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Wave Deformation and Blocking Performance by *N* Porous Bottom-mounted Vertical Circular Cylinders

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The interactions of a porous, vertical cylinder array with regular and irregular incident waves and its performance as a breakwater are investigated by numerical simulations and medium-scale experiments. The interaction theory is based on linear potential theory for *N* bottom-mounted vertical cylinders, and the porous effects are included through Darcy's law. The empirical relationship between the plate porosity and porous parameter obtained from the experiments of Cho and Kim (2008) is applied to the present problem. The numerical results agree well with the measured data for 4, 6 and 10 tightly connected porous cylinder cases. Both transmitted and reflected waves as well as wave run-up and exciting forces are significantly reduced due to wall porosity. The results show that the optimal design of seawater-exchanging breakwaters for a given sea state can be found through a systematic parametric investigation by controlling the size, number, porosity and arrangement of circular cylinders.

INTRODUCTION

Various types of permeable breakwaters have been proposed for the protection of coastal regions and construction sites. Permeable breakwaters can be used to effectively reduce both transmitted and reflected wave heights. The wave run-up and hydrodynamic forces on the structures can also be significantly reduced. Recently, the requirement to improve seawater quality inside a harbor is being increasingly implemented, and the permeable breakwater is appealing in this regard since it allows the exchange of inner and outer waters. This paper investigates the height and force reduction of both regular and irregular long-crested incident waves due to a breakwater composed of *N* bottom-mounted porous vertical circular cylinders. This type of porous breakwater can be rapidly installed by using prefabricated modules, and it can be applied to temporary breakwaters for coastal construction or temporary harbors for amphibious military operations.

The analytic solution for the diffraction of linear regular waves by a bottom-mounted vertical circular cylinder was first obtained by MacCamy and Fuchs (1954). The interaction of incident regular waves with a 3D porous vertical circular cylinder was investigated by Wang and Ren (1994), in which the performance of a concentric 2-cylinder system (exterior porous and interior solid) was solved analytically; Wang and Ren provide useful hydrodynamic information for the design of an offshore porous structure. Yu and Chwang (1994) studied the wave-induced oscillation inside a semi-circular harbor with a porous breakwater; they showed that the harbor's resonant oscillation depends closely on the properties of the porous medium, which may be concrete tetrapods or rubble mounds. Those studies, however, were limited to a single vertical circular cylinder.

On the other hand, the diffraction of incident waves by a group of impermeable vertical circular cylinders was also studied by many researchers (e.g. Ohkusu, 1974; Spring and Evans, 1984; Kagemoto and Yue, 1986; Linton and Evans, 1990; Maniar and Newman, 1997; Evans and Porter, 1999; Kashiwagi, 2000). Kim (1993) extended the Linton and Evans (1990) diffraction theory for *N* cylinders to the corresponding radiation problems.

In this paper, the interaction theory of Linton and Evans (1990) for *N* bottom-mounted vertical circular cylinders is extended to include the effect of wall porosity in the context of linear potential theory. The basic theory similar to the present study was also introduced by Williams and Li (2000). It is assumed that the circular-cylinder wall is made of a material with very fine pores so that the normal velocity of the fluid passing through it is linearly proportional to the pressure difference between the wall's 2 sides. The same porosity model, called Darcy's law, was also used by Chwang (1983), Chwang and Wu (1994), Yu (1995), Wang and Ren (1994), and Cho and Kim (2008). In the case of wave interaction with submerged porous plates, Darcy's model was validated by Cho and Kim (2008) through small- and large-scale experiments.

The primary concern in this study is the performance enhancement of an array of *N* porous vertical cylinders as a wave barrier by changing its size, number, porosity, arrangement and wave condition. Both regular and irregular incident waves are considered. Most importantly, the theory and numerical results are strongly supported by our model tests with 4, 6 and 10 porous cylinder arrays. The medium-scale experiments are conducted in a 30-m × 7-m × 1.5-m wave basin.

MATHEMATICAL FORMULATION

We consider the interaction of monochromatic waves with arrays of *N* bottom-mounted, surface-piercing, thin-walled, porous circular cylinders of radius a_j $(j = 1, 2, \ldots, N)$. For analysis, the Cartesian coordinate system (x, y, z) as well as the polar coordinate system (r, θ, z) are chosen with the origin on the undisturbed free surface and z-axis pointing vertically upwards. We also use *N* local polar coordinate systems (r_j, θ_j, z),

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