Applied Ocean Research 48 (2014) 186–201

Contents lists available at ScienceDirect

Applied Ocean Research

journal homepage: www.elsevier.com/locate/apor

Verification of a new radiation condition for two ships advancing in waves

Zhi-Ming Yuan*, Atilla Incecik, Day Alexander

Department of Naval Architecture, Ocean and Marine Engineering, University of Strathclyde, Glasgow, UK

ARTICLE INFO

Article history:
Received 4 June 2014
Received in revised form 15 August 2014
Accepted 19 August 2014
Available online 16 September 2014

Keywords:
Hydrodynamic interaction
Rankine source method
Radiation condition
Wave pattern
Forward speed

ABSTRACT

3-D Rankine source method is used to investigate the hydrodynamic interactions between two ships arranged side by side with forward speed. The radiation condition is satisfied by using a modified Sommerfeld radiation condition which takes into account the Doppler shift of the scattered waves. This new radiation condition is applicable to a wide range of forward speeds, including very low forward speed problem where the parameter τ ($\tau = u\omega/g$) is smaller than 0.25. The numerical solution is evaluated by applying the present method to two pairs of models and compared with experimental data and Green function method. Through the comparison study, we verify the new radiation condition and examine the wave patterns for a full range of forward speeds. Discussions are highlighted on the effect of the radiation conditions.

1. Introduction

Hydrodynamic interaction between two or more ships occurs in harbor area and waterways with dense shipping traffic as the vessels have to pass each other in close proximity; between tugs and vessels during escorting or maneuvering and berthing operations as well as during ship-to-ship operations for cargo transfers during oil and gas offloading operations. The behavior of two ships in waves with speed effect is of special concern to the Navy, that is, for underway replenishment, and for other commercial purposes.

Because of the hydrodynamic interactions, even relatively small wave can induce large motions of the smaller ship due to the nearness of the larger ship. When the ships are traveling with forward speed, the hydrodynamic interactions become more complicated. Fang and Kim [1] firstly took forward speed into consideration in ship-to-ship problem. They utilized a 2-D procedure, including the hydrodynamic interaction and an integral equation method, to predict the coupled motions between two ships advancing in oblique seas. They found that the roll motion was reduced while the ships were advancing. However, due to the 2-D assumptions, some deficiencies including the special treatment of the convective term still exist. Kashiwagi [2] used a unified theory to investigate the heave and pitch motions of a catamaran advancing in waves. Iwashita and Kataoka [3] used the 3D translating and pulsating Green-function method to analyze the hydrodynamic interaction between steady and unsteady flows for a catamaran. Chen and Fang [4] extended Fang's method [1] to 3-D. They used a 3-D Green function method to investigate the hydrodynamic problems between two moving ships in waves. It was found that the hydrodynamic interactions calculated by 3-D method were more reasonable in the resonance region, where the responses were not so significant predicted by 2-D method. However, their method was only validated by model tests with zero speed. More rigorous validation should be made by further experiments. The first model test of two ships advancing in waves was conducted by Li [5]. Both ships were restrained in surge, sway and yaw, as well as the free motions in heave, roll and pitch. McTaggart et al. [6] and Li [7] used that model test data to verify their numerical programs, which was based on 3-D Green function method. The numerical predictions and experiments showed that the presence of a larger ship could significantly influence the motions of a smaller ship in close proximity. But the numerical prediction of roll motion was not accurate. Another model test of two ships advancing in waves was conducted by Ronæss [8] at MARINTEK. The experiments were performed at different speeds and with different longitudinal distance between the ships. The numerical program based on unified theory was verified. It was found that heave and pitch motions could be predicted well while the roll motion was hard to predict due to the viscous effects. Ronæss's model test data was used by Xu and Faltinsen [9] to verify their numerical program based on 3-D Rankine source method. They applied an artificial numerical beach to satisfy the radiation condition. They found that the hydrodynamic peaks and spikes were

* Corresponding author at: Department of Naval Architecture, Ocean & Marine Engineering, University of Strathclyde, Henry Dyer Building, G4 0LZ Glasgow, UK. Tel.: +44 0141 548 2288; fax: +44 0141 552 2879.
E-mail address: zhiming.yuan@strath.ac.uk (Z.-M. Yuan).

0141-1187/$ – see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apor.2014.08.007

related to the resonance modes in the water gap between the hulls. However, they also failed to predict the roll motion precisely. Recently, within the frame work of Green function, Xu and Dong [10] developed a 3-D translating-pulsating (3DTP) source method to calculate wave loads and free motions of two ships advancing in waves. Model tests were carried out to measure the wave loads and the free motions for a pair of side-by-side arranged ship models advancing with an identical speed in head regular waves. Both the experimental and the numerical predictions showed that hydrodynamic interaction effects on wave loads and free motions were significant. They also pointed out that the prediction accuracy of the 3DTP method was much better than that of 3DP, especially for peak values of the free motion responses.

We find that most of the publications on two ships with forward speed problem are based on Green function that satisfies the Kelvin free surface condition, as well as the radiation condition. It is an effective method for the zero speed problems, but if the vessel is traveling with forward speed, this method still has some limitations. Firstly, it could not account for the near-field flow condition. Although some researchers [11,12] extended it to include the near-field free surface condition, the so-called irregular frequency still cannot be avoided. And it will bring singularity to the coefficient matrix equation. Secondly, it is impossible for the Green function to account for the effects of the steady flow on the unsteady potential. In the present study, the Rankine source approach will be applied, which uses a very simple Green function in the boundary integral formulation. This method requires the sources distributed not only on the body surface, but also on the free surface and control surface. Therefore, a flexible choice of free-surface conditions can be realized in these methods. The coupled behavior between steady and unsteady wave potential could be expressed in a direct formula. Meanwhile, the nonlinearity on the free surface could also be added in the boundary condition.

The Rankine source approach has been used by many investigators since it has been first proposed by Hess and Smith [13]. Investigators from MIT [14–16] applied the Rankine source approach to model steady and unsteady waves as a ship moves in waves. An analysis technique developed by Scalvounos and Nakos [14] for the propagation of gravity waves on a panelized free surface showed that a Rankine method could adequately predict the ship wave patterns and forces. Their work led to the development of a frequency-domain formulation for ship motions with a consistent linearization based upon the double body steady flow model which assumes small and moderate Froude numbers. Applications were reported by Nakos and Sclavounos [15]. This model was extended to the time domain by Kring [16] who also proposed a physically rational set of Kutta conditions at a ship's transom stern. Recently, Gao and Zou [17] developed a high-order Rankine panel method based on Non-Uniform Rational B-Spline (NURBS) to solve the 3-D radiation and diffraction problems with forward speed. Their results had very good agreement with the experimental data. However, there are still some limitations for the extensive use of the Rankine source approach. First of all, the Rankine source method requires much more panels which will considerably increase the computation time, especially when the matrix equation is full range matrix. However, the computation time will strongly depend on the numerical method and computer language. As the performance of computers increase rapidly, it only takes less than 1 min to solve a $10^4 \times 10^4$ full range matrix using Matlab. Typically, the number of panels will be no more than 10,000. The computation time is acceptable in engineering applications. Besides, the Rankine source method requires a suitable radiation boundary condition to account for the scattered waves in current. A very popular radiation condition for the forward speed problem, which is so-called upstream radiation condition, was proposed by Nakos [18]. The free surface was truncated at some upstream points, and a quiescent boundary condition was imposed at these points to ensure the consistency of the upstream truncation of the free surface. Another method to deal with the radiation condition is to move the source points on the free surface at some distance downstream [19]. The results from these two methods show very good agreement with published experimental data when the parameter τ ($\tau = u\omega/g$) is greater than 0.25, since they are both based on the assumption that there is no scattered wave traveling ahead of the vessel. However, when the forward speed of the vessel is very low, τ will be smaller than 0.25. When this case occurs, the scattered waves could travel ahead of the vessel, and these traditional radiation conditions could no longer be valid. For ship-to-ship problem, the forward speed is usually limited to a low level for the safe operation. Therefore, a new extensive radiation condition should be proposed to deal with the very low forward speed problem. Das and Cheung [20,21] provided an alternate solution to the boundary-value problem for forward speeds above and below the group velocity of the scattered waves. They corrected the Sommerfeld radiation condition by taking into account the Doppler shift of the scattered waves at the control surface that truncates the infinite fluid domain. They compared their results with the experimental data, and good agreement was achieved. They also computed the wave elevation on the free surface, and a reasonable wave pattern was obtained at $\tau < 0.25$ by using their new radiation condition. Yuan et al. [22] applied Das and Cheung's radiation condition to a Wigley III hull advancing in waves, and very good agreement had been achieved between their predictions and measurements.

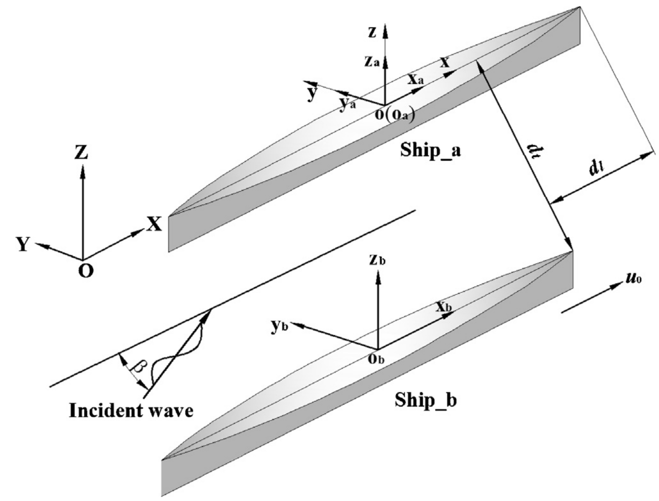

Fig. 1. An example vessels and coordinate system.

In the present study, we will extend Das and Cheung's radiation condition to the ship-to-ship problem. A 3-D panel code based on Rankine source method will be developed to investigate the hydrodynamic interaction between two vessels arranged side by side with forward speed. The motion responses of both ships will be calculated and compared to Li's and Ronæss' experimental results. Discussions will be highlighted on the wave patterns at full range of forward speeds.

2. Mathematical formulations of the potentials

2.1. Coordinate systems

The corresponding right-handed coordinate systems are shown in Fig. 1. The body coordinate systems o_a-$x_a y_a z_a$ and o_b-$x_b y_b z_b$ are fixed on Ship_a and Ship_b, respectively with their origins on the mean free surface, coinciding with the corresponding centre of gravity (CoG) in respect to x and y coordinates when both of the