Effects of Motion Responses and Drift Forces on Side-by-Side Offloading Operations of FPSO

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Abstract Offloading operations involves transfer of oil or gas from the Floating Production Storage and Offloading system (FPSO's) to a nearby stationed shuttle tanker. The hydrodynamic interaction between the FPSO and shuttle tanker is an important subject of study. The actual estimate of the vessels behavior is necessary for offloading operation. This paper aims to study the hydrodynamic behavior of side-by-side stationed vessels for offloading operations. The investigation of hydrodynamic behavior is achieved through a diffraction module of ANSYS. The present study includes studying the motion responses and drift forces of side-by-side configured FPSO and shuttle tankers in three different water depth. The obtained results are found consistent with the published work.

Keywords Side-by-side · Offloading · Hydrodynamics · FPSO

1 Introduction

The recent survey [1] of Floating Production Storage and Offloading (FPSO) revealed that, there are total of 178 FPSOs working around the globe. The worldwide distribution of FPSO [1] shows that 14 FPSOs are currently operating in Australian waters while 51 FPSOs are stationed in Southeast Asia. Malaysia alone has 6 FPSOs. The side-by-side configuration is of recent origin and is a topic of interest for many reasons like stability and lower cost of production [2]. A typical FPSO consists of turret area, process area, storage and offloading systems. The stability is one of the key concerns of design. A side-by-side vessel is more complicated and tends to undergo complex behavior [2]. The common system of transporting oil from FPSO is by using a shuttle tanker. The shuttle tanker is usually placed adjacent to the moored FPSO and the stability of shuttle tanker is achieved by tugs or hawser connected

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between the two floating bodies. Arrangement of all risers on one end and shuttle tanker interface on the other end reduces the need of complicated riser systems.

The offloading may be done by a direct transfer using a hose or by using a separate offloading system like pipeline or riser. The FPSO and the shuttle tanker in the side-by-side configuration is subjected to continuous wave forces, wind forces, current forces as well as instability due to low lying resonant or second order forces [3], a shuttle tanker is stationed to transport the oil from the FPSO. In case of occurrence of extreme wave conditions, there could be cease of offloading operations due to increase in mooring forces than permissible limits, increase in responses of vessels, greater hawser loads than the limiting value [4]. Such an event can be attributed to downtime. The offloading operation is then re-continued when feasible conditions prevail [5].

The offloading operation is affected by large hydrodynamic forces and higher vessel response [6]. It is necessary to determine the actual vessel behavior and response for a safe offloading operation. The authors in Ref. [7] has experimentally investigated the basic interaction characteristics of both tandem and side-by- side moored vessels. The experimental results have been numerically compared using higher order boundary element method. The authors in Ref. [8] has predicted the motion and hydrodynamic force between two floating structures using three dimensional potential theory and source distribution technique. The obtained results are validated with experiments. The probability for collisions and risk are found and explained. The authors in Ref. [9] have studied offloading operation in specific location of Brazilian waters. The study revolves around the tug force for safe operation and hawsers forces respectively. Offloading assistance was then defined. The FPSO and shuttle tanker in a side-by-side configuration are analyzed in ANSYS AQWA by subjecting them to diffraction analysis in three different water depths of 50 m, 100 m and 250 m respectively. The response motion and drift forces are studied for offloading operations. The findings of the result are found to be consistent.

2 Hydrodynamic Analysis and Geometric Modeling

Integration of pressure over wetted surface area yields forces due to interaction of fluids on the body [10]. These forces due to fluid can be further bifurcated into reactive and active components. The active force which is also known as wave exciting force is sum of Froude-Krylov force and the diffraction force [10]. The body motion induces radiation waves which can be attributed to radiation force, also known as reactive force. The real and imaginary parts of radiation wave potential ϕ_{rk} is substituted to produce the added mass and wave damping coefficients as given in Ref. [11].

$$F_{rjk} = \omega^2 A_{jk} + i\omega B_{jk}$$

where, A_{jk} and B_{jk} are added mass and damping coefficients respectively. A set of linear algebraic equations are solved in the AQWA solver to obtain the harmonic

Table 1 Geometric details of FPSO and shuttle tanker

Category	Detail	FPSO	Shuttle tanker
Geometric details	Total structural mass	58.2572e6 kg	23.466e6 kg
	Kxx	10.948 m	8.806 m
	Kyy	45.71 m	37.9 m
	Kzz	47.53 m	39.416 m
	Ixx	69.8263e8 kg-m^2	18.1968 kg-m^2
	Iyy	12.1722e10 kg-m^2	3.37e10 kg-m^2
	Izz	13.1655e10 kg-m^2	3.6452kg-m^2
Details of mesh	Tolerance	1 m	1 m
	Longest period	30 s	30 s
	Shortest period	3 s	3 s
	Interval period	0.5 s	0.5 s

response of the body in regular wave. These response characteristics are known as Response Amplitude Operators (RAO) and are proportional to wave amplitude. The set of linear equations of motion with frequency dependent coefficients are given in Refs. [12, 13]. The FPSO and the shuttle tanker were first subjected to hydrodynamic analysis alone without any side-by-side configuration. Subsequently, a side-by-side hydrodynamic analysis was performed under the same wave conditions. The time period of analysis was from 3 to 30 s. The wave directions considered were 180° to +180°. The details of the FPSO and shuttle tanker are displayed in Table 1. Figure 3 displays the side-by-side configuration of the models in AQWA.

3 Results and Discussions

The FPSO and shuttle tanker were subjected to hydrodynamic diffraction analysis. The results obtained then were compared to the finding of the results in Refs. [3, 4] for establishing consistency of present work with established past work respectively. It can be said that the present work was in good agreement with the findings of the past work. The prime focus of the present work is studying the behavior of vessels with and without side-by-side configuration respectively. The drift forces and responses in the six degree of freedom are primarily studied.

It is observed from Fig. 1 that the trend is almost similar for smaller time period. There is lesser shielding effect on the FPSO by the shuttle tanker for the small time period. However, shielding effect is higher for higher time period. The response in surge for quartering seas does not exhibit any shielding effect. Moreover, the presence of adjacent shuttle tanker causes the response to be more than the FPSO alone. Hence, there is effect of side vessel on sway response as shown in Fig. 1 respectively. A significant shielding effect is seen in the heave response for the

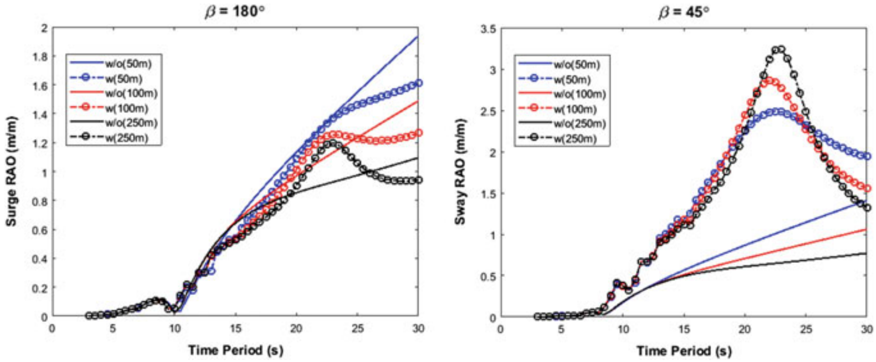

Fig. 1 Surge (180°) and sway (45°) responses of FPSO

FPSO in beam sea. There is considerate decrease in the heave response for lee side vessel but disappears eventually for higher time period as shown in Fig. 2. For the roll response, it is observed that there is no roll without shuttle tanker in head seas. The roll response is governed by resonance. Furthermore, presence of shuttle tanker causes roll significantly which clearly explains that presence of adjacent shuttle tanker causes resonance and thereby causes roll response to shoot up as displayed in Fig. 2. The vessels are very closely spaced and the water column present between the gap resonates which can be explained by Helmholtz type resonance. However, in beam seas there is significant shielding effect for the roll response due to presence of shuttle tanker which effectively reduces the roll response of FPSO as shown in Fig. 3.

Drift forces are induced due to interaction of the vessels. Large fluctuations are seen for surge drift forces due to presence of shuttle tanker as shown in Fig. 3. An interesting phenomenon is observed that there is no lateral and yaw drift forces in the absence of shuttle tanker. However, from Figs. 4 and 5 it can be seen that strong hydrodynamic interactions cause lateral and yaw drift forces. The presence of shuttle

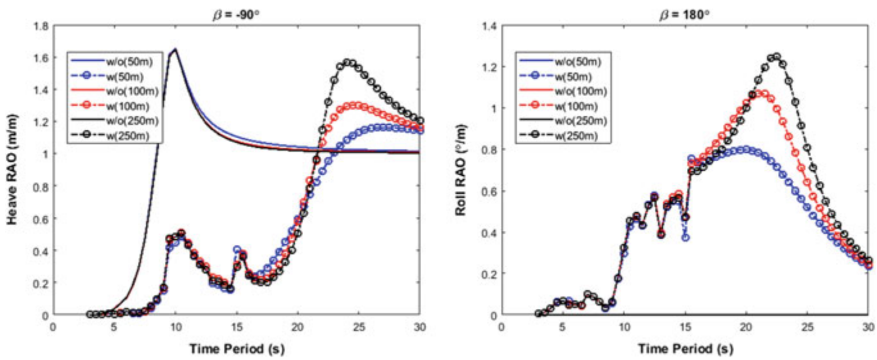

Fig. 2 Heave (−90°) and roll (180°) responses of FPSO

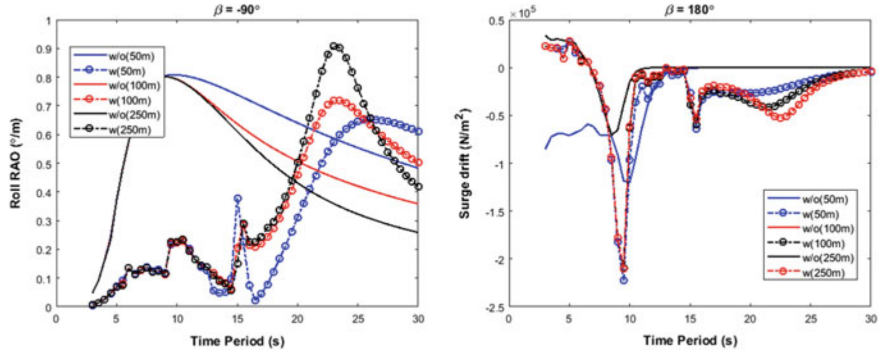

Fig. 3 Roll response (−90°) and longitudinal drift force (180°) for FPSO

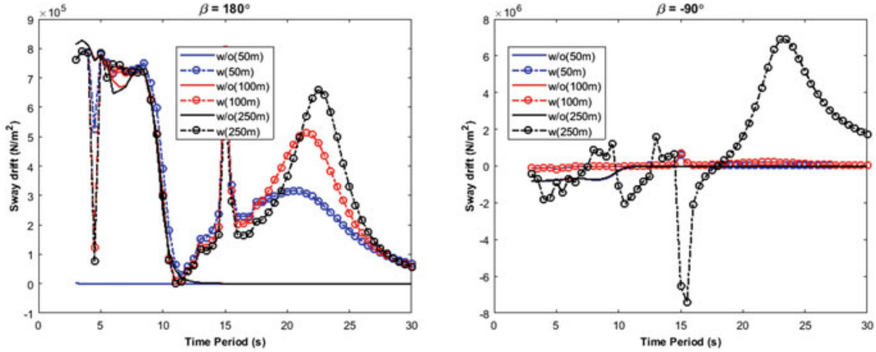

Fig. 4 Lateral drift force (180° and −90°) of FPSO

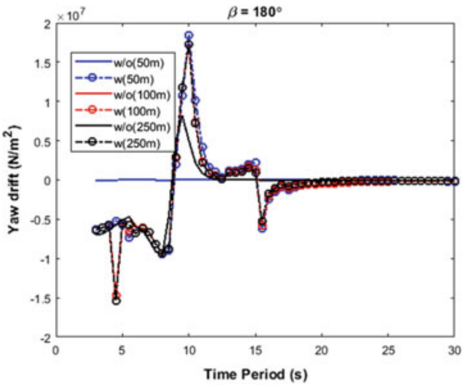

Fig. 5 Yaw drift force (180°) on FPSO

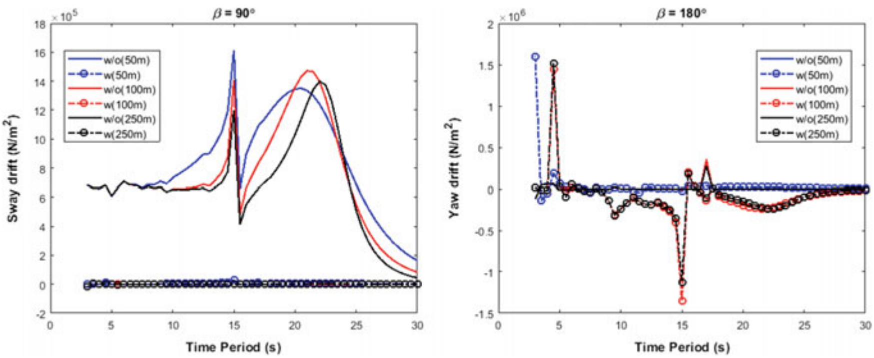

Fig. 6 Lateral drift force (90°) and yaw drift force (180°) on shuttle tanker

tanker causes the FPSO to drift in positive 'y' direction. The shuttle tanker was also observed for drift forces under the influence of FPSO. There is similar display of nature as that of FPSO. The sway and yaw drift forces at beam and head seas are shown in Fig. 6.

4 Conclusion

From the present study on the hydrodynamics of side-by-side vessels, following conclusions can be deduced as follows

1. The surge response on FPSO is affected by shielding effect for higher time period for head seas while quartering seas has no shielding effect predominantly.
2. There is significant increase in the sway response of FPSO is due to presence of shuttle tanker for quartering seas.
3. The heave response is shielded by the shuttle tanker in beam seas.
4. There is remarkable effect on the roll response of FPSO in side-by-side configuration for head seas while beam seas tend to exhibit shielding effect.
5. The presence of adjacent vessel influences the drift forces to a great extent.

Future Work The future work includes downtime analysis of offloading operations in Malaysian water conditions and developing GUI for linking motion responses to cost.

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