Chapter 3 Field Survey Report on the 2004 Indian Ocean Tsunami along the Southwestern Coast of Sri Lanka

3.1 Introduction

A huge earthquake with a magnitude of 9.0 took place to the northwest of Sumatra Island on December 26, 2004. This earthquake generated a tsunami and caused catastrophic events in all the coastal areas of the Indian Ocean. To investigate the damage, which covered a very wide area, a field survey was carried out in each of the effected countries by an internationally coordinated survey mission. This survey team was part of this international survey mission, ITST (International Tsunami Survey Team), and the team surveyed the situation of tsunami run-ups and the damage along the southwest coast of Sri Lanka between January 4th and 6th, 2005.

Sri Lanka is located 1,700km far from the epicenter and the tsunami source, so no one felt the ground shake. The characteristic of this tsunami is a so-called Oceanic/Distant Tsunami, and the tsunami hit the entire coastline of Sri Lanka around 2 hours after the earthquake. Sri Lanka (Population:19,238,575, Total Area:65,610km^2, Coastline:1,340km) is an oval island close to the Indian Continent, and the coastal sea bed falls steeply to meet the ocean floor. It is a place the tsunami behaves as the boundary wave and was influenced by the reflection and diffraction wave.

The confirmed number of casualties exceeded 30,000, and it reached more than 40,000 when the number of missing persons was added. It is important to clarify the reason why the death toll was so high. Furthermore, the tsunami damaged the traffic/transportation facilities and infrastructure, including trains, railways, roads, ports. Investigation of the amount of damage was also essential.

3.2 Field Survey

3.2.1 Measuring Tsunami Trace Heights

The team investigated the coast along the southwest of the island between the cities of Colombo and Galle. Measurements were taken of the tsunami trace/runup heights, the damage was inspected, and information on the tsunami was corrected. Table 1 shows the tsunami trace information on the investigated points after tidal correction. All the data in table 1 is reliable in which traces of the tsunami are clear. Figure 1 shows the distribution of tsunami heights of the trace at all of the investigation areas. Here, H_v shows the height (m) of traces on the mean sea level, and D_h shows the distance (m) from the shore line to the measured point. The range of the astronomical tide in this region is about ±0.7m. Since the coastal area on the land is so flat and the inundation area was so wide, it was rather difficult to reach the end of runup. We could mostly measure the heights of tsunami traces on the walls of damaged houses and trees.

Table 1 Tsunami trace information on investigated points

Location	H_v (m)	D_h (m)	Position of trace	Survey time
Waligama	4.9	54	Exterior wall of a house	11:02, 05, Jan
Koggala Airport	9.3	64	Roof of a house	11:30, 05, Jan
Galle Port	6.0	190	Exterior wall of an office	13:35, 05, Jan
Dodanduwa	4.0	24	Exterior wall of a house	16:35, 05, Jan
Hikkaduwa Fishery Harbour	4.7	54	Interior wall of a house at second floor	09:40, 06, Jan
Kahawa	10.0	228	Palm tree	10:02, 06, Jan
Ambalangoda beach	4.7	50	Exterior wall of a house	11:50, 06, Jan
Beruwala Fishery Harbour	2.4	6	Interior wall of a building	13:10, 06, Jan
North Beach of Beruwala	4.8	50	Washed up tree	14:10, 06, Jan
Paiyagala Station	6.0	36	Interior wall of a house on the second floor	14:40, 06, Jan
Panadura	5.6	150	Roof of a house	15:50, 06, Jan
Moratuwa Beach	4.4	10	Exterior wall of a house	17:10, 04, Jan

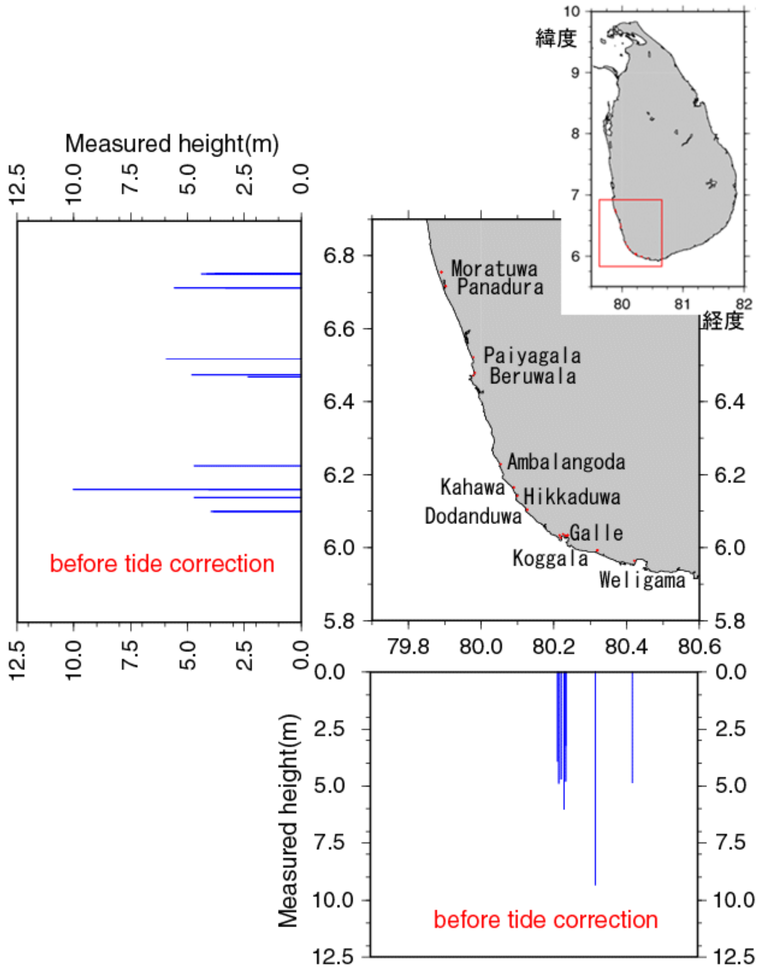

Figure 1 Distribution of Tsunami Trace Heights in southwest Sri Lanka

From these tables and figures, it is obvious that the tsunami trace heights were 6m in the Galle port and 10m in the Kahawa district, which is located 90km to the south of Colombo. However in the Beruwala district, which is located 53km to the south of Colombo, the tsunami trace heights were about 5m, and only 2.5m inside the fishing port. This suggested the effect of the wave-break and sea wall here reduced the tsunami attack. Details about this phenomenon are described in 3.3.2. It is indicated that the typical tsunami trace heights along the coast in the southwest of Sri Lanka were about 5m by the field survey, except for two points: Koggala Airport and Kahawa.

3.2.2 Tsunami Arrival Time and attacks

There are several places where the number of tsunami attacks were two or three according to eyewitnesses, as shown in Figure 2. The arrival time of the tsunami at Galle port was estimated to be 9:25AM Sri Lankan time, and it is posted at the Galle port office. In other districts, the arrival time of the first tsunami was estimated by eyewitnesses to be 9:30AM in the Moratuwa district and 9:45 AM in the Kahawa and the Beruwala districts. The earthquake was at 6:58AM Sri Lankan time, so that the tsunami reached the west coast of Sri Lanka two and a half hours later. However, the second or third tsunami waves were reported to be the largest in many places, for instance, the testified arrival time was 10:30AM in the Kahawa district and 11:05AM in the Moratuwa district. We can say that the second wave was certainly larger than the first wave and the duration time, the wave period, was estimated to be 30 minutes or more.

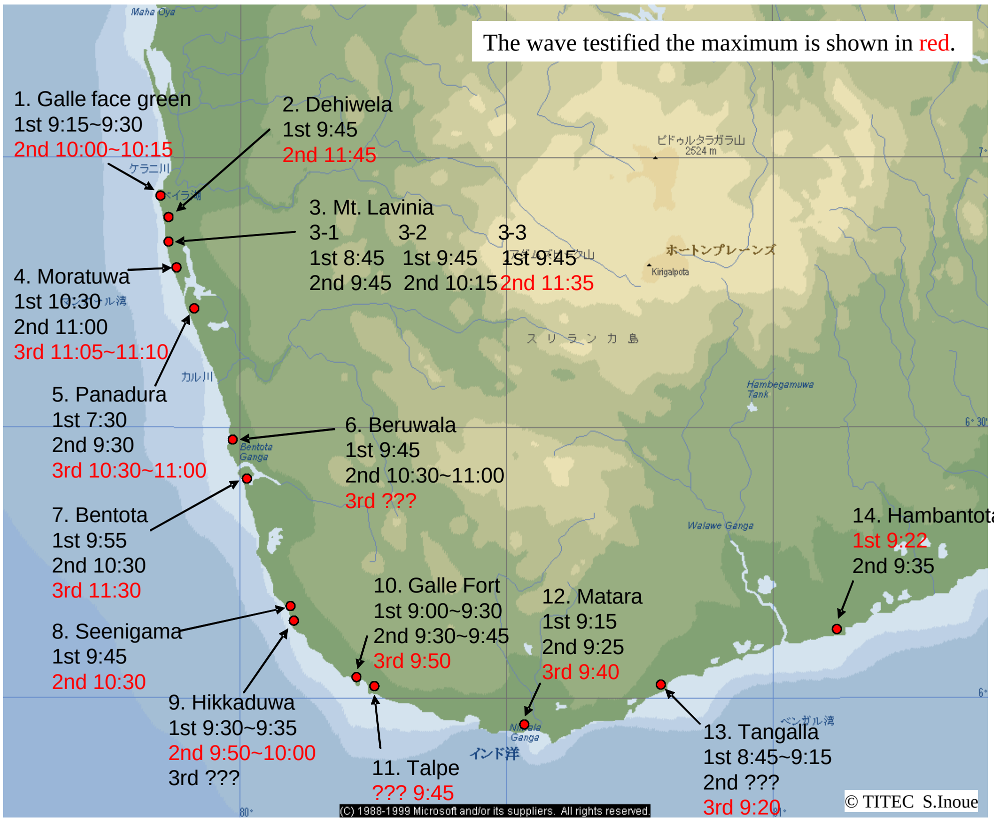

Figure 2 Estimated arrival time of tsunami and the attacks (including the report by Inoue, TITEC)

3.2.3 Overview of the tsunami damage

There were a lot of brick houses with plaster walls and wooden houses along the coast. Most of the damaged houses were these kinds of structures. On the other hand, the damage to the structures made of concrete seemed to be slight. A detailed discussion on the damage of the houses needs information on their type of structure, location, angle of contact with the flow, as well as the inundation, number of attacks and direction of the tsunamis. The following is a summary of the field investigation in the main areas in this survey.

a) *Koggala*:

Koggala, where the airport is located, is 10km to the east of Galle. And its average altitude is only 3.6m above sea level. The distance from the beach is 100m, where many trees were damaged by seawater. The measured heights are about 9m as shown in Photo 1. Because the flat land continues inland, the inundation area was large. The tsunami trace of 15cm height was found on the exterior wall of a house located 300m from the shoreline. A chain link fence 200m from the shore was crushed as shown in Photo 2, suggesting a powerful wave force acting on the wall.

Photo 1 Tsunami trace in Koggala district

Photo 2 Damaged chain link fence which is 200m inland

b) *Coast around Galle*:

In the coastal areas there are two types of houses where the heights of tsunami traces on the walls were different. For the first house, the tsunami inundation height on the ground was largely 2.6m and the trace heights were 4.8 m, where the brick house at the front facing the coast had been completely destroyed as shown in Photo 3. On the other hand, the tsunami inundation heights on the second typed house was only 0.6 m and trace height was 3.2 m, where a house at the sea side was damaged but barely remained as shown in Photo 4. The inundation/trace heights of a tsunami are influenced by the situation such as existed house/building/green on the coast, so that we should carefully report this after the investigation and it is important to obtain the distribution of tsunami heights on the land in order to look at the effects.

In the Galle Fort, surrounded by a wall 5-6 m high constructed 400 years ago, the inundation area was small and the buildings were not damaged. The tsunami flood power was reduced by the seawalls. By contrast, a new central area in Galle located 2-3 m above the sea level behind of the Fort. This is reported that he tsunami separated at the Fort could meet at the central area and inundated inland.

Photo 3 Tsunami inundation level (upper) and destroyed beachfront house (lower)

Photo 4 Tsunami inundation level (upper) and barely damaged beachfront house (lower)

c) *Galle Port*:

Tsunami traces were found on the wall of the warehouse and of the office building located at the entrance of the inland. The trace heights above the mean sea level were 5m and 6m respectively. Though breakwater was not severely damaged, the quay was destroyed as shown in Photo 5 and the port was not running when we visited after the tsunami attack. The dredger was carried onto the quay, as shown in Photo 6.

Photo 5 Damage on the quay at the Galle Port

Photo 6 Dredger ship carried onto the quay

d) *Dodanduwa*:

In Dodanduwa, which is 12 km in north of Galle, there is a concrete bridge constructed at the river mouth. It appears to have been built recently. The concrete handrail of the bridge, which has a thickness of about 20cm had broken. The handrail was 3.9m high. It was partially damaged as shown in Photo 7. It is explained from the situation that a broken fishing boat as shown in Photo 8 has been scattered that drifting debris collided. The people at this village told us that some of them were washed away by the tsunami flood though they evacuated across the bridge. Two people who had taken a motorcycle onto the bridge were also washed away by the tsunami..

Photo 7 Damaged concrete handrail of the bridge

Photo 8 Broken fishing boats at Dodanduwa

e) *Kahawa*:

Details are described in section 3.4.

f) *Ambalangoda*:

In Ambalangoda, which is about 80km to the south of Colombo, the tsunami trace was found to be 4.7m high on the exterior wall of an inundated house. Photo 9 shows coastal erosion countermeasures, consisting of stones of about 500kg in weight. It seems that the houses on the seafront were not destroyed because of the rubble revetments. However, the foundations of the railway line inland behind the village were severely scoured by the tsunami that propagated into the river, as shown in Photo 10. It is suggested that the horizontal vortex that formed after passing the river mouth would have caused the severe erosion.

Photo 9 Erosion countermeasures

Photo 10 Scouring damage to the foundations of the railway at Ambalangoda

g) *Beruwala Fishery Harbour*:

In the Beruwala district, which is located 53km to south of Colombo, the tsunami trace height outside the fishery harbor exceeded 4 m, though it was only 2.3m from the sea. The houses had not been destroyed behind the fishing port, as shown in Photo 11, it is thought that the tsunami power was reduced by the breakwaters in the harbour. A lot of fishing boats were washed away from the harbor by the tsunami back current, and were carried along the coast by the following tsunami attack, as shown in Photo 12.

Photo 11 Barely damaged houses behind the Beruwala fishing harbour

Photo 12 Fishing boats that were moved along the north coast from Beruwala fishing harbour

h) *Paiyagala*:

In Paiyagala, which is 48km to the north of Kahawa, there was a tsunami trace which was about 6m above the mean sea level. This inundation level was 4.2m inland. Photo 13 shows that only the doors and windows of concrete houses were damaged.

i) *Panadura*:

The Panadura district, which is 25km south of Colombo, is located between a river and the sea. It is indicated that the damage was caused by both the tsunami surging up the river and coming in from the sea. The impact of the tsunami, especially the lifting force, was able to destroy the concrete floor and roof of the building shown in Photo 14.

Photo 13 Barely damaged building made of concrete

Photo 14 Concrete floor damaged by the tsunami lifting force

3.3 Discussion

3.3.1 Train Damaged at Kahawa

At Kahawa a nine-car train was damaged, killing about 1,500 of its passengers. This train happened to have stopped while passing this point when the first wave of the tsunami struck. The first wave submerged the land to a depth of about 1m, not causing any damage. The land along the shoreline is a little lower than the coast road (Figure 3), so water brought by the first wave was retained there.

Figure 3 Cross section of the damaged area, Kahawa, where the train was washed away

The residents of the district saw the disaster and began to flee inland. Some of them sought refuge on the stopped train. Generally railway cars are stronger and higher than automobiles etc., so the residents probably thought they were safe. This would be why not only passengers but also residents died in the train cars. But the second wave that struck 30 to 40 minutes later, or about 15 minutes later according to other witnesses, engulfed the train, as shown in Photo 15.

Photo 15 View of the Overturned Railway Train

The traces of the second tsunami revealed a submersion depth of about 5 m, and sometimes up to 10 m. The railway cars were not severely damaged, but were filled with sea water that drowned almost all of the passengers and residents who could not escape. It is a tragedy caused by the tsunami that struck in an instant. People started to evacuate after the first tsunami, but lost their lives by seeking refuge inside the train.

Actually, there was school building about 50m from the railway which survived the tsunami. It is important to evacuate people to such a building. When a tsunami strikes, in principle, people should evacuate to a high refuge instead of a place far from the shoreline. In a district where flat ground spreads inland, a usable evacuation site such as a school or building must be prepared in advance.

3.3.2 Port and Shore Protection Facilities

The damage to the fishing ports of Beruwala and Hikkadua and to the Galle harbour were investigated. In the fishing ports, there were breakwaters with a narrow port entrance, and there were also quays and seawalls. These would have contributed to damage reduction. Therefore there was a difference in the tsunami inundation heights inside and outside the ports. However, the breakwaters were slightly damaged and many fishing boats were washed away from the harbour and left stranded.

The height of the rubble revetment was not high enough to protect the area against the tsunami flood by dissipating the energy. The rubble revetment was destroyed along the coast and heavy rubble stones were moved up to 10 meters in places where the flood velocity of the tsunami was large.

At Galle Port, the height of the tsunami trace was about 5 m, and there was damage to the quay, scouring of the quay foundations by the undertow, a dredger was lifted up onto the quay itself, and the first floors of harbour buildings were inundated. Even though the damage was not catastrophic the port stopped running. And the influence and impact on not only the rehabilitation and reconstruction but also on the local society became significant.

3.3.3 Sediment Displacement

Large-scale scouring or sedimentation was found around the buildings in the coastal area, at the foot of the bridge pier, and around the steel tower. Even though there was no damage to the superstructures, most buildings subsided due to scouring of their foundations and could not be used. Such a sand transportation is caused not only by the runup but also the undertow and current. The large-scale scouring was caused by a strong flow in one direction continuing for long period of time.

A lot of scouring at the roots of vegetation were also seen along the coast. Sand was scoured by the impulsive force and the undertow of the tsunami. In addition, the tsunami runup into a narrow river mouth and spread at a large river, which would generate a large vortex. There is an example of this situation, and it caused the scouring damage on the railway foundation as shown in Photo 10. The scouring scale was 2m in depth, 200m or more in length, and about 20m in width. There was no damage by scouring if the ground was coated with asphalt or concrete.

3.3.4 Human Suffering

In the southwest part of Sri Lanka where this survey was done, there are places where the land resembles reservoirs and where it slopes gently downward. The severity of the human loss was increased because there were few tall buildings or other evacuation sites in this region. Further, the people of Sri Lanka know nothing about tsunamis, having never had any experience of the phenomenon. No earthquake, no tsunami information and no tsunami evacuation areas were some of the main reasons why the casualties exceeded 40,000 people in Sri Lanka. Table 2 shows the number of deaths, injured, missing and displaced people in each area.

Almost 4,000 people died in the Galle region. It is a place where private homes are concentrated behind a roadway running close to the shoreline, and much of this land is lower than the road. Many of these buildings were totally destroyed because they were old and made of bricks, and therefore, not strong. Because it is a tourist region, many fatalities were a result of the large number of people attracted to the region.

Table 2 Human damage in Sri Lanka as of February 2005

District	Deaths	Injured	Missing	Displaced
Colombo	76		12	16,139
Gampaha	7			32,000
Kalutara	213	421	48	37,595
Galle	4,101	2,500		120,000
Matara	1,205	8,288	404	41,900
Hambantota	4,500			27,351
Ampara	10,436	120		183,527
Mullaitivu	3,000	2,500	1,300	24,557
Batticaloa	2,497	1,166	1,097	203,807
Trincomalee	957		335	51,863
Killinochchi	560	147	56	49,129
Jaffna	2,640	541	540	48,729
Puttlam	4			850
Vavuniya				641
Total	30,196	15,683	3,792	838,088

3.4 Summary

The detailed height of tsunami traces and damage caused by the Sumatra Offshore Earthquake Tsunami in southwest Sri Lanka was studied. The study revealed that the average tsunami height was about 5 m, and that the highest tsunami was the second tsunami that arrived about 30 minutes after the first tsunami.

The principal damage caused by the tsunami was (1) inundation of flat low coastline land far inland, (2) total destruction of most wooden and brick buildings and partial destruction of buildings made of concrete, (3) ships washed out to sea or grounded on land, and (4) superstructures damaged by scouring of the quay walls and ground. It was confirmed that breakwaters and similar port and harbor structures reduced the tsunami strength.

We wish to express our gratitude to Ichizono Toshiro (Councilor and manager of the Colombo office) of Japan Port Consultants, Ltd. and to Tatsumi Masahiro (Director of the Sri Lanka office) of Wakachiku Construction for their assistance with this survey. We also appreciate the collaboration and exchange of information and data with the experts in Sri Lanka: Prof. Samantha Hettiarachchi, Coastal Engineering and Management, University of Moratuwa; Dr. Saman Smarawickrama, Coastal Engineering and Management, University of Moratuwa; and Dr. Nimal Wijayaratna, Senior Lecturer, University of Ruhuna.

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In conclusion, we offer our prayers for the souls of the victims of this terrible disaster.

Photo 16 Meeting of experts from Sri Lanka and Japan after the field survey to report the results and to exchange information on the tsunami