Coastal Engineering 133 (2018) 142–158

Contents lists available at ScienceDirect

Coastal Engineering

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

Flow mechanism of impulsive wave forces and improvement on hydrodynamic performance of a comb-type breakwater

Zhipeng Zang [a], Zhuo Fang [b,*], Ningchuan Zhang [c]

[a] State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin University, Tianjin 300072, China
[b] Transport Planning and Research Institute, Ministry of Transport, Beijing 100028, China
[c] State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology, Dalian, Liaoning 116023, China

ARTICLE INFO

Keywords:
Numerical wave flume
Comb-type breakwater
Impulsive wave force
Critical condition
Openings

ABSTRACT

The interactions between waves and a comb-type breakwater (CTB) are numerically simulated in a 3D numerical wave flume, which is based on an internal wave generation method. The comb-type breakwater (CTB) is a new type of gravity breakwater and evolved from the conventional caisson breakwater, with part of the rectangular caisson being replaced by a thin side plate. Thus, a chamber is formed by the side plate and the bottom of superstructure between two adjacent rectangular caissons. It is found that impulsive wave pressure on the CTB is mainly induced by the chamber, which can be simplified into a vertical wall with a horizontal cantilever slab in the 2D cross-section. The synchronous analyses on wave profiles, velocity vectors, vorticity contours and wave pressure distributions are conducted to reveal the flow mechanism of the impulsive wave force. In the previous studies, the impulsive wave pressure on a vertical wall with a horizontal cantilever slab was merely observed under breaking or broken wave conditions. However, in the present results, the impulsive wave pressure was also observed on such structure under non-breaking waves. The impulsive wave force occurs when the incident wave height is comparable to the clearance between the still water level and the bottom of the super structure for non-breaking waves. Then, a non-dimensional governing parameter, which included the effects of the water depth, the bottom of the superstructure and the incident wave height, was proposed to quantify the critical conditions for impulsive wave force. Finally, a concept designs of openings on the bottom of the superstructure is proposed to reduce the impulsive wave force. The results show that even a 20% opening on the bottom of superstructure can reduce the maxima of impulsive wave pressure by up to 40%.

1. Introduction

Breakwaters are normally constructed near the shoreline for the purpose of providing calm water areas for safe navigation or protecting shorelines from wave-induced erosion. The caisson breakwater is one of the most widely used breakwater in the coastal engineering. Till now, a number of modifications have been made on the conventional caisson breakwater to improve its reflection characteristics, structural stability and economy of construction (Huang et al., 2011). These modifications included a fully or partially perforated-wall caisson breakwater (e.g. Yu, 1995; Liu et al., 2008; Zhu and Zhu, 2010), a perforated-wall caisson breakwater with a top cover plate or internal horizontal plate (e.g. Chen et al., 2007; Yip and Chwang, 2000), a curtain-wall-pile breakwater (e.g. Suh et al., 2006; Rageh and Koraim, 2010) and a comb-type breakwater (e.g. Dong et al., 2003; Fang et al., 2010), etc.

The comb-type breakwater (CTB) is one of the new types of breakwater that has emerged in recent years. It has evolved from the conventional caisson breakwater, with part of the rectangular caisson being replaced by a thin side plate (see Fig. 1(a)). From plan view the CTB looks like a comb, as shown in Fig. 1(b). In application, the CTB can be divided into a series of units (e.g. in Fig. 1(a), three units are included) and each unit consists of three portions: a rectangular caisson, two side plates and a superstructure. It can be seen from the 3D sketch that a chamber is formed by the side plates and the bottom of the superstructure between two adjacent caissons. Fig. 1(c) and (d) show the cross-sections of the CTB at different locations. In Fig. 1(c), the cutting plane is located at the middle of the side plate, i.e. crossing the chamber, and the cross-section is in shape of a vertical wall with an overhanging cantilever slab. In Fig. 1(d), the cutting plan is crossing the rectangular caisson and the cross-section is same to that of a conventional caisson breakwater. Due to

* Corresponding author.
E-mail address: fangzhuo@tpri.org.cn (Z. Fang).

https://doi.org/10.1016/j.coastaleng.2017.12.010
Received 2 February 2017; Received in revised form 1 December 2017; Accepted 16 December 2017

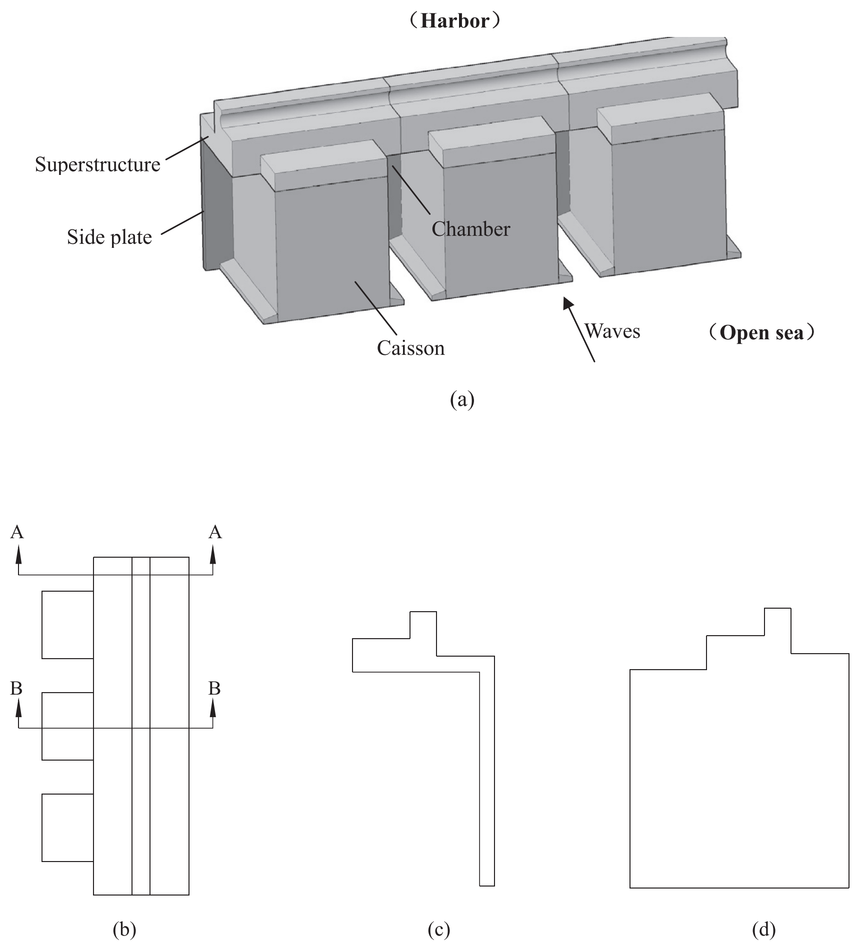

Fig. 1. A typical configuration of a comb-type breakwater, (a) 3D sketch, (b) plan view, (c) A-A cross-section, (d) B-B cross-section.

the phase difference between the front wall of the caisson and the side plate, the CTB can efficiently dissipate the incident wave energy and reduce the total wave force compared with conventional caisson breakwaters (Li et al., 2002). Moreover, due to the smaller size of the rectangular caisson compared to the conventional one, the CTB can reduce the construction cost and environmental impact, especially suitable for deep-water conditions (Niu et al., 2001).

Because the CTB is a new type of breakwater, there were still a few aspects needing to be improved for its wide application. Zhu et al. (2001) theoretically analyzed the hydraulic process and shield effect of CTB. Wang et al. (2001) conducted a structural analysis on the side plates under wave forces and suggested a reinforcement design for the side plates. Li et al. (2002) and Dong et al. (2003) carried out a series of physical experiments under both regular waves and irregular waves and empirical formulae for the wave force reduction coefficient and wave reflection coefficient of CTBs were proposed. In a recent project in Dayao Bay Port, Dalian, China, the side plate of a CTB was damaged during installation in a medium wave climate, but not an extreme storm. This is somewhat different from the common knowledge. Fang et al. (2010) conducted a model test and found that the failure of the CTB was probably caused by an impulsive wave force due to the special configuration, i.e. the chamber, of CTB. However, there were no further research effort on the flow mechanism of the impulsive wave force and improvements on the hydrodynamic performance.

Impulsive wave forces often occur on coastal structures with a suspended deck or platform. When waves break against vertical breakwaters, seawalls or coastal bridges, they abruptly transfer their momentum to the structure. This energy transfer can be very violent, and its duration can be exceptionally short (Cuomo et al., 2011). The chamber of CTB, which is in the shape of a vertical wall with an overhanging horizontal cantilever slab in the 2D cross section, is one type of the structures that are prone to suffer from impulsive wave force (Kisacik et al., 2012, 2014). The side plate is the relatively wake part of the CTB and more likely to be damaged under the high impulsive wave force than other parts of CTB. Therefore, there is a need to explore the flow mechanism and occurrence conditions of the impulsive wave forces for further assessment of the stability and structural integrity of CTB.

The qualitative and quantitative determination of impulsive wave loads on vertical walls or horizontal cantilevers has been examined intensively in the past decades (e.g. Oumeraci and Kortenhaus, 1994; Goda, 2000; Bea et al., 2001). In opposition to a single vertical or horizontal part, structures consisting of both vertical parapets and horizontal cantilever slabs have scarcely been considered. Kisacik et al. (2012) described the loading conditions due to violent wave impacts on a vertical wall with an overhanging horizontal cantilever slab under breaking or broken waves. It was found that the maximum wave pressure on the horizontal part was located at the attached corner of the structure. In their further study, a set of parameters for the uplift impulsive forces, including the incident wave height, water depth at the structure toe and incident wave period, were investigated (Kisadick et al., 2014). Till now, the flow mechanism and forming conditions of the impulsive wave force on such structure has not been explored clearly from the measurement of in experiments as above. Instead, numerical simulation is an effective method, by which the researcher can well capture the coastal engineering process and reveal its flow mechanisms (e.g. Higuera et al., 2013; Hayatdavoodi et al., 2014).

This paper numerically simulates the interactions between waves and the CTB based on a licensed ANSYS-FLUENT package. A variety of wave