PREDICTION OF LOAD ON MOORING ROPES OF A CONTAINER SHIP DUE TO THE FORCES INDUCED BY A PASSING BULK CARRIER

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Abstract: The hydrodynamic surge and sway forces and yaw moment on a moored ship induced by a another ship moving near and parallel to it are estimated. The results are compared with the values obtained by experiments carried out in the Towing tank for manoeuvres in shallow water (co-operation Flanders Hydraulics – Ghent University) in Antwerp. Subsequently, equations of motion of the moored ship are solved to determine the loads on the mooring ropes. The effect of underwater form of the ships on the forces is also discussed.

1.INTRODUCTION

A moored ship is subject to many external influences from the environment. The jetty and mooring system must be designed to keep the resultant displacement of the ship within the limits of operational requirements and to keep the mooring line loads at an acceptable level. The forces on the moored ship have impacts on cargo handling operations, mooring and fender systems and safety of people on board. In marine terminals and harbours, ships operate in close proximity resulting in imparting of forces and moments to both moored and moving ships. This hydrodynamic interaction effect is less on the moving ship and, moreover, this ship is under the helms control where a disturbance can be effectively counteracted.

The hydrodynamic forces of prime considerations coming on the moored ship due to the proximity of a moving ship are the surge, sway and yaw components. Even though the sway force is much larger than the surge force, the effect of surge very often causes exceedingly high loading in mooring lines, due to much lower damping in surge mode. Hence it requires more attention in the design of mooring systems to keep the loads within permissible limits. The design and operation estimates of the mooring and fender systems, preferably in the early design stages, help to assess the operational limitations and also can lead to an optimal system design. A reliable mathematical model representing the motion of the moored body will certainly enable the designer to try for various mooring systems.

The nature of the scenario in which the interaction takes place is very varied. The severity of consequences of the interaction depends on

* Speed of the passing ship
* Size and underwater form of vessels
* Separation distance between vessels
* Water depth of the region
* Mooring arrangement
* Material and type of construction of mooring ropes

Increase in size and speed of new generation cargo and passenger vessels and the growth of traffic density envisage the importance of a clear understanding of hydrodynamic interaction effects, where a reliable tool to predict the consequent forces on ships and mooring/fender systems become essential. The transient sway force and yaw moment experienced by a ship when proceeding in the proximity of other ships in motion have been extensively studied by Varyani et al [4] [5]. Further extension of the work to moored ship case and its eventuality on the mooring ropes have been ascertained in the work carried out by Varyani and Krishnankutty [6]. Experimental studies of Remery [1] and Vantorre et al. [7] [8] reveals the effect of the size of the passing vessels and the separation distances on the interaction forces and moments on a moored vessel for different water depths.

There are very few semi-empirical approaches, resulting in the estimation of the time histories of the forces and moments in the horizontal plane due to interaction with another ship as a function of geometry, speeds and environmental parameters. Comprehensive tests with ship models of both equal and different length in overtaking and encountering manoeuvre are described in [7] and [8]. Wang [14] estimated the hydrodynamic forces and moment on a moored ship resulting from the passing of another ship at various separation distances, water depths and passing ship sizes, using slender body theory. The hydrodynamic interaction problem between moored and passing ships was studied by Krishnankutty [10] [11] using the slender body theory with singularity distribution technique for the computation of forces in surge and sway modes and yaw moment acting on moored vessel. With an aim to consider the cross-coupling effects between different motions of interest, Dand [2] [3] used a numerical technique to solve the coupled equations of motion in surge, sway and yaw modes. The behaviour of the ship was deduced from a solution of the appropriate equations of motion with the exciting forces and moment for those motions deduced from measurements made on rigidly moored models.

The approach stage of the initial transient is most critical for the purpose of navigational safety. Yeung [12] and Yeung and Tan [13] explained that this is because the ship is subject to an attraction force towards a fixed object (moored ship) and at the same time is subjected to a "bow-in" turning moment. In these circumstances an unconstrained ship with zero rudder angle would tend to head into the fixed object. The speed and separation distance limits of a passing ship can be regulated by knowing the movement limitations of the berthed ship, be due to the restriction imposed for cargo handling facilities. For berthed tankers, the cargo handling manifolds allow a maximum movement of only ± 3.0m in surge and 3m in sway, OCIMF [9], and for berthed container ships the movements are to be more restricted due to the limited reach of the cranes.

Studies have revealed that underwater form of the ships has substantial influence on the hydrodynamic interaction forces, predominantly in sway and yaw components [6]. In the present paper the loads acting on a moored container ship due to the passage of a bulk carrier at different lateral positions are computed based on a theoretical formulation, which uses slender body assumptions and employs singularity distribution technique. Idealised distribution of ship sectional area for both the moored and passing ships are generally used as a user-handy method, but the studies here also consider the actual ship form in place. Subsequently, the solution of the equations of motion give a good idea about the moored ship motion due to the hydrodynamic interaction induced by the passage of another ship in its proximity and the consequent mooring line forces. Comparison of the present numerical values with measured and estimated values shows that the present method is reliable for preliminary engineering estimate of the loads on a moored vessel induced by a passing ship and the loads on the mooring ropes.

2.INTERACTION FORCES

The hydrodynamic interaction problem between a moored ship and the passing ship are formulated here using a slender body theory with the following assumptions.

- The transverse dimensions of the ships (beam and draft) are quite small compared to its length
- The passing ship moves at a constant speed and is parallel to the moored ship
- The fluid is inviscid and incompressible, the flow is irrotational
- The disturbances at the free surface are neglected (treated as a rigid boundary)

The co-ordinate (x_m, y_m, z_m) is fixed in the moored ship and (x_p, y_p, z_p) is fixed in the passing ship (Fig.1). Parameters with suffices m and p, respectively, refer to those related to the moored and passing ships.

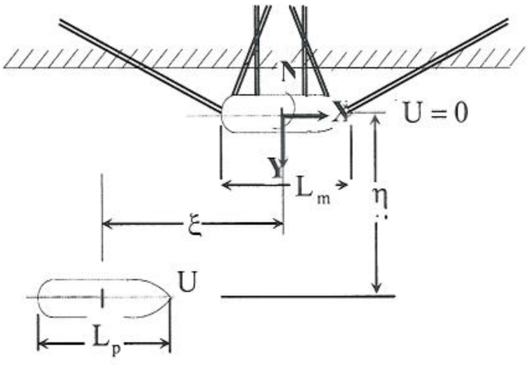

Fig. 1: Co-ordinate System in Moored-Moving Ships

In addition to the governing (Laplace) equation applied to the fluid domain, the following boundary conditions are in order

$$\frac{\partial \phi}{\partial n_m} = 0 \quad \text{on moored ship} \tag{2.1}$$

$$\frac{\partial \phi}{\partial n_p} = U \frac{\partial x_p}{\partial n_p} \quad \text{on passing ship} \tag{2.2}$$

The velocity potential due to the passing ship with reference to a fixed co-ordinate system (x,y,z), Wang(1975), is

$$\phi_p(x,y,z) = -\frac{U}{2\pi} \int_{L_p} \frac{S_p(x_p)(x - x_p - \xi)}{\left\{(x - x_p - \xi)^2 + (y - \eta)^2 + z^2\right\}^{1.5}} dx_p \tag{2.3}$$

where S_p and U are the mid-ship section area and speed of the passing ship, ξ and η are the stagger and lateral separation distances between the two ships.

The velocity components of the flow along the moored ship induced by the passing ship are derived from Eq.(2.3). The interaction potential in the unsteady Bernoulli equation gives the pressure distribution and integration of this pressure over the surface gives the net forces on the moored ship.

Assuming zero underwater sectional area at the ends of the moored ship, we get the sway and surge forces as

$$X(\xi,\eta)=\frac{\rho U^2}{2\pi}\int_{L_m} S_m^{'}(x_m)\int_{L_p}\frac{S_p^{'}(x_p)(x_p-x_m+\xi)}{\left\{(x_p-x_m+\xi)^2+\eta^2\right\}^{1.5}}dx_p dx_m \tag{2.4}$$

$$Y(\xi,\eta)=\frac{\rho U^2\eta}{\pi}\int_{L_m} S_m^{'}(x_m)\int_{L_p}\frac{S_p^{'}(x_p)}{\left\{(x_p-x_m+\xi)^2+\eta^2\right\}^{1.5}}dx_p dx_m \tag{2.5}$$

The yaw moment obtained from the slender body theory, Wang, is

$$N(\xi,\eta)=\frac{\rho U^2\eta}{\pi}\int_{L_m}\left\{x_m S_m^{'}(x_m)+S_m(x_m)\right\}$$
$$\int_{L_p}\frac{S_p^{'}(x_p)}{\left\{(x_p-x_m+\xi)^2+\eta^2\right\}^{1.5}}dx_p dx_m \tag{2.6}$$

The above equations are for the deepwater case. When the water depth becomes less than twice the draft of the ship, the shallow water effect has to be considered. The bottom condition for an assumed constant water depth of $-h$ is represented by $\partial\phi/\partial z=0$. By method of image the interaction forces and moment can be written as

$$X(\xi,\eta,z)=\frac{\rho U^2}{2\pi}\sum_{n=-\infty}^{\infty}\int_{L_m} S_m^{'}(x_m)$$
$$\int_{L_p}\frac{S_p^{'}(x_p)(x_p-x_m+\xi)}{\left\{(x_p-x_m+\xi)^2+\eta^2+4n^2h^2\right\}^{1.5}}dx_p dx_m \tag{2.7}$$

$$Y(\xi,\eta,z)=\frac{\rho U^2\eta}{\pi}\sum_{n=-\infty}^{\infty}\int_{L_m} S_m^{'}(x_m)$$
$$\int_{L_p}\frac{S_p^{'}(x_p)}{\left\{(x_p-x_m+\xi)^2+\eta^2+4n^2h^2\right\}^{1.5}}dx_p dx_m \tag{2.8}$$

$$N(\xi,\eta,z)=\frac{\rho U^2\eta}{\pi}\sum_{n=-\infty}^{\infty}\int_{L_m}\left\{x_m S_m^{'}(x_m)+S_m(x_m)\right\}$$
$$\int_{L_p}\frac{S_p^{'}(x_p)}{\left\{(x_p-x_m+\xi)^2+\eta^2+4n^2h^2\right\}^{1.5}}dx_p dx_m \tag{2.9}$$

where S_m is the mid-ship section area of the moored ship, $S_m{'}$ and $S_p{'}$ are the sectional area slopes of the moored and passing ships, n is the number of images.

Non-dimensional Factors

The forces and moments are non-dimensionalised as follows

$$X'=\frac{X}{\rho(US_m/L_m)^2} \tag{2.10}$$

$$Y'=\frac{Y}{\rho(US_m/L_m)^2} \tag{2.11}$$

$$N'=\frac{N}{\rho L_m(US_m/L_m)^2} \tag{2.12}$$

Parabolic Sectional Area Distribution

Sectional area and its slope for both the ships are given by the formula

$$\mathrm{S_i(x_i)=S_i\left\{1-(2x_i/L_i)^2\right\}} \qquad \text{for } i=m,p \tag{2.13}$$

$$S_i^{'}(x_i)=-8S_i x_i/L_i^2 \qquad \text{for } i=m,p \tag{2.14}$$

Numerical Examples – Interaction Forces

Remery [1] carried out model tests to study the phenomena occurring with a moored ship during the passage of another ship. The tests were performed by varying the size and speed of the passing ships, at a water depth of 1.15 times the draft of the moored vessel and with the ship moored parallel to the passing ship. The experimental results obtained for the forces and moment acting on the moored ship (257 m long) due to the passage of another ship (302 m long) are used for a comparison with the present method. As the details of the ship geometries are unknown, the underwater sectional area distribution has been taken as parabolic (ideal) based on Eq.(2.13), for the purpose of present study. A mid-ship section area coefficient of 0.99 has been chosen for the estimation of the section area at that section which is needed for use in this equation. As another option, to get the feel of influence of ship's form (real) on the interactive forces and moment, the geometry of a bulk carrier of 175 m long, having the same C_B value as the moored ship, has been scaled up to 257m to represent the moored ship and up to 302 m to represent the moving ship.

The experimental results for a lateral separation distance of 30m in a water depth of 1.15 times the moored ship draft are presented in non-dimensional form in Figs.2, 3 & 4. The surge force obtained by the present method, both ideal and real cases, agrees well with the experimental values in all the separation distances. The sway force deviates by about 50% in ideal case when compared to the experimental values, but the trend is fairly good and there is no phase shift. The values improved substantially for the real form case when compared to the values obtained using the idealised form (parabolic sectional area distribution). The sectional area slope, representing the flow velocity around the ship, is higher in the real form case and as the experiments are done for the real ship models these values are more appropriate. Both the present theory and Remery's experiment values for yaw moments have a fairly good trend and agreement.

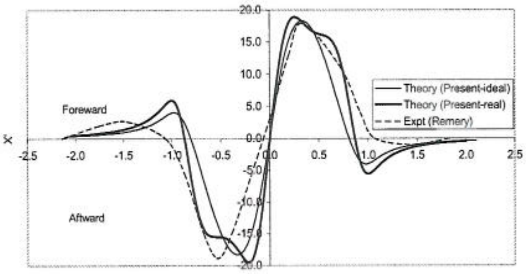

Fig. 2. Surge force on moored ship (L_m=257m) due to passing ship (L_p=302m, η=30m, h/T=1.15, ST'=2 ST/(L_m+L_p), ST=ξ; X, Y and N are non-dimensionalised based on Eqs.2.10 to 2.12)

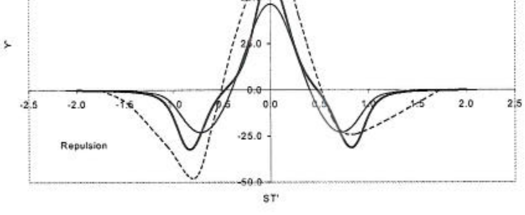

Fig.3. Sway force on moored ship (L_m=257m) due to passing ship (L_p=302m, η=30m, h/T=1.15)

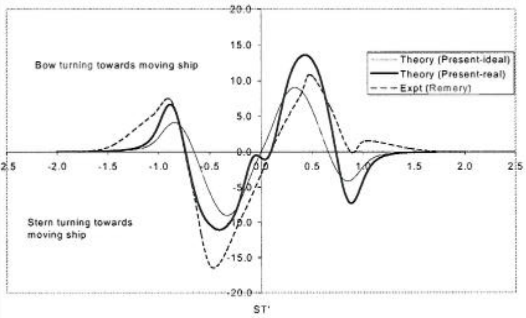

Fig. 4. Yaw moment on moored ship (L_m=257m) due to passing ship (L_p=302m, η=30m, h/T=1.15)

Subsequently, the hydrodynamic interaction effects on a moored container ship due to the passage of a bulk carrier (particulars of both the ships are given in Table 1 below) are studied. The theoretical and experimental values of surge force, sway force and yaw moment acting on the container ship for a water-depth to ship-draft ratio (*h/T*) of 1.1, separation-distance to ship-length ratio (η/L_m) of 0.167 and passing ship speed (*U*) of 4.0 knots are shown in Figs. 5 to 7. Similar representation for η/L_m=0.20 (Figs. 8 to 10), η/L_m=0.265 (Figs.11 to 13) and η/L_m=0.40 (Figs.14 to 16) are also shown below. The model tests were carried out at scale 1/75 in the *Towing tank for manoeuvres in shallow water* (co-operation Flanders Hydraulics – Ghent University) in Antwerp, Belgium.

Table 1. Particulars of moored and passing ships

	Moored Ship	Passing Ship
Ship Type	Container Ship	Bulk Carrier
Length (m)	289.804	298.828
Breadth (m)	40.252	37.969
Draft (m)	13.500	13.500
C_B	0.5804	0.8361

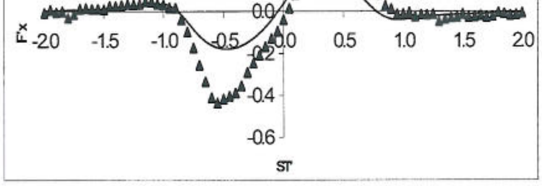

Fig. 5. Surge force on moored container ship (h/T=1.10, η/L=0.167, U=4 knots, F_x'=F_x/0.5$\rho U^2 B_1 T_1$)

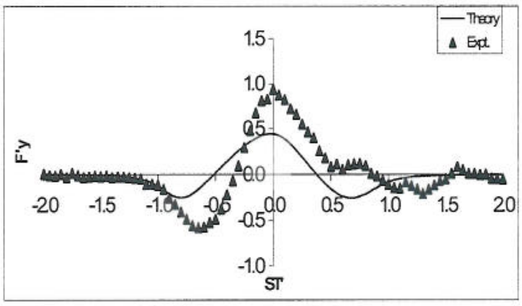

Fig.6. Sway force on moored container ship (h/T= 1.10, η/L_m=0.167, U=4 knots, $F_y'=F_y/0.5\rho U^2B_1T_1$)

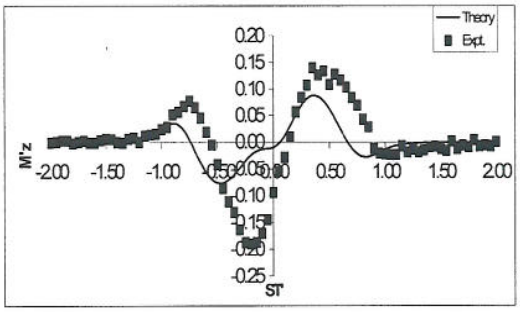

Fig.7. Yaw moment on moored container ship (h/T= 1.10, η/L_m=0.167, U=4 knots, $M_z'=M_z/0.5\rho U^2B_1T_1L_1$)

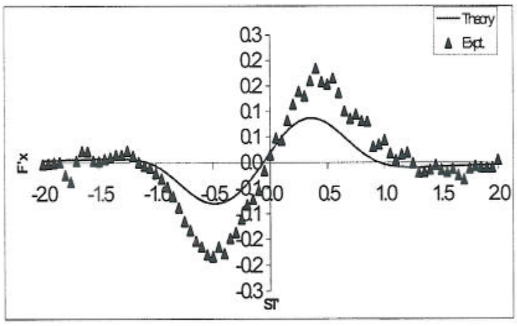

Fig.8. Surge force on moored container ship (h/T=1.10, η/L_m=0.20, U=4 knots)

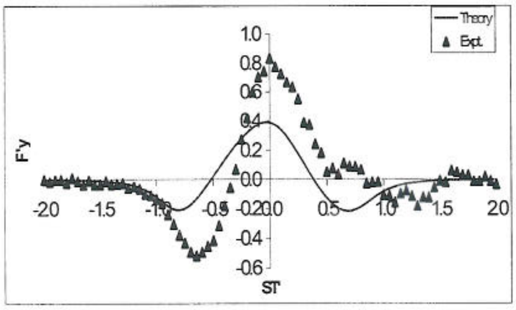

Fig.9. Sway force on moored container ship (h/T=1.10, η/L_m=0.20, U=4 knots)

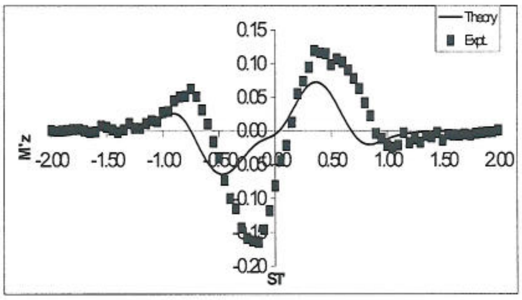

Fig.10. Yaw moment on moored container ship (h/T=1.10, η/L_m=0.2, U=4 knots)

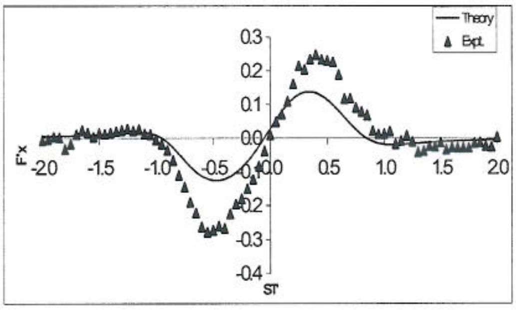

Fig.11. Surge force on moored container ship (h/T=1.1, η/L_m=0.265, U=4 knots)

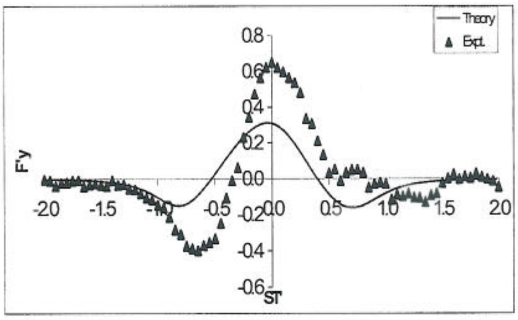

Fig.12. Sway force on moored container ship (h/T=1.10, η/L_m=0.265, U=4 knots)

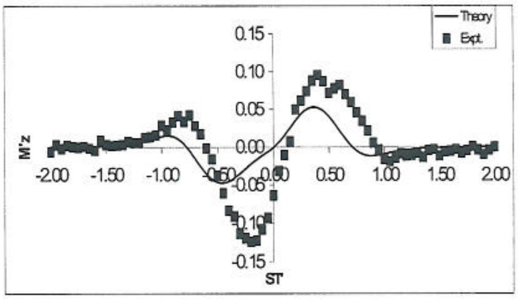

Fig.13. Yaw moment on moored container ship (h/T=1.10, η/L_m=0.265, U=4 knots)

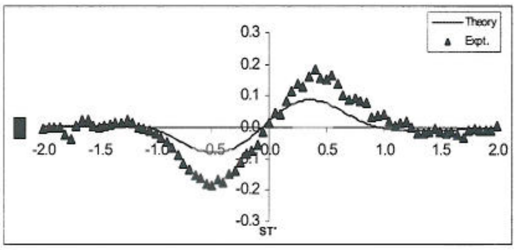

Fig.14. Surge force on moored container ship (h/T=1.1, η/L$_m$=0.4, U=4 knots)

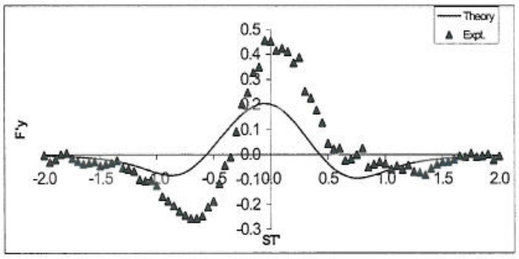

Fig.15. Sway force on moored container ship (h/T=1.1, η/L$_m$=0.4, U=4 knots)

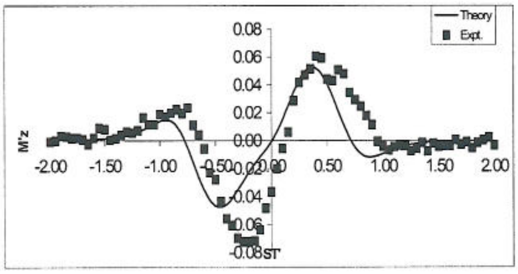

Fig.16. Yaw moment on moored container ship (h/T=1.10, η/L$_m$=0.4, U=4 knots)

The theoretical values follow almost the same trend as the experimental ones, but the magnitude of the forces and moment are more in the later case. Viscous property of water and the consequent boundary layer formation around both the ships and the surrounding boundaries, including the bottom boundary, are not considered in the theory. The underestimate of the forces and moment by the theory can be attributed to the above reason, as the effect is more at overlap positions likely to have more flow variation.

3. MOORING LINE FORCE ANALYSIS

The motions of moored vessels under the influence of an external force, such as the one induced by a passing ship, can be determined from the solution of the equation of motion. Fig.17 shows the conventional mooring rig layout of a ship. To simplify the calculation, this arrangement is idealised to heading/stern lines and the breast lines, which are treated parallel and perpendicular to the centreline of the moored ship always (Fig.18). All the ropes in the direction of x (or y) are considered of the same length, tension, material, size and construction. These assumptions enable one to treat the mooring system reaction in both directions independently.

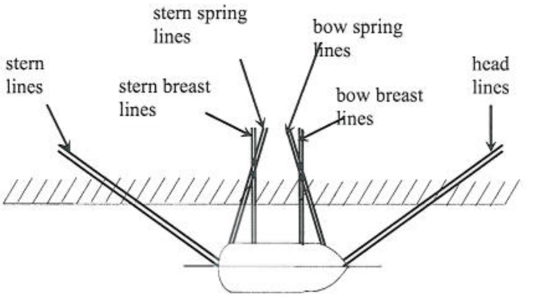

Fig.17: Mooring System Arrangement (Conventional Type)

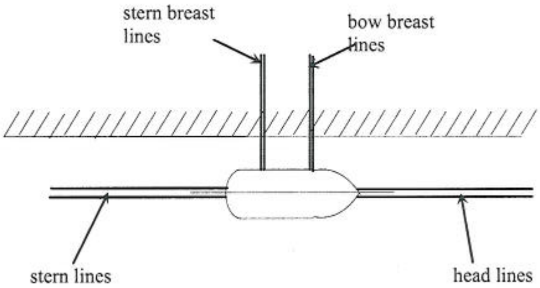

Fig.18: Mooring System Arrangement (Idealised for Analysis)

Considering the system as a spring-mass one with damping, it being oscillatory in nature, the equation of motion in x-direction can be written as

$$X(t)=(m+m'_x)\frac{d^2x}{dt^2}+D_x\frac{dx}{dt}+k_x x \qquad (3.1)$$

where $k_x=\sigma_b d^2 n_r/\delta x$, $X(t)$ is the interaction force in surge mode as a function of time t, m is the mass of the moored ship, m_x' is the added mass of the moored ship in surge, x is the displacement of the moored ship along its axis, D_x is the damping coefficient in longitudinal motion, k_x is the rope spring constant, σ_b is the breaking load of the rope, d is the rope diameter, n_r is the number of ropes and δx is elongation of the stern/head lines.

By knowing all the coefficients and force, the above differential equation can be solved for the moored ship's longitudinal displacement x. The mooring rope force can be obtained by taking the product of the rope (spring) constant k_x and x. Damping term in the equation is usually very small. That is, the oscillation in x-direction keeps on continuing for a longer time. But, the importance here is amplitude of the force rather than the period of damping out.

While considering the generation of the equation of motion in y-direction (ie., with the breast lines in mind), the contributions coming from both sway and yaw motions must be included. The formulations of the equation of motion are dealt with independently and while estimating the breast line forces, the resultant effect of sway and yaw displacements are considered.

$$\mathrm{Y(t)} = (\mathrm{m} + \mathrm{m}_{\mathrm{y}}^{'})\frac{\mathrm{d}^2\mathrm{y}}{\mathrm{dt}^2} + \mathrm{D}_{\mathrm{y}}\frac{\mathrm{dy}}{\mathrm{dt}} + \mathrm{k}_{\mathrm{y}}\mathrm{y} \tag{3.2}$$

$$N(t) = (I_\psi + I_\psi^{'})\frac{d^2\psi}{dt^2} + D_\psi\frac{d\psi}{dt} + k_\psi\psi \tag{3.3}$$

where

$$D_\psi = D_y l_b^2 \qquad k_y = \sigma_b d^2 n_r / \delta y \; k_\psi = k_y l_b^2$$

Solution of Eq.(3.2) and (3.3) give, respectively, the sway (y) and yaw displacements (ψ). The resultant linear displacements of the ship at the position of stern and bow breast lines are given by Eqs.(3.4) and (3.5) below

$$y_s = y + l_b\psi/2 \tag{3.4}$$

$$y_b = y - l_b\psi/2 \tag{3.5}$$

where $Y(t)$ and $N(t)$ are the interaction sway force and yaw moment as a function of time t, I_ψ is the mass moment of inertia of the moored ship about z-axis, m_y' is the added mass of the moored ship in sway, I_ψ' is the added mass moment of inertia of the ship about z-axis, y and ψ are the displacement of the moored ship sway and yaw, D_y and D_ψ are the damping coefficient in sway and yaw modes, k_y and k_ψ are the rope spring or restoring constants in sway and yaw modes, δy is elongation of the breast lines and l_b is the spacing between stern and bow breast lines.

Numerical Examples – Mooring Forces

In order to investigate the response of a flexibly moored ship to the loads induced by a passing ship, the equations of motion shown above need to be solved. A knowledge of the coefficients in these equations, which includes the ship mass, added mass and damping coefficients in surge and sway modes, ship mass moment of inertia, added mass moment of inertia and damping coefficients in yaw mode and the interaction forces and moment, are required for its solution. Similar investigation on mooring loads of a ship due to the passage of ships with different sizes, speeds and lateral separation distances can be found in [1]. Fig.19 shows a case of it, where the lateral mooring line (rope constant = 1609 kN/m) forces of a ship (L_m=257m) due to the passing of a ship of L_p=302m at a speed of 7.0 knots with a separation distance of 30.0m through a water depth of 1.15 times the moored ship draft are presented. The calculated and measured values of Remery compare well with the present ones, where the lateral lines are taken as breast lines on either side of the mid-ship. In athwart-ship direction the oscillation dies out fast due to high damping in the sway mode. The excitation forces and moment used here are the experimental values given in Figs.2 to 4. The values of motion displacements and velocities are taken as zero initially (ie. at t=0).

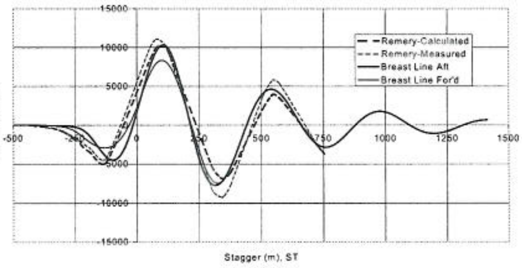

Fig.19. Lateral Mooring Line Force {Moored Vessel - 257m, Passing Vessel - 302m, U=7.0 knots, Sp=30m, h/T=1.15, Ky = 1608 kN/m}

The peak mooring forces of the container ship as a result of the interaction forces and moment induced by the passing bulk carrier (Table 1 gives details of the ships) while it operates with a speed of 4.0 knots through a water depth of 1.1 times the draft and separated by 0.167 times the ship length are shown in Fig.20 for longitudinal lines and in Fig.21 for lateral lines for a range of values of rope constants. Interaction forces obtained from the present method (Figs.5 to 7) are used in the analysis. The mooring force increases, reaches a maximum and then decreases with increase in rope constant. Here the maximum in longitudinal mooring force occurs at a rope constant of about 100 kN/m and in lateral mooring force at a rope constant of about 400 kN/m.

Extreme loadings in the moorings due to passing ships are expected when the apparent period of the interaction force history approximately equals the natural period of the ship-moorings system (here T$_n$=208s and 380s in surge and sway mode, respectively.) Therefore, the forces experienced by soft moorings, such as synthetic ropes, dues to passing ships, will be larger compared to stiff moorings, such as steel wires. On the other hand, external effects with higher frequency, such as waves and wind fluctuations, will cause more sever loading in stiff moorings. The longitudinal rope tension along with the surge excitation force is plotted in Fig.22 and the lateral rope tension along with the sway excitation force in Fig.23, both for respective maximum force rope constant values (100 & 400 kN/m). The dynamic response of the moored ship must account for the mooring force coming larger than the excitation force, where the amplification is more in surge than in sway. The oscillation in lateral direction dies out faster than that in longitudinal direction, obviously due to the higher damping in sway mode. The form of the vessels have considerable influence on the hydrodynamic interaction sway force and yaw moment [6], which implies that the type of vessels also matters in the analysis of the above problems.

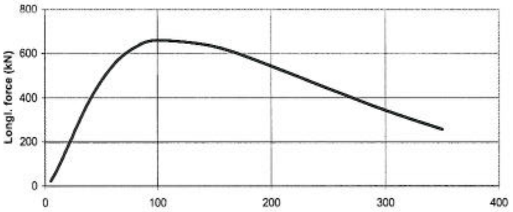

Fig.20. Maximum longitudinal mooring force against rope constant

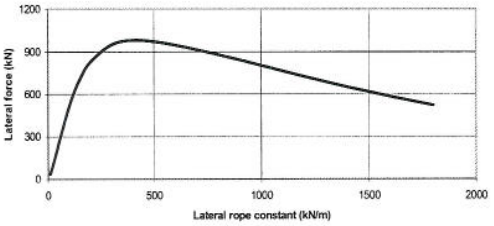

Fig.21. Maximum lateral mooring force against rope constant

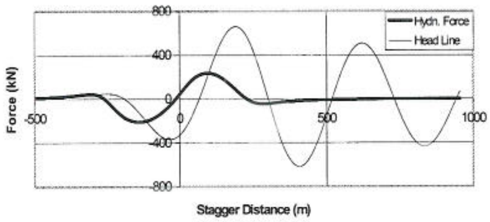

Fig.22. Longitudinal forces on the moored container ship

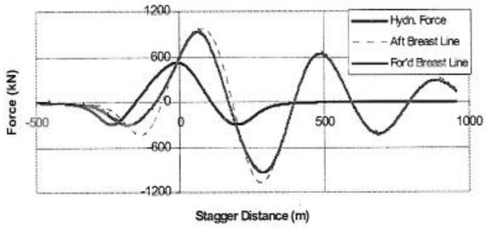

Fig.23. Longitudinal forces on the moored container ship

Extreme loadings in the moorings due to passing ships are expected when the apparent period of the interaction force history approximately equals the natural period of the ship-moorings system. Therefore, the forces experienced by soft moorings, such as synthetic ropes, due to passing ships, will be larger compared to stiff moorings, such as steel wires. On the other hand, external effects with higher frequency, such as waves and wind fluctuations, will cause more sever loading in stiff moorings.

4. SUMMARY AND CONCLUSION

The hydrodynamic interaction between a moored ship and a moving ship has been studied, where the surge and sway forces and yaw moment are estimated. The estimation of loads on the ropes of a moored container ship due to the hydrodynamic interaction effects induced by a passing bulk carrier has been carried out, by solving the equations of motion. Computations have been done for different ship combinations and have been compared with experimental and other numerical results. The mooring system considered here is a linear one and the equations of motion are uncoupled. The results given here have to be considered as a preliminary one which would give a good insight into the estimation of hydrodynamic interaction forces on a moored ship induced by a passing ship and also its effect on mooring lines.

The conclusions based on the above studies are presented as follows.

1. The character of the forces and the moment, plotted against the relative longitudinal position, is more or less the same for the variations in speeds, passing distances and water depths.
2. The forces and the yaw moment on the moored ship are inversely proportional to the water depth and the lateral separation distance.
3. The form of the ships has more influence on the yaw moment (>50% for the bulk carriers studied here when compared with the idealised parabolic form), where as the increase in sway force is more than 20% and the effect on surge force is 5 to 15 %.
4. The studies give a good idea about the moored ship motion due to the hydrodynamic interaction induced by the passage of another ship in its proximity and the consequent mooring line forces.
5. The linear mooring system considered here predicts a higher mooring force than the interaction force. The augmentation can be due to the ship motion dynamics. A further stiffer system resulted in a lower mooring force, where the excursions are expected to be small and hence the ship motion dynamics.
6. Based on the above conclusion, synthetic mooring ropes – being less stiff than steel wires – may experience important dynamic

effects due to passing ships. Especially when the apparent period of the interaction is expected to approach one of the natural frequencies of the ship-moorings system, the expected level of the mooring line forces may be exceeded.

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