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Pressures and forces due to directional waves on a vertical wall fronted by wave screens

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ABSTRACT

The knowledge on the distribution of energy with respect to the wave direction, which is commonly known as the directional spectrum, provides a better representation of the ocean's surface. A more realistic approach, considering the effect of the real sea's state would result in the optimum design of structures. The effect of wave screens on the reduction of pressures and forces on a vertical wall on its leeside due of directional waves has been investigated through physical model tests. The pressures and forces exerted on the wall due to short crested waves are found to be less than that due to long crested waves. A considerable reduction in the pressures and forces on the wall due to an increase in the angle of wave incidence is observed.

1. Introduction

Marine structures play a major role in providing safe shelter for sea going vessels, oil exploration and production as well as in protecting the shore against flooding, erosion and soil sliding. Among the various available options in choosing a type of structure, vertical wall type structures are widely adopted due to the advantages such as less space requirement and economic construction. Furthermore, globalization in trade and increased exploration and exploitation of offshore natural resources has resulted in a rapid increase in the marine transportation demand for the expansion of existing harbors with deep water vertical structures. Besides serving the purpose for which it has been constructed, these vertical faced structures pose problems like wave reflection that affects the navigation of ships, particularly near the harbor entrance, scour around its toe and erosion along the shoreline. To mitigate a few of the above drawbacks, the concept of perforated screens as wave energy dissipaters was introduced by Jarlan [1]. These perforated screens act as a wave absorbing structure that eliminate excessive wave reflection from smooth vertical walls. Apart from the above purposes, wave screens can be deployed to protect damaged or old structures. Considerable research has been done on wave screens with various configurations but limited to such structures in regular or random uni-directional wave fields. The technical note published by the US Army Engineer Waterways Experiment Station, CERC [2] emphasizes that more accurate wave predictions can be achieved when directional spectra are considered. Liu and Wu [3] reported that the transmitted wave energy decreases for a wider barrier with an increase in its submergence depth. Gardner and Townend [4] reviewed the existing results of theoretical and experimental studies on the wave transmission characteristics of horizontal slotted breakwaters and discussed the case history of a marina breakwater system. The model tests on a screen breakwater made with horizontal rectangular planks as wave intercepting elements revealed that the performance of different thickness of planks were similar. Bennett et al. [5] studied the effects of energy dissipation in the flow through the screen by using a semi-empirical nonlinear term involving a head-loss coefficient. Losada et al. [6] observed a strong reflection by a thin barrier with a horizontal gap for short waves and free transmission of longer waves past the barrier. It was reported that the reflected wave's amplitude reduced with an increase in the angle of incident waves. Allsop [7] suggested that a screen porosity from 5% to 15% provided relatively low levels of wave transmission accompanied by higher reflections. Bergmann and Oumeraci [8] investigated the hydraulic performance of perforated structures with square shaped wave intercepting elements placed in front of the vertical impermeable wall and reported that the hydrodynamic performance characteristics are good over a small range of B/L, where, B is the chamber width and L is the wave length. Sahoo et al. [9] numerically studied the performance of four different configurations of permeable barriers in oblique wave incidence. The finite angle of wave

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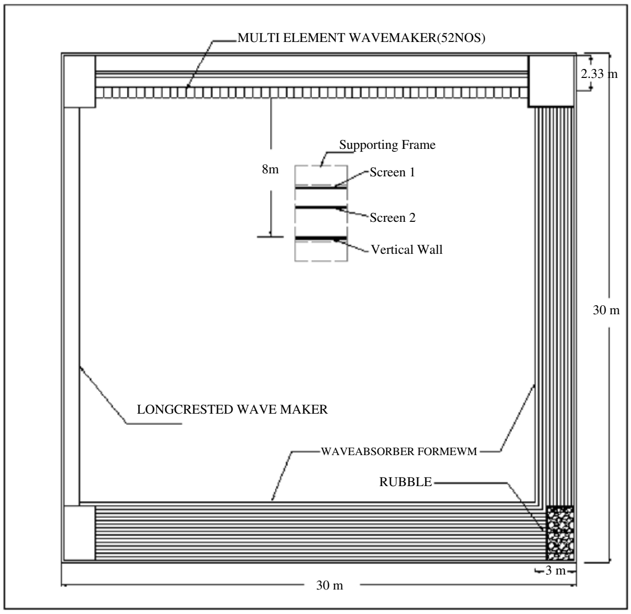


Fig. 1. Plan view of the wave basin showing the position of the models.

incidence and the porous effect of the barriers reduced the reflection of incident waves, the transmitted wave amplitude and the hydrodynamic pressure exerted on the barriers. Schuttrumpf et al. [10] conducted an experimental model test on a section of an existing caisson breakwater. The model was subjected to long and short crested waves with normal and oblique wave incidence. There was a higher reduction of forces and pressures with the increasing obliquity of waves. Balaji and Sundar [11], for a horizontal slotted structure, have shown that the circular elements perform better in terms of reflection and transmission coefficients than the sharp edged (square, rectangle, triangle) elements. The diameter of the elements was stated to have no influence on the transmission and reflection coefficient. Kriebel [12] reported that the effectiveness of the wave screens in preventing wave transmission has been drastically diminished for a depth of submergence of the wall greater than half the water's depth. The aim of this study is to investigate the performance of slotted screens in reducing the wave force exerted on a wall on its lee side and subjected to the action of multi-directional waves. Further, the changes in the dynamic pressures exerted along the vertical wall protected by single and double screens is experimentally measured and reported in this paper.

2. Experimental investigations

2.1. Test facility

A well controlled experimental program was carried out in a wave basin of 30 × 30 m size and 3.8 m deep at the Department of Ocean Engineering, Indian Institute of Technology Madras, India. The wave basin is equipped with a Long Crested Wave Maker (LCWM) on one side and Multi Element Wave Maker (MEWM) on the other side running normal to the LCWM with the absorbers housed on the other two sides to dissipate the incident wave's energy from either of the wave makers. The LCWM is capable of generating long-crested regular and random waves. The MEWM is capable of generating regular waves and random waves of predefined spectral characteristics. Waves with these wave makers can be generated without or with directional spreading of the waves referred to 2D and 3D waves, respectively.

The MEWM consists of 52 paddles, each of 0.5 m width. The paddles are hinged 1.3 m below the water surface and 1.7 m above the basin floor. Each paddle pivots independently according to the servo actuator's motion. The front surface of the 52 paddles is covered by an elastic membrane which ensures that the rear side of the wave maker is dry. The membrane is elastic and tolerates elongations beyond the working range of paddles. The maximum rotation of the paddles about their hinges is ±15°. The MEWM incorporates six main subsystems, such as a computer with software, Digital Servo Controllers (DSC), hydraulic power pack and hydraulic servo actuator. The plan view of the basin along with the position of the test models are shown in Fig. 1.

A steel frame of width and height of 2 m was installed in the wave basin to support the test models. A water depth of 3 m is maintained in the wave basin during the tests. Thus, the submerged depth of the test models is 1 m from the still water line to the crest of the frame. The schematic representations of the different tested models along with their notations are shown in Fig. 2.

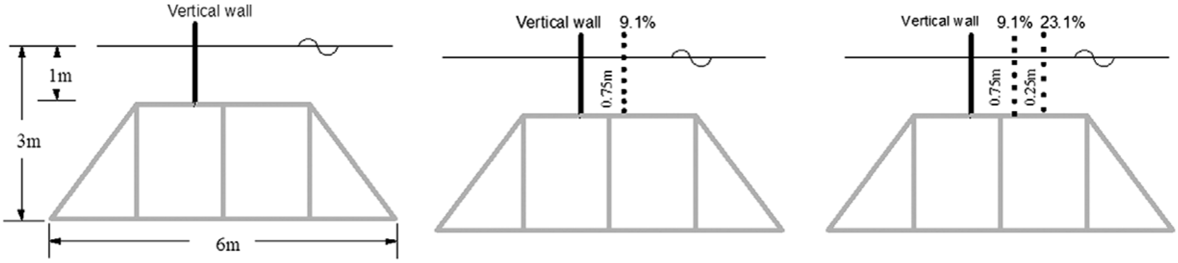
2.2. Test models

2.2.1. Impermeable wall model

The impermeable wall model was of 10 mm thick Perspex sheet of size 1.98 × 1.4 m. A proper fixing arrangement was done to avoid vibration of the impermeable wall during testing. The details of the impermeable wall model along with the position of pressure transducers are shown in Fig. 3. Four pressure transducers were placed at different positions (i.e. $z/d = 0.033, 0.067, 0.1$ and 0.167, where, z is the position of pressure transducer measured from the still water line d is the water depth) vertically across the wall to measure the pressure variation across the depth.

2.2.2. Wave screen model

The wave screen model is fabricated using a high stiffness 50 mm diameter Poly Vinyl Chloride (PVC) pipe of length 1.98 m. The series of pipes is fixed to the wooden reapers horizontally at a spacing that depends on the porosity of interest. The porosity of the screen is defined as $(s/(s+D))$ where, 's' is clear spacing between the elements and 'D' being the diameter of the individual elements. The height of the wave screen is fixed in such a way that the overtopping of waves is completely avoided. Fig. 4 shows the typical wave screen model used for the present study.



(a) VWS.

(b) SCS.

(c) DCS.

Fig. 2. Three different models subjected for the experimental study.