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Valid hydrodynamic interaction regions of multiple ships advancing in waves*

XU Yong (许勇), DONG Wen-cai (董文才)
Department of Naval Architecture, Naval University of Engineering, Wuhan 430033, China,
E-mail: nancy23670@163.com

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Abstract: Based on the 3-D surface panel method combined with the translating-pulsating source Green function, an approximate approach is developed to solve the hydrodynamic interacting problem of multiple ships advancing parallel in waves. Focus is on improving the calculating efficiency. In this approach, each ship is assumed to be in each other's far-field, and the near-field term in this Green function is neglected if the source point falls on one ship and the field point on others. Further, a matching relationship between the far-field waves and the interfered regions, which are defined as the overlapping areas between the mean wetted body surface of one ship and the propagating regions of the waves generated by another ship, is introduced to avoid the unnecessary computation of the relative terms of the Green function, if the field point is not in the overlapping areas. The approach is validated through studying the hydrodynamic terms and the free motions of two or three ships in side-by-side arrangement by comparing the obtained results with the model tests and the predictions of the exact method. The average calculating speed for the present approximate method is about 1.65-1.8 times of that for the exact method for solving the hydrodynamic interaction problem of two ships, and 2.56-2.73 times for that of three ships.

Key words: wave pattern, translating-pulsating source, calculation efficiency, model test, multiple ships

Introduction

Unlike the single ship case, the numerical simulation of the wave loads and the free motions of multiple ships advancing in waves is complex because the hydrodynamic interaction due to the presence of the other ships should be taken into account. Thus, each ship produces and scatters the radiation and diffraction waves which would excite other ships' motions and interfere each other. Therefore, theoretically, the solution to this problem is to determine the wave loads excited by these complex waves around these ships. The patterns of the radiation-diffraction waves generated by a ship with forward and oscillatory motions, are known to change drastically and dependent on the value of τ (where $\tau = U\omega_e / g$, U is the forward speed, ω_e is the oscillating frequency, and g is the gravity acceleration)[1]. There are three wave patterns, that is, the ring wave pattern, the inner V and outer V wave pattern for $0 < \tau < 0.25$, and the ring-fan wave pattern. The fan wave pattern and the inner V wave pattern exist in the total waves for $\tau > 0.25$ (see Fig.1). Except for the ring wave, other waves have a cusp, and the cusp angle is a function of τ [1]. θ_r, θ_f, θ_o and θ_i are defined as the the cusp angles of the ring-fan wave, the fan wave, the outer V wave and the inner V wave, respectively. The method for calculating these cusp angles can be found in Ref.[1].

The 3-D surface panel method is usually applied to solve the seakeeping problem for ships with forward and oscillatory motions in waves[2-5]. With the linearized and the potential flow assumptions, the velocity potential of the radiation and diffraction waves generated by a ship can be constructed by means of the 3-D translating-pulsating source Green function for solving the boundary integral equation. This Green function satisfies the classical linearised free surface condition, and represents the velocity potential induced by a per unit strength source traveling

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Biography: XU Yong (1981-), Male, Ph. D., Engineer

at a forward speed U and oscillating at a frequency ω_e. So it serves as a basic tool to describe the radiation and diffraction wave potentials in the present study. However, it is usually time consuming when applying this Green function in practice because the integrands of this function are oscillatory with high frequency[6,7], and very small integration steps are required to obtain a desired accuracy. In addition, a great number of panels are required to capture the important influence of the drastic waves especially for short waves e.g., the inner V waves for large values of τ [1]. Therefore, it may be more time consuming in dealing with the present problem because the total number of the panel elements for multiple ships is much larger than that of a single ship. Many numerical techniques, such as the fast integration method for calculating the Green function[8,9], the analytical quadrature of the Green function over a panel or a segment[10], and the spline panel element method[11,12], were proposed to improve the calculation efficiency.

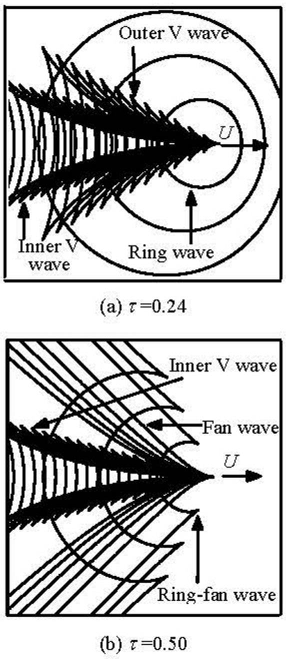

Fig.1 Definition of the diffraction-radiation wave patterns

In this paper, another method based on the 3-D surface panel method with the Havelock form Green function is proposed, which is characterized by the improvement in the calculating efficiency. A main feature of the approach is the neglect of the local flow component in the expression for the Green function in the computation of the influence coefficients associated with the interaction between the ship hulls. The numerical results demonstrate that this far field approximation is well justified, with a significant computational saving.

1. Mathematical formulas

1.1 *Velocity potentials*

To analyze the hydrodynamic interaction for two ships, an earth-fixed system O - XYZ and two body coordinate systems o_a - $x_a y_a z_a$ for ship-a and o_b - $x_b y_b z_b$ for ship-b are established, as shown in Fig.2. The origin of each system is placed on the undisturbed free surface, and the x-axis is positive in the direction of the speed U. D_x and D_y are defined as longitudinal and transverse distances between the two ships, respectively.

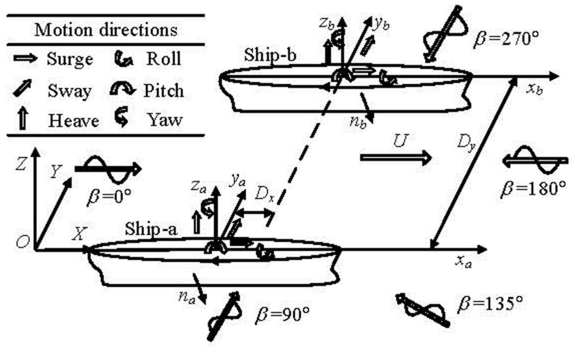

Fig.2 Coordinate systems

The fluid is assumed to be ideal and incompressible with a constant density ρ. The flow is assumed irrotational throughout, with surface tension effects neglected. The water depth is infinite. The two ships are assumed rigid and each of them oscillates in six degrees of freedom about their mean positions in regular waves. The incident wave amplitude ζ is assumed to be small so that unsteady motions of these two ships are sinusoidal in time with the encounter frequency ω_e. Then an unsteady potential Φ due to incident waves, diffraction and radiation waves can be introduced

$$\Phi(x, y, z, t) = \left(\sum_{j=1}^{6} \phi_{aj}\eta_{aj} + \sum_{j=1}^{6} \phi_{bj}\eta_{bj} + \phi_{a7} + \phi_{b7} + \phi_0 \right) \mathrm{e}^{-\mathrm{i}\omega_e t} \tag{1}$$

where

$$\phi_0(x, y, z) = -\frac{\mathrm{i} g \zeta}{\omega_0} \mathrm{e}^{k_0 z} \mathrm{e}^{\mathrm{i} k_0 (x\cos\beta + y\sin\beta)} \tag{2}$$

in which ϕ_0 is the incident wave potential, ω_0, k_0 and β are the frequency, the wave number and the incidental angle of the incident wave, ϕ_{aj} is the radiated wave potential due to the per unit amplitude motion in