Research article

Effects of Coastal Road Spacing on Deposition of Tsunami-Borne Sand

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Abstract Large-scale infrastructure for tsunami damage mitigation includes tidewater control forests and tide embankments. It is said that installing a tidewater control forest of 200 m in width along the coast is effective in mitigating tsunami damage. Since the East Japan Great Earthquake, tide embankments of about 7 m high have been under construction on coasts of tsunami-hit areas. Restoration and installation of tidewater control forests require many years, and the construction of large-scale tide embankments requires enormous cost. This study focuses on existing roads in the coastal areas. We investigated the effects of road, depending on their conditions of spacing, on tsunami sand deposition. A 0.3 m-wide, 12 m-long open channel was used for tsunami experiments. To simulate a tsunami, a removable barrier was set near the upstream end of the channel to retain water. The barrier was lifted suddenly to generate a bore. The scale of the model was 1/100. A certain amount of sand and models of a tidewater control forest, a tide embankment and roads made of acrylic were placed at the longitudinal midpoint of the channel. The movement of sand carried by the reproduced tsunami was observed. Several combinations of the tidewater control forest, tide embankment and three roads were used in the tsunami reproduction experiment, with the spacing changed for each experiment. As the result of experiments, it was clarified that when the spaces between the roads were wide, the amount of deposited sand was controlled better. It was also clarified that the amount of sand deposition at the time of a tsunami in a coastal area was able to be controlled effectively by combining roads with wide spacing between them with a tidewater control forest or a tide embankment.

Keywords tsunami, tidewater control forests, tide embankments, road, sand

INTRODUCTION

Tsunamis generated by the Sumatra-Andaman Earthquake of 2004 (Mw 9.1) and the East Japan Great Earthquake of 2011 (Mw 9.0) caused catastrophic damage in coastal areas (i.e. Kandasamy et al., 2005). In the East Japan Great Earthquake in particular, large amounts of sand were carried by tsunami waves from the sea bottom to coastal areas. The sand deposition was up to 30 cm thick, and the deposition was widespread. Because of the extreme amount and wide area of sand deposition, removal work has not progressed yet at 2013.

Large-scale infrastructure for tsunami damage mitigation includes tidewater control forests and tide embankments. It is said that installing a tidewater control forest of 200 m in width along the coast is effective in mitigating tsunami damage (Maeda, 2013). Since the East Japan Great Earthquake, tide embankments of about 7 m high have been under construction on coasts of tsunami-hit areas. Restoration and installation of tidewater control forests require many years, and the construction of large-scale tide embankments requires enormous cost.

OBJECTIVE

This study focuses on existing roads in the coastal areas. Roads take less time and money to construct than tide embankments and tidewater control forests take. We investigated the effects of road, depending of their conditions of installation, on tsunami sand deposition.

METHODOLOGY

A 0.3 m-wide, 12m-long open channel was used for tsunami experiments. To simulate a tsunami, a removable barrier was set near the upstream end of the channel to retain water. The barrier was lifted suddenly to generate a bore. The scale of the model was 1/100. A certain amount of sand and models of a tidewater control forest, a tide embankment and roads made of acrylic were placed at the longitudinal midpoint of the channel. The movement of sand carried by the reproduced tsunami was observed. Several combinations of tidewater control forest, tide embankment and three roads were used in the tsunami reproduction experiment, with the spacing changed for each experiment.

The dimensions and alignment of the model trees in the tidewater control forest were determined based on the study by Shuto et al. (1985). Acrylic sticks of 2 mm in diameter and 10.5 cm in length were arranged in a staggered pattern. The width of the tidewater control forest was set as 200 cm (200 m in field scale), which was determined based on the Disaster Prevention Plan of Minami Soma City, Fukushima Prefecture. The dimensions of the trapezoidal cross-section of the tide embankment were determined, based on the same plan, as 5 cm wide at the top, 13 cm wide at the bottom and 7.5 cm high. The road model, simulating an agricultural road, was created as a rectangle of 4.0 cm in width and 0.5 cm in height. The road models were placed immediately downstream of the tidewater control forest model or the tide embankment model in three patterns of 15 cm, 20 cm or 25 cm intervals in each experiment. To evaluate the degree of sand control of the road, the tide embankment and the tidewater control forest at the time of tsunami, Toyoura silica 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. 4.0 kg of sand was laid at 30 cm in width, 80 cm in length and 0.9 cm in thickness. The sand left in the assumed tsunami control zone, consisting of the tide embankment, the tidewater control forest and roads, after the tsunami simulation was measured for dry weight. Five experimental channel conditions were used: (1) no control structures (no models), (2) only the road models, (3) the roads and tide embankment, (4) the roads and the tidewater control forest, and (5) the roads, the tide embankment and the tidewater control forest. The interval of road was set as 15 cm, 20 cm or 25 cm in each experiment that used the road models. To reproduce tsunamis in the experiment flume, a law of similitude was used. Froude's law of similitude is generally used for studies involving open flume experiments; however, it was impossible to apply the Froude's law of similitude, because there were locations where water level differences were rapidly created by the presence of the tidewater control forest and the embankment models. In this experiment, use of a law of similitude, in which the water density and gravitational acceleration are the same for the original site as for the model, was determined based on the conditions described in the Port and Airport Research Institute Report (Kimura et al., 1968). The geometric similarity in this experiment was set as 1/100, and the height of tsunami that reached the coastal areas was assumed as 12 m, based on the Port and Airport Research Institute Report (Takahashi et al. 2011). The tsunami velocity measured in the experiment using the models was 1/10 that observed in the disaster area, which is the same as the result obtained using Froude's law of similitude (Maeda et al. 2013).

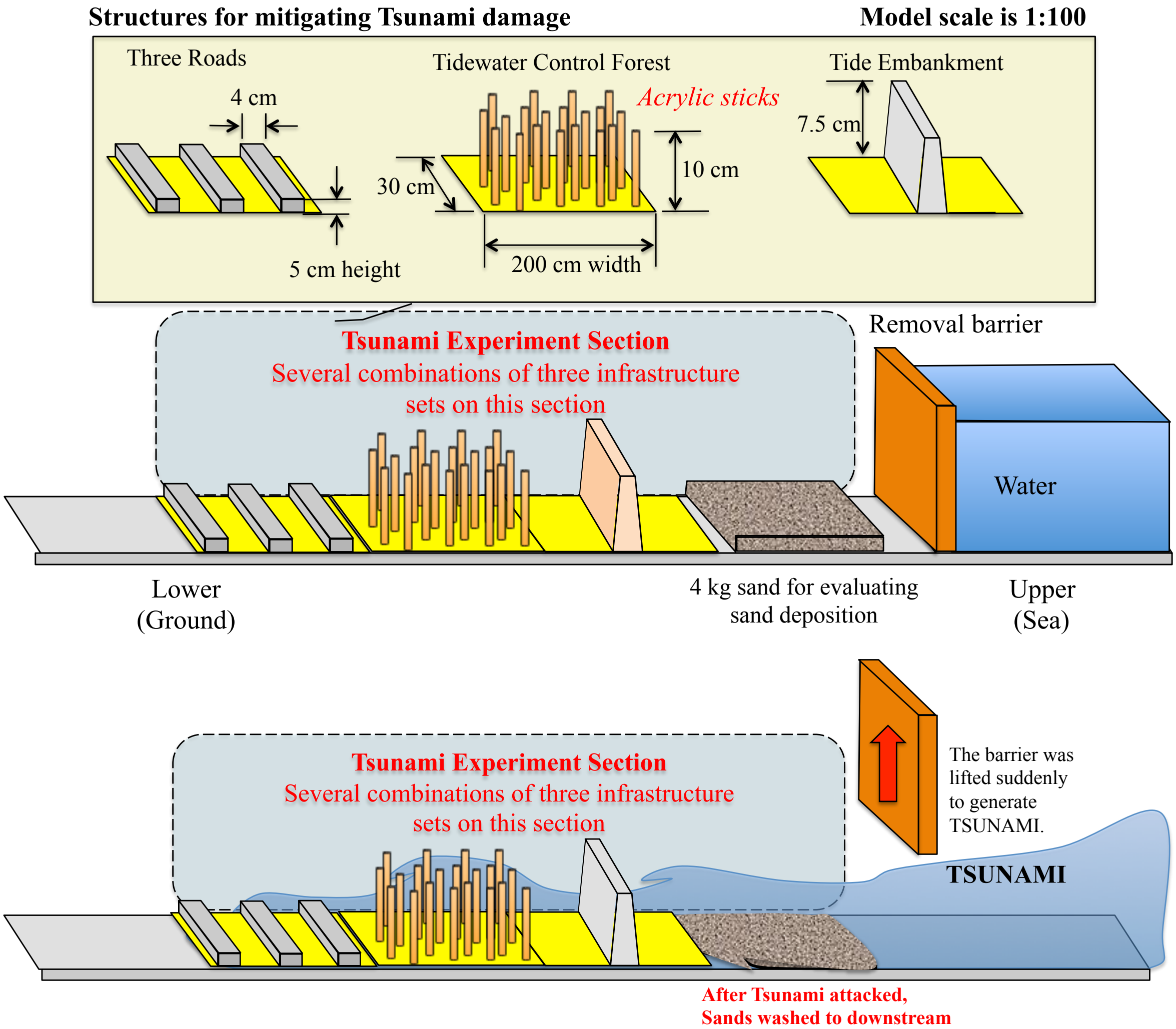


Fig. 1 Outline of Tsunami experiment

RESULTS AND DISCUSSION

Fig. 2 shows the relationship between the road interval and the amount of sand deposited by the water flow in the experiment. The values are the average and the standard deviation of three experimental flows. When road models were not installed, the sand deposition was 3.3 kg out of the 4 kg of sand in the flow. When the road models were installed perpendicular to the flow at intervals of 15 cm, 20 cm and 25 cm, the respective sand depositions were 3.1 kg (78%), 2.7 kg (68%) and 2.5 kg (63%) and it's standard deviation were 0.36, 0.16 and 0.11. It was clarified that the amount of sand deposited by the tsunami waves decreases with increases in the interval of roads. It was demonstrated that the tsunami drag force decreased when roads were installed.

Fig. 3 shows the result of experiments with four different conditions. (1) Without any structures, 3.2 kg of sand was deposited by tsunami waves. It was clarified that the amount of sand deposited by the tsunami waves decreased in stages by combining the roads with a tide embankment and a tidewater control forest, in the following order of least to most increase: (3) with roads and a tide embankment, (4) with roads and a tidewater control forest, and (5) with roads, a tide embankment and a tidewater control forest. It was clarified that combining the roads with a tidewater control forest was effective in mitigating sand deposition caused by tsunami, because the amount of sand controlled by the tidewater control forest was particularly large.

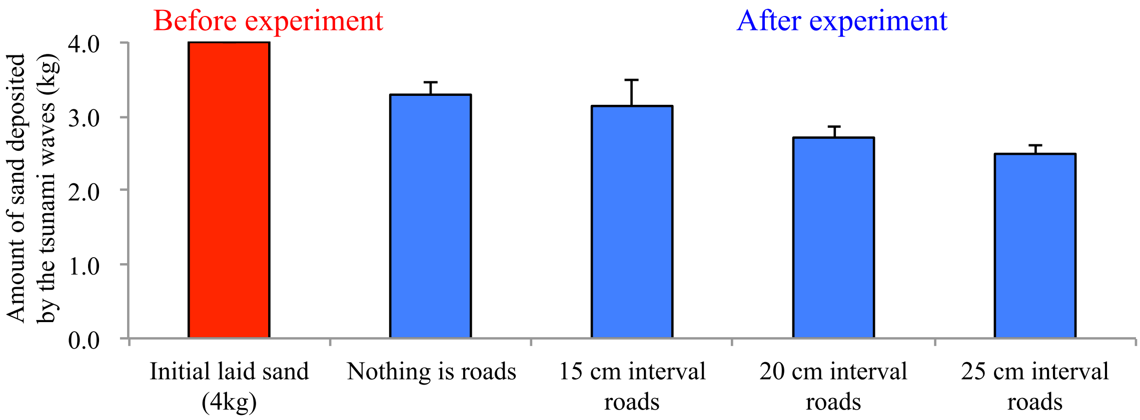
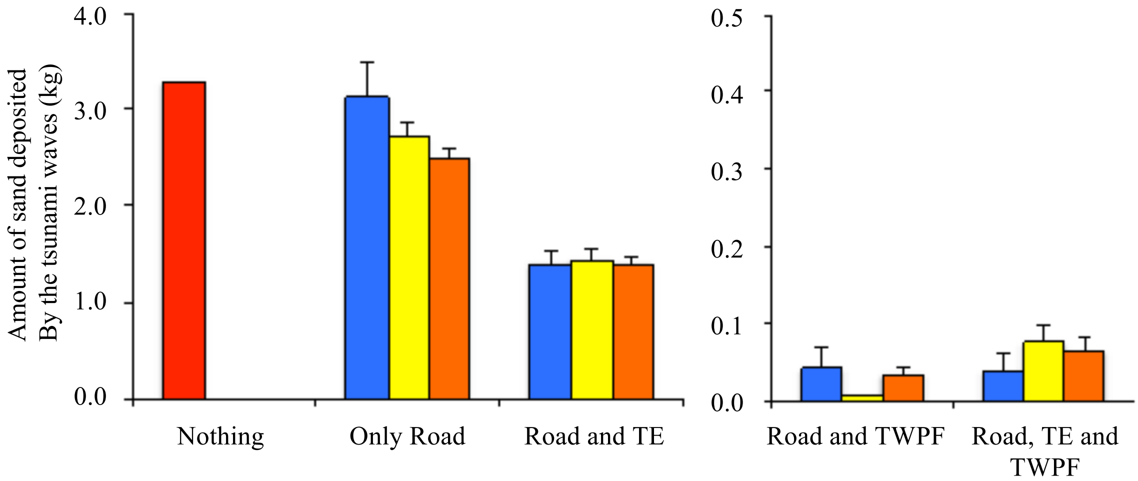


Fig. 2 Relationship between the road interval and the amount of sand deposited by the water flow in the experiment



TE and TWPF means tide embankment and tidewater embankment.
Red indicates the result of tsunami experiment without any structures. Blue, Yellow and Orange also shows the results of 15 cm, 20 cm and 25 cm interval three roads, respectively.

Fig. 3 Result of experiments with five different conditions

As the result of experiments, it was clarified that when the spaces between the roads were wide, the amount of deposited sand was controlled in better way. It was also clarified that the amount of sand deposition at the time of a tsunami in a coastal area could be controlled effectively by combining roads with wide spacing between them with a tidewater control forest or a tide embankment.

CONCLUSION

In this study, the effect of roads and each additional measure in controlling sand deposition caused by tsunami was examined and the effective interval of roads installed parallel to the coastline in mitigating tsunami damages was explored.

It was clarified that the amount of sand controlled by the roads increases with increases in the road interval and that a reduction of 98% or more was achieved in the condition with control measures compared to without control measures, assuming that a tidewater control forest of 200 cm in width (200 m in field-scale) was installed in each case.

However, these results are from laboratory flume experiments that did not consider the topography of the sea bottom or of coastal areas. The similarity of sand was also ignored in this study. To further study measures against sand deposition damage by tsunamis, it is necessary to conduct experiments that consider the similarity of sand and the topography of the sea bottom and the coastal areas in question.

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