Research on Hydrodynamic Interaction between Tandem Tankers

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Abstract

This paper addresses the hydrodynamic interaction between two tandem-moored tankers. A series of calculations are carried out using AQWA-LINE to investigate the hydrodynamic loads and responses of two different sized tankers moored in tandem. It is found that the diffraction force and steady wave drift force on the downstream tanker are significantly affected by the hydrodynamic interaction, but the added mass and radiation damping, and vessel's RAOs are only affected marginally. In addition, the effect of the hydrodynamic interaction does not decay quickly as the relative distance between the two tankers increases.

Keywords: Hydrodynamic Interaction,Tandem Tankers, Shielding Effect.

Nomenclature

Ms = Structural mass matrix
Ma = Hydrodynamic added mass matrix
C = System linear damping matrix
Ks = Total system stiffness matrix
F = External wave forces on the system (per unit wave amplitude)
X = Response motions (or RAOs)
ω = Frequency of regular incident wave
m = far field, cascade mean flow
max = maximum value
t = time
x = tangential component
y = axial component
ξ = streamwise component
η = normal to the streamwise direction
WL = water line along the structure surface
ζ_r = relative wave surface elevation
S_0 = the structure wetted surface
X = the motion at structure surface
Ms = the structure mass
R = the structure rotation matrix

Introduction

With the increasing demands for energy, activities related to the offshore oil and gas exploration, production and transportation increase rapidly. During the transfer of crude/LNG from an FPSO to shuttle tanker, tandem mooring or side by side mooring are two most frequenctly adopted options. Due to the close proximity, the hydrodynamic interaction between the two vessels becomes an issue as it can affect the motion of the vessels in waves. Obviously the extent of interaction depends on both the distance between the vessels and the sizes of the vessels. This paper presents the results of a series of calculations carried out to investigate the hydrodynamic interaction between two tandem moored tankers. The 1st and 2nd order wave forces, added mass and radiation damping, vessel motion RAOs are calculated for various distances between the two vessels and the results are compared with those when the hydrodynamic interaction is not considered.

Yonghui (Allen) Liu and L. Terry Boatman [1] do researches on the technology for transferring LNG between two floating vessels, and a duplex yoke mooring system is developed. A series of model tests are also carried out and good agreement between the predictions and measurements has verified and validated the analysis method and procedures. Hitoshi Yokozawa and Akio Ito [2] develop two programmes to estimate the motions of two tandem and side by side moored ships, and the results agree well with model test results, and they provide good tools for future design of the LNG FPSO/FSRU. Wei Ye and Yong Luo [3] analyse the mooring system response of two Side-By-Side (SBS) moored FRU and LNG Carrier (LNGC) working in Gulf of Mexico, and it is found the FRU can work safely from 40m to 100m water depth under 98% working time. C.A.C. van der Valk [4] do model tests in MARIN's offshore basin to provide insight into the relative motions and mooring forces of two tandem and side by side moored LNG and its carrier, and the advantages and disadvantages of the two different systems are summarized. Then it is quite important to do researches on the interaction of two very near vessels.

1 Discriptions of the Tandem Tankers

Two tankers of similar shape but different size have been selected for analysis. The main particulars are given in table 1. The water depth is 100m.

The AQWA-LINE [5] program is used for the hydrodynamic Radiation/Diffraction analysis and the full hydrodynamic interaction is considered. There are altogether 2156 grid cells for the model. The ISO View of two tankers is in Figure 1.

Particulars	Tanker 1	Tanker 2
Length [m]	300.0	200.0
Breadth [m]	26.5	20.0
Depth [m]	24.5	17.8
Draft [m]	15.0	11.0
Displacement [t]	196713	72635
Lcg (from stern) [m]	160.5	107.1
Tcg (from central line) [m]	0.0	0.0
Vcg (from base line) [m]	10.0	8.0
Inertia in roll (estimated) [$Kg.m^2$]	6.14E10	1.29E10
Inertia in pitch (estimated) [$Kg.m^2$]	1.107E12	1.816E11
Inertia in yaw (estimated) [$Kg.m^2$]	1.107E12	1.816E11

Table 1: Particulars of the Tankers

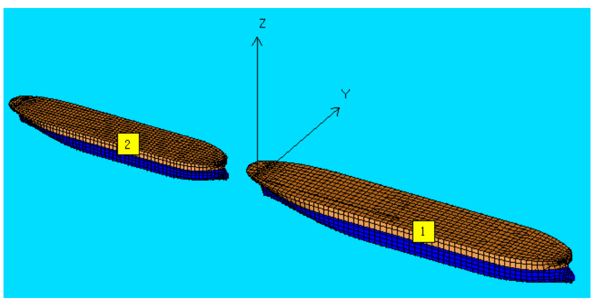

Figure 1: ISO View of two tankers (separation D=20m)

2 Methodology

In order to identify the effect of the hydrodynamic interaction on the hydrodynamic parameters of the vessels and their responses, the 1st order wave force, including added mass and radiation damping, the 2nd order mean wave drift force, and the 1st order vessel response amplitude (RAO) are calculated in regular waves for a number of wave headings and frequencies. This calculation is carried out using the 3-dimensional diffraction module AQWA-LINE. To investigate the difference of hydrodynamic interaction between tankers for different separations, various relative distances, denoted by D, are selected from 20m to 2500m.

Wave Headings* α (deg)	90, 135, 180
Wave Frequencies (rad/s)	0.10 ~ 1.26 with increment step of 0.05 to 0.1 rad/s
Distance D (m) (from the stern of tanker 1 to the bow of tanker 2)	20, 60, 100, 200, 300, 500, 700, 1000, 1500, 2500
* The wave heading is defined as: head sea = 180 deg; beam sea (from starboard)=90 deg.	

Table 2: Hydrodynamic Parameters of Calculation

AQWA-LINE solves a set of linear algebraic equations to obtain the harmonic response of the body to regular waves. These response characteristics are commonly referred to as RESPONSE AMPLITUDE OPERATORS (RAOs) and are proportional to wave amplitude. The set of linear equations with frequency dependent coefficients are obtained as:

$$\mathrm{Ms}(\omega)\ddot{\mathrm{X}} + \mathrm{Ma}(\omega)\ddot{\mathrm{X}} + \mathrm{C}(\omega)\dot{\mathrm{X}} + \mathrm{Ks}(\omega)\mathrm{X} = \mathrm{F}(\omega)$$

In AQWA, the external 1st order wave forces acting on the fixed body are usually broken down into two components, these being the FROUDE-KRYLOV and WAVE DIFFRACTION force components, both assumed to be harmonic.

The mean second order wave drift forces may be calculated by AQWA-LINE after the first order fluid flow problem has been solved. For the calculation of the mean second order wave drift forces, a near-field solution where forces in all six degrees of freedom are calculated is adopted. The mean wave drift forces on a floating body in the horizontal and vertical planes may be calculated based on the method of direct integration of pressure acting on the wetted surface of the body. The expression for the evaluation of the 2nd order mean wave drift force and moment can be written as follows:

$$\mathrm{F}^{(2)}_{\mathrm{strc}} = -\oint_{\mathrm{WL}} 0.5\rho g \zeta_r^2 \vec{n}\,dl + \iint_{S_0} 0.5\rho |\nabla\varphi|^2 \vec{n}\,dS$$
$$+ \iint_{S_0} \rho \left(X \cdot \nabla \frac{\partial\varphi}{\partial t} \right) \vec{n}\,dS + M_s \cdot R \cdot \ddot{X}g$$

$$\mathrm{M}^{(2)}_{\mathrm{strc}} = -\oint 0.5\rho g \zeta_r^2 (\vec{x}\times\vec{n}) \cdot dl + \iint_{S_0} 0.5\rho |\nabla\varphi|^2 (\vec{x}\times\vec{n})\,dS$$
$$+ \iint \rho \left(X\nabla \frac{\partial\varphi}{\partial t} \right) (\vec{x}\times\vec{n})\,dS + I_s \cdot R \cdot \ddot{X}g$$

3 Results

Since tanker 1 is on the upstream of tanker 2, the shielding effect on tanker 2 is expected to be present. Therefore in this paper the investigation of the hydrodynamic interaction is focused on tanker 2. Calculations are performed for six relative distances between the two tankers and three wave directions (α =90^0, 135^0, 180^0). The main hydrodynamic parameters are compared with those when no interaction is considered.

3.1 Added Mass and Radiation Damping

Figure 2 and Figure 3 show the comparisons of the added mass and radiation damping of tanker 2 calculated without considering interaction and with interaction considered (D=20m). The results are found to agree very well, indicating that the hydrodynamic interaction does not have any significant effect on the added mass and radiation damping for the given vessel separation.

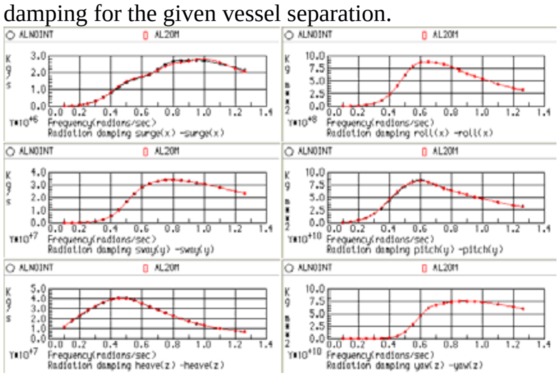

Figure 2: Radiation Damping

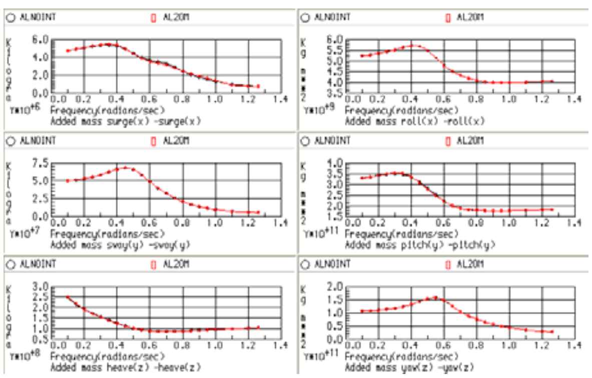

Figure 3: Added Mass

3.2 Wave Force

Figures 4, 5, 6 are the diffraction forces on tanker 2 for D=20m, 100m, 500m, 1000m, 2500m in comparison with those when no interaction is considered. Three wave headings, $\alpha=90^0$, 135^0, 180^0, are considered. It can be seen that the diffraction forces in sway, heave, roll, and yaw are only slightly affected by the hydrodynamic interaction, but in surge and pitch the impact is significant, especially for the wave heading of 90^0 where the hydrodynamic interaction can double the diffraction forces in surge and pitch for D=20m. For $\alpha=135^0$ and 180^0, the effect of interaction is still obvious, although less dramatic than the beam sea case.

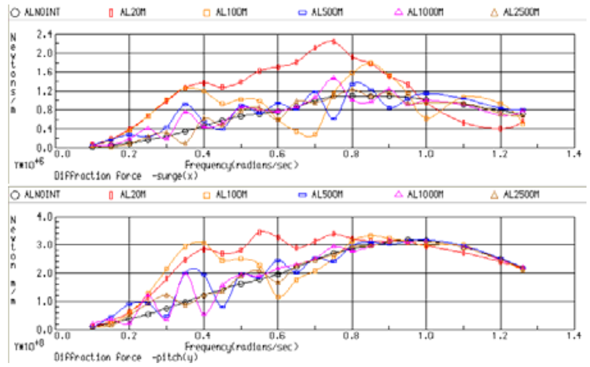

Figure 4: Compare of Diffraction Forces When $\alpha=90^0$

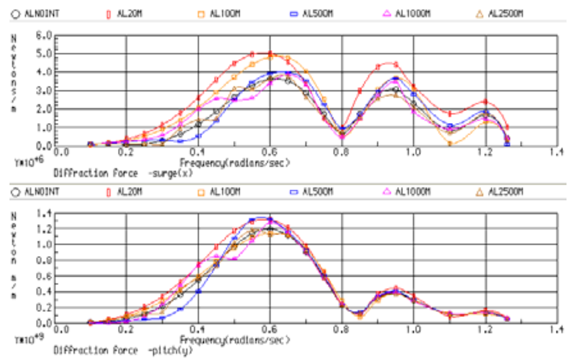

Figure 5: Compare of Diffraction Forces When $\alpha=135^0$

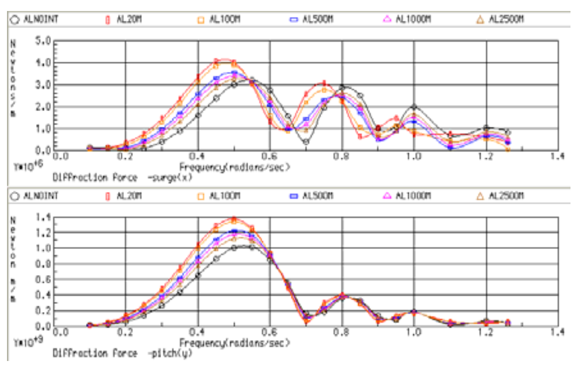

Figure 6: Compare of Diffraction Forces When $\alpha=180^0$

3.3 RAO

The above analysis has indicated that the hydrodynamic interaction has a considerable effect on the diffraction force, which will further affect the RAOs of the tankers. However since the added mass and damping are hardly affected by the interaction, the Froude Krylov force and hydrostatic force are independent of the interaction, there is no great differences between the RAOs with or without the interaction, as can be seen in Figures 7 ~ 9.

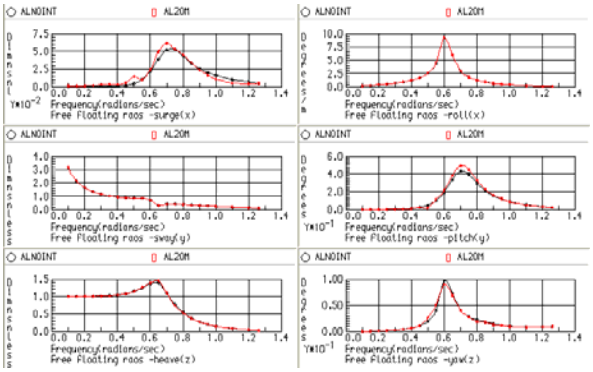

Figure 7: Compare of RAOs When α =90^0

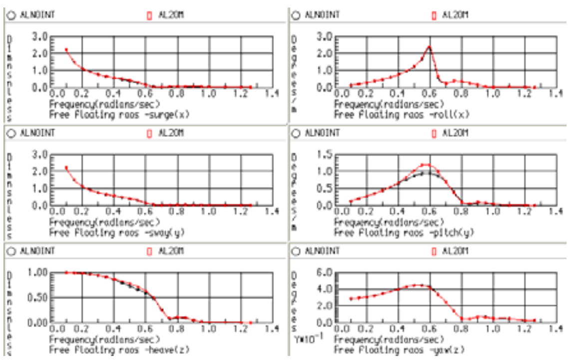

Figure 8: Compare of RAOs When α =135^0

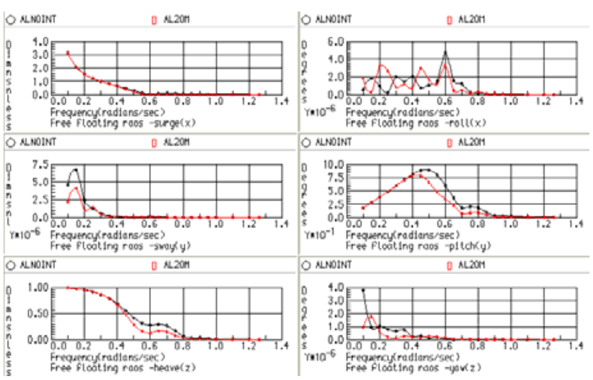

Figure 9: Compare of RAOs When α =180^0

3.4 Steady Drift Force (Mean Wave Drift Forces)

For different wave directions and relative distances, the hydrodynamic interaction has a major impact on the steady drift forces on tanker 2 in surge and pitch, and has no obvious effect for the steady drift force in other degrees of freedom. As shown in Figures10 ~ 12, for wave headings of 90^0 and 135^0, the steady drift force in surge and pitch are enhanced by the interaction, and the effect of interaction decreases quickly with the increase of the separation distance D. For wave heading of 180^0, the interaction reduces the steady drift force in surge and pitch significantly, and the smaller the separation D, the lower the drift force. It can also be seen in Figure 12 that the effect of the interaction decreases extremely slowly with the increase of the separation D for the 180^0 wave heading, even at D=2500m, the impact of the interaction is still obvious. This seemingly unrealistic phenomenon is probably due to the potential flow theory which has no energy dissipation.

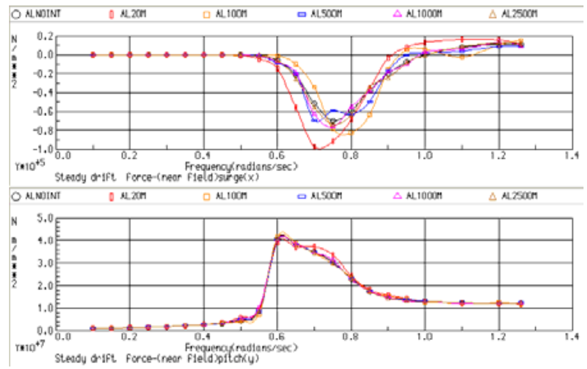

Figure 10: Compare of Steady Drift Force When α =90^0

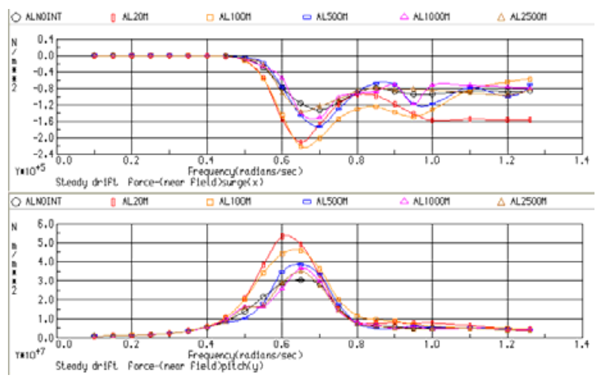

Figure11: Compare of Steady Drift Force When α =135^0

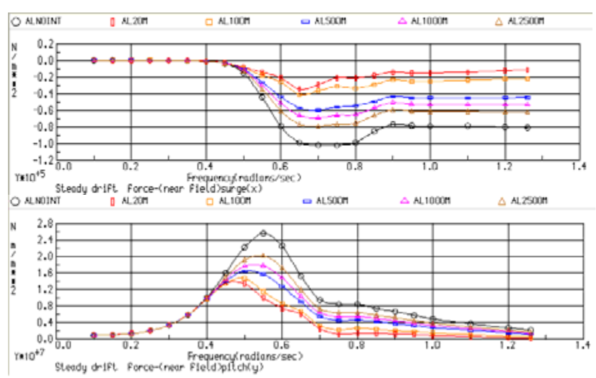

Figure 12: Compare of Steady Drift Force When α =180^0

4 Conclusions

A series of calculations are carried out using AQWA-LINE in order to investigate the effect of the hydrodynamic interaction on the hydrodynamic loads and responses of the tankers moored in tandem. The following conclusions are derived from this study for the vessel separations considered:

1) The effect of hydrodynamic interaction is insignificant on the added mass and radiation damping, and vessel's RAOs.

2) The diffraction force and steady wave drift force are significantly affected by the hydrodynamic interaction.

3) Since the RAOs are only very slightly altered by the hydrodynamic interaction, it can be concluded that for the wave frequency motion of a tandem moored system, the effect of hydrodynamic interaction can be ignored.

4) The effect of the hydrodynamic interaction does not decay quickly as the relative distance between the tankers increases. That is believed to be caused by the assumption of the invicid fluid adopted in the wave theory.

5) Due to the limited time, only two typical tankers are considered in this paper, and the effect of interaction on the vessels' slowly varying motion are not investigated. Further research can be carried out for vessels with different dimensions, and on the effect of interaction on the low frequency motion of the vessels.

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5 References

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