Interactions of Horizontal Circular Porous Plates with Waves

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ABSTRACT

As a preliminary study to search for effective breakwaters, the interactions between monochromic incident waves and circular porous plates are investigated within the context of linear potential theory. The porous plate is horizontally fixed beneath the water surface. The Darcy’s law is applied to the boundary condition on the porous plates to keep consistent with the linearity. The boundary value problem is solved by means of the Eigen-function expansion for multiple domains to obtain semi-analytical solutions. A series of Bessel-Fourier expansion is used to represent the normal velocity across the plate, which is assumed to be continuous according to the Darcy’s law. The forces acting on the plates are evaluated once the velocity potential is solved by the above methods. The wave field around the plates is examined to estimate the blockage by the porous plates. The effects of wave parameters, submerged depth and porosity of plates are studied by a series of systematic calculations.

KEY WORDS: porous plate; eigenfunctions; porosity; particular solution.

INTRODUCTION

In the past decades, a lot of theoretical and experimental studies have been made on the wave energy dissipation by porous plates. Based on the linear wave theory and Darcy’s law, Chwang (1983), Chwang and Li (1983) developed a porous wave-maker theory to investigate the porous effect on free-gravity waves and the influence of dimensionless wave-effect parameter and porous-effect parameter was discussed. By means of the matched eigenfunction-expansion method, the interaction between the scattering waves by a submerged porous disk was investigated (Chawang and Wu, 1994; Neves et al., 2000; Liu et al., 2008; Bao el al., 2009; Zhao et al., 2010; Liu and Li, 2011). Moreover, multiple horizontal plates were also studied by several researchers. (Liu et al., 2008). In the solutions, the complex dispersion relations were encountered. The complex roots of the dispersion relations were the so-called complex wave numbers. Cho and Kim (2008) extended the theory to develop multi-layer submerged horizontal porous wave absorbers in front of a rigid vertical wall and validated their analytical results by conducting a series of experiments with scaled porous plates. Cho et al. (2013) further extended the method to develop dual submerged horizontal porous plates and conducted performance of parameters such as porosity, submergence depth, and plate width and so on.

Following the quadratic relation between traversing velocity and pressure differential in the case of perforated or slotted structures, Molin and his research group (see e.g. Molin and Legras (1990), Molin and Nielsen (2004), and Molin, Remy and Ripol (2007)) made some theoretical and experimental study on solid and perforated disks. In their solution, the complex dispersion relation was avoided by expanding the traversing velocity across the porous plate. Liu and Li (2011) developed an alternative analytical solution for wave interaction with a submerged horizontal porous plate breakwater by introducing appropriate artificial velocity potentials. Also no complex dispersion relation was needed.

In the present work, the problem of a porous circular plate fixed horizontally in waves is studied. The problem is investigated within the scope of linear potential theory. Instead of finding complex wave number in the regions where the plate is located, approach suggested by Molin and his colleagues is adopted, which means that the vertical velocity across the plate is expressed in a form of Bessel-Fourier expansion. The problem is solved by the method of Eigen function expansion. The fluid domain is divided into three regions and different expansions are searched in these regions. They are matched at the common surface to determine the unknown coefficient in the expansions. The wave loads and wave field around the plate are calculated. Some calculated examples are presented and their properties are discussed.

MATHEMATICAL FORMULATION

The Boundary Value Problem

The problem to be considered here is the interaction between a circular porous plate with radius a and a train of regular waves. The plate is horizontally submerged in a water of depth h at a distance of d beneath the water surface. A cylindrical coordinate system is adopted to describe the problem. Its horizontal r=θ plane coincides with the still water plane with the z-axis pointing vertically upwards and going through the center of the circular plate (see Fig. 1).

The fluid is assumed to be inviscid and the flow to be irrotational. There exists a velocity potential \( \Phi(r, \theta, z, t) \). The fluid motion is further