Ocean Engineering 152 (2018) 154–166

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Hydrodynamic performance of floating breakwaters in long wave regime: An experimental study

Chunyan Ji [a], Yong Cheng [a,*], Jie Cui [a], Zhiming Yuan [b], Oleg Gaidai [a]

[a] School of Naval Architecture and Ocean Engineering, Jiangsu University of Science and Technology, Zhenjiang, 212003, China
[b] Department of Naval Architecture, Ocean & Marine Engineering, University of Strathclyde, Glasgow, UK

ARTICLE INFO

Keywords:
Floating breakwater
Model experiments
Long waves
Mesh cage with balls
Porous plates

ABSTRACT

Hydrodynamic behavior test of long water waves with a floating breakwater is an important mission in some near-reef sea areas. Especially, the performance of the floating breakwater becomes more complicated when its natural periods stay within the range of wave frequencies. In this study, a series of experiments were conducted under long regular wave actions to investigate the hydrodynamic behavior of four slack-moored floating breakwater models, including single box, single porous box, double cylindrical pontoon, double cylindrical pontoon with mesh cage and suspending balls. The experimental results revealed that the wave transmission and wave energy dissipation for four models had multiple turning points near the natural periods of floating structures in long wave regime, while which was not evident for the reflection coefficient. The resonant responses were also observed in the motions and mooring tensions of the four models, which further explained the turning point phenomenon that appeared in transmission and dissipation coefficients. The overall results demonstrated that the porous plates and mesh cage with balls were effective for mitigating the turning point phenomenon due to additional water mass and damping effects, and also held the potential for reducing the motions and mooring forces.

1. Introduction

Floating breakwaters (FBs) are frequently employed to protect shorelines, marine structures, moored vessels, marinas and harbors from wave attacks. Compared with traditional bottom-fixed breakwaters, floating breakwaters are less dependent on local water depth and seabed condition, and most importantly are inexpensive to construct. Moreover, floating breakwaters can be considered eco-friendly for allowing the passage of currents, exchanging waters below it, and preventing seawater pollution. In these regards, the utilization of floating breakwaters is increasing in port engineering, artificial beaches and marine aquaculture.

In the past years, several types of floating breakwaters have appeared on the scene and many achievements have been made in port engineering, artificial beaches and marine aquaculture. Hales (1981) and McCartney (1985) presented a review of these types on evaluating the performance and applicability of floating breakwaters. The simplest and most durable type of floating breakwater was of a single pontoon type, which is generally made of ferroconcrete in cuboid shapes. For the single pontoon floating breakwater (SPFB) moored by the vertical pile or mooring lines, extensive theoretical (Abul-Azm and Gesraha, 2000; Gesraha, 2004; Drimer et al., 1992), numerical (Diamantoulaki et al., 2008; Koutandos et al., 2004; Lee and Cho, 2002; Loukogeorgaki and Angelides, 2005; Wei et al., 2013; Koo and Kim, 2004; Chen et al., 2012), and experimental (He et al., 2012, 2013; Ning et al., 2016) solutions had been executed, although with different highlights such as wave reflections/transmissions, motion responses, hydroelasticities, wave loads and effects of the mooring system. Another attractive option for attenuating waves and reducing wave turbulence involved the construction of dual pontoon floating breakwaters (DPFBs). These DPFBs were constructed to increase the inertia of the floating body and remain the total mass as compared with the SPFBs. In addition, the use of DPFBs increased the width of floating breakwater euphemistically. The proponents of this design were Williams and Abul-Azm (1997), Weng and Chou (2007), Rahman et al. (2006), Tang et al. (2011) and Ji et al. (2016).

In order to further enhance the powerful abilities of dissipating wave energy from open sea, some investigators have proposed some new types of dissipative structures and examined their hydrodynamic behaviour. Dong et al. (2008) conducted physical model tests to measure the wave transmission coefficient of a broad-net floating breakwater. They discovered that the proposed broad-net floating breakwater not only reduces transmitted wave heights, but reduces current velocity by 20%. Tang et al. (2011) performed hydrodynamic analysis as well as

* Corresponding author.
E-mail address: deep_1@dlut.edu.cn (Y. Cheng).

https://doi.org/10.1016/j.oceaneng.2018.01.055
Received 7 April 2017; Received in revised form 11 January 2018; Accepted 11 January 2018

experimental tests to investigate another kind of floating breakwater with dual pontoon floating structure connected with a fish net for cage aquaculture. Mizutani and Rahman (2006) introduced the rectangular-shaped porous floating breakwater which is moored by three different types of mooring systems, and experimentally studied the dynamic behaviors of the structure including the wave reflection, transmission, motion responses and mooring line forces. Wang and Sun (2010) presented the experimental results of an investigation on the efficiency of a porous floating breakwater made of diamond shaped blocks under regular waves. Koraim and Rageh (2013) investigated experimentally the hydrodynamic properties of a rectangular box floating breakwater with some attached submerged vertical plates. Cho and Kim (2008, 2013) studied the performance of horizontal/inclined/dual porous plates as an effective breakwater by applying Darcy's law (linear relation between pressure drop and velocity) as the boundary condition for fluids across porous plates. In addition, they developed an empirical relationship between the actual plate porosity and the theoretical porous parameter by using systematic experimental data. Cho (2016) developed analytical solutions for a single pontoon floating breakwater with the vertical porous side plates using the matched eigenfunction expansion method. Through a parametric study, they concluded that both properly selected porosity and deeper protruded side plates can improve the blocking performance of this π-type floating breakwater. Cheng et al. (2016) carried out hydrodynamic analyses on a pontoon type very floating structure (VLFS) with attached dual submerged horizontal plates. Compared with a single pontoon floating breakwater, the wave transmission, motion responses of floating body, and the mooring forces can be apparently reduced by installing submerged horizontal plates. Ji et al. (2015) proposed a cylindrical floating breakwater (CFB) which consists of a main body of rigid cylinders and a flexible mesh cage containing a number of suspending balls, and studied the wave transmission characteristics, motion responses and wave induced tension of the mooring lines.

The foregoing mentioned studies provide enlightening contributions in the research activities related to the hydrodynamic behavior of the various types of floating breakwaters and regular waves where narrow prototype ranges of wave period $T = 3.0$ s–9.0 s were tested. However, in some real near-reef sea areas i.e. the South China Sea, longer waves are generated due to complicated environmental condition or swell propagating a long distance from generation. There are limited investigations, in particular experimental studies, conducted for examining the behavior of the floating breakwaters in long wave region $T > 10$ s. In addition, the natural vibration periods of the floating breakwaters are within the range of long wave periods, and the resonant motions of structure may have significant effects on wave attenuation, which cannot be ignored. Therefore, the wave dissipating effect of the floating breakwaters in long wave regime remains a topic for investigation. It triggered the research of this paper, and the performance of four types of floating breakwaters were executed under the prototype range of regular wave period $T = 4.47$ s–20.57 s. The configurations of these floating breakwaters included two new structures proposed by the same authors (Ji et al., 2015, 2016): one was a type of single pontoon-type porous rectangle floating breakwater, and another integrated a cylindrical double pontoon floating breakwater with both a mesh cage and balls. The two new types of floating breakwaters were designed to protect marine structures from wave attacks in South China Sea areas, and had been validated to be very effective in moderate-length wave region. On the other hand, as introduced above, the common types of floating breakwater included both SPFB and DPFB. Thus, comparative experiments were also conducted among the new types of floating breakwaters, traditional single pontoon-type rectangle floating breakwater and dual pontoon-type circular floating breakwater.

These floating breakwaters attenuated surface waves through one or more of the following aspects: (1) contraction of flow (2) generation of lee-wake vortices behind the structure, (3) generation of turbulence, (4) occurrence of reflections, (5) occurrence of wave breaking, and (6) effect of viscous damping. The results of Ji et al. (2015, 2016) revealed that the utilization of a cage with balls and porous plates can significantly improve the efficiency of the floating breakwater in reducing transmission coefficient and motion responses for a moderate-length incident wave, but there is a need to systematically elucidate the performance of wave attenuation in long wave region. Therefore, in the present study, a series of experiments in a two-dimensional wave flume were conducted in order to assess the structural responses (motion responses and mooring forces) and the dissipating effectiveness subjected to the action of long regular waves. Finally, the main conclusions of this paper are drawn and an engineering application of the new types of structure is suggested.

2. Physical model experiments

2.1. Test model

From the standpoint of reducing construction costs and practical

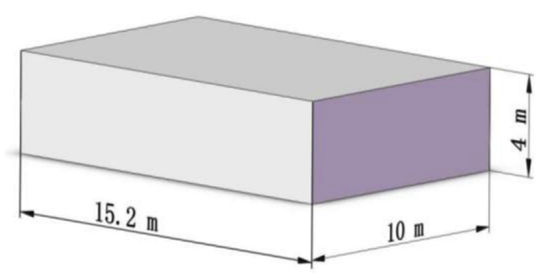

Fig. 1. Details of the Model 1: the single-box floating breakwater.

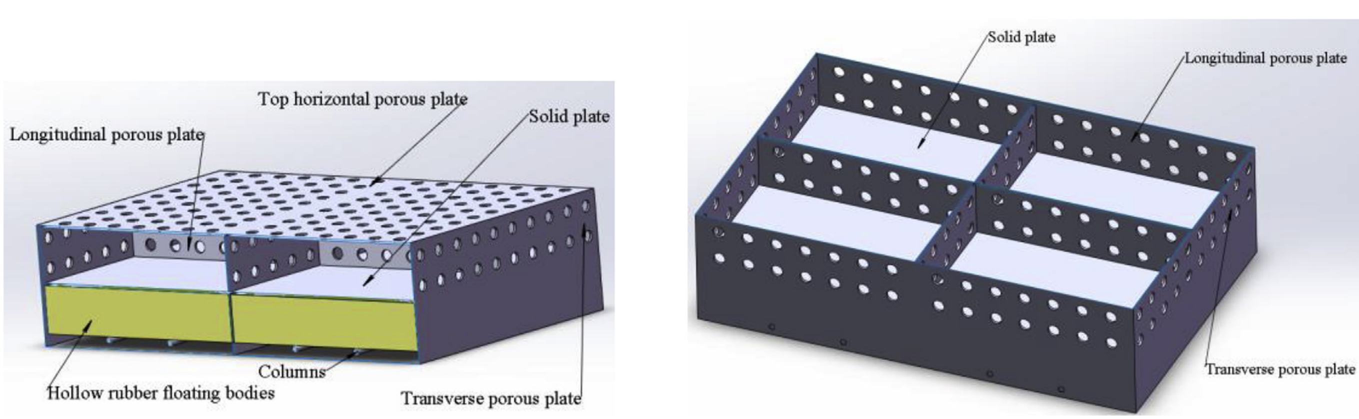

Fig. 2. Details of the Model 2: the porous floating breakwater.