Interaction of Tsunami wave propagation with coastal bathymetry and geomorphology; a case study in Sri Lanka

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Abstract

The Indian Ocean mega tsunami was the most severe natural disaster that ever happened in Sri Lanka's history. According to the available records, Sri Lanka lost more than 40,000 lives and more than 5000 are still missing. The loss of property has never been estimated.

The aim of this post-tsunami survey was to acquire ground truth data on tsunami run-up and horizontal inundations and to correlate them with coastal bathymetry and geo-morphology. The correlation of ground truth data with coastal bathymetry and morphology provided a broader view of the behaviour of tsunami wave propagation. Coastal bathymetry and geomorphology are the major factors that determine the influence and severity of the tsunami waves.

The continental shelf of Sri Lanka is narrow and the average width of the shelf is about 20 km. with a maximum width of about 35 km. The Continental slope is the world's steepest at approximately 45 degrees, spread from 500 to 4000 meters depth. The study revealed that the average width of horizontal inundation is about 2 km and maximum run up about 13 km. The measured wave observed run up versus horizontal inundation and predicted curve was plotted at the same scale. However, calculated and observed values show some differences from each other. For most of the cases, observed values exceeded the estimated values, but in some cases appear below the expected level. Later, the coastal bathymetry was considered and it revealed that the tsunami waves scattered with narrow shelf, canyons, and coastal bays to increase the tsunami wave heights. Specially, Payagala (run-up 4.5 m and inundation 0.5 km) was severely affected due to the presence of a coastal canyon. Another vital factor that was found at Paraliya (run-up 10 m and inundation 1.5 km) to increase tsunami height was the impact of near shore coral mining pits in the area.

The studies carried out on the Southern coast of Sri Lanka revealed that the coastal bays caused funnelling of the tsunami waves and the younger sand dunes at low lands between older dunes were breached by tsunami waves, causing severe damage. Also, it showed that the initial Tsunami wave arrived at the area at 08:50 am local time and the second wave arrived 20 minutes later; thus height of the second wave was further enhanced due to superimposition of the incoming wave with the reflected wave at the foreland, due to shallow and narrow continental shelf. The study clearly establishes that the coastal morphology serves as a critical parameter in protecting the coastline from ocean-based disasters. However, protective morphological barriers may cause increased severity on low land area due to the compression of tsunami waves.

Introduction

The massive earthquake which occurred in northern Sumatra was the basic reason for the most devastating tsunami which occurred on 26th December 2004. It caused severe damages to Indian Ocean coastal states specially to Sri Lanka. Almost the whole coastline was affected by the tsunami and losses more than 40,000 human lives. Although Sri Lanka did not have recent tsunami experiences there is some available paleo-tsunami evidence its history.

The first recorded tsunami was in August 1983 (Simskin and Fiske, 1983) which occurred in Karakatau Island as an impact of a volcanic eruption. Significant water level changes were recorded in different locations in Sri Lanka such as Baticaloa, Colombo, Galle and Negombo (Choi et.al, 2003). The recorded maximum run-up was 1m at the Coast and the wave travelled 5 to 7 hours from the origin (Choi et.al, 2003).

Continental Margin and coastal bathymetry of Sri Lanka

Sri Lanka lies near the southern tip of India bounded on the west by the Gulf of Mannar and the Bay of Bengal on the east (Wijayananda, 1995). The continental margin of Sri Lanka has been passive since Cretaceous India rifted away from Gondwanaland (Laughton et al., 1972). The continental slope has about 45° inclination in southern Sri Lanka (Shani, 1982). The bathymetry of the continental slope demonstrates a minimum slope of 45° at the depths between 500 and 4000 meters (Curray, 1984). However, this is considerably large value compared to world average (Shepard, 1963).
The continental shelf of Sri Lanka is narrow, averaging 21km wide with a maximum of about 35km. Also, the bathymetric compilation indicates that the continental slope is dissected by eight canyon with one of the world largest canyon at Trincomalee. The average depth of the continental shelf is approximately 200 m's (Wijayananda, 1995).

Objectives

The overall objective of this study was to gather information on tsunami wave run-up and horizontal inundation and correlate them with nearshore bathymetry and coastal geo-morphology.

Methodology

The post-tsunami survey was conducted to acquire information on run-up and horizontal inundation along the coast line of Sri Lanka, in order to evaluate the degree of damage and also to establish vulnerability and produce an inundation map for disaster management and mitigation. The study was conducted over the whole coastline and used to ascertain the impacts of coastal morphological features to protect the coastline. Damage was classified as less, moderately and highly damaged from to field observations. Also, eyewitness evidence from coastal people were gathered for future reference. The survey was designed and conduct under the post tsunami field survey field guidelines.

Results and Discussion

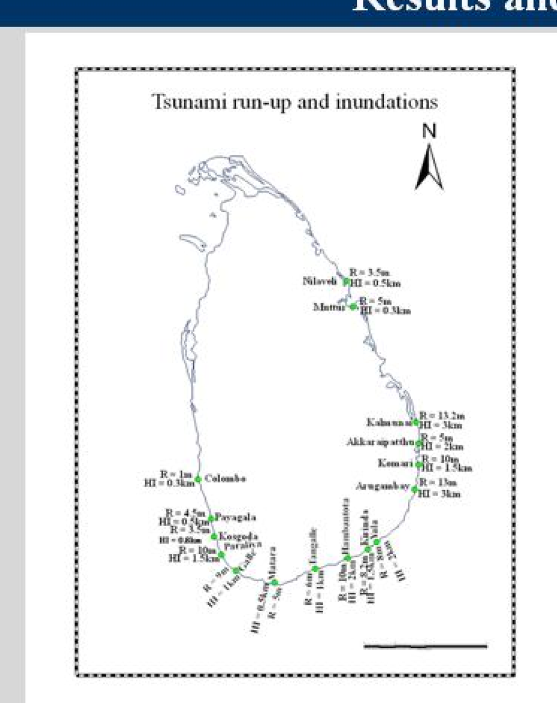

Fig 1. Tsunami run-up and inundation around country

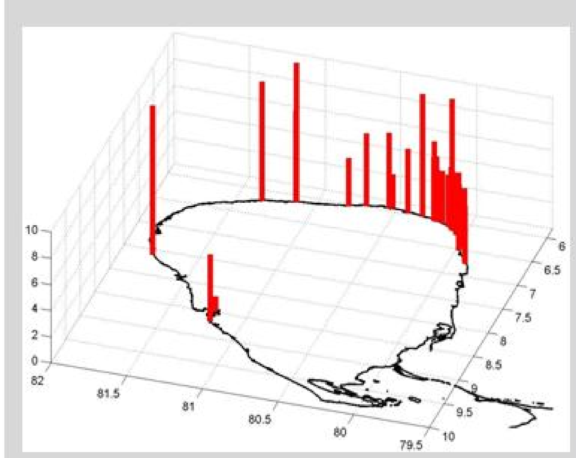

Fig 2. illustrates the maximum run-up

Horizontal inundation and run-up vary with coastal topography, geomorphology, and bathymetry of the continental shelves. Bathymetry of narrow continental shelf increases the height of the tsunami waves to dissipate the energy close to the coast. The increased height of waves is the reason for severe damages at narrow shelf areas.

The Fig. 1 shows the run-up and horizontal inundations in selected sites which were the places most severely affected by tsunami. It indicates minimum run-up of 1m at Colombo and maximum of 13.2m at Kalmunai (Fig 2).

Horizontal inundation varies from 0.3 to 3km at respective sites. Also, the study reveals that most of the areas were highly damaged due to widely spread horizontal inundation. However, field investigations indicated that horizontal inundations were below the expected level. The differences may be due to influences of coastal geomorphology and coastal topography of the area

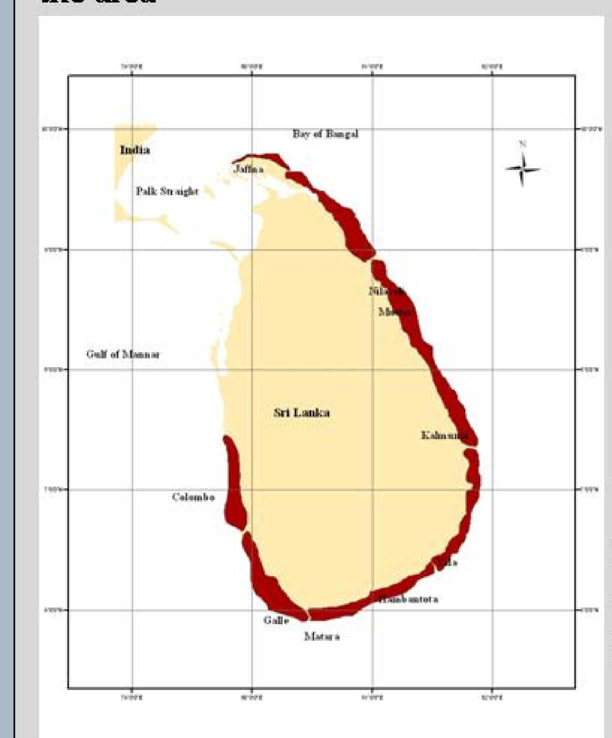

Fig 3. Horizon inundation mapping

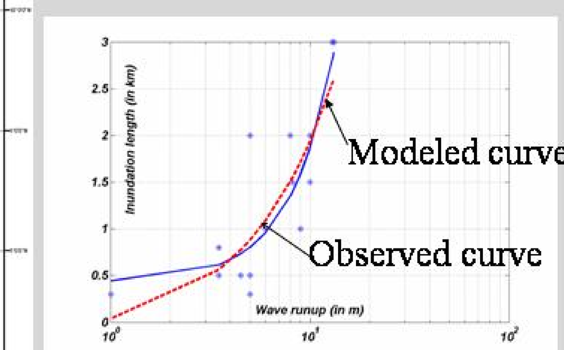

Fig 4. shows the graphs of observed and modeled tsunami wave run-up and inundation lengths.

The Figure 3 illustrates the tsunami horizontal inundation around Sri Lanka. Inundation lengths are varied from several hundreds of meter to few kilometers. The investigations revealed that coastal morphology directly influenced the flow of tsunami waves through low land up to several kilometers. Also, it reveals that higher elevations act as a barriers to decrease the inundation lengths. Figure 4 illustrates the graph of run-up verses horizontal inundation. The graph indicates that observed run-up and inundations are not always coincident with the model values and most cases lie below the modeled values. As an example, at the run-up 5m; horizontal inundation is 0.5km at Muttur, 2km Akkaraipattu, and 0.5km at Matara. However, the model curve representing the expected inundation is about 0.8km. The field observation indicated similar situations all over the country.

Fig 5. Tsunami affected area at Mahaseelava Kalapuwa (lagoon)

Fig 6. Tsunami affected area at Butawa Kalapuwa

Figure 5 illustrates the post tsunami impacted area of Mahaseelawa lagoon in Yala national park. The survey area is covered by natural barriers like sand bars and sand dunes. The mouth of the lagoon is the only low elevated area which was the possible entrance for tsunami wave. Tsunami waves were compacted by the narrow entrance and coastal morphologies which increased the impact of the damages.

Figure 6 shows the tsunami affected area of Butawa Kalapuwa. Tsunami arrival direction is marked by arrows. The adjacent headlands which are formed by sand dunes funneled water to the lagoon. Also, remnants of coastal mangroves destroyed by the Tsunami could be observed in the field. The important fact that could be observed in this area is the increases of wave impact by headland and bay structure.

Fig 7 Tsunami affected area at Patanangala area

Fig 8 Height to beach from sea level

Fig 9 Tsunami run-up at Yala Safari

Fig 10 Tsunami wave entrance through younger dunes

Tsunami wave impaction of the Patanangala area is given in Figure 7. The area is represented by a bay where entrance by sand bar influences water coming into the bay. The field observations indicated that the tsunami wave enters through younger dunes to the bay. The area was totally destroyed by the tsunami wave.
Figure 8, 9 and 10 show snapshots of tsunami impacted areas in Yala. The area is covered by two adjacent headlands which are formed by sand dunes. Figure 8 indicates the height from low tide terrace to berm crest. Figure 9 shows the height from beach to maximum height to crest of the tsunami wave. Figure 10 illustrates the area of newly formed younger dunes. Also, it shows Brown beach hotel which was the totally destroyed by tsunami wave entered over the younger dunes.

Conclusions

Coastal geomorphology act as an agent to increase damages at coastal areas. However, some coastal features such as sand barriers help to decrease the total damage. Coastal geomorphology, coastal bathymetry, and topography of seafloor are the major influencing factors to determine the severity of tsunami disasters. Also, narrow continental shelves are one major reason of increased tsunami heights. Coastal geomorphological features, coral reefs, and natural barriers hinder to wave progression towards the coast especially in east coast.
The study revealed that the places where canyons are located close to coasts are severely damaged. The major events occurring in these sites were gathered water due to the funneling effect of major canyons. In addition tsunami wave height is further enhanced due to overlapping of incoming waves with reflected waves at forelands. The study clearly establishes that coastal bathymetry directly impacted for increasing tsunami run-ups. Also, it was noticed that tidal effect acts as minor source to increase tsunami heights by few centimeters.

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