

Damage characteristic of the 2011 Great East Japan tsunami in Miyagi prefecture

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1. Introduction: The Sanriku area extends northward from Sendai, passing through Iwate to Aomori as a saw-toothed coastline more than 600 km in length. Because of its ria coast, the tsunami height can easily reach 10 m. Therefore, a number of large-scale structural mitigation facilities were in the past, especially after the 1960 Chile tsunami (Abe and Imamura, 2010). The Sanriku coast experienced tsunamis in 869 (M8.6), 1611 (M8.3), 1896 (M8.5), 1933 (M8.1) and 2011 (M9.0) (JMA, 2011). The two events in 869 and 1611 caused large tsunami inundation areas in plain areas in Miyagi prefecture. The Sendai plain was considered to have a low tsunami risk compared with the Sanriku coast. For instance, the maximum run-up height from the 1896 tsunami was 38.2 m, recorded in Ofunato Bay, but was less than 5 m in Sendai (Suppasri et al., 2012).

2. Tsunami damage field survey: A tsunami field survey was conducted to investigate the tsunami damage along the coastal areas in the Miyagi prefecture (Fig. 1). Nineteen one-day trips over four months from March to July 2011 were made to complete the general damage survey, structural damage inspection and inundation depth measurements (TTJT, 2011). The purpose of the damage survey was to investigate the impact of the tsunami on coastal structures such as breakwaters, seawalls, control forests, housing and buildings. The damage mechanism for each feature is discussed based on scientific background and compared with the findings of the survey. This investigation will be helpful for future coastal zone development. Tsunami inundation depths were measured as an important feature for developing a damage function and verification data of the tsunami numerical model simulation in the future.

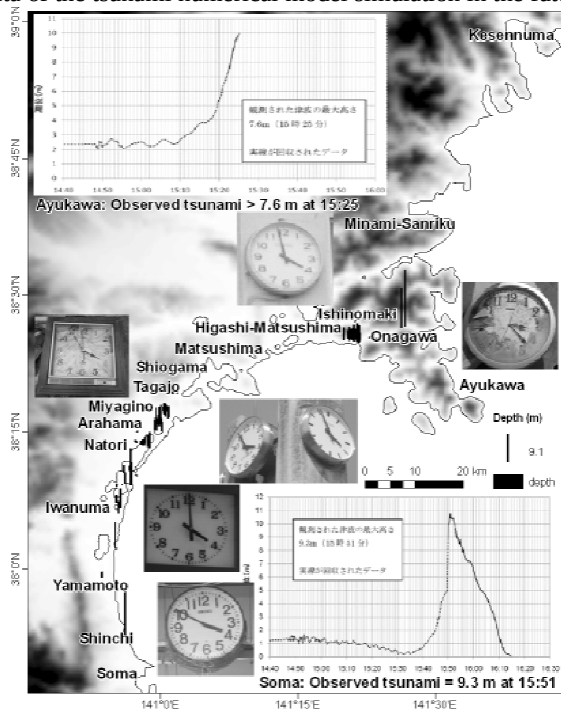


Fig. 1 Measured tsunami inundation depth and arrival time of tsunami arrival from stopped clocks

3. Damage investigation for each area:

3.1 Sanriku coast areas: Because of the large number of fishing boats near the port, many boats were found stranded among the tsunami debris in Kesennuma city (Fig. 2a). These boats increased the impact load of the tsunami to coastal structures. Around the fishery port, damage to the oil tanks was also observed, in some cases causing fire and burning for four days. A tide station was also found damaged during the survey. Minami-Sanriku town had constructed a tsunami gate, which worked against the 1960 Chile tsunami. However, the 8 m-high tsunami gate was overtopped by 15 m height tsunami and completely destroyed (Fig. 2b). The memorial park for the historical tsunami and high-rise evacuation building is located near the tsunami gate were also destroyed. In Onagawa town, the town hospital, which is located on a hill of 15 m height, was inundated on the first floor with a maximum observed tsunami height larger than 18 m. The most remarkable feature in this area is that six reinforced concrete (RC) buildings were overturned by the tsunami (Fig. 2c). All of them were 2-4 stories high and possessed shallow or pile foundations. The populated area in Ishinomaki city located in a plain-shallow water area and not in the head-on direction of the tsunami propagation experienced a lower tsunami velocity. The city was also protected by breakwaters, seawalls and control forests. Although damage to the breakwaters was not large, the seawalls were seriously damaged by erosion on their back side (Fig. 2d). However, these structures were able to protect the forests behind them.

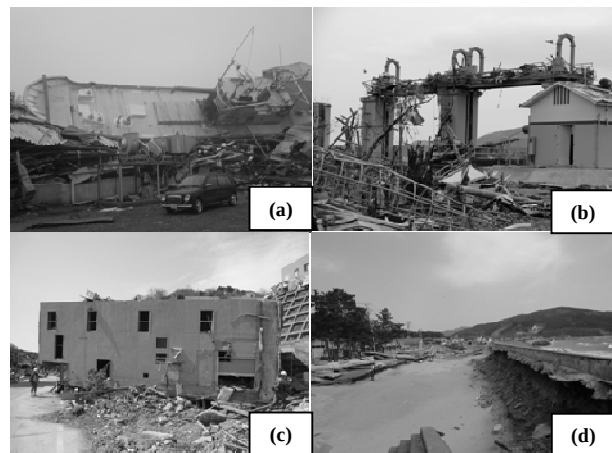


Fig. 2 (a) Debris impact in Kesennuma, (b) Damaged tsunami gate in Minami-Sanriku, (c) Overturned building in Onagawa and (d) Damaged seawall foundation in Ishinomaki

3.2 Matsushima Bay areas: Some locations in Higashi-Matsushima city, the tsunami overtopped and destroyed a seawall because the tsunami came from inland and attacked the backside of the seawall; during a design of the seawall, testing from this direction was not expected because tsunamis are commonly expected to arrive from the sea. The control forest was severely damaged as a large number of trees were uprooted (Fig. 3a). JR train and JR Nobiru station were also damaged. Matsushima town and Shioyama city

are located inside a bay. Approximately 260 tiny islands are located off of Matsushima town that make the town famous for one of the three best coastal views in Japan. Because of the large number of small islands and the shallow area inside the bay, Matsushima town was highly protected by this natural barrier. A low inundation depth and weak current acted resulted in flooding, causing small damage to these areas (Fig. 3b). The average inundation depth was only approximately 2 m. Unlike Matsushima town and Shiogama city, Shichigahama is located next to the Pacific coast and the town was hit by a tsunami height of nearly 10 m. The tsunami caused damage to the breakwaters, seawalls and roads as well as strong erosion.



Fig. 3 (a) Damaged control forest in Higashi-Matsushima and (b) Survived evacuation building in Shiogama

3.3 Sendai Plain areas: Most of the residential areas in Tagajo city are located behind the factory areas of Sendai port and the inundation depths in these areas were not as high. Therefore, a small number of washed-away houses were found. Many factories were damaged by the tsunami. The elevated park located at the center also survived the tsunami. Sand deposits were also found in a river near the JR Tagajo station. The land near a manhole receded by 40 cm. Most houses were washed away in Arahama village. The plain area underwent the maximum inundation distance of 5 km. In fact, the tsunami was accidentally blocked by the highway linking the Tohoku areas to Tokyo. Without this highway, the tsunami might have inundated further inland and caused more impact. The only high-rise building for vertical evacuation to survive the tsunami was the Arahama primary school, which was inundated up to the second floor. Tsunami hazard map (Fig. 4a) information based on the simulation of the Miyagi oki earthquake (M7.5-8.0) and tsunami estimated only 500 m inundation. Tsunami overturned most trees in Yuriage village. Some people evacuated to a shrine on an elevated hill and lost their lives because the tsunami also overtopped the shrine. Fish market was completely destroyed. Damage to an RC wall on the right side represents a common punching failure of an RC structure (Fig. 4b), whereas the non-RC wall on the left side was easier to damage and allowed water to pass through while maintaining the main structure. The Sendai airport stopped its service due to damage on the first floor caused by the 3.5 m of tsunami. Near hot spa in Watari town, the tsunami carried a large amount of sand, which was deposited around the hotel area (Fig. 4c). Fishery boats acted as debris impact and destroyed many houses, similar to events that occurred in Kesennuma city. In Yamamoto town, railway's sleepers made of wood were more heavily damaged (Fig. 4d) and overturned by the force of the tsunami while wooden sleepers with additional concrete sleepers in Higashi-Matsushima survived even the tsunami was higher. In the southern part of the town, most of the houses were washed away.

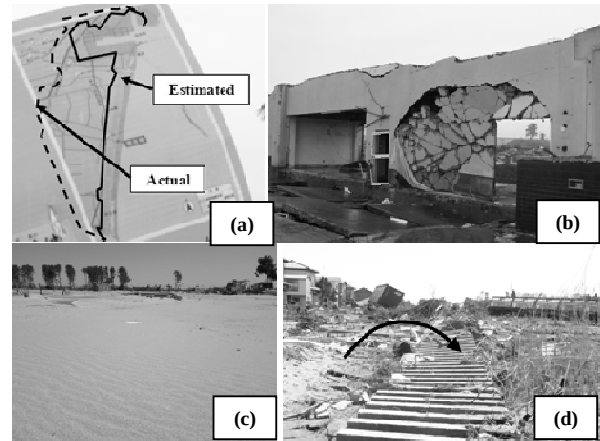


Fig. 4 (a) Tsunami hazard map in Arahama village, (b) Damaged RC wall in Yuriage village, (c) Large sand deposit in Watari town and (d) Damaged wooden railways in Yamamoto town

4. Conclusions and recommendations:

For the great tsunami such as the 2011 event, it is impossible to protect all properties. The most important factor is human life. In this case, coastal structures could help to reduce the tsunami size or retard the arrival time. For this reason, these coastal structures should be constructed properly. These structures should survive even if they are overtopped by a tsunami. For example, severe scouring should not occur at the foundations of seawalls, as seen in many examples investigated in this study, and the connection between seawalls and breakwater should be strengthened so that they will not slide or move and become floating debris that can increase damage. The height of seawalls can be increased to some degree, balancing the tsunami reduction effect and the effect on the scenery. Roads and railways may be used as second and third walls to protect against a tsunami. Because hard measures alone are not enough, soft measures such as education and evacuation will play an important role for this tsunami level.

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