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Wave trapping by porous barrier in the presence of step type bottom

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HIGHLIGHTS

- The study deals with wave trapping by porous barrier having undulated bottom bed.
- The physical problem is solved using modified mild-slope approximation.
- Number of times optimum reflection occurs is more for undulated bed than flat bed.
- Zero reflection occurs for specific undulated bed profiles.
- The present study will be useful in the creation of tranquility zone.

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ABSTRACT

The present study deals with the trapping of oblique wave by porous barrier located near a rigid wall in the presence of a step type bottom bed. The solution of the physical problem is obtained using the eigenfunction expansion method and multi-mode approximation associated with modified mild-slope equation. Assuming that the porous structure is made of materials having fine pores, the mathematical problem is handled for solution by matching the velocity and pressure at interface boundaries. Various numerical results are computed and analyzed to understand the role of bed profiles, structural porosity, depth ratio, oblique angle of incidence, distance between barrier and step edge and, the distance between the porous barrier and rigid wall in optimizing wave reflection and load on the structure/rigid-wall. A comparison of results on wave trapping by porous barriers over flat and undulated bed reveals that for the same distance between the porous barrier and rigid wall, more number of times optimum reflection occurs in case of undulated bed. The present study is likely to be of immense importance in the design of coastal structures for protecting coastal infrastructures.

1. Introduction

In recent decades, significant increase in developmental activities along the coast due to the rise in world population is exerting greater pressure on the coastal countries for protection of coastal infrastructures/facilities by various measures. In addition, with an increase in global trading, substantial increase in harbor traffic results in the deterioration of wave conditions in various ports and harbors around the world. Further, the rise in sea level is putting additional pressure on the existing coastal infrastructures. In this context, the study on wave interaction with coastal structures provides useful

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information about various physical processes associated with coastal protection or attenuating wave heights in confined water bodies such as bays/ports/harbors. Most of the coastal structures such as breakwaters, used for shore protection and/or creating a tranquility zone by reducing wave impact near harbors, are vertical and rigid in nature. These vertical rigid structures used to collapse under extreme wave climates like tsunami and storm surges. For reducing wave loads on these type of structures, perforated/wave absorbing structures of various configurations are proposed as alternatives due to their ability to dissipate wave energy. In addition, various study on wave trapping by porous structures reveal that wave loads on existing rigid wall can be minimized by introducing porous structure at a suitable distance from the rigid wall. The minimum wave reflection is often referred as wave trapping. In the context of wave interaction with coastal structures, there are mainly two class of problems namely wave scattering and trapping by porous structures are studied in uniform water depth. However, wave motion over undulated sea bed is of considerable interest in coastal engineering practices including development of infrastructures like ports and harbors. Thus, for protection of marine facilities and coastal infrastructures in coastal zones, there is renewed interest to study wave interaction with coastal structures like breakwaters in the presence of undulated bottom bed.

There is an extensive literature on wave trapping by rigid or flexible and/or porous vertical structures in the presence of uniform bottom topography. The most widely used model for wave past thin porous structure is based on the modified boundary condition derived by Yu [1] which was initially proposed by Chwang [2]. However, various study on wave trapping are based on small amplitude water wave theory and will be useful for reducing wave forces on vertical sea/harbor wall and for creating low reflection from harbor walls in various ports (as in McConnell et al. [3]). Sahoo et al. [4] studied trapping and generation of surface gravity waves by submerged vertical permeable barriers. Yip et al. [5] analyzed wave trapping by considering flexibility in porous barrier. Further, the study of Chwang and Chen [6] reveals that a knowledge of wave characteristics and harbor configurations helps in the design of new harbor walls or finding ways to determine wave absorbing sea walls by introducing suitable permeable structures at finite location near the harbor wall. Bhattacharjee and Guedes Soares [7] investigated diffraction of water waves by a finite rigid floating structure near wall, considering vertical step in uniform bottom. Applying Sollitt and Cross model, Koley et al. [8] analyzed oblique wave trapping by porous structures having finite width, placed near a rigid wall. Kaligatla et al. [9] analyzed wave trapping by flexible porous plate by converting the boundary value problem into system of integro-differential equations in both the cases of finite and infinite water depths. These studies on wave trapping are performed in homogeneous fluid of uniform water depth. On the other hand, water wave trapping by porous structures of various configurations in two-layer fluid are studied by Behera and Sahoo [10] whilst, oblique wave trapping by partial flexible and porous barriers of different configurations are studied by Behera et al. [11].

The aforementioned discussions on gravity wave interaction with porous structure are for normalized/obliquely incident waves in uniform water depth. Unlike, these plane waves travel in a fixed direction and the associated standing waves fluctuating vertically in a confined region, short-crested waves are doubly periodic along the horizontal directions, one of which is in the direction of propagation and the other being normal to it (as in Zhu [12] and Tsai et al. [13]). Song and Tao [14] studied the interaction of short-crested waves with a concentric porous cylindrical structure in a quantitative manner. Recently, Mandal et al. [15] studied the hydroelastic response of surface waves by porous and flexible cylinder system.

In the presence of varying bottom topography, using the Galerkin method proposed by Massel [16]. Suh and Park [17] developed an analytical model to predict oblique wave reflection by a perforated wall caisson mounted on a rubble mound foundation with sloping step, following the model of Fugazza and Natale [18]. However, the above mentioned Galerkin method for varying bottom beds fails to ensure continuity of mass flow at the interface between two domains. The natural mass conserving jump conditions at the bottom slope discontinuities are derived by Porter and Staziker [19] by means of variational principle. In the last two decades, there is significant progress for developing efficient model equations to deal with wave interaction with varying bottoms. Among those, a typical popular model equation is the modified mild-slope equation (MMSE) derived by Chamberlain and Porter [20]. The MMSE with correct interfacial matching conditions at the locations where the bed slope is discontinuous, has been found to be efficient model for bottom slopes up to 1. Further, MMSE was extended to study scattering of flexural and membrane-coupled gravity waves (as in Porter and Porter [21], Bennetts et al. [22], Bennetts et al. [23], Manam and Kaligatla [24]). Apart from use of MMSE for wave motion in homogeneous fluid medium having bottom undulation, the concept of MMSE is extended to study wave scattering due to bottom undulation in two-layer fluid (see Chamberlain and Porter [25] and Manam et al. [26]).

In the present paper, oblique wave trapping by thin porous barrier near a wall in the presence of step of arbitrary bottom bed is studied under the assumption of small amplitude water wave theory. In each of the fluid regions, the velocity potentials are expanded in terms of the eigenfunctions and the full solution of the mathematical problem is obtained by matching the continuity of pressure and velocity at interface boundaries. However, the extended modified mild-slope equation (MMSE) along with suitable jump conditions (as in Porter and Staziker [19]) are used to ensure conservation of mass at the interface boundaries in the fluid region having undulated bottom bed. The mild-slope equation is handled for solution using Runge–Kutta method. The reflection coefficients and wave forces are computed and analyzed for different bottom bed profiles to study the role of the porous barrier in trapping oblique gravity waves in the confined zone between the barrier and the rigid wall. For each bed profile, distance between barrier and rigid wall, distance between barrier and step edge, slope length, depth ratio and oblique angle of incidence on the reflection coefficient, wave forces acting on the barrier and rigid wall are studied. Known results available in the literature are reproduced to check the accuracy of the computational results.