Proceedings of MARTEC 2010
The International Conference on Marine Technology
11-12 December 2010, BUET, Dhaka, Bangladesh

PASSING SHIP EFFECTS ON A MOORED SHIP: A NUMERICAL STUDY

Md. Nazrul Islam[1], M. Rafiqul Islam[2] and Md. Sadiqul Baree[3]

[1]Bangladesh Shilpa Bank
Dhaka, Bangladesh.
E-mail: nazrul.islam.md@gmail.com

[2,3]Professor
Department of Naval Architecture and Marine Engineering
Bangladesh University of Engineering and Technology
Dhaka - 1000, Bangladesh.
E-mail: rafiqis@gmail.com

ABSTRACT

Sailing a ship generates wave. Not only this generated wave reaches the moored ship nearby but also the presence of sailing ship changes the flow around moored ship and cause pressure gradient along moored ship. The reached wave from sailing ship plus the pressure distribution along the hull of moored ship significantly causes forces on moored ship. Mentioned forces results motion of moored ship and influences loading / discharging operation and also causes to damage the mooring system. These hydrodynamic forces are low frequency and sometimes known as suction forces. These forces and resulting moments depend on hull size, speed of the passing ship, lateral distances between the ships, water depth, and incident wave direction, period and height. In the present paper, by using linear wave theory the mathematical model of dynamic interaction between two ships is derived. The mathematical model is solved by using 3D source distribution panel method. A general overview and findings of some numerically computed forces and motions of moored ship is presented..

Keywords: Linear Wave Theory, 3D source distribution technique, Green Function.

1. INTRODUCTION

Moored or Floating structures are subjected to hydrodynamic forces and motions due to other ships sailing nearby. These hydrodynamic actions may results to high forces and unacceptable motions, and these hinder the loading and discharging operations and also cause damage to the hull and mooring systems. The problems between two moving ships in waves studied by Gung-Rong Chen and Ming-Chung Fang (2000) [1] using Three-dimensional potential-flow theory based on the source distribution technique. The numerical solution was compared with experimental results and strip theory. They did not investigate the effect of moving ship on moored ship. J. A. Pinkster and P. Naaijen (2003) [2] studied the effects of sailing ships taking into account free surface effects for both slow and fast moving ships. In case of large and slow moving ships, free surface effects are due to the surrounding harbor geometry. In case of fast moving ships, free surface effects are due to the wash waves generated by the sailing ship that propagate into the harbor creating more or less complicated incoming wave system for the moored ship. The hydrodynamic interactions that can influence Seakeeping was studied by Kevin McTaggart, David Cumming, C. C. Hsiung and Lin Li (2003) [3]. The numerical predictions include the influence of interaction effects on hydrodynamic forces for two ships in waves. The numerical predictions and experiments showed that the presence of a larger ship can significantly influence the motions of a smaller ship in close proximity. The hydrodynamic interaction forces/moments acting on a moored ship due to the passage of another ship in its proximity is researched by K. S. Varyani and P. Krishnankutty (2006) [4] by considering the influence of ship form against the idealized approach of the use of parabolic sectional area distribution. Moving ships also create impact on moored ships and coastal structures. The forces and moments are more significant on the moored ship than on the moving ship.

2. MATHEMATICAL MODEL

2.1 Coordinate system

Ship is considered as a rigid body having six degrees of freedom. It is subjected to hydrodynamic forces due to incident waves and radiated and diffracted waves due to other ship(s). The right hand coordinate systems are defined in Figure 1.

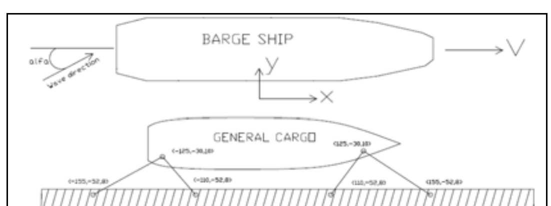

Figure 1 Mooring arrangement

2.2 Mooring particulars

The mooring particulars of the study are furnished in Table-1.

Table 1 Mooring particulars

Connector Number	Coordinates on moored ship			Coordinates on Jetty			Stiffness (KN/m)
	X_1	Y_1	Z_1	X_2	Y_2	Z_2	
1	-125	-48	10	-155	-52	8	1325
2	-125	-48	10	-110	-52	8	1325
3	125	-30	10	110	-52	8	1325
4	125	-30	10	155	-52	8	1325

2.3 Assumptions

The fluid is assumed to be incompressible, inviscid and irrotational and the vessel is assumed to be moored in open water. Then there exists a velocity potential satisfying Laplace equation together with boundary conditions on the free surface, on the body, and at the bottom, and the radiation condition in the far field. The time dependence of the fluid motion to be considered here is restricted to simple harmonic motion and accordingly the flow field can be characterized by the following velocity potential:

$$\Phi(x, y, z, t) = -\overline{U}x + \phi_s + \phi \quad (1)$$

$$\phi = \phi_0 e^{-i\omega_e t} + \phi_7^m e^{-i\omega_e t} + \sum_{n=1}^{N}\sum_{j=1}^{6} -i\omega_e X_j^m \phi_j^m \quad (2)$$

Where, $\omega_e = \omega - \frac{\omega^2 \overline{U}}{g}\cos\alpha$

$$\phi_0 = \frac{-ig\zeta_a}{\omega}\frac{\cosh[k(z+h)]}{\cosh kh}e^{ik(x\cos\alpha + y\sin\alpha)}$$

$\phi_S =$ Steady velocity potential due to mean Forward speed of the ship

$\phi_0 =$ Incident wave potential,

$\phi_7^m =$ Diffraction wave potential on body

$\phi_j^m =$ Potential due to motion of the body in j-th mode

$\omega_e =$ Encountering frequency and is defined as:

$\omega =$ Circular frequency of incident wave

$\zeta_a =$ Incident wave amplitude,

$\alpha =$ Wave heading angle from X -axis

m= number of ships

N= number of panels

The differential equation governing the fluid motion follows from the application of the continuity equation, which yields the Laplace equation.

The individual potentials are the solutions of the following Laplace equation:

$$\nabla^2\phi = 0 \quad (3)$$

2.4 Boundary condition

On the mean wetted surface area of each body S, the above linear velocity potentials must satisfy the Laplace equation and also the following boundary conditions:

The steady motion potential:

$$\overline{W}.n = 0 \quad \text{on} \quad S \quad (4)$$

where

$$\overline{W}.n = \overline{U}\nabla(\overline{\phi} - x)$$

$$\overline{U}\overline{\phi} = \phi_s$$

2.4.1 Linearised free surface condition:

$$[(i\omega_e - U\frac{\partial}{\partial x})^2 + g\frac{\partial}{\partial z}]\phi = 0 \text{ at } z = 0$$

2.4.2 Boundary condition on the sea floor:

$$\frac{\partial\phi}{\partial z} = 0 \quad \text{on} \quad z = -h$$

2.4.3 Body boundary conditions:

Due to linearization, this boundary condition may be applied on the wetted surface of the floating bodies in their equilibrium position

$$\frac{\partial\phi_0}{\partial n} + \frac{\partial\phi_7^m}{\partial n} = 0 \text{ on } S^i \text{ and } i = 1 \ldots N$$

$$\frac{\partial\phi_j^m}{\partial n} = -i\omega_e n_j^m + \overline{U}M_j^m \text{ on } S^m$$

$$\frac{\partial\phi_j^m}{\partial n} = 0 \text{ on } S^i \ (i \neq m).$$

In which n_j^m is the direction cosine on the surface of the body 'm' in the j-th mode of motion and has the following form:

$$n_1^m = \cos(n^m, x^m) \; ; \; n_2^m = \cos(n^m, y^m)$$

$$n_3^m = \cos(n^m, z^m)$$

$$n_4^m = (y^m - y_G^m)n_3^m - (z^m - z_G^m)n_2^m$$

$$n_5^m = (z^m - z_G^m)n_1^m - (x^m - x_G^m)n_3^m$$

$$n_6^m = (x^m - x_G^m)n_2^m - (y^m - y_G^m)n_1^m$$

$$M_1^m = M_2^m = M_3^m = M_4^m = 0$$

$$M_5^m = n_3^m, M_6^m = -n_2^m$$

where,

$x_G^m, y_G^m, z_G^m =$ co-ordinate of the centre of gravity of the body 'm'

$x^m, \ y^m, \ z^m =$ investigating point on the wetted surface of the body 'm'

The radiation condition of the potentials ϕ_j^m, in which in polar co-ordinate:

$$\lim_{r\to\infty}(r^{\frac{1}{2}}(\frac{\partial\phi}{\partial r} - i(\frac{\omega^2}{g})\phi)) = 0$$

2.5 Velocity Potentials

There is no analytical solution for ϕ_7^m and ϕ_j^m, so the problem should be solved numerically. According to the 3-D source sink method, the potentials ϕ_7^m and ϕ_j^m can be expressed in terms of well known Green functions that can be expressed by the following equation :

$$\phi_j^m(x,y,z)=\frac{1}{4\pi}\sum_{n=1}^{N}\iint_s \sigma_j^m(\xi,\eta,\zeta)G(x,y,z;\xi,\eta,\zeta)\,ds$$

where, (ξ,η,ζ) denotes a point on surface S and $\sigma(\xi,\eta,\zeta)$ denotes the unknown source distribution. The integral is to be carried out over complete immersed surface of the object. The Green function G (source potential) must in order of the representation in the above equation to be valid, satisfy all the boundary conditions of the problem with the exception of the body boundary conditions and have a source like behavior. As a result, boundary conditions are reduced only to on wetted surfaces of the bodies. So, the wetted surfaces should be subdivided into panels to transform integral equations to a system of algebraic equations to determine unknown source density over each panel. The appropriate Green function used in this paper to the boundary value problem posed is given by Wehausen and Laitone [6]. After getting the source density, the velocity potentials on each panel can be obtained using the above equation.

2.6 Forces and Moments

Once the velocity potential is obtained, the hydrodynamic pressure at any point on the body can be obtained from the linearized Bernoulli's equation and can be written as:

$$\frac{\partial\Phi}{\partial t}+\frac{1}{2}(\nabla\Phi)^2+\frac{P}{\rho}+gz=0 \tag{5}$$

Now after putting the value of Φ in the equation (5), the following expression is obtained,

$$-\frac{P}{\rho}=-i\omega_e\phi+\frac{1}{2}\{\nabla(-\bar{U}x+\phi_s)\}^2+\nabla(-\bar{U}x+\phi_s).\nabla\phi+\frac{1}{2}(\nabla\phi)^2+gz$$

By neglecting the higher order terms, we can write

$$P=\rho\left(\frac{\bar{U}}{2}\frac{\partial\phi_S}{\partial x}-gz\right)+\rho\left(i\omega_e\phi+\bar{U}\frac{\partial\phi}{\partial x}\right) \tag{6}$$

As first part of equation (6) is associated with the hydrostatic and steady forces, so neglecting this part, the first order wave exciting forces or moments and oscillatory forces and moments caused by the dynamic fluid pressure acting on the body can be obtained from the following integrals:

$$F_k^m.e^{-i\omega_e t}=-i\rho\omega_e e^{-i\omega_e t}\int_s\left\{\phi_0+\phi_7^m-i\frac{\bar{U}}{\omega_e}\left(\frac{\partial\phi_0}{\partial x}+\frac{\partial\phi_7^m}{\partial x}\right)\right\}.n_k^m ds$$

$$F_{kj}^m.e^{i\omega_e t}=-\rho e^{-i\omega_e t}\int_s\left\{\omega_e^2\bar{X}_j\phi_j^m-i\omega_e\bar{X}_j\bar{U}\frac{\partial\phi_j^m}{\partial x}\right\}.n_k^m.ds$$

Where, F_k^m denotes the k-th component of wave exciting forces or moments, F_{kj}^m denotes the k-th component of force arising from the j-th component of motion of the body 'm'. Moreover, it is customary to decompose the hydrodynamic forces resulting from motion of the bodies into components in phase with the acceleration and velocity of the rigid body motions. These yield the added mass and damping coefficients respectively. These coefficients can be expressed from equation as:

$$a_{kj}^{mn}=-\rho.\mathrm{Re}\left[\int_s\left(\phi_j^m+\frac{\bar{U}}{\omega_e}\frac{\partial\phi_j^m}{\partial x}\right).n_k^m.ds\right]$$

$$b_{kj}^{mn}=-\rho\omega_e.\mathrm{Im}\left[\int_s\left(\phi_j^m+\frac{\bar{U}}{\omega_e}\frac{\partial\phi_j^m}{\partial x}\right).n_k^m.ds\right]$$

2.7 Equation of motion in frequency domain

After solving the above exciting forces, added mass and damping coefficients, the motions of two ships can be solved by the following coupled equations of motions. To describe the motion of the multiple floating bodies, two co-ordinate systems, one fixed to the body and the other fixed to the space have been introduced. The two co-ordinate systems are shown in figure 1. The equation of motion is expressed by the time varying relation between these two co-ordinate systems. The equation of motion will be coupled dynamically because of hydrodynamic interaction and mechanical connections between them. So the equation can be considered by using the following matrix relationship:

$$\sum_{j=1}^{6}(M_{kj}^m+a_{kj}^m)\ddot{X}_j^m+b_{kj}^m\dot{X}_j^m+CX_j^m=F_k^m\quad(k=1.....6)$$

Where,

M_{kj}^m = inertia matrix in k - mode due to the motion in j - mode,

a_{kj}^m = added mass coefficient matrix of kj,

b_{kj}^m = damping coefficient matrix of kj,

C = hydrostatic restoring force coefficient matrix of kj,

X_j^m = vector containing the three translational and three rotational oscillations about the co-ordinate axes in j - mode.

The suffices, k, j = 1, 2, 3, 4, 5, 6 represent surge, sway, heave, roll, pitch and yaw modes, respectively and m =1, 2 number of ships.

3 RESULTS AND DISCUSSIONS

In this study General Cargo Ship is assumed moored ($U=0$). The mooring arrangement is shown in Figure 1 and the mooring particulars are given in Table 1. Barge shaped Ship has a forward speed.

In the Figures, results for single body means

Cargo Ship moored on it's own and double body means it moored in the presence of Barge Ship which is sailing nearby. The lateral separation distances (side to side), period of incident wave, Froude number are varied. To examine the effects of sailing ship for the motion of moored ship, a computer program has been developed to carry out the computation for the pair of ships mentioned above (Table 1) at head sea (180 degree) and in a depth of 260 m. The computation model is expected to be validated by the model tests. But since the tests have not been carried out yet, the results obtained from computation have been compared with published results; in this case the works of Cheng and Fang [1]. This comparison has been done in Islam M.R. etal.[5] for heave force for Fn=0.14 and separated distance (centerline to centerline) 32.476m.

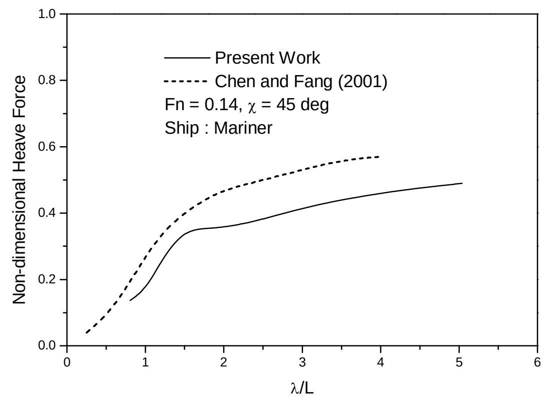

Figure 2 Comparison of heave force [Islam 2008]

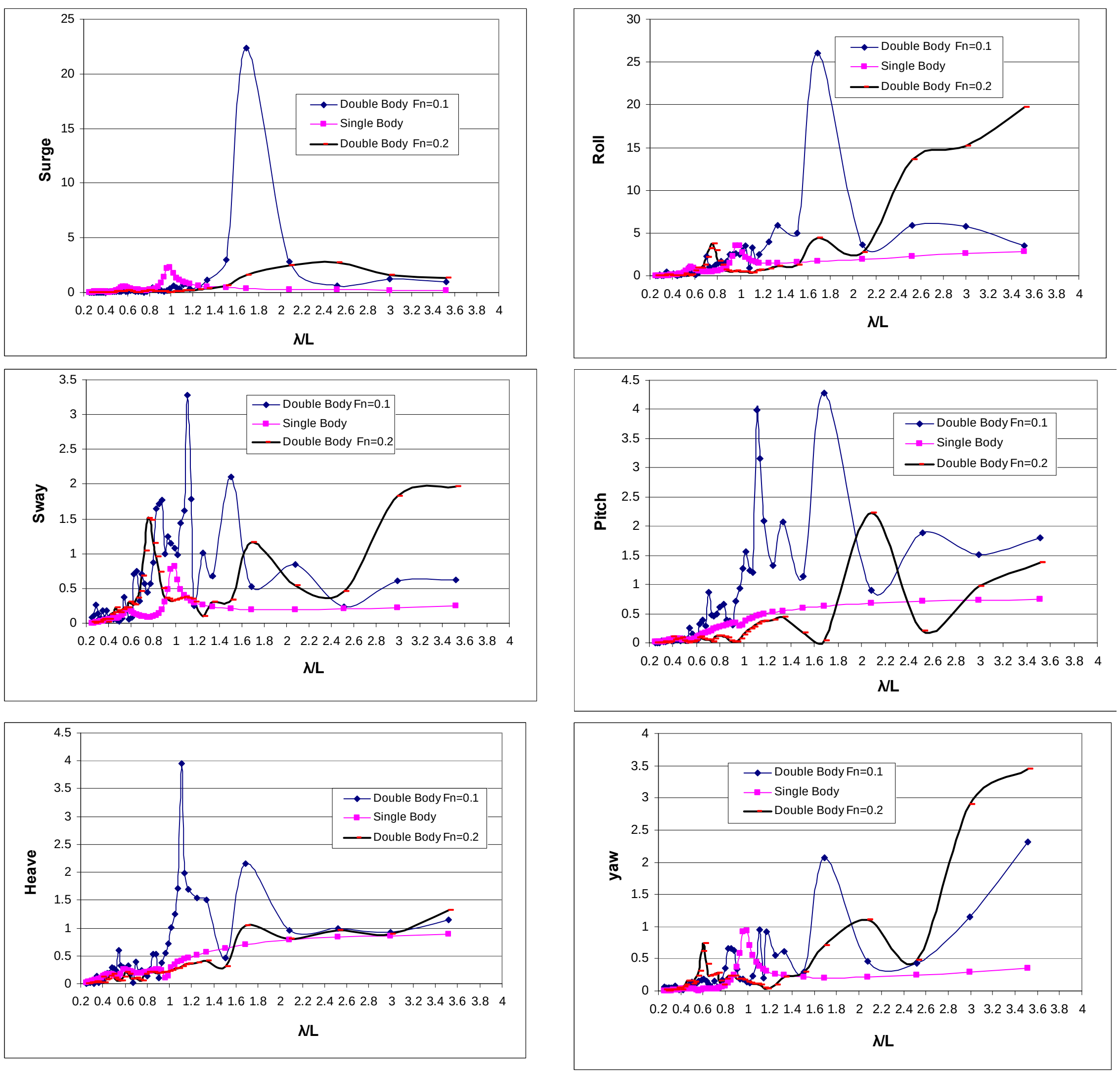

Figure 3 Non-dimensional motion of Moored Ship With/without sailing ship based on different λ/L. ($\alpha = 180^o$, and Water depth=260m)

Figure 2 indicates that the two results are similar in trend. However, the actual values differ and this may be due to the use of different Green function. In their work, Cheng and Fang [1] used zero speed Green function, whereas in the present work, Green function is computed with speed dependent Green function.

In Figure 3, the motions of moored ship in absence and presence of sailing ship have carried out based on λ/L.,

The graphs show the maximum pick of sway heave, pitch and yaw on F_n= 0.1 take place at λ/L=1.11 (T=14.6s); whereas the pick occur at λ/L=1.69 (T=18s) at surge and roll motions.

In comparison, there is no considerable increase on the other graph at low λ/L, related to F_n = 0.2, except sway motion. The mentioned motion pick occur at λ/L=0.775 (T=12.2s).

The motions of Cargo Ship are plotted against separated distance in Figure 4, at an angle of incident wave 180 degree, in a water depth of 260m, period 10s and Froude number 0.1. It is seen in Figure 4, the motions on Cargo Ship reaches the first pick at separate distance 12m.

Figure 5 shows the motions of moored ship by the effect of sailing ship at different Froude numbers.

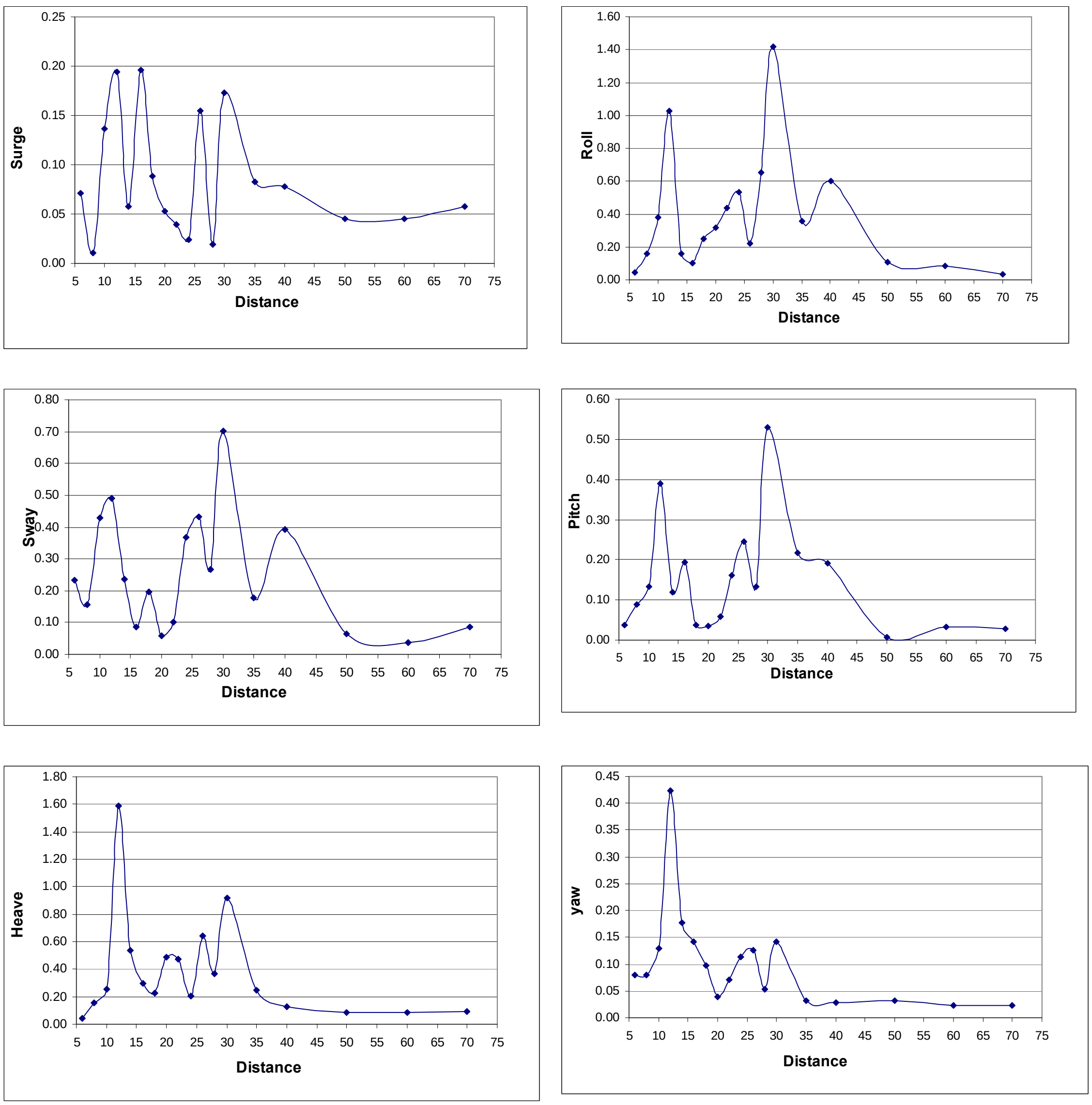

Figure 4 Non-dimensional motions of Moored Ship based on different distance.
(T=10s, Fn=0.1 , α=180^o, and Water depth=260m)

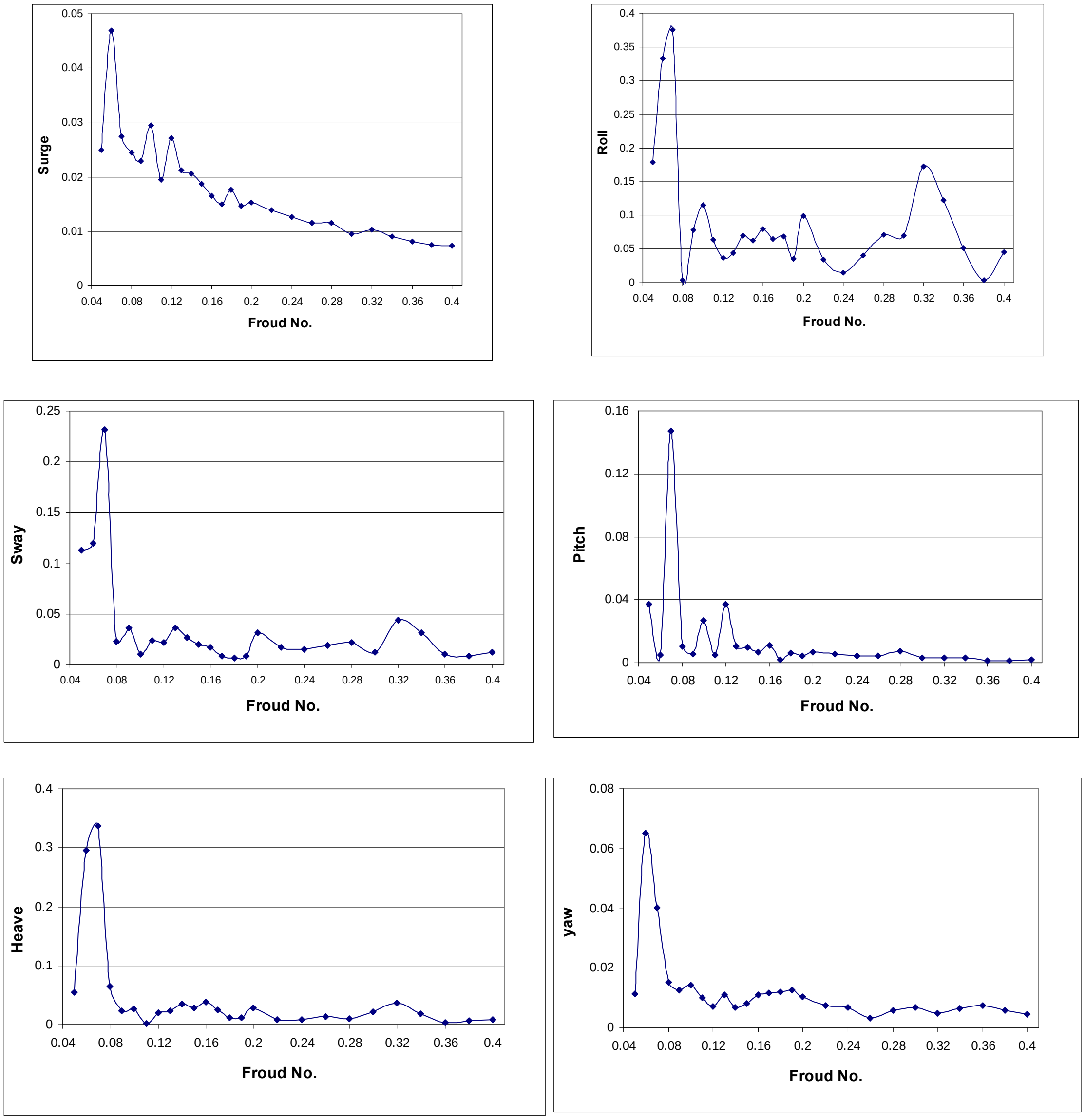

Figure 5 Non-dimensional motions of Moored Ship based on different Froude Number. (T=8s, Distance = 8.64m, α=180°, and Water depth=260m)

There are a dramatically increscent until Fn=0.07 and all motions reach a pick at Fn=0.07 except yaw motion that reach its pick at Fn=0.06. The reason of this increasing is generation of Long-wave by sailing ship at low speeds.

The results in Figure 6 carried out at pick points of Figure 3 (Distance =12m) and Figure 4 (λ/L= 1.11, T=14.6s). Graphs show the motions increased considerably when the period is 14.6s (near natural period) and distance is 12m. Comparing the results in Figures 3 and 6 , show that the treatment of curves are similar.

4 CONCLUSION

A method for and results of computational hydrodynamics studies of interaction between two ships have been presented. Preliminary results indicate that the effects of interaction on a moored ship when another ship sailing nearby is quite significant. For such interaction, motions have significant influence, which may hinder loading and unloading operation. In this paper, the model is validated only with published results with speed but the model need to be validated by model experiment. Also computations need to be carried out for various depths and different incident angles. The computations also need to be carried in calm water condition so that the effect of generated waves can be easily understood. However, the program developed for computation of motions for a moored ship while other ships sailing nearby numerically expected to be able to predict satisfactorily.

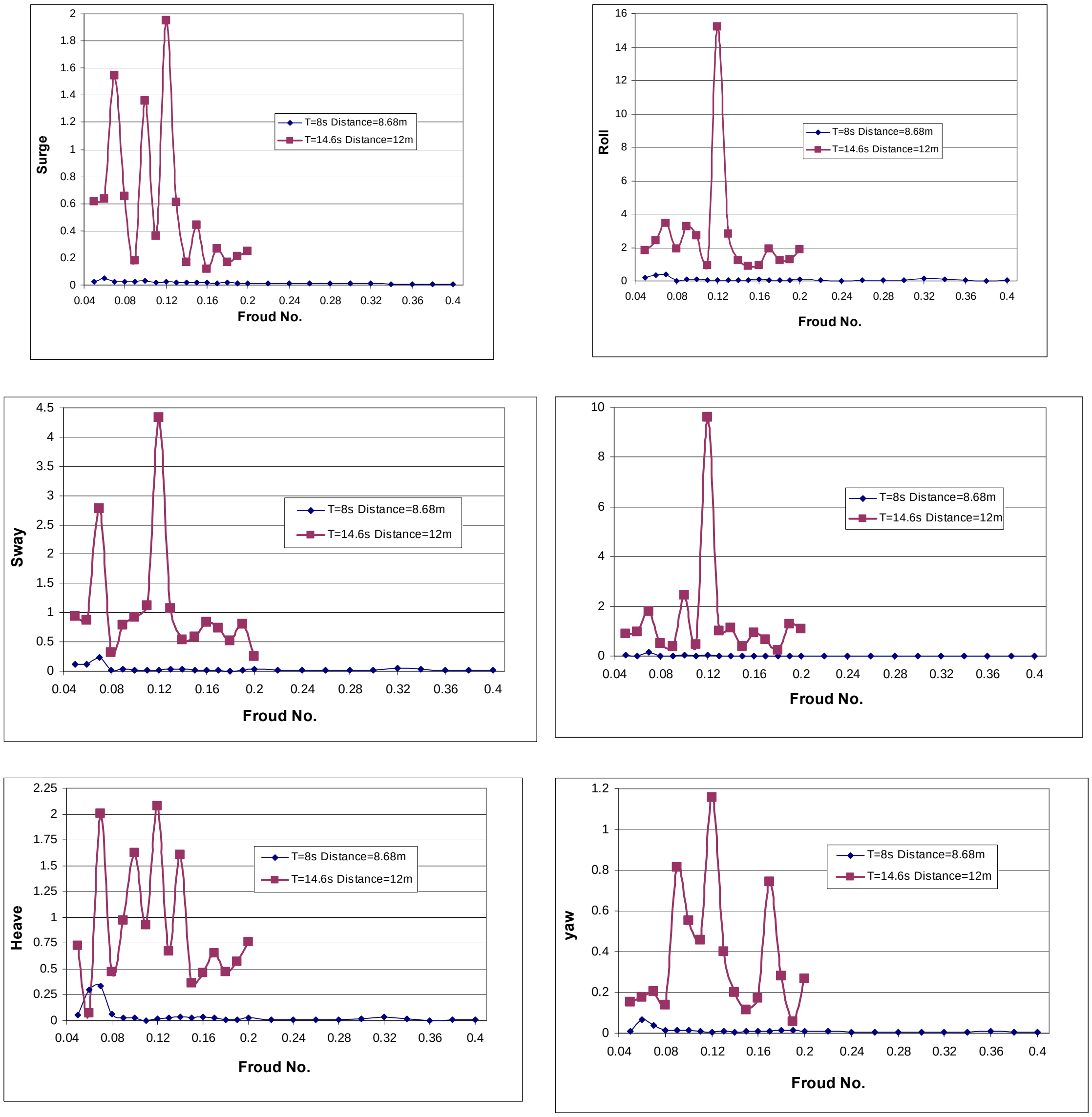

Figure 6 Non-dimensional motions of Moored Ship at Pick Points of Figures 3 and 4 based on different Froude Number. (T=14.6s, Fn=0.07, α=180^o and Water depth=260m)

REFERENCES

[1] Gung-Rong Chen and Ming-Chung Fang, "Hydrodynamic interactions between two ships advancing in waves", *Ocean Engineering*, Vol. 28, pp. 1053-1078 (2001).

[2] J. A. Pinkster and P. Naaijen, "Predicting the effect of passing ships", *International Workshop on water Waves and Floating Bodies* (2003).

[3] Kevin McTaggart, David Cumming, C. C. Hsiung and Lin Li, "Seakeeping of two ships in lose proximity", *Ocean Engineering*, Vol. 30, pp. 1051-1063 (2003).

[4] K. S. Varyani and P. Krishnankutty, "Modification of ship hydrodynamic interaction forces and moments by underwater ship geometry", *Ocean Engineering*, Vol. 33, pp. 1090-1104 (2006).

[5] Islam MR, Islam Nazrul and Maimun Adi, "Effect of Vessel Interaction On Hydrodynamic Forces While Advancing Closly In Waves", *Marine Technology Conference (MARTEC 2008*), Indonesia (2008).

[6] Wehausan and Laitone, Surface Waves, Encyclopedia of Physics, Vol. 9, Springer-Verlag, Berlin (1960).