Port Damage from Tsunami of the Great East Japan Earthquake

by

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ABSTRACT

This paper presents tsunami damage in ports caused by a tsunami of the Great East Japan Earthquake. The tsunami higher than tsunamis for plan and design of tsunami disaster mitigation structures such as tsunami breakwaters, seawalls and etc. caused destruction in some structures. Furthermore, the tsunami higher than the expected tsunamis for tsunami disaster mitigation plan in communities overflowed the tsunami disaster mitigation structures, and therefore caused devastating inundation in the communities. The tsunami whose inundation was deep on land changed big vessels and oil tanks into tsunami debris.

KEYWORDS: Debris, Destruction of Structure, Disaster, Great East Japan Earthquake, Inundation, Human Loss, Tsunami

1. INTRODUCTION

Japan has suffered many tsunami disaster experiences such as the 1896 Meiji Sanriku Tsunami in which 22,000 dead is reported. Even after improvement of coastal defense which has been implemented significantly since the 1960s, the 1983 Nihon-kai Chubu earthquake tsunami (Japan Sea tsunami) and 1993 Hokkaido Nansei-oki earthquake tsunami (Okushiri tsunami) caused 104 (100 persons were killed directly by the tsunami) and 230 dead and missing, respectively. In the Okushiri tsunami, since residents in Okushiri Island had a disaster experience of the 1983 Japan Sea tsunami that the southern part of the island was inundated and two persons were killed, many residents escaped to hills after an earthquake shock in 1993 and saved their lives. However, the tsunami came soon after the quake: for example, tsunami arrival time was 3 minutes in the northern part of the island near the epicenter. Some residents, therefore, did not have enough time for evacuation. Furthermore two anglers were dead and missing in the mouth of a river by the 2003 Tokachi-oki earthquake tsunami. Since then no tsunamis have caused dead or missing.

However, a tsunami higher than the 1896 Meiji Sanriku Tsunami was generated by the 2011 off the Pacific coast of Tohoku Earthquake of Mw 9.0 at 14:46 JST on 11 March 2011, which occurred in a subduction zone where the Pacific plate subducts beneath the North American plate (or the Okhotsk plate). The tsunami caused devastating disasters in the northern part of main island of Japan. According to the National Police Agency, as of 27 August, the confirmed death is 15,735 persons and the missing is 4,467, the number of completely-damaged houses is 115,380. Further, 84,537 people were in 1,328 refuges as of 13 June, according to NPA. The Fishery Agency reported the number of damaged fishing boats is 25.008 as of 23 August.

2. OFFSHORE MEASUREMENT OF TSUNAMI

Buoys with a GPS sensor which have been installed offshore a coast in the Tohoku region [1] measured the tsunami propagating in the Pacific Ocean [2]. Figure 1 indicates a tsunami profile measured off Kamaishi Port as an example. Although the water depth is 204 m at the measurement point, the maximum tsunami height is 6.5 m. This high tsunami in the offshore region is enlarged due to wave transformation in shallower water depth region. The tsunami 0.5 m high was sill measured 6 hours later after the

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earthquake shock. Uplift 0.55 m of the mean water level after the quake may indicate subsidence of land where a reference point was set to improve accuracy of vertical measurement with GPS.

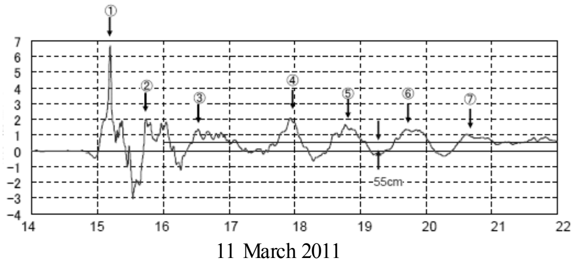

Fig. 1 Tsunami measured with GPS Buoy off Kamaishi Port.

3. TSUNAMI TRACE HEIGHTS

Since April many teams have conducted field surveys to measure heights of tsunami trace and understand tsunami damage. Useful and valuable data on tsunami inundation and runup heights at more than 5,000 points are summarized in a web page of the 2011 Tohoku Earthquake Tsunami Joint Survey Group (http://www.coastal.jp/ttjt/).

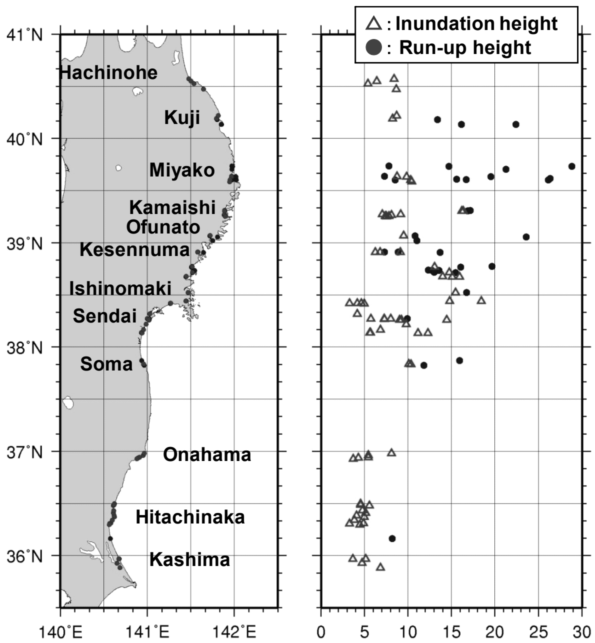

Fig. 2 Tsunami trace heights measured in major ports

Figure 2 indicates heights of tsunami trace measured by teams dispatched to major devastated ports by the Port and Airport Research Institute [3~5]. In the figure, (I) and (R) indicate inundation height and runup height, respectively. These values are height above the estimated tide level at the time of tsunami arrival.

In the Sanriku coast from Kuji to Kesennuma, which is a ria coast, tsunami inundation height is higher than those of Hachinohe and southern part from Ishinomaki. However, the tsunamis striking coasts of Ishinomaki and Sendai are more than 10 m high, and those of Soma and Onahama are still more than 5 m, which are higher than the expected tsunami heights for tsunami disaster mitigation plans in those areas.

4. TSUNAMI DAMAGE

According to the survey in Hachinohe Port [2], even at points protected by breakwaters inundation heights are 5.4 to 6.4 m. They are 2.5 to 2.9 m in terms of inundation depth above the ground surface. Since the inundation depth is deep enough to float fishing boats, some boats are landed as shown in Figure 3. On the other hand, at the points directly facing the Pacific Ocean, inundation heights are 8.3 to 8.4 m. The breakwaters may have effect of tsunami reduction in the protected area. Even in the outside of breakwater, inundation height is 6.0 m behind a coastal green belt consisting of pine trees. Although additional surveys are needed to determine direction of tsunami flooding at this point, the green belt may reduce tsunami flooding and actually prevents the fishing boats from hitting houses as shown in Figure 4.

Fig. 3 Landed boats

Fig. 4 Boats trapped by a coastal green belt

North breakwater caissons of 1,870 m out of the total length of 3,500 m were slipped out and submerged, being affected by tsunami, as shown in Figure 5. In the figure many caissons connecting to a caisson in the right side of the figure are submerged and parts of wave-absorbing blocks installed in front of caissons can be seen above the sea surface. Significant seabed scours were measured around a corner of a reclaimed island quay as well as at the mouths of the breakwaters.

Fig. 5 Damaged north breakwater in Hachinohe Port

In Kuji Port [2], the tsunami causing inundation depth of 4.4 m overtopped a line of tide protection wall of 3.6 m high, and flooded residential area. Furthermore, the tsunami causing 4.3 m inundation depth in the port area push oil tanks over sideways as shown in Figure 6. In Kesennuma, oil tanks became tsunami debris, which were landed on different places from the original positions.

Fig. 6 Damaged oil tanks in Kuji Port

In Kamaishi Port [4], the tsunami of 6.9 to 8.1 m in terms of inundation height floated and crushed wooden houses, as shown in Figure 7. Reinforced concrete (RC) buildings and large-scale grain silos were damaged but not collapsed. A number of vehicles together with destroyed houses were observed floated out on the road, as shown in Figure 8.

Fig. 7 Destruction of houses in Kamaishi

Fig. 8 Tsunami debris in Kamaishi

Offshore breakwater in Kamaishi Port was also damaged by the tsunami as shown in Figure 9. Caissons were slipped and submerged. Much difference in terms of water level between front and back of the breakwater may produce strong water pressure and fast current flowing in gaps between caissons to slide caissons [6].

Fig. 9 Damaged offshore breakwater in Kamaishi Port

In the Miyako bay including Miyako Port, almost same tsunami inundation heights were measured, as shown in Figure 10. The tsunami of 10 m overtopped a protection dike and inundated residential areas as shown in Figure 11. Vessels were landed on wharfs in the port. Logs and cars were also floated and impacted houses, as shown in Figure 12.

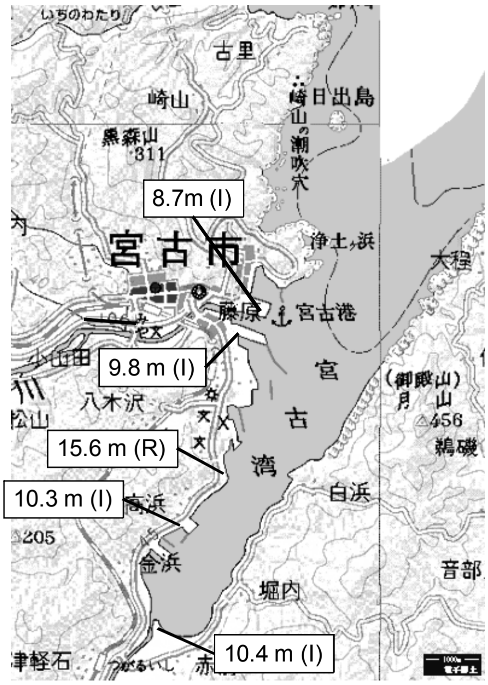

Fig. 10 Tsunami trace heights in Miyako Bay

Fig. 11 Destruction of residential area behind protection dike

Fig. 12 Debris impact

Tsunami debris are not only vessels, automobiles, oil tanks, logs but also shipping containers. In the Sendai-Shiogama port, many containers were scattered by the tsunami impact, as shown in Figure 13. In the Hachinohe port, many containers were taken away the sea.

Fig. 13 Scattered shipping containers in Sendai-Shiogama Port

4. TSUNAMI LEVELS FOR DISASTER PREVENTION AND MITIGATION

From the devastating and cruel tsunami disaster on March 11, tsunami levels are being reconsidered for tsunami disaster mitigation. Before the disaster, the tsunami level for disaster mitigation plan in a community was set based on the highest tsunami among historical tsunamis that a number of reliable data were remained on runup and inundation. Further, the tsunami level for a plan and design of tsunami reduction facilities such as a tsunami breakwater and seawall was also set based on the tsunami level for disaster mitigation plan in a community and other considerations. However, the March 11 tsunami was higher than those tsunami levels. Therefore, from now on, the maximum tsunami level in history of the area (Level-2 tsunami) is being considered to preserve human lives. Against this Level-2 tsunami, a community plan, evacuation plan and system should be integrated as well as structures to reduce tsunamis. However, it may be hard to construct the structures against such a high tsunami. Therefore, the Level-1 tsunami is also being considered. No damage is expected in a community against the Level-1 tsunami. Thus, structures prevent the tsunami of Level-1 or smaller to inundating the community.

5. CONCLUDING REMARKS

Tsunami-resilient communities should be built through integration of town/city planning, public education including evacuation drill, tsunami disaster mitigation structures, warning system and evacuation system including arrangement of emergency shelters.

Regarding tsunami reduction structures, such as breakwaters and seawall, they should have a function that prevents lives and properties from being lost by the level-1 tsunami or smaller. Even for a tsunami higher than the level-1 tsunami, their damage should be as little as possible. If damaged, it should be easily repaired. It is important to understand and explain to the public that the level-2 tsunami can overflow tsunami reduction structures and cause damage in the community.

6. REFERENCES

1. T Nagai, T., Satomi, S., Terada, Y., Kato, T., Nukada, K. and Kudaka, M.: GPS Buoy and Seabed Installed Wave Gauge Application to Offshore Tsunami Observation, *Proc. 15th Int. Offshore Polar Eng. Conf.*, ISOPE, Seoul, pp. 292-299, 2006.
2. PARI: Tsunami Measurement Result with GPS Wave Meters, http://www.pari.go.jp/files/items/3527/File/results.pdf (in Japanese), 2011.
3. PARI: Preliminary Report of Urgent Field Survey in Hachinohe and Kuji Ports, http://www.pari.go.jp/files/3523/1658995676.pdf (in Japanese), 2011.
4. PARI: Preliminary Report of Urgent Field Survey in Kamaishi and Oofunato Ports, http://www.pari.go.jp/files/3524/1287232102.pdf (in Japanese), 2011.
5. PARI: Preliminary Report of Urgent Field Survey in Sendai and Ishinomaki Ports, http://www.pari.go.jp/files/3525/696358192.pdf (in Japanese), 2011.
6. PARI: Factors to Damage Offshore Breakwater in Kamaishi Port by the 2011 Japan Earthquake and Tsunami, http://www.pari.go.jp/files/items/3544/File/20110401-3.pdf (in Japanese), 2011.
7. Takahashi S. et al.: Urgent Survey for 2011 Great East Japan Earthquake and Tsunami Disaster in Ports and Coasts, *Tech. of Note PARI*, No. 1231, 2011.