

論文 / 著書情報
Article / Book Information

itle	Stability evaluation for the caisson-type composite breakwater under tsunami condition
Authors	Kiyonobu Kasama, Kouki Zen, Yasuo Kasugai
Citation	Japanese Geotechnical Society Special Publication, Vol. 2, Issue 72, pp. 2465-2468
Pub. date	2016, 1
DOI	https://doi.org/10.3208/jgssp.JPN-094
Note	このファイルは著者（最終）版です。 This file is author (final) version.

Stability evaluation for the caisson-type composite breakwater under tsunami condition

Kiyonobu Kasamaⁱ⁾, Kouki Zenⁱⁱ⁾ and Yasuo Kasugaiⁱⁱⁱ⁾

i) Associate Professor, Faculty of Engineering, Kyushu University, 774, Motoooka, Nishi-ku, Fukuoka, 819-0375, Japan.

ii) Professor, Faculty of Engineering, Kyushu University, 744 Motoooka, Nishi-ku, Fukuoka, 819-0375, Japan.

iii) Research Managing Director, Port and Airport Research Institute, 3-1-1 Nagase, Yokosuka, 239-0826, Japan.

ABSTRACT

In order to investigate the instability mechanism of caisson-type composite breakwater under tsunami condition, a scale of 1/100 model experiment was performed in laboratory. Loading tests were also carried out to investigate the reduction of bearing capacity under the existence of seepage flow. From the results of laboratory experiment and finite element analysis, it was confirmed that the bearing capacity of rubble-mound can considerably decrease due to the tsunami-induced seepage flow. It is concluded that the effect of seepage flow in the rubble-mound should be taken into account when making a design of the caisson-type composite breakwater against tsunami. The following conclusions are drawn from this study; (1) The occurrence of seepage failure of the harbor-side rubble-mound under tsunami condition is experimentally confirmed. The rubble filled gabion on the harbor-side rubble-mound is useful for preventing from the seepage failure. (2) In this study, the reduction of bearing capacity due to seepage flow attains no less than 40% of the bearing capacity without the seepage flow. The rubble filled gabion on the harbor-side rubble-mound is not effective improving the bearing capacity of breakwater since the effective weight of rubble filled gabion is not large enough to increase the strength of harbor-side rubble-mound. (3) In the design of caisson type composite breakwaters against tsunami, the influence of seepage flow and seepage force on the stability should be taken into account. (4) The failure plane and plastic zone in the rubble-mound under tsunami condition become shallow by the effect of seepage flow and force.

Keywords: seepage flow, bearing capacity, breakwater, model test, finite element analysis

1 INTRODUCTION

The 2011 off the Pacific Coast of Tohoku Earthquake with the magnitude of 9.0 attacked Japan on the 11th of March, 2011. A tremendous tsunami was generated in association with the earthquake. The tsunami damaged a great amount of breakwaters along the northeast coast of Japan. The tsunami preventing breakwaters at the mouth of Kamaishi Harbor (called Kamaishi Harbor Mouth Breakwaters herein), which are the deepest breakwaters in the world, have been experienced the catastrophic damage due to this disaster.

The structure of Kamaishi Harbor Mouth Breakwaters is the caisson-type composite breakwater which is widely constructed along Japanese coastal areas in a last few decades. In the design of the caisson-type composite breakwater, the wave load determined from the past statistical data on the wind waves is generally applied. The most definite difference between wind waves and tsunami can be addressed that tsunami has so longer wave period that the states of wave crest and/or wave trough continue for a few minutes or more.

As for the possible causes of failure of Kamaishi Harbor Mouth Breakwaters, 1) the tsunami impact force to the caisson, 2) the difference of water level between seaside and harbor side of the caisson and 3) the tractive force of the water flow over the caisson to the rubble mound are considered from the hydraulic point of view. In addition, 4) the reduction of bearing capacity due to the seepage flow in the rubble mound is pointed out from the geotechnical point of view.

The seepage-induced instability problem has been studied extensively in the field of geo-technical engineering (Zen et al. 2013, Kasama et al. 2012, Takahashi et al. 2014). Under tsunami conditions, it is considered very significant to investigate the effect of seepage flow onto the stability of breakwaters. In this paper, the reduction of bearing capacity of rubble mound due to the seepage flow are mentioned.

2 EXPERIMENTAL METHODOLOGY

Figure 1 shows the layout of test apparatus used in the experiment. A physical model of 1/100 in scale of Kamaishi Harbor Mouth Breakwaters was installed in a

water tank. Pumps were used to reproduce the hydraulic head difference on two sides of the model caisson. The dimension of caisson model is 185 mm in length, 195 mm in height and 190 mm in width. The weight of caisson model is 13.92 kg. Water was used as a fluid in the water tank. After the physical model was established in the tank, the wave height sensors were installed onto the model caisson in order to control the water levels on both sides of model caisson.

The hydraulic gradient i were represented by the pore water pressures measured in the model rubble mound using the pore pressure gauges. Figure 1 also shows the distribution of pore pressure gauges in the model rubble mound. The pore pressure gauges collected the data when the hydraulic head differences were created steady state for a given hydraulic head difference.

In order to find out the effects of seepage flow on the bearing capacity of the rubble mound during tsunami condition, a loading test was performed with a constant loading speed with 1 mm/min. In the loading test, load were put on the center of model caisson after the constant hydraulic head difference was established. The hydraulic head differences used in the tests were 0 mm, 40 mm, 80 mm 120 mm and 145 mm. The horizontal and vertical displacements of caisson were measured by using the three displacement gauges installed onto the edges of model caisson both on sea side and harbor side to obtain an average settlement and inclined angle of model caisson. In addition, in order to improve the stability of the caisson under tsunami condition, rubble filled gabions were placed on the top of rubble mound on the harbor-side of the caisson.

Figure 2 shows a vertical hydraulic gradient for the head difference of 145 mm. It is found for the conventional type (without rubble filled gabion), that the hydraulic gradient on the top of rubble mound on the harbor-side of the caisson shows the largest value suggesting that vertical seepage force is remarkable. Actually, when the head difference is 145 mm the caisson starts to rotate towards the harbor side and the gravels on the rubble mound were gradually washed away, namely the seepage failure of the rubble mound occurs. On the other hand, by setting with rubble filled gabion on the harbor-side of the caisson, the seepage failure was prevented successively.

Figure 3 presents the load settlement curves obtained from the loading test for a given hydraulic head difference. It is noted that open markers indicates the test results for without rubble filled gabions while solid markers indicates those for with rubble filled gabions. It can be characterized that the seepage failure of rubble mound occurs at final stage of loading. Arrows in the Figure 3 shows a loading stress when the seepage failure started to occur. It might trigger the seepage failure of rubble mound at a certain value of hydraulic gradient. The bearing capacity significantly

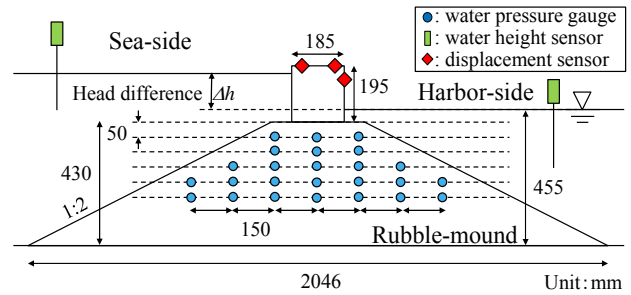
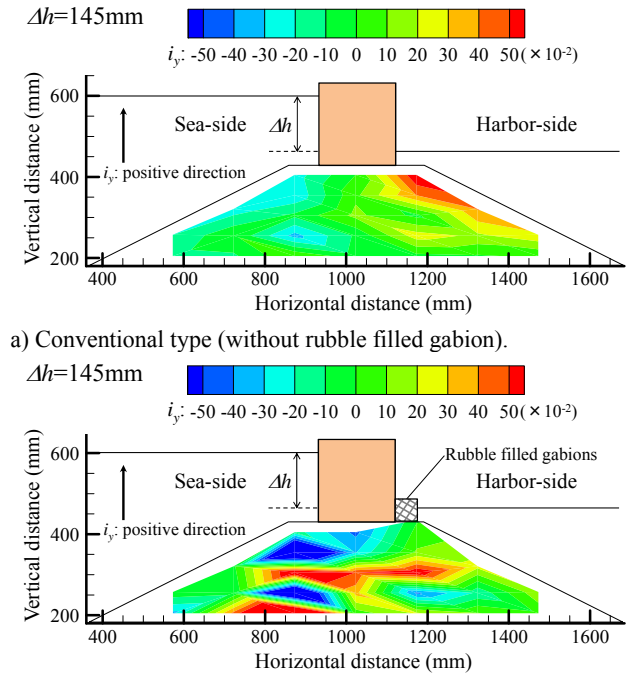


Fig. 1. Schematic diagram of testing apparatus.



a) Conventional type (without rubble filled gabion).
b) With rubble filled gabion.
Fig. 2. Seepage flow in the rubble-mound induced by tsunami.

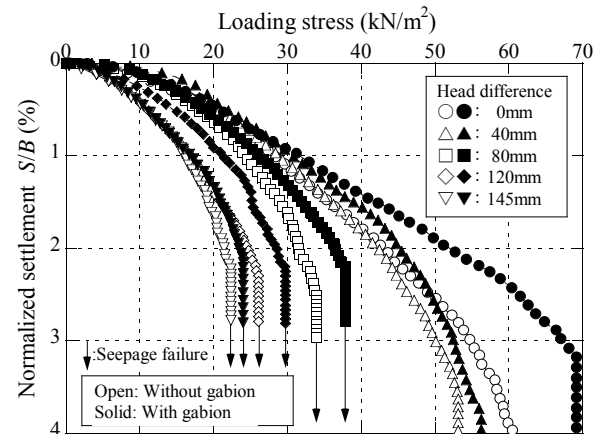


Fig. 3. Load settlement curves from experiment.

decreases with increasing hydraulic head difference while the existence of rubble filled gabion does not affect the bearing capacity of rubble mound. In other words, the seepage flow remarkably contributes to decrease the bearing capacity of rubble mound.

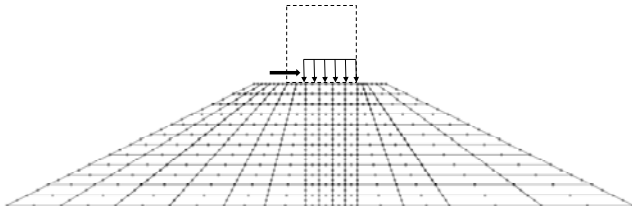


Fig. 4. Finite element mesh for loading test.

Table 1. Input parameters for rubble-mound.

Parameter	Value
Young modulus	1000 kN/m ²
Poisson's ratio	0.33
Effective unit soil weight	8.8 kN/m ³
Cohesion	0 kN/m ²
Internal friction angle	30°

3 NUMERICAL ANALYSIS

In order to evaluate the stability of the caisson-type composite breakwater under tsunami condition, finite element analysis (Kobayashi, 1984) was carried out for an initial mesh as shown in Figure 5. Rubble mound was modeled as an elasto-plastic material with the Mohr-Coulomb failure criteria. The input parameters for rubble mound is summarized in Table 1. The deformation analysis followed by seepage analysis for the caisson-type composite breakwater under tsunami condition was performed by the following steps; 1) The steady seepage flow though rubble mound for a given head difference from 0 m to 15 m was analyzed by finite element analysis. 2) The self-weight analysis of rubble mound was performed to establish an initial condition. 3) The seepage force for elements, which was calculated by water pressure obtained from the seepage analysis, was applied at nodes of element. Therefore, at this step, the deformation of rubble mound by self-weight and seepage force have already occurred. 4) An eccentric force which simulates the self-weight of caisson and the horizontal force caused by hydraulic head difference between sea-side and harbor-side of caisson, was applied as a distribution stress on the top of rubble mound as shown in Figure 4.

Figure 5 shows the load settlement curves obtained from the numerical analysis for a given hydraulic head difference. It is seen that the yield stress and bearing capacity decrease with increasing head difference while an initial inclination of the load settlement curves is similar irrespective of head difference.

In order to evaluate the effect of hydraulic head difference on the bearing capacity, Figure 6 demonstrates the reduction rate of bearing capacity drawn by arranging the data in Figures 3 and 5. The reduction rate of bearing capacity is defined as the bearing capacity compared with that without the seepage flow and rubble filled gabions, namely the hydraulic head difference is equal to 0. It is characterized that the bearing capacity decreases as the hydraulic head difference increases and it becomes

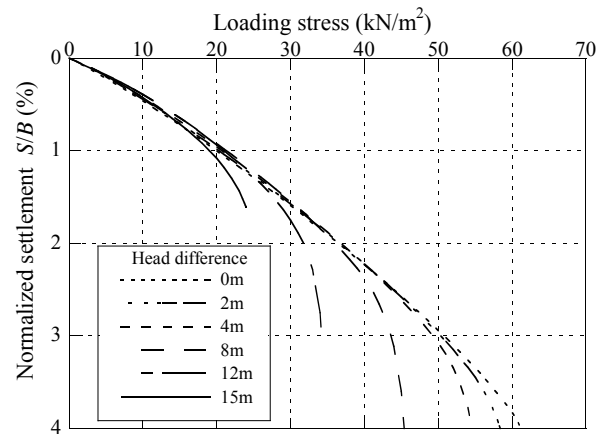


Fig. 5. Load settlement curves from FEM.

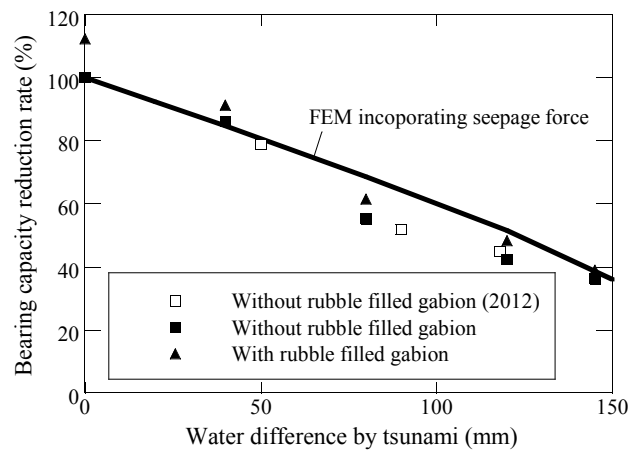


Fig. 6. Bearing capacity reduction rate.

around 40% when the hydraulic head difference is 145 mm which can be converted to 14.5 m in real scale. However, the rubble filled gabion on the harbor-side rubble-mound is not effective improving the bearing capacity of breakwater since the effective weight of rubble filled gabion is not large enough to increase the strength of harbor-side rubble-mound. On the other hand, the setting of rubble filled gabions on the harbor-side of the caisson is useful for preventing from the seepage failure, however, not useful for improving the bearing capacity of rubble mound.

Moreover, as the numerical result for bearing capacity reduction is comparable to the experimental results, finite element analysis combined with seepage analysis is useful for simulating the stability evaluation for the caisson-type composite breakwater under tsunami condition.

Figure 7 shows deformed mesh for a given hydraulic head difference when the loading stress is the yield stress. It is noted that dot line in the figure express initial mesh before loading. The harbor-side rubble mound show an upward and horizontal deformation while the sea-side rubble mound shows settlement. Sliding surface generated in rubble mound becomes shallow as a hydraulic head difference increases.

Figure 8 shows the elastic and plastic zones at final stage of analysis for a given hydraulic head difference. The elements on the harbor-side of caisson indicates plastic behavior while those on the sea-side shows elastic behavior. It is seen that plastic zone become shallow as a hydraulic head difference increases.

4 CONCLUSIONS

In order to investigate the instability mechanism of caisson-type composite breakwater under tsunami condition, a scale of 1/100 model experiment was performed in laboratory. Loading tests were also carried out to investigate the reduction of bearing capacity under the existence of seepage flow. From the results of laboratory experiment and finite element analysis, it was confirmed that the bearing capacity of rubble-mound can considerably decrease due to the tsunami-induced seepage flow. The following conclusions are drawn from this study; (1) The occurrence of seepage failure of the harbor-side rubble-mound under tsunami condition is experimentally confirmed. The rubble filled gabion on the harbor-side rubble-mound is useful for preventing from the seepage failure. (2) In this study, the reduction of bearing capacity due to seepage flow attains no less than 40% of the bearing capacity without the seepage flow. The rubble filled gabion on the harbor-side rubble-mound is not effective improving the bearing capacity of breakwater since the effective weight of rubble filled gabion is not large enough to increase the strength of harbor-side rubble-mound. (3) In the design of caisson type composite breakwaters against tsunami, the influence of seepage flow and seepage force on the stability should be taken into account. The finite element analysis incorporating the seepage flow and seepage force induced by tsunami is useful for simulating the deformation and reduction of bearing capacity of the breakwater under tsunami condition. (4) The failure plane and plastic zone in the rubble-mound under tsunami condition become shallow by the effect of seepage flow and force.

ACKNOWLEDGEMENTS

This research was supported by the Grant-in-Aid for Scientific Research (B), JSPS KAKENHI Grant Number 25289149.

REFERENCES

1) Kasama, K., Zen, K. and Kasugai, Y. (2013): Model experiment for the instability of caisson-type composite breakwater under tsunami condition, *Journal of Japan Society of Civil Engineers*, Ser. B2 (Coastal Engineering), 69(2), I_966-I_970, Doi:10.2208/kaigan.69.I_966.

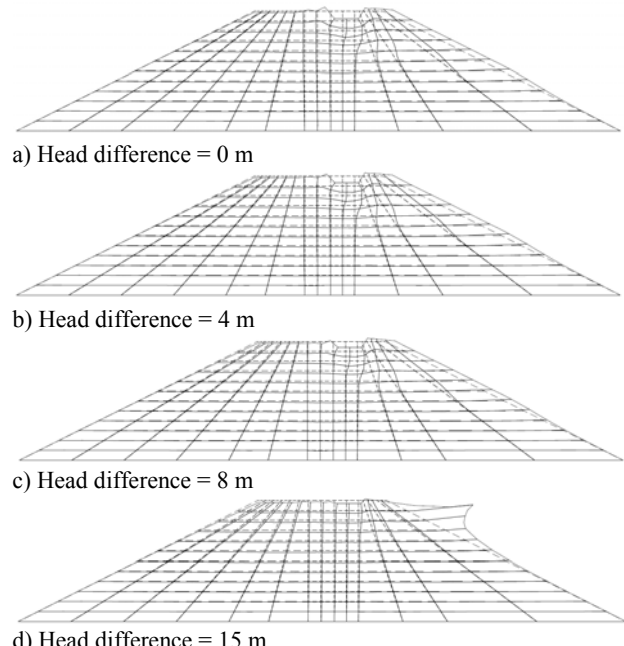


Fig. 7. Deformed mesh at failure.

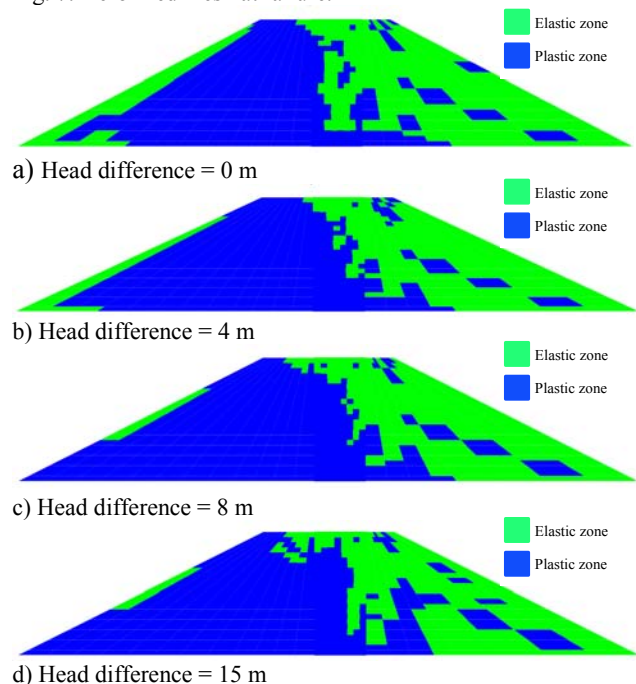


Fig. 8. Elastic zone and plastic zone at failure.

2) Kobayashi, M. (1984): Stability analysis of geotechnical structures by finite elements, *Report of the Port and Harbour Research Institute*, 23(1), 83-101.

3) Takahashi, H., Sassa, S., Morikawa, Y., Takano, D. and Maruyama, K. (2014): Stability of caisson-type breakwater foundation under tsunami-induced seepage, *Soils and Foundations*, 54(4), 789-805, Doi:10.1016/j.sandf.2014.07.002.

4) Zen, K., Kasama, K., Kasugai, Y. and Dong, S. (2013): Failure of Rubble Mound Beneath Caisson due to Earthquake-Induced Tsunami, Proceedings of the 32nd International Conference on Ocean, Offshore and Arctic Engineering OMAE2013, Paper No. OMAE2013-10059, pp. V006T10A003, Doi:10.1115/OMAE2013-10059.