EFFECTS OF MEDU AND COASTAL TOPOGRAPHY ON THE DAMAGE PATTERN DURING THE RECENT INDIAN OCEAN TSUNAMI ALONG THE COAST OF TAMILNADU

J.P. Narayan, M.L. Sharma and B.K. Maheshwari

Department of Earthquake Engineering, Indian Institute of Technology Roorkee,
Roorkee-247667, Uttaranchal, INDIA,
email: jaypnfeq@iitr.ernet.in., mukutfeq@iitr.ernet.in.

ABSTRACT

Effects of Medu (naturally elevated landmass very close to the seashore and elongated parallel to the coast) and coastal topography on the damage pattern during the deadliest Indian Ocean tsunami of December 26, 2004 is reported. The tsunami caused severe damage and claimed many victims in the coastal areas of eleven countries bordering the Indian Ocean. The damage survey revealed large variation in damage along the coastal region of Tamilnadu (India).

The most severe damage was observed in the Nagapattinam district on the east coast and the west coast of Kanyakumari district. Decrease of damage from Nagapattinam to Kanchipuram district was observed. Intense damage again appeared to the north of Adyar River (from Srinivaspuri to Anna Samadhi Park). Almost, no damage was observed along the coast of Thanjavur, Puddukkotai and Ramnathpuram districts in Palk Strait, situated in the shadow zone of Sri Lanka.

It was concluded that the width of continental shelf has played a major role in the pattern of tsunami damage. It was inferred that the width of the continental shelf and the interference of reflected waves from Sri Lanka and Maldives Islands with direct waves and receding waves was responsible for intense damage in Nagapattinam and Kanyakumari districts, respectively. During the damage survey authors also noted that there was almost no damage or much lesser damage to houses situated on or behind the Medu. Many people observed the first arrival. The largest tsunami amplitude occurred as the first arrival on the eastern coast and in the second arrival on the western coast.

INTRODUCTION

The deadliest Indian Ocean tsunami originated due to the occurrence of the Sumatra earthquake (M = 9.0, on Richter scale) of December 26, 2004 at 0:58:51 UT or 6:28:51 IST (USGS, 2005). The epicenter of the Sumatra earthquake (3.251^0N & 95.799^0E) was located about 255 km SSE of Banda Aceh, Sumatra, Indonesia at a depth of 10 km. (USGS, 2005). The thrusting type of source rupture generated the killer tsunami, which caused damage as far away as Somalia (Table 1). The damage along the coast of Indian mainland was due to only tsunami.

Table I Life loss in Sumatra Earthquake And Tsunami (UN/OCHA Relief-web*)

Country	Death	Missing
Indonesia	110,229	12,132
Sri Lanka	30,899	6,034
India	10,672	5,711
Thailand	5,303	3,396
Maldives Is.	81	21
Malaysia	68	6
Myanmar	59	3
Seychelles	3	NA
Somalia	150	NA
Total	1,57,464	27,303

**Regional overview data up to 14.1.2005*

Though the Indian subcontinent is in a seismically active region, tsunamis along the coastline of India have been rare, but not unprecedented. The coasts of Indian landmass have experienced at least four attacks of tsunamis in the last 200 years. A tsunami of height of the order of 2 - 3 m in Kutch region was reported during the June 16, 1819 Kutch earthquake (MacMurdo, 1823; Bilham, 1999). The submarine earthquakes of December 31, 1881 and June 26, 1941 beneath the Andaman Islands generated a tsunami, and the later one caused loss of life along the east coast of India (Rogers, 1883; Oldham, 1884; Murthy and Rafiq, 1991). Another tsunami struck on the west coast during the Baluchistan earthquake (M_w = 8.0) of November 28, 1945.

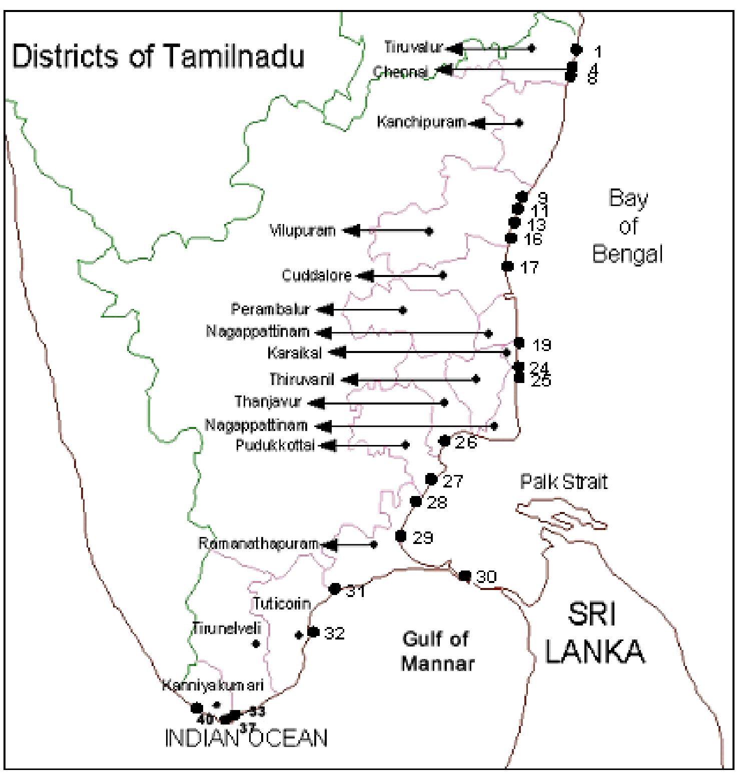

Figure 1: District Map of Tamilnadu showing locations of visited area (black circles). Refer location number in Table 2.

A team from Department of Earthquake Engineering, Indian Institute of Technology Roorkee visited the coastal region of Tamilnadu during January 6-14, 2005 for a post-tsunami damage survey. The main objectives of the team were to see the affects of tsunami on the built environment, to measure the inundation and run up and their lateral variation, to determine arrival time of the tsunami, number of waves, and to model the dynamics of the waves.

Table 2. Name of different locations visited, their serial numbers, run-up and inundation measured at each locality, reported death and arrival time of tsunami (Note: localities with * are plotted in Fig. 1).

SN		Latitude (^{0}N)	Longitude (^{0}E)	Run-up (m)	Inundation (m)	Arrival Time	Death reported	Name of Locality
1*	East coast of Tamilnadu	13.17	80.313	3-4	400		Nil	Cherain Nagar
2		13.145	80.303	3-4	10-20m		Nil	Royapuram
3		13.063	80.287	4-5	800		---	MGR/Anna Samadhi
4*		13.039	80.281	4-5	800	9:05 AM	200	Marina beach
5		13.021	80.28	5-6	1200		30	Srinivaspuri
6		13.002	80.276	4	400		9	Elliot's beach
7		12.991	80.273	3-4	300		Nil	Basant Nagar
8*		12.969	80.267	3-4	200	8:45 AM	Nil	New beach
9*		12.051	79.878	4	1000		Nil	Kudukuppam,
10		12.007	79.861	4-5	2000	8:45 AM	9	Chinnapattam
11*		11.961	79.843	4	200		Nil	Kotakuppam
12		11.931	79.837	4	20	8:30 AM	Nil	Pondicheri
13*		11.857	79.817	3	150		Nil	Nallwarkuppam
14		11.777	79.797	3	150	8:45 AM	4	Manjakuppam
15		11.765	79.794	5-6	1000	8:30 AM	36	Talenguda
16*		11.739	79.788	6-7	1000		Nil	Devanamkuppam
17*		11.525	79.763	8-9	500		130	Kuddukullam
18		11.068	79.858	8-9	2000		38	Kuddupattanam
19*		10.944	79.854	8-9			23	Kilinjal Village
20		10.936	79.853	8-9			31	Amman Kerapattu
21		10.784	79.851	10-12	3000		30	Nagapattinam Beach
22		10.778	79.852	10-12	3000		260	Nabiyarnagar
23		10.773	79.846	10-12	2500		15	Vellaipalyam
24*		10.762	79.851	10-12	1000		---	Nagapattinam Port
25*		10.679	79.854	4-5	500-7000		1000	Velanganni Beach
26*		10.201	79.253	2	700	11:00 AM	Nil	Alatikut Village
27*		9.9082	79.146	1-2.0	50	11:45 AM	Nil	Arpudapattanam
28*		9.7412	79.023	1	20	12:30 PM	Nil	Tondi
29*		9.4798	78.899	1	30	12:50 PM	Nil	Navapasanam
30*		9.1775	79.417	1			Nil	Dhanushkodi
31*		9.0748	78.366	3	20-30	10:00 AM	1	Vember
32*		8.7496	78.194	3	100	9:00 AM	Nil	Tuticorin Port
33*		8.1175	77.56	2-3	1000	10:15 AM	Nil	Aragyapuram Village
34		8.1092	77.558	2-3	300	9:45 AM	Nil	Librahmkuppam
35		8.096	77.566	3-4	450	10:30 AM	Nil	Cinnamuttam Harbor
36		8.0789	77.553	4-5	450	10:40 AM	Nil	Kanyakumari
37*	West coast	8.0883	77.487	9-10	2000	10:30 AM	70	Keelmanakudy
38		8.1414	77.304	6-7	700	10:15 AM	2	Chinnavilai Village
39		8.1557	77.29	6-8	500-1000		---	Pattupetta Village
40*		8.1705	77.256	6-8	500	10:20 AM	---	Colachal harbor

The general observations as reported by many people in the affected coastal areas of Tamilnadu are mainly tsunami crest as the first arrival i.e., the first arrival was a positive wave and the largest tsunami amplitude was observed as the first arrival on the eastern coast and the second arrival on the western coast. IOC (1998) (Intergovernmental Oceanographic Commission) post tsunami survey field guide was used to measure run-up, inundation and other useful information regarding tsunami. The hatched area shown in figure 1 depicts the surveyed locations. The names of localities, their serial number, locations, tsunami run-up and inundation, number of causalities and first arrival time of tsunami are given in table 2.

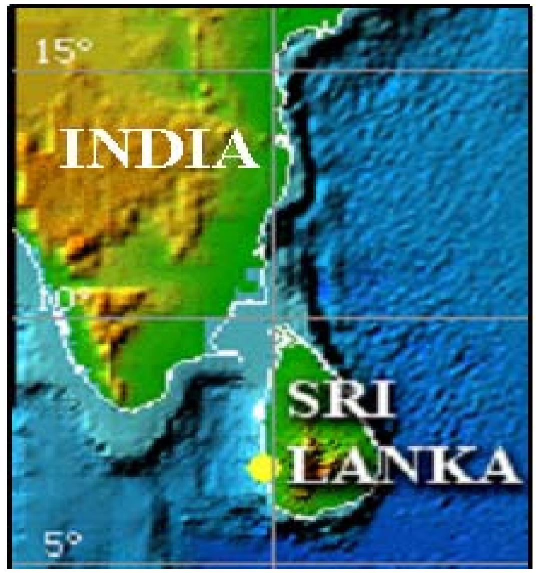

Figure: 2 Coastal and ocean basement topography around Tamilnadu and Sri Lanka.

Analysis of gathered data reveled that the measured run-up values and the damage pattern were highly variable. The districts of Nagapattinam, Kanayakumari and Chennai were the worst hit districts and almost no damage was observed in Pudukkotai, Ramnathpuram and Tuticoin districts. During the damage survey it was noticed that localities with Medu, breakwaters, mangroves, and shelter belt plantations suffered less damage (The Hindu, 2004, 2005). Such peculiar observations along with the possible physics behind the large variation in damage along the coast of Tamilnadu are documented in this paper.

EFFECTS OF WIDTH OF CONTINENTAL SHELF

It can be inferred that the amplitude of tsunami should decrease from south to north along the coast of Tamilnadu, on the basis of location of epicenter of Sumatra earthquake and the orientation of rupture plane. But, the damage survey revealed large variations in the tsunami run-up and damage pattern.

Figure 3: Depicts the damaged children's park, uprooted electric pole, damaged SINGNADH and the collapsed auditorium on Nagapattinam Beach.

Figure 4: Intense erosion of front portion of beach road, facing to the sea coast at Nagapattinum beach.

Figure 5: Uprooting of the trees and washing away of destroyed building materials in Vellaipallyam village

The southern part of Tamilnadu from Kanyakumari to Pudukkottai district, situated in the shadow of Sri Lanka, suffered the least damage (Fig. 1 & 2). But, the damage survey revealed large variations in the tsunami run-up and damage. Further, tsunami damage was highly variable from Nagapattinam to Chennai. Maximum tsunami damage (run-up 10-12 m) was observed along the coast of Nagapattinam. There was decrease in damage from Cuddalore to Kanchipuram district. Increase of damage was again observed to the north of Adyar River from Srinivaspuri to Anna Samadhi Park in Chennai district. Along the coast of Nagapattinam district run-up and inundation were 10-12 m and 2-3 km, respectively. General panic was reported every where and people were unable to understand what was happening. Many people were washed away and lost their life.

Nagapattinam beach, a newly constructed tourist spot was completely destroyed (Fig. 3). Extensive ground erosion and uprooting of trees was observed every where (Fig. 4 & 5). Many structures suffered damage of grade G4 and some destroyed. Severe damage to lifelines (road, bridges, telephone and electric poles and railway line), port and harbors took place (Fig. 5). Many big boats/vessels were thrown violently towards the coast (Fig. 6). It seems that lesser width of continental shelf near the coast of Nagapattinam district and the interference of the direct waves and the reflected waves from Sri Lanka developed largest tsunami run-up (10-12 m) in Nagapattinam district (Fig. 2). On the other hand, much lesser damage occurred along the coast of Kanchipurum district due to some what wider continental shelf (Besana et al, 2004).

Further, heavy damage was observed from Keelmanakudy village to Colachal Harbor on the west coast of Kanyakumari. Largest tsunami run-up (9-10 m) was reported during the second inundation of the tsunami. The decreasing trend of damage was observed from Keelmanakudy village to Colachal harbor. Around 70 people lost their life in Keelmanakudy Village. A newly constructed bridge on Palyar River suffered severe damage (Fig. 7a).

Figure 6: Damaged structure on the Nagapattinam Port due to the collision of a boat thrown by tsunami.

Figure 7: Damaged bridge on the Palyar River, whose spans of the deck were washed away (left), and partially collapsed Church of Keelmanakudy Village (right).

All the four spans of the deck were washed away by the tsunami and two were missing. Almost every building of good quality along the seashore suffered heavy damage (Fig. 7b). Damage to masonry buildings was quite intense; few of them not only collapsed but were completely flattened. There was intense erosion to a road linking the village to the bridge. Variation in tsunami run-up/damage along the west coast of Tamilnadu can be explained considering the interference of first receded waves with the reflected waves from Maldives Islands and the lesser width of continental shelf (Fig. 2). It has also been reported in the literature that some times the later arrivals cause more sever damage (Bryant, 2001).

It was also noticed that there was local increase of tsunami damage near the mouth of rivers, due to the refraction of tsunami waves (Harinarayan and Naoshi, 2005). The place of local increase of damage was dependent on river orientation and direction of arrival of tsunami. For example damage was relatively more towards the north of Adayar River from Srinivaspuri to Anna Samadhi Park as compared to south of it at Elliot's beach. Similarly more damage was observed at Nagapattinam beach near a river, Nagapattinam Port on Kaduvaiar River, Devanakuppam beach on Kedilum River, Velonganni beach near a river and Keelmanakudy village near Palyar River.

EFFECTS OF MEDU

During the damage survey, it was observed that at many places presence of Medu, breakwaters, mangroves and shelter belt plantations (The Hindu, 2004, 2005) saved a lot of loss of human lives and property. Although, the purpose of the breakwaters was to avoid the impacts of tidal waves but it performed well at some of the locations. Further, it was first time observed by the residents that the presence of Medu near the sea-shore may be so effective to avoid the disastrous impact of tsunami. In the following subheadings, the beneficent role of Medu at Kilinjal village, Nabiyarnagar and Nagapattinam Port, during the attack of killer tsunami is reported.

Kilinjal Medu

The Kilinjal Medu is located to the north of the Kilinjal village. Inundation in this area was around 2-3 km. The estimated tsunami height near the shore was 8 - 9 m. The population of this village is

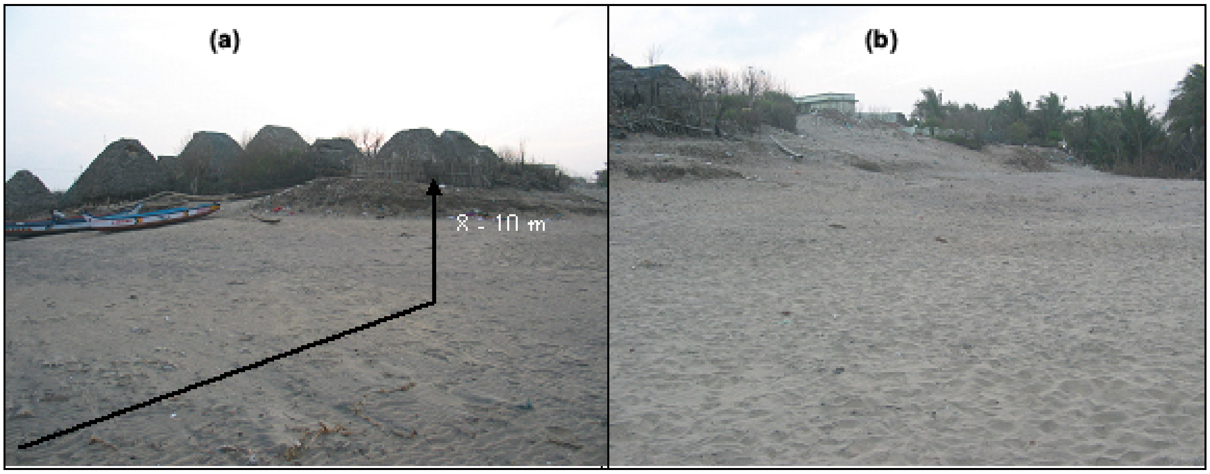

Figure 8: Illustrates the different views of the Killinjal Medu and the little damaged house/huts on the Medu.

about 2000. The loss of human life was 23. The height of Kilinjal Medu is about 8-10 m (Fig. 8a). The width of Medu parallel to the seashore was around 200m. The slope of Medu towards the sea was steep and it was flat up to 50-60 m, and thereafter-gentle slope. Similarly, slope on the north of Medu was more where there was no dwelling and it was gentle on the south side of the Medu. The residents on the Medu reported that sea water was unable to reach to the top of it during the attack of tsunami waves.

Figure 8 depicts houses and the Kilinjal Medu from different locations. We observed that there was no damage to even huts built on the Medu (Fig. 8a). The presence of Medu prevented damage of many huts/houses behind it and finally the loss of human life also. Figure 9a shows a hut, which suffered almost no damage since it was behind the Medu. Severe damage to collapse of houses occurred to the north and south of Medu. Figure 9b depicts damaged houses, which were situated to the north side of the Medu. It was general feeling of the residents of this village that Medu has saved much loss of human life and houses.

Figure 9: Depicts lightly damaged houses behind the Kilinjal Medu (left), and destroyed structures north of the same (right).

Figure 10: A sketch showing the Nabiyarnagar Medu from the left and front side.

Nabiyarnagar Medu

Nabiyarnagar Medu is situated on the northern part of Nabiyarnagar. Tsunami caused death of 260 people and around the same number was missing in Nabiyarnagar having population 5000-6000. Tsunami run-up in this area was around 10-12 m and inundation was around 3.0 km. A sketch of the Nabiyarnagar Medu from north and front side is shown in figure (10). The houses built on the Nabiyarnagar Medu were more or less safe, while others were completely destroyed (Fig. 11a). Most of built houses near the shore (between 50 –100 m) and towards the south of the Medu were either destroyed (B-type) or washed away (huts), and rest was unsafe for living. Intense damage to houses was observed even up to a distance of about 600 –700 m from the coastline.

Very less damage was observed to the buildings behind the Medu. The huts on the Medu suffered no damage, since tsunami waves were unable to cross the Medu. The height of the Medu was around 14 m. It has steep slope towards north and sea but has gentle slope towards south and behind. Some huts were also washed away which were in front of Medu and at lower elevation. It was reported that coastline has come near to the Medu by 50 m. On the south side of Medu where elevation was lesser houses suffered severe damage. Intense erosion towards north of Medu was observed (Fig. 11b).

Figure 11: Lightly damaged hut on the front portion of the Nabiyarnagar Medu (left), and intense erosion of coastal land, north of the Medu (right).

Nagapattinam Medu

Figure 12 depicts the Nagapattinam Medu, existing just in front of the southern part of the Nagapattinam Port. The height of Medu is around 7 m with respect to the port level. Tsunami crossed the Medu. There is Kaduvaiyar River between port and the Nagapattinam Medu (Fig. 13).

Figure 12: Medu in front of the Nagapattinam port.

Lesser damage occurred just behind the Medu, as can be inferred from the figure 13 in which there is lesser damage to wharf in its upper and left corner. Same was the feeling of employees of this port that Medu in front of the port reduced the damage to some extent, particularly to the structures and boats in the Kaduvaiyar River, as reported by Mr. Shajath Ali (Assistant Engineer, Mechanical). On the other hand, Nagapattinam Port suffered heavy damage and it was not in operation for 15 days. Tsunami caused heavy damage to wharfs (Fig. 13), boats (Fig. 6), compound wall and an old jetty constructed in 1972.

CONCLUSIONS

The deadliest Indian Ocean tsunami of December 26, 2004, in the recorded history, developed highly variable damage pattern due to the shadow of Sri Lanka, presence of Medu, variable width of continental shelf and interference of direct waves with the reflected waves from Sri Lanka and Maldives Islands. It seems that maximum damage observed along the coast of Nagapattinam district may be due to the lesser width of continental shelf and the interference of direct waves with the reflected waves from Sri Lanka (Besana et al, 2004).

Similarly, intense damage during the second attack of tsunami, from Keelmanakudy village to Colachal Harbor along the west coast of Kanyakumari, may be due to the lesser width of continental shelf and the interference of receded first waves with the reflected waves from Maldives Islands. It has also been reported in the literature that some times the later arrivals cause more sever damage (Bryant, 2001).

Figure 13: damaged wharf of the Nagapattinam Port.

Presence of Medu at Killinjal village, Nabiyarnagar and Nagapattinam Port reduced the damaging impact of tsunami on the built environment. It was also noticed that there was local increase of tsunami damage near the mouth of rivers, due to the refraction of tsunami waves (Harinarayan and Naoshi, 2005). The place of local increase of damage was dependent on river orientation and direction of arrival of tsunami. The southern part of Tamilnadu from Kanyakumari to Pudukkottai district suffered least damage due to the presence of Sri Lanka in the path of tsunami. Further, the level of damage in the Gulf of Mannar was more than in the Palk Strait, since only diffracted waves were able to enter into the Palk Strait.

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