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Hydroelastic analysis of surface wave interaction with concentric porous and flexible cylinder systems

S. Mandal, N. Datta, T. Sahoo *

Department of Ocean Engineering and Naval Architecture, Indian Institute of Technology, Kharagpur 721 302, India

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ABSTRACT

The present study deals with the hydroelastic analysis of gravity wave interaction with concentric porous and flexible cylinder systems, in which the inner cylinder is rigid and the outer cylinder is porous and flexible. The problems are analyzed in finite water depth under the assumption of small amplitude water wave theory and structural response. The cylinder configurations in the present study are namely (a) surface-piercing truncated cylinders, (b) bottom-touching truncated cylinders and (c) complete submerged cylinders extended from free surface to bottom. As special cases of the concentric cylinder system, wave diffraction by (i) porous flexible cylinder and (ii) flexible floating cage with rigid bottom are analyzed. The scattering potentials are evaluated using Fourier–Bessel series expansion method and the least square approximation method. The convergence of the double series is tested numerically to determine the number of terms in the Fourier–Bessel series expansion. The effects of porosity and flexibility of the outer cylinder, in attenuating the hydrodynamic forces and dynamic overturning moments, are analyzed for various cylinder configurations and wave characteristics. A parametric study with respect to wave frequency, ratios of inner-to-outer cylinder radii, annular spacing between the two cylinders and porosities is done. In order to understand the flow distribution around the cylinders, contour plots are provided. The findings of the present study are likely to be of immense help in the design of various types of marine structures which can withstand the wave loads of varied nature in the marine environment. The theory can be easily extended to deal with a large class of problems associated with acoustic wave interaction with flexible porous structures.

1. Introduction

In recent decades, there has been significant interest in the dynamic analysis of wave interaction with porous structures, for their ability to reduce wave loads on various coastal structures, via energy dissipation. Flexible structures offer the opportunity to have a quickly deployable, reusable and low cost wave attenuation and protection systems, as compared to those by the rigid fixed structures. Thus, porous and flexible structures are preferred as wave attenuators in various wave attenuation systems in the marine environment. Hence, the accurate prediction of wave loads on a flexible porous structure and the hydroelastic response of the structure to waves are of great importance in coastal-engineering designs.

* Corresponding author. Tel.: +91 32 2228 3792; fax: +91 32 2225 5303.
E-mail addresses: tsahoo1967@gmail.com, tsahoo@naval.iitkgp.ernet.in (T. Sahoo).

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Chwang (1983) developed a porous wave maker theory to analyze small-amplitude surface waves produced by horizontal displacement oscillations of a porous vertical structure. Chwang and Dong (1984) studied the wave trapping by a porous structure near a rigid wall. Wang and Ren (1993) presented a theoretical solution to investigate the various wave characteristics and dynamic response of wave interaction with a porous and flexible breakwater. It was observed that for a rigid porous breakwater, the maximum hydrodynamic force acting on the structure reduces to a great extent. Sahoo et al. (2000) studied the trapping and generation of waves by partial porous barriers placed near a vertical wall using least squares approximation method which was previously used by Lee and Chwang (2000). Chan and Lee (2001) analytically studied the scattering of surface waves by a flexible fishnet of negligible mass. Later, Yip et al. (2002) studied the wave trapping by partial porous and flexible structures. They calculated the hydrodynamic force, the overturning moment and the flexural deflection of the barrier. It was observed that the deflection at the free end was larger in case of surface-piercing barrier than for bottom-touching barrier. Recent developments on wave interaction with flexible structure of various configurations have been discussed in Chapter 4 of Sahoo (2012). Recently, Song and Faltinsen (2013) analyzed the forced harmonic heave motion of submerged and perforated horizontal plates experimentally and numerically.

On the other hand, Wang and Ren (1994) studied the interaction of gravity waves with concentric cylinder system with the outer cylinder being permeable in nature. Sankarbabu et al. (2007) extended this work for a group of dual porous circular cylinders. Darwiche et al. (1994) theoretically investigated the water wave interaction with concentric cylindrical breakwaters, with the inner rigid impermeable cylinder surrounded by a semi-porous outer cylinder. They reported that for certain combinations of the various physical parameters, the semi-porous structure significantly reduces the hydrodynamic forces experienced by the inner cylinder. Faltas (1996) studied wave trapping phenomenon due to axi-symmetric oscillations of the inner impermeable cylinder and outer porous cylinder alternately. It was found that under certain circumstances, the porous wall acts as an effective wave absorber. Zhong and Wang (2006) and Song and Tao (2007) analytically studied the works of Wang and Ren (1994) for solitary and general short-crested wave interaction with a concentric cylinder system respectively, while Vijayalakshmi et al. (2008) experimentally studied the influence of porosity using boundary integral equation method and recommended an effective range of porosity based on the experimental results. Chen et al. (2011) employed a boundary integral equation method which was referred as null-field approach to investigate the hydrodynamic diffraction induced by arrays of circular cylinders whereas Liu et al. (2012) investigated the interaction of short-crested wave with a concentric cylindrical structure with double-layered perforated walls using scaled boundary finite-element method (SBFEM). Meng and Zou (2012) studied wave interaction with arbitrary shaped single bottom mounted uniform porous cylinder using SBFEM. Liu and Lin (2013) analyzed the gravity interaction with concentric cylinder system assuming that the outer porous cylinder is of arbitrary shape using SBFEM. All the aforementioned studies are for gravity wave interaction with concentric cylinder system, in which the outer cylinder is permeable in nature and the cylinders are completely submerged. On the other hand, Abul-Azam and Williams (1987) presented an approximate method to estimate the hydrodynamic loadings and dynamic responses between flexible cylinders in waves. Finnegan et al. (2013) studied the wave scattering by floating truncated cylinder in water of infinite depth to determine an analytical approximation for the wave excitation forces.

Apart from the gravity wave interaction with cylinder system, there has been a parallel interest on the acoustic wave interaction with flexible cylinders. Avital and Miloh (2011) studied the problem of sound scattering by free surface piercing fluid-loaded cylindrical shells, where the flexibility of a cylindrical shell was utilized to find possible configurations of an external load acting on the shell that would result in the demise of the scattered waves. However, there has been no study on wave interaction with flexible porous cylinders including radiation diffraction problems.

In the present paper, the hydroelastic response of a three-dimensional porous flexible concentric cylinder system in regular waves is investigated in finite water depth using small amplitude surface water wave theory. The cylinder system consists of an inner cylinder (assumed to be rigid and fixed) and an outer concentric cylinder (assumed to be porous and flexible). The cases of completely submerged cylinders (extending from the free surface till the bottom) and truncated cylinders are analyzed, using the porous wave maker theory developed by Chwang (1983), including the inertia term as discussed in Yu and Chwang (1994). The two types of truncated cylinder system of study are (a) the surface-piercing cylinders and (b) the fully submerged bottom-touching cylinders. The flexible porous cylinder is assumed to be fixed at the bottom and free at the top. As special cases of the concentric cylinder system, wave diffraction by (i) truncated hollow porous and flexible cylinder and (ii) floating cage (modeled as flexible floating porous cylinder acting under tension having rigid bed) are analyzed. The least square approximation method is used, along with Fourier–Bessel series expansion, to derive the scattering potentials. Effects of structural flexibility, gap between the cylinders (referred as annular spacing), and porosity on the horizontal forces and overturning moments acting on the structure are analyzed from the computational results, for understanding the role of cylinder systems of various configurations.

2. Wave interaction with a concentric cylinder system

In the present section, surface gravity wave interaction with a concentric porous and flexible cylinder system is analyzed under the assumption of small amplitude water wave theory and structural response assuming that the wave past the porous structure obeys Darcy's law. The solution of the associated mathematical problem is obtained using least square approximation method and characteristics of the Fourier–Bessel series used to deal with problems in cylindrical co-ordinate system.