Evaluation of Tsunami Damage in the Eastern Part of Sri Lanka Due to the 2004 Sumatra Earthquake Using High-Resolution Satellite Images

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INTRODUCTION

In order to evaluate emergency response and rehabilitation planning after a disaster, it is important to grasp the distribution of the damaged buildings as soon as possible. Images remotely sensed from satellites are quite useful to widely capture the condition of the surface ground. Visual detection method of the building damage has been applied to the high-resolution satellite images observed before and after recent large earthquakes [Chiroiu et al. (2002) and Kouchi et al. (2004)]. However, characteristics of the image in the building damage area due to other disasters such as tsunami have not been examined in detail.

The Sumatra earthquake on 26th December 2004 (Mw9.3) brought great tsunami damage to the countries in the Indian Ocean. Sri Lanka is one of the countries that are severely damaged due to the tsunami. In order to evaluate the damage distribution in the eastern part of Sri Lanka, the visual detection method of the damage is applied to the high-resolution satellite IKONOS images observed before and after the tsunami hit.

THE 2004 SUMATRA EARTHQUAKE AND IKONOS IMAGES IN SRI LANKA

Figure 1 shows the location of the epicenter of the 2004 Sumatra earthquake and the number of the casualties in the countries of the Indian Ocean. The travel time of the tsunami computed by Active Fault Research Center (2005) are also shown in the figure. More than 120,000 people died in Indonesia, which is situated near the epicenter. Also in Sri Lanka, which is located in 1500 km distance from the source region, the deaths and missing people are about 40,000 and 5,000, respectively. Most of them were killed by the tsunami generated by the earthquake.

Figure 2 (a) shows the locations of the major cities in Sri Lanka. The tsunami damage in the cities compiled by National Disaster Management Centre Sri Lanka (2005) is shown in Table 1. The eastern and southern provinces show severer damage than the western province such as Colombo, the capital of Sri Lanka. The high-resolution satellite IKONOS images whose resolution is 1m are taken in Batticaloa that is one of the districts that severe damage is observed. Figure 2 (b) shows the pre- and post-event images in the central part of Batticaloa taken in 2000, 2001 and one month after the earthquake, respectively. The image covers about 1/10 of the coastal line in the district.

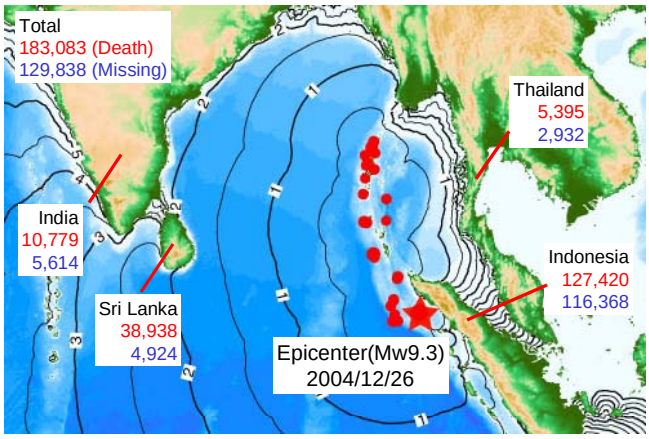

Figure 1. Number of deaths and missing people due to the tsunami compiled by AP(2005/3/26). Numbers in the figure show travel time (in hours) of tsunami after the earthquake computed by Active Fault Research Center, AIST (2005).

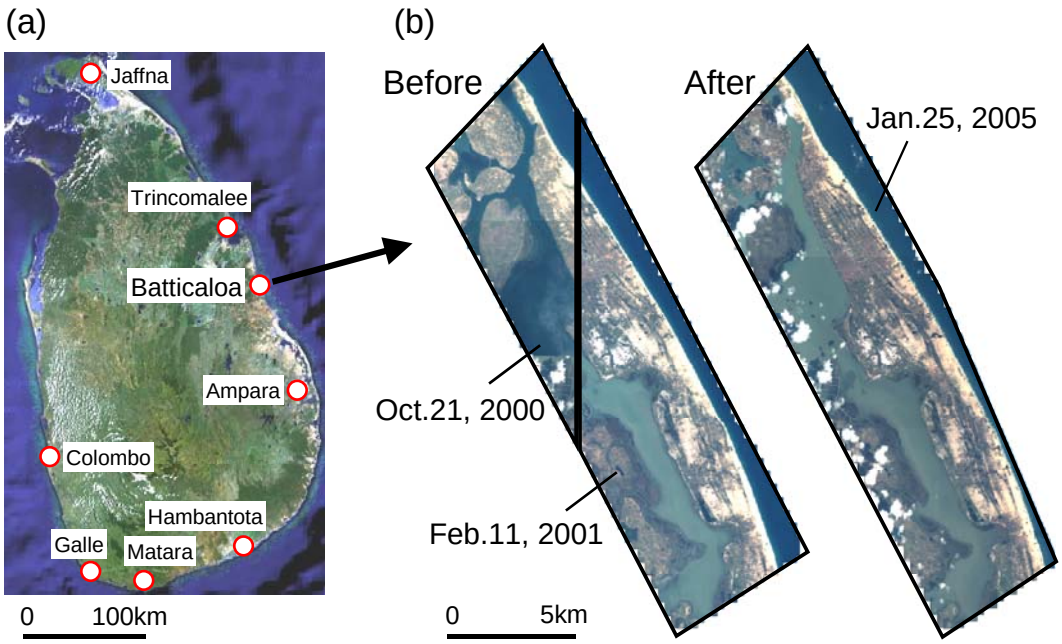

Figure 2. Map of Sri Lanka and IKONOS satellite images in Batticaloa used in this study

Table 1. Tsunami damage in Sri Lanka

Province	District	Deaths	Missing	Damaged Houses	
				Completely	Partially
Northern	Jaffna	2,640	540	6,084	1,114
Eastern	Trincomalee	1,078	337	5,974	10,394
	Batticaloa	2,840	1,033	15,939	5,665
	Ampara	10,436	873	29,199	—
Southern	Hambantota	4,500	963	2,303	1,744
	Matara	1,342	613	2,362	5,659
	Galle	4,218	554	5,525	5,966
Western	Colombo	79	12	3,398	2,210

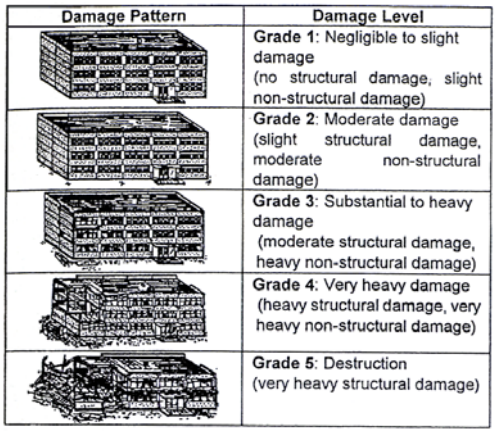

Figure 3. Classification of damage to reinforced concrete buildings [EMS (1998)]

VISUAL DETECTION OF BUILDING DAMAGE IN BATTICALOA

The visual inspection of building damage is conducted based on the classification in the European Macroseismic Scale [EMS (1998)] that is shown in Figure 3. Using the pre- and post-event images, buildings washed away by the tsunami, totally collapsed buildings (Grade 5), and partially collapsed buildings (Grade 4) are identified. It is difficult to distinguish slightly damaged buildings from no damaged buildings in the IKONOS image because the spatial resolution is not enough fine compared with aerial photographs. All the buildings for Grade 2 and 3 damage levels are judged as Grade 1 in this study.

Figure 4 shows the comparison of the images before and after the event. Figure 4 (a-1) and (a-2) represent the buildings washed away by the tsunami. While the buildings indicated by the circle exist in the pre-event image, they are completely washed away with the surrounding vegetation in the post-event image. Figure 4 (b-1) and (b-2) represent the totally collapsed buildings. In the post-event image, the colors of the buildings in the circle turn to white. It indicates that the roof and most of the walls are completely crushed and the basement of the building is exposed. Therefore, those buildings are judged as Grade 5 damage level. Figure 4 (c-1) and (c-2) represent the partially collapsed buildings. The colors of the buildings change little in the appearance. Because some part of the buildings is failed and the debris is remarkably observed in the post-event image, the buildings are judged as Grade 4. Figure 4 (d-1) and (d-2) represent no or slightly damaged buildings. Because

the significant difference of the buildings is not identified between the images, the buildings are judged as Grade 1.

The field survey was conducted to confirm the damage of the area in March 2005. Figure 5 shows the ground photographs of the washed away building and totally collapsed building indicated in Figure 4 (a-2) and (b-2). The damage level of the photographs shows good agreement with the result of the visual inspection. It indicates that the visual interpretation of the building damage is useful to capture the severely damaged area and to identify their damage level.

Figure 6 (a) shows the distribution of the classified buildings in Batticaloa. A total of about 20,000 buildings are detected in the area. More than 90% of the buildings are classified into Grade 1. About 10% of the buildings are identified as severely damaged buildings. The damaged buildings are concentrated in the eastern coastal line while no or slightly damaged buildings are distributed in the western area. The severely damaged buildings are distributed in the inland area within 1km distance from the coastal line.

In the field survey, the inundation area due to the tsunami and the tsunami height were investigated using GPS based on the evidence of the local inhabitants. Figure 6 (b) shows the result of the survey with the digital elevation model of SRTM-3 [NASA (2005)]. Solid circles and open circle indicate the location of the survey point for the boundary of the inundation area and the tsunami height, respectively. Broken line shows the estimated boundary of the inundation area. The result shows that the area of 0.8-1.5km distances from the eastern coastal line was inundated. The tsunami whose height is almost 9m hit this region. As shown in Figure 6 (a) and (b), the severely damaged buildings detected by the visual inspection are distributed within the inundation area.

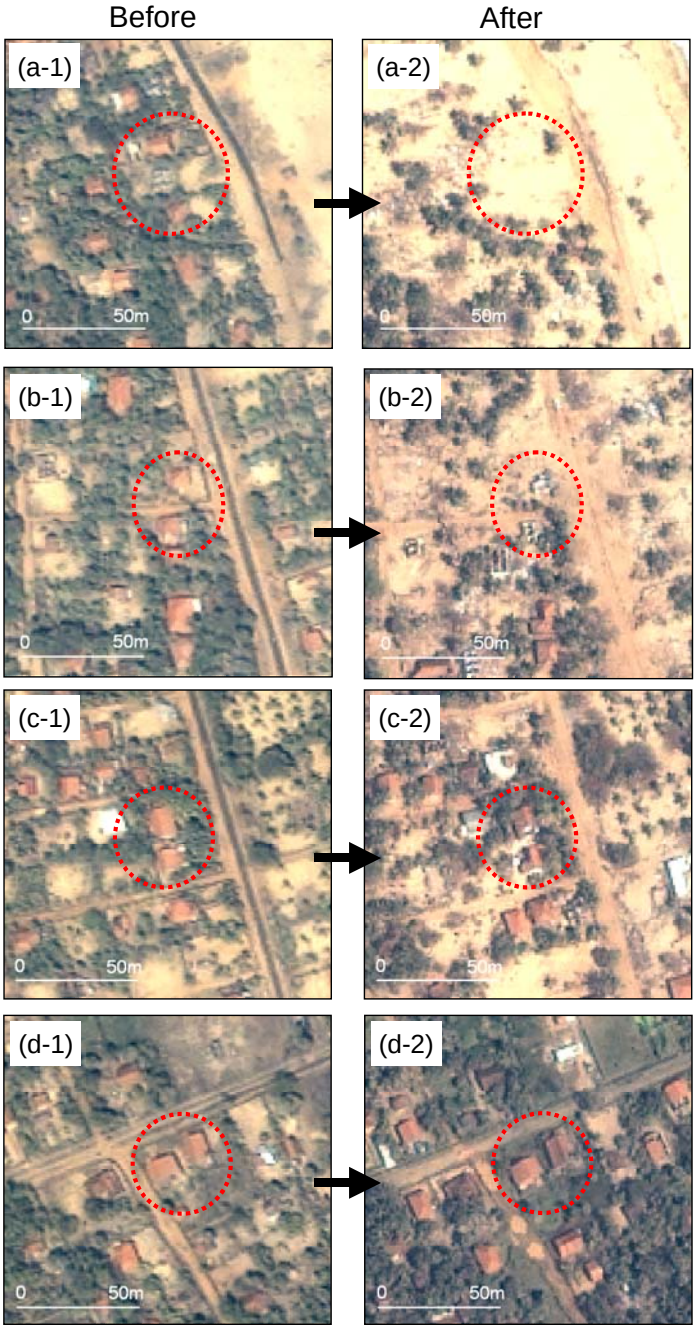

Figure 4. Comparison of images taken before and after the tsunami
(a) Washed away buildings (b) Totally collapsed buildings(Grade 5)
(c) Partially collapsed buildings(Grade 4) (d) No or slightly damaged buildings(Grade 1)

CONCLUDING REMARKS

Using the high-resolution satellite IKONOS images of Batticaloa, Sri Lanka acquired before and after the 2004 Sumatra earthquake, visual interpretation of building damage is conducted. Buildings washed away by

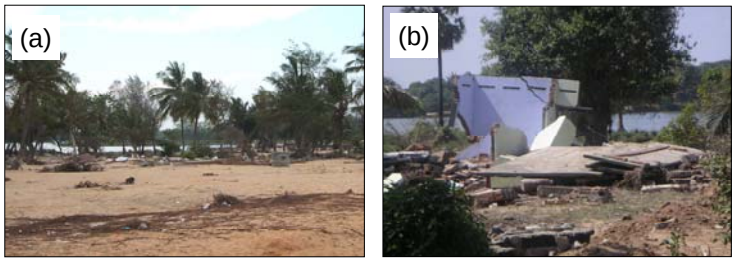

Figure 5. Ground photographs in Batticaloa. (a) Washed away buildings (b) Totally collapsed buildings

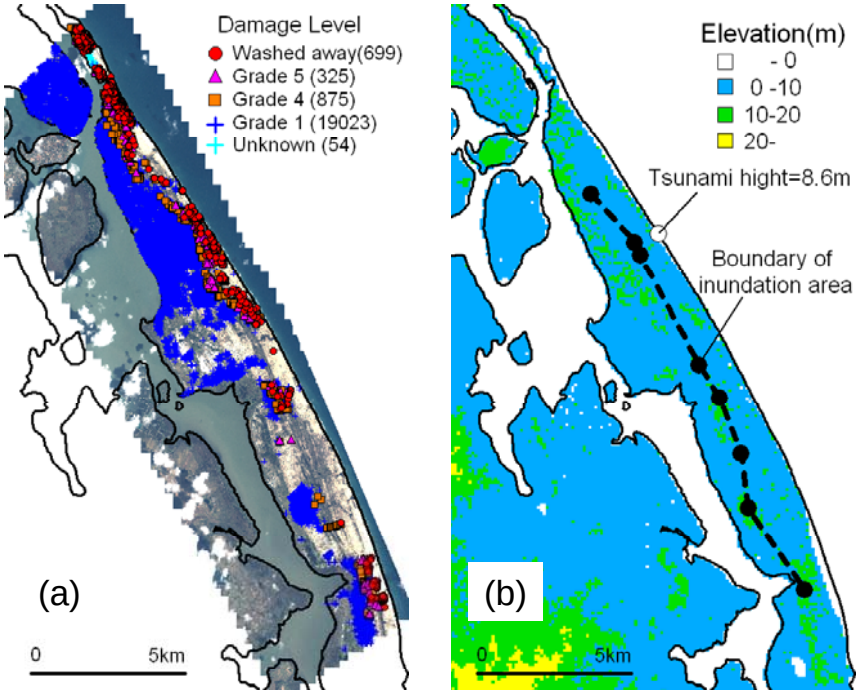

Figure 6. (a) Distribution of classified buildings (b) Survey point of inundation area and tsunami height

the tsunami, totally collapsed buildings and partially collapsed buildings are identified. The damaged buildings are concentrated along the eastern coastal line. About 10% of the buildings are classified into the severely damaged buildings. The field survey was conducted to confirm the damage of the area and to measure the boundary of the inundation area. The result of the visual interpretation shows good agreement with the actual damage. The severely damaged buildings are distributed in the inundation area.

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