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Second-Order Diffraction Forces on Floating Three-Dimensional Bodies in Regular Waves

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ABSTRACT

An efficient and accurate numerical procedure is described for computing the second-order diffraction forces on arbitrary three-dimensional bodies floating in regular waves. Green's second identity is exploited to express the second-order forces due to the second-order potential in terms of the first-order quantities alone. The resulting expressions for the second-order forces are evaluated from numerical first-order solutions based on the hybrid integral-equation method. Numerical examples are presented for a variety of geometries and compared with previous theoretical and numerical solutions as well as with model test results. Agreement is seen to be satisfactory, confirming the validity of the present approach.

INTRODUCTION

The wave loads acting on floating structures in irregular seas include the second-order, high- and low-frequency force components at sum- and difference-frequencies of the wave group, which arise from nonlinearities due to effects of finite wave elevation and finite body motions. These second-order forces may not be large in magnitude compared with first-order excitation at wave frequencies, but can never be ignored due to the possibilities of exciting resonance frequencies of lightly damped systems. Difference-frequency forces can excite large horizontal excursions of moored structures and large vertical-plane motions of floating structures of small water plane area. Sum-frequency forces can excite resonance oscillations in vertical modes of tension leg platforms.

The prediction of the second-order forces on floating bodies is usually made on the basis of potential flow assumption. The forces can be obtained by integrating the hydrodynamic pressure over the submerged body surface and by retaining terms to second order in wave slope in a consistent perturbation expansion (Ogilvie, 1983). The resulting expressions for the second-order forces involve the contribution from the second-order velocity potential. To obtain this contribution, one may use two alternative approaches. The first, hereafter designated the direct approach, obtains the forces directly from the integral of the second-order pressure over the submerged body surface (Hunt and Baddour, 1981; Kim and Yue, 1989, 1990). The second, the indirect approach, uses a reciprocal relation to obtain the second-order forces without the need for explicitly evaluating the second-order potential. Through the use of Green's second identity, the expressions can be obtained for the integrated second-order forces and moments in terms of first-order quantities alone (Lighthill, 1979; Molin, 1979). The direct approach requires the complete solution to the second-order diffraction problem, but once this is evaluated, second-order local quantities such as pressures and surface elevations are readily obtained, in addition to integrated forces and moments. The indirect approach requires only the knowledge of the first-order solution, and is relatively simple in comparison with the direct one. The formulation can be extended to evaluate the second-order pressure distribution (Eatock Taylor, Hung and Chau, 1989).

The most difficult and time-consuming part of the solution, common to both approaches, is the efficient and accurate evaluation of the free-surface integral with a highly oscillatory and slowly decaying integrand, which comes from the nonhomogeneity of the second-order free surface condition. Various authors have therefore suggested a methodology for the effective evaluation of this integral. For example, Eatock Taylor and Hung (1987) adopted an asymptotical method based on the explicit integration of the leading asymptotic in the far field. Matsui (1986, 1989), in his calculation of the difference-frequency forces in irregular waves, evaluated exactly the integral over the entire local-wave-free outer domain. He replaced the infinite integral by a finite-interval integral with a rapidly converging series as integrand. To improve the convergence of the series, Euler's transformation was employed. An alternative and more attractive method has been developed recently by Kim and Yue (1989, 1990), who performed the integration analytically in the infinite local-wave-free domain.

The solution of the second-order diffraction problem has been extensively studied for the case of a fixed vertical cylinder (Lighthill, 1979; Molin, 1979; Hunt and Baddour, 1981; Rahman, 1984; Eatock Taylor and Hung, 1987). The method can readily be extended to the second-order forces on axisymmetric bodies (Kim and Yue, 1989) and arbitrary three-dimensional bodies (Shimada, 1987). In the extension to the case of floating bodies, additional difficulties arise in the evaluation of the double spatial gradients of the first-order potentials involved in the second-order

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KEY WORDS: Nonlinear wave load, second-order diffraction force, sum-frequency force, wave springing, floating body, tension leg platform.