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Porous Flow in a Vertical Breakwater Induced by Nonlinear Waves

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ABSTRACT

A study is conducted to evaluate the wave-induced porous flow in a vertical, permeable breakwater. Experiments were performed in a 2-dimensional wave tank to study the wave-induced particle motion in a vertical, porous breakwater model. The water-surface levels were recorded on both sides of the breakwater, and a video camera was employed to monitor the motion of small particles inside the porous media. The trajectory of a particle is classified here into 6 patterns due to the chaotic motion in the pores. A variety of incident wave conditions and various properties of the porous media were examined in the experiment to explore their influence on the water-particle motion inside a porous medium. A coupled BEM-FEM model, developed by the authors, was also adapted to compute the porous flow parameters in the breakwater as well as the wave deformation in its vicinity. Comparisons have been made between the numerical and experimental results of water-surface levels around the breakwater and the average displacement of a particle in the porous media. It has been found that the numerical model predicts the wave deformation well, and provides a reasonable estimate of the particle motion in the porous media. Longer and higher waves have been found to be very efficient in causing larger net horizontal displacement of the particles. On the other hand, larger porosity and/or diameter of solids in the porous media are found to cause less chaotic motion and larger net displacement of the particles.

INTRODUCTION

The wave-induced flow in a porous medium and the corresponding travel time of a small solid particle through the pores from the offshore to the onshore side are very important parameters with respect to the water quality onshore a breakwater. The pores contain tiny air bubbles necessary for the oxidation of micro-organisms carried by waves into the breakwater. In other cases, the Dissolved Oxygen (DO) in the seawater may be used for the oxidation of organic material trapped inside the porous media. Thus, the travel time in the porous media affects the biological processes in the pores, hence the water quality inside and onshore a breakwater. The water-particle velocity is generally reduced as it travels through the porous media by the effect of damping friction. On the other hand, unless a sufficient flow of water goes to the onshore side of a breakwater at relatively high velocity, the water quality on the onshore side deteriorates due to lack of water circulation. Evaluating the parameters affecting the water-particle motion in a porous structure is tedious due to the fact that the motion is basically chaotic in a porous medium. Moreover, the interaction between the wave domain and the porous media is a rather complicated problem to solve.

Sollit and Cross (1972) studied the interaction between linear waves and a porous vertical breakwater. They linearized both the wave and porous flow equations and developed an analytical solution to study the wave field around a vertical breakwater. Madsen (1974) simplified the Sollit and Cross theory in the case of long normally incident waves to reduce the computational time at a comparable accuracy to the original theory. However, such techniques can only provide an overview of the problem investigated without sufficient details. This is due to ignoring the nonlinear wave deformation along with the possible occurrence of non-Darcy flow in a porous breakwater.

A mixed numerical model for the simulation of wave motion in rubble mound breakwaters was developed to check the dynamic stability of the seaward slope under severe wave attack (Hannoura and McCorquodale, 1985). They utilised the modified Navier-Stokes equations for flow in a porous medium and laboratory records of the wave pressure as a boundary condition for the numerical model. Losada et al. (1995) conducted laboratory experiments to study the wave-induced flow in a porous structure. They studied the temporal and spatial variations of the pore water's kinematics and examined the validity of the theory developed by Sollit and Cross (1972). They reported that the linearized porous flow equations commonly adopted by other researchers are not valid in case of flow in a very porous structure or at least in the main layers of a rubble mound breakwater.

Losada et al. (1998) investigated the wave-induced mean flow in vertical rubble mound structures using second-order waves and linearized porous flow equations. They showed that a porous breakwater is mechanically equivalent to the surf zone in the sense that it may cause wave set-up/set-down as well as a mean flow analogous to undertow. Sulisz (1998) studied the interaction between second-order surface waves and a rectangular cylinder over a rubble base. He focused on the wave forces acting on the cylinder and the contribution of the wave components, while using the linearized porous flow equation in the computations. He revealed that second-order wave loads may exceed by many times the corresponding first-order quantities.

Mizutani et al. (1996) developed modified Navier-Stokes equations for flow in a porous medium by comparing the resis-

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KEY WORDS: Wave-structure interaction, porous flow, water quality, boundary element method, finite element method.