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Iterative Rankine HOBEM analysis of hull-form effects in forward-speed diffraction problem*

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Abstract: A time-domain numerical algorithm based on the higher-order boundary element method and the iterative time-marching scheme is proposed for seakeeping analysis. The ship waves generated by a hull advancing at a constant forward speed in incident waves and the resultant diffraction forces acting on the hull are computed to investigate the hull-form effects on the hydrodynamic forces. A rectangular computational domain travelling at ship's speed is considered. An artificial damping beach for satisfying the radiation condition is installed at the outer portion of the free surface except the downstream side. An iterative time-marching scheme is employed for updating both kinematic and dynamic free-surface boundary conditions for numerical accuracy and stability. The boundary integral equation is solved by distributing higher-order boundary elements over the wetted body surface and the free surface. The hull-form effects on the naval hydrodynamics are investigated by comparing three different Wigley models. Finally, the corresponding unsteady wave patterns and the wave profiles around the hulls are illustrated and discussed.

Key words: Naval hydrodynamics, iterative scheme, higher-order boundary element method, exciting force, time domain, seakeeping

Introduction

The numerical prediction of hydrodynamic loads and motions of ships is not only of fundamental interest in marine engineering, but also useful in early stages of hull design, especially in selecting the hull form[1]. Various theoretical and numerical approaches for seakeeping analysis were developed since the last several decades. Among them, the strip theory, a potential-flow-based method, has been widely used in the calculations of the wave loads and the ship motions for research and ship design, since it is more practical and efficient than other methods.

However, the strip theory has inherent applicability limitations, such as, the slender hull form, the low forward speed of ship, and the high frequency of motions. The development of a sophisticated 3-D seakeeping analysis tool is considered as a promising way to overcome the limitations of the strip theory. The 3-D methods for seakeeping analysis can be classified into two major groups: the free-surface Green-function method and the Rankine panel method. Both of them can be applied in the frequency and time domain analyses. The free-surface Green-function method was adopted by many researchers, such as Lin and Yue[2], and Datta and Sen[3]. In the time-domain analysis, the free-surface temporal Green-function method involves a heavy computational burden in long-term simulations due to the convolution nature of the integral, especially, for body-nonlinear problems[3].

The Rankine panel method is expected to be more efficient for seakeeping analysis in the time domain, especially for nonlinear problems. It is one of the reasons why we choose the Rankine panel method. The steady ship-wave problem was studied by time-domain analysis methods, such as Kara et al.[4], and He and Kashiwagi[5]. Many studies of the unsteady ship-wave problem were reported. Yasukawa[6] analyzed the ship motion problems of a Wigley hull with a forward speed. He and Kashiwagi[7] studied the radiation and diffraction problems of a slender and a blunt Wigley

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hull by an explicit time-marching Rankine panel method. Kohansal and Ghassemi[8] used a BEM-based Rankine panel method to predict the hydrodynamic characteristics of various hull forms with large Froude number. Based on the linear and weakly-nonlinear theory, Kim et al.[9] developed an in-house code to analyze ship hydrodynamic problems. The Rankine panel method is flexible in treating the free surface, allowing more complicated free-surface conditions. On the other hand, the Rankine panel method has a drawback that the free surface surrounding the body must be discretized, which increases the number of unknowns and also introduces numerical dispersion, dissipation, and instability. Although the time-domain Rankine panel methods for the calculation of wave loads and ship motions have been widely applied, a robust and efficient seakeeping analysis tool of the panel method remains to be developed, as a great challenge. This is one of the main reasons why the strip theory is still widely used in the industry.

According to the shape function used for the geometry description and the representations of unknowns, the panel methods can be generally divided into the lower and higher order methods. In the former method (e.g., the constant or first-order panel methods), the planar panel is employed, and both the geometry and the physical variables are assumed to be constant or vary linearly over the panel. Good numerical accuracy can be achieved with a large number of panels. The higher-order panel method is expected to be more efficient and accurate, with the use of higher-order shape functions to describe the surface geometry and the unknown physical variables. Recently, the higher-order boundary element method (HOBEM) becomes popular because it is flexible and suitable even for complicated geometries and multi-bodies, without increasing difficulty in the computer code. More details of the HOBEM method can be found in Bai and Eatock Taylor[10], Ning and Teng[11], Gou et al.[12], He and Kashiwagi[7,13].

The seakeeping problem can be divided into three levels, involving linear, weakly-nonlinear, and weak-scatter assumptions[14]. This paper develops a nonlinear, robust and efficient seakeeping analysis tool. As the first step, a 3-D linear seakeeping analysis code was developed. An iterative time-marching scheme enjoys numerical accuracy and stability. By combining advantages of the Rankine HOBEM method and the iterative time-marching scheme, an iterative Rankine HOBEM for the time-domain seakeeping analysis was proposed. This iterative Rankine HOBEM was validated by a steady wave-making problem of a submerged prolate spheroid and a surface-piercing ship, and the sensitivity of the ship-generated waves to the water depth was studied through a modified Wigley hull[15]. Using this method, the wave-making resistance and pressure distributions on a standard Wigley were further studied in He and Kashiwagi[5]. Then this approach was successfully extended to the diffraction problem and was validated systematically through a Wigey hull with forward speed[16].

In the present paper, the proposed iterative Rankine HOBEM approach is extended to investigate the hull-form effects in the forward-speed diffraction problem. The optimization of the hull form was extensively studied, but the effects of the detailed factors on the ship hydrodynamics remain an issue. Most of studies were based on the minimization of the wave making resistance[17,18]. In this study, the unsteady diffraction problem is considered and the effects of the hull-form on the ship hydrodynamics are investigated. The HOBEM is extended from a 2-D direct boundary integral-equation method used in He and Kashiwagi[19]. A rectangular computational domain travelling at the vessel's speed is used. As the free surface is truncated in the practical computation, an artificial damping beach is installed at the outer portion of the free surface except the downstream for satisfying the radiation condition. Some numerical techniques are also employed to reduce the computational time while keeping the accuracy and robustness. The wave exciting forces on three different Wigley hulls in a wide range of frequencies of the incident wave are calculated to reveal the effects of the hull form on the naval hydrodynamics. Finally, the corresponding wave patterns and wave profiles around the hulls are also illustrated and discussed.

1. Problem formulation

The mathematical formulation is similar to that described in previous published papers[5,16], but for convenience of explanation, it is also outlined here. A ship moving at a constant speed U in waves is considered. A Cartesian coordinate system, (x, y, z), travelling at ship's speed U is used and illustrated in Fig.1. The x-axis is positive in the direction of the forward motion, the z-axis is positive upwards and the y-axis is determined by the requirement of the right-handed system, with its origin placed on the body center.

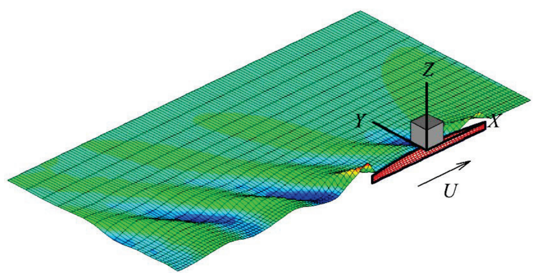

Fig.1 (Color online) Coordinate system and a typical mesh in the analysis