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Investigation of Influence of Mooring system in Response of FPSO

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ABSTRACT: FPSOs are useful in newly established offshore oil regions where there is no pipeline infrastructure in place, or in remote locations where building a pipeline is cost-prohibitive. In this study, hydrodynamic analysis of FPSO is inquired based Boundary Element Method (BEM) and wave forces/moments, added mass and damping coefficients of degrees of freedom are obtained by AQWA software. FPSO moored with mooring lines and developed a MATLAB code to calculate stiffness matrix. Then the responses of FPSO for three conditions, without mooring line, with three mooring lines and twelve mooring lines are illustrated. The results show that mooring system is effective in the reduction of surge response, but it has not major effect in increasing of heave and pitch responses.

Keywords: *FPSO; Hydrodynamic; Mooring lines; Hydrostatic stiffness*

INTRODUCTION

A Floating Production, Storage and Offloading (FPSO) unit is a floating vessel used by the offshore oil and gas industry for the production and processing of hydrocarbons, and for the storage of oil. A FPSO vessel is designed to receive hydrocarbons produced by itself or from nearby platforms or subsea template, process them, and store oil until it can be offloaded onto a tanker or, less frequently, transported through a pipeline. Floating production, storage and offloading vessels are particularly effective in remote or deep water locations, where seabed pipelines are not cost effective. FPSOs eliminate the need to lay expensive long-distance pipelines from the processing facility to an onshore terminal. This can provide an economically attractive solution for smaller oil fields, which can be exhausted in a few years and do not justify the expense of installing a pipeline. Furthermore, once the field is depleted, the FPSO can be moved to a new location (Investopedia, 2015). A Floating Storage and Offloading unit (FSO) is essentially a simplified FPSO, without the capability for oil or gas processing. Most FSOs are converted single hull supertankers.One of the major means of oil exploration at such locations isby way of Floating Production Storage and Offloading (FPSO) system. In deepwater offshore Nigeria for instance, a couple of FPSOs have so far been installed while many others are under various stages of design and construction. The most recent one, Akpo, which came on stream in 2008 operates at about 1700m water depth. More are still coming and the next in line is Usan and after it Egina (Ba, 2012). Ba and Chan presented the analysis of a coupled multi-component mooring/riser/FPSO system in ultra deepwater due to the first and second order wave induced motions in time-domain (Ba and Chan, 2011). Nuno Fonseca *et al* investigated the vertical motions and bending moments of an FPSO platform in regular waves. Also, they carried out an experimental program with a scaled model in a seakeeping tank. The experimental data was systematically compared with numerical results

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from a nonlinear time domain strip method in order to assess the capability of the method to estimate extreme vertical responses(Soares *et al.*, 2006). Guedes Soares et al presented an analysis of structural design wave loads on an FPSO. The vertical bending moment at mid-ship induced by rogue waves are compared with rule values (Fonseca *et al.*, 2010). Fonseca and Guedes studied the vertical motions and wave induced loads on ships with forward speed in the time domain. The method is based on a strip theory, using singularities distributed on the cross sections(Fonseca and Guedes, 1998).Wu *et al.* (2014) investigated the influence of the legs underwater on the hydrodynamic response of the multi-leg floating structure. Also, they studied the hydrodynamic responses of the structure in different cases numerically simulated by applying the three-dimensional potential theory (Wu *et al.*, 2014). Tabeshpoure and malayjerdi studied hydrodynamic analysis a TLP based on BEM theory. They carried both frequency and time domain analyses out and show that pitch motion can affect tendon tension severely in some wave periods (Tabeshpoure and malayjerdi, 2016). The effect of symmetric and asymmetric mooring configurations in terms of line azimuth angles on the platform responses is studiedby (Montasir *et al.*, 2015). Dongsheng et al investigated the global responses of an innovative deep draft platform using catenary, semi-taut,and taut mooring models, respectively (Dongsheng *et al.*, 2014).

MATERIALS AND METHODS

Governing Equations

In this paper, wave forces based on Boundary Element Method (BEM) are calculated. The fluid forces are calculated by integrating the pressure over the wetted surface of the body. By using from Bernoulli equation as follows:

$$p(t) + \rho\frac{\partial\varphi}{\partial t} + \frac{1}{2}\rho|\nabla\varphi|^2 + \rho gz = cte \qquad (1)$$

Where $p(t)$ is dynamic pressure, ρ is water density, φ is potential function and ρgz is hydrostatic pressure. Then by assuming that fluid is ideal and non-rotational we can derive dynamic pressure due to wave.

$$p(t) = -\rho\frac{\partial\varphi}{\partial t} \qquad (2)$$

Where φ is composed three components: incident, diffraction and radiation potentials. The total wave force is derived due to the incident and diffraction potentials. The wave forces are applied on floating body are found as follows:

$$\sum\vec{F} = \int_A p(t)\vec{n}\,dA + \vec{F}_h = \int_A -\rho\frac{\partial\varphi}{\partial t}\vec{n}dA + \vec{F}_h \qquad (3)$$

Where $\vec{F}$ is vector of the total force, $\vec{F}_h$ is hydrostatic force, n_{in} is a unit vector normal to the body surface and A is the wetted surface of the body in equilibrium position.The total moments of wave forces are estimated as follows:

$$\sum\vec{M} = \int_A \rho\frac{\partial\varphi}{\partial t}\vec{r}\times\vec{n}_{out}dA + \vec{M}_h \qquad (4)$$

Where $\vec{M}$ is moment vector, $\vec{r}$ is the place vector of element of body respect to the region, which is located in the center of flotation and $\vec{M}_h$ is hydrostatic moment vector.

The equations of motion of FPSO in frequency and time domains can be written as follows:

$$\sum_{i=1}^{6}\left[-\omega^2\left\{M_i + A_i(\omega)\right\} + i\,\omega C_i(\omega) + K_i\right]q_i(\omega)\,e^{i\omega t} = F_i(\omega) \qquad (12)$$

Where $[M_i]$, $[A_i(\omega)]$, $[K_i]$, and $[F_i(\omega)]$ are mass matrix, wave frequency, added mass matrix, damping matrix, stiffness matrix, displacement amplitude and wave force for every degree of freedom.

Case Study

The studied floating body is a FPSO that specifications given in Table 1:

Usually for catenary mooring system in deep waters, multi part catenary is used to avoid the cost. Therefore,in this study mooring line consists three parts, platform chain, wire rope and anchor chain. The properties of the mooring system used in numerical simulation are as follows:

Table 1: Propertices of FPSO

Draft		9 m
Weight		46 KN
Length		207 m
Width		37 m
Height		17 m
Center of gravity	X	109 m
	Z	8.5 m
Roll radius of gyration		13.6 m
Pitch radius of gyration		60 m
Yaw radius of gyration		62 m

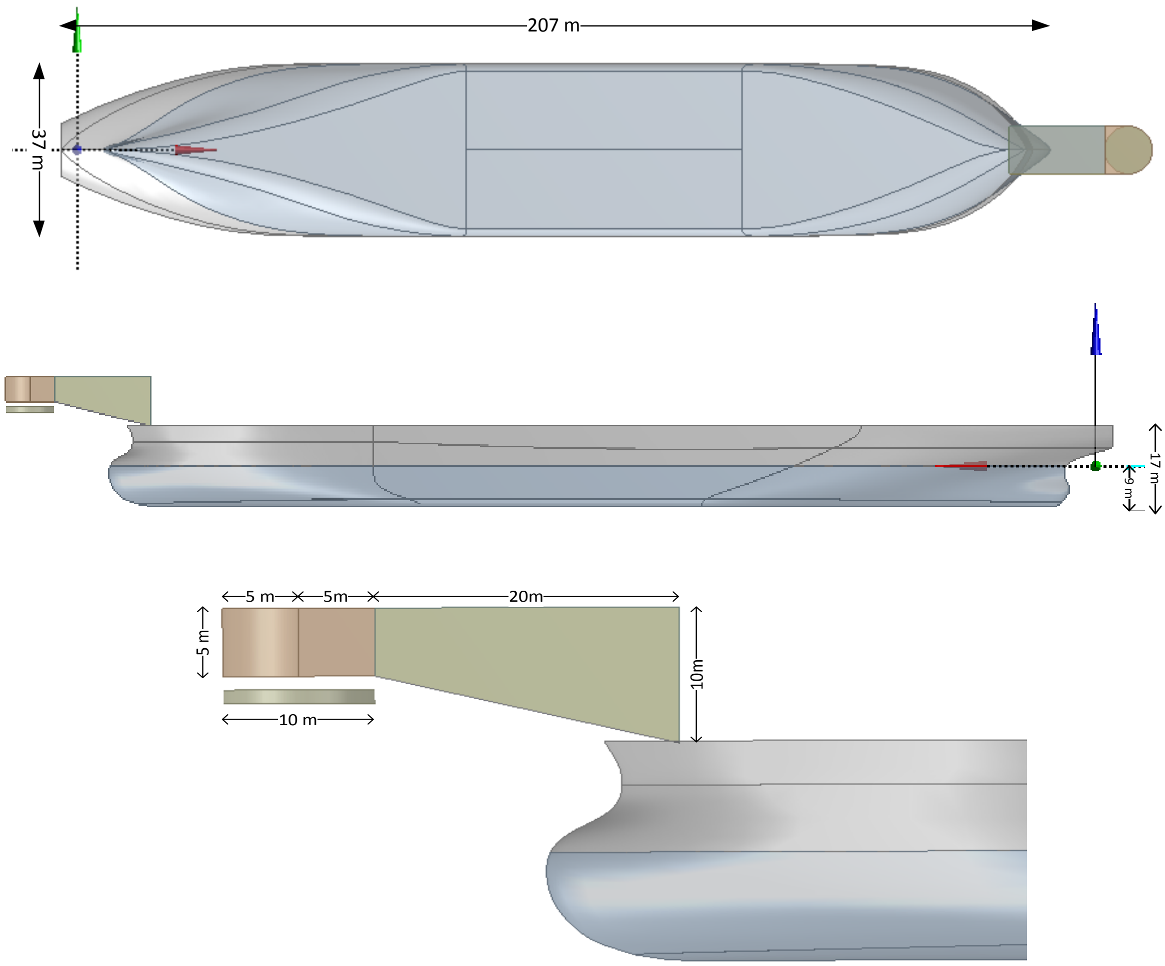


Fig. 1: Properties of FPSO used in numerical simulation

Table 2: properties of the mooring system used in numerical simulation

Designation	Platform chain	Wire rope	Anchor chain
Length	400 m	500 m	500 m
Weight in water	150 kg/m	120 kg/m	170 kg/m
Equivalent diameter	.2	.25	.2
EA	6 E+08	9 E+08	9 E+08
Equivalent cross section	.01 m^2	.01 m^2	.01 m^2

In this study, three load conditions for simulation are considered that are expressed as follows:

Load condition (LC1)	Free floating (without mooring system)
Load condition (LC2)	3 mooring lines
Load condition (LC3)	12 mooring lines

Fig.s 2 and 3 show mooring system configuration for when FPSO is moored with three and twelve lines respectively.

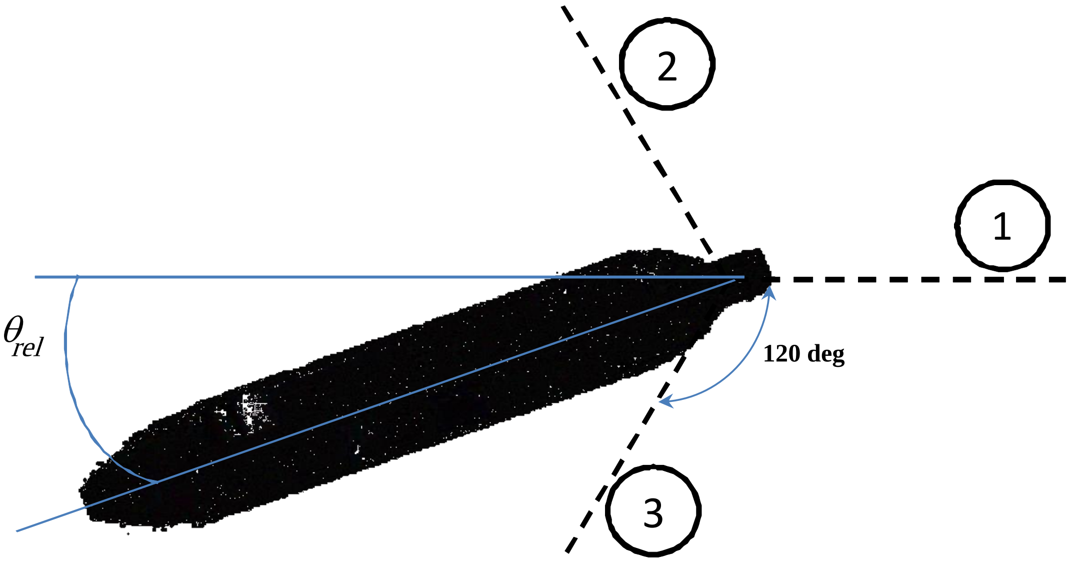


Fig. 2: Mooring system configuration (LC2).

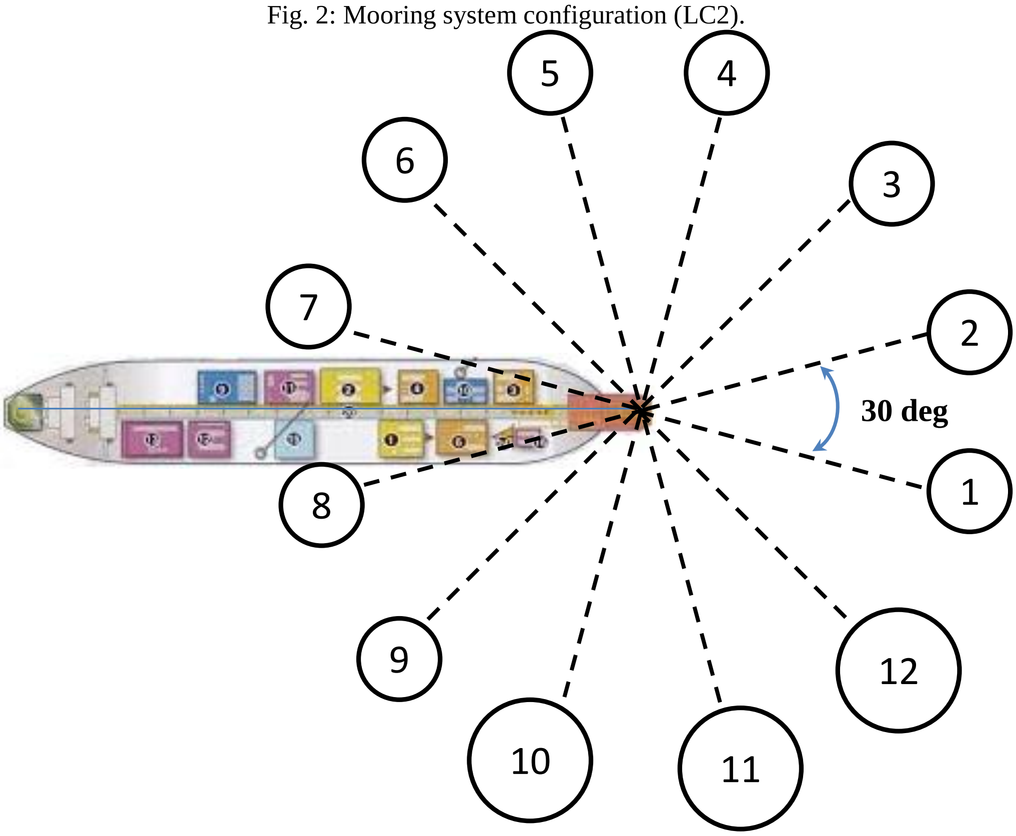


Fig. 3: Mooring system configuration (LC3).

RESULTS AND DISCUSSION

Numerical results

In this paper, the influence of mooring system in the behavior of FPSO is studied. In this section, the responses of surge, heave and pitch motions the FPSO under a irregular wave with incident angle 0 degree are investigated.The target incident wave for the numerical study in this paper is assumed JONSWAP for $H_S = 5m$.

Fig. 4 illustrates surge response of FPSO for LC1, LC2 and LC3. Fig. 5 shows max surge response for LC1, LC2 and LC3. The stiffness of surge for LC1, LC2 and LC3 is shown in Fig. 6. There is not the hydrostatic stiffness for surge. Therefore, by adding mooring system, surge response is decreased. It is seen that max surge response for LC3 is %30 smaller than for LC1 and the percentage of response decreasing for LC2 is %17. Therefore, when mooring system adds to FPSO, surge response is reduced. Also, FPSO has a heavy weight and is created a greateinertia force. Therefore, inertia force has a large portion in reduction of response.

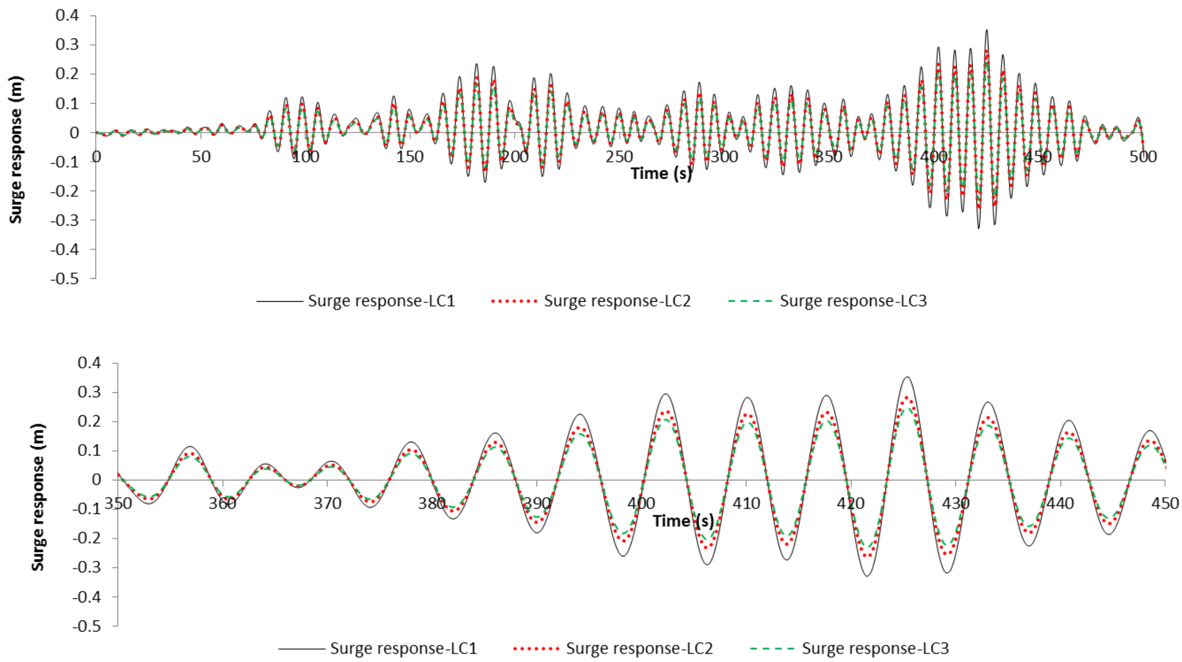


Fig. 4: Surge responses for LC1, LC2 and LC3.

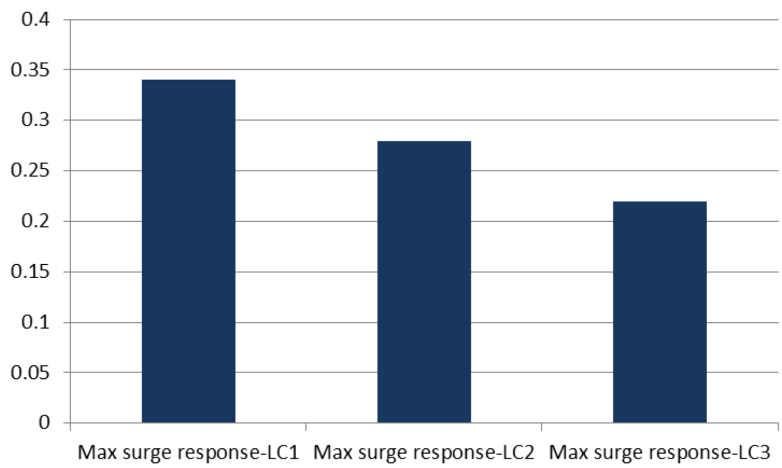


Fig. 5: Max response of surge for LC1, LC2 and LC3.

Fig. 7 illustrates heaveresponse of FPSO for LC1, LC2 and LC3. Fig. 8 shows max surge response for LC1, LC2 and LC3. The stiffness of heave for LC1, LC2 and LC3 is shown in Fig. 9. The stiffness of heave comprised of hydrostatic and mooring stiffness. The hydrostatic stiffness is very larger than mooring stiffness. From Fig. 7 it is clear that reduction of heave response is insignificant when FPSO moored with mooring system. Therefore, mooring system is not efficient for heave motion.

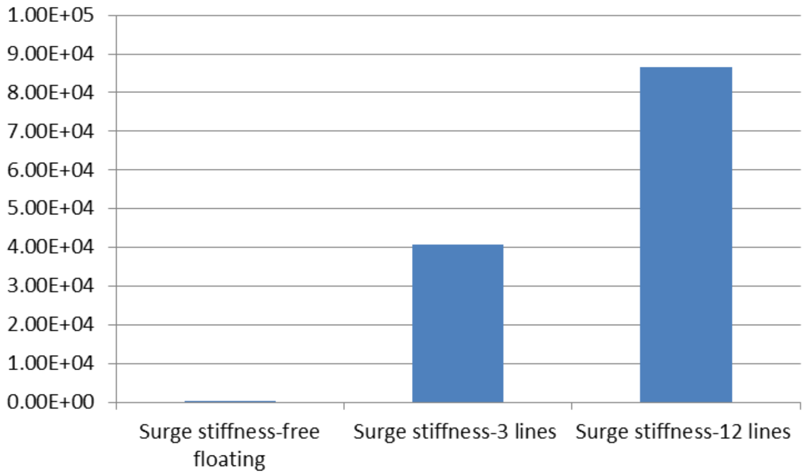


Fig. 6: Stiffness of surge for LC1, LC2 and LC3.

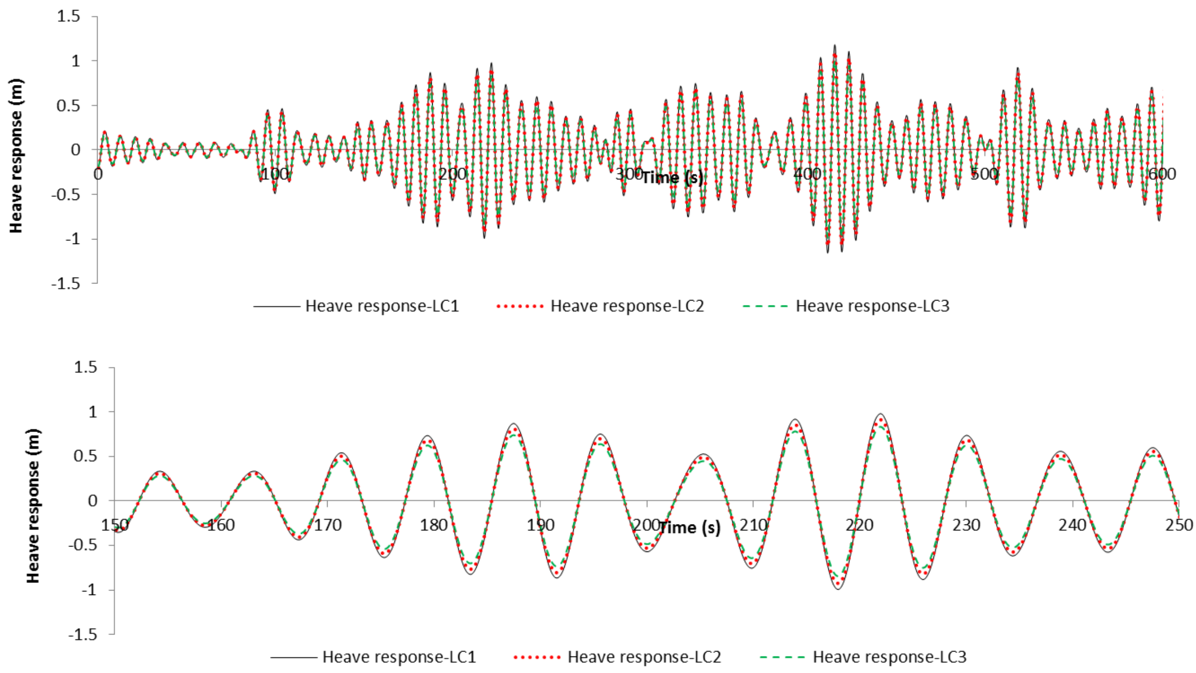


Fig. 7: Heave responses for LC1, LC2 and LC3.

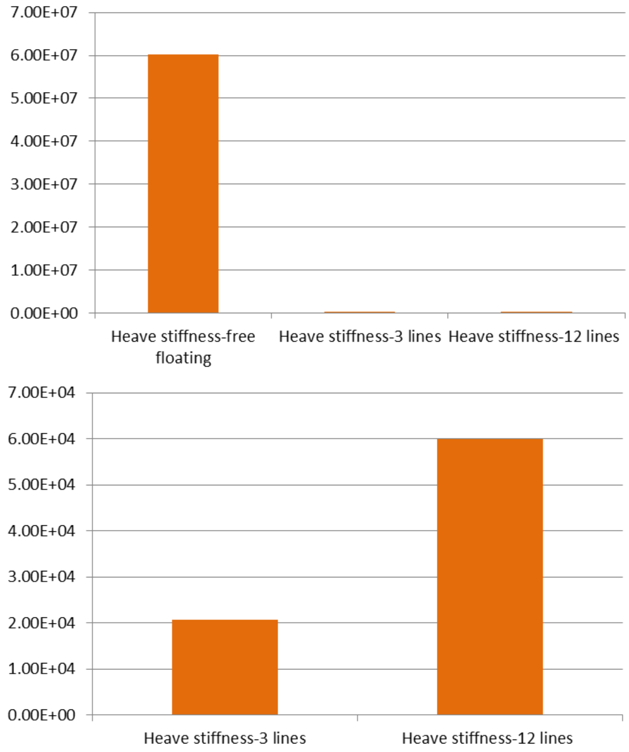


Fig. 8: Stiffness of heave for LC1, LC2 and LC3.

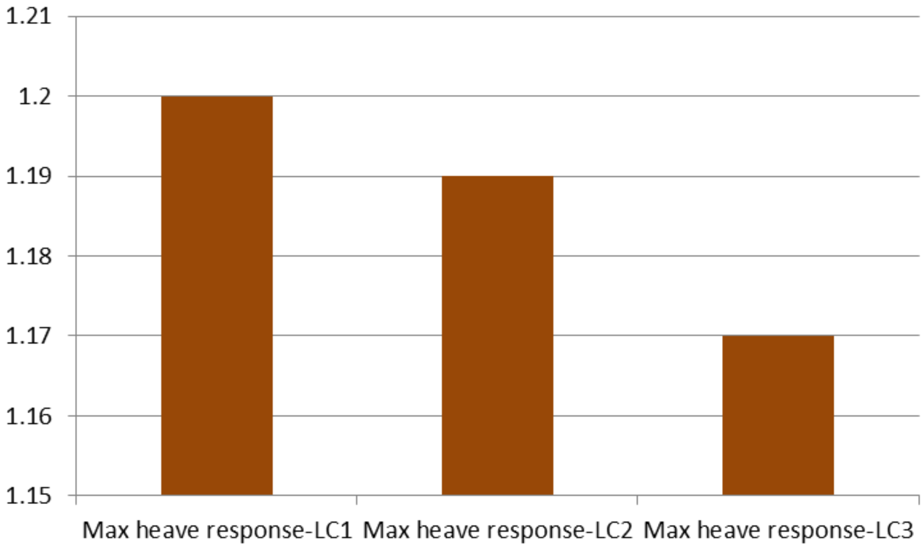


Fig. 9: Max response of heave for LC1, LC2 and LC3.

By comparing Fig.s 4 and 7, it can seen that heave response of FPSO is more than surge response because wave force of heave is very greater than surge (see Fig. 10).

Pitch response of FPSO for LC1, LC2 and LC3 are shown in Fig. 11. Fig. 12 illustrates pitch stiffness for LC1, LC2 and LC3. The hydrostatic stiffness of pitch is significant and mooring system is very smaller than hydrostatic stiffness. From Fig. 10, it can be seen that pitch response for LC1, LC2 and LC3 are approximately close.

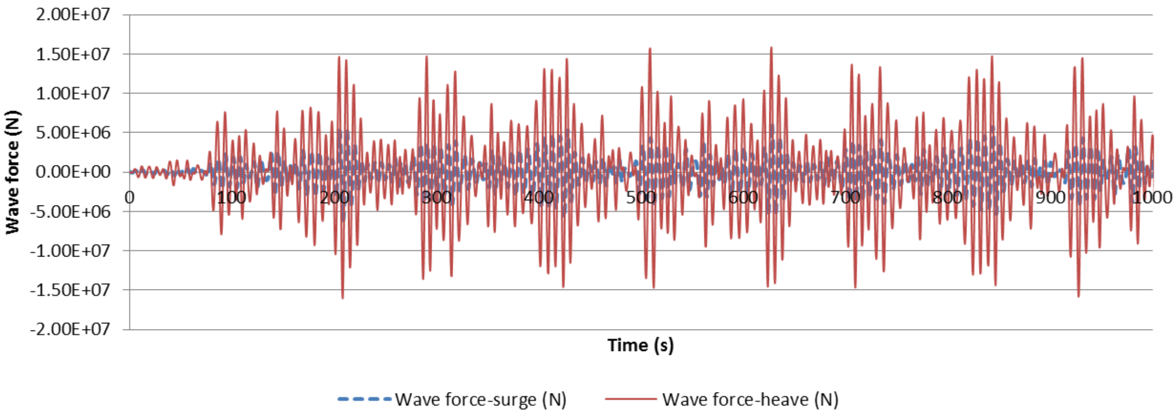


Fig. 10: Wave force of heave and surge.

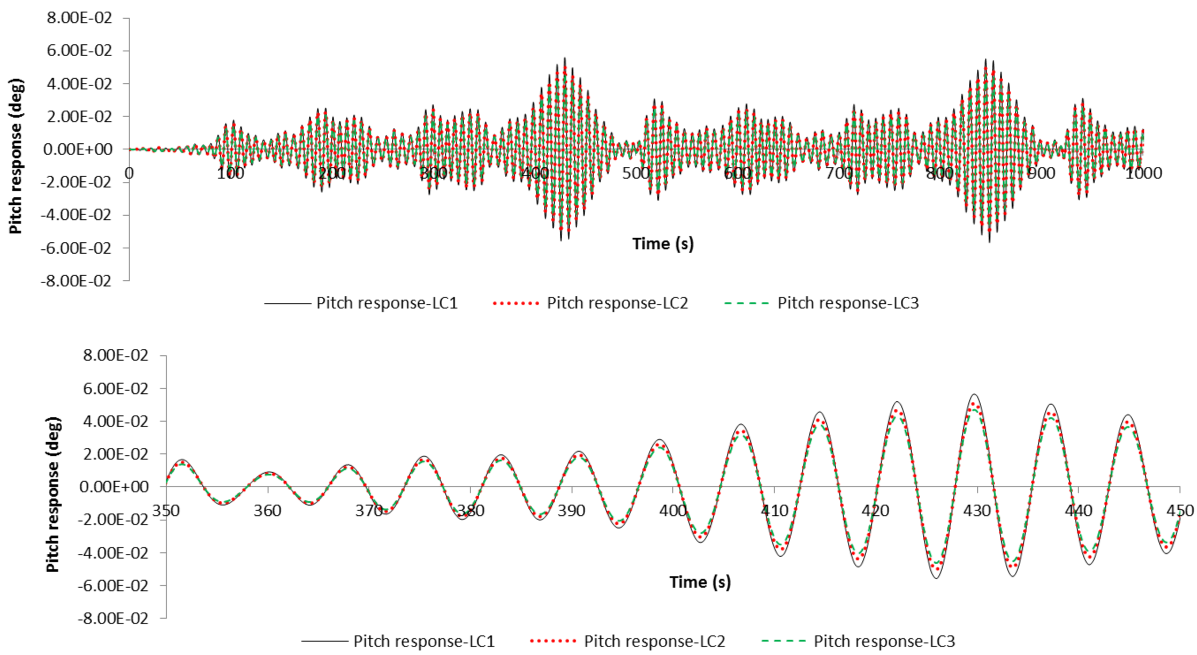
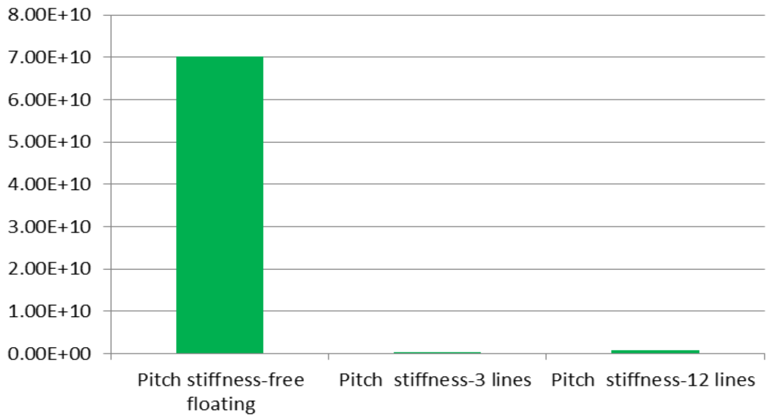


Fig. 11: Pitch responses for LC1, LC2 and LC3.

CONCLUSION

From the numerical results, some points are reported as follows:

- Heave response of FPSO due to a significant wave force is larger than surge response.
- There is not hydrostatic stiffness in surge. Therefore, when FPSO moored by mooring lines surge response is reduced.
- 12 mooring lines are more effective than 3 lines in reduction of surge response.
- The hydrostatic stiffness in heave and pitch motions is significant and lead that mooring system had a little effect to increase heave and pitch responses.
- FPSO is a heavy weight ship and created a large inertia force and it damped the responses.



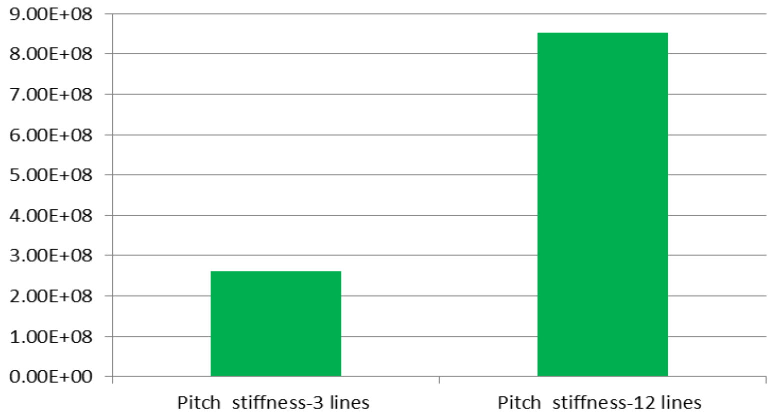


Fig. 12: Stiffness of pitch for LC1, LC2 and LC3.

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