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論 文

A study on the Manoeuvring Motion Under the Condition of External Forces in Restricted Waterways

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ABSTRACT : *In the present paper, the emphasis is on the safe navigation between ships moving each other in restricted waterways under the external force, such as wind or current. The numerical simulation of manoeuvring motion was carried out to propose an appropriate safe speed and distance between ships, which is required to avoid marine disasters from the viewpoint of marine safety. From the inspection of this investigation, it indicates the following result. In case of proximal navigation between ships under the wind and current, the low-speed vessel is potentially hazardous because the rudder force of low-speed vessel needed for steady-state course-keeping is not sufficient, compared to the high-speed vessel. The manoeuvring characteristic based on this investigation will be very useful for keeping the safety of navigation from the practical point of ships design and traffic control in restricted waterways.*

KEY WORDS : *Safe navigation, Safe speed, Safe distance, Restricted waterways, Marine disasters, Manoeuvrability*

1. Introduction

In restricted waterways, potential hazards of collision and grounding are maximum, and control errors could result in costly damages to both the ship and environment. The increasing number of ship collisions and the resulting ship grounding, etc., have led to a massive effort of improving ship manoeuvrability performance because the situation in these areas is being made more complex by local currents, changing tides, confined maneuvering boundaries, and considerable hydrodynamic effects of ships moving closer each other. It is important that the ship operator should be able to maintain full control of the ship during operations. For this to be possible, the hydrodynamic interaction between ships in restricted waterways should be properly understood, and the works on this part have beenreported for the past years. But, the detailed knowledge on maneuvering characteristics for the safe navigation while avoiding terrible
collision between ships, particularly under the wind and current, is still being required to prevent marine disasters from the viewpoint of marine safety.

A large number of papers have been described on the hydrodynamic interaction between ships. Thus, some improved results were obtained. (Yeung et al. 1978) analyzed hydrodynamic interactions acting on a ship moving near the fixed obstacles. Similar works were also reported by (Davis 1986). (Kijima et al. 1991) studied on the interaction effects between two ships in the proximity of bank wall. Meanwhile, (Lee et al. 2002) obtained the evaluation on the safe navigation including the interaction forces between ships, and between ship and some fixed obstacles under various conditions.

The main subject of this paper is to propose an appropriate safe speed and distance between ships required to avoid marine disasters from the viewpoint of marine safety.

2. Background of Numerical Method

The coordinate systems fixed on each ship and on the earth are shown by $o_i - x_i y_i \, (i=1,2)$ and $o-xy$, respectively 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 finite water depth h. S_{P12} and S_{T12} represent the

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lateral and longitudinal distances between ship 1 and ship 2 in Fig.1. V_W, V_c, ν, α mean the wind velocity, current velocity, wind direction and current direction, respectively. Both calculation methods and theoretical backgrounds related in this were reported in the previous research work (Lee et al. 2002), but non-dimensional expression for the lateral force, CF_i, and yawing moment, CM_i, affecting upon two vessels is given by

$$CF_i = \frac{F_i}{\frac{1}{2}\rho L_i d_i U_i^2}, \quad CM_i = \frac{M_i}{\frac{1}{2}\rho L_i^2 d_i U_i^2} \tag{1}$$

where L_i is the ship length of ship i and d_i the draft of ship i. ρ is the water density.

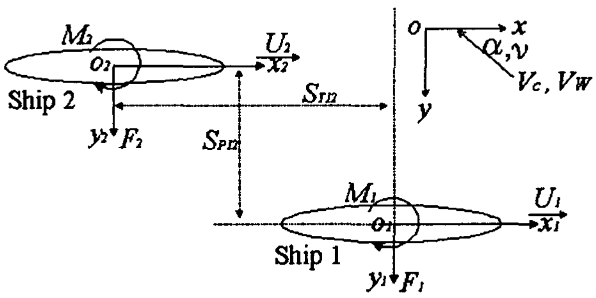

Fig. 1 Coordinate systems

3. Condition of calculation

In case where the wind and current velocity are very small, compared to the advance speed of the ship, it is possible to turn the ship to the left or right with moderate helm angle. However, as the wind or current velocity becomes large, it becomes difficult to turn her to the direction as one demands. So, the manoeuvering motion between ships while overtaking in congested areas under the current and wind is potentially hazardous. A parametric study on the numerical investigations has been conducted on the general cargo ship as shown in Table 1 and Table 2, which both ship 1 and ship 2 are always similar form. A typical overtaking condition was investigated as shown in Fig.1. Provided that the speed of a ship 1 (denoted as U_1) is maintained at 10 kt, the velocities of overtaking or overtaken ship 2 (denoted as U_2) were varied, such as 6 kt, 12kt and 15kt, respectively. As shown in Table 3, for the cases of external force, the wind direction (ν) and velocity (V_W) were considered from 0 to 350 and 10m/s, respectively, and the current direction (α) was considered as 0 and 180 and also current velocity (V_c) was considered as 4k.

Table 1 Principal dimensions of ships

	General cargo ship
Length L(m)	155.0
Breadth B(m)	26.0
Draft d(m)	8.7
Block coef. C_B	0.6978

Table 2 Types with parameters L_2/L_1 and U_2/U_1

	Ratio between two ships	
	L_2/L_1	U_2/U_1
Type 1	1.0	0.6, 1.2, 1.5

Table 3 Conditions of external force

External force	direction	velocity
wind	0 ~350	10m/s
current	0~,180	4kt

4. Results and discussion

4.1 Equation of ship manoeuvring motions under the influence of the hydrodynamic interaction force

The ship manoeuvring motions are simulated numerically by using the predicted hydrodynamic interaction forces and using the ship manoeuvering model (Kijima et al. 1990), and the external force and moment acting on two ships moving each other in restricted waterways under the condition of current and wind can be expressed as follows:

$$\left(m_i' + m_{xi}'\right)\left(\frac{L_i}{U_i}\right)\left(\frac{\dot{U}_i}{U_i}\cos\beta_i - \dot{\beta}_i \sin\beta_i\right) + \left(m_i' + m_{yi}'\right) r_i' \sin\beta_i - \left(m_{xi}' - m_{yi}'\right)\frac{V_{ci}}{U_i} r_i' \sin(\psi_i' - \alpha) = X_{Hi}' + X_{Pi}' + X_{Ri}' + X_W' \tag{2}$$

$$-\left(m_i' + m_{yi}'\right)\left(\frac{L_i}{U_i}\right)\left(\frac{\dot{U}_i}{U_i}\sin\beta_i - \dot{\beta}_i \cos\beta_i\right) + \left(m_i' + m_{xi}'\right) r_i' \cos\beta_i - \left(m_{yi}' - m_{xi}'\right)\frac{V_{ci}}{U_i} r_i' \cos(\psi_i' - \alpha) = Y_{Hi}' + Y_{Ri}' + Y_{Pi}' + Y_W' \tag{3}$$

$$\left(I_{zzi}' + i_{zzi}'\right)\left(\frac{L_i}{U_i}\right)^2\left(\frac{\dot{U}_i}{L_i}r_i' + \frac{U_i}{L_i}\dot{r}_i'\right) = N_{Hi}' + N_{Ri}' + N_{Ii}' + N_{W}' \quad (4)$$

where, m_i' represents non-dimensionalized mass of ship i, m_{xi}' and m_{yi}' represent x, y axis components of non-dimensionalized added mass of ship i, β_i means drift angle of ship i, respectively. The subscript H, P, R, I and W mean ship hull, propeller, rudder, component of the hydrodynamic interaction forces between two ships and wind respectively, and also, V_c, α, ψ_i mean current velocity, current direction and heading angle of ship i, respectively. X, Y and N represent the external force of x, y axis and yaw moment about center of gravity of ship, respectively. Wind forces and moments acting on ships were estimated by (Fujiwara et al. 1998). A rudder angle is controlled to keep course as follows:

$$\delta_i = \delta_{0i} - K_1(\psi_i - \psi_{0i}) - K_2 r_i' \quad (5)$$

where δ_i, r_i' represent rudder angle, non-dimensional angular velocity of ship i, respectively. Subscript '0' indicates initial values and also, K_1 and K_2 mean the control gain constants.

4.2 Result of Simulation under the condition of external forces

Fig.2 shows the result of manoeuvring simulation for model ship with function of the external force for the case of 1.2 in U_2/U_1. In this case, the wind velocity (V_W), current velocity (V_c) and current direction (α) were taken as 10m/s, 4kt and 0 , respectively. However, the wind direction(ν) were taken as 40~90 and 120 , respectively. The separation between two ships, S_{P12}, was taken as 0.3 times of ship 1 and L_2/L_1 was taken as 1.0 in $h/d_1 = 1.2$. The control gain constants used in these numerical simulations are $K_1 = K_2 = 5.0$, and maximum rudder angle, $\delta_{max} = 10$. Fig.2 indicates the following result. When and if one ship passes the other ship, any yawing moments of the overtaken vessel as shown in Fig.2 show strong motion due to the hydrodynamic interaction forces between ships. Then once initiated such a turn would develop rapidly, the rudder force of the overtaken vessel under the condition of $\delta_{max} = 10$ was not large enough to stop this tendency. In case of 120 of wind direction(Fig.2(c)), there was a most clear tendency for the overtaken vessel to deviate to starboard, compared to the cases of (a) and (b) in Fig.2. However, in case of (a) in Fig.2, two ships' courses are not almost deviated from the original direction under the condition of $\delta_{max} = 10$ because the effect of external force under the condition of 40 of wind direction is not large.

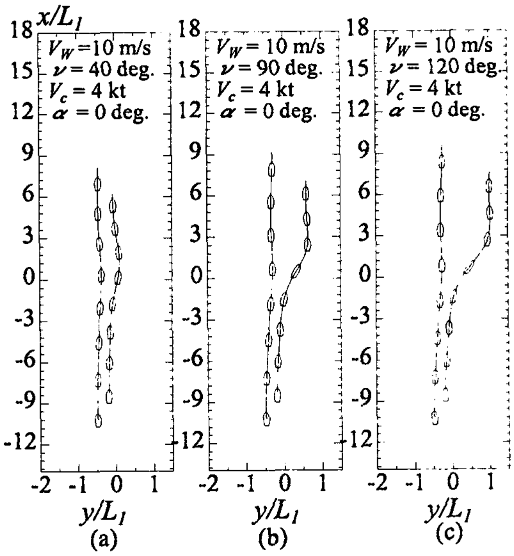

Fig.2 Ship trajectories under the external forces with rudder control

4. Conclusions

The following conclusions can be drawn from the numerical calculation for hydrodynamic interaction forces between two ships while overtaking in open sea.

When compared to the case of overtaking vessel, among other things, the effect of hydrodynamic interaction forces acting on the overtaken vessel is increasingly larger with increase of velocity ratio. Furthermore, if the lateral distance between two ships is about one times of a ship-length the hydrodynamic interaction forces were disappeared.

From the simulation of ship manoeuvering motions using numerical data, the following conclusions can be drawn. Firstly, lateral distance between ships are required for the velocity ratio of 1.2, compared to the cases of 0.6 and 1.5. Secondly, in case of proximal navigation between ships under the wind and current, the low-speed vessel is potentially hazardous because the rudder force of low-speed vessel needed for steady-state course-keeping is not sufficient, compared to the high-speed vessel.

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