Wave Forces on Multiple Large Surface-Piercing Cylinders Mounted on Conical Shoals

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ABSTRACT

In this investigation, we considered the wave force on multiple large surface-piercing cylinders mounted on a shoal. Instead of conventional approaches, e.g. Helmholtz equation for constant water depth or ignoring rapid undulations of the bottom, the modified mild-slope equation (MMSE) was adopted to calculate the wave potential and the linear Bernoulli equation was used to estimate the wave force. About the numerical method, we employed the dual reciprocity boundary element method (DRBEM) to reduce the corresponding complicated domain integration. The numerical results were compared with the analytic solutions of Liu and Lin (2007) and MacCamy and Fuchs (1954), respectively. Comparisons between numerical results and analytic solution showed excellent agreements. We used two types of shoal with different slopes as numerical cases in this study. We also carried out numerical experiments for incident waves with normal and 45-degree angles. We found that when the length of incident wave is twice the spacing between columns, larger wave height occurs at downstream columns, because of interactions between waves and columns. The wave force oscillates in sync with incident wave.

KEY WORDS: Dual reciprocity boundary element method; wave force; modified mild-slope equation; large structure.

INTRODUCTION

The accuracy in predicting water wave interactions with near-shore structures on irregular bathymetry plays an important role in planning, designing, constructing and maintaining coastal facilities. Varieties of approaches, both theoretically and numerically, have been developed to predict the interactions. Cylindrical plies are widely used in coastal and ocean engineering, such as for breakwaters, wharfs, lighthouses, artificial islands and platforms for research or petroleum extraction. The cylindrical structures can be divided into two types by their relative diameters to the wavelength: small- and large-scales. The wave force exerted on small cylinder structure can be formulated by the Morison equation. However, the Morison equation is based on the assumption that the presence of the object does not affect the characteristics of the incident wave; this equation fails to predict the wave induced forces exerted on the large-scale cylinder. As the diffraction effects increases, the wave loads exerted on large-scale cylinders must be computed by the diffraction theory. The theoretical and numerical investigations into large-scale cylindrical structures with the diffraction theory are numerous. For example, MacCamy and Fuchs (1954) first derived the well-known analytical solution for linear waves force on a pile structure with a constant water depth. Besides, Au and Brebbia (1983) computed the wave force by using boundary element method (BEM). However, the non-homogeneous terms in BEM would lead to complex domain integration. The corresponding domain integration can be reduced into boundary integration again by using the dual reciprocity boundary element method (DRBEM) proposed by Nardini and Brebbia (1983). Zhu (1993a) successfully employed the DRBEM to solve the mild-slope equation, a well-known wave diffraction-refraction equation, and obtained reasonable results. Moreover, Silva, Borthwick and Taylor (2005) adopted the modified mild-slope equation (MMSE) derived by Chamberlain and Porter (1995) to demonstrate the monochromatic wave scattering by multiple cylinders located on a constant depth. In their works, the wave energy dissipation terms due to wave breaking and bottom friction are considered in the governing equation. In contrast to previous studies, we will evaluate the wave force on a group of four vertical surface-piercing cylinders, which located on a conical shoal, using the MMSE as the governing equation. To avoid the complicated domain integration, the DRBEM is applied in this investigation. By solving the MMSE, the wave potential is obtained and the corresponding wave force calculated by integration around the cylinder. Furthermore, we conduct a series of numerical experiments with different bathymetries and incident wave periods to study the difference between conventional MSE and MMSE.

THEORETICAL BACKGROUND

Governing equation and boundary conditions

A Cartesian coordinate system \((x,y,z)\) is adopted with the \(z\)-axis directing vertically upwards with \(z=0\) on the undisturbed free surface. The fluid is assumed to be inviscid and incompressible and its motion irrotational. Under these assumptions a velocity potential \(\Phi(x,y,z,t)\) exists which satisfies Laplace’s equation. We therefore have

\[ \nabla^2 \Phi = 0 \]

(1)

throughout the fluid. The velocity potential can be expressed as...