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Finite Element Analysis of Offshore Jacket Affected by Marine Forces

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ABSTRACT
Design requirements for offshore marine platform subjected to forces and moments caused by wave can play a major role in offshore structures design. A good estimate of wave loads is necessary for economical and reliable design. In this paper we analyze the linear response of a fixed offshore platform under the wave forces. This structure is created based on finite element discretization method and wave and modeled current flow kinematic created using linear Airytheory. Wave force acting on the elements is calculated using Morison equation. Hydrodynamic loads on horizontal and vertical tubular members and the dynamic response of offshore fixed platform with coupled with distribution of displacement, axial force, and bending moment along the base of the platform for regular and severe cases have been investigated. The structure must be able to maintain production in a one-year wave return period condition and also to be able to continue with the hundred-year storm return period. The results of this study showed that bending moment values with a one-year wave return period condition for the base platform and junction of platform to deck are 51 percent and 4 percent, respectively more than bending moment with a one-year wave return period. The direction of wave hit has significant effects on the shift platform response, also linear response is important for the safe design and operation of offshore.
Keywords: *Finite element method, Fixed jacket platform, Linear response of structure, Wave-structure interaction*

INTRODUCTION

The total number of offshore platforms in the Gulfs and oceans throughout the worldsis increasing year by year. More of these platforms are of jacket platforms types installed in water depths of 32 meters to 200 meters for exploration of oil and gas. Analysis, design and installation of offshore structures compatible with the environmental conditions are of the most challenging and innovative works in this area. Offshore jacket platforms are typically designed using offshore structures standard. Main standards include (API RP2A WSD, 2000), (API RP2A LRFD, 1993) and (ISO 19902, 2007). Nonlinear static analysis, i.e. the Pushoveranalysis is widely used in offshore standards such as API, ISO and DNV to study the nonlinear behavior and the final capacity of offshore platforms against the sea loads. In the method, the corresponding load pattern evenly increases until the collapse of the structure on the jacket platform installed on the site under marine environment affected by special loads, for example, the (wave return period of 100 years). Chakarabarti & Tam (1975) conducted some studies on the effect of different wave's patterns on offshore structures [1]. Hallam et al (1978) presented studies on offshore structures under the action of the wave's effects [2]. Chakarabarti (1987) carried out studies in the field of nonlinear hydrodynamic forces and their effects on the nonlinear response by platforms [3]. Barltrop & Adams (1991) presented studies on designing reliable offshore structures under the action of the waves [4]. Abel-Rohman (1996) made studies on the dynamic response of a steel jacket platform with an effective specific activity and control under the wave's load [5]. Suneja & Datta (1998) presented the effect of an active control system for a jacket platform under wave loading [6]. Venkataramana, et al (1998) analyzed the time domain of dynamic response of simplified offshore structures under the concurrent effects of accidental loads and seismic wave [7]. Kawano & Venkataramana (1999) studied dynamic response reliability analysis of offshore structures under the effects of marine waves, ocean currents and earthquakes [8]. Eicher, et al. (2003) undertook studies on the analysis of wave effects such as wave loads and the corresponding responses of structures as well as the construction of fixed offshore structures [9].

Mahadik & Jangid (2003) conducted studies on the response of jacket platforms with active mass dampers under the force of the waves [10]. Chakarabarti (2005) did studies in the field of loading, response and design of jacket platforms [11]. Takewaki et al (2011) showed the effects of seismic estimates on coastal and offshore structures according to the most recent earthquakes [12]. In this paper, linear analysis is formulated for reliable assessment of the response of jacket platform under constant loads and wave structure. A three-dimensional finite element model is used to estimate the displacement and stress in steel platforms under combined loads of structural and waves. This analysis includes a variety of linear properties produced due to changes in the linear drag force. The structures are discredited using finite element method. Wave and current flow kinematicare generated by the Airylinear theory. The effect of wave forces on members is calculated by Morison formula. Numerical results were studied at various load compositions. Natural periods and modes of the system are calculated. Wave kinematic is a very important factor due to the interaction between structures and waves. Wave induced loads on fixed offshore platform under the sea storms is calculated using a nonlinear drag term in Morrison equation and changes in wave height. Moreover, the fixed jacket platform response under the ultimate structural loads is a function of the behavior of components in the range of linear deformations.

The environmental loads

The water force can be classified into waves force and the current flow force. The wind blows over the ocean moves the water causing the current flow and the waves. Ocean waves force on the platforms is dynamic and natural, although the static design of platforms in shallow waters is also acceptable. With increasing waters depth, the platforms are flexible with more dynamic effects.

Current flow forces: Wave leads to the orbital motion of the water. The orbital motion in a closed cycle, but slightly drive forward due to surface wind effect. Current flow isgenerated by the wave. The current flow in a wave tends to drag wavelength. The induced current flow force on the cylindrical structure is defined as follows [13]:

$$F_D = C_D \frac{\rho}{2} A U^2 \quad (1)$$

In this equation, F_D, C_D, ρ, A, and U, are the drag force in KN, drag coefficient, sea water density per ton per cubic meter,cross section depicted in terms of square meter and current flow rate in meters per second, respectively. The flow rate is usually between 0.1 and 2.3 meters per second. Profiles of sea currents in the Gulf of Mexico are shown according to the API [14] in (Figure 1).

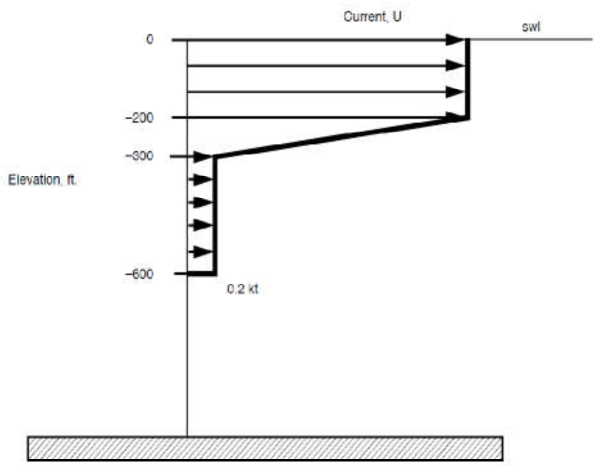


Figure 1 Sea currents profile in the Mexican Gulf

Wave forces: The regular wave theories are used to calculate the forces on fixed offshore structures, illustrated in Figure 2, and based on the three parameters of water depth (d), wave height (H) and wave period (T), respectively [13].

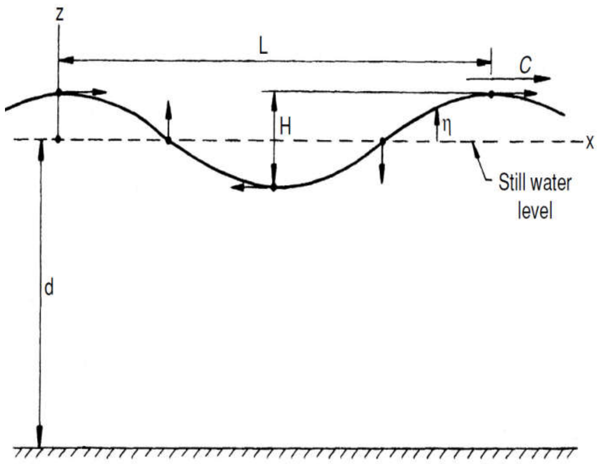


Figure 2 Wave parameters profiles

Hydrodynamic force vector is calculated in all degrees of freedom. The intensity of the wave force on each meter of the structure is calculated based on Morison formula shown in Equation 2, [13].

$$F = \rho C_m V \frac{du}{dt} + \frac{1}{2}\rho C_d A u|u| \quad (2)$$

Where, F, C_m, u, du/dt, and V are total force exerted on an object, the coefficient of inertia, current flow rate, current flow acceleration and object size, respectively.

Platform structural model

The studied platform in this paper is a fixed jacket platform that had been designed and proposed for installation in Venezuela Gulf in 1977 [15]. The platform is composed of 8 bases made of hollow cylindrical steel. Outside diameter of vertical, horizontal and diagonal elements are 1.8, 1 and 0.5 meter, respectively; and the thickness of vertical, horizontal and diagonal elements are 2.5, 1.55 and 1.1 centimeter, respectively. In order to meet the hardness requirements on platform, cross bracing was used on both sides of the bases. Also, platform height is 57.5 meter with sea water density of 1.0252 tons per cubic meter. To simplify the model, platform, all deck loads were model in one story. Steel profile used in this platform is shown in the table below:

Table 1 Properties of Mechanical steel used in the platform

Mechanical Properties	Value	Unit
Specific weight	7850	Kg/m^3
Elastic Modulus	2.1×10^9	Kg/m^2
Shear modulus	8.077×10^8	Kg/m^2
Yield stress	360	MPa
Ultimate tensile stress	420	MPa

The platform finite element analysis

Finite element analysis of platform is performed under various wave loads. Structural model is focused on a detailed description of the deformation properties of the column loads. These platform columns are modeled by equivalent beams. For the present analysis, the dead weight of all fixed equipment located on the deck of 7.25 ton/m^2 and a live load objects on deck of 0.3ton/m^2 is taken. This platform has been installed in water depth of 54.5 meters. C_d and C_m parameters were considered equal to 0.65 and 1.6, respectively according to API regulation. A one- year and 100-year wave parameters are shown in Table 2. Wind speed of 1 and 100 years of 85 and 100 (Knot) were considered according to API regulation.

Table 2 wave parameters

Definitions	Water depth (m)	Wave height (m)	Wave period (s)
Wave with a return period of 1 year of operation	54.5	10	7.2
Wave with a return period of 100 years for safety		16	10.6

Figure 3 depicts two-dimensional and three-dimensional view of the platform model. Columns 1 and 2 are considered to analyze the platform. Also,the Nodes a_0, a_1, a_2, a_3 and $a_4$are considered to show displacement and stress on the columns.

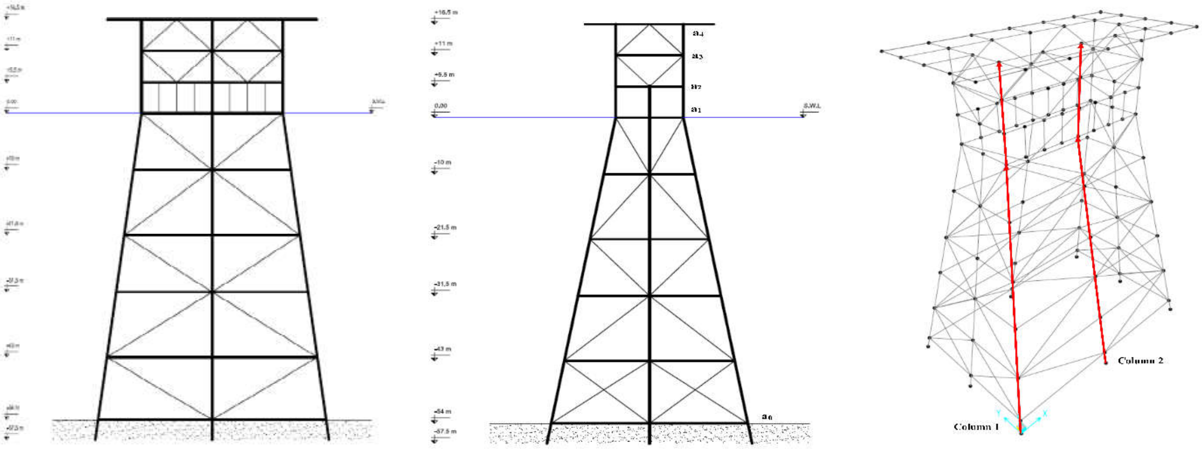


Figure 3 three-dimensional and two-dimensional view of modeled platform from different views

Marine wave parameters and current flow directions of±0º, ±45º, ±90º, ±135º and ±180º intended for the analysis of these platforms. 11 different load cases have been shown for analysis at this platform (Table 3) [16].

Table 3. Loading combinations

Loading combination	Description	Loading combination	Description
Load 1	DL+LL	Load 7	DL+LL+$(W_a)_{100yr}$+W_a/ C_u 0º
Load 2	DL+LL+$(W_a)_{1yr}$+W_a/ C_u 0º	Reload 8	DL+LL+$(W_a)_{100yr}$+W_a/ C_u 45º
Load 3	DL+LL+$(W_a)_{1yr}$+W_a/ C_u 45º	Reload 9	DL+LL+$(W_a)_{100yr}$+W_a/ C_u 90º
Load 4	DL+LL+$(W_a)_{1yr}$+W_a/ C_u 90º	Loading 10	DL+LL+$(W_a)_{100yr}$+W_a/ C_u 135º
Load 5	DL+LL+$(W_a)_{1yr}$+W_a/ C_u 135º	Loading 11	DL+LL+$(W_a)_{100yr}$+W_a/ C_u 180º
Load 6	DL+LL+$(W_a)_{1yr}$+W_a/ C_u 180º		

In the above table DL, LL, W_a and C_u, represent dead load, live load, wave load and sea current load, respectively.

Numerical results

For more effective and accurate design, a finite element model to estimate the internal forces and columns displacements of offshore platform under structural loads and the waves were evaluated. Structural vertical loadsare actually static loads, whereas the lateral wave is in oscillation in the time domain directly linked with the angle of the incident wave. The model used in this research is a steel platform proposed in 1977 to the Gulf of Venezuela. Three-dimensional finite element model of the platform is designed in SAP2000 software. Second hand parts such as ladders, stairs and so forth are not directly modeledand only the weight effects are applied. Z axis in a Cartesian system is in the direction of water depth. Fixed end boundary condition is located at 3.5-meter mud line/seabed along with the bases (depth 57 m). Natural periods and related vibration modes shapes are analyzed by Eigen values. Table 4 shows12 vibrating modes of the platform.

Table (4) natural periods of offshore platform

Mode No.	Period (s)	Mode No.	Period (s)	Mode No.	Period (s)
1	0.332	5	0.208	9	0.129
2	0.269	6	0.191	10	0.122
3	0.243	7	0.150	11	0.104
4	0.211	8	0.142	12	0.104

Structure displacement response: In order to better understand the behavior of fixed offshore platform, the analysis of these platforms in water to a depth of 54.5 meters under the sea waves and currents were studied. Maximum deformations under mentioned loads have been precisely calculated. deformations responses of U_1, U_2 and U_{abs} (which represents the absolute horizontal displacement is equal to the square root of the sum of squares U_1 and U_2) and is depicted in the following figures in line with platform height under the action of waves loads and sea currents with return period of 1 year (operating conditions) and 100 year (extreme conditions/ storm). U_1, U_2 deformation are in X and Y directions, respectively**.**

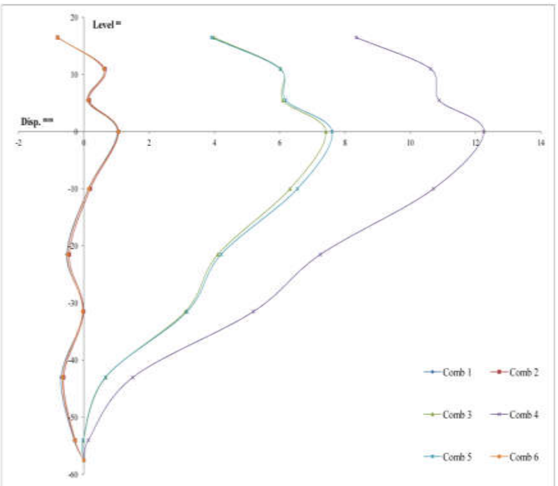


Figure 5 Column 1 displacements in the Y direction with 1 year wave wave

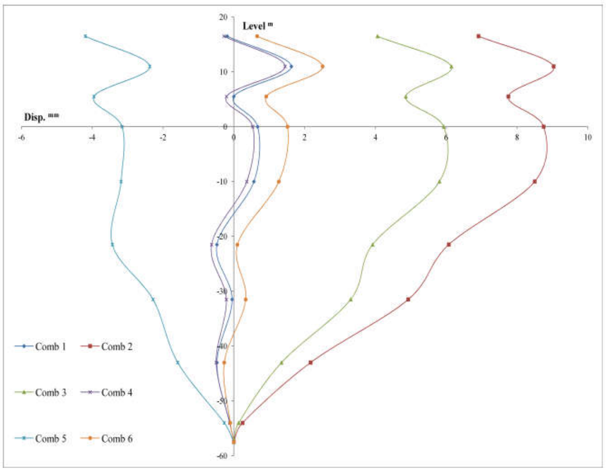


Figure 4. Column 1 displacements in the X direction with 1 year

For operating conditions of platform**,** based on (Figure 4), with increasing angle of the wave hits and sea current angle from zero to 90, platform displacements is reduced and increasing angles from 90 to 180 degrees platform displacements is increased**,** so that the angle of zero degrees shows the maximum displacement and 90 degrees exhibits the minimumdisplacement in the X direction**.**According to Figure 5, this condition is contrary for the Y direction with angle of 90 degree showing the maximum displacement and the minimum displacement are with zero and 180 degrees angle.

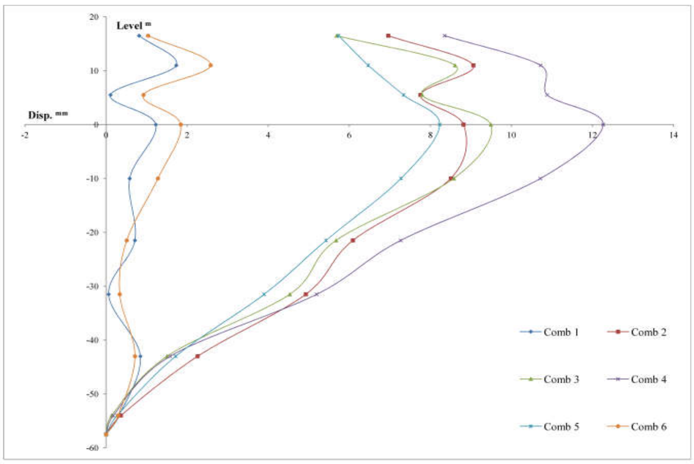


Figure (6) Column 1 absolute displacement with a 1 year wave

As Figure 6 illustrates hits with 90 degree angle create the maximum displacement, while hits with 180 degree angle create the minimum displacement. The average value displacement difference for a 1 year wave of combination number 4(maximum absolute displacement) and combination number 6(minimum absolute displacement) is at about 8 percent.

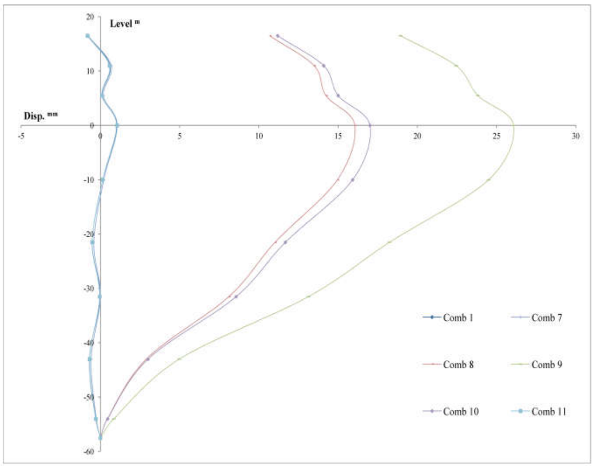


Figure 8 Column 1 displacements in the Y direction with 100 year wave wave

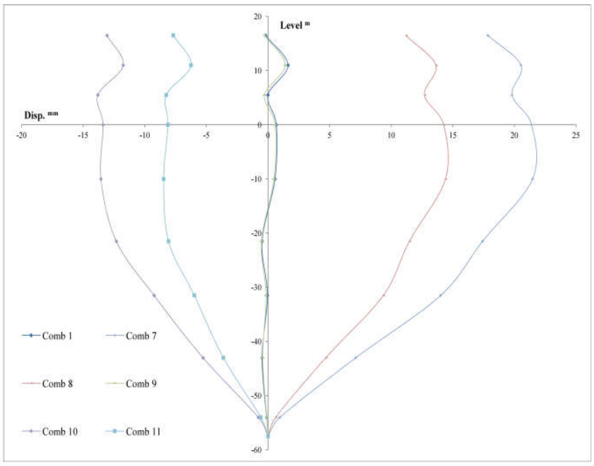


Figure 7 Column 1 displacements in the X direction with 100 year

To take advantage of the platform (Figure 7) the angle of zero degrees shows the maximum displacement and the angle of 90 degrees, the minimum displacement in the X direction. According to Figure 8, this situation is contrary for the Y direction with angle of 90 degree showing the maximum displacement and the minimum displacement is with zero degrees angle.

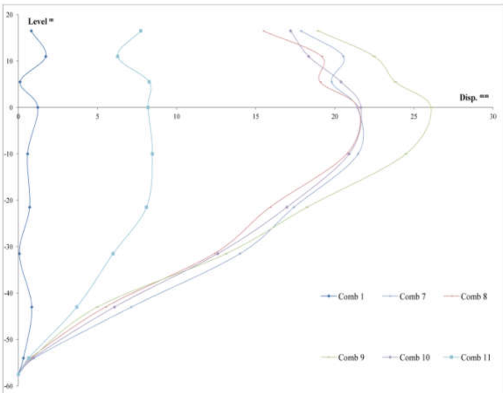


Figure (9) Column 1 absolute displacement with a 100 year wave

As shown in Figure 9 hits with 90 degree angle create the maximum displacement, while hits with 180 degree angle create the minimum displacement. The average value displacement difference for a 100 year wave of combination number 9 (maximum absolute displacement) and combination number 11 (minimum absolute displacement) is at about 3 percent.(Figures 10 and 11), that respectively, indicates that the maximum displacement at a_1 (still water level) and a_4 (junction between deck and jacket) are under the combined effect of all the loads.

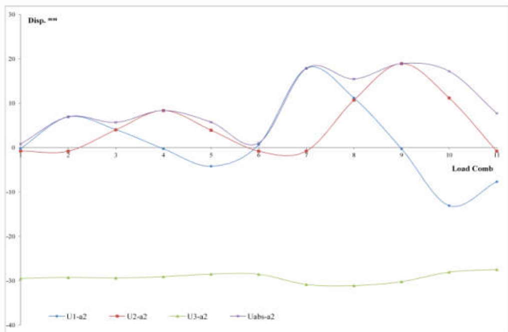


Figure (10), Column 1 displacement frequency for $a_1$level

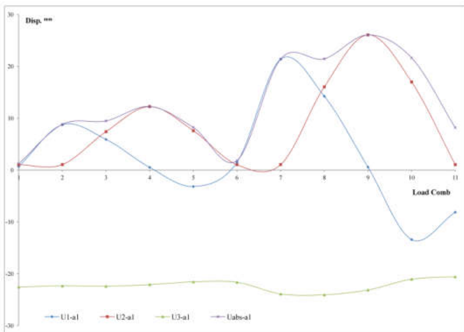


Figure (11), Column 1 displacement frequency for a_2 level

As the figure suggests, by changing the operating mode to a severe state, column 1 displacement becomes more. The average displacement value for the node $a_1$in two modes of 1 and 100 years with the same wave and sea current hit anglesis about 33 percent and for the node $a_4$this difference is about 39 percent.

Axial forces and bending moments Responses: Figure 12 shows the maximum bending moment at the critical points of the pillars of the platform. Maximum values of the bending moment are at the end of the platform base and in connection with the seabed. As shown, in both operational and windy states, with increasing angle of the wave and the sea current hit, the bending moment is reduced. The average value of bending moment for two states of 1 and 100 years with the same wave hit angles and sea currents is at about 49 percent. Also, Figures 13 and 15 show the bending moment $M_{2\text{-}2}$, $M_{3\text{-}3}$ and absolute levels of a_0 to $a_3$levels. The values for the bending moments of a_1 to $a_3$levels are almost uniformly and changes in hit angles of the wave and sea currents have little effect on the bending.

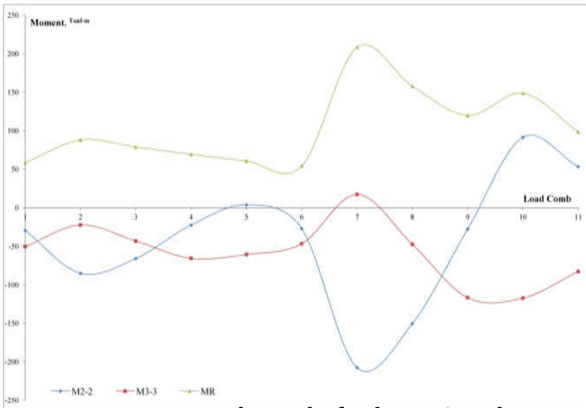


Figure (12) A bending moment response at the end of column 1 with various combinations of loads

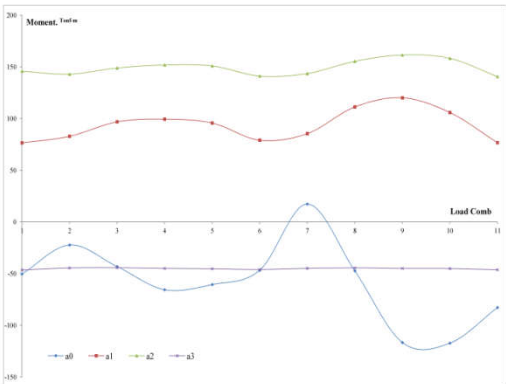


Figure (14) Column 1 flexural $M_{3\text{-}3}$ for different levels

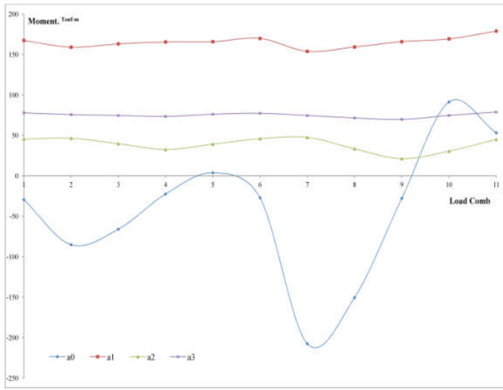
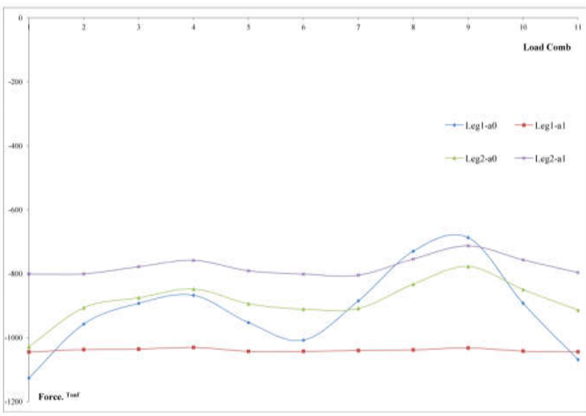


Figure (13) Column 1 flexural $M_{2\text{-}2}$ for different levels



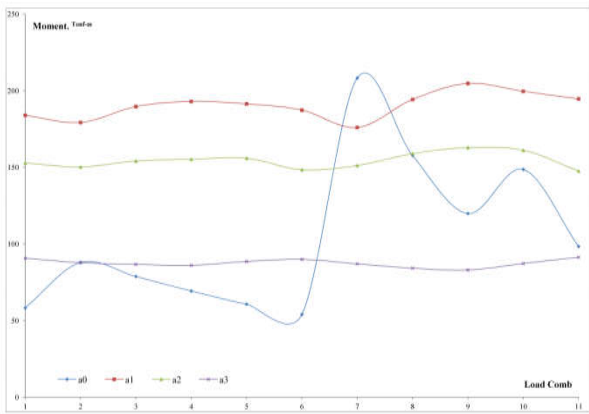


Figure (16) columns 1 and 2 axial force for a_0 and $a_1$levels Figure (15) column 1 absolute flexural for different levels

Figure 16 shows the maximum axial force at critical levels in line with the height of the jacket platform structure. It is important in the design of a platform bases that the maximum axial force to be estimated, because the thickness of the base platform can be reduced with respect to the maximum stresses.

CONCLUSION

Designing effective and affordable offshore platforms largely depends on the proper evaluation of the responses hit during the useful life of the structures.However, the performance of the platform in various operations in bad weather requires that the entire structure is designed to meet the final condition. The design depends on the site of the platform. It is important that the response of the offshore platform to reduce according to environmental loads. In general, offshore structures dynamic stress range reduction to about 15 percent leads to double increase of the service life and thus reduced the maintenance costs. Periodic and regular inspections of offshore platforms to issue the certificates assurances require studying the structural response according to wave forces. In this study a finite element formulation is developed to study the linear response of offshore fixed platform in which a three dimensional element including large-scale displacements and the time-dependent wave forces. Structural offshore analysis has been conducted in order to obtain a platforms shift response under different loads. Deformation of platform under combined waves loads and ocean current flow was investigated. 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 showed that different angles of sea currents have little impact on the response of the horizontal displacements; while the wave hit directions showed significant effects on the value of displacements response. Displacements response U_1 increases nonlinearly with increasing platform height, but a significant curvature in displacements response $U_2$is observed in the height of the platform. The results show that the wave-current flow direction showed little effect on the wave bending moment in a one-year return period, while sea current flow impact direction has a significant effect on the amount and direction of the bending moment. The wave bending moment with a return period of 100 years for the a_0 (the base of the platform) and a_1 (junction platform deck) are respectively 51 percent and 4 percent higher than the wave bending moment with a return period of 1 year.

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