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Performance evaluation of a semicircular breakwater with truncated wave screens

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ABSTRACT

A semicircular breakwater model with rectangular perforations and with truncated wave screen(s) of different porosities has been developed in this study which could act as an anti-reflection wave barrier, providing wave protection to coastal and marine infrastructures. The hydrodynamic performance of the breakwater model is evaluated through wave measurements in a wave flume under irregular waves. The experiments are undertaken with three setups; (i) a wave screen is attached to the front curved wall of the semicircular breakwater and none at the rear wall, (ii) a wave screen is attached at the rear curved wall of the semicircular breakwater and none at the front wall and (iii) wave screens one each is attached to the front and rear walls of the semicircular breakwater. The wave surface elevations are measured at different locations upstream and downstream of the breakwater model and the coefficients of wave transmission, reflection and energy dissipation are determined. Wave climate in the vicinity of the breakwater and the horizontal wave force on the model are also measured and analysed. The results show that the semicircular breakwater with double screens of 25% porosity is the most viable design that offers reasonably good hydraulic performance as this acts as an energy dissipater rather than a wave reflector. Further, empirical models developed using a multi-regression method for estimation of reflection, transmission and energy loss coefficients as well as the normalised wave force coefficients, correlates well with the experimental data.

1. Introduction

Protection of coastal infrastructures, amenities and communities from destructive waves has been one of the most challenging tasks for coastal engineers for many years. Engineers have proposed and developed several design options of breakwaters which could provide good tranquillity conditions in ports, harbours and marinas for safe navigation and berthing within the perimeter of the basin. In an environmentally sensitive site where complete wave tranquillity is not needed, the so called free surface breakwaters may be a viable alternative to the conventional gravity-type structures such as the rubble mound breakwaters.

Free surface breakwaters, also known as open breakwaters, have generated a great deal of interest in the coastal and ocean engineering in recent years. They are essentially barriers located near the free surface where the energy flux is maximal. They are built to obstruct the orbital motion near the sea surface, where the water particle amplitudes and velocities are higher. The total height of such barriers is far smaller than the water depth, thus permitting water circulation beneath the structures. The barriers could be installed on a group of piles or even held floating by mooring cables. These structures control the height of the incident waves mainly by reflection and energy loss, and are found to be most effective when used at locations where wave conditions are relatively mild.

Although a number of studies have been reported in the literature associated with the bottom-seated semicircular breakwaters, the free surface semicircular breakwater still remains unexplored to date. Teh et al. (2010) developed a perforated free surface semicircular breakwater (SCB) that is particularly suitable to be used in coastal waters. Experiments carried out to study its performance has shown that the semicircular breakwater with 9% porosity (denoted as SCB9) was an effective energy dissipater and an anti-wave reflection structure. Further, the SCB9 model was found to be particularly helpful in preventing increased wave activity in front of the structure. Nevertheless, the performance of the SCB9 model was somewhat less satisfactory at lower immersion depth (*i.e.* the breakwater draft to water depth ratio, $D/d=0.071$), particularly when subjected to longer period waves, as substantial transmission of waves underneath the SCB occurred. The transmission rate for the SCB9 model at lower immersion depth ranged from about 60–98%, which is rather high for many coastal and marine related applications.

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Nomenclature

B	width of the breakwater
C_C	wave climate coefficient at the breakwater's chamber
C_F	wave climate coefficient at the front of the breakwater
C_L	energy dissipation coefficient
C_R	wave reflection coefficient
C_T	wave transmission coefficient
D	immersion depth of the semicircular caisson
D'	immersion depth of the skirt breakwater
d	water depth
F	the measured positive/negative peak wave forces
$F_{n,t}$	the negative peak force coefficients due to wave troughs
$F_{n,c}$	the positive peak force coefficients due to wave crests
g	acceleration due to gravity
$H_{m0,c}$	significant wave height at the breakwater chamber in frequency domain
$H_{m0,f}$	significant wave height at the front of the breakwater in frequency domain
$H_{m0,i}$	incident significant wave height in frequency domain
$H_{m0,r}$	reflected significant wave height in frequency domain
$H_{m0,t}$	transmitted significant wave height in frequency domain
$H_{1/3}$	incident significant wave height in time domain
L_p	wavelength corresponding to the peak period, T_p
L_s	wavelength corresponding to the significant wave period, T_s
T_p	peak wave period
T_s	significant wave period
ρ	density of the water
ε_{SCB9}	porosity of the front curve wall of the semicircular caisson
ε_{screen}	porosity of the wave screen

The present study aims to tackle the above problem by adding wave screen(s) as an auxiliary structure attached underneath the SCB caisson. The optimum screen configuration and its porosity are initially ascertained by experiments conducted in a wave flume. Then the hydrodynamic characteristics of the SCB coupled with wave screen(s) are investigated through extensive laboratory tests using irregular waves. This experimental exercise is to provide better understanding of the wave-structure interactions as well as the hydrodynamic loadings on the breakwater as a whole. An attempt has also been made to develop several robust empirical prediction formulae to estimate the hydrodynamic performance of the SCB with screen(s) within the test limit. The experimental set-up, measurement of wave elevations and wave forces on the SCB caisson and wave screens, analysis and discussion of the results are presented in the following sections.

2. Background literature

2.1. Free surface breakwater

There are various designs of bottom-seated breakwaters developed to provide wave protection to small ports and marinas. Extensive studies on such breakwaters were undertaken by several researchers, *e.g.* Tanimoto et al. (1989), Sasajima et al. (1994), Xie (1999), Dhinakaran et al. (2002), Yuan and Tao (2003) and Zhang et al. (2005). The hydrodynamic performance of the free surface semicircular breakwater with different porosities and immersion depths were reported in Teh et al. (2010, 2011,2012). The experimental results obtained for the SCB9 model with wave screens attached to the front and rear walls of SCB9 are presented in this paper.

Teh et al. (2010) classified the fixed free surface breakwater designs into four categories based on their configurations: solid-type, caisson-type, plate-type and multipart-type. The solid-type barriers are generally simple in design and have high effective mass for stability. They reduce the wave energy mainly by wave reflection. Caisson-type barriers are quite similar to the solid-type in terms of their physical appearance but these structures are with interference chambers for further energy dissipation. Plate-type barriers consist of a single or a combination of multiple plates with different alignments located at various submergence depths in water domain. The multipart-type barriers are made of a large number of structural elements (*e.g.* pipes, concrete and wooden planks, vertical rods, *etc.*) that are highly porous to the incoming waves and thereby reducing significant amount of horizontal wave force and reflection in front of the structures.

2.2. Wave screens

Wave screens have a number of desirable features that have encouraged their use within harbours, *i.e.* easy navigation within the harbour due to reduced wave activity, permitting water exchange and maintenance of water quality within the basin, and reduced wave loads on the barrier. The basic structure of a wave screen consists of a series of slots or holes, so that energy is dissipated by viscous eddies formed by the flow through the perforations. They will reflect wave energy from the screen face and the intensity depends mainly on the porosity and configuration of the screen. In general, there are two types of wave screens used in harbour, namely (a) the horizontally slotted screens and (b) the closely spaced piles.

2.2.1. Horizontally slotted screens

A typical slotted screen is composed of a series of closely spaced elements (*e.g.* precast concrete or timber planks) mounted on a supporting frame extending from the seabed to well above the water surface. For a single screen with low porosity, wave reflection is less influenced by the change of wave height because there is little flow through the screen and most of the energy is reflected. The influence of screen porosity on wave reflection is only apparent for small wave heights (Bennett et al., 1992). In some cases, a solid back wall or a similar perforated screen is placed at a distance away from the front screen to enhance the wave attenuation level within the harbours; however, standing waves may form within the space. Allsop and Hettiarachchi (1988) studied screens of 14–28% porosities for a broad range of relative screen spacing, $0 < B'/L < 1.2$, in which B' is the width of the breakwater's chamber and L is the wavelength. They found that the lowest wave reflection occurred at $B'/L \approx 0.25$ and 0.75, and the highest reflections at $B'/L \approx 0.5$ and 1.0; and the influence of screen porosity was only apparent when the wave reflection was small. The design formulae for prediction of reflection performance for single and double wave screens were further developed by McBride et al. (1994).