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Second-Order Wave Radiation of Three-Dimensional Bodies by Time-Domain Method

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ABSTRACT

The nonlinear wave radiation of a surface-piercing body of arbitrary shape in three dimensions is investigated by a time-domain second-order method. In this approach, Taylor series expansions are applied to the body surface boundary condition and the free surface boundary conditions, and Stokes perturbation procedure is then used to establish corresponding boundary value problems at first and second order with time-independent boundaries. These are treated by a time-stepping procedure, in which the wave field at each time step is solved by a boundary integral equation method based on Green's theorem. Numerical results including free surface profiles and hydrodynamic forces are presented for the case of a truncated surface-piercing circular cylinder undergoing specified sinusoidal surge and heave motions. Contributions to the hydrodynamic force from the various second-order force components are highlighted. It is found that steady state solutions are attained over a reasonably short duration of simulation time, and that the method is accurate, computationally efficient, and numerically very stable.

INTRODUCTION

Demand from the offshore industry to refine existing design procedures has led to increased interest in hydrodynamic research on the development of nonlinear wave diffraction-radiation theory in order to predict the effects of extreme waves on offshore structures. In general, two categories of method are used to treat nonlinear wave interactions with large fixed or floating structures. One approach is a frequency-domain second-order solution based on a Stokes perturbation procedure which is somewhat analogous to the simulation of second-order Stokes wave propagation (e.g., Eatock Taylor and Hung, 1987; Abul-Azm and Williams, 1988; Kim and Yue, 1989). Such methods enforce a weak far-field condition and are considered to be algebraically complicated. The other approach involves a numerical solution to the full nonlinear problem by using a time-stepping scheme, in which a suitable field equation is solved at each time step as the free surface moves to a new position (e.g., Vinje and Brevig, 1981; Isaacson, 1982; Grosenbaugh and Yeung, 1989). This method involves a number of numerical complications and demands considerable computing resources.

An alternative approach is a time-domain second-order method, recently developed by Isaacson and Cheung (1991) to study wave diffraction around a fixed two-dimensional body. In this method, Taylor series expansions and the Stokes perturbation procedure are applied to reduce the problem to one with a time invariant computational domain, and a time-integration is adopted to treat the free surface boundary conditions and radiation condition to second order. A subsequent extension of this formulation has been made to the case of fixed structures of arbitrary shape in three dimensions (Isaacson and Cheung, 1992). Comparisons of their numerical results with previous experimental and theoretical studies have been carried out in order to validate the method and have generally been favourable. In addition, through extensive numerical experiments, the resulting algorithm has been found to be both computational efficient and numerically stable.

The development of nonlinear solutions to the related wave radiation problem has important applications to predicting the motion response of the floating offshore structures. A comprehensive review of available theoretical approaches for predicting second-order effects on floating offshore structures has been given by Ogilvie (1983). Most previous theoretical studies have treated the second-order problem using a frequency-domain approach and have been restricted to the case of two-dimensional bodies (Parissis, 1966; Lee, 1968; Potash, 1971; Kyozuka, 1982). In addition, second-order problems related to the calculation of steady forces, difference-frequency forces and sum-frequency forces have been widely studied (Maruo, 1960; Pinkster, 1979; Molin, 1979). However, numerical results for the three-dimensional second-order wave radiation problem, to the knowledge of the authors, has not widely been reported.

Based upon the recent development of the time-domain method for the second-order wave radiation problem in two dimensions (Isaacson and Ng, 1993), the present paper describes an extension of the method to the three-dimensional case of a surface-piercing body of arbitrary shape undergoing specified oscillations. Hydrodynamic forces are calculated by a direct integration of the pressure over the wetted body surface, best-known as the near-field approach. In order to demonstrate and examine the method, numerical results are given for the case of a truncated surface-piercing circular cylinder undergoing forced oscillatory surge and heave motions. It is expected that the method can eventually be extended to study the combined three-dimensional wave diffraction-radiation problem to second order, which is of considerable engineering importance.

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