Coastal Dynamics 2017
Paper No. 064

LABORATORY EXPERIMENTS ON EROSION CONTROL PERFORMANCE OF AN L-SHAPED PERMEABLE STRUCTURE

Yuuji Maeda[1], Masayuki Unno[2], Masafumi Sato[2], Takao Kurita[2], Takaaki Uda[3] and Shinji Sato[4]

Abstract

A new type of structure will be constructed on the Shimizu coast for erosion control. The structure is L-shaped permeable structure; a shore-parallel permeable detached breakwater supported by steel piles and a shore-normal rubble mound jetty covered by flat concrete blocks. This study aims to examine the erosion control performance of the new type of structure through movable-bed experiments. Significant entrapment of sand behind shore-parallel breakwaters was observed despite larger wave transmission due to permeable structure. The erosion control performance of the structure was found insensitive to the gap between the shore-normal jetty and the shore-parallel breakwater. Supplementary nourishment was found effective to mitigate the downdrift erosion and accelerate the entrapment of sand behind the shore-parallel breakwater.

Key words: Mihonomatsubara, Mt. Fuji, World Cultural Heritage, detached breakwater, S-VHS, jetty, movable-bed experiment

1. Introduction

The Shimizu coast, located on the west side of the Suruga Bay in Shizuoka Prefecture (Figure 1), is known as a tourism spot with beautiful coastal landscape backed by Mt. Fuji and coastal pine trees called Mihonomatsubara (Figure 2). The coast is composed of a mixture of gravel and sand, and it is protected by a series of concrete block structures installed along the shore. Upon the designation as the World Cultural Heritage, the coastal manager planned to replace ugly concrete block structures with L-shaped low-crest structures which are expected to improve coastal scenery.

Owing to the very steep slope of nearshore bathymetry, the structure was designed as a hybrid structure;

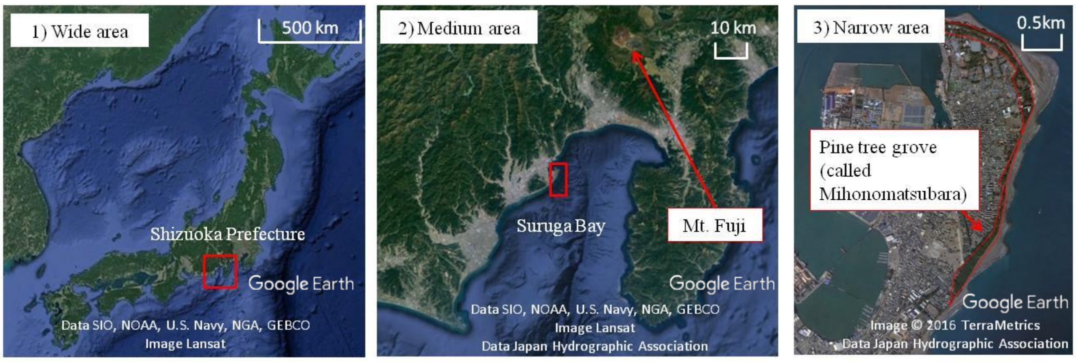


Figure 1. Site of Shimizu coast.

[1]Institute of Tech., Penta-Ocean Co., Ltd., 1534-1 Yonku-Cho, Nasu-Shiobara, Tochigi 329-2746, Japan. Yuuji.Maeda@mail.penta-ocean.co.jp
[2]Shizuoka Public Works Office, Shizuoka Pref., 2-20 Ariake-Cho, Suruga-Ku, Shizuoka City, Shizuoka 422-8031, Japan. masafumi1_sato@pref.shizuoka.lg.jp
[3]Public Works Research Center, 1-6-4 Taito, Taito-ku, Tokyo 110-0016, Japan. uda@pwrc.or.jp
[4]Dept. of Civil Eng., The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan. sato@coastal.t.u-tokyo.ac.jp

a shore-parallel permeable detached breakwater supported by steel piles (it is called S-VHS) and a shore-normal rubble mound jetty covered by flat concrete blocks (Figures 3 and 4). S-VHS is usually installed for wave control as detached breakwater. For example, Nishihata et al. (2010) studied wave and current fields around S-VHS by experiment and numerical simulation, and Anno et al. (2010) studied erosion features around the pile. The erosion control performance of the structure was studied by Nishihata and Sato (2010) and Nishihata et al. (2011). Uda et al. (1995) evaluated obstruction rate of longshore sand transport due to a groin built on the Seisho coast in Japan by using a predictive model. However, few studies can be found for the hybrid structure; a permeable detached breakwater combined with a jetty. This study aims to examine the erosion control performance of the new structure through movable-bed experiments conducted with a scale of 1/50.

2. Outline of experiment

Figure 5 illustrates the layout of the experiments. The bottom configuration and the incident wave angle were decided to reproduce the prototype conditions of the Shimizu coast. The seabed slope was 1/7 in the nearshore zone connected with a milder slope 1/17 in the offshore. Waves were obliquely incident with an angle of 20° relative to the direction normal to the shoreline. Fine sand with median diameter of 0.32 mm was filled on the bed with a thickness of 10 cm. Figure 6 shows grain size distribution. Two types of monochromatic waves were generated to simulate nomal and storm wave climate. Storm waves were applied to the final morphology developed by average waves in order to examine the durability of the beach. Bathymetric changes due to wave can be classified. Sunamura and Horikawa (1974) classified the features of bathymetry into 3 types by following equation:

$$\frac{H_o}{L_o} = C \tan\beta^{-0.27}\left(\frac{d}{L_o}\right)^{0.67} \tag{1}$$

where H_0 is deepwater wave height; L_0 is deepwater wave length; C is a parameter for classifying the beach profile; d is diameter of sand. Figure 7 shows the each feature of the profiles. The bathymetric change caused by nomal waves is classified as type III, whereas the other is classified as type II.

In order to keep the uniform longshore sand transport during wave generation, sand was fed at a constant rate of 67 l/hour at the updrift end of the wave basin as indicated by a red circle in Figure 5. The sand feeding rate will be discussed later in next section. Two kinds of parameter studies were taken into account, with or without supplementary nourishment, and the gap between the shore-normal jetty and the shore-parallel breakwater. Table 1 shows conditions of each case in experimental scale.

Figure 2. Coastal landscape from the Shimizu coast.

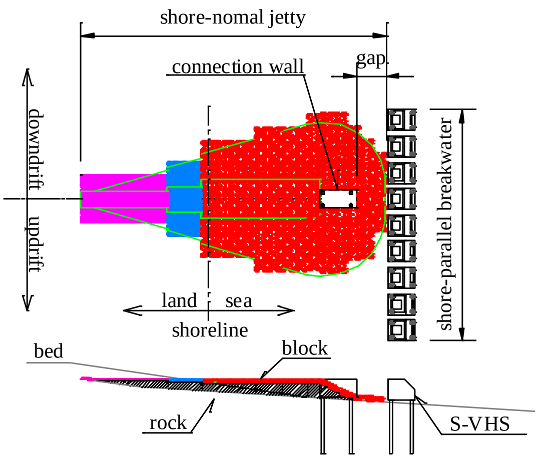


Figure 3. Shape of the hybrid structure.

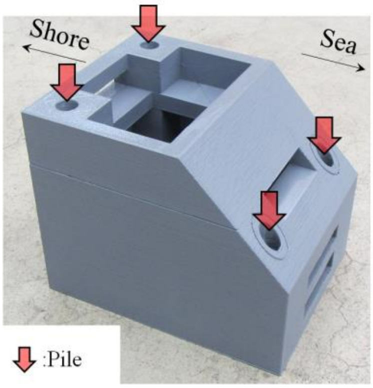


Figure 4. Shape of S-VHS.

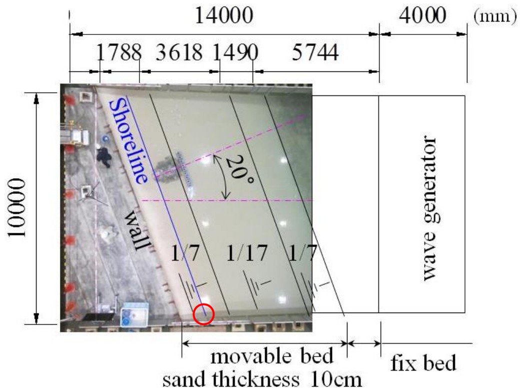


Figure 5. Experiment condition.

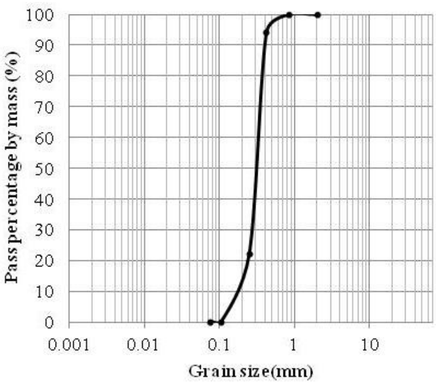


Figure 6. Cumulative curve of grain size.

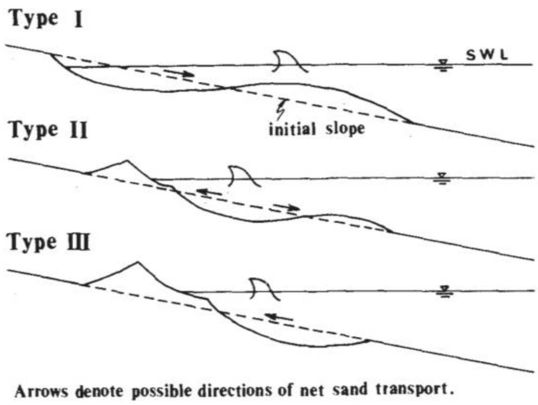


Figure 7. Beach profile classification by Sunamura and Horikawa (1974).

Table 1. Experimental condition in each case.

Case No	Supplementary nourishment	Gap between the jetty and the breakwater	Wave condition	Wave generation time
1-1	0 cm^3	204 mm	Average Height: 30 mm Period: 1.1 sec	8 hours
1-2			Storm Height: 90 mm Period: 1.6 sec	2 hours
2-1		70 mm	Average	8 hours
2-2			Storm	2 hours
3-1		- (without jetty)	Average	8 hours
3-2			Storm	2 hours
4	Downdrift side of jetty: 96,000 cm^3 Updrift side of jetty: 144,000 cm^3	204 mm	Average	8 hours

3. Pre-experiment

To know appropriate wave generation time and rate of sand feed, pre-experiment was conducted without structures for average wave. Figure 8 shows shoreline changes. The difference in the shoreline change after 8 hours and 18 hours is insignificant. Thus, the beach is considered to be under condition of equilibrium at

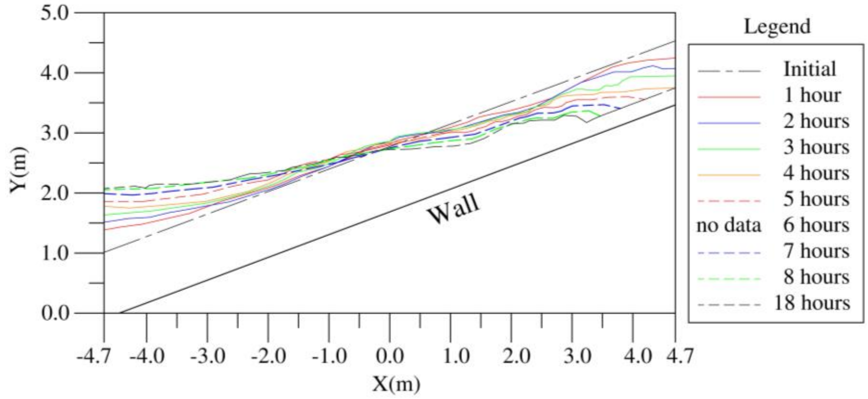


Figure 8. Shoreline change in pre-experiment without structures.

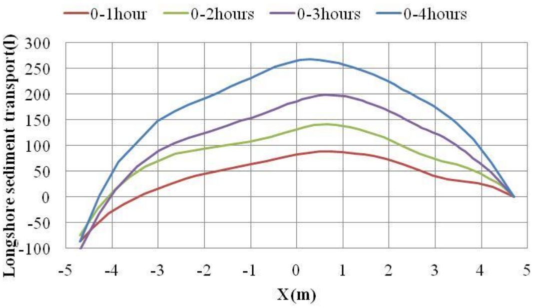


Figure 9. Total amount of sand transported alongshore.

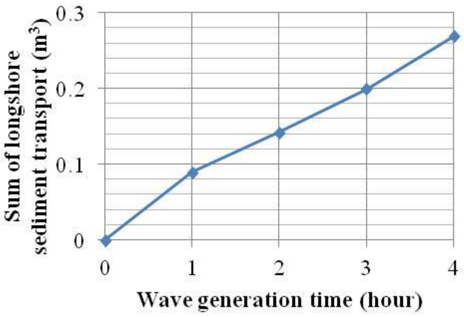


Figure 10. Longshore sediment transport rate up to 4 hours.

8 hours. However, the amount of sand on the updrift side was not enough for evaluating erosion control performance of the hybrid structure. Figure 9 shows the total amount of sand transported alongshore calculated from bathymetry surveys, and Figure 10 shows the longshore sediment transport rate calculated from Figure 9. The sediment transport rate was calculated as 67 l/hour. Therefore, average wave was generated for 8 hours with the rate of sand feed 67 l/hour.

4. Experimental Results

Figure 11 shows shoreline changes in Case 1-1. The shoreline on the downdrift side of jetty was stable from 2 hours to 8 hours, indicating amount of sand transport from updrift to downdrift side was insignificant. The shorelines on the updrift side of jetty from 7 hours to 8 hours were almost the same. This result indicates that the experiment duration is appropriate since the bathymetry reaches equilibrium in 8 hours.

Three characteristic phenomena were observed; the positions and height of berms varied over time, sand was slowly transported to behind the breakwater, and a few amount of sand was transported to offshore from the end of updrift end of the breakwater.

Figure 12 shows the bathymetric changes in the Case 1-1 at 8 hours. A large amount of sand is deposited on the updrift side of jetty. Figure 13 shows the bathymetric change in Case1-2. Areas 1 and 3 are deposited-area and Area 2 is eroded-area. The bathymetric change in Area 2 is insignificant. Amount of the transported sediment from updrift to downdrift area over the jetty was mostly transported through the gap between the jetty and the breakwater by visual confirmation. Figure 14 shows the changes in longitudinal profiles. In Case 1-1, sand was eroded under the detached breakwater, whereas it was deposited in Case1-2 at X = -1 m. However, sand was deposited under the detached breakwater in Case 1-1, whereas it was eroded in Case 1-2 at X = -2 m. On-shore sediment movement was dominated in Case 1-2, and a large

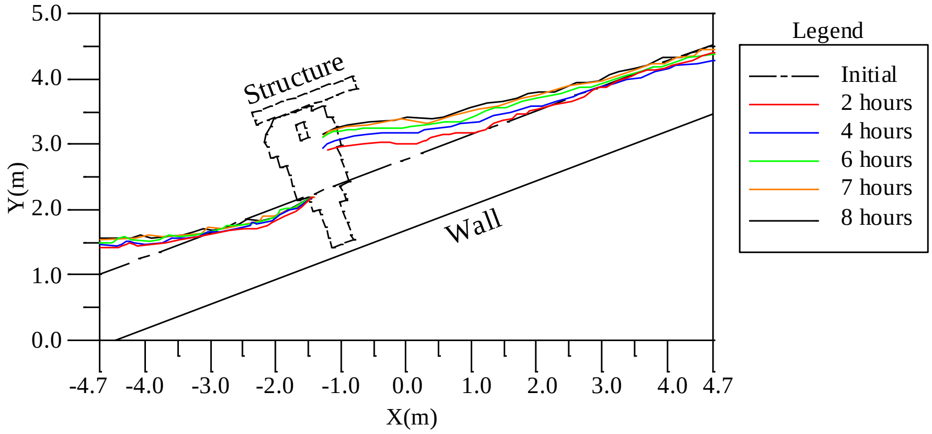
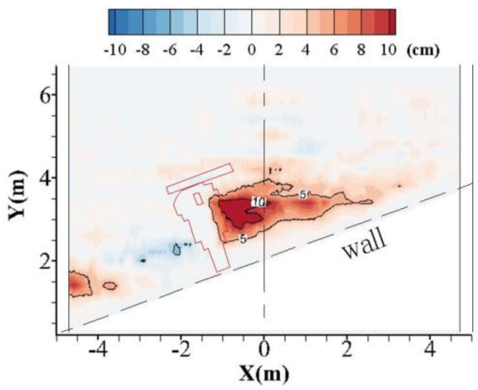


Figure 11. Shoreline changes in Case 1-1.



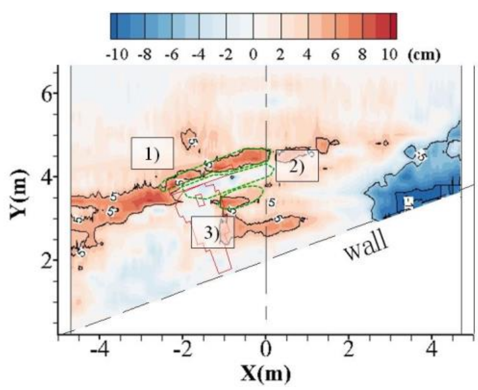
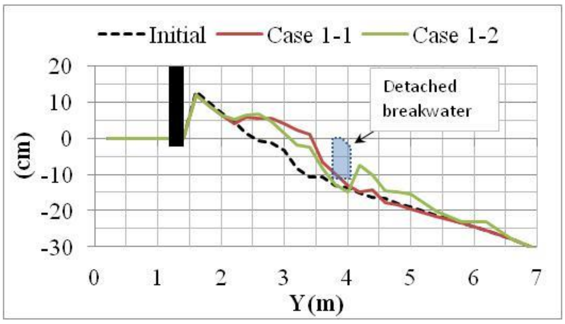
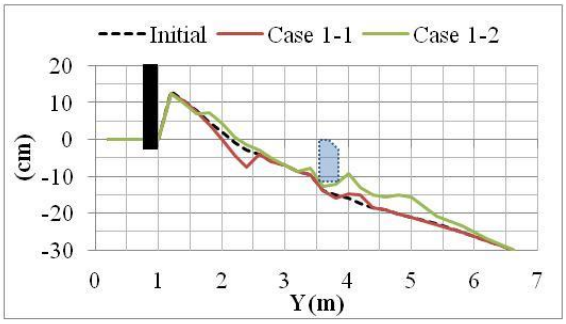


Figure 12. Bathymetry change in Case 1-1. Figure 13. Bathymetry change in Case 1-2.



1) X = -1 m



2) X = -2 m

Figure 14. Cross-section of bathymetric change.

amount of sand behind the detached breakwater on X = -1 m (updrift side of jetty), although a few amount of sand deposited on X = -2 m. It is considered that this difference caused the spatial bathymetry features as described previously.

Waves and currents were observed at the points shown in Figure 15. Figure 16 shows averaged wave height and averaged water level in Case 1-1. Averaged wave height includes reflected wave component. Wave height at Pt. 6 and 7 are lower than Pt. 4 about 30% caused by the detached breakwater. Figure 17 shows UV-plot of current. Difference of water level between Pt. 4 and 6 (Figure 15) generates the flow toward updrift at Pt. 6. However, there is almost no longshore current at Pt 7. These flow caused the deposit of sand around Pt. 7.

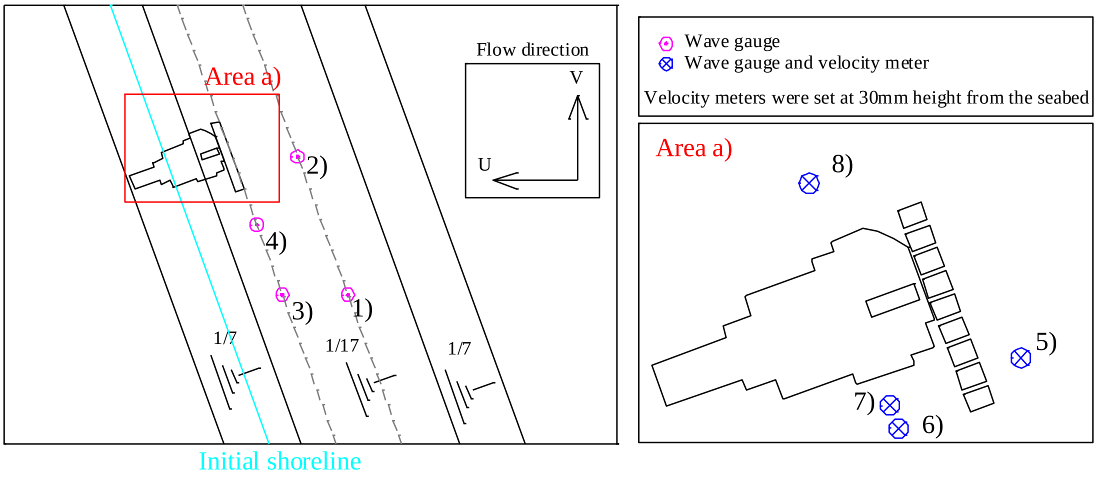


Figure 15. Locations of wave gauges and velocity meters.

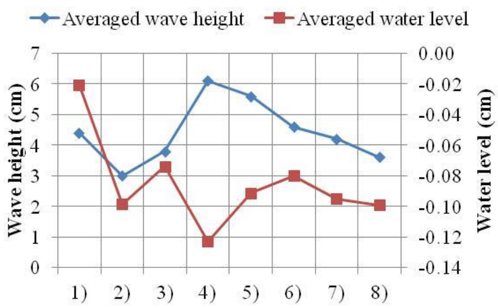


Figure 16. Wave height and water level in Case 1-1.

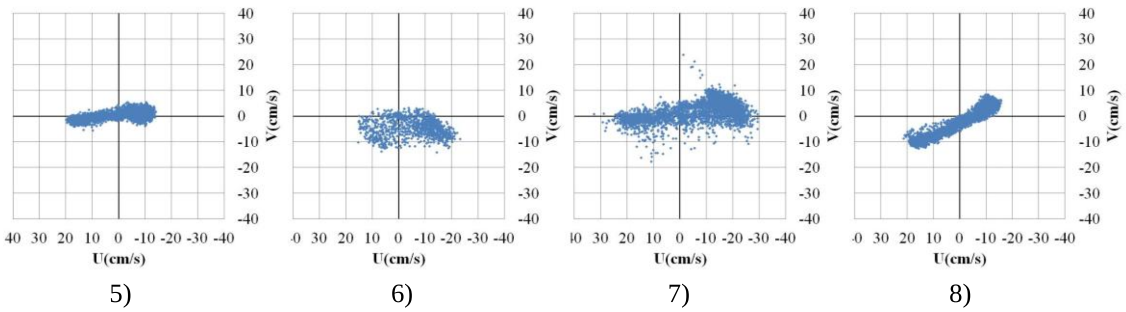


Figure 17. UV-plot of current in Case 1-1.

4.1. *Effect of gap between the jetty and the breakwater*

Figure 18 shows the difference of bathymetry between Cases 1-1 and 2-1 after 8 hours. The positive difference shows the higher seabed elevation of Case 2-1. There are several local differences. The berm height in Case 2-1 is higher than in Case1-1 in Area 1 and 2. However the difference is insignificant. The positions and height of berms varied over time as previously explained, so this difference does not indicate the effect of the gap. In Area 3, the amount of deposited sand in Case 2-1 is larger than in Case1-1, although the difference is not significant. Figure 19 shows bathymetric change of Case 1-2 and 2-2 after 2 hours generation of storm waves from the final bathymetry of Cases 1-1 and 2-1, respectively. There is no significant difference between Cases 1 and 2. Therefore, the effect of the gap to the change of bathymetry is considered to be minor.

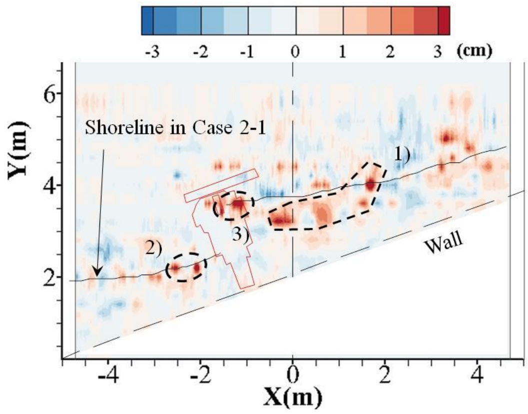
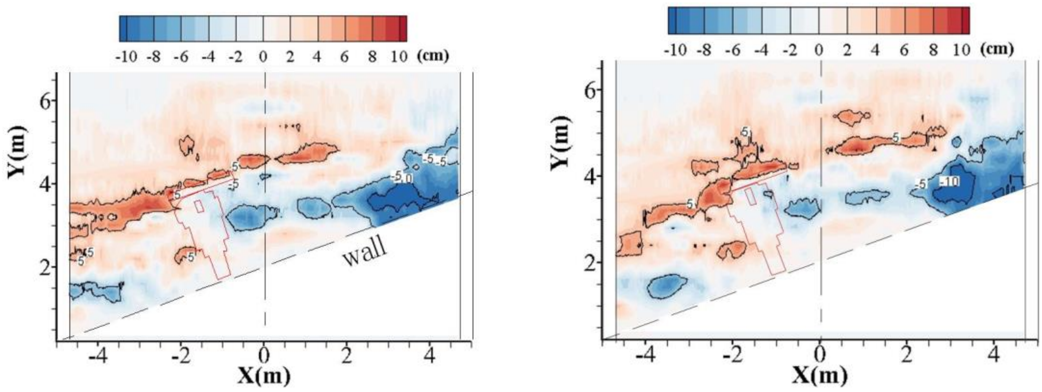


Figure 18. Difference in batymetry between Cases 1-1 and 2-1.



1) from end of Case 1-1 to end of Case 1-2

2)from end of Case 2-1 to end of Case 2-2

Figure 19. Bathymetry change after 2hours of storm waves.

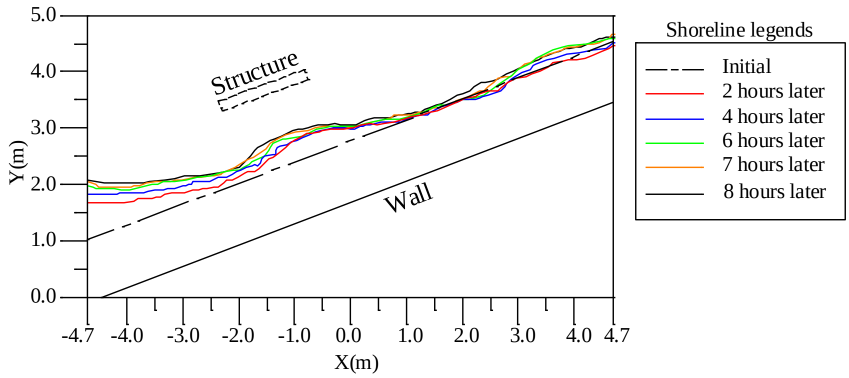
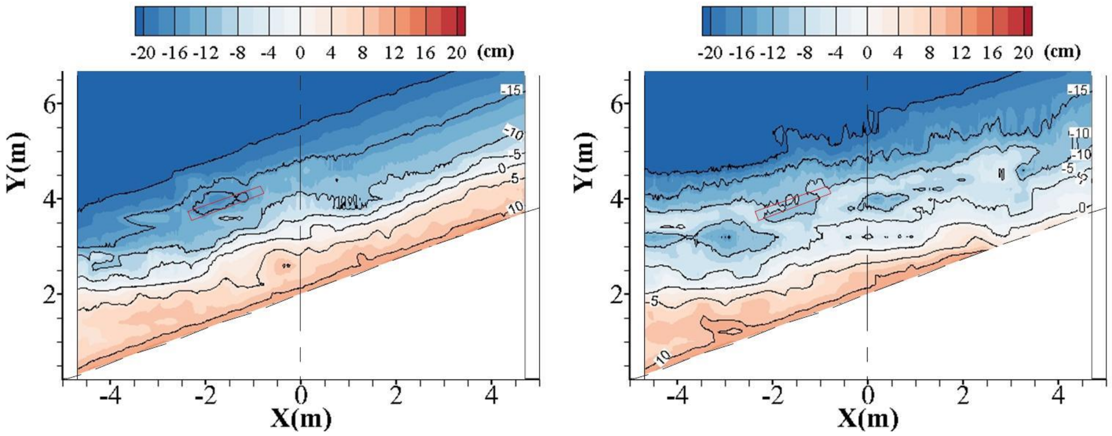


Figure 20. Shoreline change in Case 3-1.

4.2. *Effect of breakwater*

Figure 20 shows shoreline change in Case 3-1. The shoreline quickly changes up to 2 hours, and then slowly decays after that. The shoreline behind breakwater advances as much as 0.5 m. Figure 21 shows bathymetry in Cases 3-1 and 3-2. Deposited sand behind breakwater is transported to the downdrift side in Case 3-2, although significant amount of sand still remains on the updrift side.



1) Case 3-1 2) Case 3-2

Figure 21. Bathymetry in Cases 3-1 and 3-2 (elevation from water level)

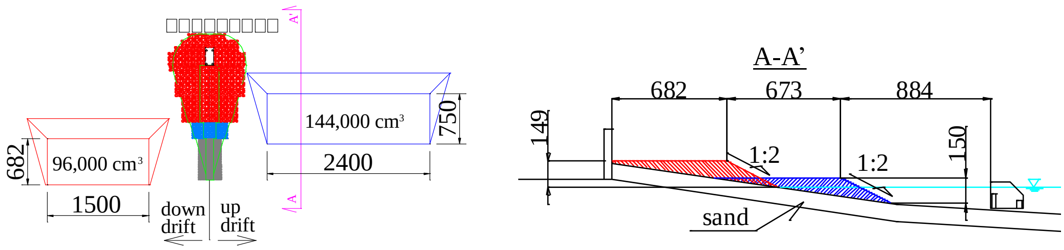
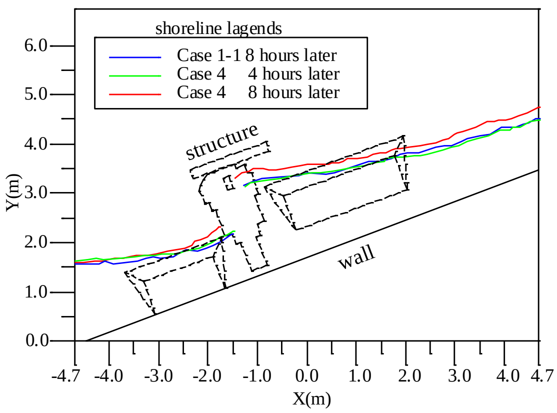


Figure 22. Supplementary beach nourishment.



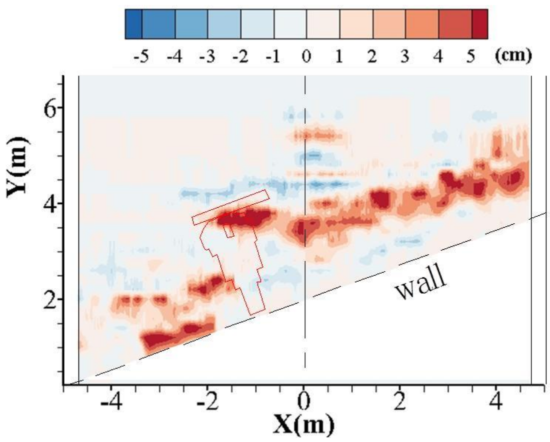


Figure 23. Shoreline change in Cases 1-1 and 4.

Figure 24. Difference of bathymetry between Cases 1-1 and 4

4.3. *Effect of supplementary beach nourishment*

Supplementary beach nourishment is introduced for Case 1 in Case 4 (Figure 22). Figure 23 shows shoreline change in Cases 1-1 and 4. Shoreline in Case1-1 at 8 hours and it in Case 4 at 4 hours are almost the same. This shows that beach nourishment accelerate the speed of shoreline advance. Figure 24 shows the difference of bathymetry between Cases 1-1 and 4. Around the shoreline, bathymetry in Case 4 is higher over 5 cm than Case 1-1. Figures 25 and 26 are photos of the beach and the detached breakwater in Case 4 after experiment. Sand was deposited in the breakwater from No.1 to 7.

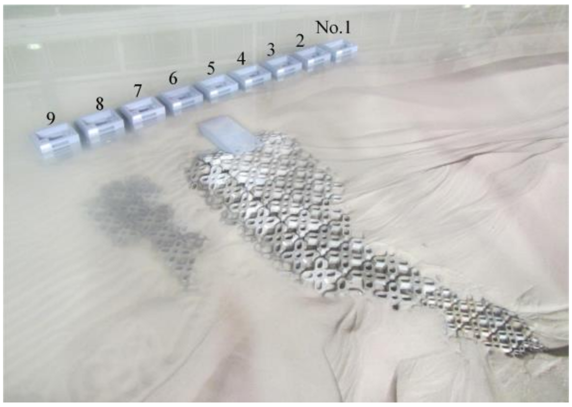
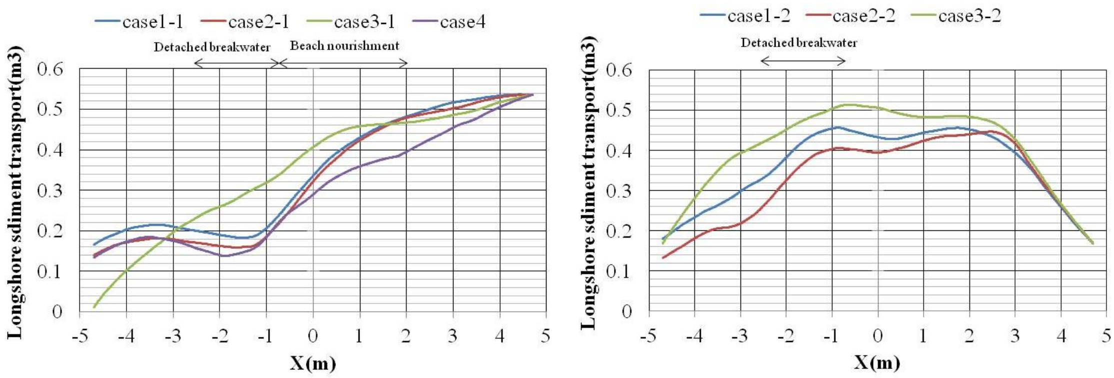


Figure 25. Bathymetry after experiment in Case 4.

Figure 26. Breakwater around Nos.4 and 5.



1) Average waves in 8 hours

2) Strom waves in 2 hours

Figure 27. Total amount of sand transported along shore.

5. Longshore sediment transport rate

Figure 27 shows the total amount of sand transported along shore. The amount at the updrift end of the wave basin is not zero because sand is continuously supplied from the point. The amount of longshore sand transport in Case 2-1 is smaller than in Case 1-1 from X = 1 m to the end of downdrift side that shows the effect of the gap between detached breakwater and jetty. The amount in Case 4 is smaller than in Case 1-1 in all area that shows the supplementary beach nourishment influence to the updrift area of beach nourishment. In Case 3, the large gradient from X = 1 m to downdrift side means that only detached breakwater can reduce erosion from updrift side. The amount in Case 2-2 is smaller than in Case 1-2, which shows that the small gap between detached breakwater and jetty can reduce erosion in storm waves. In all storm cases, the gradient changes steep toward downdrift side around X = -1 m where the updrift end of the detached breakwater exists. The detached breakwater is therefore considered to decrease erosion without jetty.

6. Landscape

Figure 28 shows current landscape of the Shimizu coast and Figure 29 shows composite photograph using 3D model of the L-shaped structure and experimental result in Case 4. The landscape will be improved because the visible area of structure as indicated by a red line in Figure 29 is smaller than that in Figure 28.

Figure 28. Current landscape.

Figure 29. Composite photograph.

7. Conclusions

Main conclusions of this study are summarized as follows:
(1) Significant entrapment of sand behind shore-parallel breakwaters was observed despite larger wave transmission due to permeable structure. Shoreline advancement as much as 25 m in the prototype scale was observed behind the structure even in Case 3, where the jetty was not installed. It is therefore concluded that the existing concrete block structures can be replaced with the new structure.
(2) The erosion control performance of the structure was found insensitive to the gap between the shore-normal jetty and the shore-parallel breakwater. The larger gap examined in Case 1 was therefore considered to be appropriate. However, local difference of flow direction, especially an area of retention behind shore –parallel breakwater, was observed.
(3) Supplementary nourishment was found effective to mitigate the downdrift erosion and accelerate the entrapment of sand behind the shore-parallel breakwater.

References

Nishihata, T. Tajima Y. and Sato, S., 2010. Numerical analysis for wave and nearshore current fields around perameable detached breakwaters with low crests. *J.JSCE, Ser. B2 (Coastal Engineering)*, Vol.66, No.1: 701-705. (in Japanese)

Anno, K. Moriya, Y. Yamamoto, A. Kumagai, T. Yoshiho, N. and Okui, J., 2010. Performance of permeavle wave-dissipating structure with effect of decreasing wave force in Shimonikawa coast. *Civil Engineering in the Ocean, JSCE*, Vol.26: 987-992. (in Japanese)

Nishihata, T. and Sato,S., 2010. Experimental study on sand drift control performance of pile-supported detached break waters. *Civil Engineering in the Ocean, JSCE*, Vol.26: 1143-1148. (in Japanese)

Nishihata, T. Tajima, Y. and Satou, S., 2011. Study on numerical analysis for sediment transport around permeable detached breakwater. *J.JSCE, Ser. B2 (Coastal Engineering)*, Vol.67, No.2: I_516-I_520. (in Japanese)

Uda, T. Kawasaki, S. and Mitsuke, K., 1995. Estimation of the obstruction rate of littoral transport due to a groin built on the Seisho coast. *Proceedings of coastal engineering, JSCE*, Vol.38: 671-675. (in Japanese)

Sunamra, T. and Horikawa, K., 1974. Two-dimensional beach transformation due to waves. *Proc. 14th Coastal Eng. Conf., ASCE*: 920-938.