaking at several locations along all land masses adjoining this arc. More prominent were the tsunamis caused by this subduction at the seafloor. A preliminary estimate of the maximum intensity of shaking along the A&N Islands may be placed at about VII on the MSK scale and that along the mainland Indian coast at about V.

A reconnaissance survey was undertaken in the A&N Islands after the 2004 Sumatra earthquake. The overall pattern of geomorphological changes was captured by aerial surveys over most of the A&N Islands. This was augmented by field investigations at four of the Andaman Islands (namely North, Middle, South and Little) and two of the Nicobar Islands (namely Car and Great).

The Great Nicobar Island marks the southernmost tip of India, located (N7° lat.) ~200 km NW of Sumatra and closest to the 26 December 2004 event. This region is characterized by hilly terrain with maximum elevation up to 600 m. The southern portion of the Great Nicobar Island seems to have subsided by about 3 m, as supported by changes in the natural water levels. At the Coastguard Headquarters Building in Campbell Bay, the average water level has increased after the earthquake by about 2 m, as demonstrated by the ocean water lashing the floor of the building located a few metres from the sea. According to the Coastguard Officer, during the high tides prior to the earthquake, at least 25–30 m of beach used to be exposed in front of the building, and during low tide, it was more than 100 m. In contrast, now no beach can be seen. Such submergence is also observed at Indira Point, the southernmost tip of India. Here, the 23 m high lighthouse tower is now standing submerged by at least about 3 m at its base; several houses, the helipad and vegetation near the light house have been washed away by the tsunami (Figure 1).

Evidence of subsidence was also observed at the Car Nicobar Island (N9.2° lat.), the northernmost among the Nicobar group of islands. Topographically, this island is characterized by almost flat terrain to the east and an elevated terrain with maximum elevation of about 70 m to the west. This island was worst affected in terms of damage and loss of life. The eastern coast was destroyed; the Indian Army and Air Force township adjacent to the airstrip and the civilian township at Malacca were swept away. The most remarkable evidence signature was that of the MES Inspection Bungalow, a two-storey RC frame structure with hollow block masonry infills earlier located about 100 m from the shoreline under high tide conditions. This building now remains exposed with sea water lashing right up to the individual footings of the front side columns (Figure 2 *a* and *b*).

Aerial as well as field surveys were carried out along the North, Middle and South Andaman Islands. Land subsidence is also noted in the Port Blair area. For example, in the bazaar area at Bamboo Flat near Port Blair, the water level has risen by about 1.2 m; this is evident from the 0.3 m of water during high tide in the street-front shops along the shore (Figure 3 *a*). Inundation of land and water-logging up to 1.0 m were also common in the low-lying areas (Figure 3 *b*). Also, observations of tide chart levels recorded by the Andaman and Lakshadweep Harbor Works, suggest that while a difference of 1.2 m was recorded on 26 December 2004, a steady difference of about 0.93 ± 0.30 m is obvious from 30 January 2004 to 8 January 2005.

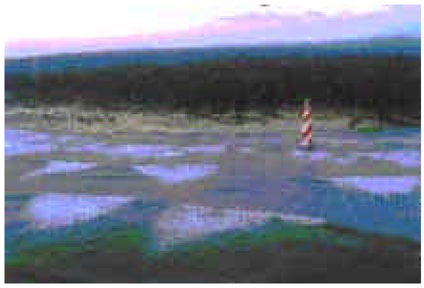

Figure 1. Flooding of lighthouse base due to land subsidence at Indira Point, southernmost tip of India at Great Nicobar Island. Submergence is about ~3 m caused by the *M* 9(3) megathrust earthquake (Photo courtesy: Flight Commander Rajesh Makwana, Indian Coast Guard, Port Blair.)

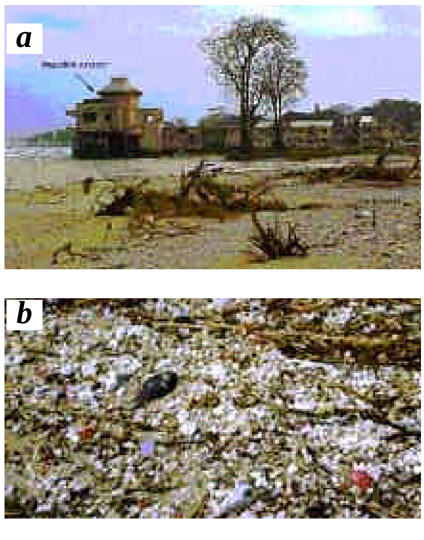

Figure 2. ***a***, Two-storey RC frame Inspection Bungalow at east coast of Car Nicobar Island, located about 100 m from the shoreline under high tide conditions. This building now remains exposed with sea water lashing right up to the individual footings of the front side columns, suggestive of the subsidence of the coastline along the eastern side of Car Nicobar. Present-day exposed beach shows gravel transported and deposited by tsunami on 26 December 2004. ***b***, Close-up of poorly sorted coral deposit at Car Nicobar. Clasts of coral fragments range in size from 25 to 350 mm.

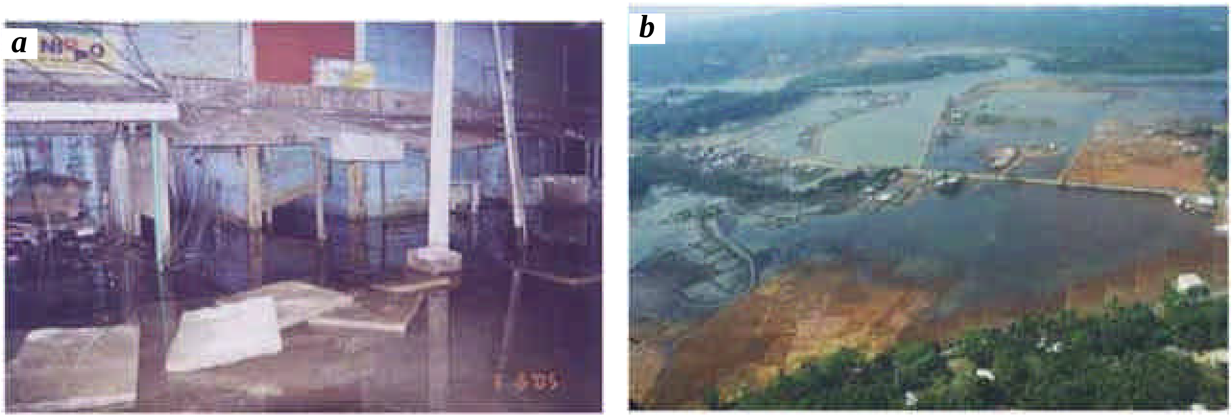

Figure 3. ***a***, Inundation of land in bazaar area of Bamboo Flats near Port Blair. Due to land subsidence, water level has risen by about 1.2 m from the normal high tide level. This is evident from the 0.3 m of water in the street-front shops along the shore. ***b***, Inundation of land and waterlogging up to 1.0 m in low-lying areas around Sippyghat near Port Blair.

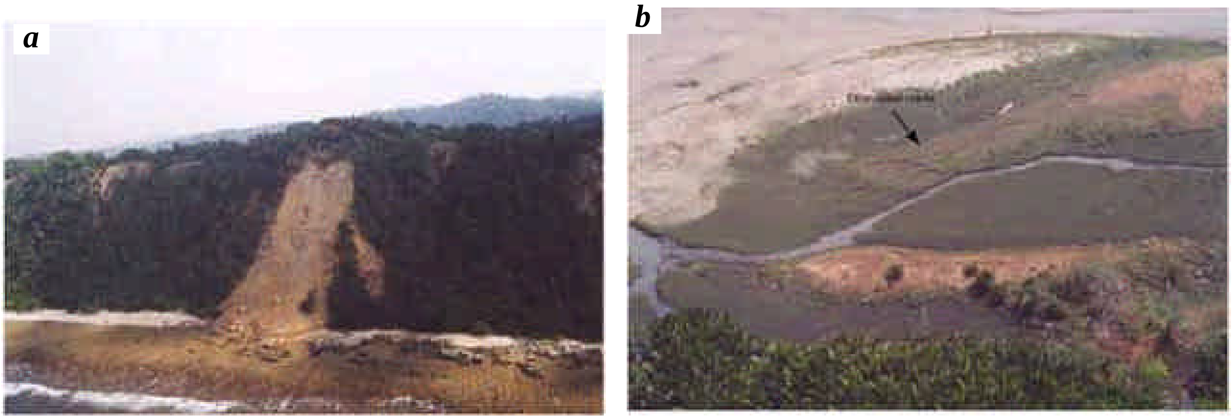

Figure 4. ***a***, Evidences of earthquake-induced landslides along the western coastline margin of South Andaman Island near Defence Island. ***b***, Lateral spreading was more common along the eastern coast due to earthquake around Betapur.

Aerial survey carried out using a helicopter between Port Blair (South Andaman Island) and Betapur (North Andaman Island), concentrating mainly along the west and east coasts of the Andaman Islands, revealed important evidence of landscape changes due to the 26 December 2004 mega-thrust event. In general, most of the area along the western coastline is marked by rocky cliffs, whereas the eastern part shows gentle slope. This rocky shoreline comprises stratified sedimentary rocks, with beds showing inclination towards east. Evidences of earthquake-induced landslides were recorded along the western margin of the coastline (Figure 4 *a*), whereas lateral spreading was more common along the eastern coast (Figure 4 *b*). Also, coral beds with sheet-rocks having algae cover are exposed along the west coast (Figure 5 *a*), but along eastern coast the coral beds are seen submerged under water (Figure 5 *b*). At some places along the coast, submergence of trees up to about 1.5 m was prominent. The above observations are consistent with those made during land surveys at Port Blair, Rangat, Mayabunder and Diglipur in the Andaman Islands. Land surveys at Diglipur and Mayabunder jetties confirm a vertical uplift of the land up to 1.2 m from the pre-earthquake levels; exposed piles of the jetties and the receded waterline at these jetties stand a testimony to this.

The *Mw* 9.3 earthquake of 26 December 2004 along the subduction zone of the Sunda has resulted in tilting of the plate along the EW direction with a tilt towards the east. The relative subsidence of the Burma Plate along an East–West strike is about 1.2 ± 0.2 m; the consequent angle of tilt over the 15–25 km width of the A&N Islands results in only a marginal tilt of up to 1 mm even in a tall structure like the 23m high lighthouse at Indira Point. Therefore, despite this subsidence-related tilt of the Burma Plate, no prominent tilt was visible in the civil engineering structures. Also, there is a gradually varying vertical movement along the east coast of the A&N Islands: (i) about 3 m submergence at Indira Point at the southern tip of the Nicobar Islands; (ii) about 1.2 m at Car Nicobar military residential colony in Car Nicobar Islands; (iii) about 1.0 m submergence at Port Blair in South Andaman Island, and (iv) about 1.2 m uplift at Ariel Jetty in the North Andaman Island. Islands closer to the epicentre of the subduction event experienced more relative subsidence than those to the north.

Similar co-seismic landscape changes took place after the *Mw* 7.9 1881 Car Nicobar earthquake, where vertical uplift of about 0.6 m with relative subsidence of less than 0.5 m has been estimated[3]; it was also suggested that the island had tilted down to the east. Emergence of new freshly exposed sheet-rocks and coral beds on the east and subsidence of forests into the ocean waters on the west due to the recent earthquake are consistent with the inferences made related to land-level changes during the 1881 earthquake by Ortiz and Bilham[3]. Understandably, the land-level changes estimated[3] for the 1881 event (*M* 7.9) are smaller than the observations after the 2004 event (*Mw* 9.3), since the 1881 event was smaller in magnitude. Clearly, this *Mw* 9.3 event of 26 December 2004 has thrown open new challenges to geophysicists; in-depth understanding of the landscape changes is needed based on precise GPS measurements in the region.

1. DeMets, C., Gordon, R. G., Argus, D. F. and Stein, S., *Geophys. Res. Lett.*, 1994, **21**, 2191–2194.
2. Paul, J. *et al.*, *Geophys. Res. Lett.*, 2001, **28**, 647–651.
3. Ortiz, M. and Bilham, R., *J. Geophys. Res.*, 2003, **108**, 2215.

ACKNOWLEDGEMENTS. We acknowledge financial support by DST, New Delhi; the logistics by officers and engineers of the various government departments of A&N Islands (including APWD, Coastguard, Indian Army and Indian Air Force); a critical review of the manuscript by Prof. Sudhir K. Jain, IIT Kanpur, and help rendered by Mr Suresh Dash, IIT Kanpur, during fieldwork.

Received 14 February 2005; accepted 2 April 2005

JAVED N. MALIK*
C. V. R. MURTY

Department of Civil Engineering,
Indian Institute of Technology,
Kanpur 208 016, India
**e-mail: javed@iitk.ac.in*

a
b

Figure 5. ***a***, Up-throw of coral beds and rock strata due to uplift on the western coast of Middle Andaman Island near Flat Island. ***b***, Submerged coral beds, beach and forest area along the eastern coast of Southern Andaman Island near Baratang Island. Submergence is due to tectonic subsidence of the east coastline by the *Mw* 9.3 event of 26 December 2004.