Evaluation of Improved Breakwater Foundation Subjected to Earthquake and Tsunami Loading

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1. Introduction

In 2011 the earthquake and tsunami struck the pacific coast of Tohoku region, Japan, which led to catastrophic damage to waterfront structures such as breakwaters [1]. As the potential Nankai earthquake may happen and trigger a huge tsunami, it would be an enormous threat for human lives and public property. To improve breakwater's damage during earthquake and tsunami such as sliding, collapsing and mound scouring, the previous researchers used gabion, sheet pile, impervious filling material and wave-dissipating block [2,3,4] to make the breakwater resilient. However, not all of these materials were tested in both earthquake test and tsunami test. And the breakwater's displacement and mound scouring can be improved. As the seepage is a major factor of breakwater's failure, the models were redesigned with reinforcing materials. Then models were tested in the earthquake test and tsunami test by shaking table to evaluate the efficiency of improved models.

2. Research Methodology

As the Miyazaki port breakwater may suffer the damage of potential Nankai earthquake, it was chosen as the breakwater prototype. The prototype to model (Fig. 1) ratio was 64. The reinforcing materials (Fig. 2) including gabion (protecting the mound from scouring), sheet pile (decreasing the seepage in the foundation), impervious filling material (decreasing the seepage by closing the gap between breakwater and sheet pile) and wave-dissipating block (dissipating some wave and decreasing mound scouring) were used on the breakwater. With these reinforcing materials, six improved models (Fig. 3) were designed on the basis of model 0. Then the models were tested in the 1 g shaking table test. The research used shaking table to simulate the earthquake test and tsunami test. The earthquake loading was imported to the breakwater first including foreshock and main shock. The acceleration of foreshock and main shock was 0.1 g and 0.3 g respectively. They shared the same frequency 15 Hz and the same shaking time 8 seconds. After the earthquake loading, the tsunami loading was imported to the same model. The water flow rate was 440 L/min.

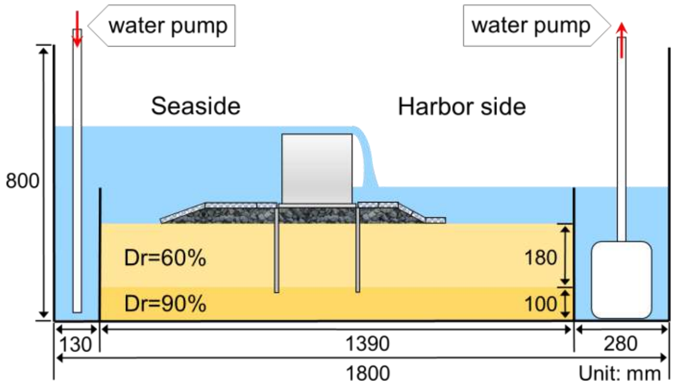

Fig. 1 Shaking table setup [2]
(Model 0)

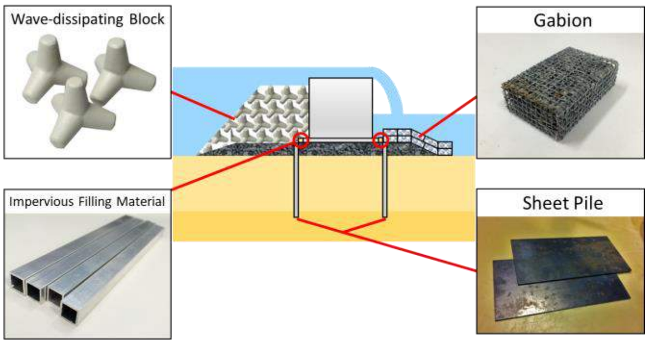

Fig. 2 Reinforcing material

3. Experiment Results

Figs. 4 and 5 show the average horizontal and vertical displacements of breakwater. In the foreshock of earthquake shaking, the breakwater had little displacements. While in the main shock, the breakwater had much displacements. And the breakwater displaced during the tsunami loading as well. In model 6 which had just one sheet pile under the breakwater, its displacement was more than that of other models. The displacements of models 1, 2, 3, 4 and 5 which were reinforced with impervious filling material decreased comparing with the displacement of model 1. Comparing models 2 and 3, model 3 had more displacements which canceled the gabion at the sea side. Models 4 and 5 which were reinforced with wave-dissipating block had better performance comparing with other models.

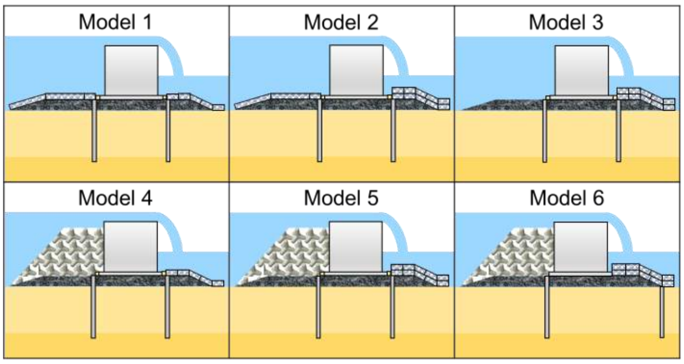

Fig. 3 Models

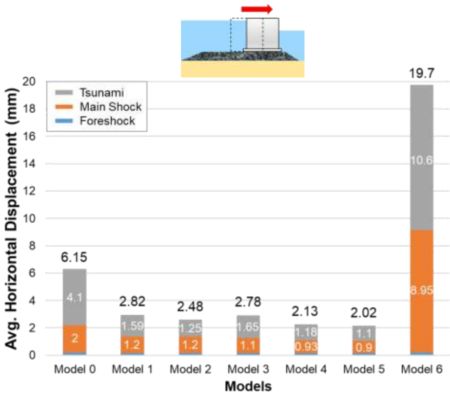

Fig. 4 Avg. horizontal displacement

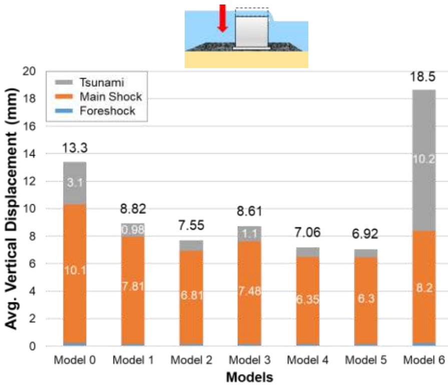

Fig. 5 Avg. vertical displacement

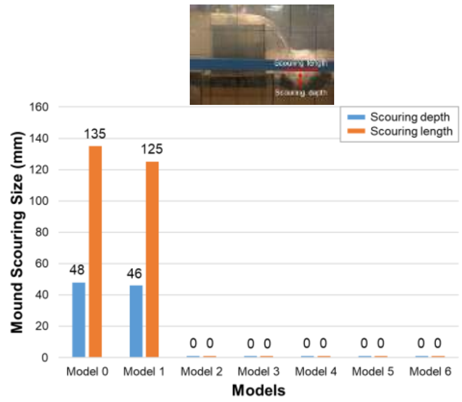

Fig. 6 Mound scouring size

Fig. 6 shows the scouring depth and length for the mound of each model. Model 0 and model 1 had mound scouring as they had single gabion at the harbor side. The mounds of models 2, 3, 5 and 6 were not scoured as the mound at the harbor side was covered with double gabions. However, model 4 with single gabion at the harbor side was also not scoured as the wave-dissipating blocks were set at the sea side.

The pore water pressures were shown in Figs. 7, 8 and 9. The data values of model 6 were the highest among them as model 6 slided during the tsunami loading. Considering its performance, the stability of model 6 was not satisfactory. The pore water pressure of models 1, 2, 3, 4 and 5 confirmed the effectiveness of breakwater's improvement.

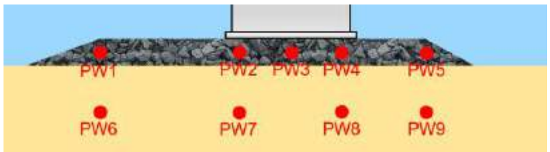

Fig. 7 Pore water pressure gauges

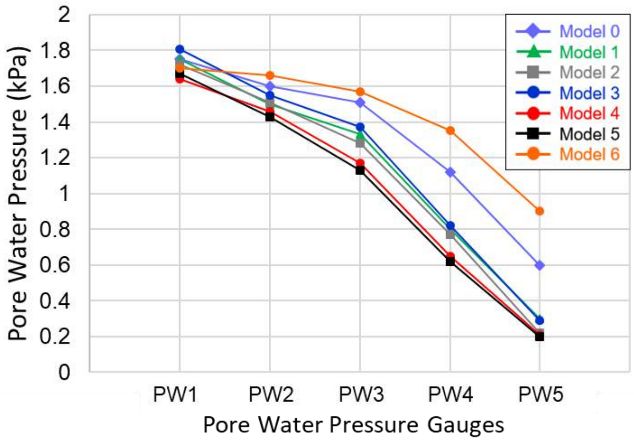

Fig. 8 Pore water pressure
(in the mound)

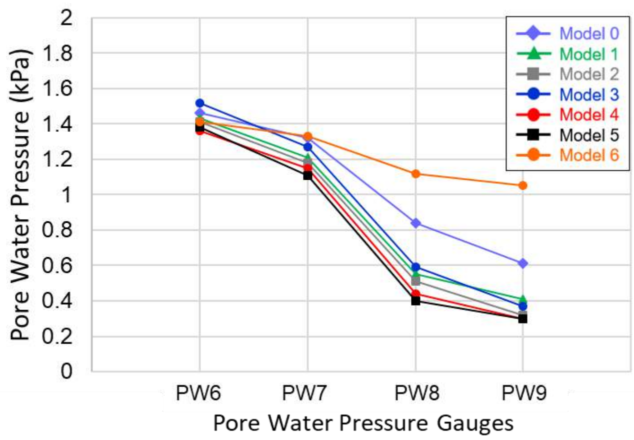

Fig. 9 Pore water pressure
(in the foundation)

4. Summary

1. The sheet pile can decrease the seepage in the foundation to some extent and protect the breakwater from sliding.
2. The impervious filling material can try to close the gap between breakwater and sheet pile to decrease the seepage in the mound and foundation to keep the breakwater stable.
3. The wave-dissipating block can dissipate some wave and do some effects to decrease mound scouring to keep the breakwater stable.
4. The gabion can keep the mound intact during the earthquake shaking and keep the foundation stable. And the gabion with suitable thickness can avoid the scouring of mound due to tsunami.

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Reference

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