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Time-domain Simulation of Wave-Current-Body Interaction

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ABSTRACT

A time-domain numerical model is established with a higher-order boundary element method to study the problem of wave-current interaction with structures. Using regular perturbation with two small parameters ε and δ associated with wave slope and current velocity, respectively, the boundary value problem is decomposed into a steady double-body-flow problem at $O(\delta)$ and an unsteady wave problem at $O(\varepsilon\delta)$ and $O(\varepsilon)$. A 4th-order Runge-Kutta method is applied for the time marching. An artificial damping layer is adopted to dissipate the scattering waves. Validations of the numerical model on wave-current force and run-up on a bottom-mounted vertical cylinder and a complex bridge pier are carried out.

KEY WORDS: Time-domain; boundary element method; regular perturbation; wave run-up; double-body-flow problem; artificial damping layer; wave-current.

INTRODUCTION

The problem of wave-current interaction with bodies has been widely studied in the frequency domain (Grue and Palm, 1985; Wu and Eatock Taylor, 1987; Matsui et al, 1991; Zhao and Faltinsen, 1988; Nossen et al, 1991; Teng and Eatock Taylor, 1993; Teng and Eatock Taylor, 1995; Teng et al, 2001). Although the frequency-domain analysis has been presented for a long time, it is in general mathematically complicated and cannot be easily extended to nonlinear problems.

Isaacson and Cheung (1992) employed an alternative time-domain analysis to solve the same problem by a constant panel method. However, accurate computation of the second-order spatial derivatives of the velocity potential on the integral surface is very difficult. A time domain analysis based on a higher-order boundary element method is then developed. Using regular perturbation expansion with wave steepness ε to the mean position of the non-stationary boundaries, a solution of time-domain higher-order boundary element method (THOBEM) for 3D wave radiation and diffraction in a current was proposed (Buchmann et al, 1998). They presented the results of the diffractive run-up of wave-current interaction with a structure in a flume. Using the solution of THOBEM and applying a perturbation expansion with two small parameters ε and δ associated with wave steepness and current velocity, Kim and Kim (1997) investigated exciting force, mean drift force and run-up of wave-current action on a vertical cylinder. The time-domain solution can be much better than the frequency-domain one while the irregular seas, transient effects or highly non-linear effects are considered.

In this paper, a time-domain model of wave-current action on 3D bodies is set up by applying a THOBEM. Under the assumption of small flow velocity, the velocity potential and the wave run-up are expressed as the sum of different order parts using a perturbation expansion method. Based on the two small parameters ε and δ, the boundary value problem is decomposed into a steady double-body flow problem at the zero-order of wave steepness and an unsteady wave problem at the first-order of wave steepness. An artificial damping layer is adopted to dissipate the scattering waves (Ferrant, 1993). The boundary surface is discretized into a set of higher-order boundary elements, which are composed of eight-node quadrilateral elements and six-node triangular elements. They can be transformed to isoparametric elements in local coordinates (ξ,ς). Thus the velocity potential and the geometry coordinates in each element can be interpolated by the values of various nodes and shape functions. Validation of the numerical method is carried out for a bottom-mounted vertical cylinder. The effects of uniform steady current (or small forward velocity) on exciting force and wave run-up are investigated. The model is then applied to compute the wave force and the wave run-up on a complex bridge pier.

NUMERICAL SIMULATIONS

Governing Equation and Boundary Conditions

For analysis, a Cartesian coordinate system with the origin on the mean free surface and the *z* axis positive upward is used, as shown in Fig. 1. In this work, we consider the wave interaction with a body moving forward with a small constant forward speed *U*, or a body under the action of waves in a weak current directing in the negative *x* direction with velocity *U*. Under the assumptions of ideal fluid and no surface tension, the fluid velocity vector $\vec{V}(\vec{x},t)$ can be defined as $\nabla\phi$, with the velocity potential $\phi(x,y,z,t)$ satisfying the following Laplace