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Hydrodynamic Interaction of Three Floating Structures

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ABSTRACT

This study will highlight the motion characteristics of single body and multiple bodies of offshore structures due to the effect of hydrodynamic interaction by considering the gap distance, the presence of number of neighboring structures and the wave direction headings. In order to analyze the added mass, radiation damping and motion responses that are developed during the interaction between structures, commercial software ANSYS AQWA is used. The analysis are executed by using 100 m diameter of round-shaped FPSO as the reference point for a single body where it is compared with two bodies and three bodies by using 70 m diameter round-shaped FPSO and LNG vessel for gap distance of 25 m and 50 m and wave directions at 00, 450, 900, 1350 and 1800 headings. The results show same trend with previous studies and researches in which the motion responses due to the effect from other structures occur significantly on surge and pitch motions compare to heave motion though there are small interactions. As for overall, the gap distance between structures, the presence of number of neighboring structures and the wave directions affect the motions of multiple bodies of offshore structures due to hydrodynamic interaction.

KEY WORDS: *Round-Shape Floating Production Storage Offloading; Hydrodynamic Interaction; Gap Distance.*

NOMENCLATURE

FPSO : Floating Production Storage Offloading
LNG : Liquefied Natural Gas
RAO : Response Amplitude Operator

1.0 INTRODUCTION

The development of oil and gas area regarding the offshore structures which considered as a challenge in the past has become a common thing nowadays where the effects of hydrodynamic interaction on the motion of the offshore structures have to be carefully taken into consideration for their safe operation. There are many researchers have been done regarding to hydrodynamic interaction effect on multiple bodies of offshore structures. The researches have been done analytically and numerically in order to solve the problems regarding the hydrodynamic analysis between multiple bodies. Some previous researches have been used as a guideline to the present researches. There are many researchers have been done regarding the problem of hydrodynamic interaction between multiple bodies and strip theory and potential theory are normally used to analyze the motions of the floating structures.

For the hydrodynamic behavior of a single body of offshore structure, Saad et al. (2009) used a mono-hull production platform in real environmental conditions which is in Brazilian waters. They also compared the data obtained from the field measurements with the results from the numerical simulations as well as the results acquired from model tests performed during the design phase. The hydrodynamic behavior of the mono-column showed satisfactory results and valid even though there are quite conservative to those related to the higher period amplitude. Cueva et al. (2010) presented the numerical and experimental models for motion evaluation by using a circular shaped floater which is also a mono-column structure. The results for both numerical and experimental evaluations are presented in terms of Response Amplitude Operators (RAOs) for heave and pitch/roll motions. The results obtained for both numerical and experimental models are quite satisfactory except that there are slight differences and they are still valid.

Ohkusu (1974) adopted strip theory to analyze the ship's motion around large floating structure. The results described clearly the effects of position of a smaller body in opposition to a large body. Ohkusu's method is extended by Kodan (1984) to investigate the hydrodynamic interaction between two parallel structures in oblique waves. In order to support the validity of strip theory, he compared his investigation with model experiment but neglecting the speed effect and the results obtained are satisfactory with the experimental results. Fang and Kim (1986) also utilized the strip theory to predict the motion between two ships due to hydrodynamic effect in oblique sea. Their method is different with previous researcher where the speed effects are taken into account, however, some deficiencies popped up due to the assumptions of two-dimensional.

Van Oortmerssen (1979) solved the hydrodynamic interaction problem between two floating structures in waves by using the three-dimensional linear diffraction theory to solve. The results obtained for the numerical calculation achieve an agreement with the data obtained from the experiment but the speed effects are not considered as well as he did not applied his method to the ship configuration. Loken (1981) used three-dimensional sink-source method to investigate the wave-induced motion and wave-drifting forces and moment on several close vessels in waves and the results obtained were satisfactory but the results for resonance region were quite unsatisfactory. Wu et al. (1997) reviewed numerically and experimentally on the motion of a moored semi-submersible in regular waves and the wave-induced internal forces in the semi-submersible. For numerical method, the linearized equations of motions of the semi-submersible which is modelled as an externally constrained floating body are obtained in a common reference system fixed on the body. The results between the numerical and experiment in the practical wave-frequency range achieved very good agreement.

As the ability to compute is evolved, three-dimension approach to solve the hydrodynamic problems has become popular. Choi and Hong (2002) employed a higher-order boundary element method (HOBEM) or wave Green function to analyze numerically the hydrodynamic interactions of multi-body system for twin barges and FPSO-shuttle systems. The results obtained show that there are rapid changes in hydrodynamic loads and responses along the wave frequencies caused by the hydrodynamic interaction. M. Kashiwagi and Q. Q. Shi (2010) investigated numerically the wave interaction theory of four identical box-shaped floating bodies to compute the pressure distribution and integrated forces on body surfaces using the separation distance between the multiple floating bodies. The results obtained from the wave interaction theory are compared to HOBEM because the results obtained from HOBEM are accurate with respect to the separation distance between bodies. Clauss et al. (2002) analyzed numerically and experimentally the sea keeping behavior of a semi-submersible in rogue wave. A panel-method program is used for wave or structure interactions in time-domain which is TiMIT (Time-domain investigation developed at the Massachusetts Institute of Technology) to evaluate the motions of the semi-submersible. The results showed good agreement with model test despite the fact that TiMIT theory is strictly linear and applicable for moderate sea conditions only.

Zhou Xianchu et al (1997) applied the linear potential theory to investigate the hydrodynamic interaction between two vertical cylinders in water waves where the diffraction wave and radiation waves are considered. It is found that the incident angle which is the angle between the incident wave direction and the line joining two cylinder centers is depended on the magnitude of wave excited forces on cylinders. M.S. Kim and M. K. Ha (2002) studied the motion responses between two offshore floating structures due to hydrodynamic interaction by using linearized three-dimensional potential theory with various heading waves. They used three-dimensional source distribution method for twelve coupled linear motion responses and elative motions of the barge and the ship in oblique waves to solve the numerical calculation. The results obtained provide a good correlation with the experimental results. Zhu et al. (2008) applied time domain method to research the influence of the separation distance on the wave forces for hydrodynamic resonance of three-dimensional multiple floating structures. The results obtained from the time domain method for the peak force response on each floating body show similar resonant phenomena and hydrodynamic interaction when compared with frequency domain method, thus the time domain method is said as practically efficient.

M. T. Ali et al (2010) investigated the first order wave exciting forces and motion responses due to hydrodynamic interaction between two unequal-sized freely floating three-dimensional rectangular boxes in regular waves using 3-D source distribution method through different wave headings angles and separation distances (gaps). The results obtained show that the magnitude of the amplitude of motion responses and wave exciting forces for the smaller box can be increased or decreased depending on the wave heading while high peak frequencies is obtained as the gaps between two floating rectangular boxes is reduced. Z. Tajali et al. (2011) carried out the hydrodynamic analysis of a floating multiple bodies of floating pier interacting with incident waves in the frequency domain. They used three-dimensional diffraction theory to predict the dynamic response of modules in irregular waves. The pier is modeled as a rigid body platform and pontoons are connected to each body of the floating piers by hinge. The results showed that for a fixed length of the pier, the amplitude of heave and pitch motions increased as the number of pontoons increased.

As presented by Siow et al. (2014), the diffraction potential theory is less accurate to predict the structure heave motion response when the wave frequency is close to the structure's natural frequency. In this situation, the heave response calculated by the diffraction potential theory is significantly higher compared to experimental result due to the low damping represented by the theory. Then, the heave response tendency will follow a large drop and show an underestimating result compared to experimental results before it returns to the normal tendency (Siow et al. 2013).

Wackers et al. (2011) reviewed the surface discretisation methods for CFD application with different codes. Besides, simulation of fluid flow Characteristic around Rounded-Shape FPSO had also conducted by Efi et al. (2013) using RANs Method. Jaswar et al (2013) study the hydrodynamic interaction between Tension Leg Platform (TLP) and semi-submersible and the characteristics of multiple floating bodies when placed near to each other in regular waves. The experiment tests were carried out to find out the effect of hydrodynamic interaction to the motions of the structures. They applied Fourier Transform method to get the data in frequency domain by converting the data in time domain. The result shows that the hydrodynamic interaction will occur due to the scattering wave and radiation wave generated by another floating body which can cause the increase to the magnitude of the motions of the structures.

2.0 PRINCIPAL THEORY

2.1 Motions of Floating Body

At sea, a floating structure experienced the motions responses due to waves where the motions are divided into 6 degrees-of-freedom in which three of them are linear while the other three are rotational about the three principal axes as in Figure 1.

The linear motions are surge (x-axis), sway (y-axis) and heave (z-axis) while the rotational motions are roll (x-axis), pitch (y-axis) and yaw (z-axis). From the six motion responses, heave, roll and pitch are considered as oscillatory motions since they are moving about a neutral point while for surge, sway and yaw, they do not return to their original equilibrium unless they are forced by exciting forces or moments.

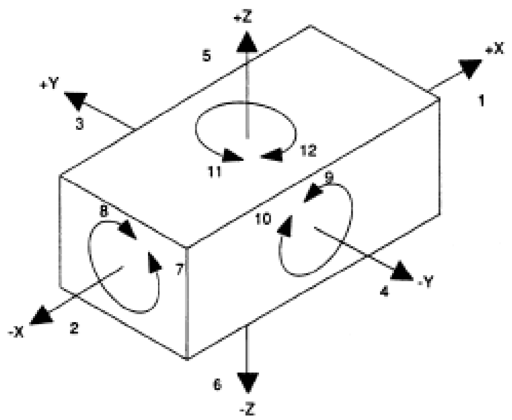


Figure 1: Six degree-of-freedom of a floating body

The equation of motion of floating body can be expressed as

$$(m_j + a_{jj})\ddot{x}_{j(t)} + b_{jj}\dot{x}_{j(t)} + c_{jj}x_{j(t)} = f_{j(t)} \quad (1)$$

where x is displacement, $\dot{x}$ is velocity, $\ddot{x}$ is acceleration and f is exciting force.

The displacement can be expressed as

$$x_{j(t)} = x_{jo} \cos(\omega t - \varepsilon_j) \quad (2)$$

the velocity can be expressed as

$$\dot{x}_{j(t)} = -x_{jo}\omega \sin(\omega t - \varepsilon_j) \quad (3)$$

the acceleration can be expressed as

$$\ddot{x}_{j(t)} = -x_{jo}\omega^2 \sin(\omega t - \varepsilon_j) \quad (4)$$

and the exciting force can be expressed as

$$f_{j(t)} = f_{jo} \cos(\omega t) \quad (5)$$

where; m_j is mass of the system, a_{jj} is hydrostatic reaction in phase with acceleration (added mass), b_{jj} is hydrostatic reaction in phase with velocity(damping coefficient), c_{jj} is stiffness, x_{jo} is amplitude of motion, f_{jo} is amplitude of force and ε_j is phase angle.

2.2 Concept of Interaction of Floating Bodies

Based from potential flow theory, the fluid flow around the bodies can be described by velocity potential by satisfying the conservation of mass and momentum equations using Laplace's equation. It is assumed that the fluid flow around bodies as incompressible, inviscid which is frictionless and irrotational where the fluid particles are not rotating due to the viscous effects which are limited to the boundary layer. The velocity potential can be defined as $\Phi(x,y,z)$. The velocity potential can be divided into three parts; incident wave Φ^I, scattered wave Φ^S and radiation wave Φ^R.

$$\Phi(x,y,z) = \Phi^I(x,y,z) + \Phi^S(x,y,z) + \Phi^R(x,y,z) \quad (6)$$

Eq.6 can be simplified as

$$\Phi(x,y,z) = \frac{gA}{i\omega}\{\emptyset_I(x,y,z) + \emptyset_S(x,y,z)\} + \sum_{k=1}^{6} \omega X_k \emptyset_R(x,y,z) \quad (7)$$

Where; g is gravitational acceleration (9.81 m/s^2), A is amplitude of incident wave, $\emptyset_I$ is an incident wave potential, $\emptyset_S$ is Scattering wave potential, $\emptyset_R$ is radiation wave potential due to motions, X_k is amplitude of motions and k is direction of motion.

The diffraction wave is the scattered wave from the fixed body caused by the incident wave. The radiation wave represents the wave propagated by the oscillating body in calm water. The diffraction wave and radiation wave can cause a significant effect on the bodies of floating structure in deep water.

It is assumed that the phase and amplitude for both the incident wave and diffraction wave are the same but the radiation wave is affected by each type of motions of each single floating body in the system. As a result, the total potential for radiation wave for a single body is the summation of the radiation waves generated by each type of motions of body which are surge, sway, heave, roll, pitch and yaw.

$\emptyset_I$ is the incident wave potential which can be written as

$$\emptyset_I(x,y,z) = -\frac{igA}{\omega}\frac{\cosh[k_0(z+h)]}{\cosh kh} e^{ik_0(x\cos\alpha + y\sin\alpha)} \quad (8)$$

Where; α is angle where the incident waves propagate relative to x-axis

$\emptyset_S$ is the scattering wave potential due to the continuous surface of fluid can be represents as

$$\emptyset_S(x,y,z) = \frac{1}{4\pi}\iint_S \sigma_S(a,b,c)\ G(x,y,z;a,b,c)\,ds \quad (9)$$

$$\emptyset_S(x,y,z) = -4\pi u_n(x,y,z) \quad (10)$$

where; $\sigma_S(a,b,c)$ is source of strength function, $G(x,y,z;a,b,c)$ is Green's function, (x,y,z) is coordinates of the field and (a,b,c) is coordinates for source point.

Diffraction wave potential $\emptyset_D$ can be obtained from the sum of incident wave potential and scattering wave potential.

$$\emptyset_D(x,y,z) = \emptyset_I(x,y,z) + \emptyset_S(x,y,z) \quad (11)$$

The diffraction wave potential $\emptyset_D$ must be satisfied with the boundary conditions:

- Laplace's equation:
  - $\nabla^2\emptyset_D = 0$ for $0 \le z \le h$
- Free-surface condition:
  - $\frac{\partial\emptyset_D}{\partial z} + K\emptyset_D = 0$ a t $z = 0$ where $K = \frac{\omega^2}{g}$
- Bottom boundary condition:
  - $\frac{\partial\emptyset_D}{\partial z} = 0$ at $z = h$
- Radiation condition:
  - $\emptyset_D \sim \frac{1}{\sqrt{r}}e^{-ik_0 r}$ should be 0 if r is ∞
- Body boundary condition:
  - $\frac{\partial\emptyset_D}{\partial n} = -\frac{\partial\emptyset_I}{\partial z}$ on the boundary

Thus,

$$\emptyset_D(x,y,z) = Re\left[\frac{gA}{i\omega}\{\emptyset_I(x,y,z) + \emptyset_S(x,y,z)\}e^{-i\omega t}\right] \quad (12)$$

The boundary conditions for the radiated wave potential are the same with the boundary conditions for incident wave potential. For radiated wave potential which is related to the motions of the body can be given as

$$\emptyset_R(x,y,z) = \sum_{k=1}^{6} \omega X_k \emptyset_R(x,y,z) \quad (13)$$

The radiated wave potential due the motions of the body can be obtained from as shown below

$$2\pi\emptyset_R(x,y,z) + \sum \emptyset_R(a,b,c)\iint_{S_B} \frac{\partial G(x,y,z,a,b,c)}{\partial n}dS = \sum \emptyset_R(a,b,c)\frac{\partial\emptyset_R(a,b,c)}{\partial n}\iint_{S_B} G(x,y,z,a,b,c)dS \quad (14)$$

where; S_B is wet body surface of the floating body

3.0 SIMULATION SET UP

Simulation of hydrodynamic interaction of three floating bodies was arranged as shown in Figure.2. The simulation was carried out at different wave directions as follows: 0^0, 45^0, 90^0, 135^0 and 180^0 headings using parameters of environmental conditions at KIKEH field as shown in Table.1.

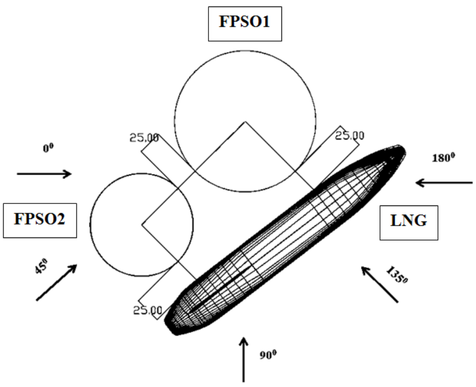


Figure 2: Wave Direction at 0^0, 45^0, 90^0, 135^0 and 180^0 headings

Table.1: Environmental condition in KIKEH operation.

Description	Value	Unit
Sea Water Characteristics		
Water Depth	1320	m
Water Density	1025	kg/m^3
Wave Characteristics		
Type	Range of Directions, No Forward Speed	
Wave Range	-180^0 to 180^0 (-PI to PI)	
Interval	45^0	
Number of Intermediate Directions	7	

The FPSO's and ship are analyzed using commercial software which is Rhinoceros for design and ANSYS AQWA Hydrodynamic Diffraction and ANSYS AQWA Hydrodynamic Time Response. Figure.3 shows drawn of FPSO-1, FPSO-2 and ship by Rhinoceros viewed from top, front, and right sides. Table.2 and Table.3 show principal dimensions of FPSO and ship, respectively.

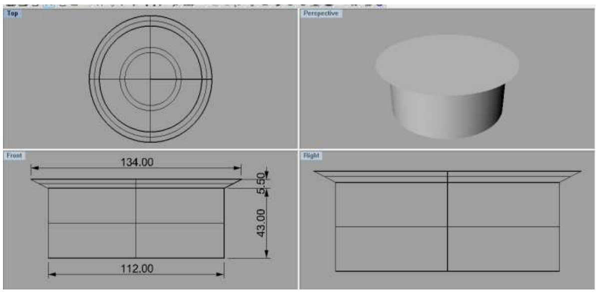


Figure.3.a: View of FPSO-1 from top and front

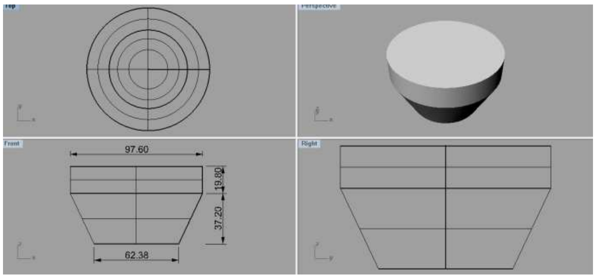


Figure.3.b: View of FPSO-2 from top and front

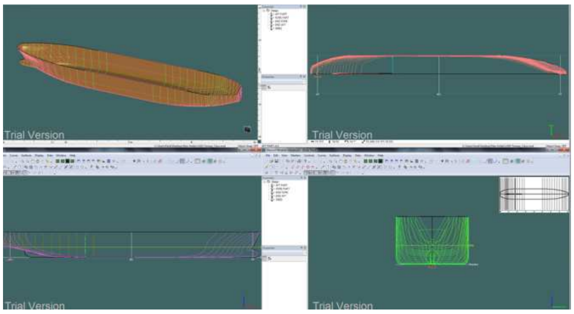


Figure.3.c: View of ship from top, front and side

Table.2: Principal dimensions of FPSO.

Parameter	FPSO-1	FPSO-2
Diameter at Upper Deck (m)	134.00	97.60
Diameter at Base (m)	112.00 m	62.38
Draught (m)	32.00	37.20

Table.3: Principal dimensions of LNG ship.

Parameter	LNG
Length	270.70 m
Breadth	44.30 m
Draught	11.13 m

4.0 RESULTS AND DISCUSSION

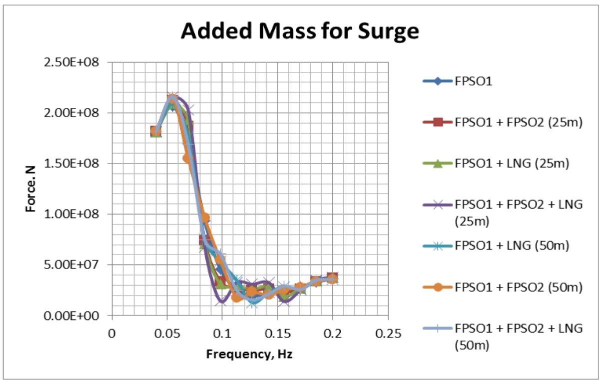
The results in relation to the hydrodynamic analysis of single body, two bodies and three bodies of offshore structures for added mass, damping coefficients and response amplitude operators (RAO) are analyzed for every added mass, damping coefficients and RAO for each direction are presented by using graphical method the data that has been extracted from ANSYS AQWA Hydrodynamic Diffraction and ANSYS AQSA Time Response. These results will be discussed on the differences between the motion of single body, two bodies and three bodies of offshore structures due to hydrodynamic interaction.

4.1 Added Mass

Figure 3 shows the results of added mass on surge, heave and pitch motions against frequency for single body of offshore structure (FPSO1) with two bodies of offshore structures (FPSO1 with FPSO2 and FPSO1 with LNG) and three bodies of offshore structures (FPSO1 with FPSO2 and LNG) for two different gap distance which are 25 m and 50 m respectively. All the figures show that all the added mass for surge, heave and pitch motions have same trend despite there are small differences between due to more interaction between numbers of floating structures are involved in smaller gap distance.

However, the results of added mass on heave and pitch motions are larger compare to the results of added mass on surge motion which show that more reactions occur in heave and pitch motions. The trends for the added mass at 25 m gap distance are different with the trend for the added mass at 50 m gap distance where the values of added mass decreases rapidly at the resonant frequency as the gap distance increases.

As a result, this shows that gap distance and presence of other structures can give different effects to the values of added mass for the hydrodynamic interaction between two bodies and three bodies of offshore structures.



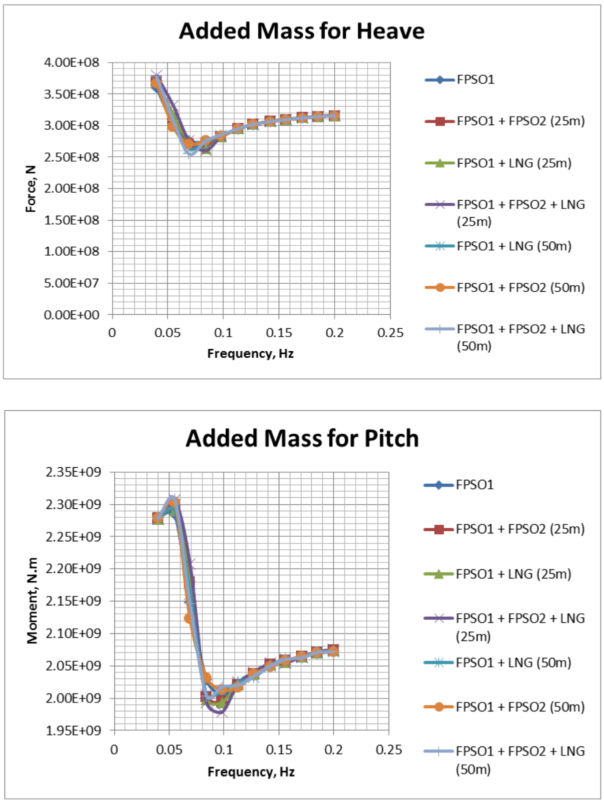


Figure 3: Added Mass on Surge, Heave and Pitch Motions

4.2 Radiation Damping Coefficient

Figure 4 shows the results of radiation damping on surge, heave and pitch motions vs frequency for single body of offshore structure (FPSO1) with two bodies of offshore structures (FPSO1 with FPSO2 and FPSO1 with LNG) and three bodies of offshore structures (FPSO1 with FPSO2 and LNG) for two different gap distance which are 25 m and 50 m respectively.

From the figures, all the radiation damping on surge, heave and pitch motions have experienced same trend though there are small differences in the values obtained. For the results of radiation damping, more reactions have been experienced by the structure on surge motion since the radiation damping values obtained on surge motion are larger than the radiation damping values obtained on heave motion.

Apart from that, the radiation damping for three bodies of offshore structures have the highest values on surge, heave and pitch motions compare to others especially at the gap distance 25 m due to the motion effects of two other structures experienced by one structure.

The trends for the radiation damping at 25 m gap distance are slightly different compare to the trend for the radiation damping at 50 m gap distance in which the radiation damping values drop down rapidly at the resonant frequency as the gap distance increases.

Therefore, gap distance and presence of other structures plays important roles in affecting the radiation damping values for the hydrodynamic interactions between two bodies and three bodies of offshore structures.

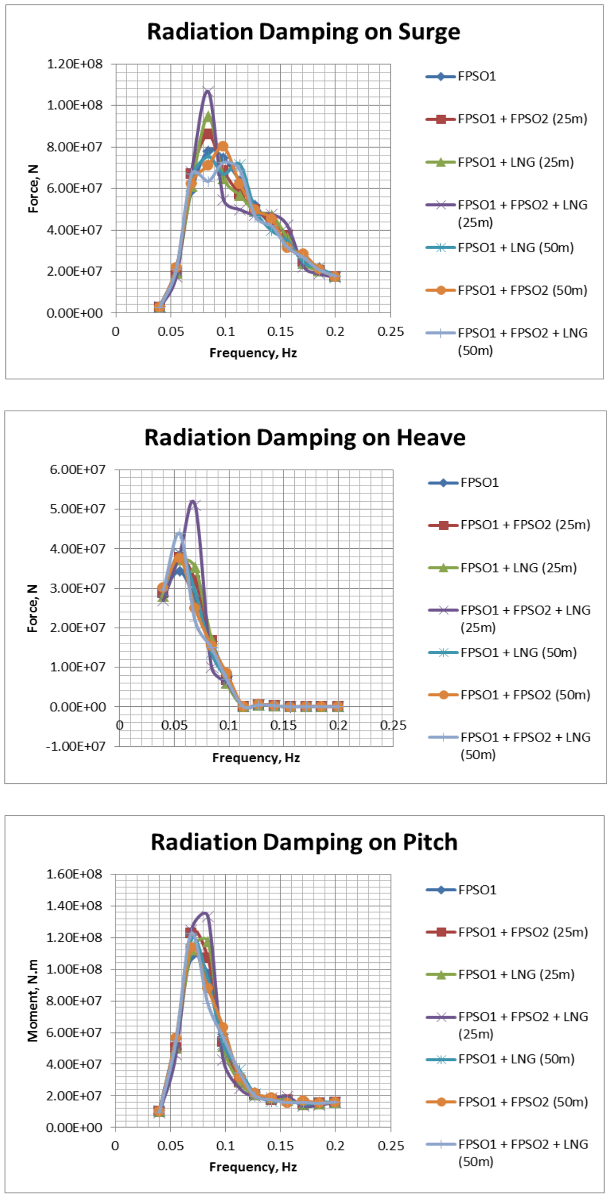


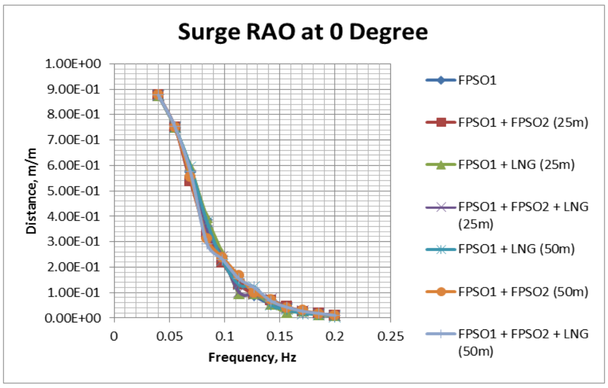
Figure 4: Radiation Damping on Surge, Heave and Pitch Motions

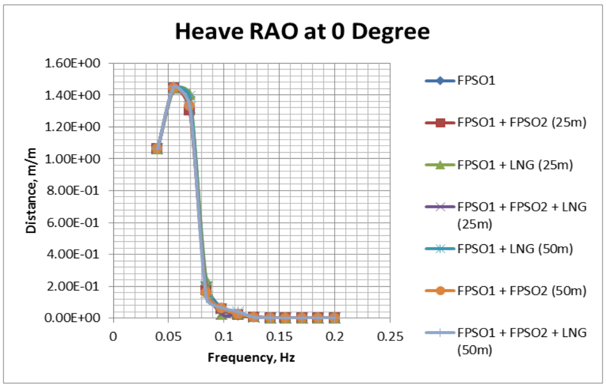
4.3 Response Amplitude Operators

Figure 5 shows the wave directions for five different headings which are 0^0, 45^0, 90^0, 135^0 and 180^0. RAO on surge, heave and pitch motions of single body, two bodies and three bodies of offshore structures for different headings are analyzed in order to know the effects of wave direction to the motion responses of the structures.

Figure 6 shows the results of RAO on surge, heave and pitch motions against frequency at 0 degree heading for single body of offshore structure (FPSO1) with two bodies of offshore structures

(FPSO1 with FPSO2 and FPSO1 with LNG) and three bodies of offshore structures (FPSO1 with FPSO2 and LNG) for two different gap distance which are 25 m and 50 m respectively. From the figures, each graph has its own trend for surge, heave and pitch motions where there are almost no changes for motions response on surge and heave motions compare to motion response on pitch motion. On the pitch motion, there are slight differences between the motion responses of the structures at 25 m and 50 m in which the motion responses at 50 m are higher than the motion responses at 25 m. Although there are small differences on pitch motion with the presence of neighboring structures, there are slight motion responses between multiple bodies of offshore structure for the direction of wave at 0 degree heading and it is proved there are hydrodynamic interactions between multiple bodies of offshore structures.





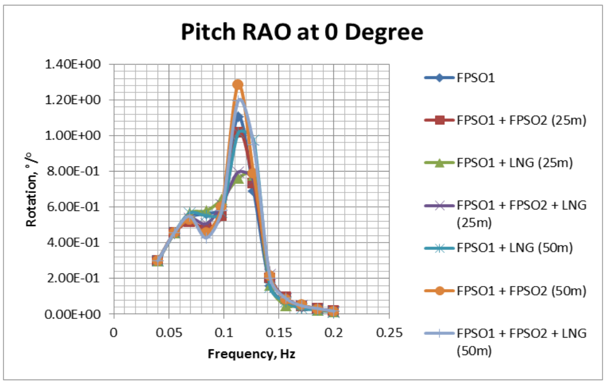
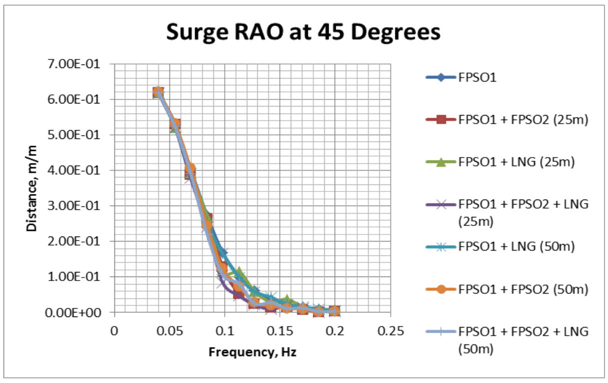
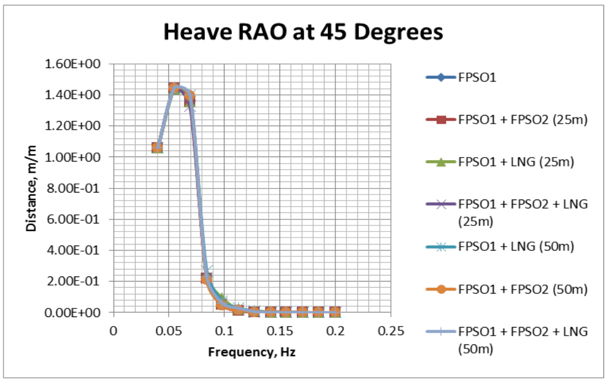


Figure 6: Surge, Heave and Pitch RAOs at 0 Degree

Figure 7 shows the results of RAO on surge, heave and pitch motions against frequency at 45 degrees heading for single body of offshore structure (FPSO1) with two bodies of offshore structures (FPSO1 with FPSO2 and FPSO1 with LNG) and three bodies of offshore structures (FPSO1 with FPSO2 and LNG) for two different gap distance which are 25 m and 50 m respectively. The trends for surge, heave and pitch motions are same with the trends at 0 degree heading but there are slight differences for surge motion, no changes for heave motion and relatively large differences for pitch motion between structures. On surge motion, the slight reactions for motion responses between two bodies and three bodies of offshore structures occur at 0.07 Hz and normalized back at 0.200 Hz while on pitch motion, all the reactions for motion responses between two bodies and three bodies of offshore structures are different but the maximum values for all motion responses occur at 0.115 Hz. This shows that there are effects for the wave direction at 45 degrees heading to the motions response for two bodies and three bodies of offshore structures with the presence of neighboring structure.





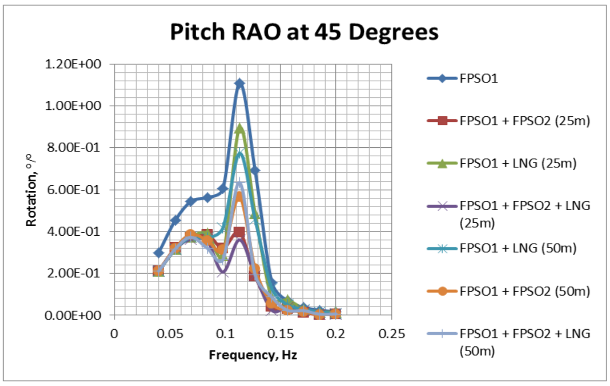
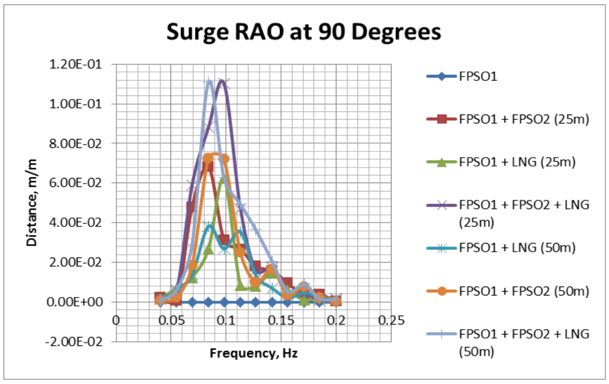
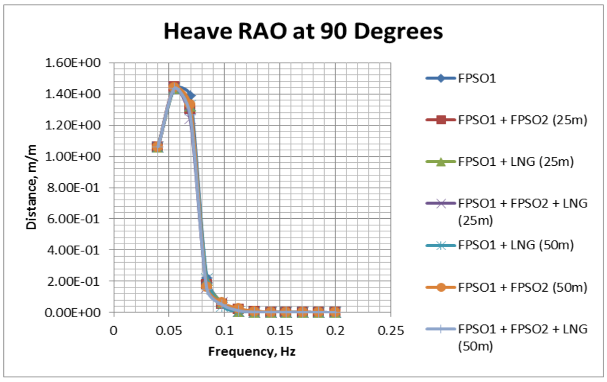


Figure 7: Surge, Heave and Pitch RAOs at 45 Degrees

Figure 8 shows the results of RAO on surge, heave and pitch motions against frequency at 90 degrees heading for single body of offshore structure (FPSO1) with two bodies of offshore structures (FPSO1 with FPSO2 and FPSO1 with LNG) and three bodies of offshore structures (FPSO1 with FPSO2 and LNG) for two different gap distance which are 25 m and 50 m respectively. The trends for heave and pitch motions are same with trends at 0 and 45 degrees but it is different for surge motion where the trend is same with pitch motion. In comparison with surge and pitch motions between multiple bodies where there are significant changes on the motion responses, heave motion has no change at all because there are effects the radiated waves from other structures in gap distance. In addition, the maximum values for the amplitude of motion of surge and heave motion are almost the same. As a consequence, the presence of neighboring structures as well as the 90 degrees heading of wave direction can causes the difference on the amplitude of motion responses on surge and pitch motions aside from heave motion.





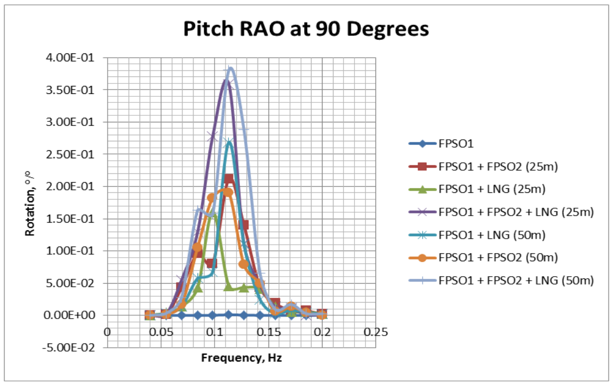


Figure 8 Surge, Heave and Pitch RAOs at 90 Degrees

Figure 9 shows the results of RAO on surge, heave and pitch motions against frequency at 135 degrees heading for single body of offshore structure (FPSO1) with two bodies of offshore structures (FPSO1 with FPSO2 and FPSO1 with LNG) and three bodies of offshore structures (FPSO1 with FPSO2 and LNG) for two different gap distance which are 25 m and 50 m respectively. The trends for surge, heave and pitch motions are same with 45 degrees heading where there are slight differences for surge motion, no changes for heave motion and relatively large differences for pitch motion between structures. On surge motion, the slight reactions for motion responses between two bodies and three bodies of offshore structures occur at 0.07 Hz and normalized back at 0.200 Hz while on pitch motion, all the reactions for motion responses between two bodies and three bodies of offshore structures are different but the maximum values for all motion responses occur at 0.110 Hz. This shows that the effects for the wave direction at 135 degrees heading are same with 90 degrees heading for the motions response for multiple bodies of offshore structures with the presence of neighboring structure.

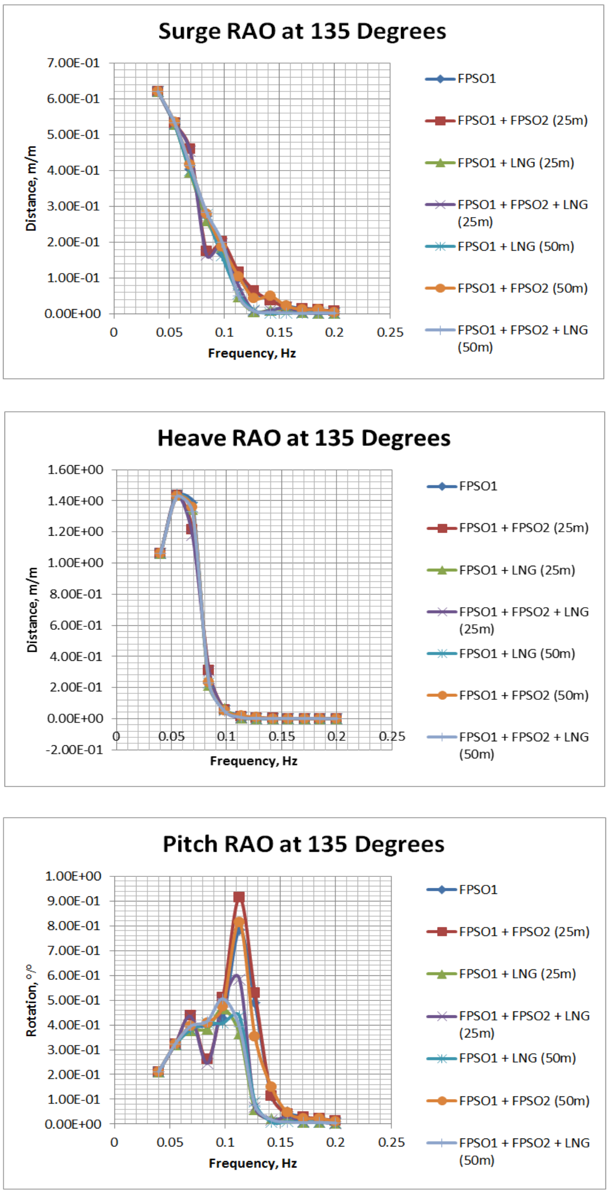


Figure 9: Surge, Heave and Pitch RAOs at 135 Degrees

Figure 10 shows the results of RAO on surge, heave and pitch motions against frequency at 180 degrees heading for single body of offshore structure (FPSO1) with two bodies of offshore structures (FPSO1 with FPSO2 and FPSO1 with LNG) and three bodies of offshore structures (FPSO1 with FPSO2 and LNG) for two different gap distance which are 25 m and 50 m respectively. The trends for surge, heave and pitch motions are same with 0 degree heading there are almost no changes for motions response on surge and heave motions compare to motion response on pitch motion. On the pitch motion, there are slight differences between the motion responses of the structures at 25 m and 50 m in which the motion responses at 50 m are higher than the motion responses at 25 m. Although there are small differences on pitch motion with the presence of neighboring structures, there are slight motion responses between multiple bodies of offshore structure for the direction of wave at 180 degrees heading and it is proved there are hydrodynamic interactions between multiple bodies of offshore structures.

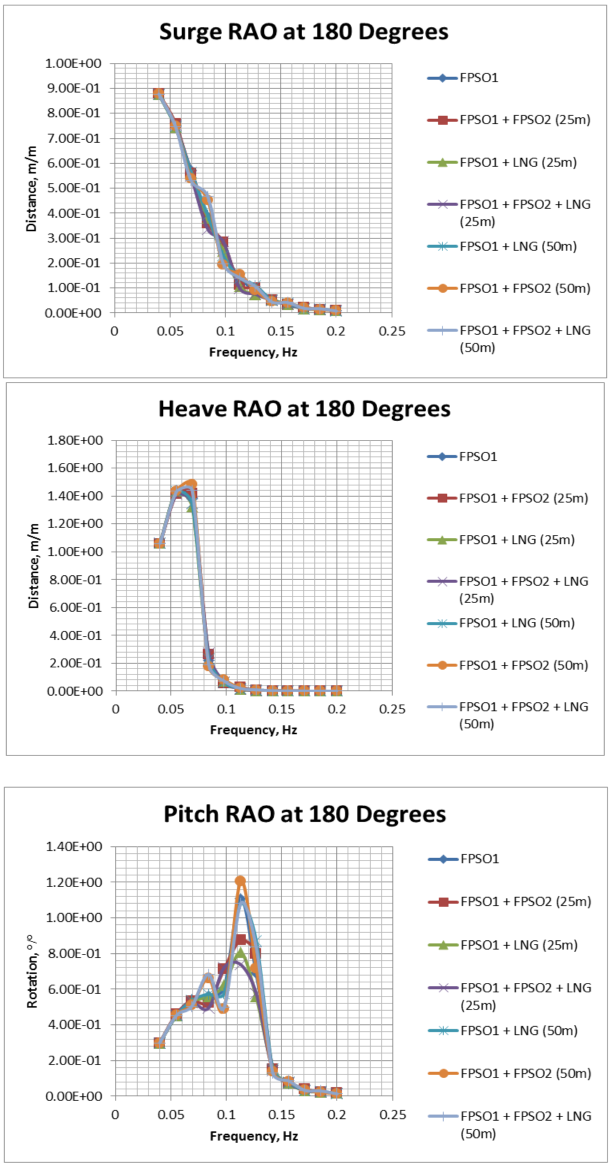


Figure 10 Surge, Heave and Pitch RAOs at 180 Degrees

5.0 CONCLUSION

Hydrodynamic interaction between three floating structures was simulated using ANSYS AQWA for five different heading angles as follows 0^0, 45^0, 90^0, 135^0 and 180^0 and two different gap distances which are 25 m and 50 m. The results show that added mass for heaving and pitching are larger compared to surging. More reactions have been experienced by the structures on surging since the radiation damping values obtained on surging are larger than the radiation damping values obtained on heave motion. Apart from that, the radiation damping for three bodies of offshore structures have the highest values to others especially at the gap distance 25 m due to the motion effects of two other structures experienced by one structure.

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