Evaluating countermeasures for caisson type composite breakwater during tsunami flow

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1. Introduction and Purpose

On March 11, 2011 a Mw=9.0 earthquake (The 2011 earthquake off the Pacific coast of Tohoku) occurred in the Tohoku region, and caused a massive tsunami. This tsunami was the biggest that Japan had ever seen, and left the Kamaishi breakwater (the world's deepest breakwater then) useless. Researchers believe that the tsunami induced instability problems like the tsunami-induced seepage flow and the overflow played a big part in the breakwater's failure. (Arikawa et al. (2012); Maruyama et al. (2014))

This study focuses on model testing of countermeasures for a 1/100 scale prototype of Kamaishi breakwater during tsunami-induced seepage flow and overflow. This study uses the efficient and cost-effective idea of using rubber sheets to counter the effects of seepage flow. To reduce the effects of scouring, this study uses Permex armour blocks due to their unique shape and stability. Four kinds of countermeasure model types were tested, analysed and evaluated in order to find the optimum countermeasure for the concerned breakwater. The model types are: Model-1: no reinforcements, Model-2: rubber layers put in the mound, Model-3: Permex blocks on the surface of harbor side mound, Model-4: combination of rubber and Permex.

2. Methodology

In order to examine the failure mechanism and effect of the countermeasures, a 1/100 scale prototype of the southern dike section 4 of the Kamaishi breakwater, the deepest part in the whole of the breakwater, was used. The rubble mound (rubble size 2-19 mm) was created in three layers, with evenness achieved by a compactor. The dimensions of the complete model are shown in Table 1.

For this study, a total of 25 water pressure gauges were put in the rubble mound to map the water pressures at different locations. Additionally, two wave-height, one displacement and one wave speed sensor were used for a deeper analysis. Making use of two pumps, the water difference for simulating the tsunami was created and the data for the sensors were recorded at different wave heights. The side-view of the complete model for Model-1 (no reinforcement case) is shown in Figure 1.

Model Scale	1:100
Caisson Size (L x B x H)	190mm x185mm x195mm
Caisson Density	2.03 g/cm^3
Mound Gradient and Dimensions	Gradient 1:2, Upper base 326 mm, Lower base 2046 mm, Height 430 mm
Mound Particle Weight W	.002 N- .027 N
Mound Saturated Density γ_s	1.867 g/cm^3
Mound Specific Gravity G_s	2.700
Mound Void Ratio e	.560

Table 1: Breakwater model specifications

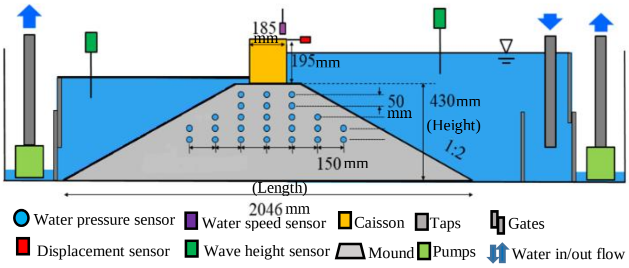

Figure 1: Layout of Model-1

The obtained data was analysed by using a computation fluid processing post-analysis software called Tecplot to map the seepage patterns, while the following equation (Inoue et.al, 2015) was used to evaluate the stable weight of the mound.

$$W = \frac{k_a{}^3 \gamma_s C_D u^6}{8 k_v{}^2 g^3 \left[\left\{ f_r \left(\cos\theta - \dfrac{1+e}{G_S - 1} i \right) - \sin\theta \right\} \left(G_S - 1 \right) \right]^3}$$

Equation 1: Stability of mound equation

3. Experimental Results

After successfully conducting tests for all four kinds of the proposed experimental models, it was observed that Model-1 (no reinforcement case) failed at wave heights of 140 mm with a seepage induced failure mode (pattern shown in Figure 2a). With the addition of the rubber sheets a highly significant reduction in the seepage (as seen in Figure 2b) and little displacement of the caisson was observed and no failure was reported even at heights of up to 160 mm. However, a considerable amount of scouring was observed in the harbor-side of the breakwater. In the case of the Model-3 (Permexonly) because of the seepage flow a significant displacement of the Permex blocks was noticed even before the scouring started and the scouring was considerably less than observed in the previous cases and no failure was reported.

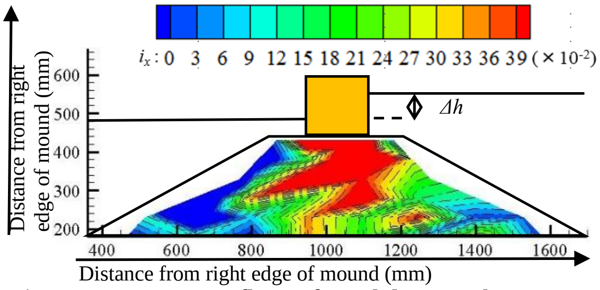

Figure 2a: Seepage flow of Model -1 at Δh=140mm

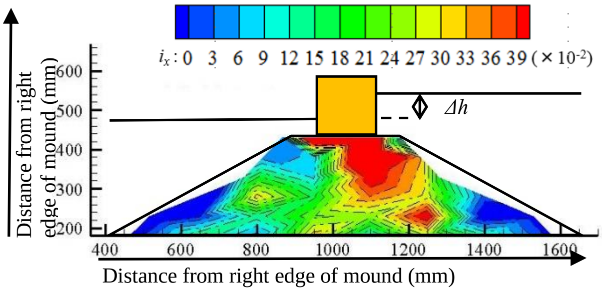

Figure 2b: Seepage flow of Model -3 at Δh=140mm

The final countermeasures of combining Permex blocks with rubber sheets (Model-4) vastly reduced the scouring with minimal displacement of the caisson (as seen in Figure 3 and Figure 4) as well as that of Permex blocks, and no failure was reported. Lastly, the effective weight of the mound (and hence stability of mound) was higher during the use of Permex blocks as compared to the no-reinforcement case, thus showing that Permex blocks do increase the mound stability.

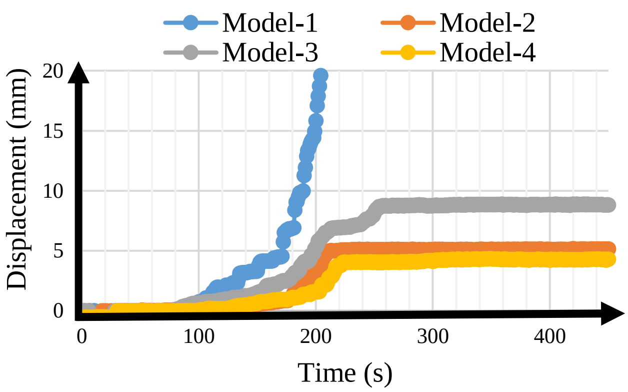

Figure 3: Displacement-Time graph (of the main caisson) for all the countermeasure models

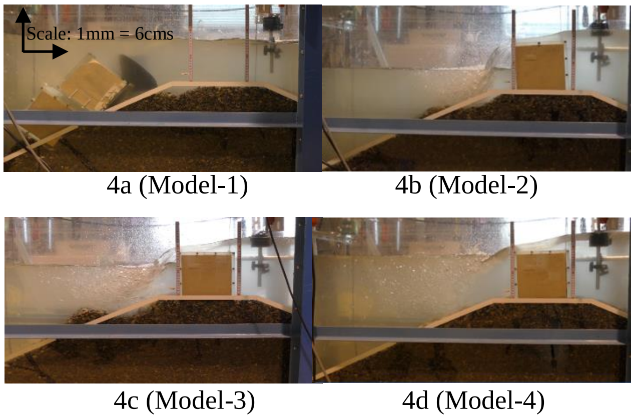

Figure 4: Final displacement states of all the models

4. Conclusion

This study found that the countermeasure of Permex blocks combined with rubber sheets (Model-4) yields the best results because the Permex blocks greatly reduces the degree of scouring while the rubber sheets drastically reduces the degree of seepage and overall cause minimum displacement of caisson. The use of rubber sheets is also cost-effective since it can be made from scrap tire and hence widens the scope of workability of the countermeasure proposed. Further scopes of improvement involve testing of different rubber arrangements to find the optimum arrangement, varying the harbor water level to see the impact on scouring, studying more on the effects of the wave speed and lastly and thinking of ways to embed rubber sheets into existing breakwater.

5. References

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Inoue, S., Kasama, K., Hirasawa, M., Zen, K., Furukawa, Z., & Yahiro, Y. (2015). Calculation and hydraulic model experiments for the stable weight of rubble-mound considering the overflow and seepage flow. Japanese Geotechnical Society Special Publication, 1(6), 58-62.

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