Research article

Evaluation of Tide Embankment and Protection Forest Width on Tsunami Disaster Using Tsunami Simulator

YOUKI MAEDA
Graduate School of Agriculture, Tokyo University of Agriculture, Tokyo, Japan

HIROMU OKAZAWA*
Faculty of Regional Environment Science, Tokyo University of Agriculture, Tokyo, Japan
Email: h1okazaw@nodai.ac.jp

YASUSHI TAKEUCHI
Faculty of Regional Environment Science, Tokyo University of Agriculture, Tokyo, Japan

TOMONORI FUJIKAWA
Faculty of Regional Environment Science, Tokyo University of Agriculture, Tokyo, Japan

Received 14 December 2012 Accepted 10 June 2013 (*Corresponding Author)

Abstract The tsunami that occurred after the Tohoku Earthquake of March 11, 2011, devastated the infrastructure in Tohoku, including roads and water channels. This study reports the results of a tsunami simulation experiment using an open channel for evaluation of tide embankments and protection forest in controlling the force of tsunami waves and flow of sand carried by tsunami. Coastal areas in Minami Soma City, Fukushima Prefecture, that were devastated by the Tohoku Earthquake were assumed as the experimental location. A 0.3 m-wide, 12 m-long open channel was used for the tsunami experiment. To simulate a tsunami, a removable barrier was set near the upstream end of the channel to retain water. The barrier was lifted to generate a bore. The scale for the model was 1/100. A model protection forest and a tide embankment made of acrylic were placed at the longitudinal midpoint of the channel. To examine the sand control effect of the tide embankment and protection forest at the time of tsunami, Toyoura silica sand was laid in the channel bottom upstream of the tide embankment and protection forest. The sand left behind after the tsunami simulation was measured for dry weight. The speed of the wave beyond the protection forest tended to decrease with increases in forest width. The amount of sand carried by the tsunami was found to decrease with increases in forest width. The results, however, are from a simplified model channel experiment. It is necessary to perform experiments that more closely reproduce the original sites in terms of topography and vegetation.

Keywords tsunami, protection forest, tide embankment, sand, earthquake

INTRODUCTION

Japan is among the most earthquake-prone countries in the world. The tsunamis that occurred after the Tohoku Earthquake of March 11, 2011, devastated the infrastructure in Tohoku, including roads and water channels. A total area of 443 km^2 was inundated, and 238 km^2 (54 %) of this was almost paddy field (The Geospatial Information Authority of Japan, 2011). Coastal sand carried by the tsunamis deposited in the affected paddy fields in wide areas. Considerable time and labor have been spent in removing the deposited sand.

Restoration and reconstruction of the infrastructure and agricultural lands are underway in the disaster-hit areas. At the same time, the value of establishing tide embankments and tidewater control forests has come under review as a part of efforts to make tsunami-resistant communities. Two tsunami mitigation effects were suggested by Shuto (1985): 1) the forests prevent objects such as boats that drift from sea to land from moving into areas with houses and other buildings, and 2) the forests reduce the speed of tsunami waves by exerting drag, which limits the flooding. However, the effects of tidewater control forests in mitigating damage have not been fully examined. No studies have addressed the scale of tidewater control forest required to mitigate damage against large-scale tsunamis (wave heights of 10 m or greater) caused by mega-earthquakes (magnitudes around M9.0).

OBJECTIVE

This paper reports the results of tsunami simulation experiments using an open water channel for evaluation of tide embankments and tidewater control forests of several widths in controlling the force of tsunami waves and the amount of sand carried by the tsunamis. The disaster prevention measures of Minami Soma City in Fukushima Prefecture (Fig.1), which was devastated by the Tohoku Earthquake tsunamis, were used as a reference case.

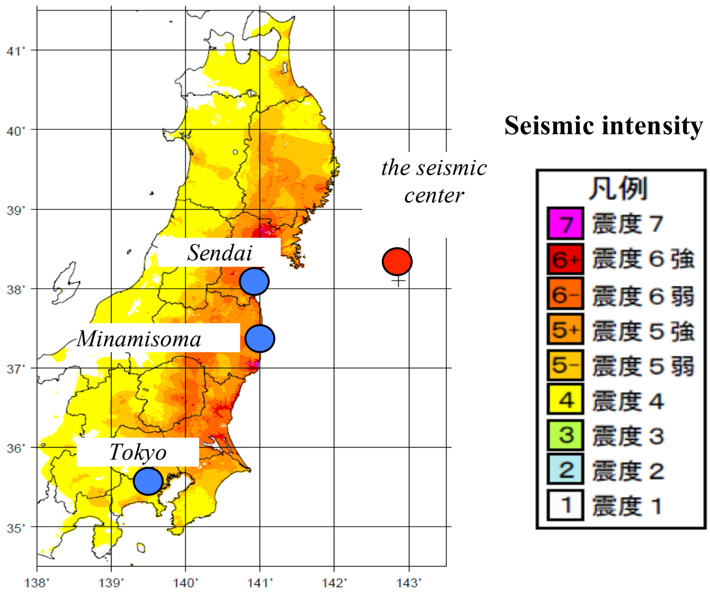

Fig. 1 Seismic intensity's map of the Tohoku Earthquake (March 11, 2011)
Source: Japan Meteorological Agency

METHODOLOGY

A 0.3 m-wide, 12 m-long open channel was used for the tsunami experiment (Fig. 2). To simulate a tsunami, a removable barrier was set near the upstream end of the channel to retain water. The barrier was rapidly lifted to generate a bore. The scale for the model was 1/100. The height of the model waves was set as 12 cm, based on the 12 m height of the actual waves that reached the coastal areas (Takahashi et al., 2011). Tidewater control forest and tide embankment models were placed at the longitudinal midpoint of the channel. The dimensions and alignment of the model trees of the tidewater control forest were determined based on the study by Shuto (1985). Acrylic sticks 2 mm in diameter and 10.5 cm in length were arranged in a staggered pattern. The tide embankment had a trapezoidal cross section, a top width of 12 cm, a bottom width of 16 cm and a height of 45 cm. To examine the sand control effect of the tide embankment and tidewater control forest at the time of tsunami, Toyoura silica sand (Japanese standard sand), which was chosen to reproduce the sea bottom sand at the site, was laid in the channel bottom upstream of the tide embankment and tidewater control forest. The 4.0 kg of sand was laid 30 cm wide, 80 cm long, and 0.9 cm thick. The sand left behind after the tsunami simulation was measured for dry weight.

The experiment conditions are given in Table 1. There were 12 experiment treatments:

without a tide control forest (indicated as 0cm) and with a tide control forest of 20 cm, 30 cm, 40 cm, 50 cm or 60 cm in width, in each case with and without a tide embankment. The tsunami simulation was videotaped, and the speed of the waves after they passed the tidewater control forest was calculated from the video data.

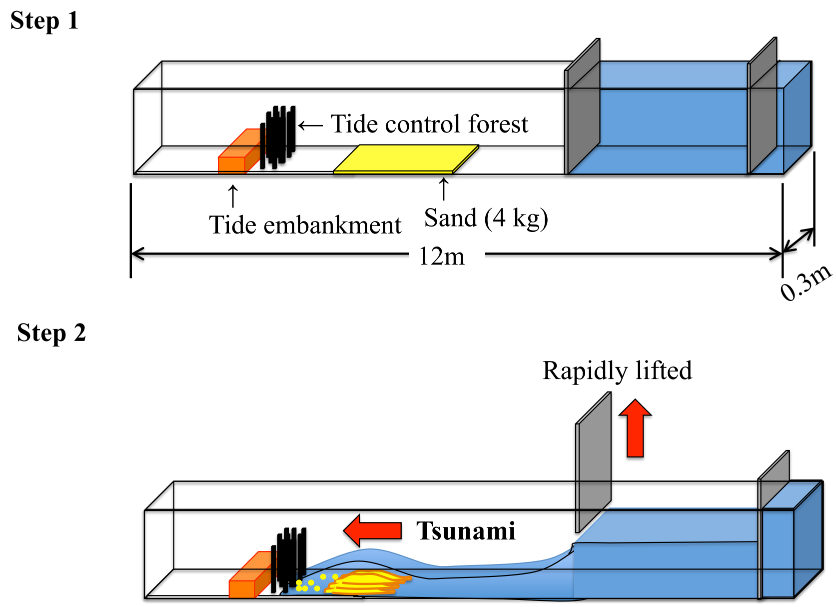

Fig. 2 Outline of the Tsunami Simulator using experimental open channel (0.3 m-wide, 12 m-long)

Table 1 The experiment conditions using Tsunami Simulator

	Width of tide control forest						
With a tide embankment	0 cm	10 cm	20 cm	30 cm	40 cm	50 cm	60 cm
Without a tide embankment	0 cm	10 cm	20 cm	30 cm	40 cm	50 cm	60 cm

As the flow velocity of waves changed in a short time in this experiment, it was impossible to apply the Froude's law of similitude, which is used in normal channel experiments. Referring to Kimura et al. (1968) and based on the condition that the density and gravitational acceleration of water were the same for the original site and for the model, the following two rules of similitude were determined (Eqs. (1)- (3)).

$$\frac{T_2}{T_1} = \left(\frac{L_2}{L_1}\right)^{1/2} = \frac{1}{n^{1/2}} \tag{1}$$

$$\frac{V_2}{V_1} = \frac{L_2 \cdot T_2^{-1}}{L_1 \cdot T_1^{-1}} = \frac{1}{n^{1/2}} = \frac{1}{100^{1/2}} = \frac{1}{10} \tag{2}$$

$$\therefore V_1 = 10\, V_2 \tag{3}$$

where L is length (m), n is reduction scale, V is flow velocity (m/s)and T is time (s). The subscripts 1 and 2 indicate the original and the model, respectively.

After conversion by using Eq.(1) to (3), the speed of tsunami waves measured in the model experiments was found to be 1/10 that of the flow velocity observed at the original site.

RESULTS AND DISCUSSION

Fig. 3 shows the relationship between forest width and flow velocity of tsunami waves. It was clarified that the flow velocities for the case with a 0.2 m-wide forest were reduced to 77% (case without a tide embankment) and to 84% (case with a tide embankment) that of the case without a tide control forest (forest width 0m). However, the differences in flow velocities were small under the condition with forest width of 0.3 cm or wider. Therefore, it can be assumed that flow velocities decreased for the forests with widths of up to 0.2 cm, but did not decrease appreciably at widths greater than that. For cases with a forest of a given width, it was found that, in the case with a tide embankment, the maximum flow velocity decreased to 80% that of the case without a tide embankment.

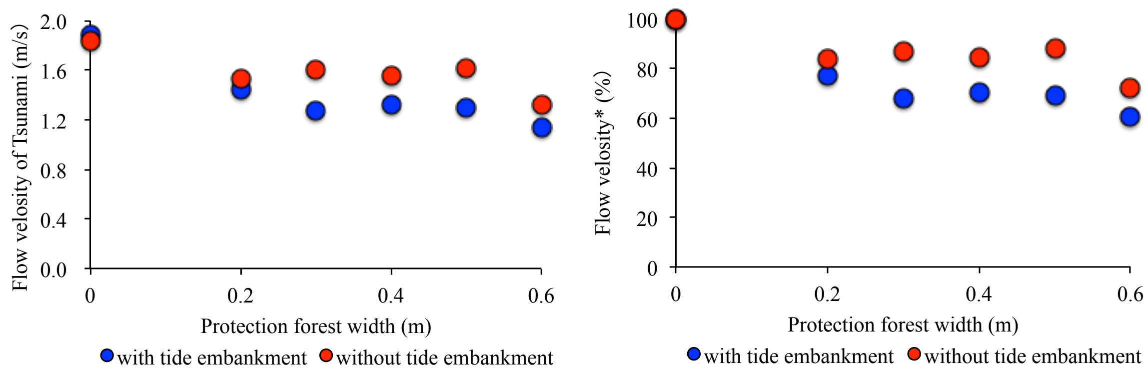

Fig. 3 Relationship between flow velocity of tsunami and protection forest width

**Ratio of flow velocity (m/s) in the case of 20-60 m forest width on that of 0 m forest width*

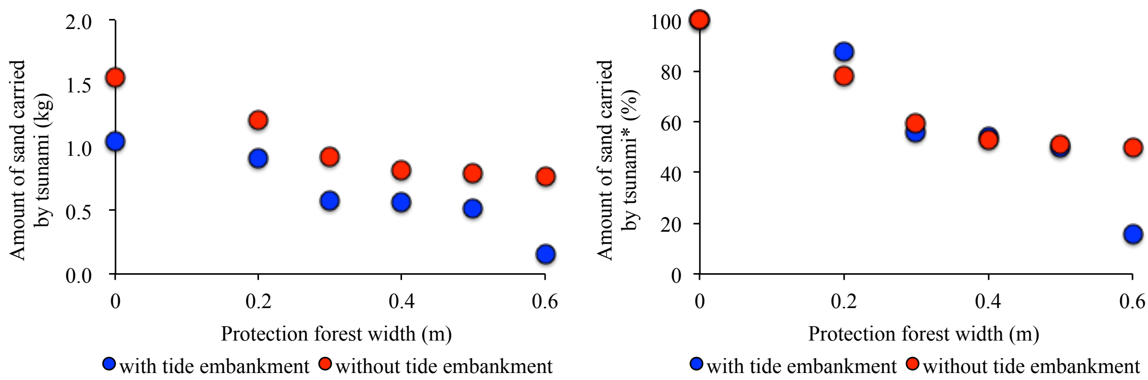

Fig. 4 Relationship between flow velocity of tsunami and amount of sand carried by tsunami

**Ratio of* sand (kg) *in the case of 20-60 m forest width on that of 0 m forest width*

The relationship between forest width and amount of sand carried by tsunami (sediment) is shown in Fig.4. At the forest width of 0m, i.e., without a tidewater control forest, sediment was 1.040 kg in the case with a tide embankment and 1.550 kg in the case without a tide embankment. It was clarified that even without a tide control forest; sediment reduction to 67% was achieved by using a tide embankment. For the cases with a forest of a given width, the sediment for the case with a tide embankment was found to be constantly about 60% that of the case without a tide embankment. Based on the above findings, it is thought installation of tidewater control forests combined with tide embankments can reduce sediment to about 60% that of tidewater control forests alone.

When the relationship between forest width and changes in sediment deposition was examined, it was found that sediment deposition tended to decrease for the forest widths of 0.2 m and 0.3 m, irrespective of the presence of a tide embankment. Sediment in the cases with a forest width of 0.3 m was 56% with the tide embankment and 60% without the tide embankment of those in the cases without a forest (forest width of 0m). However, the changes in sediment were small in the cases with forests of 0.3 m or greater in width. The above findings clarified that sediment reduction to 60% is possible by installing a forest of 30 m in width (equivalent to the 0.3 m width in the model) and that increases in forest width beyond 30 m would not afford greater reductions in sediment deposition.

CONCLUSION

These experiments examined the effects of a tidewater control forest and a tide embankment on the speed of tsunami waves and the amount of sand carried by a tsunami under the assumption of a tsunami with the scale of those that occurred after the Tohoku Earthquake in Japan on March 11, 2011. Laboratory experiments demonstrated that the minimum width for a tide control forest effectively reduces the speed of tsunami waves and the amount of sand carried by a tsunami is 20 to 30 m. It was also clarified that use of a tide embankment in combination with a tidewater control forest is effective in mitigating the tsunami damage. The results, however, are from a simplified model channel experiment. It is necessary to perform experiments that closely resemble the original sites in terms of detailed topography and vegetation.

ACKNOWLEDGEMENTS

This research was supported by Eastern Japan Support Project from Tokyo University of Agriculture, Japan. We would like to express our gratitude to Prof. Dr. Shigeyuki MIYABAYASHI (Tokyo University of Agriculture). The authors are also grateful for the research assistance provided by the students of the laboratory of Hydro-structure Engineering, Tokyo University of Agriculture.

REFERENCES

Kimura, H., Kudo, K. and Shibayama, A., 1968. A Model Experiment on the Tsunami Breakwaters at the port Kochi. Report of the Port and Airport Research Institute. 7-2. 3-64. (in Japanese).

Shuto, N., 1985. Effect of salty wind protection forests on protection against tsunami and its limit. Coastal Engineering Journal. 32. 465-469. (in Japanese).

Takahasi, S., et al. 2011. Urgent survey for 2011 great east japan earthquake and tsunami disaster in ports and coasts. Technical Note of the Port and Airport Research Institute. 1231. 31-44.

The Geospatial Information Authority of Japan. 2011. (http://gisstar.gsi.go.jp/2011TaiheiyouOki/LandUse/LandUseArea.pdf (2012.12.13 Perusal))