Analysis of damages in Hikkaduwa and South West Coast of Sri Lanka in 2004 Dec Sumatra tsunami

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This study focuses the impact of 2004 Sumatra tsunami to Sri Lankan west and south coast and mechanisms behind such devastation ever experienced in the history of Sri Lanka. Objective of the research aiming at tsunami initiation, its propagation and damage to south and west coast of the Sri Lanka. Direction of the research goal was set based on the information and data collected after the extensive post tsunami survey carried out in Sri Lanka. The survey was basically focused on revealing the mechanisms of rhythmic pattern of damage and effectiveness of coastal structures. Considering the scale of the damage and the human dimension of the risk. It was understood that strong edge wave formed by trapping of tsunami wave was the main cause of damages in the west and south west coast. Shape of the near continental shelf of Sri Lanka is important in understanding the variation of damages in different zones. In depth survey was carried out in Hikkaduwa. Analysis of the survey results confirmed that existing coastal structures were effective up to certain extent in guarding the tsunami waves.

Introduction:

On Dec 26 the 2004, on a bright sunny morning, sea was calm, the Sri Lankan coastline witnessed a devastating impact of a boxing tsunami, an unknown phenomenon to many Sri Lankans. Since this was hitherto many Sri Lankans, the damages caused to their lives were unbelievable. This was recorded as the highest tsunami experienced ever in the history for the last 50 yrs. The tidal waves were caused by a series of earthquakes, measuring 8.9 on the Richter scale that occurred in the sea near Sumatra, Indonesia at a depth of around 6.2 miles below the mean sea level.

Initial burst of earthquake resulted in two waves known as leading wave (traveling towards the Sri Lanka) and negative wave (traveling towards Indonesia). Leading set of waves were the most important since it carried the higher amount of the energy absorbed from the initial burst and also witnessed by the Sri Lanka.

This leading tsunami waves made a huge destruction to Sri Lanka by affecting more than 70 % of the country's total coastal zone (1650 km), claiming more than 30,000 lives,(see figure 1.1) displacing more than 200,000 families, wiping off all the costal infrastructure facilities and ultimately weakening the overall economy of the country.

Scale of damages to Sri Lanka

Sri Lanka is geographically positioned around 1400 kilometer westward from the epicenter of the earthquake. Enormous amount of energy released from series of earthquakes was transported by the leading wave front inundating Sri Lanka, India and even further west countries. Due its close proximity, it took only 2 hrs to receive morning attacks of the Tsunami waves after the initial earthquake occurrence at 00:58:50 GMT.

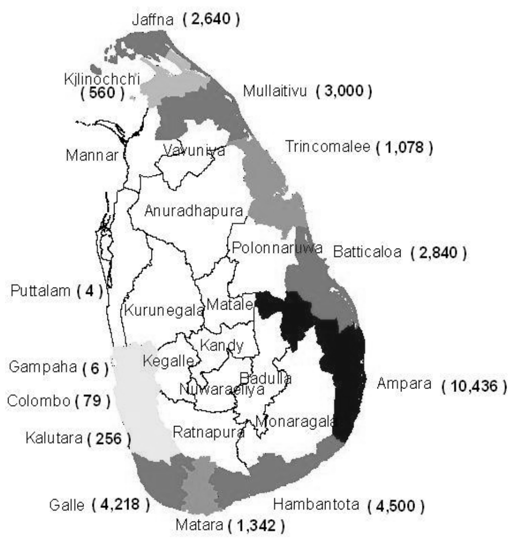

Fig 1.1 Number of casualties in Sri Lanka during 2004 Dec Sumatra tsunami.

Based on the field observations and computer simulations it was very much convincing that Sri Lanka was located right middle of the propagated tsunami waves traveling all the way from the source of the earthquake. As it was approaching the near shore, waves started transforming its kinetic energy to potential energy by forming a several meters high tidal bore. Those high momentum and energetic bore waves were easily smashed inside most of the low line coastal areas and wiping off everything all the way before breaking.

Geographical shape and the near shore morphology of Sri Lanka (fig 1.2) could be identified as the main cause of massive damage to the Sri Lankan coastal zone even extending further west coast of country. it can be reasonably argued that most of the wave energy have concentrated and refracted towards the southern coast of Sri Lanka. Those edge waves (fig 1.1) were again reflected and refracted back towards the South west coast of Sri Lanka forming series of moving edge waves. Which resulted massive destruction to Galle, Hikkaduwa, Akurala, Payagala, Kalutara and many other places along the south west coast? Rhythmic nearshore topography consisting capes, valleys and bays would be one of the causes of alternative pattern of local damages in some populated areas along the southwest coast. Presence of coastal wetlands, bays, headlands and river mouths made it difficult for most of the scientists to understand the most immediate cause of damages.

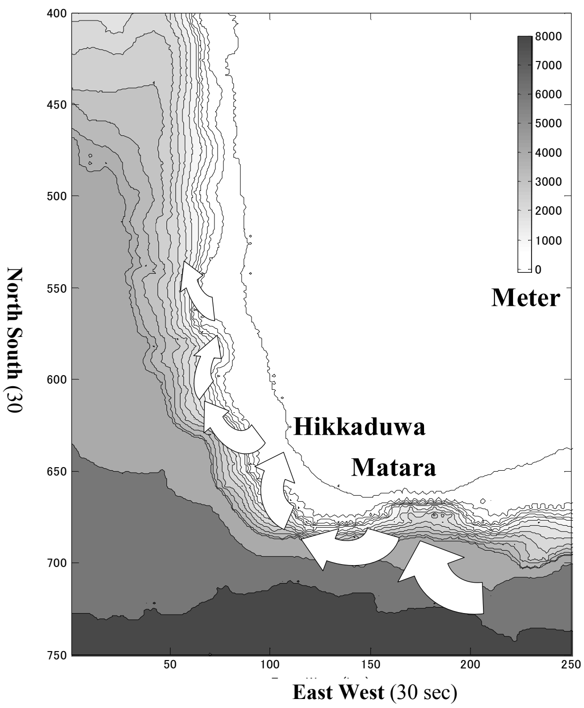

Fig 1. 2 . Propagation of edge waves in shallow Continental Shelf in South &

Field Observation and research framework.

Field investigation in south and west coast of Sri Lanka (Feb 24 th to March 02 nd , 2005) had two main objectives out of several key objectives. Primary objective was to study the overall damage to the affected coastal zone from North of Negombo, Marawila (07o 22' 35.3"N, 79 o 49' 23.1"E) up to Yala (06o

20' 38.3"N, 81 o 29' 50.8"E) in general to identify any relationship between alternative damage pattern and the nearshore topography and nearshore morphology.

Final stage of the survey was to carry out detail investigations in the view of finding any effectiveness of coastal structures in minimizing the effect from wave attack and flooding.

Mechanisms of Damages

Based on the inundation heights measured in the south and southwest coast (North of Negombo to Yala) (Fig 1.3.) it was clearly confirmed that the reduction of the wave energy as it refract around the country. Also it could clearly visible that combined nearshore transformations converged wave energy into south west coast of Sri Lanka (Galle, Unawatuna, Hikkaduwa, and Akurala) experienced unexpected high waves. The phenomena can be explained as unbroken tidal waves concentrated (funneled) into the shallow continental shelf of south west coast and amplified immensely. (Fig 1.2)

Such waves could easily propagate with high momentum in low line areas with fewer obstacles. This was clearly identified from the captured videos from Akurala to South of Hikkaduwa.

Detail survey of Hikkaduwa was meant to reveal if there was any positive contribution from existing coastal structures (such as breakwaters, revetments, groynes and sea walls) and land structures in the coastal zone (such as hotels, houses and boundary walls) towards diminishing the damages to sheltered areas by those structures.

Analysis of damages observed in Hikkaduwa City

Based on the measurements obtained in the field survey (see fig 1.5) along the railway line, it can be seen that higher inundation heights around the North of the Hikkaduwa city area.

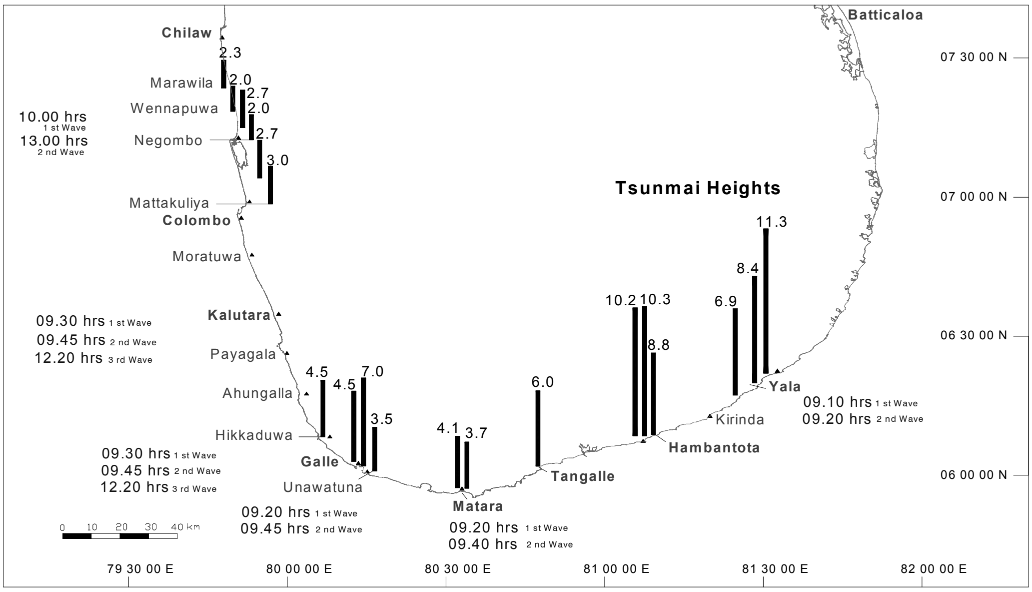

Fig 1.3. Tsunami Inundation Heights and tsunami arrival times in the South Coast and South West Coast with the arrival time of tsunami by victims

There were no such high inundation heights within the south of the Hikkaduwa city. When it compared with the inundation heights obtained along the road survey and rail survey, it was clearly evident that higher inundation heights were observed near the buildings closer to the sea. Another important observation made was

The high inundation heights measured near the area behind the North breakwater and around mouth of fishery port.

Summary of the most immediate causes for damages in Hikkaduwa Township could be as;

1. convergence of waves around north breakwater and south headland
2. Topography of the Hikkaduwa town area confined with low line areas within the fist few hundred meters from the shoreline.
3. Entrance of tidal waves through Hikkaduwa River, flooding low line areas.
4. Most of the damaged housed were fairly old and not strongly built for any kind of flooding.
5. Amplification of waves in the shallow water bathymetry in Hikkaduwa.

Numerical simulation of tsunami propagation, deformation and run-up.

Hindcasting of a tsunami by numerical simulations is a lengthy and a tedious process including complicated deductions. Only available observations are kind of run-up heights, tidal records both, which are possibly of less accurate and not sufficient to confirm the reliability of numerical models. Meanwhile there are many source errors in estimation of the initial profile of the tsunami. Therefore the results of the numerical simulations are providing only a guideline for estimation of risk and future planning.

Focus of this research is to understand the generation, propagation, deformation and run-up of tsunami. Because of the time limitations more attention was given to propagation of tsunami and run-up of tsunami.

Propagation Tsunami

tsunami propagation model is based on the Aida (1978) and Imamura (1995). Governing equations are given as follows;

Continuity equation

$$\frac{\partial \eta}{\partial t}+\frac{\partial P}{\partial x}+\frac{\partial Q}{\partial y}=0$$

Momentum equation

$$\frac{\partial P}{\partial t}+\frac{\partial}{\partial x}\left(\frac{P^2}{d}\right)+\frac{\partial}{\partial y}\left(\frac{PQ}{d}\right)+gd\frac{\partial \eta}{\partial x}+\frac{\tau_x}{\rho}=fQ$$

Eq.1.1. Tsunami Initiation source data

However Leapfrog scheme is highly unstable in calculating non –linear waves. Hence upwind scheme has been used to express the non-linear terms. Calculations were done based on two initial boundary conditions, Koshimura, 2005 and Earthquake research Institute of University of Tokyo, 2005. Both the cases generated results with good agreement.

Based on the propagation modelling it was shown that tsunami propagation time and was matched with the field observations. Also it was clear that the inundation heights are in the order of what is observed in the field. It was further shown that damaged were localized due to the effect of the strong refraction in the shallow water.

It was also convinced that 2004 Dec Sumatra earthquake was an extreme event and much of the damages took place as a result of tsunami initiated from the north of Sumatra.

Deformation of Tsunami

Tsunami deformation was calculated based on Alternate Direction Implicit Model (ADI) by Kabiling (1994) which is originally based on the depth integrated two dimensional Boussinesq equations of motion and water conservation was developed by Peregrine (1967). Equations considered the dispersion effect of waves, which is far better in representing near shore deformations.

Deformation modelling clearly showed that formation of a strong dynamic edge wave in South coast and propagates towards west coast of Sri Lanka. Also it was clearly seen that there were multiple formation of edge waves, which made several wave attacks to most of the South west coast.

Inundation model

Inundation calculations were done in Hikkaduwa to identify the effect of structures and to find out the maximum inundation height. The calculations were based on the model developed by Tajima. Y (2005), which is originally based on the shallow water wave equation.

Results of the numerical model showed that there was an effect from breakwaters, headland in the south of Hikkaduwa and series of Hotels in the middle of Hikkaduwa. It was shown that there was an effect from the hotels in energy dissipation and there is a considerable effect from the breakwaters. However it as seen that around breakwaters and headland there was a high convergence of waves. Effect of river mouth and low line area around North of Hikkaduwa was identified as a supportive mechanism for early inundation.

Conclusion

Overall

Based on the field observations it can be concluded that the localized damages were identified along the south west coast and some part of south coast. Nearshore deformation of tsunami as responsible for such changes. Anyhow effect of the shape of the continental shelf was more dominant in formation of strong edge wave in the south west coast, which intern made a rhythmic variation of damages along the south west coast.

The propagation model shows a some degree of numerical damping in results. Anyhow the trend of the damages was almost agreed with the field observations.

Hikkaduwa

There was an effect from breakwaters protecting the surrounded are behind the south breakwaters. Effect of the north breakwater was not highlighted since the heavy flow took place around the river mouth. It can be argued that tsunami waves were not effectively obstructed by those shallow breakwaters.

From the inundation heights observed, it was clearly evident that there was an effect from hotels and buildings in reducing the energy of incoming waves and shielding the landside. This was further convinced by the Inundation modelling in Hikkaduwa.

Coastal topography was again an important factor for Hikkaduwa in tracing the roots of the damages. It is also very important in preparation of future hazard maps and disaster preparation and management studies.