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The investigation of ship maneuvering with hydrodynamic effects between ships in curved narrow channel

Chun-Ki Lee, Serng-Bae Moon*, Tae-Gweon Jeong

Division of Navigation Science, Korea Maritime and Ocean University, Pusan, South Korea

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Abstract

The hydrodynamic interaction between two large vessels can't be neglected when two large vessels are closed to each other in restricted waterways such as in a harbor or narrow channel. This paper is mainly concerned with the ship maneuvering motion based on the hydrodynamic interaction effects between two large vessels moving each other in curved narrow channel. In this research, the characteristic features of the hydrodynamic interaction forces between two large vessels are described and illustrated, and the effects of velocity ratio and the spacing between two vessels are summarized and discussed. Also, the Inchon outer harbor area through the PALMI island channel in Korea was selected, and the ship maneuvering simulation was carried out to propose an appropriate safe speed and distance between two ships, which is required to avoid sea accident in confined waters. From the inspection of this investigation, it indicates the following result. Under the condition of $S_{P12} \leq 0.5L$, it may encounter a dangerous tendency of grounding or collision due to the combined effect of the interaction between ships and external forces. Also considering the interaction and wind effect as a parameter, an overtaken and overtaking vessel in narrow channel can navigate while keeping its own original course under the following conditions; the lateral separation between two ships is about kept at 0.6 times of ship length and 15 degrees of range in maximum rudder angle. On the other hand, two ships while overtaking in *curved* narrow channel such as Inchon outer harbor in Korea should be navigated under the following conditions; S_{P12} is about kept at 1.0 times of ship length and the wind velocity should not be stronger than 10 m/s.

Keywords: Ship maneuvering; Hydrodynamic force; Narrow channel; Safe speed and distance; Wind

1. Introduction

The increasing number of large vessels because of the rapid development of shipping leads to a high density of vessels in confined waters, so that the lateral and longitudinal spacing between vessels become smaller and the unpredictable interaction effect between them happens in restricted waterways such as in a harbor or narrow channel. When two large vessels navigating closely, the asymmetric flow around a vessel induced by the vicinity of other vessel causes pressure differences between port and starboard sides, thus two vessels may suffer an attractive force or a repulsive force and bow inward moment or bow outward moment. So, the hydrodynamic forces and moments acting on a vessel in confined waters are more complicated than those in unrestricted waterways, and it will become difficult to steer the vessel because of the hydrodynamic interaction effects between two vessels. Specially, proximal navigation of large vessels including overtaking, and congested vessel traffic in curved narrow channel is potentially hazardous. Therefore, it is of great significance to study the hydrodynamic interaction forces and moments between two vessels to ensure a safe navigation. For this to be possible, the hydrodynamic forces and moments between two vessels in confined waters should be properly

* Corresponding author.
E-mail address: msbae@kmou.ac.kr (S.-B. Moon).
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understood, and the work of hydrodynamic interaction effects between vessels have been made by researchers. Newman (1965, 1972) reported the force and moment on a slender body of revolution moving near a wall and some theory for ship maneuvering. Yeung and Tan (1980) analyzed hydrodynamic interactions of a slow-moving vessel with a coastline or an obstacle in shallow water using slender-body theory. In this paper, the assumptions of the theory are that the fluid is inviscid and the flow irrotational except for a thin vortex sheet behind the vessel. Similar works were reported by Beck et al. (1975), Beck (1977), Cohen et al. (1983), Davis (1986), Landweber et al. (1991). Also, Kijima et al. (1991) studied on the interaction effects between two ships in the proximity of a bank wall, and Korsmeyer et al. (1993) analyzed the theory and computation for the interaction forces among multiple ships or bodies which are operating near to each other. Also, Yasukawa (2002) studied on the maneuvering motions between two ships navigating in the proximity. Despite the past investigations, the hydrodynamic interaction force and moment between two vessels in narrow channel still needs to be considered from the viewpoint of safe maneuvering. Also, in the perspective of safe maneuvering, this paper will consider the safe spacing and velocity between two vessels for the sake of reducing sea accidents in curved narrow channel, and create a base for traffic safety system in restricted waterways. Therefore in this paper, the Inchon outer harbor area through the PALMI island channel in Korea was selected, and the ship maneuvering simulation was carried out to propose an appropriate safe speed and distance between two large vessels, which is required to avoid sea accident from the viewpoint of marine safety in confined waters.

2. Formulation of the problem

The coordinate system fixed on each vessel is shown by $o_i - x_i y_i (i = 1, 2)$ in Fig. 1. Consider two vessels designated as ship 1 and ship 2 moving at speed $U_i (i = 1, 2)$ in an inviscid fluid of depth h. In this case, each vessel is assumed to move at each other in a straight line through calm water. In Fig. 1, S_{P12} and S_{T12} are transverse and longitudinal distance between two vessels. Also, V_w and υ mean the wind velocity and wind direction.

Assuming small Froude number, the free surface is assumed to be rigid wall, which implies that the effects of

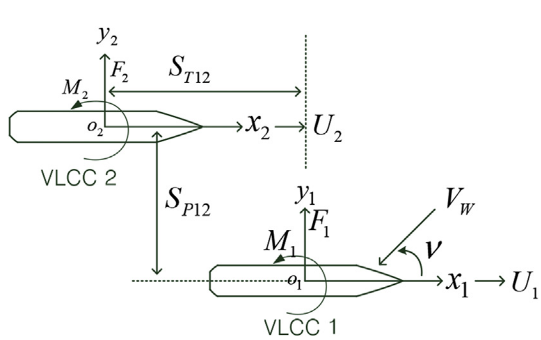

Fig. 1. Coordinate system.

waves are neglected. Then, double body models of the two vessels can be considered. The velocity potential $\phi(x, y, z; t)$ which expresses the disturbance generated by the motion of the vessels should satisfy the following conditions:

$$\nabla^2 \phi(x, y, z; t) = 0 \tag{1}$$

$$\left|\frac{\partial \phi}{\partial z}\right|_{z=\pm h} = 0 \tag{2}$$

$$\left|\frac{\partial \phi}{\partial n_i}\right|_{B_i} = U_i(t)(n_x)_i \tag{3}$$

$$\phi \to 0 \text{ at } \sqrt{x_i^2 + y_i^2 + z_i^2} \to \infty \tag{4}$$

Where, B_i is the body surface of vessel i. $(n_x)_i$ is the x_i component of the unit normal $\overrightarrow{n}$ interior to B_i. A following assumptions of slenderness parameter ε are made to simplify the problem.

$$L_i = O(1),\ B_i = O(\varepsilon),\ d_i = O(\varepsilon)(i = 1, 2),\ h = O(\varepsilon),\ S_{P12} = O(1)$$

Under these assumptions, the problem can be treated as two-dimensional in the inner and outer region.

2.1. Inner and outer solution

The velocity potential $\Phi_i (i = 1, 2)$ in the inner region can be replaced by the velocity potential representing two-dimensional problems of a vessel cross section between parallel walls representing the bottom and its mirror image above the water surface. Then, Φ_i can be expressed as follows (Kijima et al., 1991):

$$\Phi_i(y_i, z_i; x_i; t) = U_i(t)\Phi_i^{(1)}(y_i, z_i) + V_i^*(x_i, t)\Phi_i^{(2)}(y_i, z_i) + f_i(x_i, t) \tag{5}$$

where, $\Phi_i^{(1)}$ and $\Phi_i^{(2)}$ are unit velocity potentials for longitudinal and lateral motion, V_i^* represents the cross-flow velocity at $\sum_i(x_i)$, and f_i is a term being constant in each cross-section plane, which is necessary to match the inner and outer region. In the meantime, the velocity potential ϕ_i in the outer region is represented by distributing sources and vortices along the body axis (Kijima et al., 1991):

$$\phi_i(x, y; t) = \sum_{j=1}^{2} \frac{1}{2\pi} \left\{ \int_{L_j} \sigma_j(s_j, t) \log\sqrt{(x-\xi)^2 + (y-\eta)^2}\, ds_j + \int_{L_j w_j} \gamma_j(s_j, t) \tan^{-1}\left(\frac{y-\eta}{x-\xi}\right) ds_j \right\} \tag{6}$$

where $\sigma_j(s_j, t)$ and $\gamma_j(s_j, t)$ are the source and vortex strengths, respectively. L_j and w_j denote the integration along vessel j and