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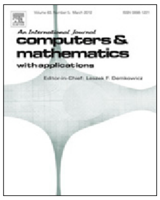

Numerical investigation on the obliquely incident water wave passing through the submerged breakwater by singular boundary method

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ABSTRACT

This short communication presents the Singular Boundary Method (SBM) to solve the obliquely incident water wave passing through the submerged breakwater. The SBM is a recent boundary-type collocation method with the merits of being meshless, integration-free, mathematically simple, easy-to-program, well suited for unbounded domain problems. The accuracy and efficiency of the SBM is first verified in several benchmark examples in comparison with the boundary element method. Then the effects of the position, size and geometry of the breakwater on water wave propagation are investigated through numerical experiments, and some new observations are concluded.

1. Introduction

In hydraulic engineering, the submerged breakwater has widely been used to reduce transmitted water wave energy, and it also has the advantages of allowing water circulation allowance, fish passage, and provision of economical protection. Usually, a thin barrier has been considered a good modeling of submerged breakwater. The prediction of the water wave interaction with the submerged breakwater has previously been studied for many kinds of configuration of water barrier in linear wave diffraction theory. Under the assumption of linear wave theory, various analytical and numerical methods have been implemented to calculate the reflection and transmission of obliquely incident water wave past a submerged barrier with a finite width, such as the eigenfunction expansion method (EEM) [1], the boundary element method (BEM) [2–6], and the regularized meshless method (RMM) [7].

In recent years, several meshless methods have been proposed, such as the method of fundamental solutions (MFS) [8], the modified method of fundamental solutions (MMFS) [9], the boundary distributed source method (BDS) [10], the non-singular method of fundamental solutions [11], the singular boundary method (SBM) [12] and so on. In the literature [13], Chen et al. applied the SBM to modified Helmholtz equations involving a simple case for the obliquely incident water wave past one-breakwater rigid barrier. In contrast, this study makes a systemic investigation on the obliquely incident water wave past the submerged barriers including the effects of the position, size, number, and geometry of the breakwater barriers on water wave propagation.

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The singular boundary method was proposed by Prof. Chen in 2009 and belongs to the strong-form boundary collocation method. It places the source points on the physical boundary, and uses the fundamental solutions as its basis functions. In particular, it introduces the concept of source intensity factors to avoid the singularities of the fundamental solutions at the origin. Under the extensive studies, the four popular techniques have been proposed to determine the source intensity factors (SIFs) of both the fundamental solutions and their derivative, such as inverse interpolation technique (IIT), semi-analytical technique with the desingularization of subtracting and adding-back method (SAT1) [14], semi-analytical technique with integral mean value approach (SAT2) [15], and semi-analytical technique with the empirical formula (SAT3) [16]. Numerical investigation shows that the SBM can provide accurate solutions in potential [17], Helmholtz [18], wave [19,20], stokes flow [21], and elastic wave [22] with arbitrarily complex-shaped computational geometries. And it also avoids singular numerical integrals in the boundary element method (BEM) [23–25], circumvents the ill-conditioning resultant matrix in the eigenfunction expansion method (EEM) [26–28].

This short communication extends the SBM application to the water wave interaction with the submerged breakwater. A brief outline of the short communication is as follows. Section 2 describes the singular boundary method formulation of the water wave interaction with the submerged breakwater. In Section 3, the accuracy and efficiency of the SBM is first verified in several benchmark examples in comparison with the boundary element method, and then the effects of the position, size and geometry of the breakwater on water wave propagation are investigated through numerical experiments. Finally, Section 4 concludes this short communication with some remarks.

2. Singular boundary method for water wave interaction with the submerged breakwater

Consider 2D obliquely incident water wave past a submerged barrier as shown in Fig. 1(a). Time-harmonic water wave with the incident wave angle θ propagates towards the submerged structure in a constant water depth h, where L is the truncation length of region II, D denotes the distance between two barriers, d is the height of the barrier, b the width of the barrier in Fig. 1(a), b_1 the width of the left barrier in Fig. 1(b), and b_2 the width of the right barrier in Fig. 1(b). Assuming an inviscid, incompressible fluid and irrotational flow, the mathematical model of this water wave problem can be expressed as [1]

$$\nabla^2 u - (k \sin(\theta))^2 u = 0, \quad (x_1, x_3) \in \Omega_3 \tag{1}$$

where ∇^2 is the Laplace operator, the wavenumber $k > 0$. The boundary conditions of the interested domain can be written as follows:

(1) Linearized free water surface boundary condition

$$\frac{\partial u}{\partial x_3} = k \tanh(kh)\, u, \quad (x_1, x_3) \in \Gamma_f. \tag{2}$$

(2) Seabed boundary condition

$$\frac{\partial u}{\partial x_3} = 0, \quad (x_1, x_3) \in \Gamma_s. \tag{3}$$

(3) Submerged barrier boundary condition
Rigid boundary condition

$$\frac{\partial u}{\partial x_1} = 0, \quad (x_1, x_3) \in \Gamma_{b_1} \tag{4}$$

$$\frac{\partial u}{\partial x_1} = 0, \quad (x_1, x_3) \in \Gamma_{b_2} \tag{5}$$

$$\frac{\partial u}{\partial x_3} = 0, \quad (x_1, x_3) \in \Gamma_{b_3}. \tag{6}$$

Absorbing boundary condition

$$\frac{\partial u}{\partial x_1} = ikG_1 u_1, \quad (x_1, x_3) \in \Gamma_{b_1} \tag{7}$$

$$\frac{\partial u}{\partial x_1} = ikG_2 u_2, \quad (x_1, x_3) \in \Gamma_{b_2} \tag{8}$$

$$\frac{\partial u}{\partial x_3} = 0, \quad (x_1, x_3) \in \Gamma_{b_3} \tag{9}$$

where u_1 and u_2 are the potential of both front and back sides of the breakwater and G_1 and G_2 represent the corresponding absorbing parameters, respectively.