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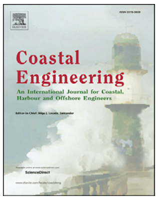

An experimental and numerical study of floating breakwaters

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ABSTRACT

Breakwaters are used to provide sheltered areas for loading and unloading of ships, and coastal protection. Often the breakwaters are bottom mounted such as rubble mound breakwaters. However, there can be several advantages to use a Floating Breakwater (FB). Therefore, the objective of this paper is to study the effect of two different damping mechanisms of a floating breakwater. Three basic cross-sections of FBs were tested and analysed in 2D; a regular pontoon (RG), a regular pontoon with wing plates attached (WP), and a regular pontoon with wing plates and porous media attached to the sides (WP P100). The damping of the FB motions was due to wave radiation and viscous damping. The viscous damping originated mainly from vortex generation around the edges of the structure and due to energy loss inside the porous material attached to the vertical sides of the floating breakwater. Attaching wing plates to the floating breakwater significantly reduced the motion, which was also anticipated. When the porous sides were attached the motion of the FB increased compared to the (WP) cross-section, but the wave transmission was reduced. The possibility for incorporating the effect of the damping in the radiation/diffraction code WAMIT was assessed. The study showed that the cross section with wing plates reduced the motions of the breakwater to the largest extend, while the cross section with wing plates and porous media attached to the sides reduced the reflection and transmission most effectively.

1. Introduction

Breakwaters are used to provide sheltered areas for loading and unloading of ships, and for coastal protection. Often the breakwaters are bottom mounted such as rubble mound breakwaters. However, there can be several advantages using a Floating Breakwater (FB). For instance, they can be moved to another location with relatively little effort. When the water depth increases, the costs of a bottom-mounted breakwater increase substantially, which makes the floating breakwater concept economically attractive. Further, if the soil conditions are not suited for high loads, a FB might be the only solution to attenuate the incoming wave field.

The use of FBs can get an enhanced attention in the coming years due to an anticipated development of the ocean space. European oceans will be subject to massive development of marine infrastructure in the near future, see (Christensen et al., 2015). The development includes energy facilities, e.g. offshore wind farms, exploitation of wave energy, and development and implementation of marine aquaculture. This change of infrastructure makes the concept of multi-use offshore platforms (several functionalities in the same area/or same platform) particularly interesting, where FBs can play an important role in protecting service platforms and offshore terminals.

The single pontoon FB has gained much attention. Most of these studies have been made with the assumption of a very long structure, which allows for analysing the problem in 2D. For instance (Drimer et al., 1992) developed an analytical model for a single pontoon (Sannasiraj et al., 1998). studied a single pontoon breakwater experimentally and theoretically (Abul-Azm and Gesraha, 2000), and (Gesraha, 2006) studied the hydrodynamics under oblique waves (Koutandos et al., 2004) developed a Boussinesq model coupled with a 2DV elliptical model to study the hydrodynamic behaviour of fixed and heave motion FBs (Rahman et al., 2006). studied the single pontoon breakwater with a VOF-type Navier-Stokes solver (see for instance (Hirt and Nichols, 1981) for the original introduction to VOF-method).

Other types of FBs have also been studied. For instance (Dong et al., 2008), studied different configurations of partly open breakwaters, i.e.

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single-box FB, double-box FB, and board-net FB (Wang and Sun, 2010). examined a porous breakwater where the structure was fabricated with large numbers of diamond-shaped blocks arranged to reduce transmitted wave height and the mooring force. Their results showed that the porous FB reduced transmission of a large part of the incident wave energy through dissipation rather than reflection of the wave energy (Ji et al., 2015). and (Ji et al., 2016) used experiments to optimize the configuration of FBs. They found that a FB consisting of two pontoons with a mesh between them gave the best performance in wave attenuation. Further, they suggested that this could be combined with porous structures in order to improve the functionality of the structure (Tang et al., 2011). presented another dual pontoon floating structure, where the pontoons supported a fish net for aquaculture. In this case the fish net acts as a very open porous structure, which in (Wang and Sun, 2010) was found to increase the wave attenuation caused by energy dissipation. Examples of full three-dimensional studies of FB can for instance be found in (Loukogeorgaki and Angelides, 2005) and (Loukogeorgaki et al., 2014).

Traditional breakwaters can be divided into reflective, such as vertical wall breakwaters, and dissipative such as rubble mound breakwaters. These two types of breakwaters have been intensively studied and it is out of the scope of this paper to give a further introduction to them. However (CIRIA et al., 2007; Goda, 2010), give a good introduction to their function and design. The transmission through a vertical breakwater will typical be very small and originates from diffraction and overtopping processes. Diffraction and overtopping processes are also important for rubble mound breakwaters, but rubble mound breakwaters are also subjected to transmission of wave energy depending on the width and height of the structure and, furthermore, on the porous material of the interior. The effect of the porous media on the incoming waves has in recent years gained attention with the use of advanced numerical models as discussed for example by (Garcia et al., 2004; Jacobsen et al., 2015; Jensen et al., 2014; Losada et al., 2005). The single pontoon FB reflects rather than dissipates the wave energy. Compared to the vertical breakwater the transmission of energy is of course much higher as the wave energy is translated under the pontoon and through wave radiation caused by the motion of the breakwater. The wave radiation is often related to the roll motion of the FB, which can be reduced by adding wings or in ship terminology, bilge keels, to the pontoon, which increases the viscous damping. Another way could be active roll control devices, see for instance (Perez and Blanke, 2012). The active roll control devices might be less attractive for a FB as this will lead to a more complex and thus, a more expensive structure. Wings increase wave attenuation by dissipating energy, and a smaller part of the incoming wave energy is transmitted due to reduced wave radiation caused by rolling of the FB.

This paper presents experimental and numerical analyses of the motion of a FB, and its reflection, dissipation and transmission of wave energy. The basic geometry of the cross section of the FB was based on a single pontoon, which was modified in several steps in order to examine the effect of roll damping wings and porous media on the side of the breakwater. Therefore, the objective of this paper is to study the effect of two different damping mechanisms, and how they influence the reflection and transmission of waves. Section 2 describes how we measured the motion of the FB with particle tracking techniques as well as with accelerometers in a laboratory wave flume. The surface elevation was measured with wave gauges on the front and lee side of the FB. Section 3 presents the analyses of the measured data, where the response amplitude operator (RAO) and the derived wave characteristics from surface elevations are presented. The set-up of the numerical model is described in section 4 that included an attempt to account for external viscous damping, and to model the mooring system as an external stiffness matrix. The numerical analyses were compared to the experimental results in section 5.

2. Experiments with a floating breakwater (FB)

The objective of this study was to evaluate the effect of two different approaches to reduce the transmission of wave energy to the lee side of a single pontoon FB. Therefore, we evaluated three main cases; a regular pontoon (RG), a pontoon with wings (bilge keels) attached (WP), and a pontoon with wings and porous sidewalls (WP P100).

We use the common notation for the six DOF (degrees of freedom) of which only the sway, heave and roll were studied as sketched in Fig. 1. The figure also indicates that a cross-section of the FB was examined in the study (see Fig. 2).

The normalized Response Amplitude Operator (RAO) is the ratio of the amplitude of the FB motion to the amplitude of the incoming wave:

$$RAO_i(\omega) = \frac{\xi_i}{A}, i = 1 \sim 6 \tag{2.1}$$

Where RAO_i is the response amplitude operator for motion i, that is a function of frequency ω. ξ_i is the amplitude of the ith DOF, and A is the amplitude of the incoming periodic waves.

In the experimental and numerical analyses we only analysed the sway, heave and roll, corresponding to $i = 2,3,4$. To estimate the response amplitude and the reflection and transmission of waves, the wave elevation at several positions and the motion of the FB were evaluated. The following sub-section describes the wave flume and experimental set-up.

2.1. The wave flume and experimental set-up

The tests were carried out in a wave flume in the hydraulic laboratory at the Technical University of Denmark. The flume is 28 m long, 0.6 m wide, and the sidewalls are 0.8 m high, see Fig. 2. The pontoon took up almost the entire width of the wave flume to reduce side effects in the two-dimensional experiments. The distance from the wave piston paddle to the end of the wave absorber was 25 m. The flume was used with waves alone even though it also had the ability to include currents. The sidewalls of the flume consisted of a long range of glass that made it possible to follow the motions of the FB. The flume was equipped with a piston-type wave maker at one end and a wave absorber at the other end. The water depth in the flume was 0.615 m.

2.1.1. Wave measurements and analyses

One of the major objectives of the experimental set-up was to distinguish between the incident, H_I, reflected, H_R, and transmitted, H_T, wave heights. From the measured wave heights, the reflection and transmission coefficients were defined as:

$$C_R = H_R/H_I \tag{2.2}$$

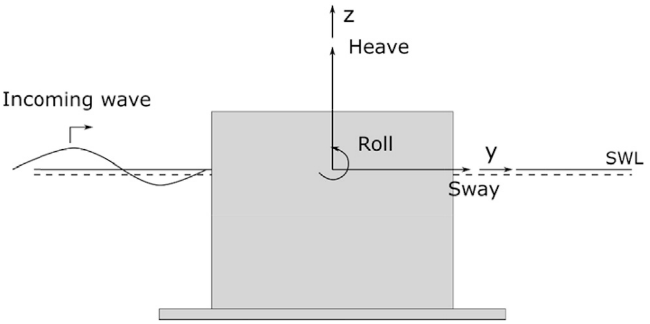

Fig. 1. Definition sketch of the DOF (Degrees Of Freedom) that was examined in this study.