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A numerical study on ship-ship interaction in shallow and restricted waterway

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ABSTRACT: *In the present study, a numerical prediction method on the hydrodynamic interaction force and moment between two ships in shallow and restricted waterway is presented. Especially, the present study proposes a methodology to overcome the limitation of the two dimensional perturbation method which is related to the moored-passing ship interaction. The validation study was performed and compared with the experiment, firstly. Afterward, in order to propose a methodology in terms with the moored-passing ship interaction, further studies were performed for the moored-passing ship case with a Reynolds Averaged Navier-Stokes (RANS) calculation which is using OpenFOAM with Arbitrary Coupled Mesh Interface (ACMI) technique and compared with the experiment result. Finally, the present study proposes a guide to apply the two dimensional perturbation method to the moored-passing ship interaction. In addition, it presents a possibility that the RANS calculation with ACMI can applied to the ship-ship interaction without using a overset moving grid technique.*

KEY WORDS: Ship-ship interaction; OpenFOAM; Two-dimensional perturbation method; Reynolds averaged navier-stokes (RANS); Manoeuvrability.

INTRODUCTION

Over the last 20 years, Very Large Crude Carriers (VLCCs) and large containerships have been developed, manoeuvrability of such large ships have become important in terms of ship operation (or navigation), port design and ship-ship cargo transfer. Especially, ultra large containerships over 20,000 *TEU* class are developed, and size of the port becomes relatively narrow so that the ship-ship interaction should not be neglected. The VLCCs are in the same situation as the ultra large containerships. Many ports are not suited to receive ships of these size. They may not be deep enough, have narrow entrance or small berth preventing the tankers to be accommodated. Therefore, the time spent in the harbor must be as short as possible. This time is mostly determined by the time needed to unload and re-load the ship. In order to solve it, a lightering operation such as ship-ship cargo transfer has been applied. In such case of ship-ship cargo transfer, the distance between two ships shall be considered, carefully. In order to safely operate under this situation, the assistance of specialized personnel is needed. As knowledge is very limited on this situation, practical experience is of great value. But very little theoretical knowledge has been acquired on this topic.

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Although there have been a number of different approaches in study of the ship-ship interaction such as empirical models, theoretical calculations and model test, it is difficult to study because there are too many parameters to consider. A number of mathematical models were published on the ship-ship interaction based on the model test by Dand (1981), Kijima (1987), Vantorre et al. (2002), Lee (2012) and etc. More importantly, as the ship-ship interaction occurs in shallow water for most of the time, the model tests should be carried out in a basin where shallow water can be realized. However, there are not many model basins that can realize such test set up for the ship-ship interaction in shallow water so that several empirical formula models have been studied based on the limited number of model test data. As for numerical approach, Tuck and Newmann (1976) and Kijima et al. (1991) studied two dimensional perturbation (or slender body) method. Also, beginning with the two dimensional perturbation method, Varyani et al. (1999) proposed an empirical formula for predicting the peaks of the lateral force and the yaw moment during the interaction between two meeting ships. But this formula has the limitation that the moored-passing ship interaction cannot be considered.

Other than the potential theory based method, Chen et al. (2003) performed a RANS based numerical simulation using an overset moving grid (or chimera) on a head-on encounter case, one of a series of model tests performed by Dand (1981). It is notable that he showed a possibility to apply the RANS simulation on the ship-ship interaction. However, the RANS simulation on the ship-ship interaction takes much more computation time than the two dimensional perturbation method or the empirical formula. Considering that there are many parameter to be taken into account on the ship-ship interaction, the computation time may be the one of important factor in the engineering fields with the practical point of view.

Therefore, the numerical simulation based on the two dimensional perturbation method by Kijima et al. (1991) was performed for a case of the model test by Dand (1981) in order to examine suitability of the results and proposes how to apply the moored-passing ship interaction mentioned previously. The proposed method is to perform the sensitivity test by using the two dimensional perturbation method and compare the experiment by Vantorre or other comparable data such as a RANS simulation. Unfortunately, there were no same hull forms used in the experiment, most similar hull forms (KVLCC1 and KCS) were selected as the studied hull forms. In addition, in order to obtain the other comparable data, the RANS simulation was performed

The RANS simulations performed in the present study did not use the overset moving grid but Arbitrary Coupled Mesh Interface (ACMI), another moving grid method. The overset grid has a great strength where the various ship motions can be simulated freely. However, the computational cost is relatively high and the stability of the solver is weak due to the possibility of orphan cells from the hole-cutting process for the overset grid. On the other hand, the ACMI technique has limitations in simulating the ship motions but is more stable in solving with less computational cost. Also, it is not difficult to use the ACMI technique in RANS simulation as it has been developed and included in OpenFOAM (Jasak, 2009) which is an open-source CFD toolkit.

THEORY

Basic assumptions

In principle, there are many considerable situations for the ship-ship interaction in the restricted water area. But in this study, the situation will be restricted as follows,

- one own ship and one encounter ship in the opened shallow water
- one own ship and one encounter ship in the shallow water with restricted vertical side wall

The encounter situation of two ships can be either overtaking or head-on encounter. Based on these restrictions, the coordinated systems for the ship-ship interaction study can be defined as Fig. 1. In the coordinate system shown in Fig. 1, $O-xy$ represents the calm water plane. Right-handed coordinate systems are defined in this study. The origin of the ship-fixed moving coordinate system is located on the midship of the hull and the x-axis is directed toward to bow. The right-handed coordinate system is considered as the ship-fixed coordinated system for each ship as well.