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Hydrodynamic characteristics of porous seawall protected by submerged breakwater

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ABSTRACT

In this paper, the hydrodynamic efficiency of a new type porous seawall is experimentally studied by using physical models. The seawall consists of front steel screen, back solid wall and filled rock-core. A submerged breakwater with different parameters is installed in front of the seawall. The wave run-up on the seawall and the wave reflection due to the seawall with or without the submerged breakwater are investigated. The wave transmission due to the submerged breakwater is investigated also. The results indicate that the run-up and reflection coefficients due to the seawall only decrease with increasing of: the relative water depth (h/L); the wave steepness (H_i/L); the relative seawall width (b/h); and the seawall porosity (n). The submerged breakwater decreases the run-up on the seawall and the wave reflection by about 20–60% and less than 70%, respectively. In addition, the submerged breakwater is achieving low transmission coefficients with increasing of the relative breakwater height (D/h) and the relative breakwater width (B/h).

1. Introduction

Seawalls are onshore structures with the principal function of preventing or alleviating wave overtopping and flooding of the land and the structures behind. This is due to storm surges and waves. Seawalls are built parallel to the shoreline as a reinforcement of a part of the coastal profile. Quite often seawalls are used to protect promenades, roads, and houses placed seaward of the crest edge of the natural beach profile. In these cases a seawall structure protruding from the natural beach profile must be built. In addition, seawalls are considered good methods to control the probable sea level rising due to the climate changes. Seawalls may be vertical face structures e.g. massive gravity concrete walls, tied walls using steel or concrete piling, and stone-filled cribwork. May be also, sloping structures with typical surfaces being reinforced concrete slabs, concrete armor units, or stone rubble.

The key functional element in seawall design is the crest elevation to minimize the overtopping from storm surge and wave run-up. There are three main parameters affecting on seawall crest level: tidal range; wave run-up; and sea level rising. The reflection and run-up characteristics of a seawall, in addition to its stability, are important parameters to be studied. The reflection from the vertical and slightly battered walls of impermeable type will be around 90–100%. The reflection from these structures causes standing waves, which are accompanied by increased water particle velocities. This result in more erosion along the face of the wall and may lead to undermining the structure (Mallayachari and Sundar [27]).

The construction of sloping rubble mound walls will reduce the level of reflections to limit the problem of local scour. This is when waves approach normal to the shore. These structures require large quantity of stones especially when the water depth and wave height increase. Moreover, to avoid this point, the vertical porous seawall can be used instead of the sloped one. The simplest form of the vertical porous seawall is rock-filled work. In which the seawall consists of front screen (steel screen suspended on nearly spaced piles), back solid wall and filled rock-core.

The present investigation with porous, vertical seawall has been carried out with the following objectives:

1. To propose a new type seawall helping in crest level reduction by dissipating the part of incident wave energy.
2. To investigate experimentally the wave run-up and reflection due to the proposed seawall only for different wave and seawall parameters.
3. To investigate the effect of the front submerged breakwater on the run-up on the seawall, transmitted waves and the wave reflection due to this system.

2. Previous work

In recent decades, porous structures have been widely used in coastal areas. Many investigators studied the phenomena of wave interaction with these structures theoretically and experimentally. In addition, the submerged breakwaters were used individually for protecting the coastal areas from waves and erosion. There are several studies that were carried out to investigate theoretically and experimentally the hydrodynamic performance of these breakwater types.

2.1. Porous seawalls

Theoretical and experimental investigations pertaining to the interaction of waves with permeable structures have previously been carried out by several investigators. Straub et al. [38] reported the reflection characteristics of permeable wave absorbers of

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different porosities, lengths and configurations through an experimental program. Since Straub et al. [38], numerous theoretical or experimental studies have been performed to investigate its hydrodynamic characteristics of the porous structures e.g. Lean [18], Sollitt and Cross [36], Madsen [25], Madsen [26], Sulisz [39], Dalrymple et al. [6], Huang and Chao [10], Losada et al. [22], Mallayachari and Sundar [27], Yu [47], and Liu et al. [21].

Recently, Isaacson et al. [12] presented a theoretical analysis and an associated numerical model used to assess the performance of a breakwater. The breakwater consisted of a perforated front wall, an impermeable back wall, and a rock-filled core. The numerical method was based on an Eigenfunction Expansion and utilizes a boundary condition at the perforated wall that accounts for energy dissipation. Requejo et al. [34] proposed a mathematical model to solve the potential flow around and inside a porous breakwater. The reflection, transmission, dissipation, horizontal and vertical forces and overturning moment were solved. Twu et al. [43], Twu and Liu [44] developed a computational model to investigate the wave damping characteristics of a periodic array of vertically porous structures. This is under normal and oblique regular waves. The wave transmission, reflection and energy dissipation coefficients were evaluated relating to the physical properties and geometric factors of the structure.

Hsu et al. [9] derived an analytical solution of oblique water waves impacting on thin porous walls. This is based on the concept that the wave direction remains unchanged as it permeates into the thin porous medium. Lin and Karunarathna [20] studied the solitary wave interaction with porous breakwaters by using a two-dimensional numerical model. The flows outside of porous media were described by Reynolds-averaged Navier–Stokes equations. Theocharis et al. [40] investigated experimentally a new type of wave absorbing quay-wall with a partial wave chamber containing a rock-armored slope. In addition to the basic design containing a wave chamber with an impermeable back wall, several alternative absorbing systems use rock within the core of the wave chamber. Koraim and Rageh [17] experimentally studied the efficiency of the emerged porous structures under regular waves with wide ranges of wave heights and periods.

2.2. Submerged breakwaters

Since the pioneering study by Jeffreys [13] on the wave transmission due to the rectangular submerged breakwater several studies were investigated e.g. Dick and Brebner [8], Madsen [25], Seeling [35], Abdul Khader and Rai [1], Kobayashi and Wurjanto [15], Abul-Azm [2], Lee and Liu [19], Isaacson et al. [11], Losada et al. [23] and [24].

Recently, Twu et al. [42] studied theoretically the problem of wave transmission over rectangular and vertically stratified with multi-slice porous material. This is by using the eigenfunction expansion method. Koraim [16] investigated experimentally and theoretically the wave interaction with different impermeable submerged structures resting on horizontal and sloping beaches. Stamos et al. [37] conducted experimental study to compare the reflection and transmission characteristics of submerged hemi-cylindrical, rectangular rigid and water-filled flexible breakwater models. Ting et al. [41] investigated how the porosity of submerged breakwaters affects non-breaking wave transformations. Eight models with six different porosities, from 0.421 to 0.912, were also tested.

Cokgor and Kapdasli [5] carried out an experimental study on the improvement for the problem of wave transmission in slightly submerged breakwaters. The breakwater shape, effect of the porosity, water depth regarding the breakwater crest height and, dynamic stable deformed breakwater were examined. Min et al. [29] investigated the submerged breakwaters that were made up of a plurality of concrete modules. This is for controlling shoreline erosion in coastal wetlands. Small-scale model tests were conducted to assess the wave transmission characteristics of the modular submerged breakwaters. Ahmed and Anwar [3] investigated experimentally the efficiency of the submerged breakwater as shore protection structure. The type of wave breaking and the position of wave breaking were simultaneously recorded with a digital video camera. Koraim and Rageh [17] experimentally studied the efficiency of the vertical submerged porous structures under normal and regular waves with wide ranges of wave heights and periods.

2.3. Walls defense by breakwaters

There is a little information about the effect of the breakwaters on the wave run up occurred on the seawalls. Wu et al. [45] investigated the wave reflection by a vertical wall with a horizontal submerged porous plate applying the linear water wave theory and the eigenfunction expansion method. Jeng et al. [14] studied experimentally the interaction between water waves, a submerged breakwater, a vertical wall and a sandy seabed. They conducted experiments to record the water surface elevation and the pore pressures inside the seabed foundations. Reddy and Neelamani [32] curried out a series of experiments to assess the influence of the offshore low-crested breakwater as a defense structure in reducing the wave forces on vertical seawall.

Neelamani and Sumalatha [31] investigated the hydrodynamic performance in terms of wave reflection, run-up and run-down and wave pressures on plane seawalls protected by an offshore breakwater in a random wave field. Reddy et al. [33] presented the numerical and experimental investigations on the performance of an offshore-submerged breakwater in reducing the wave forces and wave run up on vertical wall. A two dimensional finite element model was employed to study the hydrodynamic performance of the submerged breakwater under the action of regular and random waves. Zheng et al. [48] analyzed analytically the radiation and the diffraction of linear water waves by an infinitely long floating rectangular structure. The structure was submerged in water of finite depth with leeward boundary being a vertical wall using the eigenfunction expansion method.

The detailed literature review reveals that there are some references available on similar models. There are little works, in particular experimental investigations, carried out for studying the vertical porous seawalls with or without the submerged breakwaters. In the present study, the efficiency of the vertical porous seawall that consists of front screen, back solid wall and filled rock-core is experimentally studied using physical model. In addition, the effect of the submerged breakwater with different characteristics on the seawall efficiency is investigated. Different wave and structure parameters are investigated e.g. the incident wave length and height, the seawall porosity and width and the submerged breakwater height, width and shape.

3. Experimental work

Two different series of experiments are carried out in two different wave flumes in the Faculty of Engineering, Zagazig University, Zagazig, Egypt. The wide wave flume of 17.0 m long, 1.2 m deep, and 2.0 m wide is in the Irrigation and Drainage Laboratory. A flap type wave generator with maximum stroke distance of 0.25 m is installed at one end of the flume. It generates regular wave trains with wave periods and heights of $T = 0.88–1.8$ s and $H_i = 0.03–0.10$ m. A gravel wave absorber with slope 4:1 is installed at the other end of the flume. The narrow wave flume of 13.0 m long, 0.45 m deep, and 0.30 m wide is in the Hydraulics and Water