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Performance of a Submerged Wave Focusing Structure in a Current

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ABSTRACT

A time-domain numerical model is developed to examine the performance of a wave energy focusing structure in combined waves and a current. With the current assumed to be slow and the structure fully submerged, the wave-current interaction problem can be reduced to a linear wave diffraction problem in a uniform surface current. The diffraction of regular incident waves around a submerged narrow structure of the shape of a parabola is considered. The energy focus is achieved by reflecting the incident waves through a predetermined focal point. Through numerical simulations, the numerical model is shown to be effective in modeling the wave-current interaction problem, and the current speed and direction are shown to affect significantly the location, amplitude and sharpness of the focus.

INTRODUCTION

The enormous potential of ocean wave energy has prompted many studies to investigate the technical and economic feasibility of wave energy extraction. In particular, wave energy focusing structures have been proposed to amplify the incident wave height at a predetermined focal point, where the converged wave energy is harnessed by means of a mechanical power generator. A number of studies have been performed on various wave focusing devices to investigate their performance under different wave conditions.

A horizontal thin plate submerged under the free surface was proposed by Helstad (1980). The concept was further examined numerically and experimentally by Kudo et al. (1987), Imai et al. (1988) and Murashige and Kinoshita (1992) using thin plates of different shapes and dimensions. The use of lens-shaped vertical structures on the seabed has been examined by Mehlum and Stamnes (1980) and McCormick et al. (1980). Ertekin and Monopolis (1985) investigated the use of a parabolic step for wave energy focusing through a series of experiments and later studied the problem numerically (Yang and Ertekin, 1990). Gug and Lee (1992) considered the use of submerged structures on the seabed and the convergence of wave energy is achieved by refracting the incident plane waves over the gentle side slopes of the structure.

A different type of wave focusing structure is considered here, in which the wave energy is reflected by a submerged narrow structure on the seabed through a predetermined focal point. The centerline of the structure is defined by a parabola, similar to that of an optical reflector. The dimensions of the structure considered here are much smaller than those examined by Mehlum and Stamnes (1980), McCormick et al. (1980) and Gug and Lee (1992), and the focal point is located in front of the structure. However, the work of Cheung et al. (1995) on wave-current interaction has shown that the presence of a current would modify significantly the diffracted wave field and amplitude near the structure. Accurate predictions of the performance of this wave focusing structure in combined waves and currents are therefore important in its design and operation in a coastal environment.

An approach to treat the wave-current interaction problem is to separate the flow field into a steady component associated with the current and a propagating component associated with the waves. With the assumption of a slow current, the free surface boundary conditions for the steady current component can be reduced to a rigid-wall condition, while the linear free surface boundary conditions for the propagating wave component are extended to include the modified current field. Based on this approach, Isaacson and Cheung (1993) and Cheung et al. (1995) provided a time-domain solution for the two- and three-dimensional problems, respectively. Comparisons of the numerical models have been made with the frequency domain solutions of Zhao and Faltinsen (1988) and Nossen et al. (1991), and indicate favorable agreement.

The numerical model of Cheung et al. (1995) deals with the effects of a collinear current on the diffraction of regular waves around a three-dimensional surface piercing structure. The structure considered here is fully submerged, and the wave-current interaction problem can be simplified and reduced to a wave diffraction problem in a uniform surface current. The numerical model is extended to include effects of oblique incident waves and a current. The performance of the wave focusing structure in combined waves and a current is investigated. Emphasis is placed on the relations between the location, amplitude and sharpness of the focus, and the current speed and direction.

THEORETICAL FORMULATION

Problem Statement

With reference to Fig. 1, the boundary-value problem is defined with a right-handed Cartesian coordinate system (x, y, z), in which x and y are measured horizontally and z is measured vertically upwards from the still water level. The water depth in the computational domain is constant and is denoted by d. A sub-

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