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Experimental investigation on hydrodynamic effectiveness of a water ballast type floating breakwater

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ABSTRACT

This paper proposes a new type of water ballast floating breakwater. The structure consists of a water ballast double floating box and a vertical plate, which uses several wave attenuation mechanisms. The hydrodynamic effectiveness which is presented as a function of the wave transmission coefficient is investigated experimentally. The action of 2D regular waves with wide ranges of wave heights and periods is considered. The motion responses of the floating breakwater without mooring line have also been measured. Emphasis is given on the effect of the incident wave characteristics, the height of the vertical plate, different draft, water or dry sand ballast, with and without top baffle. Comparison of the new structure is also made with other novel floating breakwaters reported in the previous literature. Experimental results show that ballasting with water in the floating box not only enhances the seakeeping performance of the floating breakwater, but also increases the incident wave attenuation when compared to dry sand ballast. Heightening the height of the vertical plate and/or the draft of the floating body is conducive to decreasing the wave transmission. Adding an extra baffle on the top of the floating body, however, does not seem conducive to the wave attenuation effectiveness. Compared to the previous well-known floating breakwater model, the water ballast type in this paper has competitive effectiveness.

1. Introduction

Floating breakwaters have been increasingly used to protect coasts, harbors and marine structures from wave attacks. As alternatives to the traditional bottom-mounted breakwaters, they are built floating on the water using a classical wave mechanism that a large proportion of wave energy unites in the surface water. While not able to completely block all the wave propagation, they are still very efficient in weakening the wave energy, thus, are of natural advantages in terms of construction, economics, environment and ecology, and are especially competitive in areas with deep water depth, large tidal range, high water quality requirement and poor bottom foundation when compared to the ponderous bottom-mounted breakwaters.

In the past few decades, investigation regarding the floating breakwater has gained more and more recognition. To date, a lot of floating breakwaters with novel configurations have been proposed under various circumstances for a better performance and/or high cost-effectiveness, for instance, the double Y-frame pontoon (Murali and Mani, 1997), the tethered spar buoy fence (Liang et al., 2004), the submerged box-type floating breakwater (Rahman et al., 2006), the horizontal interlaced multilayer mats (Hegde et al., 2007), the floating board with nets (Dong et al., 2008), the porous assembled blocks (Wang and Sun, 2010), the box-type floating breakwater with truss (Uzaki et al., 2011), the box-type floating breakwater with dual pneumatic chambers (He et al., 2012, 2013), the asymmetrical energy-capturing pontoon (Madhi et al., 2014), floating breakwater with flexible connectors (Loukogeorgaki et al., 2014), the double cylinders with mesh cage and balls inside (Ji et al., 2015, 2016), the floating breakwaters with double-layered perforated walls (Xiao et al., 2016), the oscillating buoy WEC-type floating breakwater (Ning et al., 2016) and the asymmetrical F-type pontoon (Duan et al., 2017), etc.

All of the above designed breakwater structures have utilized multifarious wave attenuation mechanism of the floating breakwater including wave reflection, wave energy dissipating, and restriction of the

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radiated wave's generation, etc. Compared with the traditional bottom-mounted breakwaters, the wave mechanisms surrounding the floating breakwaters are more complicated. For example, the incident waves are partially scattered and partially dissipated, the wave induced motion responses of floating breakwater radiate waves towards both the sea-side and leeside. The transmitted waves are a combination of waves scattering underneath the breakwater and waves radiating towards the leeside, thus are essentially inevitable for floating breakwaters. The essential problem for designing a floating breakwater is how to reasonably choose wave attenuation mechanism to reduce the transmitted waves.

In order to lastingly operate in real seas, the floating breakwater with a cross-section of simple geometry is preferable in view of durability, a rectangular box-type floating breakwaters are a suitable scheme which has been extensively studied (Black et al., 1971; Christian, 2001; Drimer et al., 1992; Ning et al., 2017; Sannasiraj et al., 1998; Zheng and Zhang, 2016; Zheng et al., 2004). The box-type floating breakwater mainly relies on the reflection to reduce the wave transmission, and the relative width and draft are the two most important design parameters determining the protection effectiveness as well as the cost. A satisfactory protection effectiveness can be obtained only if the relative width and draft are large enough. However, the increase in either width or draft will also increase the cost. To balance the effectiveness and the cost, some few quasi-box type structures were proposed. A relatively inexpensive method is mounting vertical plates to the breakwater bottom to increase the draft. For instance, Blumberg and Cox (1988) attached one plate to the middle part of the breakwater bottom, termed T-shaped floating breakwater; Koutandos et al. (2005) attached one porous plate to the front part of the breakwater bottom; Gesraha (2006) attached two plates to the both sides of the breakwater bottom, termed π-shaped floating breakwater; Huang et al. (2014) attached three rows of slotted barriers to the breakwater bottom, etc. The attached vertical plates increase the local draft and strengthen the wave reflection, and meanwhile the edges of the attached plates may also excite more vortices and enhance the dissipation of wave energy. However on the other hand, it can be considered as a extra radiating wave source that may intensify the generation of motion-radiated waves if the motion amplitude of floating breakwater are large, against the wave attenuation characteristic (Ruol et al., 2013).

To reduce the generation of motion-radiated waves, a feasible method is restricting the movements of the floating breakwater. In practice, the movements are usually restrained by two categories of mooring systems: one category is the rigid vertical piles which straightly protrude from the seabed to above the sea level; the other category is the flexible lines/chains which connect the breakwater to the anchors on the seabed. The vertical piles can restrict the horizontal motion and permit only the vertical motion, thus effectively tranquilize the motion-radiated waves. However, the pile-restrained implementation is relatively expensive, and in addition it has the shortcomings such as withstanding large wave loads, suffering strong abrasion between the piles and breakwater, and being infeasible to the deep water and poor foundation (McCartney, 1985). In comparison to the vertical piles, the other category is to use the flexible line/chain mooring system which is of wider adaptability, but it impose relatively lesser restrictions on the movements of floating breakwater (Ozeren et al., 2011).

Another important issue to consider is that the effectiveness exertion of wave attenuation is affected by the used materials. Most of the previous floating breakwaters were built of reinforced concrete or steel. However, these traditional materials must contend with the fact that and the former is fragile under the dynamic loading and harsh marine environment and the latter is highly corrosive under the seawater. In practice, for the concrete structures, each two floating breakwater elements should keep a distance to avoid impact, which intensifies the wave transmission. For the steel structures, the corrosion is a very painful problem, which led them to only consider filling with such as polystyrene foam in the interior of floating body to avoid water leakage when cracks, rather than the seawater which can help to increase the stability itself.

The motivation of the present study is to propose a new type of water ballast floating breakwater. The new configuration is a quasi T-shape box-type, i.e., a floating box mounting with a middle vertical plate. Unlike the traditional floating breakwater, the new structure uses the Fiber Reinforced Plastic (FRP) material which has high-performance in anti-corrosion, crashworthiness and fatigue resistance as well as inexpensive cost. This allows the floating box which is conventionally ballasted with fixed rocks or sands to be ballasted with the low-cost seawater. The floating water box forms an anti-rolling structure similar to the passive anti-rolling tank common in the naval architecture, where the ballasted seawater can slosh against the motion of floating breakwater. In addition, the increase of draft can be easily realized by adding enough amount of water in the tank. For the restrictions of the movements of floating breakwater, a dual-tensional mooring line system is designed. Several wave attenuation mechanisms, including wave reflection, wave energy dissipating, wave breaking, water sloshing and the suppression of the radiated waves, etc, are used. All these help to mitigate the transmitted waves, improving the performance in wave attenuation characteristic.

In this paper, the hydrodynamic effectiveness of the proposed floating breakwater is carefully investigated under the regular waves over a broad range of wave periods in a 2D wave flume. The effects of wave condition, height of the vertical plate, draft and ballast are examined and the wave transmission characteristics are especially emphasized. To evaluate the effectiveness of the floating breakwater, we also make a comparison on the wave transmission characteristics with other novel floating breakwaters reported in the literature.

The remainder of this paper is structured as follows. In Section 2, the design philosophy for the floating breakwater is introduced. Section 3 describes the physical model, experimental setup and test condition. Section 4 discusses the hydrodynamics of the floating breakwater especially for the wave transmission characteristics in detail. Finally, conclusions are drawn in Section 5.

2. Design of the water ballast floating breakwater

2.1. Design principles

It is well known that the floating breakwater structure design mainly relies on the wave attenuation mechanism. Usually, it is designed to be wave reflection type, wave breaking type, friction type, pneumatic chamber type or hybrid type, etc. The main design ideas include changing the movement direction of water particle, motivating the water vortex shedding, prompting friction collision force between waves and floating body, enhancing the wave-wave interference.

Inspired by the anti-rolling tank which has been widely used in the field of naval architecture (Moaleji and Greig, 2007), a water ballast type floating breakwater has been proposed. The wave attenuation mechanisms expected are pictured in Fig. 1. This structure can be regarded as an extension of the quasi box-type whose cross-section consists of a double floating box and a vertical plate. Unlike the traditional box type, the floating box is ballasted with seawater, which forms an anti-rolling structure similar to the passive anti-rolling tank, where the ballasted seawater can slosh against the motion of floating breakwater. In addition, the freeboard of the floating body is designed to be low enough to allow for wave overtopping and breaking. For the restriction of the floating body, the traditional way is to reserve a free length at the bottom end of the mooring line (see e.g. He et al., 2013), i.e., the mooring lines are flabby when the floating body is in the quiescent state. In this paper, however, the mooring line is designed to be dual-tensional in order to obtain more restrictions on the movements of floating breakwater.

The expected wave attenuation mechanisms for this floating breakwater including: