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3-D Time Domain Numerical Model for the Prediction of Ship Motions in Random Seas

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ABSTRACT

In this paper, we describe a new time-domain mathematical model by which the problem of a ship hull, as a 3-D body, moving at a constant speed and oscillating amongst sea waves, is solved. Perturbation caused by the ship motion is considered as a distribution of normal velocities on the reference wetted surface of the hull. Furthermore, the general normal velocity on the wetted surface is expressed as a finite series in terms of the incident wave potential and the geometry of the wetted surface. A precise linear decomposition for general normal velocity distribution on the wetted surface of an arbitrarily shaped hull is presented. This enables the body boundary conditions to be exactly fulfilled. Integral equations for the impulsive and memory part of the modal scattering potential due to radiation and diffraction potentials and their interactions are also deduced. Diffraction and radiation problems are considered simultaneously in the analysis. In this way the basic dichotomy of linear theory between radiation and diffraction problems is removed. The treatment also allows hydrodynamic forces to be calculated separately from the motions. No restrictions apply to the wave direction, and motion amplitudes can be large. To validate the mathematical model, three cases, including both radiation and diffraction, are investigated. Results of calculations are compared with experimental and theoretical results published elsewhere, and the comparison shows excellent agreement.

INTRODUCTION

The problem of ship motion in waves has been studied extensively using frequency domain analysis (Bruce, 1990). For arbitrary motions, however, it is necessary to solve the problem in the time domain for a 3-D body that is moving at a constant forward speed and oscillating in waves.

Linear time-domain analysis in the solution of the radiation problem for a body moving at a constant forward speed has been employed by Liapis (1985). In work by Lin (1990), Ferrant (1990) and Beck et al. (1991), a so-called body-nonlinear analysis is employed in a time-domain approach for the prediction of large amplitude motions of a submerged or surface-piercing body in a seaway. More recently, Zhang and Dai (1992) solved the diffraction problem under conditions similar to those stipulated by Liapis. It can be stated, however, that neither approach is applicable to the general case of radiation-diffraction essential for the study of ship motion amongst waves.

In this paper, we develop a theory, based on the work of Liapis, but applicable to the case of the combined radiation-diffraction. The unified solution to the radiation-diffraction problem has in fact been suggested by Pawlowski (1988). His treatment, however, is two-dimensional and is applicable to the 3-D case only in the context of a strip theory. Stability problems usually concern small length ships and, therefore, it is essential to account for three-dimensional effects.

The method suggested by Pawlowski is extended to the 3-D case, enabling the solution of the radiation-diffraction problem to be made in a rigorous manner in which the impermeability condition is exactly fulfilled. The disturbance caused by a ship motion is considered as a distribution of normal velocities on the wetted surface of the hull. A precise linear decomposition of the normal velocity distribution is then obtained. In the same time, the integral equations for the impulsive and memory part of the modal scattering potential due to radiation and diffraction potentials and their interactions are also derived and presented.

The new theory is applied to three situations involving radiation and diffraction. With respect to the radiation problem, the case of heave motion of a hemisphere released from an initial displacement, on the free surface, is investigated. Computations are also made to predict wave diffraction forces on a sphere submerged below the free surface and on a Wigley ship model, both moving with a constant speed against regular waves. Computed results are shown to coincide with theoretical and experimental data published elsewhere, thus validating our numerical model.

It is shown that the treatment allows hydrodynamic forces to be calculated separately from the motions. No restrictions apply to the wave direction, and motion amplitudes can be large.

Calculations are now being made to predict the motion behaviour in severe seas of a large catamaran ferry and a Series 60 hull form cargo ship. The project also includes an experimental validation programme in a large seakeeping basin. Results will be published in due course.

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KEY WORDS: Time domain, three-dimensional, ship motions.

THEORETICAL MODEL

Coordinate Systems

A ship is considered to be advancing with a constant velocity U in the horizontal direction and oscillating on the free surface. The flow field is assumed to be irrotational and the fluid is inviscid