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Time-Domain Second-Order Wave Interaction with Three-Dimensional Floating Bodies

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ABSTRACT

This paper studies second-order wave interactions with a large three-dimensional floating body of arbitrary shape by a time-domain method. The method involves the application of Taylor series expansions and the use of Stokes perturbation procedure to establish the corresponding boundary value problem with respect to a time-independent fluid domain. A time-stepping scheme together with a suitable iterative procedure is adopted to solve the coupled fluid-structure governing equations, and an integral equation method based on Green's theorem is used to calculate the wave field at each time step. As an illustration, the method is applied to the case of a floating truncated circular cylinder. Numerical results presented relate to the transient motion of a freely floating cylinder with a specified initial vertical displacement, and to the diffraction-radiation problem of Stokes second-order waves interacting with a moored floating cylinder. Second-order hydrodynamic effects associated with the forces and motions of the floating structure subjected to regular waves, as well as corresponding free surface profiles and wave amplitudes, are discussed. The present method is found to be accurate, computationally efficient, and numerically very stable.

INTRODUCTION

Over the past decade, the study of nonlinear wave-structure interactions has been an important topic of ocean engineering research, with practical applications relating to load and response predictions for large fixed and floating structures subjected to steep waves. Complications of the full nonlinear problem are that the solution is required to satisfy the two nonlinear free surface boundary conditions, and the formulation should include a suitable treatment of the radiation (far-field) condition. In general, the emphasis of previous research has been on solving the wave diffraction and radiation problems separately. Two approaches have been used to solve the nonlinear wave diffraction problem. One approach is a frequency-domain second-order solution based on a Stokes perturbation procedure (e.g., Molin, 1979; Kim and Yue, 1989; and Chau and Eatock Taylor, 1992) and the other approach is a full nonlinear solution to the resulting flow based on a time-stepping scheme (e.g., Isaacson, 1982; Grosenbaugh and Yeung, 1989; and Yang and Ertekin, 1992). The former approach is considered to be algebraically complicated and is restricted to simplified geometries while the latter approach demands considerable computing resources. An alternative method, developed by Isaacson and Cheung (1991, 1992), may be considered as a hybrid of these two approaches, and involves the application of Taylor series expansions to the free surface boundary conditions, the use of Stokes perturbation procedure, and a time-integration scheme to obtain the resulting flow development.

The related nonlinear wave radiation problem has also been studied extensively using frequency-domain formulations (e.g., Potash, 1971; Papanikolaou and Nowacki, 1980; and Kyozuka, 1981). Most studies have been restricted to the case of two-dimensional bodies, though recent work by Isaacson et al. (1993) has presented a second-order solution to the wave radiation problem for a three-dimensional structure undergoing forced sinusoidal motions.

The combined nonlinear diffraction-radiation problem involves the motions of the structure as well as nonlinear interactions among the incident, diffracted and radiated wave components, and although the separate nonlinear wave diffraction and radiation problems have been studied quite extensively, results for the combined problem are scarce. Zaraphonitis and Papanikolaou (1991) have considered the three-dimensional floating body problem to second order based on a frequency-domain formulation. More recently, the case of second-order wave interactions with a two-dimensional floating body has been studied by the time-domain method (Ng and Isaacson, 1993).

Based upon the recent development of a time domain method for second-order wave interactions in two dimensions, the present paper describes an extension of the method to the three-dimensional case of a surface-piercing body of arbitrary shape. Thus, this paper represents the final one of the following sequence:

- diffraction problem, two dimensions (Isaacson and Cheung, 1991)
- radiation problem, two dimensions (Isaacson and Ng, 1993)
- diffraction-radiation problem, two dimensions (Ng and Isaacson, 1993)
- diffraction problem, three dimensions (Isaacson and Cheung, 1992)
- radiation problem, three dimensions (Isaacson, Ng and Cheung, 1993)
- diffraction-radiation problem, three dimensions (present paper)

As an illustration, the method is applied to the case of a floating truncated circular cylinder. Numerical examples presented relate to the transient motion of a freely floating cylinder with a specified initial vertical displacement in otherwise still water, and the interaction of regular waves with a moored floating cylinder. Second-order hydrodynamic effects associated with the forces and motions of the floating structure subjected to regular waves, together with corresponding free surface profiles and wave ampli-

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