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Nonlinear Diffraction Effects Around a Surface-Piercing Structure

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ABSTRACT

In the present paper the interaction of a wave system with a fixed body is studied. The wave diffraction in finite-depth water around a vertical cylinder and a simple shaped shoal is computed; the results are discussed in comparison with analytical solutions and experimental data. The linearized and the fully nonlinear mathematical models are studied in the frame of irrotational incompressible flow hypothesis. The numerical solution is gained by means of an integral formulation. The body surface is discretized by a classical zeroth order panel method, whereas a desingularized scheme is implemented on the free boundary. A time marching Runge-Kutta algorithm is used for the computation of the wave pattern and the velocity potential at each time step. The simulation of wave diffraction around fixed obstacles confirms and extends the theoretical results of the second order analysis (Kriebel 1990, 1992): The linear model yields a very good estimation of the force amplitude acting on the body, while the wave profiles are poorly evaluated when compared with the fully nonlinear simulation and the experimental data.

INTRODUCTION

At present, several closed form solutions are available for the diffraction problem, in the case of linear interaction of waves with bodies of very simple shape. See, for instance, Havelock (1940) for the deep water solution and MacCamy and Fuchs (1954) for the finite-depth solution.

The nonlinear problem is much more difficult to study in analytical form. Some solutions for the interaction of a wave train with a surface-piercing cylinder are sought through a perturbation expansion (Kriebel, 1990, 1992, and his bibliography) that yields separate linear boundary value problems to be solved for each term in the power series. In this case, second-order analysis shows that nonlinear wave patterns differ significantly from linear theory. In the up-wave region (weather side), linear theory predicts a partial standing wave system, with amplitudes that decay like $r^{-1/2}$ and that decay in θ as well. In the down-wave region (lee side), linear theory does not predict any significant spatial modulation. In the second-order theory, the mutual and self interactions of the incident and scattered waves lead to very complicated wave features. The partial standing wave system is preserved in the up-wave region; however, wave crest amplitudes are increased by more than 20%. In the down-wave region, the diffraction pattern is rather different. In fact, while linear theory predicts almost constant wave amplitude, in the second-order theory the solution oscillates at the rear of the cylinder, with a large increase (up to 40%) in wave crest amplitudes with respect to the incident wave.

In spite of the significant differences in the wave pattern, second-order force amplitudes seem to depart from linear ones by only a few percent. However, nonlinearities play a significant role in several problems of marine hydrodynamics. Namely, second-order effects are responsible for non-zero mean forces (Grue and Palm, 1993) and are important in stability analysis (Takarada et al., 1984) as well as in hydroelasticity (Newman, 1993).

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Nonlinear wave load prediction on complex structures requires numerical techniques. One feasible approach relies upon perturbation expansion methods, in which the problem is preliminarily recast as a set of linear problems, solved numerically either in the frequency domain (Kim and Yue, 1989) or in the time domain (Isaacson and Cheung, 1992; Liu et al., 1992). Alternatively, the exact nonlinear problem can be handled in the time domain by solving a boundary value problem at each time step (Isaacson, 1982; Dommermuth et al., 1987).

This paper presents a numerical method for fully nonlinear free surface flow computation about rigid bodies of arbitrary shape. The velocity potential is split into the sum of an incident wave term and a perturbation potential. Such decomposition avoids the need of generating the incident wave train by means of a numerical wave maker and simplifies the damping of the outgoing signals at the boundary of the discretized free surface. The numerical solution of the initial-boundary value problem is based on an integral representation of the perturbation velocity potential. The body surface is discretized by a classical zeroth order panel-method, whereas a desingularized scheme is implemented for the free surface. Free boundary conditions in Eulerian form are integrated in time by a fourth-order Runge-Kutta scheme.

In this work some free surface flows, for which analytical solutions and experimental data are available, are considered to test the proposed numerical model. In the first problem, waves and forces about a vertical cylinder (for both the submerged and the free surface piercing cases) in finite depth water have been calculated. Forces have been compared with the experimental data obtained by Hogben and Standing (1975). In this case it is observed that both linear and nonlinear solutions show a good agreement, since nonlinear effects seem not to be so evident with respect to experimental uncertainties. On the other hand, the envelope of the wave pattern around the cylinder (run-up) has been compared with analytical solutions and experimental data (Kriebel, 1990-1992): The good agreement between the results of linear simulation and the corresponding analytical solution shows the accuracy of the numerical algorithm, whereas the large differences between the linear and the nonlinear predictions are confirmed.

Next, we have turned our attention to the diffraction of a Stokes wave past a parabolic shoal; the numerical prediction is discussed