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Axisymmetric gravity wave diffraction by flexible porous cylinder system in two-layer fluid

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ABSTRACT

The present study deals with the hydroelastic analysis of axisymmetric gravity wave interaction with concentric flexible porous cylinder systems in two-layer fluid having a free surface and an interface in water of finite depth. The cylinder system consists of a rigid cylinder and an outer flexible porous cylinder. Both the cases of complete and partial cylinders such as bottom-standing and surface-piercing partial cylinders are considered. The mathematical problem is handled using a generalized orthogonal relation suitable for two-layer fluid along with the least squares approximation method. Further, the role of flexible porous cylinder in attenuating wave forces on the rigid cylinder is analyzed in various cases. The effectiveness of the cylinder systems in trapping surface waves are analyzed from the numerical results in different cases by analyzing the reflection coefficients, wave elevations in surface and internal modes, deflection of the flexible porous outer cylinder under wave action and wave forces acting on both the inner and outer cylinders. The study reveals that full wave reflections in surface and internal modes occur when the annular distance between the cylinders is approximately an integer multiple of half of the wave length and the phenomenon is independent of the barrier configurations.

1. Introduction

The rise in sea water level is one of the greatest menaces to coastal community. To protect various marine infrastructures along the coast, there is a need to create tranquility zone. In recent decades, there is a significant interest in the dynamical analysis of wave interaction with porous structures due to their ability to reduce wave loads on various coastal structures via energy dissipation. As compared to rigid fixed structures, flexible structures are environmental friendly, reusable, and can be used to develop low cost wave attenuation and protection system. Thus, the study of wave interaction with flexible porous structures is of immense importance in ocean engineering.

The classical problem of forced axisymmetric wave motion generated by a harmonically oscillating impermeable cylindrical wave maker in a homogeneous fluid of constant density was first studied by Havelock (1929). Rhodes-Robinson (1971) extended this study to include the effect of surface tension. Chwang (1983) developed the porous wave maker theory under the assumption of small amplitude water wave theory. Lee and Chwang (2000) used least squares approximation method to study wave scattering by partial porous barriers. Yip et al. (2002) analyzed wave trapping by partial flexible porous structure located near a fixed rigid wall using the porous wavemaker theory of Chwang (1983). Faltas (1996) investigated trapping of oblique surface waves due to axisymmetric oscillation of an inner impermeable cylinder surrounded by an outer porous cylinder and found that under certain circumstances, the outer cylinder can work as an effective wave absorber. Sahoo (1998) investigated the generation of cylindrical surface waves by a concentric cylinder immersed vertically in the water of infinite depth. Shipway and Evans (2002) studied wave trapping by axisymmetric concentric cylinders and found that wave trapping can occur in the annular region between two partially immersed vertical concentric cylindrical shells for certain values of radii and frequencies. Mavrakos (2005) predicted the hydrodynamic radiation forces due to heaving motion in the case of independently moving partially immersed concentric cylinders.

Apart from axisymmetric gravity wave problem, there is a significant development on the scattering of short-crested gravity waves by concentric cylinder system in single layer fluid. Wang and Ren (1994) studied gravity wave interaction with concentric cylinder system in which the outer cylinder is porous. Sankarbabu et al. (2007) studied wave interaction with a group of dual porous circular cylinders and investigated the influence of multiple

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interactions between the cylinders in the group. Further, Sankarbabu et al. (2008) extended their earlier study to investigate hydrodynamic performance of a dual cylindrical caisson breakwater. Zhong and Wang (2006) and Song and Tao (2007) extended the work of Wang and Ren (1994) in both the cases of solitary and general short-crested waves interaction with concentric cylinder system respectively. Interesting study on short-crested waves interaction with a concentric cylindrical structure can be found in Liu et al. (2012) and Lin and Liu (2012). Vijayalakshmi et al. (2008) studied the hydrodynamic performance of twin perforated cylinder systems. Liu and Lin (2013) studied the gravity wave interaction with concentric cylinder system where the outer porous cylinder is of arbitrary shape. All the aforementioned studies are in single layer fluid with the outer cylinder being assumed to be rigid and permeable. Recently, Mandal et al. (2013) studied wave interaction with concentric truncated cylinder system consisting of an inner rigid cylinder and an outer flexible porous cylinder in single layer fluid by analyzing various structural and wave parameters. They found that wave forces attain zero minimum for the same annular spacing irrespective of the cylinder draft.

In the recent decades, there is an increasing interest on the study of wave–structure interaction problems in two-layer fluid. Unlike the case of wave motion in a single layer fluid, in the case of two-layer fluid, due to the presence of free surface and interface, there exist two progressive wave modes in surface and interfacial modes which are referred as waves in surface mode (SM) and waves in internal mode (IM) respectively. Often, the mutual interaction between the waves in SM and IM yields interesting physical consequences which are of significant interest for wide varieties of problems in marine science and engineering. The classical problem of two-dimensional small amplitude wave motion of two superposed non-mixing fluids separated by an interface with the upper fluid having a free surface is discussed in Lamb (1932) and Wehausen et al. (1960). Linton and McIver (1995) developed a general theory to deal with the problem of two-dimensional wave scattering by horizontal cylinders in two-layer fluids in which the upper surface of the upper fluid is free. They solved the problems of wave scattering by a horizontal circular cylinder using multipole expansions. Cadby and Linton (2000) generalized the work of Linton and McIver (1995) to three dimension. Further, Linton and Cadby (2002) extended the work of Linton and McIver (1995) to analyze oblique wave interaction with horizontal circular cylinder in either the upper or lower layer. Sherief et al. (2003) analyzed the forced gravity wave motion by a porous wave maker immersed vertically in a two-layered fluid under the assumption of linear water wave theory. This work was generalized by Sherief et al. (2004) to study the axisymmetric wave motion in the presence of a cylindrical porous wave maker immersed vertically in a two-layered fluid. Manam and Sahoo (2005) studied wave scattering by porous structures in a two-layer fluid. Kumar et al. (2007) analyzed the wave scattering by flexible porous membrane in a two-layer fluid. Behera et al. (2013) investigated the oblique wave trapping by flexible porous barrier near a wall in two-layer fluid in water of finite depth. They derived explicit relation for full reflection in surface and internal modes. Recently, Sahoo (2012) highlighted the significant developments on wave interaction with vertical flexible porous structures both in single and two-layer fluids. However, there is no study on axisymmetric gravity wave interaction in two-layer fluid with concentric cylinder system where outer cylinder is flexible porous in nature.

In the present study, the axisymmetric gravity wave interaction with a concentric cylinder system in two-dimensions is studied in finite water depth under the assumption of small amplitude water wave and structural responses in two-layer fluid having a free surface and an interface. The cylinder system consists of an inner rigid non-porous cylinder surrounded by a flexible porous outer cylinder which is under the action of uniform compressive force. The types of cylinder system analyzed in the present study include the complete cylinders extended from free surface till the bottom and the two types of partial cylinders namely (a) surface-piercing cylinders and (b) bottom-standing cylinders. In both the cases, the outer flexible porous cylinder is assumed to be fixed at the bottom and free at the top. Using a Fourier–Bessel series type expansion formulae and the least squares approximation method, the mathematical problem is handled for solution to derive the expression for the velocity potentials, wave amplitude at free surface and interface, structural responses and wave loads on the structure. Effects of different structural, wave parameters and annular

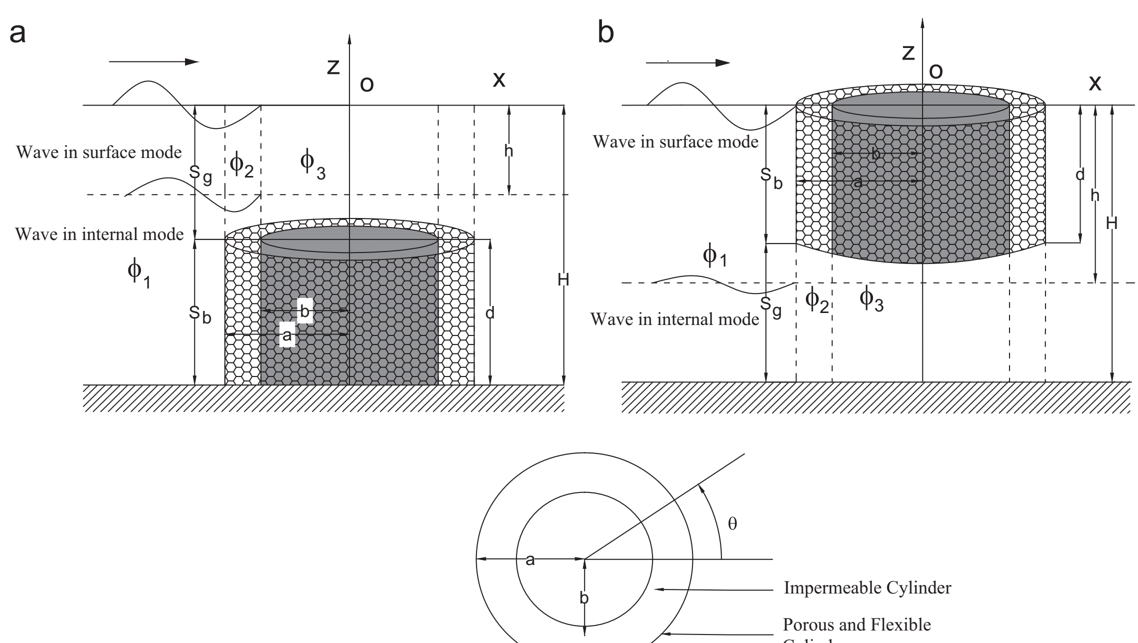

Fig. 1. Schematic diagrams of partial concentric (a) bottom-standing and (b) surface-piercing cylinder systems.