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On the Manoeuvring Motion Considering the Interaction Forces in Confined Waters

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Abstract : *The emphasis is put on the detailed knowledge on manoeuvring characteristic for the safe navigation while avoiding terrible collision between ships and on the guideline to the design and operation of the ship-waterway system. The numerical simulation of manoeuvring motion was carried out parametrically for different ship types, ship-velocity ratios, separation and stagger between ships. As for the calculation parameters, the ratios of velocity difference (hereafter, U_2/U_1) between two ships were considered as 0.6, 1.2, 1.5. From the inspection of this investigation, it indicates the following result. Considering the interaction force only as parameter, the lateral distance between ships is necessarily required for the ship-velocity ratio of 1.2, compared to the cases of 0.6 and 1.5 regardless of the ship types. Furthermore, regardless of the ship-velocity ratio, an overtaking and overtaken vessel can be manoeuvred safely without deviating from the original course under the following conditions; the lateral distance between two vessels is approximately kept at 0.5 times of ship-length and 5 through 10 degrees of range in maximum rudder angle. 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, Interaction force, Restricted waterways, Sea accident, 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. So, the control of ships in confined waters, particularly in narrow waterways, has been receiving a great deal of attention in recent years because of the ever-increasing size of ships such as tankers and bulk carriers. Also, the problem of ship controllability in confined waters due to the effect by restricted waterways, such as shallow water effect or inherently restricted nature of waterways is the concern not only of naval architects and ship operators but also of engineers who will design future waterways. So, the ship manoeuvring and ship-ship interaction in confined water have been important problems in channel design and ship operation in harbours, and the problems are complicated because of the shallow water effects as well as ships are operating near other ships. Therefore, the manoeuvring motion due to the hydrodynamic interaction forces between vessels moving each other in close proximity in restricted waterways, such as in a harbour, or in a narrow channel, has been of considerable interest, because the safe operation and effective control of the vessel require a good understanding of the hydrodynamic interaction forces that encounter. In particular, the situation for the specific case of overtaking between ship and ship in restricted waterways is made more complex by restricted manoeuvring boundaries, and the interaction effects of ships on each other. So, it is extremely 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 been reported for the past years(Beck, 1977 ; Yeung, 1978 ; Yeung, 1980 ; Davis, 1986 ; Kijima., 1991 ; Landweber, 1991 ; Korsmeyer, 1993).

However, in many of the above-mentioned papers, the transient sway force and yaw moment experienced by a ship in transit near other ships was investigated. Thus, the detailed knowledge on manoeuvring characteristic for the safe navigation while avoiding terrible collision between ships is still being required to prevent marine disasters.

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 depth h. In this case, each ship is assumed to move each other in a straight line through calm water of uniform depth h. S_{P12}

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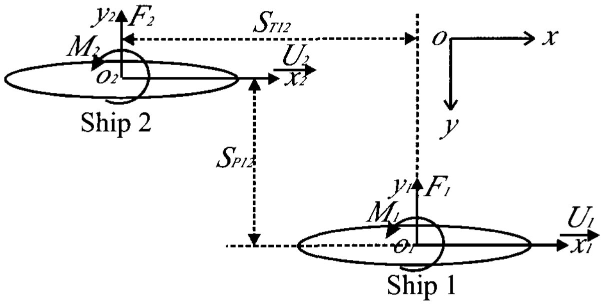


Fig. 1 Coordinate systems

and S_{T12} are lateral and longitudinal distances between ship 1 and ship 2 in Fig.1. Both calculation methods and theoretical backgrounds related in this were reported in the previous research work(Kijima et al., 1990), but non-dimensional expression for the lateral force C_{Fi}, and yawing moment C_{Mi}, affecting upon two vessels is given by

$$C_{Fi} = \frac{F_i}{\frac{1}{2}\rho L_i d_i U_i^2} \quad , \quad C_{Mi} = \frac{M_i}{\frac{1}{2}\rho L_i^2 d_i U_i^2} \tag{1}$$

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

3. Hydrodynamic interaction forces between ships

3.1 Condition of calculation

In this section, the hydrodynamic interaction forces acting on two ships while overtaking in shallow waters have been examined. A parametric study on the numerical calculations has been conducted on four different ship types as shown in Table 1. As shown in Table 2, for the case of 1.0 in L_2/L_1, and for the cases of 0.6, 1.2 and 1.5 in U_2/U_1 as the parameters, the hydrodynamic interaction forces between two ships in open sea have been computed. In this case, provided that of a ship 1 (denoted as U_1) is maintained at 10kt, the velocities of overtaking or overtaken ship 2 (denoted as U_2) were varied, such as 6kt, 12kt and 15kt, respectively.

Table 1 Principal dimensions of ships

	Cargo	Container	PCC	VLCC
Length L(m)	155.0	175.0	190.0	325.0
Breadth B(m)	26.0	25.375	32.26	53.0
Draft d(m)	8.7	9.502	10.0	22.05
Block coef. C_B	0.6978	0.5717	0.6178	0.830

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

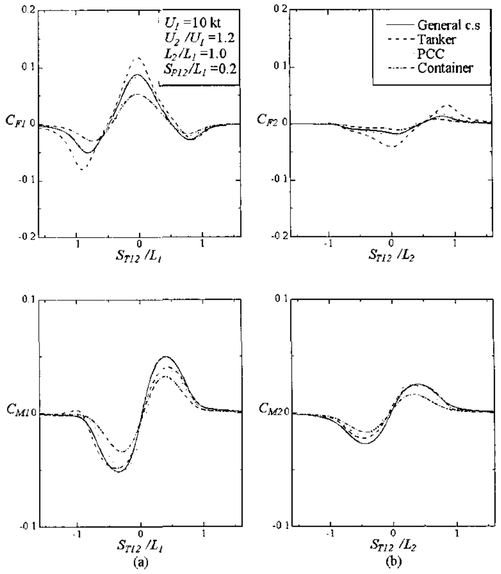


Fig. 2 Lateral force and yawing moment coefficients

3.2 Hydrodynamic interaction forces in case of overtaking situation

Fig. 2 displays the computed lateral force and yawing moment coefficients between two ships with various different ship types in $h/d_1 = 1.2$. The separation between two ships was chosen to be $0.2L_1$ under the condition of $U_1/U_2 = 1.2$. The solid lines show the result of interaction forces and yawing moment for the case of general cargo ship. The dashed lines mean the result of interaction forces and yawing moment for the case of tanker, and the dotted lines show the result for the case of PCC. The dash dot lines mean the result for the case of container. From this figure, regardless of the ship types, the effect of hydrodynamic interaction forces acting on the overtaken vessel is bigger than the one of the overtaking vessel.

4. Results and discussion

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

In this section, the ship manoeuvring motions are simulated numerically using the predicted hydrodynamic interaction forces and the ship manoeuvring model(Kijima et al., 1990), and the external force and moment acting on two ships in confined water can be expressed as follows:

$$(m'_i + m'_{xi})\left(\frac{L_i}{U_i}\right)\left(\frac{\dot{U}_i}{U_i}cos\beta_i - \dot{\beta}_i sin\beta_i\right) + (m'_i + m'_{yi})r'_i sin\beta_i = X'_{Hi} + X'_{Pi} + X'_{Ri} \quad (2)$$

$$-(m'_i + m'_{yi})\left(\frac{L_i}{U_i}\right)\left(\frac{\dot{U}_i}{U_i}sin\beta_i + \dot{\beta}_i cos\beta_i\right) + (m'_i + m'_{xi})r'_i cos\beta_i = Y'_{Hi} + Y'_{Ri} + Y'_{Ii} \quad (3)$$

$$(I'_{zzi} + i'_{zzi})\left(\frac{L_i}{U_i}\right)^2\left(\frac{\dot{U}_i}{L_i}r'_i + \frac{U_i}{L_i}\dot{r}'_i\right) = N'_{Hi} + N'_{Ri} + N'_{Ii} \quad (4)$$

where m'_i represents non-dimensionalized mass of ship i and m'_{xi}, 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 subscribt H, P, R, I mean ship hull, propeller, rudder, component of the hydrodynamic interaction forces between two ships. A rudder angle is controlled to keep course as follows:

$$\delta_i = \delta_{0i} - K_1(\psi_i - \psi_{0i}) - K_2 r'_i - K_3(S_{Pi} - S_{P0i}) \quad (5)$$

where δ_i, ψ_i, r'_i represent rudder angle, heading, non-dimensional angular velocity of ship i, and S_{Pi} is non-dimensionalized predicted course. Subscript '0' indicates initial values.

Fig. 3 and Fig. 4 show the results for deviated maximum lateral distance from the original course with function of the S_{P12}/L_1 for the case of overtaken and overtaking vessel. , In this case, the wind effect was not taken into account. The lateral separation between two ships was chosen to be 0.3 to 0.5 times of L_1 under the condition of $L_2/L_1 = 1.0$. The control gain constants are $K_1 = K_2 = 2.0, K_3 = 0.0$, $K_1 = K_2 = 5.0, K_3 = 0.0$, $K_1 = K_2 = 2.0, K_3 = -1.0$, $K_1 = K_2 = 5.0, K_3 = -1.0$, respectively and U_2/U_1 was taken as 1.2 in $h/d_1 = 1.2$. In Fig. 3 and Fig. 4 an overtaken vessels course is not largely deviated from the original direction under the condition of $\delta_{\max} = 10°$ regardless of control gain constants. Also, an overtaking vessels course is not almost deviated from the original course under the condition of $\delta_{\max} = 5°$ regardless of the control gain constants, even though lateral separation between two ships is about 0.3. L_1 Furthermore, if the lateral separation between two ships is about 0.5 times of ship length, an overtaking and overtaken vessel is not almost deviated from the original direction under

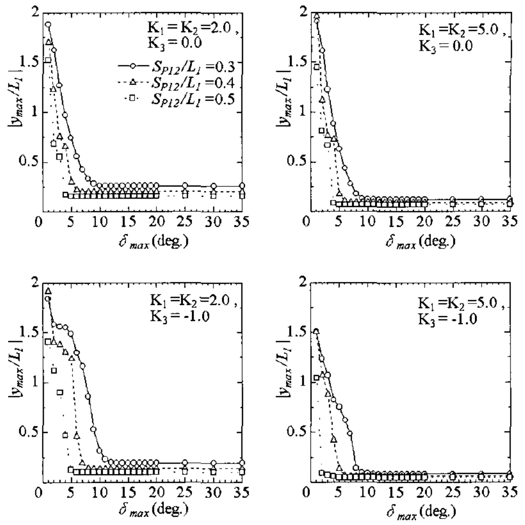


Fig. 3 Deviated maximum lateral distance from the original course for the case of overtaken ship

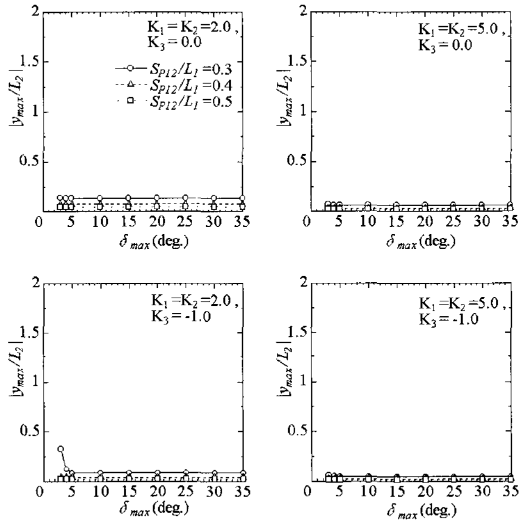


Fig. 4 Deviated maximum lateral distance from the original course for the case of overtaking ship

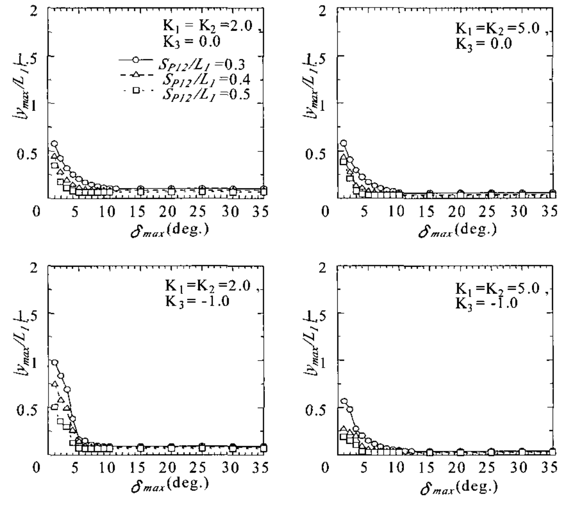


Fig. 5 Deviated maximum lateral distance from the original course for the case of overtaken ship

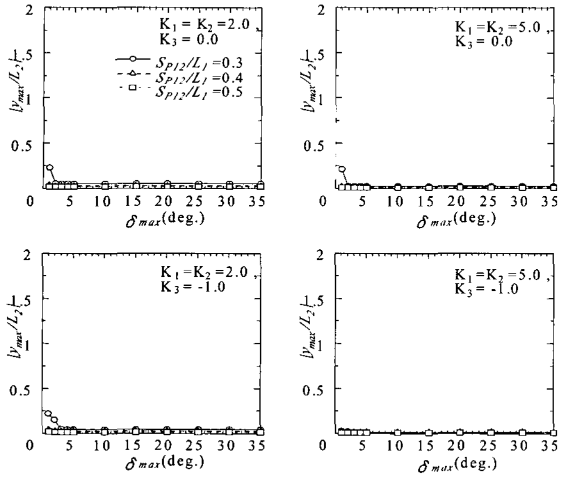


Fig. 6 Deviated maximum lateral distance from the original course for the case of overtaking ship

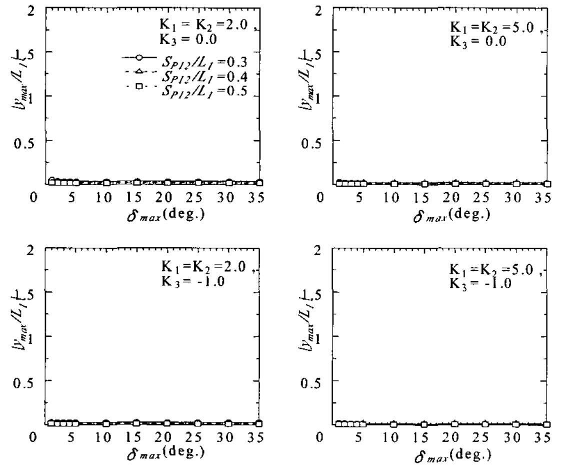


Fig. 7 Deviated maximum lateral distance from the original course for the case of overtaking ship

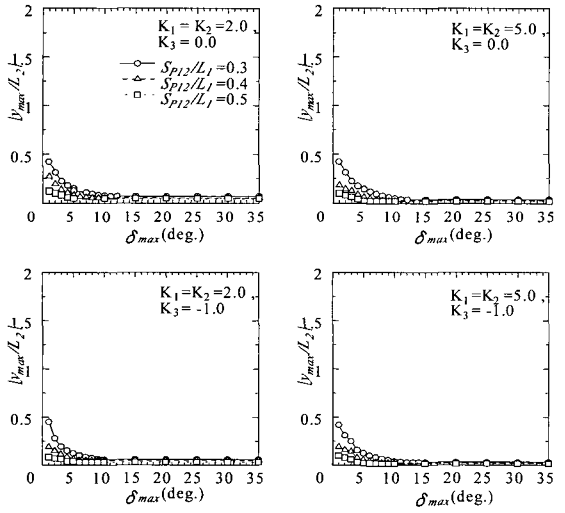
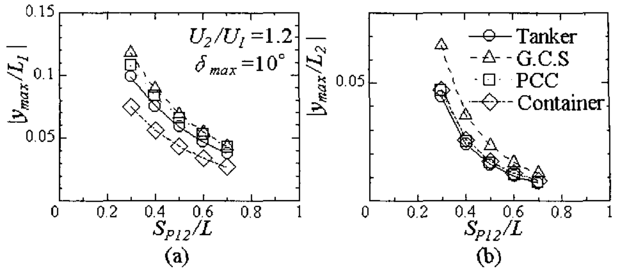
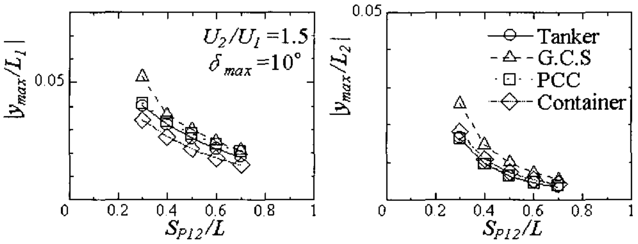


Fig. 8 Deviated maximum lateral distance from the original course for the case of overtaken ship



(a) (b)

Fig. 9 Deviated maximum lateral distance from the original course with function of S_{P12}



(a) (b)

Fig. 10 Deviated maximum lateral distance from the original course with function of S_{P12}

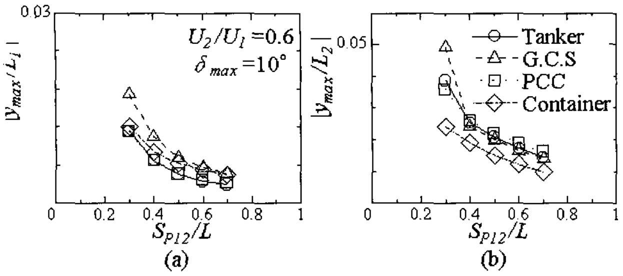
the condition of $\delta_{\max} = 5°$ regardless of the control gain constants.

The deviated maximum lateral distance from the original course with function of the S_{P12}/L_1 for the case of $U_2/U_1 = 1.5$ are shown in Fig. 5 and Fig. 6. As shown in these figures, an overtaking and overtaken vessels course is not almost deviated from the original course under the condition of $\delta_{\max} = 5°$ regardless of the control gain constants, even though the lateral separation between ships is $0.3L_1$.

Fig. 7 and Fig. 8 show the results for deviated maximum lateral distance from the original course with function of the S_{P12}/L_1 for the case of $U_2/U_1 = 0.6$. As expected, an overtaking and overtaken vessel with ranges of 5 degrees in maximum rudder angle is not almost deviated from the original course regardless of the control gain constants, even though the lateral separation between two ships is about $0.3L_1$

4.2 Prediction of Safe Navigation Based on the Simulation of Ship Manoeuvring Motions

Fig. 9, Fig. 10 and Fig. 11 show the results for deviated maximum lateral distance from the original course for the different ship types with function of S_{P12} for the case of overtaken and overtaking vessel, respectively. The lateral separation between two ships was chosen to be 0.3 to 0.7



ig. 11 Deviated maximum lateral distance from the original course with function of S_{P12}

mes of L_1, respectively, under the condition of δ_{max}=10°. he control gain constants used in these numerical imulations are $K_1=K_2=5.0, K_3=0.0$ in $h/d_1=1.2$. Ship ypes selected for comparison were PCC, VLCC, general argo ship and container. From these figures, the lateral istance between ships is necessarily required for the hip-velocity ratio of 1.2, compared to the cases of 0.6 and .5 regardless of the ship types.

5. Conclusions

The manoeuvring simulation was carried out arametrically for different ship types, the ratios of hip-velocity and ship-length difference, lateral separation nd stagger between ships. Ship types selected for omparison were PCC, tanker, general cargo ship and ontainer. From the simulation of ship manoeuvring motions n the safe navigation between ships while overtaking in hallow waters, the following conclusions can be drawn.

Considering the interaction force only as parameter, the ateral distance between ships is necessarily required for he ship-velocity ratio of 1.2, compared to the cases of 0.6 nd 1.5 regardless of ship types. Also, regardless of the ontrol gain constants, the consideration of lateral distance etween ships and rudder angle are much more required for he ship-velocity ratio of 1.2 than for the cases of 1.5 and .6, respectively. In the meantime, regardless of the ship-velocity ratio, an overtaking and overtaken vessel can be manoeuvred safely without deviating from the original course under the following conditions; the lateral distance between two vessels is approximately kept at 0.5 times of ship-length and 5 through 10 degrees of range in maximum rudder angle.

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