Experimental Investigation of Dynamic Response and Wave Dissipation of a Horizontal Plate Breakwater

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Abstract. In recent years, floating breakwaters are considered for protecting the offshore engineering structures in the deep sea. Further, to expand the capabilities of the horizontal plate breakwater, an elastic supported horizontal plate (ESHP) breakwater is developed as an eco-friendly and high energy dissipation structure. In this study, the wave dissipation effect of an ESHP breakwater is investigated with experimental tests. Then the hydrodynamic coefficients and the wave force acting on the breakwater are analyzed with a variable stiffness of support spring and wave conditions. The experimental study shows that the interaction between the radiation wave of the heaving plate and scattered waves causes additional vortex flow, and the wave height is reduced rapidly at the lee side of the breakwater. Then the wave dissipation mechanism of ESHP breakwater for incident waves with different incident wave heights is discussed. At last, the wave force changes due to plate motion are also revealed to ensure the robustness of the structure.

Keywords: Breakwater · Heaving horizontal plate · Wave dissipation · Dynamic responses

1 Introduction

Different types of breakwaters for wave protection are mainly used to resist wave attacks on the nearshore structures such as coastline or harbors. Especially, the floating breakwater was recommended as an economical and efficient wave protection structure [1, 2]. Ji et al. conducted extensive experimental and analytical work on a new type of floating breakwaters [3, 4]. He and Huang [5] experimentally investigated the hydrodynamic performance of a pile-supported oscillating water column structure as a breakwater. Compared with floating breakwater, submerged horizontal plate (SHP) breakwater have the advantage of low construction costs and has been attracting increasing attention and there has been extensive research.

Recently, there has been extensive research on the wave dissipating performance of SHP breakwaters and the wave impact around the breakwaters. Patarapanich and Cheong [6] proved that the submerged horizontal plate has a great wave blocking performance when the radio of the plate width to wave length above the plate was in the rage of 0.5–0.7 and the ratio of plate submergence to water depth was within 0.05–0.15. The nonlinear transmission of waves over the SHP was analyzed by Liu and Huang et al. [7]

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by using a fully nonlinear numerical wave tank based on the desingularized boundary integral equation method. Porter discussed the scattering of incident waves and radiation of waves by forced motion by thin horizontal plates using a Galerkin method. In the dynamic characteristics studies of the SHP breakwater, Poupardin et al. [8] showed the vortex dynamics generated by the interaction of a submerged horizontal plate through experiments. Hayatdavoodi et al. [9] experimentally measured horizontal and vertical forces caused by Conidal waves on a submerged horizontal plate.

The elastic support structure is a widely used vibration damping device in mechanical engineering. Combining it with the horizontal plate breakwater, Koo and Kim [10] found that the movable floating horizontal plate has better wave dissipation effect than the fixed one and the heaving motion of the horizontal plate leads to an essential role in it. In the numerical studies of a heaving horizontal plate breakwater, it was found that a suitable spring stiffness could dissipate the vortex energy at the back wave surface of the structure under the resonant response of the floating plate [11–13]. In the dynamic characteristics studies of the elastic supported horizontal plate breakwater, the phenomenon of impact pressure forces induced by water waves was first examined by Wilde et al. [14]. Bing et al. [15] indicate that the uplift forces and acceleration of the elastically plates with small natural frequencies are different from those of the plates with a larger natural frequencies. However, investigations into the interaction between wave dissipating performance, wave force, and motion response of a submerged ESHP breakwater are not yet found in the published literature.

This paper proposes a submerged fixed plate breakwater and a submerged ESHP breakwater [16]. The addition of the spring support system is intended to improve the performance under incident waves. Motion response and wave force acting on the breakwater were examined using physical model tests in a two-dimensional wave flume. The design of the model test including incident wave condition, submergence ratio, etc. is discussed in the following section.

2 Experimental Setup

The experiments were conducted in a two-dimensional wave flume of the hydrodynamic Laboratory of Ningbo Institution of Technology. The wave flume is 11 m long, 0.6 m wide, and 1 m in height. The physical model of the heaving plate was made of acrylic and the dimensions of the model are the length (L) of 0.58 m, and the width (B) of 0.06 m. In the present experiment, the sides of the heaving plate were in contact with the flume, and the 0.01 m gap was filled by two universal wheels on both sides. In addition, a steel rod and two flanged ball bearings were installed on the horizontal plate which ensures the movement of the horizontal plate only in the heave direction.

Three wave probes were installed at front and rear of the breakwater (Fig. 1) to measure the wave height. 8 pressure sensors (YPS301-L) were fixed on the top and bottom sides of the plate (P1-8). In addition, a motion sensor (FASTRACK, POLHEMUS) was fixed on the plate surface for capturing the motion response.

In order to investigate the wave protection effect of the ESHP breakwater, the wave force and hydrodynamic characteristics of the fixed horizontal plate under wave actions were first tested. The water level in the wave flume is $d = 0.4$ m. The incident wave

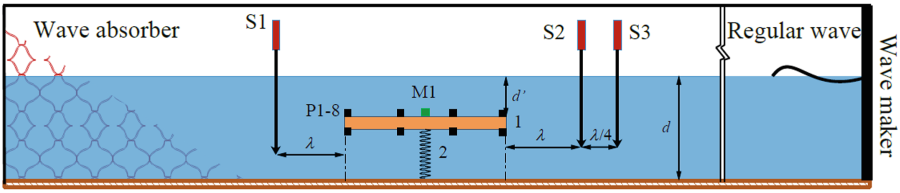

Fig. 1. The layout of the experimental wave flume and parameter setup; (1) horizontal plate, (2) spring, (P1-8) pressure sensors, (S1-3) wave probes. (M1) motion sensor, λ is the wavelength, d' is submergence depth, d is water depth in the water flume.

with a period of $T = 1$ s and the incident wave height (H) varied from 0.03m to 0.04m. The submergence depth d' was adjusted through a coupling and the submergence depth ratio d'/d ranged from 0.1 to 0.3.

The wave force and hydrodynamic characteristics of the ESHP breakwater under wave actions were then tested. A spring supporting system was considered in this condition. The stiffness coefficient of spring K varied from 154 kg/m to 537 kg/m. In the discussion, the K^* was nondimensionalized into $K/\rho d'H$ (from 21.9 to 76.5).

The duration of each test is set to 90 s and the stable intermediate data 30–80 s was intercepted for the following analysis. The motion response amplitude of each direction was obtained and the wave force was calculated by the pressure data obtained by the 8 pressure sensors.

3 Results and Discussion

3.1 Hydrodynamic Characteristics of ESHP and Fixed Plate Breakwater

Figure 2 exhibits the transmittance coefficient of two different horizontal plate breakwater under three wave height conditions. It implies that the wave dissipation effect of ESHP breakwater is better than that of the fixed breakwater, especially in deeper submergence depth ($d'/d = 0.02, 0.03$). This may be related to the added mass surrounding the plate [12]. From Fig. 2, the minimum transmittance coefficient of ESHP breakwater occurs at $h = 0.03$m and $d'/d = 0.2$. In this case, the transmitted wave height is 27% of the incident wave height. In addition, Fig. 3 shows the frequency domain of transmitted wave height behind the breakwater. The results indicate that the ESHP breakwater suppressed the wave amplitude at first and second-order wave frequencies.

Differing from the ESHP breakwater, the SHP breakwater is particularly effective at $d'/d = 0.1$. In this condition, the amplitude of the transmitted wave height is about half that of the other two cases. Moreover, the effect of the incident wave height (H) does not play a significant role here.

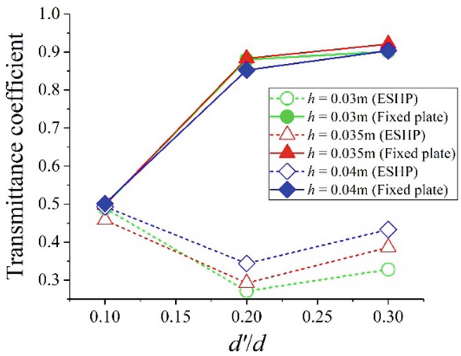

Fig. 2. The transmission coefficient of ESHP breakwater and fixed plate breakwater under different wave conditions.

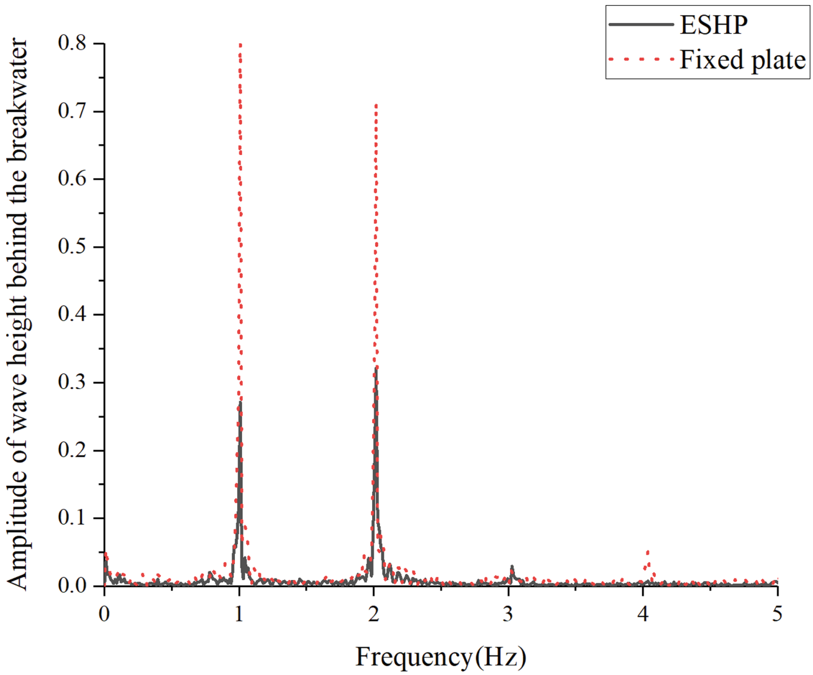

Fig. 3. The amplitude of wave behind the breakwater.

3.2 Spring Stiffness

In order to understand the wave dissipation effect of ESHP breakwater, the test condition with (H = 0.03, d'/d = 0.02) the best dissipating performance in Fig. 4 is chosen for further analysis. One of the most important factors was the stiffness of the spring which supported the horizontal plate. It offered the rigid force for the ESHP breakwater and meanwhile controlled the motion of the horizontal plate. It can be seen that a low spring stiffness in the ESHP breakwater system has a better dissipating performance. Meanwhile, the motion response of the breakwater is greater, with a portion of wave energy transformed into the kinetic of the breakwater.

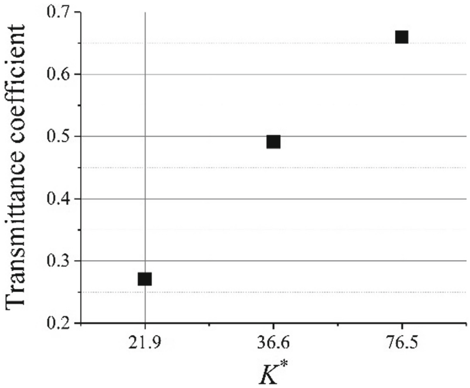

Fig. 4. Transmittance coefficient of ESHP breakwater ($H = 0.03$, $d'/d = 0.02$).

3.3 Wave Force and Motion Response of ESHP Breakwater and Fixed Plate Breakwater

The test conditions in this section are shown in Table 1. In this section, the K^* of spring of ESHP breakwater with the best wave dissipating effect (21.9) is considered, and the wave force was obtained by integrating the maximum value of the data from pressure sensors on the horizontal plates and shown in Fig. 5. It can be seen that the wave force increases as the incident wave height is gradually increases. This may be due to the fact that the higher value of wave height, has a greater wave energy and more wave force impact on the horizontal plate. Moreover, it is worth noting that the wave force significantly increases during the wave dissipating performance of the fixed plate breakwater gets better in Fig. 2. The remarkable upwards indicates that the wave force influences the wave dissipating performance of the fixed plate breakwater.

Table 1. Test condition of 9 cases in Fig. 5.

Cases	H(m)	d' (m)	d'/d
1	0.03	0.04	0.1
2	0.035	0.04	0.1
3	0.04	0.04	0.1
4	0.03	0.08	0.2
5	0.035	0.08	0.2
6	0.04	0.08	0.2
7	0.03	0.12	0.3
8	0.035	0.12	0.3
9	0.04	0.12	0.3

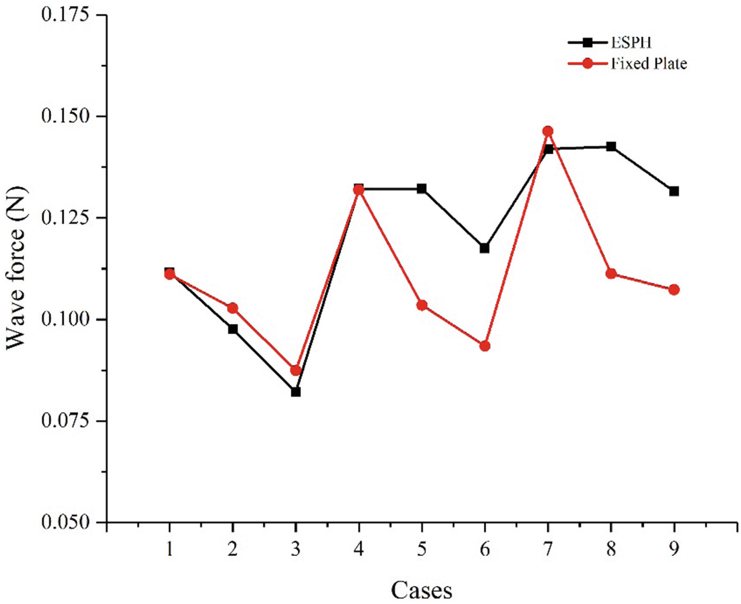

Fig. 5. Wave force of ESHP and fixed plate breakwater.

Figure 6 depicts the motion response, wave force and transmission coefficient of ESHP breakwater. It is clear that the wave dissipating performance is better than that of the smaller amplitude of motion response of the ESHP breakwater. The motion response of the ESHP breakwater is partly converted from the wave energy, which means that the wave would have an extra force on the structure.

In Fig. 7, as the spring stiffness enlarges, the amplitude of the motion response of the breakwater decreases and shows a worse wave dissipating performance. Meanwhile, the wave force increases with the increase of the supporting stiffness. This also strengthens the fact that the ESHP breakwater has a better wave dissipating performance than fixed plate breakwater.

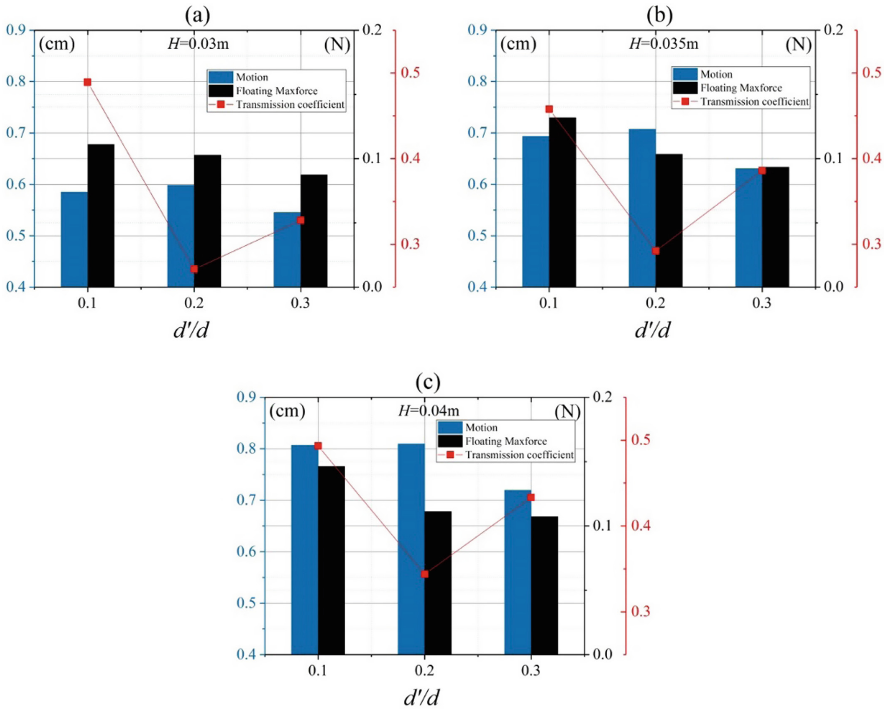

Fig. 6. Variation of motion response, wave force and transmission coefficient of ESHP breakwater.

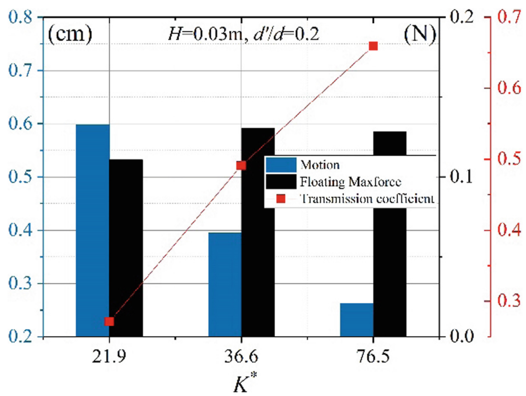

Fig. 7. Variation of motion response, wave force and transmission coefficient of ESHP breakwater.

4 Conclusions

The wave dissipation effect, wave force and the motion response of ESHP breakwater and fixed plate breakwater were investigated based on the experimental test in this research. The incident wave height, spring stiffness and submergence ratio of the plate were adjusted as variables. The main conclusions are listed as follows:

1. The wave dissipating performance of ESHP breakwater is better than that of fixed plate breakwater, the minimum transmission coefficient could reach 27%, which occurs at submergence ratio $(d'/d) = 0.2$. This may be due to the present elastic support system causing the additional energy dissipation and the larger the amplitude of motion response of the horizontal plate.
2. The wave height reduced rapidly at the leeside of the breakwater with elastic support.
3. Incident wave height has the minimal effect on wave dissipation, wave force and motion response of the breakwater.

References

1. Hales, L.Z.: Floating breakwaters: state-of-the-art literature review. US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, USA (1981)
2. Tong, C., Yan, Y.: Study on wave dissipation characteristics of floating breakwaters. Water Transp. Eng. **08**, 32–35 (2002)
3. Ji, C.-Y., Chen, X., Cui, J., Yuan, Z.-M., Incecik, A.: Experimental study of a new type of floating breakwater. Ocean Eng. **105**, 295–303 (2015)
4. Ji, C.-Y., Guo, Y.-C., Cui, J., Yuan, Z.-M., Ma, X.-J.: 3D experimental study on a cylindrical floating breakwater system. Ocean Eng. **125**, 38–50 (2016)
5. He, F., Huang, Z.: Hydrodynamic performance of pile-supported OWC-type structures as breakwaters: an experimental study. Ocean Eng. **88**, 618–626 (2014)
6. Patarapanich, M., Cheong, H.F.: Reflection and transmission characteristics of regular and random waves from a submerged horizontal plate. Coast. Eng. **13**(2), 161–182 (1989)
7. Liu, C., Huang, Z., Tan, S.K.: Nonlinear scattering of non-breaking waves by a submerged horizontal plate: experiments and simulations. Ocean Eng. **36**(17–18), 1332–1345 (2009)
8. Poupardin, A., Perret, G., Pinon, G., et al.: Vortex kinematic around a submerged plate under water waves. Part I: experimental analysis. Eur. J. Mech. B Fluids **34**, 47–55 (2012)
9. Hayatdavoodi, M., Ertekin, R.C.: Wave forces on a submerged horizontal plate-Part I: theory and modelling. J. Fluids Struct. **54**, 566–579 (2015)
10. Koo, W.C., Kim, D.H.: Numerical analysis of hydrodynamic performance of a movable submerged breakwater. J. Soc. Naval Archit. Korea **48**(1), 23–32 (2011)
11. Liu, C., Huang, Z., Chen, W.: A numerical study of a submerged horizontal heaving plate as a breakwater. J. Coast. Res. **33**(4), 917–930 (2017)
12. He, M., Xu, W., Gao, X., Ren, B.: SPH Simulation of wave scattering by a heaving submerged horizontal plate. Int. J. Ocean Coastal Eng. **1**(2), 1840004 (2018)
13. Wang, X., Zhao, X., Ding, F.: Numerical simulation of wave interaction with undulating horizontal plate breakwater. Mar. Eng. (China) **37**(3), 61–68 (2019)
14. Wilde, P., Szmidt, K., Sobierajski, E.: Phenomena in standing wave impact on a horizontal plate. Coast. Eng., 1489–1501 (1998)

15. Ren, B., Liu, M., Li, X.-L., Wang, Y.-X.: Experimental investigation of wave slamming on an open structure supported elastically. China Ocean Eng. **30**(6), 967–978 (2016). https://doi.org/10.1007/s13344-016-0063-1
16. Jin, H., Chen, J., Song, R., Liu, Y., Zhao, Z.: An elastic supported pontoon type breakwater, China, CN108643120B (2020)