# Prediction of Hydrodynamic Forces on Passing Ships

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## 1. Introduction

As the ship's speed and size have increased, the passing ship effect has increased and it has raised the safety issues on the moored ship. In this study, for the prediction of passing ship loads acting on the mooring ship, the passing ship loads were simulated using two types of numerical model, the Double-body model and the Free-surface model, and the effect of passing ship speed, separation distance and water depth were analyzed. The peak passing ship loads were evaluated, and the applicability and limitations of those numerical models were discussed.

## 2. Numerical method

In order to solve the passing ship problem by the numerical method based on 3-dimensional potential flow models, the fluid is assumed to be inviscid, incompressible and the flow is assumed to be irrotational. In the Double-body model (Pinkster(2004)), free-surface was assumed as a rigid wall boundary, and the normal velocity at the mean water level is zero. The governing equations and boundary conditions of the Double-body model are as shown in Fig. 1.

In the previous studies, it was confirmed that the suction effect, which is the primary component for the low speed passing could be calculated through the Double-body model, and since the Double-body model neglects the free-surface fluctuation, the time-dependent terms do not remain in the boundary conditions. Therefore, calculations of before and after for the specific time step are not needed and the total amount of calculation time are greatly reduced.

On the other hand, in the Free-surface model, the fluid domain varies in time due to the moving boundary $\overline{S_{B1}}(t)$ of the passing ship, and linearized free-surface boundary conditions are applied as shown in Fig. 1.

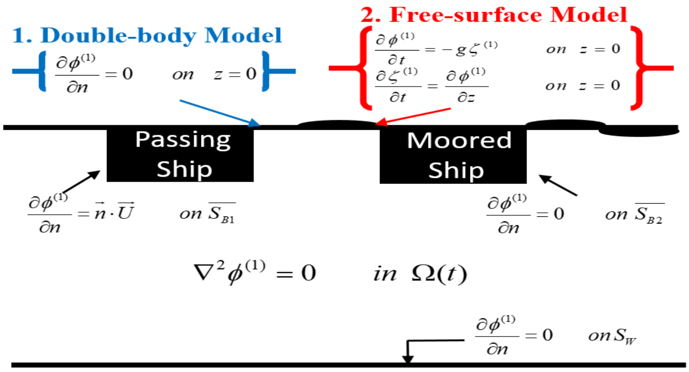



**Fig. 1 Linear boundary value problem for Double-body model and Free-surface model**

For the simulation of the hydrodynamic interaction of the passing ship problem, the total meshes including passing ship and moored ship were solved directly by the classical finite element method. The weak formulation of the governing Laplace equation is obtained by the test functions $\psi$ applying integration by parts in Eq. (1). The fluid domain is discretized with a finite number of elements, and the velocity potential and wave elevation at any point are approximated by the nodal values. The velocity potential is approximated by the linear summation of the product of nodal velocity potential using the three-dimensional basis function with eight-node hexahedral element, and the wave elevation is approximated by the linear summation of the product of nodal wave elevation using two-dimensional basis function with four-node quadrilateral element.

$$\iiint_{\Omega} \nabla \phi^{(1)} \cdot \nabla \psi \, dV - \iint_{\partial\Omega} \frac{\partial \phi^{(1)}}{\partial n} \psi \, dS = 0 \qquad (1)$$

In both of numerical models, a linear algebraic equation is derived by the discretization method, and the velocity potential is calculated by solving the linear equation using conjugate gradient method. Only in Free-surface model, the velocity potential and wave elevation are derived by time integration of free-surface boundary conditions using the fourth-order Adams-Bashforth-Moulton method on the free-surface.

## 3. Results

The passing ship load can be classified into three types of effect, the suction effect by the low speed passing ship, the wake wash effect by the high-speed passing ship and the long-period standing wave effect which occurs when the large ship enters the channel from relatively open waters(Pinkster, 2009). Since the long-period standing wave effects occur in a specific situation under the influence of the surrounding topography, the suction and the wake wash effects are considered for the passing ship problem.

Fig. 2 shows the horizontal hydrodynamic forces acting on the moored ship induced by the passing ship when the passing ship departs from a far back position and it moves parallel to the moored ship. The two numerical results, the Double-body model and the Free-surface model, are compared. The two numerical results show that the positive and negative peaks occur at about the same time, and the overall trends are similar. However, the magnitudes of the peak forces of the Free-surface model are slightly larger than that of the Double-body model. In this case, it can be seen that the small waves caused by the passing ship exert an additional force on the moored ship, which is included in the numerical simulation using the Free-surface model.

The X-direction force shows negative and positive peak when the center of the moored ship is located at the boundary between the positive and negative pressure field. Since the bow and stern shapes of the series 60 hull is close to symmetrical, the shape of the X-direction force curve with the change of x/L is a sine-wave shape symmetrical to the point where x/L is zero. When the horizontal distance is zero, the positive peak Y-direction forces are exerted on the moored ship in the direction pulling toward the passing ship due to the pressure field formed around the moored ship. On the other hand, when the horizontal distance, x/L, are -0.75 and +0.75, the negative peak Y-direction forces are exerted on the moored ship in the direction away from the passing ship. The Y-direction force curve is a cosine-wave shape symmetrical to the Y-axis and the positive peak force is about twice as large as the negative peak force, since the negative field is larger than the positive field. The moment(Cm) shows a similar load change as the X-direction force. The moment curve is also a sine-wave shape symmetrical to the point where x/L is zero, and as passing ship moves, the negative peak, zero and positive peak moments are observed in order.

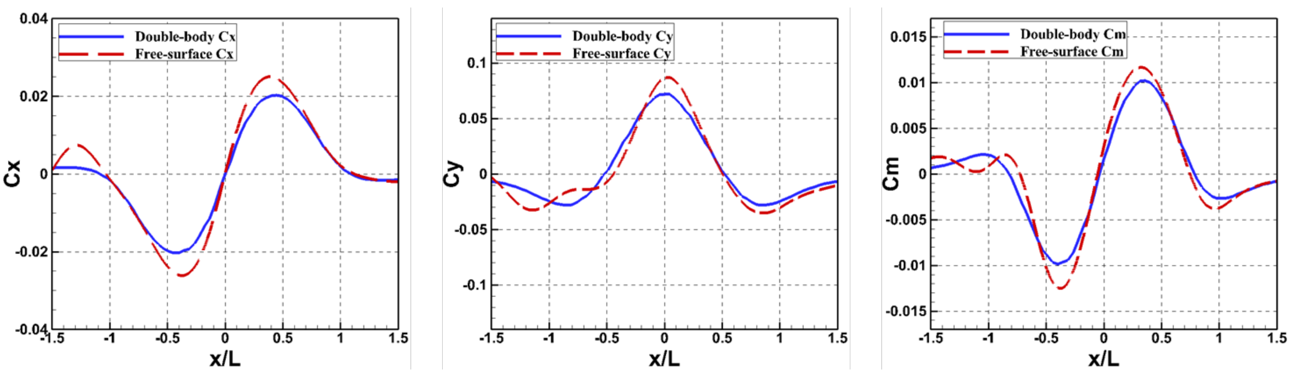
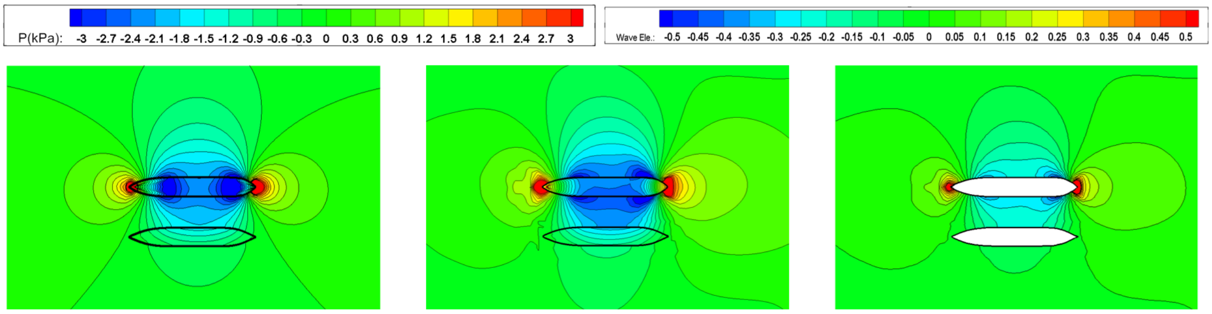



**Fig. 2 X-direction, y-direction forces and moment according to the horizontal distance**

Fig. 3 shows the pressure and wave elevation fields at the water surface for the analysis of the hydrodynamic interaction between the passing ship and the moored ship. The pressure fields show the similar spatial distribution between Double-body model and Free-surface model. The magnitude of the pressure field in the Free-surface model is relatively larger than that of the Double-body model and asymmetric pressure field is formed at the bow and stern. This is because in the Free-surface model, the wave elevation field, whose spatial distribution is similar to the pressure field, is generated and it increases the pressure field.




**(a) Double-body Model Pressure** **(b) Free-surface Model Pressure** **(c) Free-surface Model Elevation**

**Fig. 3 Pressure fields of Double-body and Free-surface model at x/L of zero (Fn: 0.142)**

Fig. 4 shows the forces and moment according to the increase of the passing ship speed. In the Double-body model results, because the pressure field formed around the passing ship is proportional to the square of the passing ship speed, the load calculated from the sum of the pressure fields around the moored ship also increases in proportion to the square of the passing ship speed. The Free-surface model forces increase proportionally to an exponent value higher than the square of the passing ship speed, because of the effect of the ship-generated wave which increases the pressure field around the moored ship.

In Fig. 5, the load coefficients of both of the numerical results were compared with the increasing separation distance. Numerical simulations show similar load coefficients according to the separation distance variations. The loads increase with decreasing separation distance gradually due to the increase of the pressure field and, especially, loads increase sharply in the range where the S/B is less than four. The Free-surface model results show a slightly higher load coefficient than the Double-body model results. The differences between the results of Double-body model and Free-surface model are maintained at around 10% even with changes in separation distance. This shows that the suction effect due to the pressure field is more dominant than the wake wash under this relatively low speed condition and the effect of the wake wash on the free surface affects a similar level of load over this wide water surface area with an S/B of seven.

Fig. 6 shows the passing ship load according to the change of water depth. Both numerical results show that the load coefficients increase as the water depth decreases and, especially, when the water depth becomes shallower with the d/D of less than 1.5, the load increases exponentially. At relatively deep water depths with d/D of 1.5 or more, the loads are similar in both numerical results, but at shallow water depth with d/D of less than 1.5, the difference between Double-body model and Free-surface model also increases as the water depth shallower. At very shallow water depths where the d/D is less than 1.2, since the difference in the Y-direction force is more than 30%, consideration of the free-surface effect is essential, and further analysis of the effects of nonlinear phenomena and fluid viscosity should be conducted to predict the exact passing ship load.

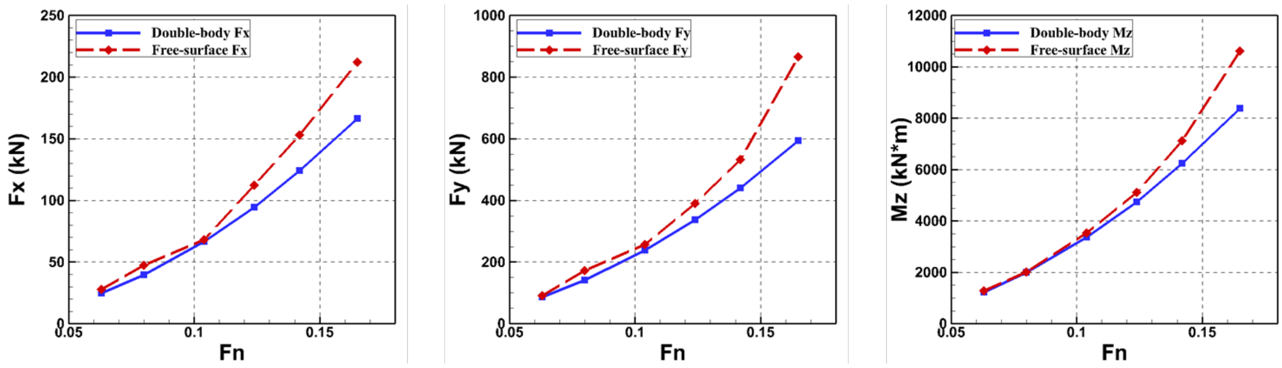



**Fig. 4 Passing ship loads according to passing ship speed**

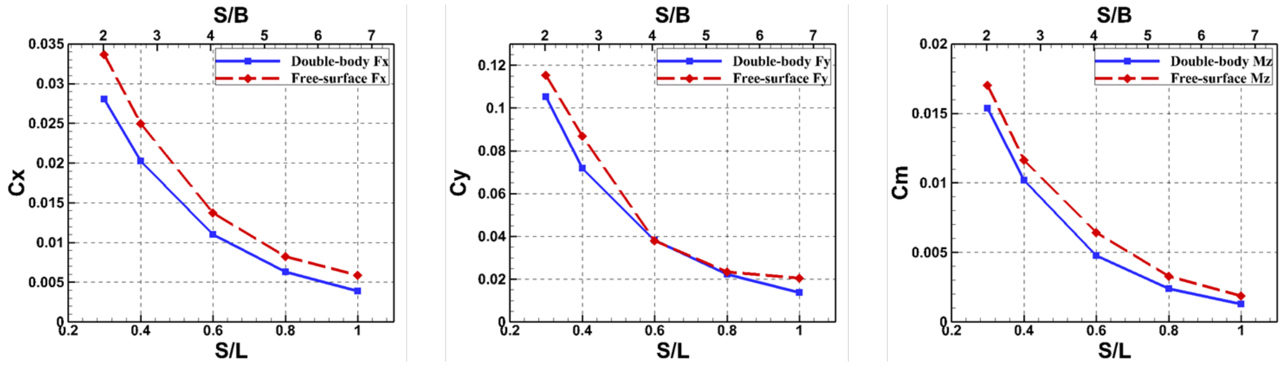



**Fig. 5 Force coefficients for difference separation distances**

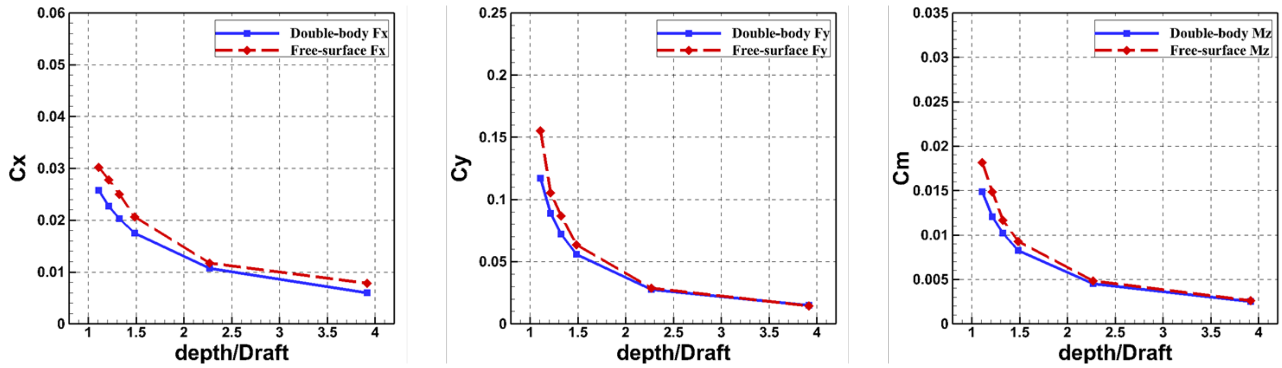



**Fig. 6 Force coefficients for the different depth-draft ratio**

## 4. Conclusion

In this study, the load acting on the moored ship by passing ship was analyzed with the two types of free-surface boundary conditions of the Double-body model and Free-surface model, and the results are summarized as follows.

- The loads acting on the moored ship increase with the passing ship speed, and if the ship length-based Froude number is larger than 0.12, the passing ship loads are proportional to more than 2 power of passing ship speed and it is necessary to calculate the passing ship load considering the free-surface effect.
- The passing ship loads increase gradually with decreasing separation distance, and especially, the loads increase sharply in the range where the S/B is less than four. The passing ship loads also increase as the water depth decreases, and at very shallow water depths where the d/D value is less than 1.2, the consideration of the free-surface effect is essential.

## ACKNOWLEDGEMENTS

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