Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (41) No. (3) July, 2019

Enhanced Stability for an Existing Fixed Jacket Type Offshore Platform

Ashraf M. Abou-Rayan[1], Mohamed D. Khedr[2], Nasr-Eldin Ahmed[3] and Mohamed E. Fayed[4]
[1]Department of Civil Engineering, Benha Faculty of Engineering, Benha University, Benha, Egypt.
[2, 3, 4]Department of Basic Science, Benha Faculty of Engineering, Benha University, Benha, Egypt.

الملخص

تم إجراء دراسة عددية لنموذج حقيقي من المنصات البحرية (الثابتة) الموجودة فى البحر الأحمر بجمهورية مصر العربية في مجال زمني للتحقق من الخصائص الديناميكية عن طريق تغيير معاملات الموجه (إرتفاع الموجة، فترة الموجة، إتجاه الموجة) حيث أن القوة الهيدروديناميكية تتضمن (الرياح، الموجة والمؤثرات الحالية على المنصه البحرية).

تم استخدام نظرية الموجة الخطية للحصول على النتائج المشتمله على الإزاحة والسرعة والعجلة فى مجال زمنى مع تغيير معاملات مختلفة للموجة. الهدف الرئيسي من الدراسة هو دراسة الاستجابة الديناميكية للنموذج الأصلى تحت موجات منتظمة وعشوائي.

Abstract:

A numerical study of a scaled real model is carried out in time domain to investigate the dynamic characteristics of an existing jacket offshore structure located in the red sea in Egypt. The hydrodynamic force includes wind, wave, and current effects on the structure. A parametric study is considered for multiple wave parameters (wave height, wave period and wave direction). Airy's linear wave theory is used, the results include displacement, velocity and acceleration in time domain with the different wave parameter. In this study, a numerical study were carried out for a two modified models (I, II) for the existing (in operation) fixed jacket type platform. The main objective of the study is to compare the dynamic response of the two modified models with the existing one under regular and random waves. Improvement of responses were observed as will be shown in the results.

Keywords: Dynamic Characteristics, Morison Equation, Wave Forces,

1. Introduction

The oil and gas industry have developed well over the last few decades. The offshore exploration began in the United States when Henry Williams began extracting oil from the Summerland field of the Californian coast near Santa Barbara in the 1890’s. Since the installation of the first platform in the Gulf of Mexico, the offshore industry has seen many innovative structures placed in deeper waters and more hostile environment. Slowly and gradually by 1975, structures were installed in water depths until 475 ft. (144m). By 1980s, the water depths increased significantly to more than 300m.

There are many previous studies that have studied the dynamic behavior of jacket type offshore structures under the influence of hydrodynamic forces. Elsayed et al. (2016), have investigated the probability of platform collapse due to abnormal level seismic loading was computed by using a finite-element reliability code. Zadeh et al. (2015), have investigated deformation of platform under combined waves, wind and ocean current flow loads. Offshore platform displacements, axial forces bending moments and free vibration frequencies were evaluated. The maximum displacement of all nodal points for wave and ocean currents with different angles of incidence was analyzed. The results show that different angles of sea currents have little impact on the response of the horizontal displacements; while the wave hit directions shows significant effects on the value of displacements response. Ishwarya et al. (2016), have investigated the Base shear and overturning moment values due to earthquake forces for jacket with soil condition are about 25% more in time history analysis than response spectrum method. Oluwole and Odunfa (2015), have investigated the overall response of the structure is sensitive to the frequency of the wave applied as stipulated in the governing equations. Wave characteristics represented by wave theories used in the present work have a smaller effect on behavior and response of the offshore platform.

Raheem (2013), has investigated the deflection of the platform is studied for individual and combined wind and wave forces. Offshore platform jacket displacement, axial forces, bending moments, and natural modes and frequencies of free vibration are evaluated. A comparison of the maximum displacement at all nodal points for various wave and current incidence angles is introduced. Bai and Teng (2013), have investigated the wave diffraction around a bottom-mounted cylinder and the wave radiation induced by a truncated cylinder under-going forced oscillations, the present numerical model can provide substantial second-order components, which contribute to the solution to second order. However, the calculated second-order component for the body in the forced heave motion is larger than the conventional frequency domain result when the nonlinearity is strong at higher frequencies; this is probably caused by the corner effect and the current numerical method is well able to handle this problem. Raheem et al. (2012), have investigated a significant effect of the current incidence direction. Both the maximum deck acceleration and the maximum Deck to top of jacket displacement were important response parameters affecting the performance of equipment, vessels, and pipelines. Ali et al. (2012), have investigated comparison between the results of forced vibration analysis that applied the periodic load to exciting force expressed by natural frequency results. Elshafey et al. (2009), have investigated the calculation of the dynamic response by the work of a real miniature model in the laboratory and was compared by finite element method and found a difference of not more than 13% in the value of the reaction force estimated from the strain measurements and the value which was obtained numerically. It was observed that the reaction at the foundation decreased as the mass of the model increased. This is consistent with the forced response of a single degree of freedom system. Terro and Abdel-Rohman (2007), have investigated a comparative study of estimated wave-induced forces using the linear and nonlinear Morison's equations in offshore structures. A parametric analysis has been conducted using a numerical computer model of an offshore structure. A modified form of the linear Morison's equation has been suggested to give better estimates of the nonlinear response of the structure than those observed when using the traditional linear model.

Abou-Rayan (1999) has studied the dynamic response of fixed type offshore structures. Haritos (2007), has investigated overview of some of the key factors that need be considered in the analysis and design of offshore structures. Reference has also been made to a number of publications in which further detail and extension of treatment can be explored by the interested reader. Jin et al. (2007), have investigated the effectiveness of cylinder Tuned liquid dampers (TLD) in controlling earthquake response of jacket platform. Meanwhile, TLDs are applied to CB32A oil tank platform to prove its feasibility. And the larger the mass ratio is the more effective the controlling earthquake response is. However, the cost will increase as well. It is economic for cost and effective for vibration reduction that the mass ratio ranges from 1% to 5%. Fayed et al. (2005), have investigated the general tendency of the value of the Damping Amplification Factor (DAF) is to be inversely proportional to the ratio between the wave period to the platform fundamental period. Onoufriou and Forbes (2001), have investigated the recent developments in the treatment of the resistance within system reliability analyses of fixed steel offshore platforms under extreme environmental loading. Assessment of existing jacket platforms under hydrodynamic forces has rarely been studied.

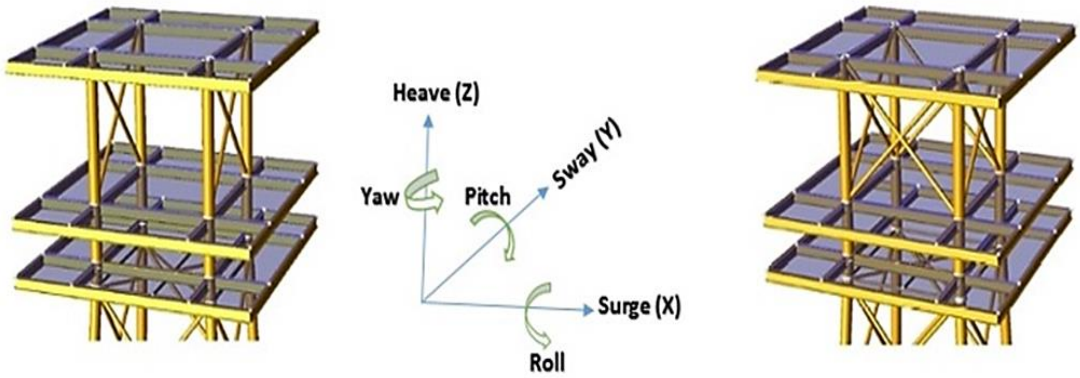
The main objective of this study is to propose different models (two models) for an existing fixed jacket offshore structure in red sea to enhance its stability, i.e. to reduce the responses in the six degrees of freedom which in return will enhance the platform stability. The environmental forces were taken as wind, regular waves and random waves in multi-direction ($0^0, 30^0, 45^0$ and90^0). Wind and regular wave properties were taken according to the meteorological data for the red sea (Egyptian Meteorological Authority). Random waves were generated according to pierson-moskowitz spectrum (Abou-Rayan and Hussein 2015). Finite element models were developed for the three configurations using SACS software. A numerical scheme was written using MATLAB program for computing the PSD'S.

2. Description of the jacket model

The platform considered in this study is a four-legged fixed type oil platform located in the central Gulf of Suez region (Egypt) and is part of an offshore production complex. It consists of a steel tubular space frame. The platform was originally designed/built in the 1970s as a four-pile platform installed in a water depth of $37.2\ m$. The topside structure consists of a helideck with square dimensions of $15.24 \times 15.24\ m$ at $16.46\ m$ height above the mean sea level (MSL). The production deck is located at an elevation of $7.92\ m$ above the MSL with square dimensions of $15.24 \times 15.24\ m$. There are diagonal brace members in both vertical and horizontal planes in the unit to enhance the structural stiffness. The jacket legs are horizontally braced with tubular members at four levels $(-33.5, -18.9, -7.01\ + 3.04\ m)$ as shown in Fig. 1 and Table 2. In the vertical direction, the jacket is X-braced with tubular members. The platform is permanently fixed on four piles driven to a penetration depth of about $64\ m$. Standard steel material A_{36} was used in the platform jacket fabrication. Steel density is $7800\ kg/m^3$, Young's modulus is $200\ GPa$, Poisson's ratio is 0.30, shear modulus is 79.3 GPa, yield strength is 250 MPa and ultimate tensile strength is $400\ MPa$. A global model of the platform was created using the SACS software. Platform leg members were modelled using beam elements whereas decks were modelled using plate and shell elements with longitudinal and transverse stiffeners. Fig. 1 shows a computer-generated three-dimensional (3D) view of the jacket platform model at a water depth of $37.2\ m$. The total weight of the platform is approximately $1053.06\ kg$, see Table 1.

Fig. 1 A 3D view of the original model platform.

In this study, two proposed modifications to the original model were considered to investigate responses reductions which will enhance stability of the model. Two types of bracing were proposed for the upper part of the structure (helideck). In the first model there are two bracing in the direction of YZ. In the second model there are four bracing in the direction of YZ and XZ, as shown in Fig. 2.



(a) Modified I (b) Modified II

Fig. 2 A 3D view of the proposed (modified) two models platform.

Table 1 Self-weight and functional loads for jacket platform.

No.	Load description	Weight (kg)
1	Jacket-generated dead weight	241.27
2	Topside-generated dead weight	85.49
3	Topside live loads	511.18
4	User-applied dead load (topside)	215.12
Total		1053.06

Table 2 Configuration properties.

Structure	Dimensions	Elevation (z) above MSL
Helideck	$15.24 \times 15.24\,m$	$16.46\,m$
Production deck	$15.24 \times 15.24\,m$	$7.92\,m$
Jackets legs	Outer diameter $D_o = 83.82\,cm$ Thickness $t = 2.54\,cm$	$-7.01\,m \leq z \leq +3.04\,m$
	Outer diameter $D_o = 83.82\,cm$ Thickness $t = 1.27\,cm$	$-33.5\,m \leq z \leq -7.01\,m$
Horizontal bracing	Outer diameter $D_o = 21.9\,cm$ Thickness $t = 0.81\,cm$	$+3.04\,m$
	Outer diameter $D_o = 27.3\,cm$ Thickness $t = 0.92\,cm$	$-7.01\,m$
	Outer diameter $D_o = 32.38\,cm$ Thickness $t = 0.95\,cm$	$-18.9\,m$
	Outer diameter $D_o = 35.56\,cm$ Thickness $t = 0.95\,cm$	$-33.5\,m$
Vertical X-bracing	Outer diameter $D_o = 32.38\,cm$ Thickness $t = 2.14\,cm$	$-7.01\,m \leq z \leq +3.04\,m$
	Outer diameter $D_o = 32.38\,cm$ Thickness $t = 0.95\,cm$	$-33.5\,m \leq z \leq -7.01\,m$
Piles	Outer diameter $D_o = 76.2\,cm$ Thickness $t = 3.17\,cm$	$64\,m$ penetration depth

3. Environmental condition

The environmental conditions were taken according to the Egyptian Meteorological Authority (EMA) from the available data for the red sea northern region. Where, the maximum conditions according to the EMA were as following: a) maximum wave height $= 5m$ maximum wind speed $= 10\ m/sec$. In this investigation the regular wave height were taken to be 8 m, wave period is 8 sec, constant wind velocity is 18 m/sec, the frequency of wave excitation $= 0.785\ rad\ /sec$ and current is $(0.5\ m/s, 1.5\ m/s)$ at elevation $(18.6m, 37.2m)$, respectively. It should be noted that, the wind velocity was taken in the direction of the wave. A regular wave forces were considered acting on multi-directions on the model configurations with wave heading angles $(0^o, 30^o, 45^o, 90^o)$ as shown in Fig. 3.

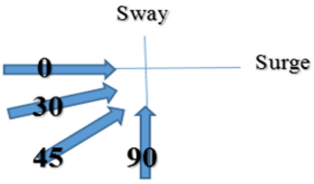


Fig. 3 A Multi-directional wave in degrees.

4. Results and discussions

Finite element models with a numerical scheme were developed to obtain the dynamic characteristics for the original model and the two proposed models (modified I and modified II). Since there are a numerous number of figures, only the essential ones are shown (the response pattern for $180^0\ WHA$ is the same for $0^0\ WHA$, also for $45^0\ WHA$ has the same response pattern as for $135^0\ WHA$ for all DOF'S). Also, because of the structural type (fixed), responses stiff in the roll, pitch, yaw and heave (DOF'S) are very small so, they are not shown. It should be mentioned that time histories shown are only for a portion of the steady state responses (stationary responses) and results are shown for the helideck of the structure.

4.1 Natural vibration analysis

Eigenvector analysis determines the un-damped free vibration mode shapes and frequencies of the system. These natural modes provide an excellent insight into the behaviour of the structure. They can also be used as the basis for response-spectrum or time-history analyses, although Ritz vectors are recommended for this purpose. Eigenvector analysis involves the solution of the generalized eigenvalue problem as shown in Table 3.

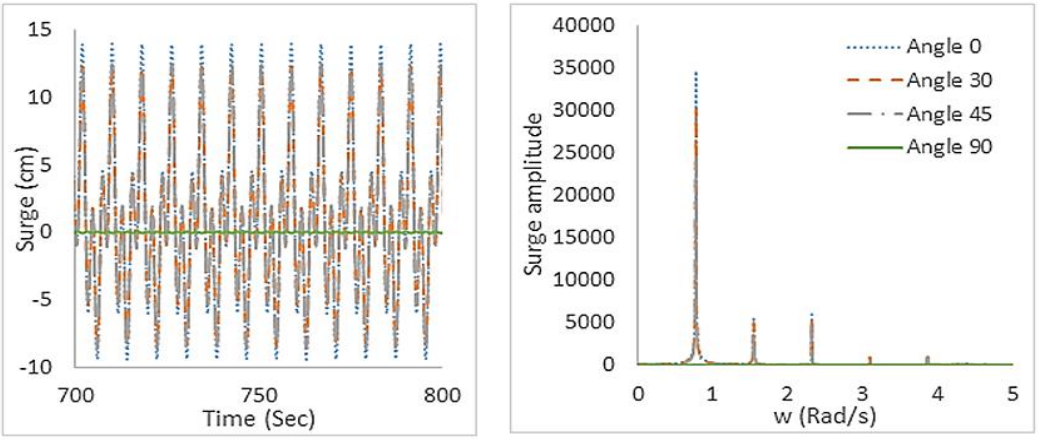
4.2 Surge response

The surge responses of the original model is shown in Fig. 4 for the purpose of comparison. Time histories and Power spectrum densities (PSD'S) are shown in Fig. 5 and Fig. 6 for the two proposed models for responses under regular waves. From Fig. 5(a) and Fig. 6(a), it is clear that maximum responses are for the $0^o\ WHA$. The responses have decrease when the WHA increased $(30^0, 45^0$ and $90^0)$ with about the same response differences as before $(20\%, 33\%$ and $45\%)$. Also, the surge response dies out for the case of $WHA = 90^o$ while the sway response reaches its maximum value. It is clear that, for the modified model I the response are less than the original model for all wave directions by about 50%, whereas for the modified model II by about 75%. For all cases, it is clear from the PSD that the response has a semi-periodic pattern with period bifurcation of order three and max peak response at the wave excitation frequency $= 0.785\ rad/sec$, see Fig. 5(b) and Fig. 6(b). Moreover, it is observed that, increasing the WHA decreases the surge response and giving raise to the sway response to a limit where both are almost equal in amplitude magnitude(case of $WHA = 45^o$), which is expected.

Time histories response and Power spectrum densities (PSD'S) are shown in Fig. 7 and Fig. 8 (only for the two modified models are shown) for$(0^0, 30^0, 45^0$ and $90^0)$ under random waves. All responses have a maximum frequency peak at almost half the excitation frequency. In general, the two modified models have the same response patterns (i.e. quantitatively) as those due to regular waves. Except that responses in the case of random waves are defiantly chaotic in nature as it is seen from figures. It is obvious the PSD'S have multiple frequency responses contributions coming from almost all degrees of freedom.

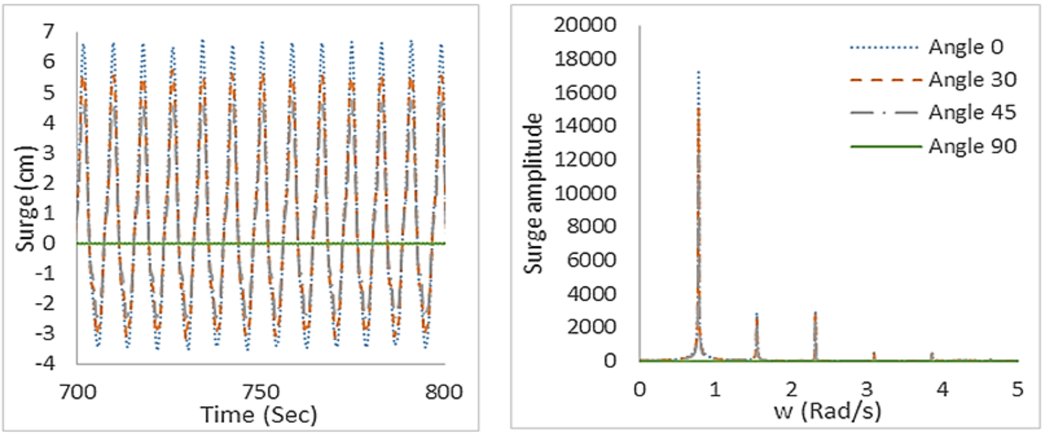
Table 3 First six mode frequencies of the platform.

Mode	Original Model		2 Side Bracing (Model I)		4 Side Bracing (Model II)	
	Frequency HZ	Period Sec	Frequency HZ	Period Sec	Frequency HZ	Period Sec
1	0.392	2.550	0.686	1.457	0.815	1.226
2	0.392	2.550	0.814	1.228	0.818	1.226
3	0.411	2.430	0.885	1.130	0.914	1.094
4	0.941	1.062	1.676	0.597	3.284	0.304
5	0.986	1.015	2.859	0.350	3.487	0.287
6	1.003	0.977	3.262	0.307	3.939	0.254



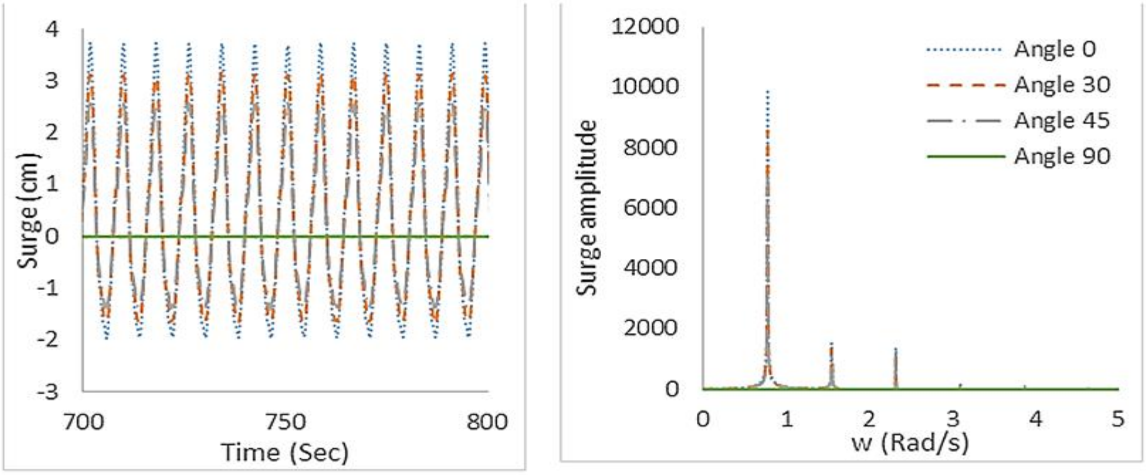
(a) Time history (b) Power spectrum density

Fig. 4 Regular surge response of original model.



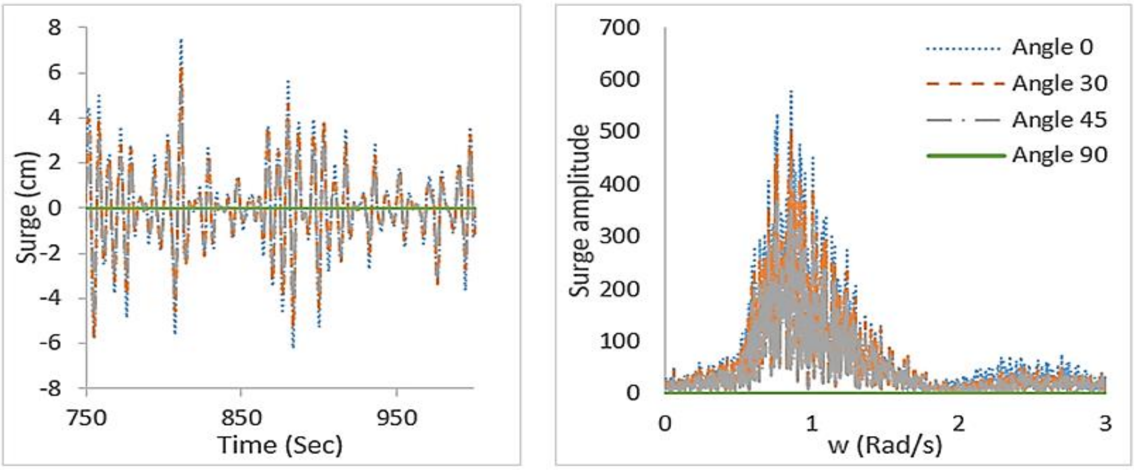
(a) Time history (b) Power spectrum density

Fig. 5 Regular surge response of modified I.



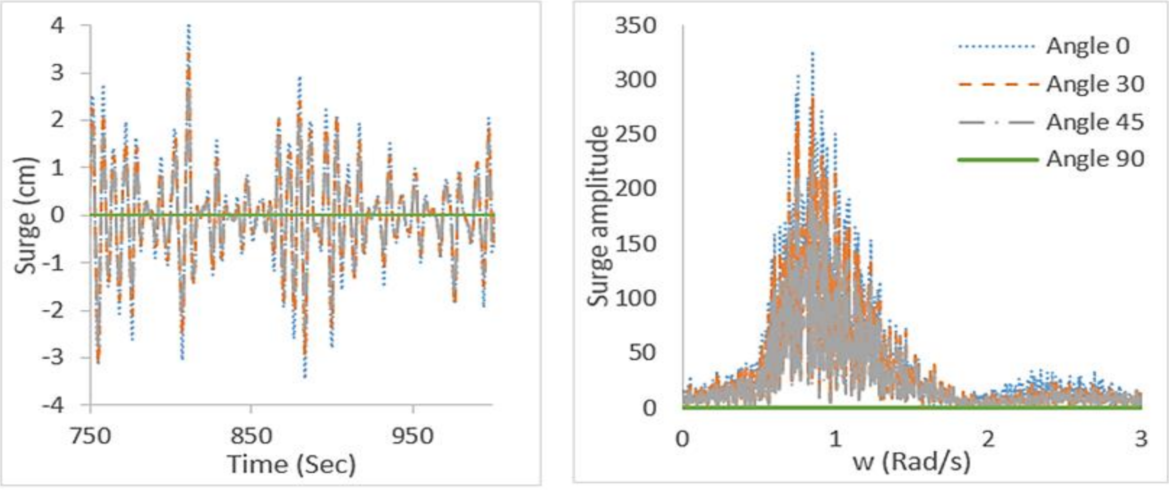
(a) Time history (b) Power spectrum density

Fig. 6 Regular surge response of modified II.



(a) Time history (b) Power spectrum density

Fig. 7 Random surge response of modified I.

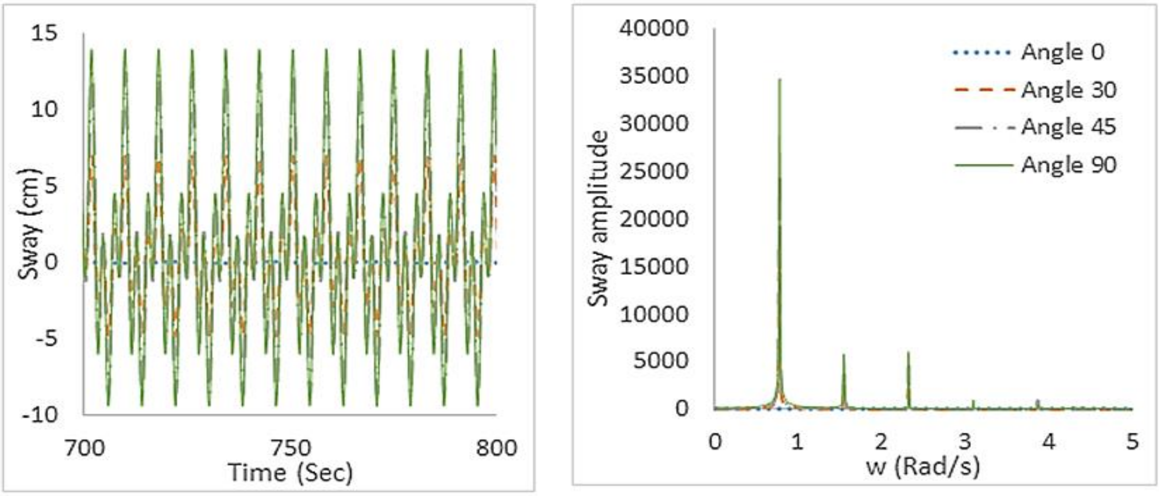


(a) Time history (b) Power spectrum density

Fig. 8 Random surge response of modified II.

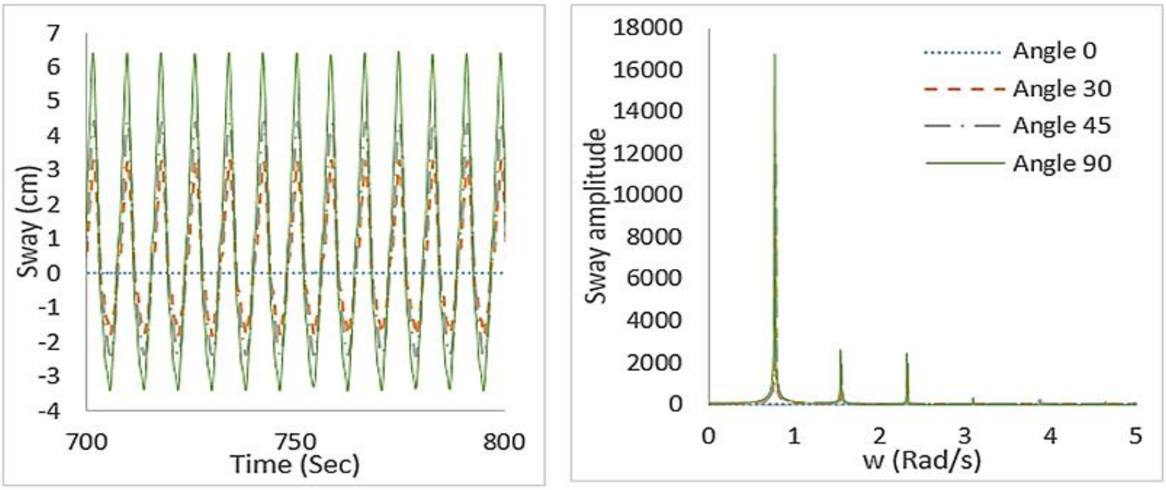
4.3 Sway response

The same behavior patterns, for regular and random waves, as in the surge response are observed but in a reverse order, see Figs. 10-13 (show responses under regular waves only with (WHA 0^o,30^o, 45^o and 90^o). It is noticed that, increasing the WHA activates the response in the sway direction from almost from zero to $7\ cm$ and $4\ cm$ for the modified I and modified II respectively (due to regular waves). Also, the sway response dies out for the case of $WHA = 0^o$ while the surge response reaches its maximum value (contrary to the case of $WHA = 90^o$). Again, for all cases, it is clear from the PSD that the response has max peak response at the wave excitation frequency = 0.785 rad/sec, see Fig. 10(b) and Fig. 11(b).



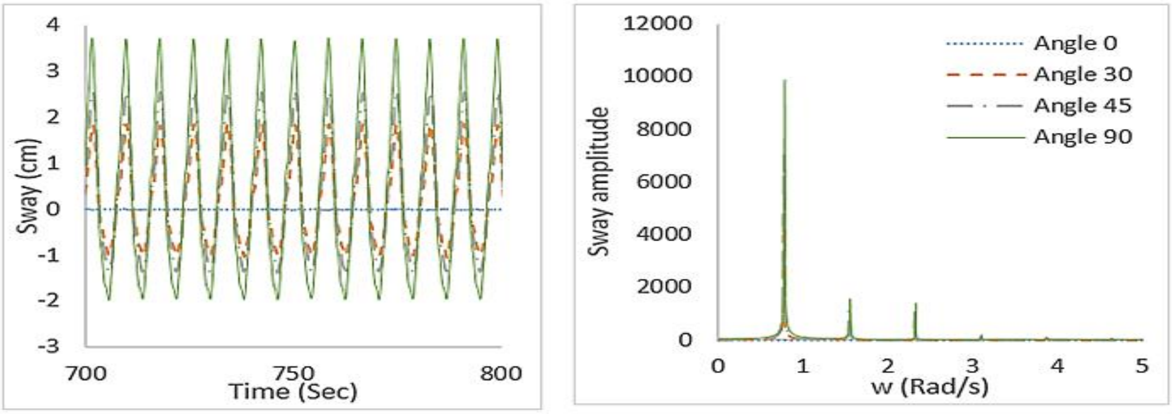
(a) Time history (b) Power spectrum density

Fig. 9 Regular sway response of original model.



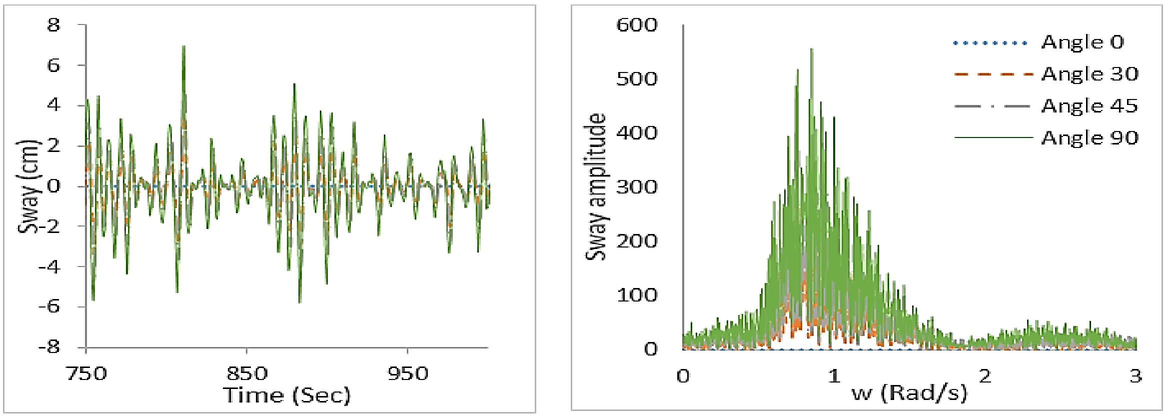
(a) Time history (b) Power spectrum density

Fig. 10 Regular sway response of modified I.



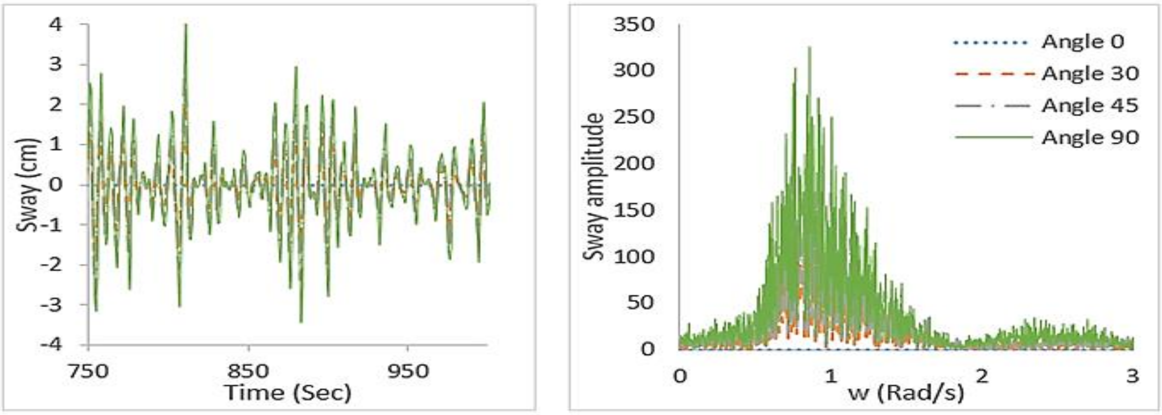
(a) Time history (b) Power spectrum density

Fig. 11 Regular sway response of modified II.



(a) Time history (b) Power spectrum density

Fig. 12 Random sway response of modified I.



(a) Time history (b) Power spectrum density

Fig. 13 Random sway response of modified II.

5. Conclusions

In this investigation, the main purpose is to determine the dynamic characteristics of two modified models for an existing jacket type offshore platform structure under the influence of hydrodynamic forces to enhance its stability. Wave's excitation, regular and random were considered acting on multi-direction and different wave parameters were considered.

Based on the aforementioned results and discussions, the following conclusions can be drawn.

- It is observed that the original model gives high responses in comparison with the two modified models.
- It was observed that dynamic response increases in modified I than modified II at the same wave height, wave period and wave angle**.** Also, responses in surge have decreased when the WHA increased $(30^0, 45^0 \text{and } 90^0)$ with about $(20\%, 33\% \text{ and } 45\%)$, respectively.
- It is observed that the maximum peak for PSD was found to be at the wave excitation frequency which is logic and expected.
- Responses in yaw, pitch and roll are very small because of the structure type.

From the above conclusion it obvious the proposed modification for the existing jacket type platform, have enhanced the stability of the platform with much less responses, especially for proposed model II.

References

Abou-Rayan, A. (1999). "Dynamic Response of Offshore Structures Due to Hydrodynamic Forces", *Civil Engineering Research Magazine*, Al-Aazhar University 21(2), 335-344.

Abou-Rayan, M. A. and S. O. Hussein (2015). "Influence of wave approach angle on square tlp's behavior in random sea", *Proceedings of the 2015 world congress*, ASEM15, Incheon, Korea, August.

Ali, A. A. M., A. Al-kadhimi and M. Shaker. (2012). "Dynamic behavior of jacket type offshore structure", *jordan journal of civil engineering* 6(4), 418-435.

Bai, W. and B. Teng. (2013). “Simulation of second-order wave interaction with fixed and floating structures in time domain”, *ocean engineering* 74, 168-177.

Elsayed, T., M. El-shaib and k. Gbr. (2016). “Reliability of fixed offshore jacket platform against earthquake collapse”, *ships and offshore structures* 11(2), 167-181.

Elshafey, A. A., M. R. Haddara and H. Marzouk. (2009). “Dynamic response of offshore jacket structures under random loads”, *marine structures* 22(3), 504-521.

Fayed, S., M. Zidan and M. Harb. (2005). “Dynamic response of fixed offshore structures under environmental loads”, *Eleventh international colloquium on structural and geotechnical engineering*.

Haritos, N. (2007). “Introduction to the analysis and design of offshore structures–an overview”, *electronic journal of structural engineering* 7(Special Issue: Loading on Structures), 55-65

Ishwarya, S., M. Arockiasamy and R. Senthil. (2016). “Inelastic nonlinear pushover analysis of fixed jacket-type offshore platform with different bracing systems considering soil-structure interaction”, *journal of shipping and ocean engineering* 6, 241-254.

Jin, Q., X. Li, N. Sun, J. Zhou and J. Guan. (2007). “Experimental and numerical study on tuned liquid dampers for controlling earthquake response of jacket offshore platform”, *marine structures* 20(4), 238-254.

Oluwole, L. And A. Odunfa. (2015). “Investigating the effect of ocean waves on gravity based offshore platform using finite element analysis software ansys”, *int. J. Sci. Eng. Res* 6(8), 24-33.

Onoufriou, T. And V. Forbes. (2001). “Developments in structural system reliability assessments of fixed steel offshore platforms”, *reliability engineering & system safety* 71(2), 189-199.

Raheem, S. E. A. (2013). “Nonlinear response of fixed jacket offshore platform under structural and wave loads”. *coupled syst*, Mech 2(1), 111-126.

Raheem, S. E. A., E. M. A. Aal, A. G. A. Shafy and F. K. A. Seed. (2012). “Nonlinear analysis of offshore structures under wave loadings”, *Proceedings of the 15th world conference on earthquake engineering* (15wcee).

Terro, M. J. and M. Abdel-rohman. (2007). “Wave induced forces in offshore structures using linear and nonlinear forms of morison's equation”, *journal of vibration and control* 13(2), 139-157.

Zadeh, S. M. G., R. S. Baghdar and S. M. S. V. K. Olia. (2015). “Finite element numerical method for nonlinear interaction response analysis of offshore jacket affected by environment marine forces”, *open journal of marine science* 5(04), 422.