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Numerical analysis of added resistance on ships in short waves

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ABSTRACT

In the present study, a Rankine panel method, which is based on the potential theory and a Cartesian-grid method, which solves the Euler equation directly, are applied to calculate ship motion and added resistance. In the Rankine panel method, a near-field method which calculates added resistance by integrating the second-order pressure on a body surface is adopted. In the Cartesian grid method, the wave–body interaction problem is considered as a multiphase problem, and volume fraction functions are defined in order to distinguish each phase in a Cartesian grid system. The added resistance is calculated by subtracting the steady surge force from the mean surge force measured in motion problems. This study focuses on added resistance under short wave conditions. Calculation capacities of the Rankine panel method and Cartesian grid method in short wavelength are systematically analyzed for several models, including Series 60 hulls (C_B=0.7, 0.8), S175 containerships and KVLCC2 hulls. In addition, established asymptotic methods in short wavelength are examined.

1. Introduction

Traditionally, ship resistance problems have been considered in still water conditions. Ocean-going vessels, however, often meet sea conditions which influence ship resistance and propulsion efficiency, and ship's forward speed decreases compared to that in calm sea conditions, because of added resistance. It is reported that the magnitude of added resistance is about 15–30% of calm-water resistance. An accurate prediction of this added resistance, therefore, is important in prescribing an appropriate propulsion power to a ship. Moreover, in recent years, the International Maritime Organization (IMO) has made regulations relating to the measurement of energy efficiency level such as Energy Efficiency Design Index (EEDI) to restrict green-house gas emissions from ships. For these reasons, ship designers should find optimum hull forms to minimize resistance in ocean waves, and pay more attention to added resistance problem.

Added resistance due to waves is one of the major components affecting ship performance. Since 1970s the added resistance problem due to waves has been widely studied by conducting experiments, and several results have been introduced into this field. Gerritsma and Beukelman (1972) showed that added resistance varies linearly, as the square of wave height and the influence of surge motion on added resistance may be negligible. Storm-Tejsen et al. (1973) measured added resistance on a destroyer, a high-speed displacement hull and the five Series 60 parent hulls. Added resistances on a S175 containership were measured by Fujii and Takahashi (1975) and Nakamura and Naito (1977). Also, added resistances on Wigley hull forms were measured by Journee (1992). Guo and Steen (2011), Sadat-Hosseini et al. (2013) and Lee et al. (2013) studied added resistance on KVLCC2 model hulls.

Meanwhile, there are two major numerical approaches which can be used to analyze the added resistance problem: the far-field and near-field methods. The far-field method, which is based on the momentum conservation theory, was introduced by Maruo (1960). It was further elaborated by Newman (1967), Gerritsma and Beukelman (1972) and Salvesen (1978). Recently, Kashiwagi et al. (2009) used Maruo's approach to calculate added resistance by applying enhanced unified theory, and they introduced a practical factor which complements of the calculation of added resistance at short wavelengths. Liu et al. (2011) applied a hybrid time-domain Rankine source-Green function method to solve this basic seakeeping problem; then Maruo's approach is adopted for the calculation of added resistance. Another numerical approach is the near-field method, which calculates added resistance by integrating the second-order pressure on a body surface. Faltinsen et al. (1980) used the near-field approach, with good validation results. They also introduced a simplified asymptotic method to complement the deficiency of this approach in short waves. Ye and Hsiung (1997) applied wave Green function to the added resistance problem. These efforts on added resistance problem were mostly based on frequency-domain approaches, and have had some major successes. There were a few researches based on the Rankine panel method which is widely applied today to both linear and nonlinear ship motion problems. Bunnik (1999) applied Rankine panel method to calculate added resistance on ship and compared effect of linearization schemes (uniform flow, double-body flow and

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non-linear) on added resistance. According to this study, three different linearization schemes give similar motion responses while there are discrepancies among added resistance results; generally non-linear scheme gives good result. Zhang et al. (2009) used time-domain Rankine panel method to calculate the drifting forces in the horizontal plane for ships moving with forward speed. They applied both linear scheme and approximate body nonlinear scheme (hydrostatic/Froude–Krylov forces are solved over the instantaneous wetted hull surface) to calculate added resistance. Joncquez (2009) analyzed the added resistance problem by using a time-domain Rankine panel method, applying both far- and near-field methods. Kim and Kim (2011) and Kim et al. (2012) also applied the higher-order Rankine panel method to the added resistance problem using the far- and near-field methods. The analysis of added resistance in irregular waves was carried out, and the proper criteria of time window and number of wave frequencies were suggested for irregular waves.

Added resistance in short wavelength is another main concern on this area because it is difficult to calculate added resistance accurately using previous calculation methods. In short wavelength conditions, incident waves are almost fully reflected, and diffraction waves are mainly generated near the ship bow. This increases nonlinear effects which are not considered in the prescribed methods, resulting in a relatively large difference between the numerical results and experimental data in short wavelength. To complement this problem, a few researches were carried out. Fujii and Takahashi (1975) derived the semi-empirical formula of added resistance in short wavelength conditions, by adopting some complement coefficients to drift force formula of a fixed vertical cylinder. Faltinsen et al. (1980) also derived asymptotic formula of added resistance in short wavelength conditions by assuming that the ship has vertical side at the water plane and that the wave length is small compared to the draft of the ship. These two approaches give good results for relatively blunt bodies; however, some poor results can be obtained for fine hull like containerships. In order to improve this drawback, the National Maritime Research Institute (NMRI) in Japan has proposed an improved expression based on the method of Fujii and Takahashi's (Kuroda et al., 2008; Tsujimoto et al., 2008). They modified compliment coefficients using experimental data.

Recently, thanks to the rapid development of computer power, computational fluid dynamics (CFD) has been applied to some seakeeping problems. A few groups have been studying numerical methods to solve field equations for the added resistance problem. Orihara and Miyata (2003) solved ship motions in regular head wave conditions, and evaluated the added resistance of a SR-108 containership in waves, using a CFD simulation method called WISDAM-X. The Reynolds-averaged Navier–Stokes (RANS) equation was solved by the finite-volume method with an overlapping grid system. In a recent comparative study on seakeeping computation tools (Bunnik et al., 2010), two groups – Kyushu University/Osaka University and Ecole Centrale de Nantes – calculated the added resistance of a containership in head seas. Hu and Kashiwagi (2007) developed a CFD-code which adopted a constrained interpolation profile (CIP) based Cartesian grid method. In the CIP-based formulation, the wave-body interaction problem is considered as a multi-phase problem. Different phases are recognized by a density function that has a definition similar to the volume fraction function in the VOF method. To calculate the volume fraction of solid phase, virtual particles were used. Visonneau et al. (2010) solved the trim and sink of a frigate advancing in regular head waves, using the free-surface capturing viscous solver ISIS-CFD. They used an unstructured hexahedral grid and an analytical weighting mesh deformation approach to treat the moving body problem. This program was also validated by Guo et al. (2012) for calculating the added resistance of KVLCC2 type hulls in head waves. Recently, Sadat-Hosseini et al. (2013) presented the added resistance calculation of KVLCC2 by both experiment and numerical method using CFDShip-Iowa v4.5 (Carrica et al., 2010), which is an overset, block structured CFD solver with RANS and DES for turbulence modeling and a single-phase level-set method for free-surface capturing.

In the present study, added resistances on ships have been estimated by using two numerical methods: the Rankine panel method and the Cartesian grid method (Seo et al., 2013; Yang et al., 2013). The Rankine panel method, which is based on the potential theory, is applied to solve this seakeeping problem, and to calculate the first-order potential and linear ship responses, as a necessity for the added resistance calculation. Additionally, the near-field method is adopted for the calculation of added resistance on a ship. Cartesian grid method, which solves the Euler equation directly, is also applied to estimate added resistance. In this method, the wave-body interaction problem is considered as a multiphase problem, and volume fraction functions are defined, in order to distinguish each phase in a Cartesian grid system. The added resistance is calculated by subtracting the steady surge force from the mean surge force measured in motion problems. In this study, we focus on added resistance in the short wave region, which is practically important because wave energy is concentrated. To this purpose, calculation capacities of Rankine panel method and Cartesian grid method in short wavelength are systematically analyzed using several models, including Series 60 hulls (C_B=0.7, 0.8), S175 containership and KVLCC2 hulls. In addition, established asymptotic methods in short wavelength are examined.

2. Mathematical background

2.1. Coordinate system

Let us consider a ship advancing with a certain forward speed, U, in the presence of incident waves. The ship's motion is defined in a mean-body fixed coordinate system, as shown in Fig. 1. Here, A, ω and β represent the incident wave amplitude, frequency and heading angle, respectively. S_B and S_F denote the body surface and the free-surface, respectively.

The ship is assumed to have a rigid-body, and the wave-induced body motion can be written as follows:

$$\vec{\delta}(\vec{x},t)=\vec{\xi}_T(t)+\vec{\xi}_R(t)\times\vec{x} \tag{1}$$

where, $\vec{\xi}_T=(\xi_1,\xi_2,\xi_3)$ and $\vec{\xi}_R=(\xi_4,\xi_5,\xi_6)$ are rigid-body translation and rotation, respectively.

2.2. Rankine panel method

2.2.1. Boundary value problem and equation of motion

The adoption of potential theory is a typical approach for ship motion analysis. Under the assumption of incompressible, inviscid

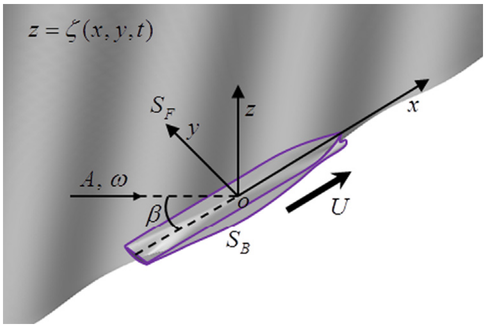

Fig. 1. Coordinate system for the ship motion problem.