Introduction of A Methodology to Mitigate Tsunami Disaster by The Pre-evaluation of Tsunami Damage Considering Damage Investigation of 2004 Tsunami Disaster in the Indian Ocean

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Abstract

The tsunami disaster caused by the Earthquake off the coast of Sumatra, 2004 presented many subjects that we have to consider to mitigate future tsunami disasters. Japan is a high risk country of tsunami disasters historically. Government of Japan is preparing to mitigate tsunami disasters that will be exactly occurred by huge inter-plate earthquakes such as Tounankai and Nankai Earthquakes. NILIM and PWRI conducted field investigation of the 2004 Tsunami Disaster in the Indian Ocean. NILIM is now conducting research to develop pre-evaluation method of Tsunami disaster considering the results of the investigation. At the first, the results of the field investigation are presented in this report. Then a concept of a methodology to mitigate tsunami disaster is introduced. The methodology is consist of the pre-evaluation of tsunami damage and its evaluation.

1. Damage Investigation of 2004 Tsunami Disaster in the Indian Ocean

1.1. Summary of Investigation

Two of authors participated as members of "The Investigation Delegation of the Japanese Government on the Disaster caused by the Major Earthquake off the Coast of Sumatra and Tsunami in the Indian Ocean" The investigation was conducted in Thailand and Sri Lanka from March 13 to 21, 2005. Authors investigated damage of coastal roads in both countries. Hearing to governmental organization was also conducted. Since few traces of damage was observed in Thailand, the damages in Sri Lanka are reported here.

1.2 Road Damage in Sri Lanka

(1) Condition of Roads and Bridges in the Damaged Area

In Sri Lanka, an arterial road (R-A2) was located along the beach and many of its sections were affected by tsunami. As for the arterial road between Colombo and Hambantota, the extension of the section which contacts the beach or runs within one or two hundred meters from the beach is quite long. Sections which contact the beach are protected by a rock-mound breakwater. There are fairly long bridges over the rivers that

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are boundaries of towns or cities. There are many small bridges and causeways over small rivers and waterways. With regard to the East coast between Kalmnai and Batticaloa, the distance from the coast to highway was about one kilometer except Lagoon area. There are sand dunes with a height of 4 to 6 meters along the coast. Behind the sand dunes are lowlands where villages and towns are located. Most of the households are engaged in fishing.

(2) Over view of damages from viewpoint of socio-economical aspect

Damages from viewpoint of socio-economical aspect are summerized below:

- The amount of damage is LKR 6.3 billion according to JBIC and ADB
- Urgent restoration of the network was completed within two weeks making the roads and bridges passable except for the Arugam Bay bridge in the eastern province.
- The major damage can be categorized as three types: the erosion of the road embankments and the pavements, the collapse of structures, and completely or partially washed away.
- In the hearing by the Road Development Authority, the damage to the roads resulted in a disruption of traffic and of the supply of necessary goods.
- According to the hearing at the Galle GA office, there was no serious problem caused by road damage, because there were small roads that could be used as detour routes, even when the arterial roads were not passable.
- There were still some negative effects such as traffic jams.
- Cars driving along the highway were damaged also.

(3) Typical Examples of Damage of Main road Facilities

1) The East Coast

a) Bar Road

A single span bridge, 8 meters long and 4 meters wide on Bar Road which runs along the Battocaloa Lagoon and connects with the East Coast Highway, collapsed and fell into the water (see Photo-1). The right-hand side of the photo is the lagoon and the left-hand side is a small inlet. As shown in the photo, the abutments were displaced and parts of the approaching fills were scoured. The mechanism that caused the damage is deduced from our observations: (1) The approaching fills were first scoured by the backflow of tsunami water. (2) The abutments lost their stability due to the scouring of the fills and foundation soils. (3) The abutments displaced outward. (4) The bridge lost support which caused it to fall into the water. Photo-1(2) was taken from the opposite side of the bridge.

（1）Batticaloa Lagoon on the right. （2）The fallen bridge girder

Photo-1. Collapsed simple digit bridge（Bar Road）

（1）The scoured out causeway mound （2）Damage to the sign post and curb

Photo -2. The damage to the Koddaikkallar Causeway

b）Koddaikkallar Causeway

The causeway is located a few kilometers south of Batticaloa Bridge. The total length is about 200 to 300 meters, and the most parts consist of soil fill supported by vertical concrete block retaining walls. At the central part is an opening for water with a width of about 5 meters（see Photo-2）. Both ends of the causeway were scoured by the tsunami as shown in Photo-2（1）. The central part of the causeway was less severely scoured. Photo-2（2）shows concrete poles that were completely folded down and roadside concrete blocks（curb）broken at the bottom. These suggest that the height of the tsunami was at least 3 meters from the road level and some floating debris in the back flow of the tsunami collided with the concrete poles and roadside blocks.

Photo-3. Periyakallar Causeway

Photo-4. A Road in Kalmnai

c) Periyakallar Causeway

This causeway is located a few kilometers south of Koddaikkallar Causeway. There was an opening for water flow at the central part of the causeway. Unlike the damage to Koddaikkallar Causeway, the sections near the opening were completely scoured out by the tsunami. In Photo-3 taken from the south looking north, the left-hand side is a lagoon and the right-hand side is the sea. The opening had been at the far end of the temporary detour seen on the right that merges the causeway. In the rebuilding work that was proceeding when we visited, a mixture of concrete debris and sea sand was used in the lower part of the fill and well-graded soil with gravel was used in the upper part. These are considered to be proper usage of fill materials since the concrete debris from demolished structures was recycled as it was suitable as sub-grade material.

d) The Roads in Kalmnai

As was mentioned, the tsunami washed up over the road in sections within the city. In the road sections where there were houses alongside, no damage was observed. However, in the embankment road sections with a height of around one meter over marshlands or paddy fields, damage was observed. It included the erosion of the road shoulders (see Photo-4) and the erosion of embankments at culverts. This damage tends to have occurred at locations where the land was lower than the surrounding area. It is presumed that the back flow of the tsunami was concentrated on the relatively low lands, causing erosion or the scouring out of embankments and culvert backfills.

(4) The South Coast

As for the arterial road on the south seashore an investigation was conducted on the section between Colombo and Hambantota. In particular, special attention was paid to the section between Hikkaduwa and Tangalla Photographs of the damaged sites are shown below (Photos-5 to 12). The location where the photographs were taken is illustrated in Figure -1.

Photo-5. The Akurala bridge（91Kp）
（① in the map）

Photo-6. Scouring of a bridge（103Kp）
（② in the map）

Photo-6. Restored bridge near to downtown Galle（91Kp, ③ in the map）

Photo-7. Erosion at approach
（near 120Kp, ④ in the map）

Photo-8. Bridge collapse due to erosion
（137Kp ⑤ in the Map）

Photo-9. Culvert damaged（144Kp ⑥ in the map）

Photo -10. Damaged causeway with water pipes（145Kp ⑦ in the map）

Photo-11. Undamaged bridge and recovered facilities in the upper stream（166kp, ⑧ in the map）

Photo-12. A bridge in Hambantota and damage around the bridge（⑨ in the map）

Figure-1. Locations of the Photos Taken（The South Coast of Sri Lanka）

With regard to collapsed bridges, Erosion at the piers were observed. It is considered that bridge collapse was caused by erosion of pier, but direct impact of wave force is not cause of collapse. In addition, generally the damage to the roads was small even though damage along the road was serious. For example, in Kahawa where a train was washed away, the damage was enormous; however, there were some roads and a bridge in the area that went undamaged.

（5）Findings of the investigation

The results of the investigation of the roads may be summarized as follows:

1）Damage to roads induced by the tsunami included erosion of embankments, erosion of abutment backfills, and collapse of bridges following the loss of stability of the abutments.
2）Erosion of embankments tended to have occurred at locations where the land was relatively low, presumably because the back flow of the tsunami concentrated on those parts of the land.
3）No bridge girders were washed away by the direct impact force of tsunami.
4）Damage of people and vehicle on the road is serious problem
5）Existence of detour and quick restoration weakened the socio-economical impact of the damage.

With regard to item 3）, it is too optimistic to conclude that bridges are always safe against impact force of the Tsunami. We have to consider there are investigations which report that some bridge girders were washed away by the tsunami in Sumatra.

2. Following study being conducted after the investigation

The results of the investigation are suggesting a direction of study to be conducted for future mitigation of tsunami disaster:
1）Investigation shows that road facilities are generally strong against tsunami. To protect passengers from tsunami is the most important issue.
2）Existence of detour and quick restoration weaken the serious damage. We have to check what will be detour and access route, to plan crisis management and restoration operation beforehand actually tsunami occurs.
3）Though road facilities are generally strong against tsunami, there is risks that bridges are washed away by tsunami. Collapse of bridges which cross long river influences emergency operation and socio-economical activity for a long time.

With regard to item 1）and item 2）, it is the most important to divide inundated sections by tsunami and passable sections at the time of tsunami disaster beforehand. To mitigate damage we also have to know relation between damage and impact or extension of facility damage. With regard to item 3）, it is necessary to evaluate tsunami force acts on bridges.

NILIM's ongoing study is stepping forward under consideration written above. The study aims to mitigate tsunami disaster by utilizing pre-evaluation of tsunami damage and consists of three items to develop methodologies written below.

1）Methodology to evaluate risk of bridge washed away
2）Methodology that shows aspects of tsunami damage
3）Methodology to estimate effects of counter measures

3. Introduction of some results at present

3.1 Methodology to evaluate risk of bridge washed away

A series of wave force measurement was conducted by using a wave channel in the NILIM. We consider that bridge girder itself is not broken by wave force. Bridge will be washed away by the damaged at the support. We measured total drag force and lift force act on girder by a force balance. We have no plan to use pressure distribution that is measured by pressure tap. Figure-2 shows cross sections of bridge girder tested. and the setting of experiment. Photo-2 shows the process of tsunami attacking bridge girder. The analysis of measurement has not yet completed. Figure-3 shows an example of measured time history of drag force acted on bridge girder. The wave impact force has quite steep peak at the moment of attacking. Since bridge girder and peers are elastic, the effective force acts on support of bridge is considered smaller than the peak value. Numerical analysis using model shown in Figure-4 is on going to evaluate effective impact force acts on support of bridges.

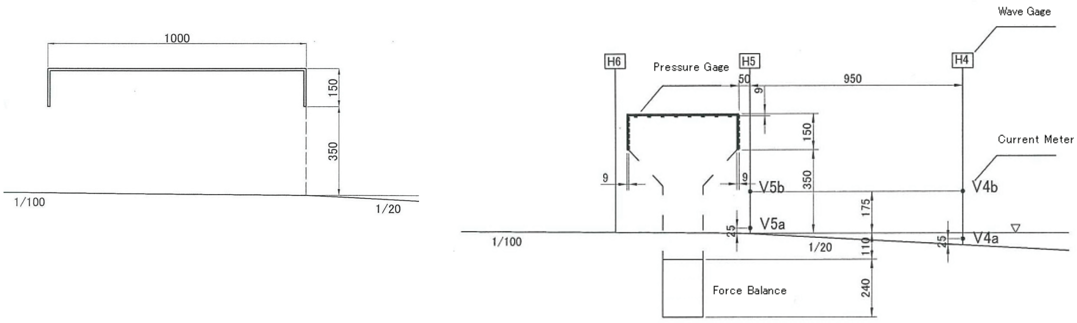


Figure-2. A Cross Sections of Bridge Girder and the Setting of Experiment

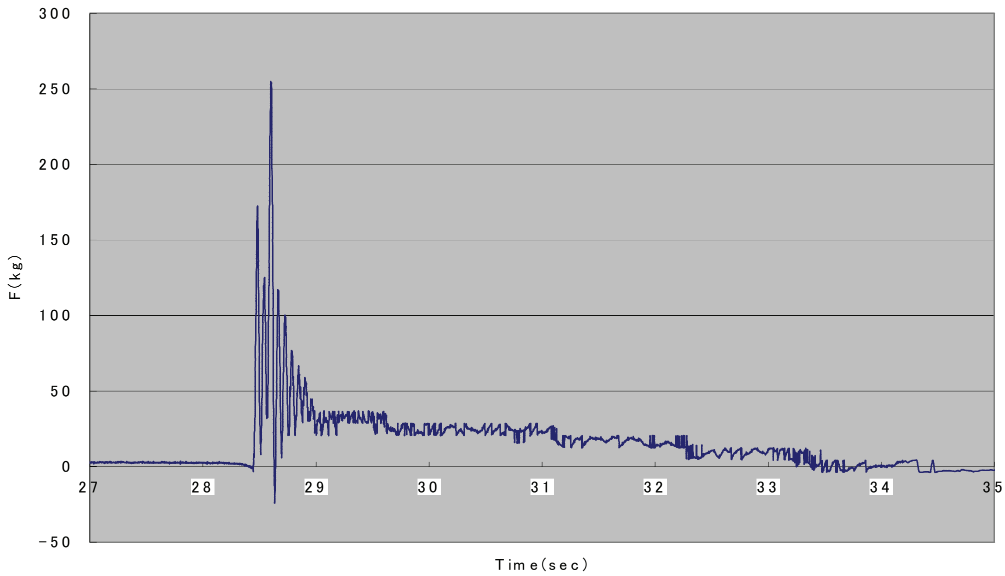
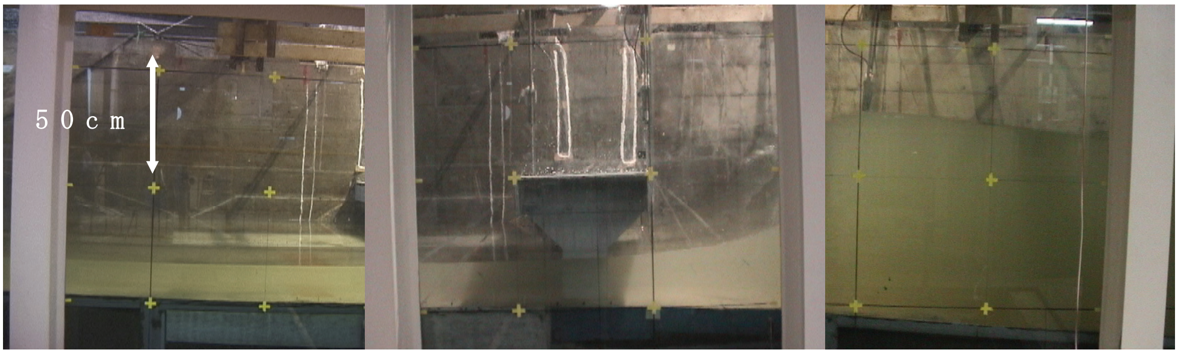


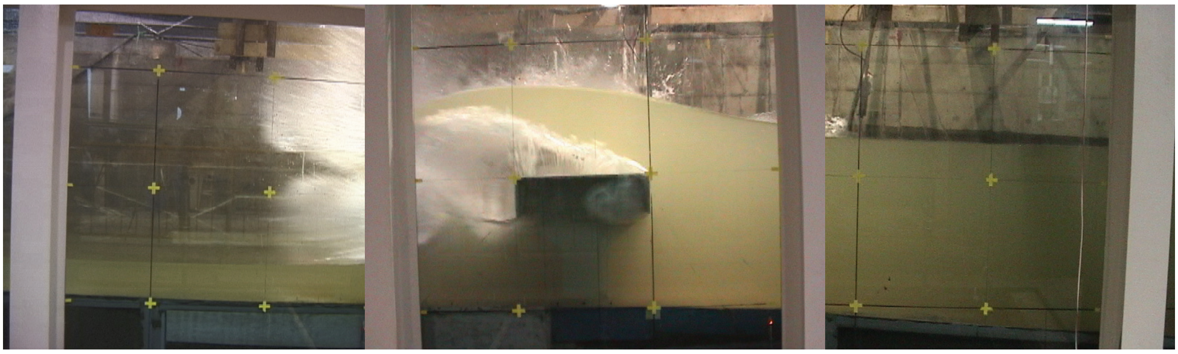
Figure-3. An Example of Measured Time History of Drag Force

−0.4sec



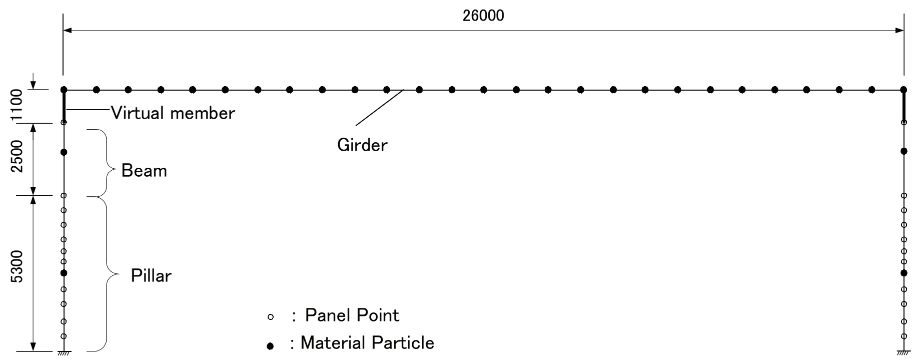
−0.2sec

The moment when the maximum wave force was observed



Wter Level: +17.5cm Wave hight: 40cm

Photo-2 Process of Tsunami Attacking Bridge Girder



Wave force acts on Material Perticles of the girder

Figure-4. On going Analysis to Evaluate Effective Impact Force

3.2 Meohodology that shows aspects of tsunami damage

A target of this study is to draw Figure-5 that shows inundation, damaged facility by tsunami, influence of driftage, and so on. It is quite common to discuss tsunami disaster mitigation plan by using map of estimated inundated area. The difference between the map illustrated in Figure-5 and the common method is to consider damage of facility. In this study damage of dike, bridges port are evaluated. Operation of water gate is also considered.

The challenge in the ongoing study is not finished by drawing Figure-5. The tsunami disaster is series of events. It is quite important for mitigation planning to understand structure of event tree. Figure-6 is a part of event tree, that is concerning road, developed in this study. The methodology that will be proposed is how to draw Figure-5 and how to find and evaluate serious event pass from the event tree.

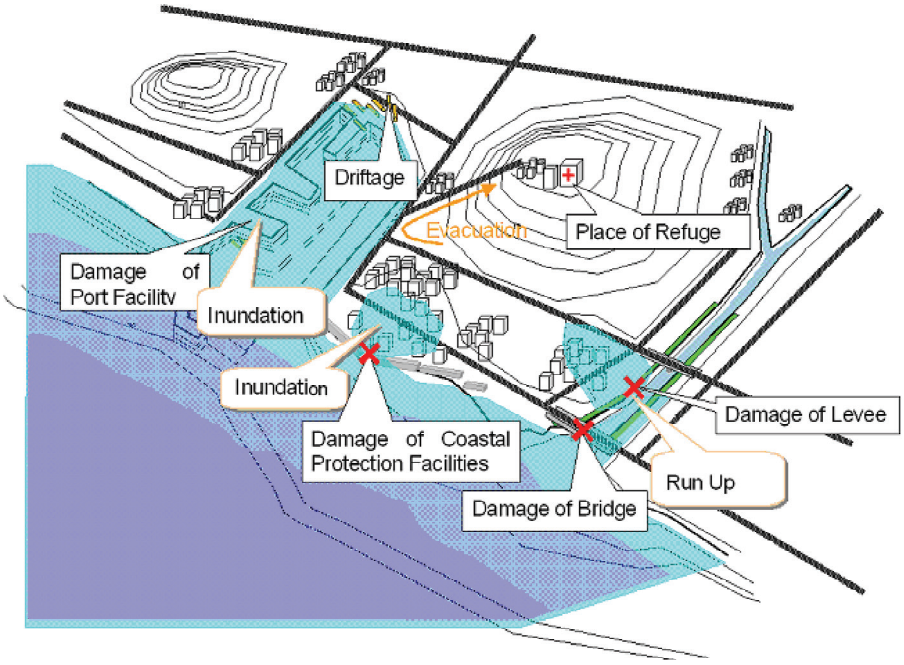


Figure-5. Image of Tsunami Disaster

3.3 Methodology to estimate effects of counter measures

The final step of mitigation planning is to evaluate effects of counter measures. Two approach is studied here; One is quantitative analysis estimation of cost benefit B/C to evaluate effects of damage and countermeasure. Since every problem caused by tsunami damages cannot be evaluated quantitatively, the other approach is to check the mitigation by un-quantitative method. With regard to evaluation of B/C, socio-economic loss due to the detour is calculated by road network analysis using Origin-Destination (OD) matrix of usual. The loss which occurs by first aid activity's being obstructed is computed as the option. As for the way of checking the effectivity of the measure, which is un-quantitative method, it is thinking as follows currently. A check sheet such as Table-1 will be derived by using the event tree illustrated in Figure-6. Counter measures are discussed for each subject, that will be written in the first column from left, in Table-1. How a problem will be solved is described in the checklist.

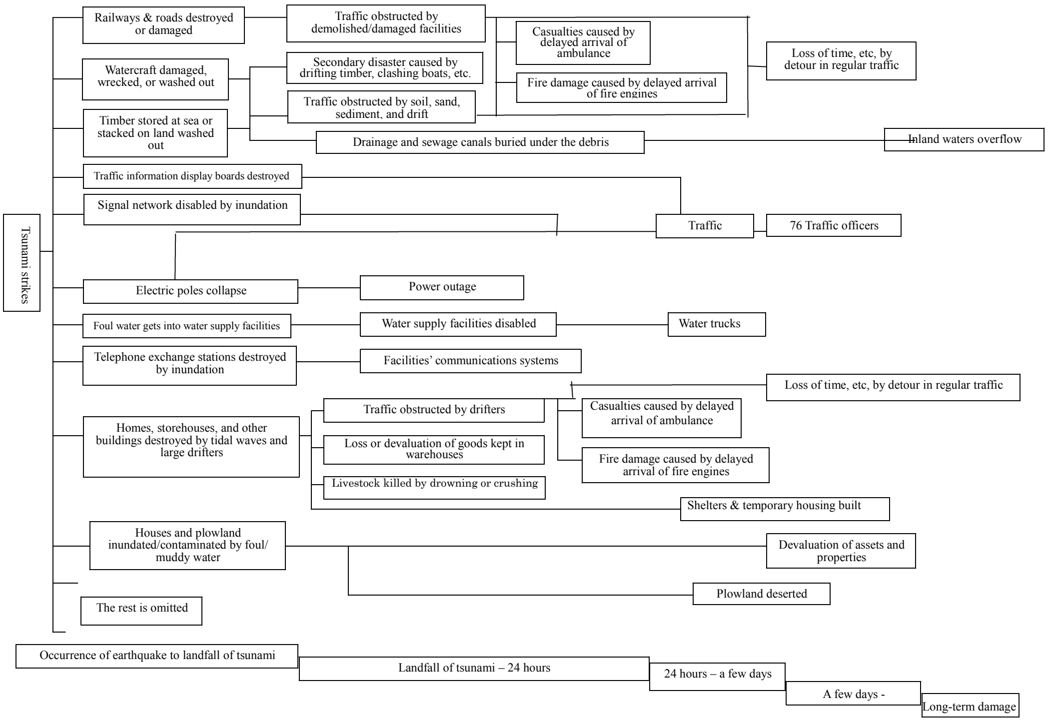


Figure-6. A Part of Event Tree（An Tentative Image）

Table-1. Image of the check list for disaster mitigation planning（un-quantitative method）

Subject	Place	Events	Scale of Damage	Risk to Human life	Influence to emergency activities	Influence to usual Activities	Counter measure Target/Measure	Effects of countermeasure
Trafic jam caused by unadequate information of blocked Road	City/ Adress	・Trafic jam occurred by vihicles enterd impassable section ・Faile to get out in time from second attack of tsunami by the traffic jam ・Obstacle of emergency activity	Wide area	High Risk Reason:	Big Reason:	Small Reason:	① Emergency Activities/ Deside Detor beforehand	Big Reason: Requirement:
							② Human Life/Timely Information to gide safe section	Big Reason: Requirement:

4. Concluding Remarks

Introduced in this paper are the results of field investigation of the tsunami damage in Sri-Lanka, some tentative outputs or output image of on going study. The study by NILIM will be concluded in 2007. Case study will be conducted this year to draw concrete disaster image and event tree. An actual methodology of disaster mitigation planning, which was introduced in 3.3 is discussed upon the case study.

Reference

The December 26, 2004 Tsunami Disaster in the Indian Ocean, Report of Investigation, June 2005, The Investigation Derigation of the Japanese Government on the Disaster caused by the Major Earthquake off the Coast of Sumatra and Tsunami in the Indian Ocean