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Experimental study on configuration optimization of floating breakwaters

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ABSTRACT

In this paper, four types of floating breakwaters (FB) are proposed: cylindrical floating breakwater (CFB), porous floating breakwater (PFB), mesh cage floating breakwater type-I (MCFB-I) and mesh cage floating breakwater type-II (MCFB-II). The hydrodynamic performance of each type has been tested to identify the most effective configuration for wave attenuation. The experiment was conducted in a wave flume in which regular waves were produced. The incident and transmitted waves, the tensions in the mooring lines and the motion responses of all of the four types of floating breakwaters were measured. It is shown that all proposed types of floating breakwaters can effectively reduce transmitted wave amplitude. Among them the MCFB-I is seen to yield the most attenuating effect on incident wave amplitude.

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1. Introduction

Floating breakwater is a type of harbor protection structure aimed at attenuating incoming wave. The reduction of transmitted wave energy is critical for the safety of other floating structures and ships.

Compared with the traditional bottom-fixed breakwaters, floating breakwaters has some advantages. Firstly, the cost of traditional bottom-fixed breakwater increases rapidly with water depth, while floating breakwaters offer a cheaper solution. Secondly, floating breakwater is friendlier to the ocean environment. Floating breakwaters can also be installed and disassembled more easily.

In 1811, a wood floating breakwater which is regarded as the first in the world was built in Plymouth Harbor. From then on, floating breakwaters were used to protect harbors, and their ability to decrease wave energy was proven. Since then people have been searching for a most effective configuration for floating breakwaters.

The most common configuration of floating breakwater is single pontoon. (Drimer et al., 1992; Sannasiraj et al., 1998; Abul-Azm and Gesraha, 2000; Koutandos et al., 2004; Gesraha, 2006; Elchahal et al., 2008; He et al., 2012, 2013; Peng et al., 2013; Koraima and Rageh, 2013).

Based on single pontoon, floating breakwaters with double pontoons were designed, the inertia of which can be increased by adjusting the distance between the two pontoons without adding total weight. Both types of floating breakwaters mainly attenuate transmitted wave by reflecting incident wave, but double pontoon floating breakwater can also reduce waves between two floating pontoons. Williams and Abul-Azm (1997) investigated theoretically the hydrodynamic properties of a dual pontoon floating breakwater consisting of a pair of floating cylinders of rectangular section, connected by a rigid deck. The results reveal that the draft and spacing of the pontoons and the mooring line stiffness influence strongly the wave reflection properties of the structure. In 2006, Rahman et al. (2006) investigated a two-dimensional numerical estimation method of calculating dynamics of a pontoon type submerged floating breakwater and the forces acting on its mooring lines due to the wave action. Comparing the numerical with the experimental results, the validity of the numerical model and the good performance on wave energy dissipation is confirmed. In addition, the results illustrated that the clear space has a great effect upon responses of the structure; it not only changes the natural frequency of the structure, but causes heave motion to have a peak response in high frequency range. Another dual pontoon floating structure with a fish net for cage aquaculture is studied (Tang et al., 2011). The resonant responses of roll and tension RAO generally decrease as net depth increases, but the magnitudes of these changes are very small. The influence of net width on the dynamic motions is not only large, but also more complicated than the influence of net depth.

Both single and double pontoon floating breakwaters are reflective structures. Some other floating breakwaters are dissipative structures,

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where a certain amount of the incident energy dissipates by friction and turbulence, etc. Wang and Sun (2010) conducted an experimental study of a porous floating breakwater in 2010. The transmission coefficient decreased with the increase of both the width of the breakwater and the initial mooring force, and the dissipation of wave energy increases with the width of the breakwater. Another experimental study on the performance of a porous perpendicular pipe breakwaters was conducted by Shih (2010). They found that performance is greatly influenced by increased incident wave heights for shorter waves under identical pipe diameter and that larger pipe length is effective in reducing the reflection coefficient.

Traditional floating breakwaters are built of concrete and their strength is relatively low. Flexible structures are used on floating breakwaters to reduce cost. In 2008, Dong et al. (2008) conducted physical model tests to measure the wave transmission coefficient of the broad-net floating breakwater. The experimental results show that the board-net floating breakwater, which is a simple and inexpensive type of structure, can effectively protect fish and fish cages and may be adopted for aquaculture engineering in deep-water regions. Interaction of surface gravity waves with multiple vertically moored surface-piercing membrane breakwaters in finite water depth is analyzed based on the linearized theory of water waves (Karmakar et al., 2012). The comparison of the results for various fixed and moored edge conditions is analyzed for reflection and transmission coefficients. The conclusion showed that in the case of single surface-piercing membrane, with the increase in the length of the membrane and tension of the membrane the wave reflection increases and the presence of multiple floating breakwater helps in the reduction of wave height in the transmitted region. Hegde et al. (2008) studied the mooring forces in horizontal interlaced moored floating pipe breakwater with three layers. They found that the maximum force in the seaward side mooring for model with $S/D=4$ is lower compared to that for the breakwater model with $S/D=2$ (S is the spacing of pipes and D the diameter of pipe). Koraim (2013) conducted a new type of breakwater which consisted of one or more horizontal rows of half pipes suspended on supporting piles. With the number of rows increasing, the efficiency of breakwaters increases.

This paper introduces designs of four different floating breakwater (FB) models. Experimental study was conducted to measure the wave attenuating capability and hydrodynamic performance of each model. By analyzing the experimental results, the best structure configuration among the four types of floating breakwaters was determined.

2. Configuration design

The first FB model, i.e. model 1, is of a cylindrical double-pontoon configuration. Using the double pontoon configuration, the inertia of the FB can be increased to reduce its motion responses, and the FB can be built with larger width. Here a cylindrical FB structure is proposed consisting of two 4 m wide × 15.2 m long cylinders and nine 0.4 m diameter × 2 m long cylinders, as shown in Fig. 1. The material of the cylinders is reinforced concrete. This type of FB is referred to in this paper as the cylindrical floating breakwater.

Model 2 is a type of porous FB. The porous FB are well studied and proved efficient in wave attenuation. Due to exposure to wave load and sunlight, the traditional concrete FB is easy to crack and then sink due to flooding of inner enclose space. In this paper, a new structure design of the porous FB is introduced to prevent water leakage. The structure consists of two vertical plates, three longitudinal plates, three transverse plates and eight columns forming eight cabins. The holes are placed at the top parts of the vertical plates and the longitudinal and transverse plates. Four

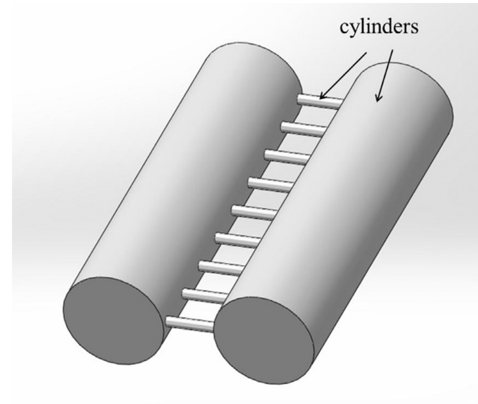

Fig. 1. Structure of Model 1: the cylindrical FB.

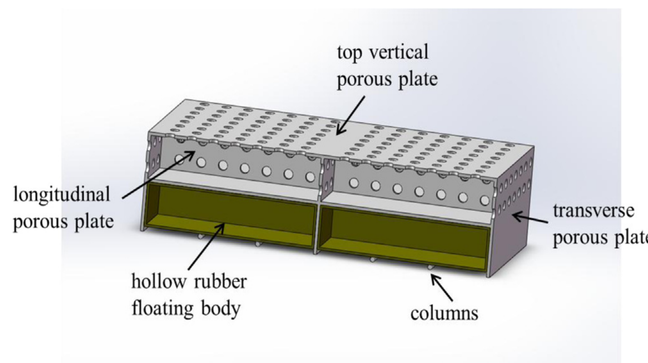

Fig. 2. Cross section of Model 2: the porous FB.

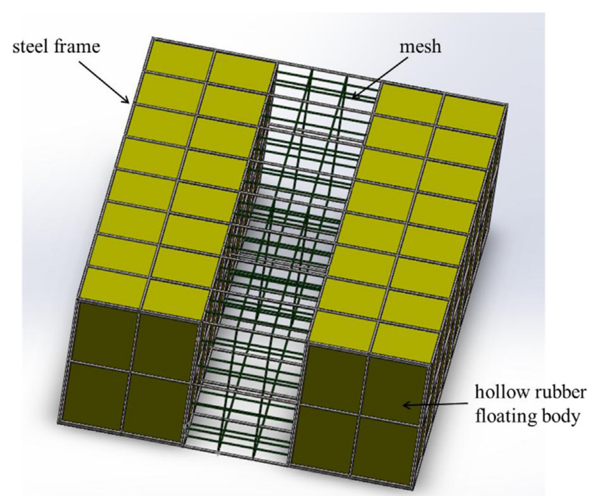

Fig. 3. Structure of Model 3: the mesh cage FB type-I.

hollow rubber floating bodies with long fatigue life are stuffed into the lower four cabins to provide buoyancy. The FB will remain afloat when one of the cabins is flooded. In the following contents Model 2 is referred to as the porous floating breakwater. The main structure of model 2 is shown in Fig. 2.

The structure configuration of Model 3 includes a cage and is referred to as the mesh cage FB type-I. It has a lower production cost than the two FB models introduced above. As shown in Fig. 3, the main frame of model 3 is made of steel. Two hollow rubber floating bodies are placed at the front and back of the floating breakwater, to

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