Journal of Research in Ecology

An International Scientific Research Journal

Journal of Research in Ecology

Original Research

The use of cable elements with different arrangements in offshore fixed platforms

Authors:
Hossein Moghadaszadeh Naghibi[1], Morteza Naghipoor[2] and Mehdi Hamidi[3]

Institution:
1. MSc, Hydraulic Structures, Babol Noshirvani University of Technology, Babol, Iran

2. PhD, Assistant Professor, Faculty Member of Babol Noshirvani University of Technology, Babol, Iran

3. PhD, Associate Professor, Faculty Member of Babol Noshirvani University of Technology, Babol, Iran

Corresponding author:
Hossein Moghadaszadeh Naghibi

ABSTRACT:

Today, offshore platforms are installed for the extraction and exploitation of hydrocarbon reservoirs. The cyclical waves are the most important environmental loads exerted on offshore platforms that have a random nature. The actual behavior of the structure under the force, and normal or hurricane circumstances is of particular importance. The aim of this study was to evaluate the use of cable elements with different arrangements in offshore fixed platforms. Therefore, in this paper, ANSYS 14 software is used to analyze fixed offshore structures. The platform studied in this research is located in the Persian Gulf. The results of this study indicated that the use of cable elements on offshore fixed platforms, lead to the integration in platform flours and if a proper combination is used, it can reduce the structural motions in all directions (X, Y, and Z).

Keywords:

Cyclical wave, force, Cable elements, fixed offshore structures

Email Id:
hoseinmoghadaszade95@gmail.com

Web Address:
http://ecologyresearch.info/documents/EC0180.pdf

Article Citation:
Hossein Moghadaszadeh Naghibi, Morteza Naghipoor and Mehdi Hamidi
The use of cable elements with different arrangements in offshore fixed platforms
Journal of Research in Ecology (2017) 5(1): 473 –485

Dates:
Received: 05 Nov 2016 **Accepted:** 09 Nov 2016 **Published:** 28 Feb 2017

INTRODUCTION

Much of the installed offshore platforms are used in order to extract and exploit hydrocarbon reservoirs. In many cases, the absence of sufficient strength of structural components and fittings against environmental loads applied to the structure reduces the life of these type of structures, and in some cases, irreversible damages are incurred. On the other hand, due to the placement of these structures in the marine environment, the replacement and repair of damaged components are so hard and costly. The most important environmental loads acting on offshore platforms are the cyclical waves that are random in nature. The actual behavior of the structure under the force, under normal or hurricane circumstances are of particular importance (Winkel and Smith, 2009). In an earthquake, a lot of force is loaded on the platform jacket. However, earthquakes can bring larger waves, that the force of waves and earthquakes on the platform can cause many lateral shifts in jackets and platform, which large ones may cause serious damage and even destruction. Due to the sensitivity mentioned, many researchers have investigated this, and numerous stages such as the use of diagonal members, and the use of shape memory alloys in offshore fixed platforms, to confront and withstand the enormous forces by the jacket, have been offered (Sætre, 2013). When the waves and the earthquake hit the fixed platform, a lateral shift will be occurred in the platform. The wave hydrodynamics is calculated using Airy wave theory and Morison equation and the earthquake force is obtained and imported to the software by previous recorded accelerograms. In this vein, the aim of this paper is touse of cable elements with different arrangements in fixed rigs offshore.

Sea waves

In a general category, capillary waves can be formed due to surface tensions caused by the wind, gravity waves, rotation of the Earth, and sidereal waves. Waves may be periodic; i.e. the movement pattern and surface profiles are repeated at equal intervals. Waves that move progressively towards a fixed point are progressive, and the motion direction of a wave is in the progress direction. Standing wave are the waves which just go up and down. The motion of water particles in a wave period, if the path is closed or almost closed, will form an alternative or almost an alternative wave (Sætre, 2013; Umeyama, 2012).

The theory of sea waves

In this section, we briefly discuss about the classic theory of waves that are usually used in the calculation of wave forces on offshore structures. In an overall view, the theory of surface sea waves is categorized in two general categories viz., linear and nonlinear. Because of the simplicity in calculations, and to perform initial estimate for platforms, usually linear theory is used in the everyday tasks of engineering. However, in certain circumstances, we are forced to use non-linear theory, which is described below (Lighthill, 1965). In order to define the main parameters of the wave theory, consider sine wave. The highest wave height is called wave peaks, and the lowest point is trough. The distance between two peaks or two troughs (a full cycle wave) is measured in wavelength (λ), and is the time interval (T) between two specific points (Figure 1). In other words, it's the time that the wave passes a full cycle. Horizontal central axis is the level of standing water. Thus, in the first moment (t = 0), height of the each point is a function of the horizontal distance, and is expressed as the harmonic function given below (Lighthill, 1965).

$$\eta_i{=}0 = A \cos kx \qquad (1)$$

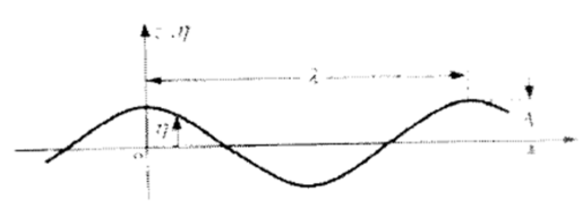

Figure 1. Sine wave

In this equation, A indicates the wave magnitude and K is a wave constant that is calculated by the wavelength as follows:

$$k = \frac{2\pi}{\lambda} \quad (2)$$

Generalized equation for a harmonic progressive wave with the speed of C, in the positive direction of the x axis is as follows:

$$(x,t) = A \cos k(x - ct)\eta \quad (3)$$

By defining the parameters of angular frequency ω, as the number of rotations (in radians) in a second as $\omega = \frac{2\pi}{T}$, the wave equation will have the general form as given below:

$$(x,t) = A \cos (kx - \omega t)\eta \quad (4)$$

It should be noted that by reciprocating the harmonic motion of the wave with moving on the trigonometric circle, a full wave cycle is equivalent to a complete circle, or 2π radians. In Figure 2, the harmonic wave propagation in both the axes of time and location are displayed.

Wave force applied to the structures

Calculating wave forces on offshore structures is one of the primary objectives in the design of structures, and at the same time, it is one of the most difficult stages. That's because of the complexity of wave interaction with structures. In addition, the random nature of the sea, and the inability of existing theories (even the non-linear theories) to provide accurate and real solutions has have caused further problems. However, a number of theories existed that gave exact solutions to researchers. As previously mentioned, there are numerous types of offshore structures including cylindrical jackets with small components, weighing bulky structures with large components, and tension leg platforms having diagonal, horizontal and vertical components with square or circular cross sections. Based on the size and type of structures, different procedures and formula are applied for wave forces on structures (Zienkiewicz, 1978). In general, these formula and methods can be divided into three major categories:

1. Morrison equation
2. Froude – Krilov theory
3. Diffraction theory

In Morrison equation it is assumed that the force of the waves applied to the structure have in total two components, namely the drag force and the force of inertia. The Morrison equation is used when structural

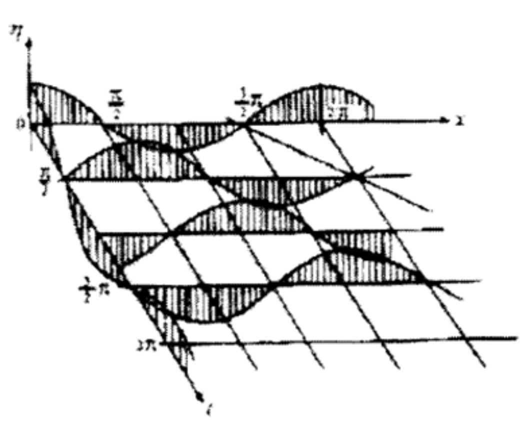

Figure 2. Propagation of a harmonic wave in both axes of time and location

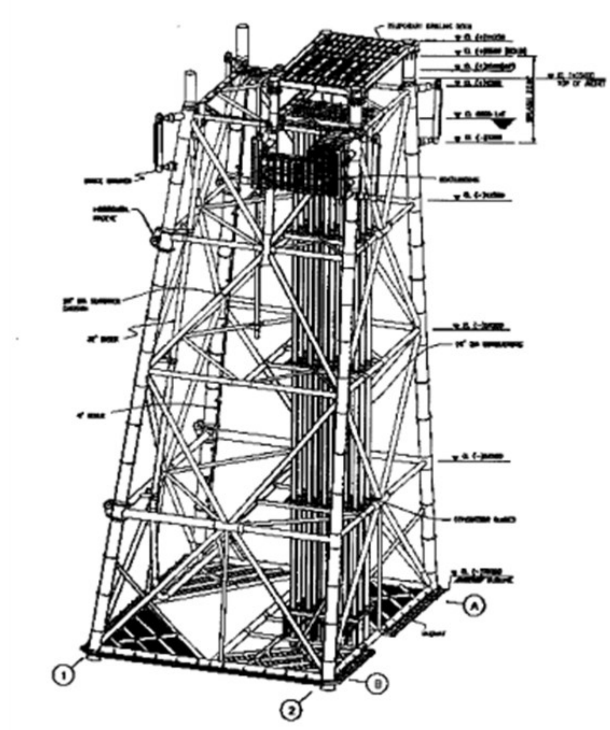

Figure 3: Three dimensional figure of jacket platform

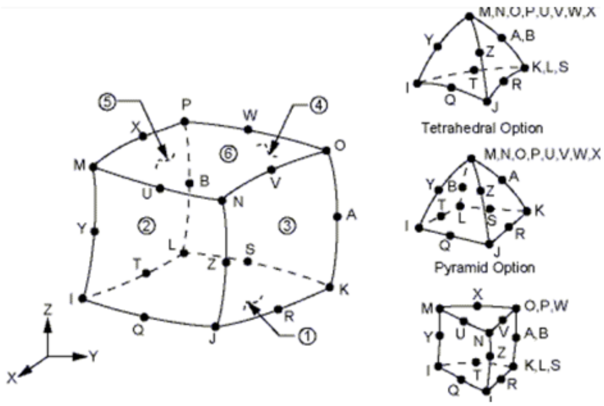

Figure 4. Solid 186

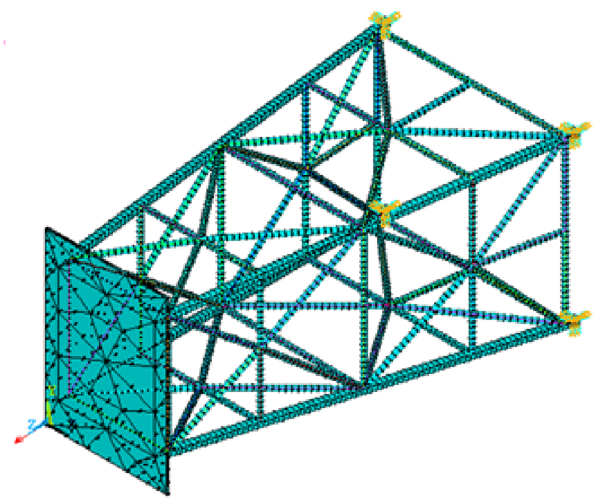

Figure 6. 3D model of platform S1

components, compared with the wavelength are small (Jia *et al.,*2015). In the cases of small drag force, much inertia force and the structurally small wavelength compared to the normal are seen and the Froude-Krilov theory can be used. One advantage of this theory in symmetrical geometric structures includes simplicity of appearing terms, and also easy determination of force coefficients (Raed *et al.*, 2015).

When the drag force is low and the inertia is dominant as well as the structure is still smaller than the wave length, the Freud-Kreil of theory can be used. A benefit of the theory for symmetrical structures is simple express of the applied force and the coefficients of force can be easily calculated.

When the structure size is bigger than the wavelength, the structure changes the field and form

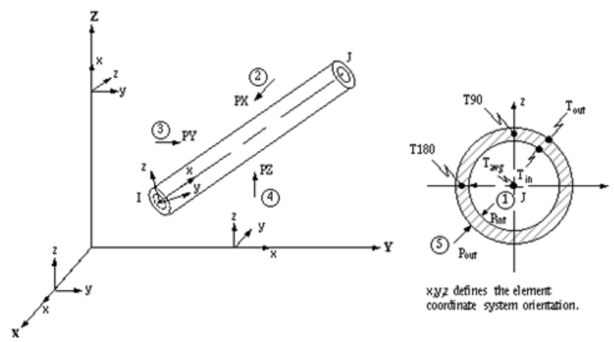

Figure 5. Pipe 59

of the wave adjacent to the wave and the diffraction theory must be used in structure loading (Jia *et al.,* 2015).

In this case, the wave diffraction from the structure surface must be considered in calculation and determination of wave force. In some simple cases, closed and short solutions can be obtained based on this theory. But most of the time, numerical methods for solving Laplace equation and boundary conditions are required.

To figure out which of the three modes can be used in the theory, a dimensional analysis can be done. Force (f) applied to the structural component of diameter D can be written as a function of the following parameters:

$f = \psi$ (t, T, D, L, u0, ρ, υ) (5)

Where, t = time, T = wave period, L = wavelength of maximum horizontal velocity of water particles, ρ = density of water and ν = kinematic viscosity.

So $(\frac{D}{L})$ can be used as an indicator to determine the appropriate method to obtain the force:

1. $(\frac{D}{L})$ <0.2 using Morison equation
2. 0.2< $(\frac{D}{L})$ <1 using Froude – Krilov
3. 1< $(\frac{D}{L})$ using diffraction theory

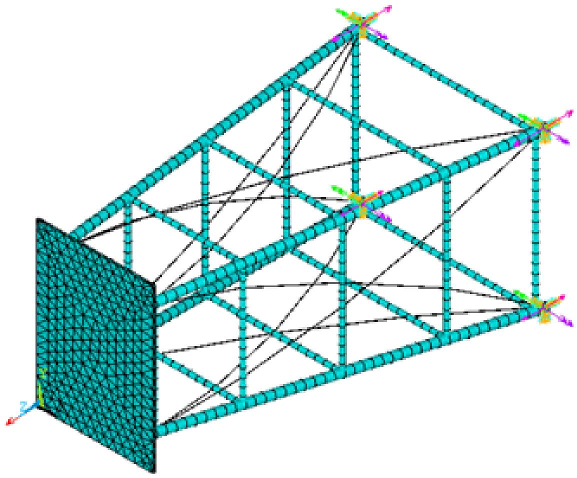

Figure 7. 3D model of platform S 2

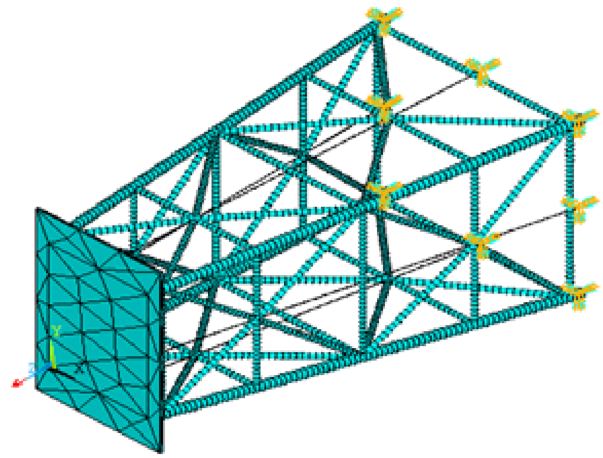

Figure 8. 3D model of platform S

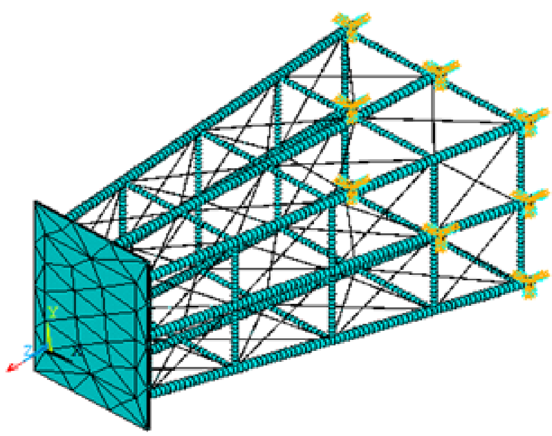

Figure 9. 3D model of platform S 4

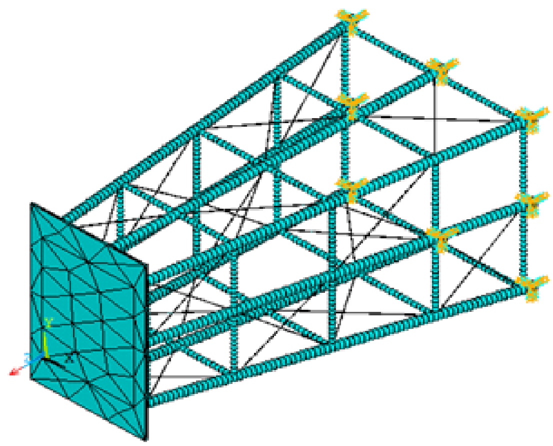

Figure10. 3D model of platform S5

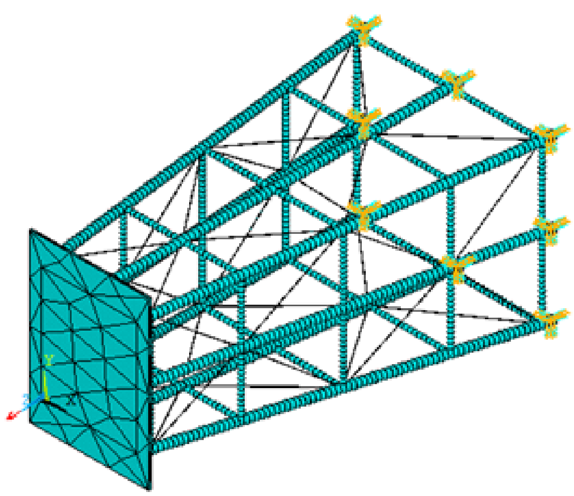

Figure 11. 3D model of platform S6

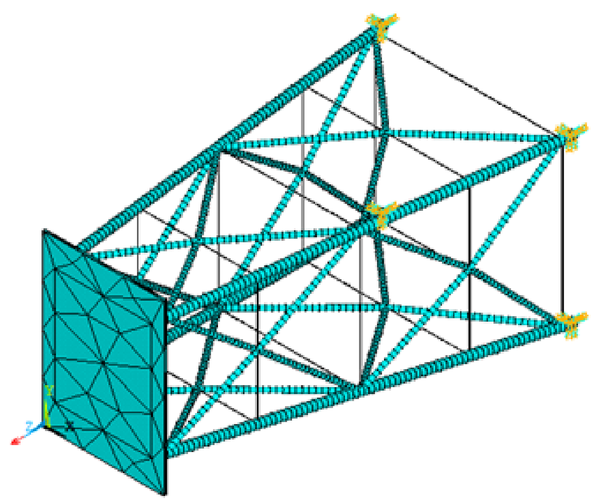

Figure 12. 3D model of platform S7

Because in the structures of this research, the ratio is smaller than 0.2, so the Morrison equation is used for loading.

Earthquake

Earthquakes are shakes and movements of earth caused by the release of energy due to rapid failure in the

Table 1. Analyzed models

Platforms	Tabas earthquake	Northridge earthquake	San Fernando earthquake	7m wave
S 11	√			√
S 12		√		√
S 13			√	√
S 21	√			√
S 31	√			√
S 32		√		√
S 41	√			√
S 42		√		√
S 43			√	√
S 51	√			√
S 61	√			√
S 62		√		√
S 71	√			√
S 81	√			√
S 82		√		√
S 91	√			√
S 92		√		√
S 93			√	√
S 101	√			√
S 102		√		√
S 103			√	√

earth's crust in a short time. Earthquake source is called deep center, and point at ground located on epicenter is the original source of earthquake. Before the main earthquake, usually relatively weaker earthquakes occur in the region, which are known as pre-earthquake. Next earthquakes also occur with less intensity and different time intervals (a few minutes to a few months) which are called aftershocks. Earthquake happens in three forms of vertically, horizontally and wave which is the most common type (Jia *et al.,*2015).

The earthquake is the result of a sudden release of energy from the earth's crust that creates seismic waves. Earthquake is recorded by seismometer or seismograph. The magnitude of an earthquake (Richter) is reported in accordance with the contract, which states that the energy is released. Earthquakes smaller than '3' are often imperceptible, while ones larger than '7' usually cause serious damage. Seismic intensity is measured by the modified method of Mercalli, which represents the effects of the earthquake on the ground, and its scale is '1' to '14'. Nearer to the Earth's surface, earthquakes appear as vibration, or sometimes Ground Handling. When the epicenter is in the sea, the very rapid transformation of the seabed causes a tsunami, which usually severe earthquakes happen. Earthquake can cause landslides and occasionally volcanic activity. In order to record earthquakes, a device called seismometers or Accelerometer are used. Data obtained from this device, is either as series of numbers indicating acceleration, which are (acceleration - time) grouped, or just a series of numbers representing the acceleration of the earth. In the latter case, at the beginning of the data, seconds between data are specified (Wen, 2001).

MATERIALS AND METHODS

In general, the methods of structural analysis can be divided into quasi-static and dynamic methods (time domain and frequency domain). Analysis and design of offshore fixed platforms considering the forces of waves and earthquakes in theory, in addition to its own difficulty, takes a lot of time. By advances in the computer science, these problems have been largely resolved. Therefore, different software for the analysis of fixed offshore platforms are commonly used, such as ANSYS, SACS, and ABAQUS. The software ANSYS 14is used in this study (Vaghefi and Bagheri, 2010). After analysis completion on the force of the waves and earthquakes and after determination of lateral platform

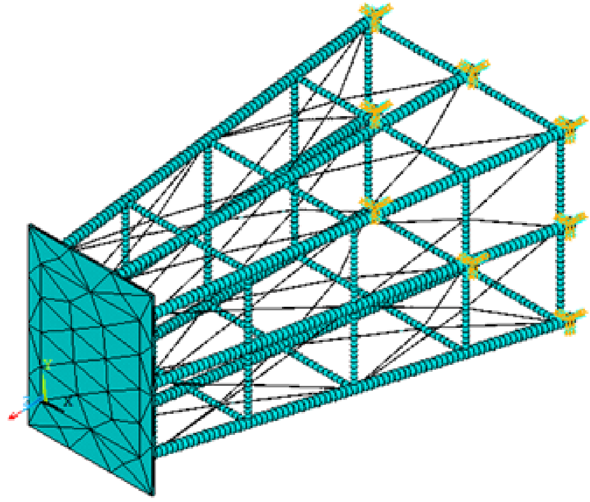

Figure 13. 3D model of platform S8

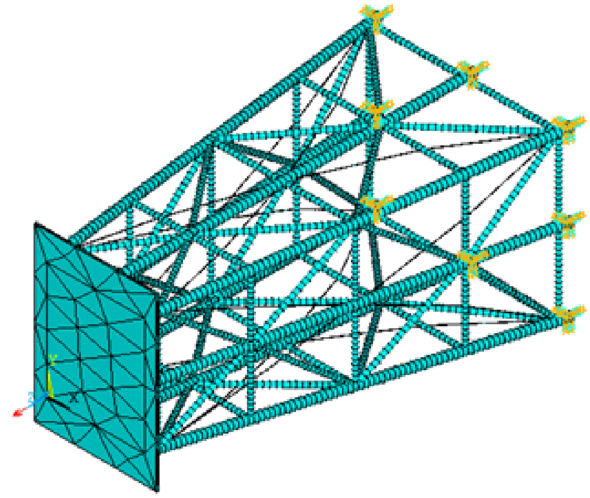

Figure 14. 3D model of platform S9

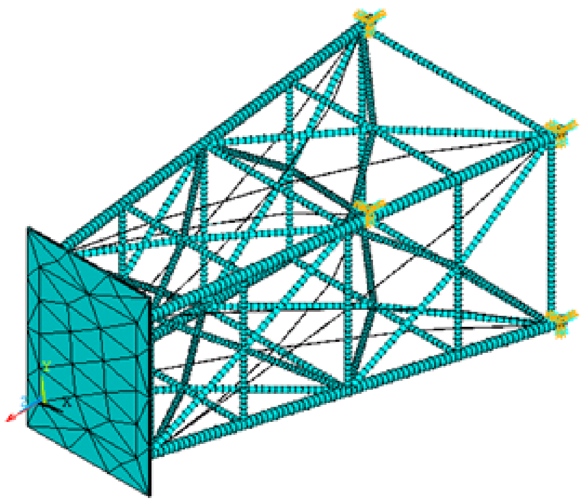

Figure 15. 3D model of platform S10

shifts, respectively, a retrofit of platforms is done, in order to decrease damage to the platform. Because of the placement of these structures in the marine environment, it's hard to replace and repair damaged organs, and sometimes entails many costs. To retrofit, metal fixed platforms have offered many ways including the use of diagonal analysis as well as the use of shape memory alloys. But in this study, the combination of diagonal and cables are used for the platform retrofitting. Cable, addition to a very high tensile strength, reduces lateral shift in the stands as well as the integrity and uniformity in the structure. This chapter describes the method of structural analysis and gets the response. In this research, by using mentioned software, structural response is calculated.

The use of fixed operating platforms in deep waters and sea conditions needs inspection and possible repair of some parts of the underwater platform. The inspections and repairs are very costly, and must be performed by special and advanced equipment. Today, the emphasis is on the design that reduces the costs, and not on lowering the cost of initial construction. The platform studied in this research is located in the Persian Gulf. The platform is a Well Head Platform (WHP), designed for drilling by lifting equipment. WHP platform is a platform having four legs, and its dimensions are 24 x 20 m. It includes four decks, which are as follows: upper deck, central deck, lower deck and drain deck.

Jacket Specifications

Geometry: four-leg jacket with four main columns to support Well Head Panel (WHP). The space among legs is 20×24 m in working level.

Legs slope: The slope of row 2 is vertical (100%) and there is just a slope of 1:8. The slope of row 1 is 1:8 in both directions.

Piles: The piles diameter is 60 inch (1524 mm). The piles are installed through jacket legs and no gout is poured between the pile and the jacket.

Also, in this section we introduce the elements

Table 2. Ranking of the platforms under different loads and seismic waves

Platform	Platform rank in Tabas earthquake	Platform rank in Northridge earthquake	Platform rank in San Fernando earthquake	Platform rank in Total
S 11	4	4	4	4
S 21	10	-	-	10
S 31	6	6	-	6
S 41	2	2	1	2
S 51	8	-	-	8
S 61	7	7	-	7
S 71	9	-	-	9
S 81	5	5	-	5
S 91	1	1	2	1
S 101	3	3	3	3

Table 3. Ranked fourth top platform under different loads and seismic waves

Platform	Platform rank in Tabas earthquake	Platform rank in Northridge earthquake	Platform rank in san Fernando earthquake	Platform rank in Total
S 11	4	4	4	4
S 41	2	2	1	2
S 91	1	1	2	1
S 101	3	3	3	3

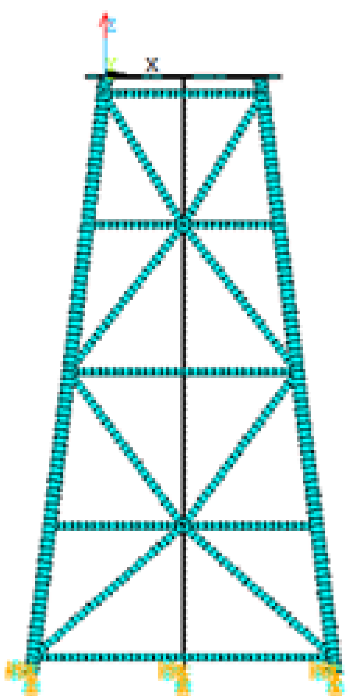

Figure 16. A view of platform S4

used in this study their uses are described. In this study, three finite elements called Solid 186, pipe 59 and Link 180 are used.

The element of Solid 186

In the present research, for gridding the platform deck which is formed a block, Solid 186 is employed. Solid 186 is a element with 20 nodes and three degrees of freedom.

The element of Pipe 59

To supply the elements of the jacket, Pipe 59 is utilized. This has 6 degrees of freedom in every node (three degrees for linear motion and three degrees for rotary motion) around x, y and Z axis. It bears tension, compression, torsion and bending around single axis. This element is similar to pipe 16. The only difference is that the applied forces to pipe 59 involve hydrodynamic and floating impacts of waves and water flow.

The element of Link 180

In order to supply the elements of cables, link 180 is employed. A cable is a thin tensile member that bears high tension and supports no compressive force. Therefore, in the current research, link 180 is used to model the cables because Link 180 can just bear tensile force.

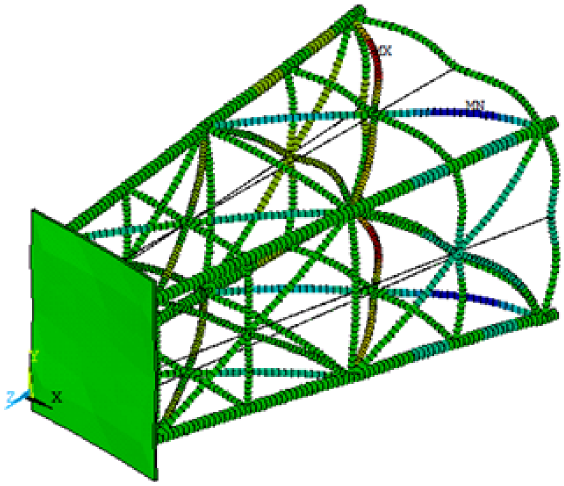

Figure 17. 3D model of platform S4 shift along X axis

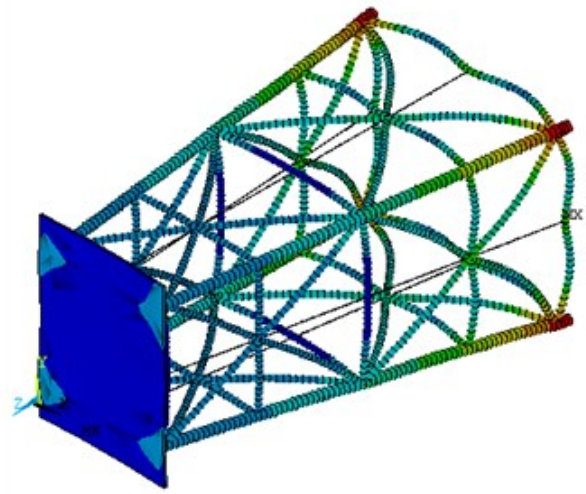

Figure 18. 3D model of platform S4 shift along Z axis

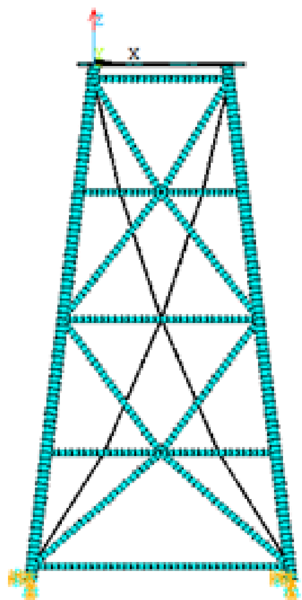

Figure 19. A view of platform S10

RESULTS

In this study, a model of offshore fixed platform in the Persian Gulf was used. By combining elements of cables and diagonal components, nine new models were built. Then all the various models under load and seismic waves were analyzed and evaluated. The models are displayed below by their nicknames.

In Figures 6 and 7, the how meshing of the S1 and S2 samples are indicated. As it can be observed, in the S1 samples only the overall angle brace is used; while in S2 sample, in addition to the terminal brace covering two altitudinal levels, the vertical components are used in the lower level. Also, the meshing of S1 sample is carried out more suitable rather than the S2.

The geometry of the S3 and S4 samples (Figure 8, 9) are similar to each other, but the sections of the vertical and diagonal intermediate components are different in both samples. Moreover, it can be seen that the how meshing is similar in both samples.

As it can be observed, the arrangement of the diagonal components is different in S5 and S6 (Figure 10, 11), but they are similar in other arrangement of components as well as meshing.

In the samples S7 and S8 respectively (Figure 12, 13), 4 and 9 vertical components are used. In addition, the way of angle braces is different in both samples. The how meshing of the samples except in the deck also is different. In the samples S9 and S10, the modelling is like this.

Table of platforms

Each different arrangement is analyzed under different loads and seismic waves. In “Table 1”, different arrangements according to the various earthquakes are named.

According to the analysis made in the previous section, this section tries to interpret the results.

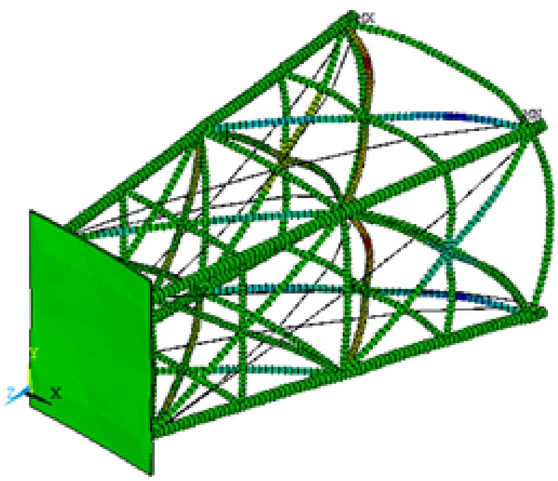

Figure 20. 3D model of platform S10 shift along X axis

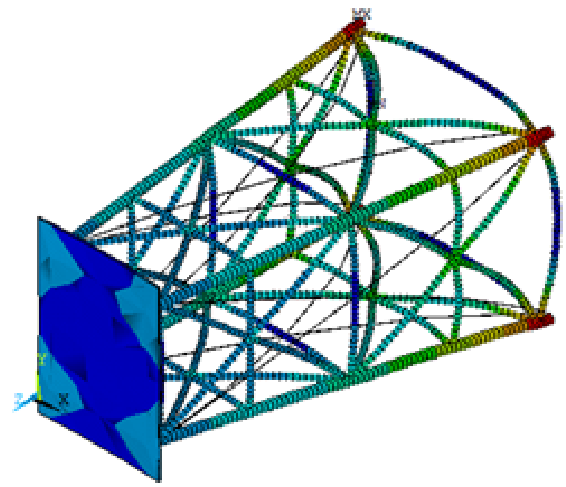

Figure 21. 3D model of platform S10 shift along Z axis

Table 2 indicates the entire built models whilst Table 3 shows the four-platform rating which are analyzed under all earthquakes.

The results showed that platform S 9 is the best jacket version (Figure 14). But this model is very costly; because it is designed by eight main bases, horizontal and diagonal components, as well as the cables. So the best model platform is S 4; because the platform is cost-effective, and due to the low cost, high performance can be extracted; and also creates least shift under different earthquakes and wave load.

S4 platform is composed of 4four main base and horizontal and diagonal components, which is similar to the main platform. The main difference is the usage of cable as a basic element. Cable height is equal to the height of the main base and the platform is connected to the ground. Elements of the cable passes through the horizontal components, and with this connection, jacket and platform integration are created. Also, by connecting the cable to the ground, jacket and platform shift due to wave load and earthquake are reduced.

Platform S 10 (Figure 15) relative to the cost has appropriate reactions against waves and earthquakes. Platforms S 10 is the same as the main platform, but its elements are cross cabled connecting upstairs to downstairs. Cable elements pass through the middle horizontal and diagonal components, and like the platform S 4, the integrity of the entire structure is preserved.

Cable element in the platform of S 10 is more than the platform S 4, so it costs more. Also, according to the results of surveys, shift of platform S 4 due to wave loads and earthquake, is less than the platform S 10. S 4 and S 10 models both have fewer shifts compared to the S 1 that is the main platform.

Introducing S 4 and S 10 platforms

Fixed offshore platforms are always subjected to large forces caused by waves and earthquakes. In most fixed offshore platforms, diagonal components are used to deal with these forces. In this study, a new way to retrofit offshore fixed platforms using cable systems and diagonal components are proposed. Cables, due to high tensile strength and ease of implementation, can be used to retrofit replacing other systems or to retrofit existing structures.

This study introduces two new models, which use a combination of diagonal components and cables in offshore fixed platforms. Despite low cost, it showed higher resistance against waves and earthquakes. As you know, due to the force of the waves and earthquakes on offshore fixed platforms, the probability of injury is high for platform and jackets, and given the difficulty of replacement and repairing damaged components, great cost will be imposed to the operating company. So podium by S 4 and S 10, the best model for offshore jacket platform are fixed. So platforms S 4 and S 10 are the best models for offshore fixed platform jacket.

Introducing the platform S 4

S4 contains 4four main bases, and to retrofit it, horizontal and diagonal components, as well as cable components are used (Figure 16). Horizontal and diagonal elements are similar to the original model's platform. The difference is that instead of horizontal components in the middle of the first floor, cable components are used in structural modeling. As Cable components are used in the model, the platform is connected to the ground and cable passes through the horizontal components. Cables are installed on four sides of the platform, and in the middle of two major bases.

As it can be seen, displacement of the platform S4 along the x is 7.1% less than platform S1, along the y is 5.63% less than platform S1, and along the z is 2.46% less than S1. So it can be concluded that platform 4 is more efficient than the platform 1. Also, the displacement of the platform S4along the x is 13.19% less than S9, along the y is 3.48% less than S9. And also the movement of the platform S4 along the z is six times more than the platform S9. The results mentioned above show that the platform 9 is more efficient than the platform 4.

Introducing the platform S10

Platform S10 as platform S4 has followed the main model, and only is different in cable design (Figure 19). At this stage, cable components are crossed, and connect upstairs and downstairs of the jacket together. Cables are installed on all four sides of the platform, and each side uses two cables. The major difference in the design of S4 and S 10 platform is that cable components in the platform S4 connect the platform to the ground, and on the way, pass through the middle of the horizontal cross components. In this way, the integrity of the structures will be remained. It also reduces shifts in the structure. But the cables in the platform S10 connect upper side of the platform diagonally and improve the integrity of the jacket structures. As can be seen from the results, this operation reduces the shift from the main platform.

The displacement of the platform S10 along the x is 2.35% more than platform S4 and along the z is 70.8% more than the platform S4, but along the y, it is 3.04% less than S4. As a result, platform S4 has better performance than the platform S10. The movement of the platform S10 along the x is 15.85% more than the platform S9 and along the z is 10.27 times more than the platform S9; but along the y, it is 6.63% less than the platform S9. Moreover, it can be concluded that the platform S9 is more efficient than the platform S10.

DISCUSSION

According to the findings of the present research and the studies on the literature about the offshore platforms, most of the previous studies have been about the stability of the offshore fixed platforms as well as their strengthening. Hedayati *et al.* (2002) studied the linear and non-linear analyses in the states with and without the interaction of soil. The results showed that without considering the non-linear geometric effects and interaction of soil for the platforms with actual dimensions, the significant errors occur in the calculations and designing without considering these effects will be invalid and in some cases uneconomical. Furthermore, Etemad *et al.* (2005) provided a three-dimensional model of a template fixed platform in the Persian Gulf region. Their results indicated that the fuzzy delay parameter plays a considerable role in the maximum response of the structure. In addition, Raziei and Asgarian (2008) analyzed the soil-candela-structure collection of the metal fixed offshore platforms under the effect of different earthquake records. The results of their research about the sample platform are presented under the effect of various records of the earthquake and the impact of different parameters such as the interaction of soil, structure, and candela is investigated. However, in the current study, waves and earthquake forces are used to analyze and design the offshore fixed platforms. Somehow, the results of present study show that the offshore fixed always are accidentally exposed to the huge forces from the water flow and winging loads caused by waves and earthquakes. These forces crashing with the platform causes the lateral displacement in the platform. Also, Barghian and Maghsoudpour (2009) investigated a new system called integrated cable system including pre-stressed cables in order to increase the lateral stiffness. Their findings indicated that by usage of cable system, besides the significant reduction of the relative lateral displacement, their values will be in uniform. In this regard, current study has used the composition of the diagonal components and cable for strengthening the platform. The results indicated that using the cable in the structures reduces the lateral displacement of the structure as well as causing the uniformity in the whole structure. Therefore, the results of the Barghian and Maghsoudpour (2009) are consistent with the results of this study.

CONCLUSION

In this section, most comparisons are relative to the main platform, the platform S1. And also the rest of platforms, platform S 9 at rank 1, platform S 4, at rank 2, S 10 at rank 3, and also S 2, in which diagonal components has not been used, and only the cable is used. To compare platforms platform analysis under wave load and Tabas earthquake is used.

In comparison between S1 and S2, it can be said that the shift of S2 along X axis is 6.33 times more than S1, along Y is 20.68 times more than for S1, and along Z it's 2.06 times more than for S1. So we can conclude that diagonal components are so effective in platforms.

In comparison between S1 and S9, it can be said that the shift of S9 along X axis is 17.52% less than S1, along Y is 2.07% less than for S1, and along Z it's 6.16 times more than for S1. So we can conclude that platform S9 is stronger than S1.

In comparison between S1 and S4, it can be said that the shift of S4 along X axis is 7.1 % less than S1, along Y is 5.63% less than for S1, and along Z it's 2.46% less than for S1. So we can conclude that diagonal components are so effective in platforms.

In comparison between S1 and S10, it can be said that the shift of S10 along X axis is 4.66% less than S1, and along Y it is 8.84% less than for S1. So we can conclude that S10 is stronger than S1.

In comparison between S4 and S10, it can be said that the shift of S10 along X axis is 2% more than S4, and along Y it is 70.8% more than for S1. But it's 3.04% less along Z. So we can conclude that S4 is stronger than S10.

In comparison between S4 and S9, it can be said that the shift of S4 along X axis is 13.19% more than S9, along Y it is 3.48% less than for S9, and it's '6' times more than S9 along Z. So we can conclude that S9 is stronger than S4.

In comparison between S10 and S9, it can be said that the shift of S10 along X axis is 15.85% more than S9, and along Z it is 10.27 times more than for S9. But it's 6.63% less along Y. So we can conclude that S9 is stronger than S10.

Shift in the S4 platform is smoother and more integrated related to another platforms' shift.

Shift in S9 is less than other platforms, but imposing a lot of cost.

REFERENCES

Barghian M and Maghsoudpour S. (2008). The retrofit of concrete buildings using cable systems and improvement of cable form and limiting the pre-stressing force. *Sharif Journal*, 24(44): 117-124.

Etemad S, Ahmadi G and Tavakoli B. (2005). Designing the Jacket platforms under sea loads by reliability and performance levels. 5th International Conference on Coasts, Ports and Marine Structures. Tehran: Ministry of Roads and Urban Development, Ports & Maritime Organization.

Hedayati MH, Naghipour M and Taghipour GH. (2002). Nonlinear analysis of metal fixed platforms by considering interaction among water, structure and soil. 5th International Conference on Coasts, Ports and Marine Structures. Tehran: Ministry of Roads and Urban Development, Ports & Maritime Organization.

Jia D, Schofield P, Shen J and Malachowski J. (2015). Modelling of Wave-Structure Interaction of a Cylinder in Regular Sea Waves With Vessel Motions Using Coupled Transient CFD and Diffraction Methodology. ASME. International Conference on Offshore Mechanics and Arctic Engineering, *Volume 2: CFD and VIV* ():V002T08A020. doi:10.1115/OMAE2015-41462.

Lighthill MJ. (1965). Contributions to the theory of waves in non-linear dispersive systems. *IMA Journal of Applied Mathematics,* 1(3):269-306.

Raed K, Karmakar D and Soares CG. (2015). Uncertainty modelling of wave loads acting on semi-submersible floating support structure for offshore wind turbine. Taylor & Francis Group, London.

Rezaei E and Asgarian M. (2008). Reaction reduction of fixed maritime platform using adjusted damper. 1st National Conference on Structure and Steel. Tehran: Iranian Association of Steel Structures.

Sætre JBM. (2013). Collision between Platform Deck and Service Vessel Wheelhouse (Master's thesis, Institutt for marinteknikk).

Umeyama M. (2012). Eulerian–Lagrangian analysis for particle velocities and trajectories in a pure wave motion using particle image velocimetry. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, *370* (1964):1687-1702.

Vaghefi M and Bagheri H. (2010). ABAQUS, Ansys and SACS softwares application analysis in non-linear marine structures study. *Quarterly of Marine Technology and Science*, *54*(54): 1-10

Wen YK. (2001). Reliability and performance-based design. *Structural Safety, 23*(4):407-28.

Winkel M and Smith I. (2009). Structural behavior of wood light-frame wall segments subjected to in-plane and out-of-plane forces. *Journal of Structural Engineering,* 136(7):826-36.

Zienkiewicz OC and Bettess P. (1978). Fluid structure dynamic interaction and wave forces. An introduction to numerical treatment. *International Journal for Numerical Methods in Engineering, 13*(1):1-6.