

3.2 Matsushima town and Shiogama city

Matsushima town and Shiogama city locate inside a bay with about 20 km far from Sendai city. There are about 260 tiny islands locate off Matsushima town that make the town become famous as one of the three best coastal views in Japan. Many souvenir shops and restaurant can be found in Matsushima and fresh Oyster is very famous. Because of the large number of small islands and shallow area inside the bay, Matsushima town was highly protected by this natural barrier. Low inundation depth and weak current acted like a flood causing small damage in Matsushima town (Fig. 11 (a)). As a result, the maximum inundation depth was measured to 1-2 m where other locations in Miyagi prefecture were larger than 10 m. (Fig. 12). Most of sightseeing place such as temples and islands survived with only small damages were observed (Fig. 13)

In the other hand, Shiogama city is the most dense population in Tohoku region and famous for sea food product. Sightseeing ferries are available for a trip between Shiogama and Matsushima. Similar to Matsushima town, Shiogama city was protected by the previous mentioned condition yield the average inundation depth of only about 2 m (Fig. 14). Sightseeing ferry terminal which was a designated evacuation building performed very well. People evacuated to the third floor and tsunami reached up to the second floor (Fig. 15).



Fig. 10 Area map of Matsushima town and Shiogama city

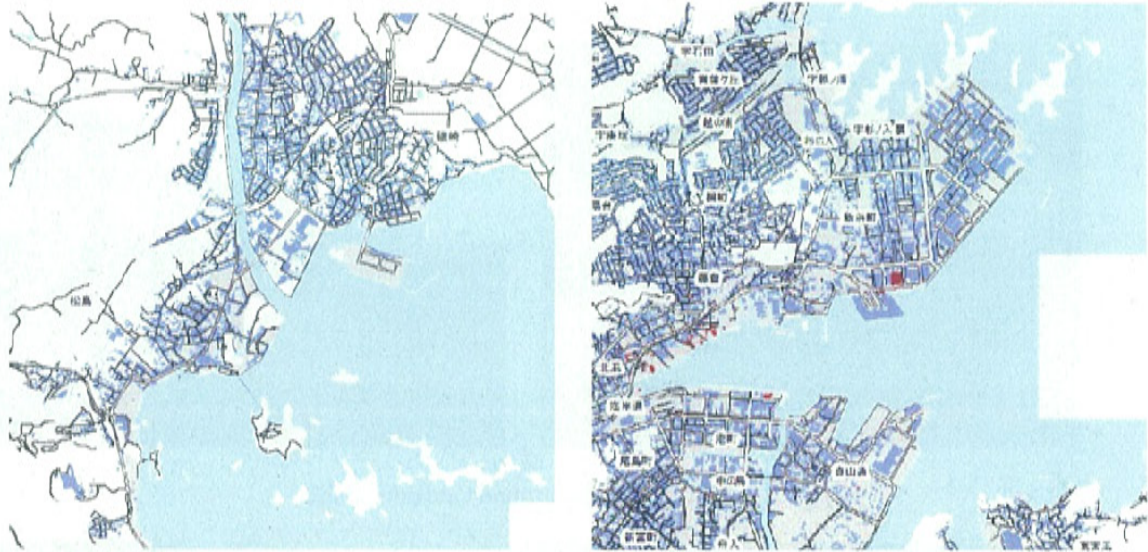


Fig. 11 (a) Tsunami affected area in Matsushima town and (b) Tsunami affected area in Shiogama city (Blue: surviving house, Red: washed away house and Gray: inundated area)



Fig. 12 (a) Inundation depth was lower than window level and (b) About 1.2 m depth in fish market



Fig. 12 (c) Damage in Souvenir shop (1.4 m inundation depth) and (d) Damage in hotel near the coast of Matsushima town



Fig. 13 Damages around Godaido temple



Fig. 14 Damaged sightseeing ferry from Shiogama to Matsushima and (b) Damaged shop near Shiogama station (1.75 m inundation depth)



Fig. 15 Survived sightseeing ferry terminal used and designated evacuation building

3.3 Shichigahama town

Shichigahama town is popular for its beaches during summer. The town was hit by almost 10 m of tsunami. Tsunami damaged breakwaters and seawalls (Fig. 17). As a result, most of the town area was inundated by the tsunami and reached over 2 km inland.

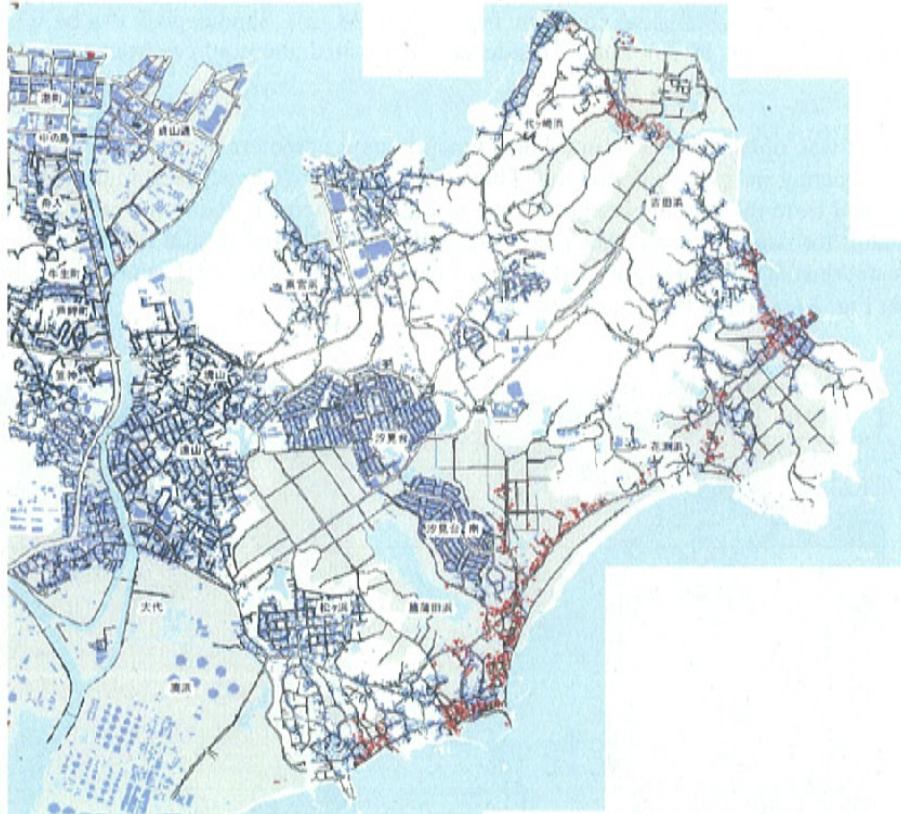


Fig. 16 Tsunami affected area in Shichigahama town (Blue: surviving house, Red: washed away house and Gray: inundated area),



Fig. 17 Damaged breakwaters and seawalls

3.4 Tagajo city and Sendai port (Miyagino ward, Sendai city)

Historical record of the year 869 Jogan tsunami indicates that there were about 1,000 deaths as a result for this event including the former land area of Tagajo city. Tsunami inundation depths from survey are varying from 1.5-4.0 m while the maximum runup near shoreline is between 6 - 7 m. Most of residential areas are locating behind the factory areas and the inundation depth was not so high. Therefore, small number of washed away house is found in Tagajo (Fig. 18 (a)). Sand deposit can be found in a river near JR Tagajo station (Fig. 18 (b)). Land subsidence is estimated about 40 cm from a manhole level (Fig. 18 (c)).

Sendai port was opened in 1971 providing function as a commercial port and also later has become a distribution center in the Tohoku region. Thus, large number of damaged containers and cargo trains can be confirmed from the satellite images shown in Fig. 19. There are many factories that were damaged by the tsunami, for example, beer, washing powder (Fig. 20 (a)) and instant noodle (Fig. 20 (b)). Elevated Park located just at the end of the port also survived from the tsunami. Tsunami trace from debris line is shown in Fig. 21, about 5 m from the ground.

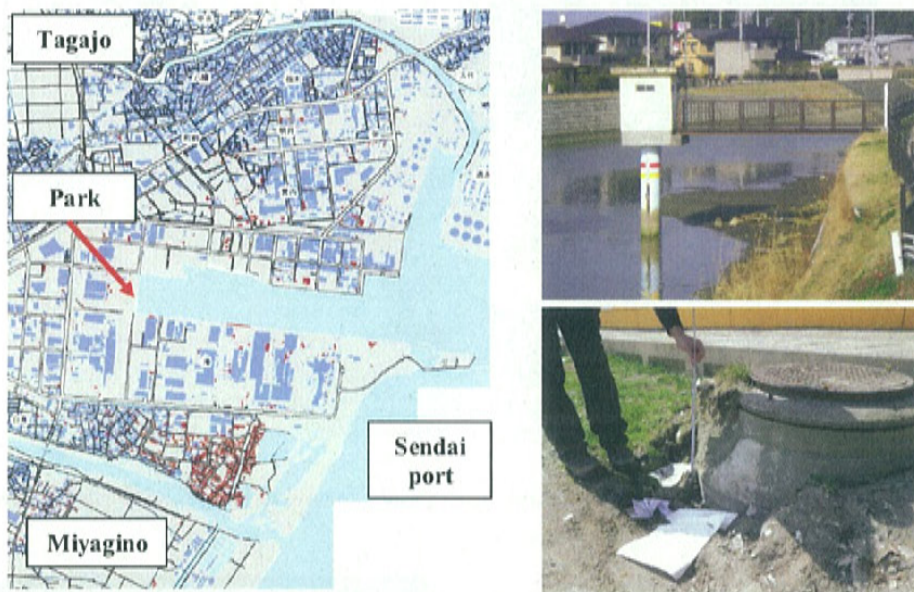


Fig. 18 (a) Tsunami affected area around Sendai port (Blue: surviving house, Red: washed away house and Gray: inundated area), (b) Sand deposit at water level monitoring location and (c) Land subsidence by 43 cm

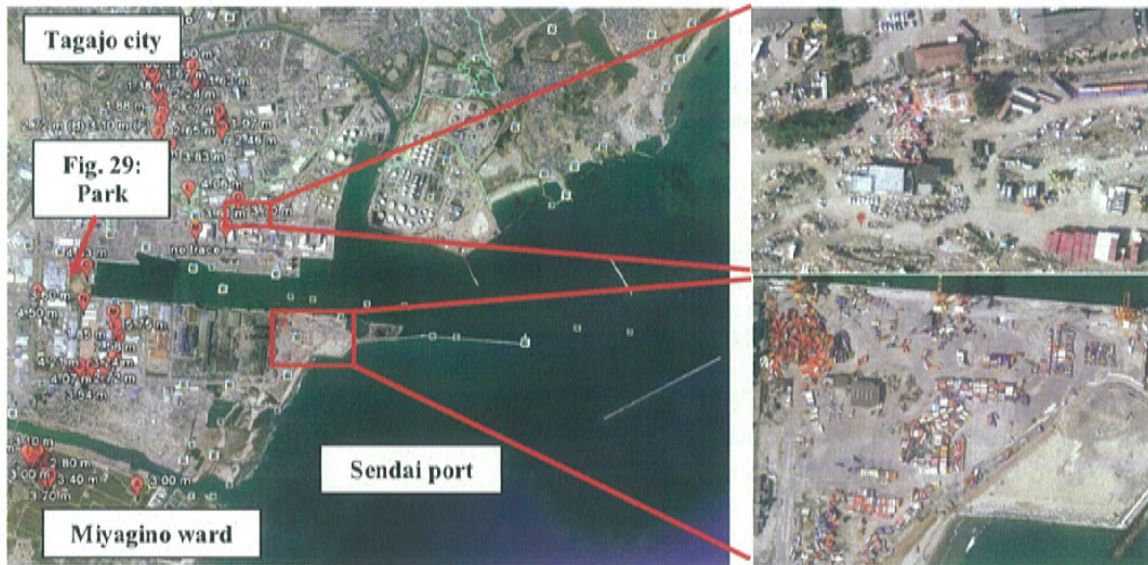


Fig. 19 Area map of Tagajo city and Sendai port (Miyagino ward, Sendai city) and damaged containers



Fig. 20 Damaged factories and containers, instant noodle (a) and washing powder (b)



Fig. 21 Elevated park and tsunami trace

4. Discussions and conclusions

It can be seen from the field survey results that there are many type of damage made by tsunami. Following section summarize those damages in five categories, namely, casualty and evacuation, housing and building, control forests, coastal structural structures and transportation facilities.

4.1 Casualty and evacuation

Total number of dead and missing from the March 2011 earthquake and tsunami is around 22,000. About 99 % of them are from the three prefectures along the east coast; Iwate, Miyagi and Fukushima (Suppasri et al., 2011b), in Miyagi alone is about 14,000. According to the autopsy records of the 13,135 victims in Iwate, Miyagi and Fukushima prefectures, 92.5% of the victims are due to drowning. Also 65% of the victims are more than 60 years old (IOC, 2011). From questionnaires in Kamaishi and Natori, 90% of the sample evacuated with 60% evacuated quickly. The main reason for their evacuation is "I thought a tsunami will come" (65%) and "People around me recommended me to evacuate" (13%). High awareness Dominant intervals for start evacuation time were, "less than 10min" (60%) for Kamaishi and "21 to 30min" (30%) for Natori (CeMI, 2011).

4.2 Housing and Building

Before the March 2011 tsunami, it is common to evacuate to a high rise or reinforced concrete (RC) building. Nevertheless, this event shows that this idea might not always safe. Six RC buildings in Onagawa were overturned and one of them was moved by 70 m before stop at a hill. All buildings were inundated by 18-20 m height. One main reason is that opening areas compared to a wall area of those buildings are very small. Therefore, pressure was suddenly accumulated at a wall that lying on tsunami direction and broke building's foundation.

One good example of the different impact of tsunami into three different types of houses is shown in Ishinomaki city. Though, three houses were inundated by the same inundation depth of 4 m, damage is totally different. The RC 2-story office had no structural damage, only broken windows. The 2-story wooden house was damaged in some walls and columns. The 1-story wooden house was totally collapsed. Tsunami fragility curved developed from the previous tsunamis show that a damage possibility of 4 m inundation depth for a RC house, mix type house and wooden house is 0.9, 0.7 and 0.3 respectively (Suppasri et al., 2011a).

4.3 Control forests

In general, control forest could withstand a tsunami up to 3-5 m (Shuto, 1985). Example of severely damaged control forest is in Natori city where Sendai airport is located. About 10 height of the 2011 tsunami overturned the whole forest with only some of pine trees remained around the back line of the forest. However, this help protected the airport as a measured tsunami inundation depth is only 4 m. Unlike the example in Natori city, pine trees in the control forest in Ishinomaki are almost survived. Possible reasons are the tsunami height at Ishinomaki was smaller (about 7-8 m) and sea wall (later destroyed) might help protecting the trees. Also, location of Ishinomaki city is not in the straight direction of tsunami propagation so that wave current might not so strong compared to other areas.

4.4 Coastal structures

Three examples of coastal structures namely, breakwater (Watari), water gate (Minami-Sanriku) and Seawall (Ishinomaki) are given. Tsunami overtopped breakwaters in Watari and transported large amount of sand to deposit in hotel area behind seawalls and control forest. Water gate in Minami-Sanriku was constructed after the town was damaged from many tsunamis namely, the 1896 tsunami, 1933 tsunami and 1960 Chile tsunami. Although, the 2011 tsunami overtopped the 8 m-gate with the height of more than 15 m (20 m in average) causing damaged area larger than 90%. Example of damaged seawalls is in Ishinomaki. The seawalls have their height of 3.5 m but not enough to protect the tsunami inundation which reached 8 m. Nevertheless, most of pine trees behind the seawalls were survived.

4.5 Transportation facilities

Unlike other tsunami events that only cars and boats were damaged, the March 2011 tsunami also caused damage to airplanes and trains. Ferry terminal in Sendai port for a trip from Nagoya to Hokkaido was also affected from the tsunami. The Sendai airport stopped their service due to the damaged with a 4 m inundation depth at the first floor. The airport was reopened with a limit number of flight on 13th April 2011. The tsunami also caused damaged to the Japan Railway (JR) in many locations such as Onagawa town, Higashi-Matsushima city and Yamamoto town. They reported 23 stationed were washed away, 65 train lines (about 60 km) were damaged and 101 pillars were damaged (IOC, 2011).

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APPENDIX

Arahama town (Wakabayashi ward, Sendai city)

In an ancient time, Arahama town are said to be half farming and half fishing. Since last 400 years ago in the Edo period, canal was slowly digging with the total length of about 33.4 km starting from Sendai port and divided in three sections. Purpose of the canal is for the water transport for a clan supported the budget as a logistics route to send the rice to Edo or Tokyo at the present. Arahama beach is also famous for a swimming during middle of July to middle of August. The town was greatly damaged by the tsunami and most houses were washed away as shown in Fig. 37. Arahama town locates in Sendai plain where the maximum inundation distance was 5 km. Only way to survive from the tsunami is the Arahama primary school (Fig. 38) which was inundated until the second floor (about 4 m inundation depth). Damaged seawall and control forest is shown in Fig. 39 (a) where severe local scour is shown in Fig. 39 (b). Tsunami warnings sign was found (Fig. 40) which providing hazard map information based on the simulation of Miyagi oki earthquake (M7.5-8.0) and tsunami. Hence, the inundation area in Fig. 40 was relatively much smaller compared to the inundation area by present tsunami. Figure 41 is Namiwake shrine where legend of the 869 Jogan tsunami is remained.

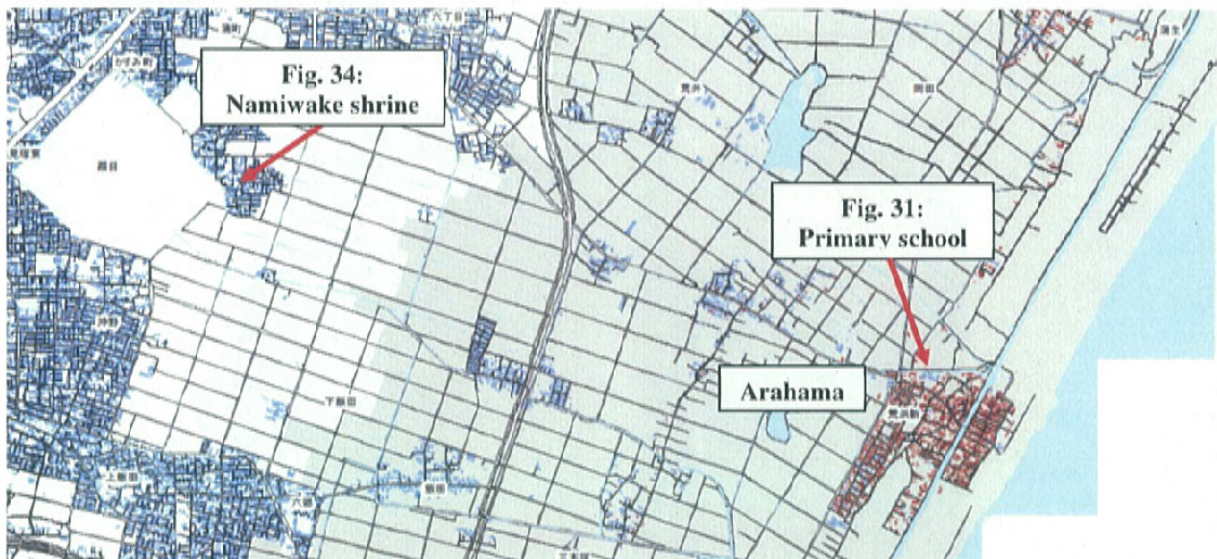


Fig. 37 (a) Tsunami affected area in Arahama town (Blue: surviving house, Red: washed away house and Gray: inundated area)



APPENDIX

Fig. 38 Arahama primary school, stair for emergency event was built behind the building



Fig. 39 (a) Damaged seawall and control forest and (b) Severe scouring at house's footing



Fig. 40 Tsunami warning sign in Arahama town

