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International Journal of Naval Architecture and Ocean Engineering 8 (2016) 53−65
http://www.journals.elsevier.com/international-journal-of-naval-architecture-and-ocean-engineering/

Transmission coefficients of a floating rectangular breakwater with porous side plates

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Received 9 July 2015; revised 24 September 2015; accepted 6 October 2015
Available online 21 January 2016

Abstract

The interaction between incident waves and a floating rectangular breakwater with the vertical porous side plates has been investigated in the context of the two-dimensional linear potential theory. The matched eigenfunction expansion method(MEEM) for multiple domains is applied to obtain the analytic solutions. The dependence of the transmitted coefficients and motion responses on the design parameters, such as porosity and protruding depth of side plates, is systematically analyzed. It is found that the non-dimensional wavelength where the sudden drop of transmission coefficients occurs, corresponds to the heave resonant frequency obtained from Ruol et al. (2013) for π-type floating breakwater. It is concluded that both properly selected porosity and deeper protruding depth of side plates are helpful in reducing the transmission coefficients and also extending the wider applicable extent of incident wavelength for performance enhancement.

Keywords: Floating breakwater; Transmission coefficient; Motion responses; Porous side plates

1. Introduction

A floating breakwater is an alternatives to conventional gravity-type breakwaters for several reasons. Firstly, the construction cost of the floating breakwater is slightly dependent on the water depth and the floating breakwater can be easily placed on soft bottom ground. Secondly, the floating breakwaters have the ecological advantage of sea water circulation, biological exchange and sediment transport beneath the structure and thirdly, the placement location of the floating breakwaters can be easily changed and the construction period is much shorter compared to the fixed-type breakwater. Due to the above mentioned advantages, the floating breakwater has been constructed for limited purposes such as a portable breakwater for preserving aquacultural facilities and a floating wharf for yachts and recreational boats. Various methods have been proposed to improve the performance of the floating breakwaters. As such, this paper considers the changes in the performance of the floating breakwater due to the attachment of vertical porous plates to its up-wave and down-wave sides.

Mei and Black (1969) and Black et al. (1971) applied Schwinger's variational formulation to the radiation of surface waves due to small oscillation of circular and rectangular cylinders, and the wave exciting forces on the body due to a plane incident wave were obtained by means of Haskind theorem. Drimer et al. (1992) presented a simplified approach for a floating breakwater where the breakwater width and incident wavelength are taken to be much larger than the gap between the breakwater and the seabed. Wu et al. (1995) used the matched eigenfunction expansion method to analyze the wave induced responses of an elastic rectangular floating plate using modal expansions of the structural motion. Lee (1995) presented an analytical solution to the heave radiation problem of a rectangular structure in an infinite domain with constant water depth. The generated waves, the added mass and the radiation damping coefficients were investigated. Abul-Azm and Gesraha (2000) examined the hydrodynamic

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Peer review under responsibility of Society of Naval Architects of Korea.

http://dx.doi.org/10.1016/j.ijnaoe.2015.10.002

properties of a long rigid floating pontoon interacting with linear waves in water of finite depth by use of the eigen-function expansion method. Zheng et al. (2004) presented an analytical solution to the diffracted and radiation potential including sway, heave and roll by a rectangular body under the action of normal incident waves. Zheng et al. (2006) considered the linear wave radiation by a floating rectangular structure in oblique waves. The expressions for the radiation potentials in oblique waves were derived analytically by use of the method of separation of variables. Gesraha (1998, 2006) investigated the reflection and transmission of incident waves interacting with a long rectangular breakwater with two thin impermeable side plates protruding vertically downward. Through comparison to the rectangular one having the same mass; it was found that the proposed configuration of breakwater experiences lower transmission coefficients and wave exciting forces.

Bai (1975) presented a finite element method to study the diffraction of oblique waves by an infinite cylinder in water of finite depth. The reflection and transmission coefficients and wave exciting forces and moment were computed for oblique waves incident upon a vertical flat plate, a horizontal flat plate and rectangular cylinders. Garrison (1984) used a Green's function method to compute the oblique wave interaction with a cylinder of arbitrary section on the free surface in water of infinite depth. Andersen and Wuzhou (1985) presented an integral equation formulation for the calculation of hydrodynamic coefficients for long, horizontal cylinders of arbitrary section. Isaacson and Nwogu (1987) developed a generalized numerical procedure based on Green's theorem to compute the wave exciting forces and hydrodynamic forces due to the interaction of oblique waves with an infinitely long, semi-immersed floating cylinder of arbitrary shape. Sannasiraj et al. (2000) used the finite element method to the study of the diffraction-radiation of multiple floating structures in directional waves. Politis et al. (2002) developed a Boundary Integral Equation (BIE) method for the oblique water-wave scattering by cylinders in water of infinite depth and four geometric configurations were chosen to investigate the numerical performance of the BIE method.

During the past decades, there have been many theoretical and experimental studies regarding the wave-absorption performance by porous plate. For example, the wave transmission of a thin vertical porous plate placed in deep water was investigated by Tuck (1975). He discussed the application of Darcy's law for flows across porous plates and suggested that in the case of sinusoidal oscillations the velocity across the material with fine pores can be related to the pressure drop by a complex-valued frequency dependent parameter, which accounts for both viscous and inertial effects. Along the same line, Chwang (1983) developed a porous wavemaker theory and found that the porous effect reduces the wave amplitude as well as the hydrodynamic force on the wavemaker. Later, Evans (1990) analyzed the wave reflection by a number of thin porous plates fixed in a narrow wave tanks and showed that the reflected wave energy is largely reduced if the front porosity is greater than the rear porosity. Wu et al. (1998) provided a good literature review on the subject, implementing a continuous approximation via a porous effect parameter making the assumption that the material structure of the plate consists of very fine pores and thus the normal velocity of the fluid passing through the plate is linearly proportional to the pressure jump across it—akin to a viscous Darcy type law. Cho and Kim (2008) studied the wave energy dissipation of a horizontal porous plate as a wave absorber and their experimental results reasonably followed their analytical predictions. Crowley and Porter (2012) provided the boundary condition at the slatted screen, using a screen-averaged linear relationship between the flux and pressure drop. This was modeled via a complex coefficient which includes a real part associated with the added inertia (blockage coefficient) and an imaginary part associated with energy dissipation across porous screen.

In this paper, the effect of the addition of two porous side plates on the performance of a rectangular breakwater is studied. For this, matched eigenfunction expansion method is applied and a new analytical expression for the diffraction and radiation velocity potential is obtained. The parametric study for optimal design of porous side plates was conducted, which includes the dependence of reflection, transmission, and energy-loss coefficients on various design parameters, such as porosity, protruding depth of side plates, and wave conditions.

2. Mathematical formulation

The diffraction and radiation problem including sway, heave, and roll motion of a rectangular floating breakwater with porous side plates is considered. The geometry of a rectangular breakwater and the Cartesian coordinate system are shown in Fig. 1. The origin of the coordinate system is at the undisturbed water surface with the positive z pointing upwardly and the positive x pointing to the right. Here, a rectangular breakwater is assumed infinite in the y direction, so the problem considered here is two dimensional. The width and draft of the rectangular breakwater is $2a$, and d, respectively. The water depth is fixed at h, the two porous plates are protruded vertically with depth s from the each side of bottom of the breakwater, and the plate thickness is assumed to be zero in the analysis described below. If the fluid is assumed incompressible and inviscid and the motion is irrotational,

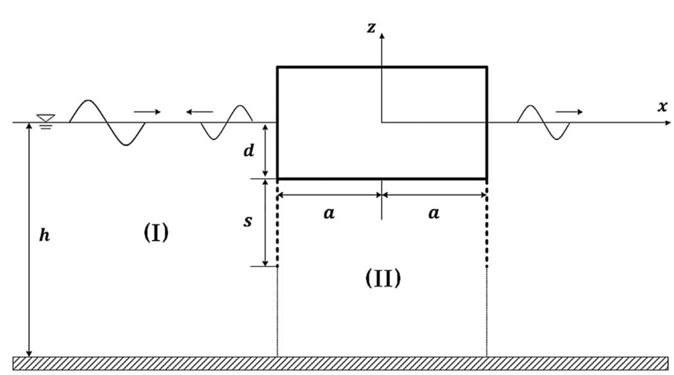

Fig. 1. Schematic diagram of a rectangular floating breakwater with porous side plates.