Run-up and inundation limits along southeast coast of India during the 26 December 2004 Indian Ocean tsunami

The M 9 earthquake off Sumatra in the Andaman Sea generated a tsunami in the Indian Ocean, which lashed low-lying towns adjoining the coastline of eleven countries, including Indonesia, Thailand, Malaysia, India and Sri Lanka, causing more than 150,000 deaths[1]. Andaman and Nicobar Islands were the worst hit among the Indian regions. Apart from the Andamans, coasts of Andhra Pradesh, Kerala and Tamil Nadu were also hit by the tsunami, the Tamil Nadu coast being the most affected (Figure 1). This correspondence is based on a survey carried out along the Tamil Nadu coast adjoining the Bay of Bengal, covering the coast from Vedaranyam to Chennai and Krishnapatanam in Andhra Pradesh. The post-tsunami survey was carried out to study inundation limits and run-up heights of the tsunami following the UNESCO IOC manual[2].

The post-tsunami survey consisted of ascertaining inundation limits at different locations and measurement of cross-section profiles from the water line till the inundation limit using standard survey equipment. A total of 24 locations (23 along Tamil Nadu coast and 1 along Andhra Pradesh) were surveyed during 15 January 2005 to 6 February 2005 (Figure 2). Positions were taken at the survey locations using a hand-held Magellan Global Positioning System. Among the 24 locations, at 19 locations the cross-section profile survey could be carried out till the inundation limit and hence only these data are presented here. The average wave uprush and down-rush was considered as mean water level at the time of survey. This was corrected to the tidal elevation at that particular time so as to obtain the levels with respect to the Chart Datum (CD). Tide level at each of the locations was arrived at based on linear interpolation of predicted tide values between the established stations of Point Pedro in Sri Lanka, Nagapattinam, Cuddalore, Pondicherry and Chennai in Tamil Nadu and Sacramento Shoal in Andhra Pradesh.

Inundation limits were ascertained based on visual observations at the location from the debris line present on shore in case of open lands and watermarks left by receding waters on compound walls and from eyewitnesses. A cross-section profile along the line of sight starting from the waterline till the inundation limit is taken to arrive at the elevation of the inundation limit with respect to the waterline at the time of survey. This elevation is later reduced to the Chart Datum by considering the tide at that time of survey, thus arriving at the run-up height with respect to the Chart Datum. The stations and their geo-positions are shown in Table 1. More than one profile was taken at three stations (Periyakalapet, Nagore and Sadarangapattinam), whereas a single profile was taken at all other stations.

The inundation limit (Figure 3) shows the vulnerability of the southern region of the Tamil Nadu coast due to its flat topography compared to the northern region. It is obvious that the tsunami wave attack normal to the coast has a higher impact on inundation limits and run-up heights than an oblique attack. However, inundation would be larger only if there is no obstruction to the water flow and the topography is conducive for transport of this water mass. From the survey carried out on the inundation limits, it is observed that regions where the hinterland is un-

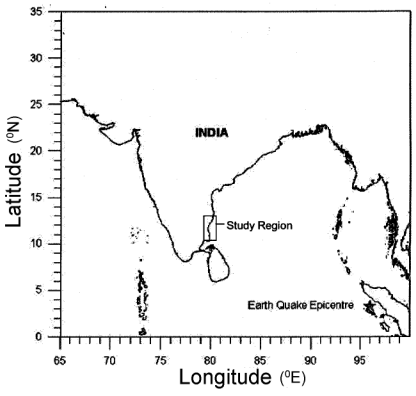

Figure 1. Location map and study region.

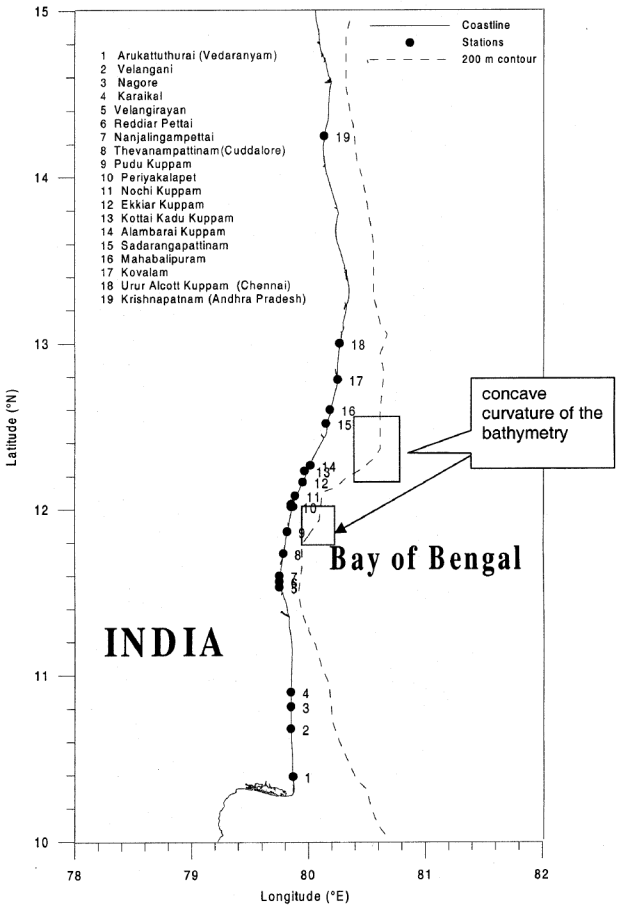

Figure 2. Locations of post-tsunami survey.

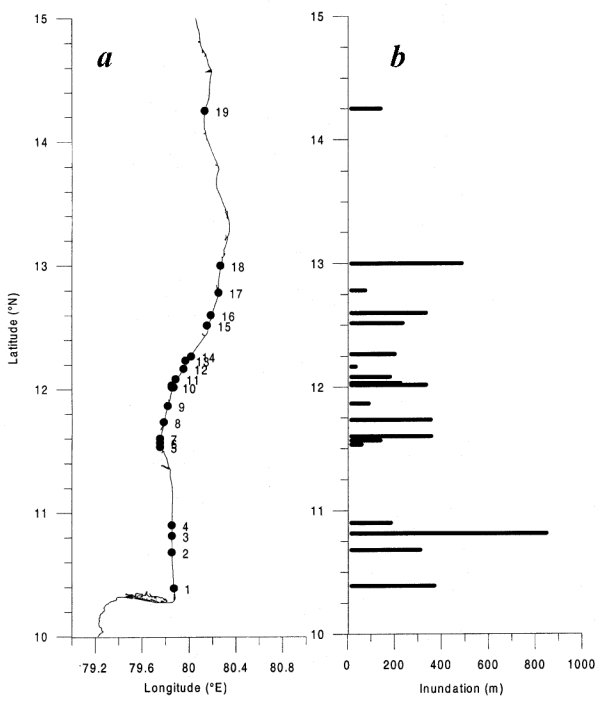

Figure 3. Plot showing (*a*) locations and (*b*) inundation limits.

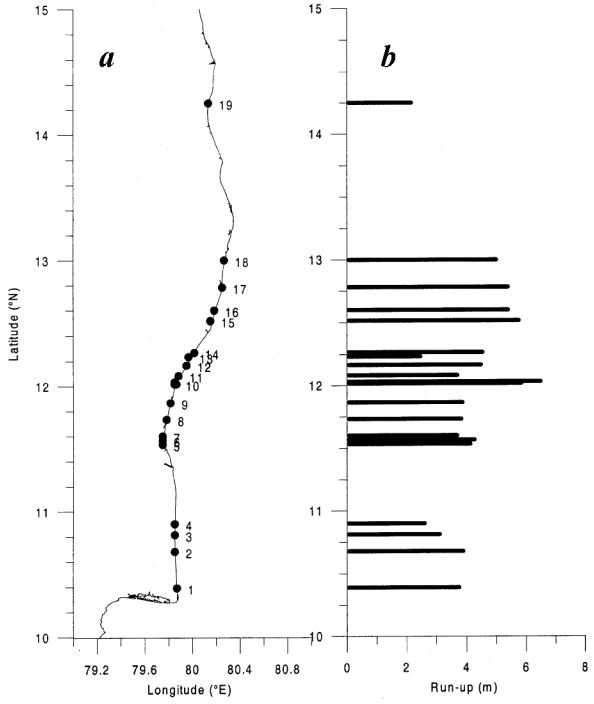

Figure 4. Plot showing (*a*) location and (*b*) run-up height.

Table 1. Post-tsunami survey locations

Sr. No.	Station	Position	
		Latitude (°N)	Longitude (°E)
1	Arukattuthurai	10°23′30.51″	79°52′07.14″
2	Velangani	10°40′48.68″	79°51′02.22″
3	Nagore	10°48′47.52″	79°51′04.38″
4	Karaikal	10°54′50.03″	79°51′08.04″
5	Velangirayan	11°32′15.04″	79°45′44.07″
6	Reddiar Pettai – 1	11°34′34.00″	79°45′28.06″
6A	Reddiar Pettai – 2	11°34′34.00″	79°45′28.06″
7	Nanjalingampettai	11°36′45.03″	79°45′34.08″
8	Thevanampattinam	11°44′40.00″	79°47′18.09″
9	Pudu Kuppam	11°52′03.00″	79°49′09.36″
10A	Periyakalapet – 1	12°1′27.18″	79°51′56.08″
10	Periyakalapet – 2	12°01′40.08″	79°52′02.52″
10B	Periyakalapet – 3	12°2′03.18″	79°52′17.07″
11	Nochi Kuppam	12°05′08.46″	79°53′55.01″
12	Ekkiar Kuppam	12°10′49.00″	79°57′37.03″
13	Kottai Kadu Kuppam	12°14′42.00″	79°58′59.04″
14	Alambarai Kuppam	12°16′04.92″	80°00′55.02″
15	Sadarangapattinam – 1	12°31′22.09″	80°09′56.28″
15A	Sadarangapattinam – 2	12°31′31.00″	80°09′58.56″
16	Mahabalipuram	12°36′55.05″	80°11′56.08″
17	Kovalam	12°47′19.09″	80°15′16.02″
18	Urur Alcott Kuppam	13°00′35.28″	80°16′34.05″
19	Krishnapatnam	14°15′00″	80°08′16.56″

protected by coastal dunes, had higher inundation values compared to places where the coast is protected by dunes. Also, wherever there are openings in the dunes (either due to anthropogenic activity or due to other reasons), inundation was higher as these openings provided a gateway for the water mass to travel through them into the hinterland. Along the Vedaranyam–Nagore coastal stretch the inundation is high due to the low-lying areas, though a wide continental shelf exists,

which should have reduced the tsunami effect.

The run-up heights (Figure 4) are higher on the northern region, which could be attributed to higher intensity of the tsunami in the north compared to the south. Estimation of run-up heights is directly proportional to wave height, including tsunami waves[3]. Due to refraction, the waves propagate parallel to the bathymetry contours. However, due to the irregular bathymetry, these waves either converge or diverge as they encounter either curved-in (concave) contours or convex contours respectively. The possibility of increase in tsunami height in the northern regions of Tamil Nadu coast and particularly along Periyakalapet (station 10) is high due to the offshore bathymetry in that region, wherein the 200 m CD contour forms a concave with station 10 at its centre. The possibility of convergence of the tsunami wave in this region thereby increases the tsunami wave height and corresponding run-up height at Periyakalapet. A similar increase in the run-up heights is also seen for Mahabalipuram and Sadarangapattinam stations. However, due to wider continental shelf, it is possible that the tsunami height would be less compared to Periyakalapet which is seen from the run-up heights and inundation limits.

1. Jain, S. K., Murty, C. V. R., Rai, D. C., Malik, J. N., Sheth, A. and Jaiswal, A., *Curr. Sci.*, 2005, **88**, 357–359.
2. UNESCO-IOC Manual No. 37, Post Tsunami Survey Manual, 2002.
3. Gedik, N., Irtem, E. and Kabdasli, S., *Ocean Eng.*, 2005, **32**, 513–528.

ACKNOWLEDGEMENT. We thank Dr Satish R. Shetye, Director, National Institute of Oceanography, Goa for support and encouragement. NIO contribution no. 3996.

Received 6 April 2005; revised accepted 5 May 2005

S. JAYAKUMAR*
D. ILANGOVAN
KIRTI A. NAIK
R. GOWTHAMAN
GURUDAS TIRODKAR
GANESH N. NAIK
P. GANESHAN
R. MANI MURALI
G. S. MICHAEL
M. V. RAMANA
G. C. BHATTACHARYA

National Institute of Oceanography,
Dona Paula,
Goa 403 004, India
**e-mail: jay@darya.nio.org*