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Investigating of clamp effects on fatigue damage in the fixed platforms riser

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Abstract

The riser is one of the components of offshore platforms, which consists of a thin cylinder that is vertically connected to the deck of the platform from one side and the other side is connected to the seabed and delivering oil and gas to the platform. Marine risers are exposed to many environmental forces, which cause vibrational oscillation of riser in different directions so-called conventional vortex-induced vibration and thus causing fatigue damage and reducing the riser's life. In this study, the riser platforms jacket was controlled in different class levels to reduce the risk of fatigue exacerbation using supportive systems known as clamp and part of the platform components. Finally, life expectancy of riser pipes against the fatigue was estimated for a case study.

Keywords: Riser; Fatigue damage; Clamp; Risk.

1. Introduction

Marine risers are the structures used to transport crude oil, natural gas, hydrocarbons, petroleum products, mud and economic resources of submarines. Exploration of oil, gas, and hydrocarbon materials at offshore has forced engineers and marine industry experts to build platforms for installation in depths of over 2000 meters. Marine risers are usually very thin and elongated structures are made of steel pipes and if they are not restrained, they will be buckled under their own weight. A platform may have more than 20 risers with different diameters and hydrodynamic characteristics. The most important hydrodynamic forces on

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the fixed risers are two types; the Inline Forces expressed in the Morrison equation and the Transverse Forces that is commonly called in lift force. The Inline Forces are due to the potential flow and inertia. Transverse Forces are due to vortices created around the riser, which are often known as Vortex Induced Vibrations. Of course, other hydrodynamic forces are also introduced on these cylindrical structures, such as the hydrostatic pressure due to the internal and external fluid of the fixed risers.

The importance of this research is that all oil and gas platforms are designed exclusively for the Riser pipelines and, given the crucial role of Riser and its geometric structure, engineers and technicians need to consider all conditions for designing Risers.

Many studies have been conducted on vibrations caused by vortex dispersion, which have a relatively long history. Over the past five decades, various forms of marine risers containing fluid in flow have been investigated by the experts. In 1968, Feng began examining orthogonal vibrations on a circular cylinder. With gradual increasing of the velocity, he measured the frequency of vortex distribution, the vibration frequency, the amplitude of vibration, and the phase difference between the cylinder's vibration and the lift force. Then, these values were plotted as a function of decreasing velocity (Feng, 1968).

Irani and Modi (1987) studied the dynamical behavior of marine risers with a uniform flow inside the tubes in a three-dimensional model of finite element. The results indicated that the internal flow decreases the rigidity of the riser and creates a Negative Damping Mechanism.

Moe and Chucheepsakul (1988) investigated the importance of the effect of the riser inflow on reducing the riser bending stiffness. Their results showed that the natural gas frequencies of the riser were reduced very slowly at a low inflow rate. However, the faster it is the very large decrease in the natural frequencies occurs. Huang (1993) investigated the kinematic governing equations for the mass transfer inside the riser under tension forces in three modes: Lagrangian, Eulerian and Coriolis. Boundary conditions and the parameters such as water depth, friction coefficient, geometric, materials used in the riser, wall thickness of the riser, and sea environmental conditions, and resonance, all are effective in the fatigue phenomenon.

Ferrari and Bearman (1998) obtained various modes of riser using a static model. In 2006, Vendireur *et al*. studied the fatigue due to high vibrational forces. They stated the hydrodynamic description of the observation of these vibrations and showed that over the open span, the importance of high vibrational modes is more than the vibration with the natural frequency of the system. They examined the displacements and curves of a sample riser and compared their outcomes with the laboratory results and then validated the model (Vandiver *et al*., 2006). Baarholm *et al*. (2006) presented a test to estimate the fatigue life of marine risers in the presence of forces on the marine riser in flow direction and in a vertical direction. Ebara (2006) studied the occurrence of corrosion fatigue using a work breakdown structure. They also investigated the effect of oil on fatigue crack growth in steels (Ebara *et al*., 1993).

More researches were conducted on hydrodynamic analysis of marine risers due to the interaction of forces by just one environmental factor or the effects of vortices and their frequency on the risers. Many studies have been done on vibrations in vortex distribution, but so far no study is available about the effect of platform on the riser fatigue risk in the South Pars region, where is one of the deepest parts of the Persian Gulf. It is worth considering the useful life of riser in the study area.

2. Materials and methods

2.1. Governing equations

The pipelines may be exposed to large-scale vibrations in a steady currents or wave. When the free-span pipelines are subjected to these currents, it will vibrate. These vibrations lead to fatigue damage in pipeline welds, which could reduce its life. The differential equation of motion of this structure is as follows:

$$m y^{\bullet\bullet}(t) + c y^{\bullet}(t) + k\, y(t) = F(t) \quad (1)$$

which m is total mass of system, the $^{\bullet}$ sign shows the derivative order relative to time. F(t) is the Morrison force obtained from the following equation:

$$F(t) = \frac{1}{2}\rho\, C_D D\, (-y^{\bullet})|-y^{\bullet}| + \rho\, C_m A\, (-y^{\bullet\bullet}) \quad (2)$$

On the right side, the part of $\rho\, C_m A$, is considered as m', hydrodynamic mass in the span. Thus, the equation of motion is:

$$(m + m')\, y^{\bullet\bullet}(t) + c y^{\bullet}(t)\; \frac{1}{2} + \rho\, C_D D\, |y^{\bullet}| y^{\bullet} + k\, y(t) = 0 \quad (3)$$

Solving the Equation (3), the following relation is obtained for the riser motion:

$$y = A_y \exp(-\zeta\, \omega_d t) \cos(\omega_d t) \quad (4)$$

which ζ is the total attenuation factor includes structural and viscous damping. The ω_d is angular frequency of damping as follows:

$$\omega_d = \omega_n (1 - \zeta^2)^{1/2}$$

which:

$$\omega_n = \sqrt{k/(m + m')}$$

ω_n is undamped frequency. As the ζ is naturally very small in comparison with the unit, ω_d is estimated by ω_n:

$$\omega_d = \omega_n (1 - \zeta^2)^{1/2} \cong \omega_n \quad (5)$$

$$f_n = \frac{\omega_n}{2\pi} = \frac{1}{2\pi}\sqrt{k/(m + m')} \quad (6)$$

<u>*Boundary conditions:*</u>

$$\text{Down:} \quad \begin{cases} x\,(t_0) = 0 \\ EI\, (\delta^2 x / \delta z^2)\,(t_0) = 0 \end{cases} \quad (7)$$

$$\text{Up:} \quad \begin{cases} x\,(t_1) = 0 \\ EI\, (\delta^2 x / \delta z^2)\,(t_1) = 0 \end{cases} \quad (8)$$

2.2. Fatigue damage in marine risers

Mechanical fatigue is a phenomenon that results in the failure of metals due to repeated and intermittent stresses (even less tensile strength of the metal). The more alternation stress, the shorter the metal's failure time will be. In other words, repeated loading and unloading, even if tensions are not much flow, can cause failure of the material. The phenomenon of reduced resistance under the influence of repetitive forces is called material fatigue. Fatigue occurs even under ideal conditions. Ideal conditions are the conditions in which there is no stress concentration, the behavior of materials are completely ductile, the stress is one axial, and finally, the material is high endurance. In addition to the ground structures, this is also a destructive mechanical phenomenon on marine structures. Marine platforms are one of the structures that are influenced by fatigue loads due to the impact of their waves and their specific environmental conditions. Today, the study of fatigue in structures and joints of sea platforms is one of the most important issues in analyzing the strength of these platforms. The main reason for the risk of fatigue failure is that it occurs without any prior awareness and visibility. The fracture surface on the macroscopic scale is perpendicular to the main stress, and often the fracture surface due to metals' fatigue is detected by its appearance. The fracture surface due to fatigue is formed from a smooth area resulting from the abrasion action and a rugged area with crack propagation in the section that is broken when the load is not tolerated by the cross section. The main source of fatigue due to variable tensions is the effect of waves on a fixed platform and its risers. Other sources can be vibrations caused by vortices, wind vibrations, transportation, platform installation, and lateral equipment and loading of pipelines. The service life is the interval time when the platform structure is expected to be capable of operating efficiently on a fixed platform since the platform is in place, and the period of pre-services such as construction on land, transportation to the place, and installation is not considered.

2.3. The applicable software

As one of the most important parameters in evaluating the performance of the platform is the wave propagation coefficient, using of software capable of displaying water level changes is appropriate for this study. Hydrodynamic software can be used to model marine structures.

The model used in this study is ANSYS Workbench software and to obtain the marine environmental forces, Aqwa ANSYS is applied which acquires hydrodynamic forces. To calculate fatigue, using nonlinear waves, time history of an irregular wave was obtained. These hydrodynamic forces were used to analyze the stress distribution at the riser surface with the ANSYS Structural. Then, the distribution of stress was used for calculating the amount of fatigue on the riser in the MATLAB software called the Rain Flow Counting to calculate the amount of stress on the riser and the fatigue life by coding.

In this way, the step-by-step analyzing of the platform structure due to wave and flow passage can obtain a non-linear time histories of the hydrodynamic force, which taking into account the absolute magnitude of the stress variation of each wave, the range of tensions associated and consequently the fatigue were achieved. For fatigue analysis, considering the fetch limitation in the Persian Gulf and its undeveloped state, two-parameter formulation of the JONSWAP spectrometry was used. The wave period used in the formulation must be compatible with the periods obtained from the dispersion diagram.

2.4. Riser modeling

One of the basic assumptions is the incommensurability of water. With regard to this assumption, using modeling of the continuity and momentum equations, the pressure and velocity are obtained. The riser structure is typically modeled as a beam-column, in which the fluid flow is inside. It is assumed that the two ends are joint connections, the end of which is connected to the well's head, and its beginning is connected to the level of the platform, which is located above the water surface. After installation, they are subjected to the forces of wave, flow, riser's weight, internal and external hydrostatic pressure, and tube deviations, and they reach the equilibrium by changing their shape. The materials in the riser tube are homogeneous and it is assumed that the materials are in linear elastic type and follow Hooke's law. This study platform is a gas extraction area located in phase 7 of the south Pars gas field.

2.5. Damage Center of Wave

For fatigue analysis, it is necessary to calculate the wave characteristics in the center of damage wave from the scatter plot. The information of the damage wave are obtained as a block from the wave's dispersion diagram, in which the wave height, wave period, and an event as a representative of the corresponding block, called the wave damage center (Table 1). To calculate the wave profile of damage center the following formula are used.

Wave height of damage center:

$$H_{COD} = \frac{\sum d*H}{\sum d} = \frac{\sum(nH^{6.732}*H)}{\sum(nH^{6.732})} \quad (9)$$

Wave period of damage center:

$$T_{COD} = \frac{\sum d*T}{\sum d} = \frac{\sum(nH^{6.732}*T)}{\sum(nH^{6.732})} \quad (10)$$

In this research, the main goal is to find out the effect of jacket platform connections to the riser on damaging the fatigue riser (Table 2). Thus, the riser is modeled into two modes:

The first mode models how to connecting the platform and the riser. The riser structure is modeled as a column beam that has a liquid flow inside (Figure 1). It is assumed that the two ends are connection of a joint, which its end is joined to the well head, and its beginning is connected to the four-base with level of 5.75 m and more above the water level.

In the second mode, the modeling is based on the presence of a platform with real elements in the study, and also the supports that are part of the main components of the jacket platform located at the jacket levels and required to restrain the riser at different heights (Figure 2). These supports in the jacket class level, which are commonly referred to the clamp, is caused the riser to be connected to the platform in several areas, which in the oscillatory vibration of the riser, responsible for the riser fatigue greatly affects on these clamps. Therefore, the effect of the clamp presence on the riser is determined by these riser and platform joints.

Table 1. Wave scattering histogram in three marine situations in the study area

Damage wave information	T_p (s)	Hs (m)	Probability of occurrence
Block 1	7.3	5.3	0.001
Block 2	5.4	4.25	0.003
Block 3	4.9	3.5	0.008

Table 2. The characteristics of the studied jacket platform in the study area

Depth of water at the platform site (m)	65
Jacket height (m)	70
Riser characteristics	Diameter 32 inch Thickness 2.88 cm
Radiation angle of the sea waves enters the platform (degree)	With 45 º rotation

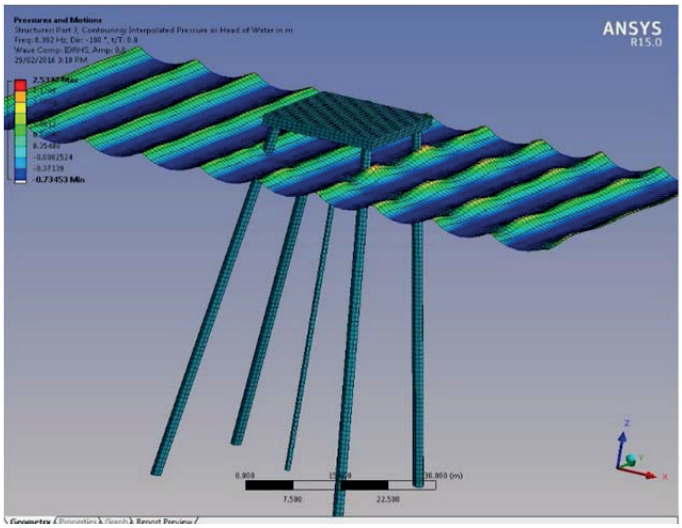

Figure 1. An overview of the application of hydrodynamic force in the first model

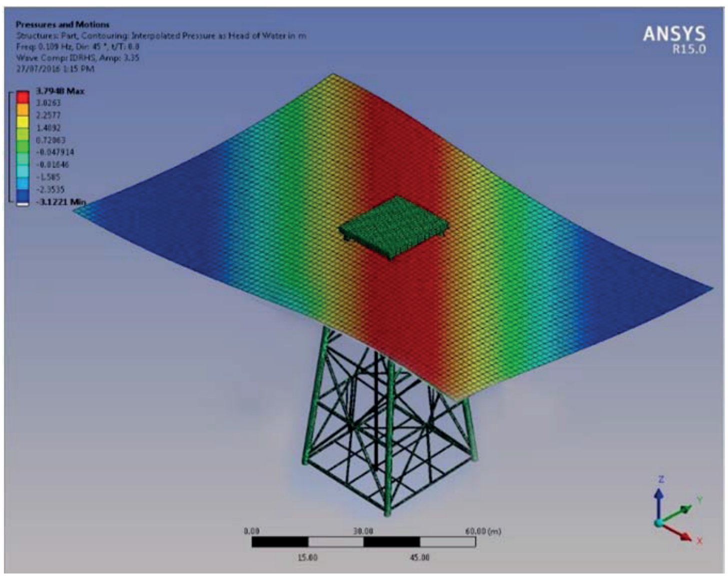

Figure 2. An overview of the application of hydrodynamic force in the second model

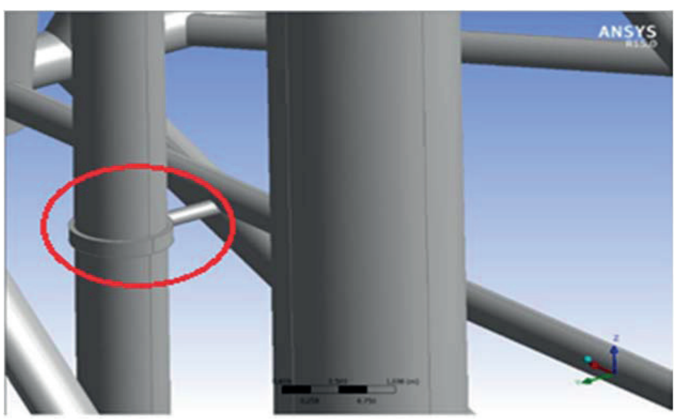

Figure 3. Riser connection with clamp

The joints at the beginning and the end of the riser are considered the same as the first one.

In the second case of modeling, the connection of the platform and the riser is in form of the two ends of joint and along with two clamps attached to the platform (Figure 3), are in two class levels of -12 and -44 of the riser.

Modeling and analysis processes in the Aqwa ANSYS are divided into three parts:

1. Geometry Modeling: The most important boundary condition for using this software is to identify the surface of the platform below the water level. For modeling the platform, two mesh types are defined. If a part of the structure is below the water level, the diffraction square element is defined as, and if it is above the water surface, the square element is defined, that the elements defined above the water level do not have much effect on the platform performance.
2. Frequency domain analysis: Parameters such as water depth, direction and frequency of the collision wave and the modeling range are determined at this stage. Due to the dependence of the hydrodynamic coefficients on the wave frequency, the appropriate frequency range of the waves is selected according to the environmental conditions of the sea. Water depth is also an important parameter because of the energy differences in deep and shallow water.
3. Time historic analysis: Time analysis is required due to nonlinear issues at sea and the calculation of output power. At first, a regular wave; the Stokes wave of 5-order is applied. Then, to calculate the fatigue life of the structure, it is necessary to use irregular waves, which was defined as the JONSWAP irregular wave.

3. Results

3.1. Hydrodynamic Force Analysis

Waves are irregular with sporadic nature, and their time history analysis is very important for assessing offshore structures. According to different theories, the JONSWAP is the most suitable spectrum in the study area. In this research, time history of hydrodynamic force was obtained for the irregular and accidental wave in each block of marine states by Aqwa ANSYS software. This analysis is the most appropriate method for estimating fatigue life. In fact, the time of the force based on the time set in the Aqwa ANSYS was considered 1000s with

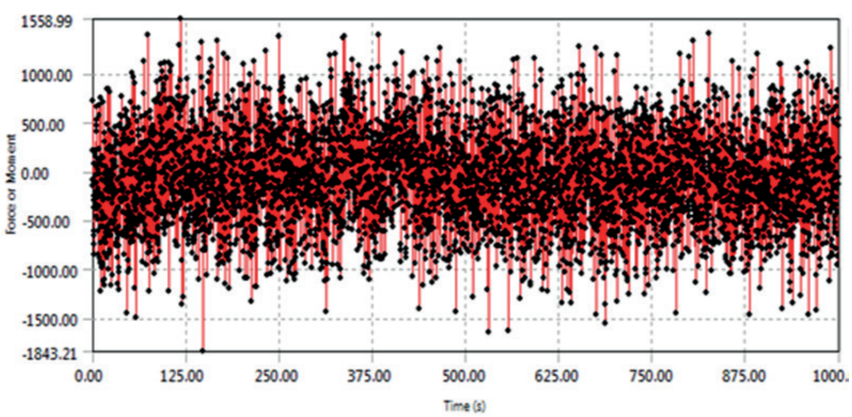

Figure 4. Variations of total hydrodynamic forces of the irregular wave entering the structure relative to time in the marine state 1

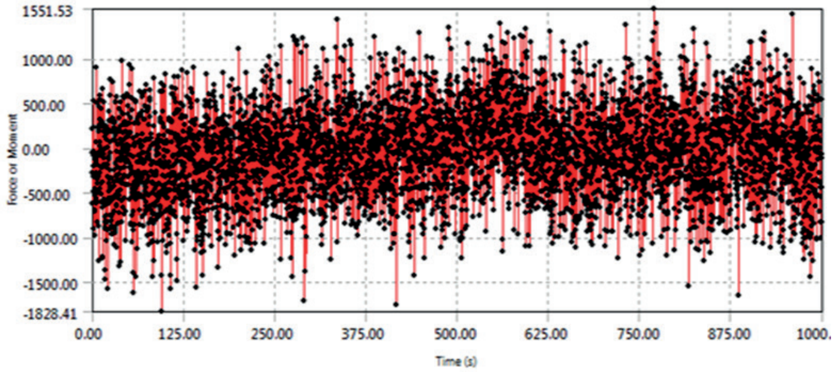

Figure 5. Variations of total hydrodynamic forces of irregular wave entering the structure relative to time in the marine state 2

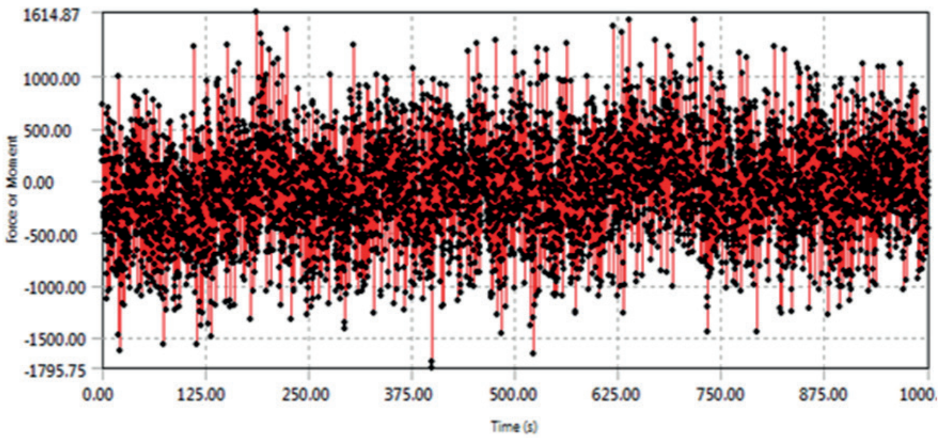

Figure 6. Variations of total hydrodynamic forces of irregular wave entering the structure relative to time in the marine state 3

0.2 time interval on the riser that was obtained separately for each of the 3 marine states on basis of the data in Table 1 (Figures 4 to 6).

3.2. Analysis of stress distribution

In this section, the random wave force in the time and thus the effects of stress and bending changes in Riser are analyzed. Fatigue damage from any sea state is carried out by using a flow counting method that transmits a range of tension series in a stress histogram. The tension histogram describes the number of occurrences for each domain of tension. At this stage, the time history forces were extracted for each of the three marine states separately, and to calculate the stress distribution, each of the forces entered the structural ANSYS, and the structure was analyzed under the marine forces with regard to the irregular wave in the X axis direction relative to time. Finally, using three distributions of the stress could investigate the fatigue of riser fixed platform in the range of stress variation. Von Mises stress indicates the average of main stress on the riser tube. Figures 7 to 12 show Von Mises stress based on the hydrodynamic force introduced in each of the sea states, which indicates that the first state riser tolerates more stress and deformation than the second state.

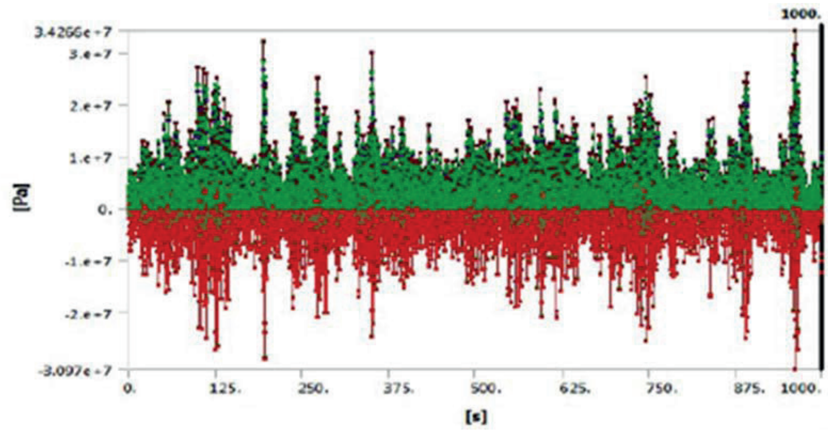

Figure 7. Von Mises stress along the X-axis in the riser first model in marine state 1

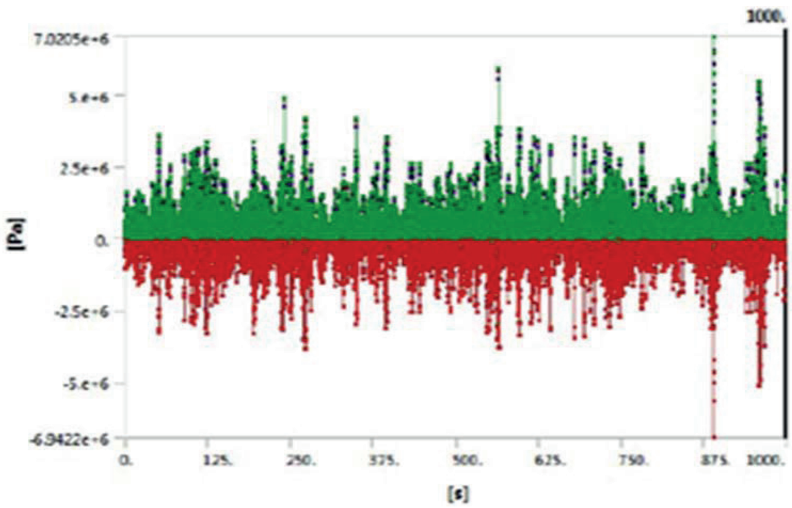

Figure 8. Von Mises stress along the X-axis in the riser second model in marine state 1

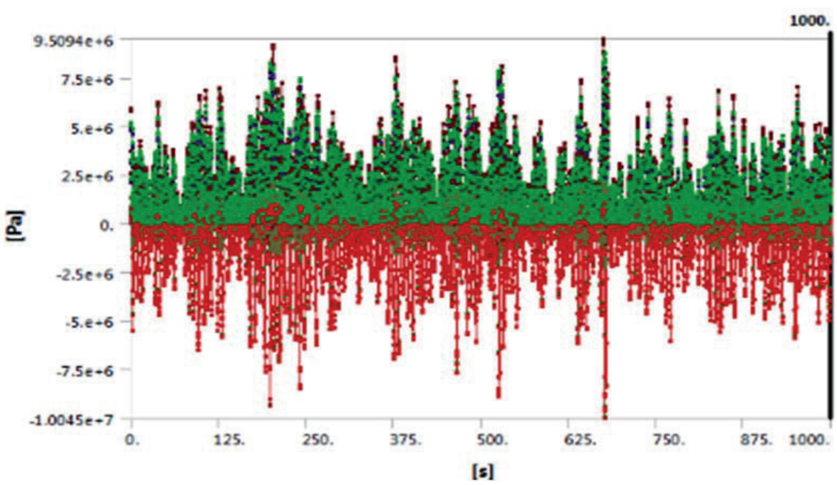

Figure 9. Von Mises stress along the X-axis in the riser first model in marine state 2

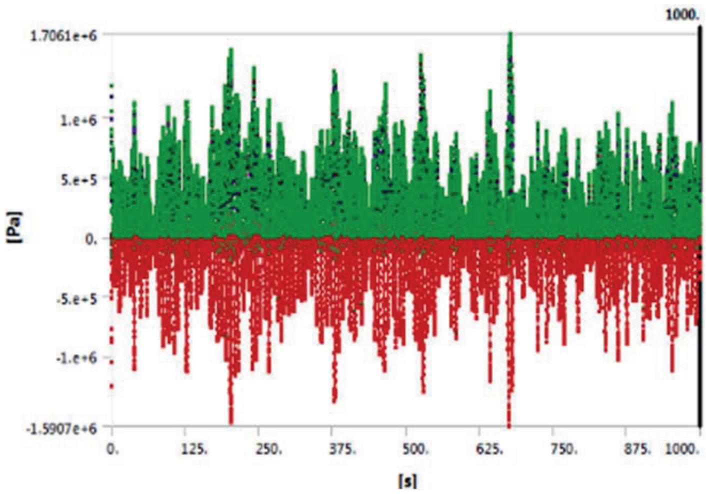

Figure 10. Von Mises stress along the X-axis in the riser second model in marine state 2

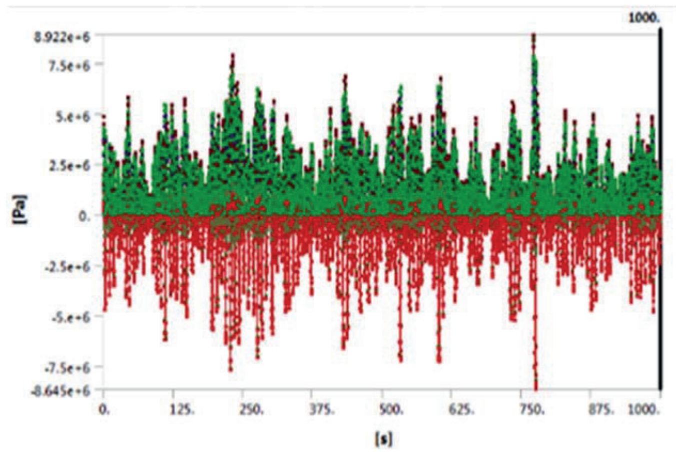

Figure 11. Von Mises stress along the X-axis in the riser first model in marine state 3

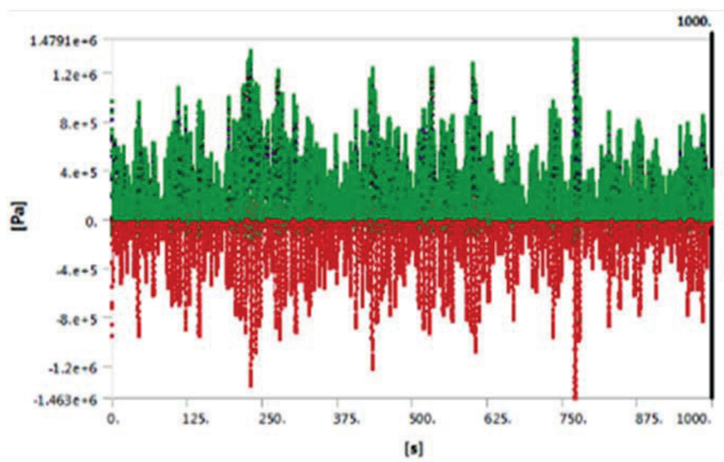

Figure 12. Von Mises stress along the X-axis in the riser second model in marine state 3

3.3. Analysis of fatigue damage

The distribution of stresses for each riser was entered as an input file into the Rain flow counting code of MATLAB software. In the API bylaw for designing the riser fatigue life of jacket platforms, riser's Lifetime is considered 3 times of the jacket's life due to the importance of the riser's tasks. The life of Jacket Platform is designed based on the API for 25 years until the creation of capillary cracks. Figures 13 to 18 express the results of the cyclical calculation in tensile changes efficiency. The horizontal axis shows the changes range of tensile stresses in Pascal and the vertical axis indicates the number of counted cycles.

Finally, after obtaining cycles counting of the riser tension, the amounts of damage and fatigue life in the risers were obtained. As shown in Table 3, the useful life of structure against fatigue failure was estimated to be 44.7 years in the riser first model, and in Table 4, the useful life of structure to the fatigue in the riser second model was estimated to be 75.67 years.

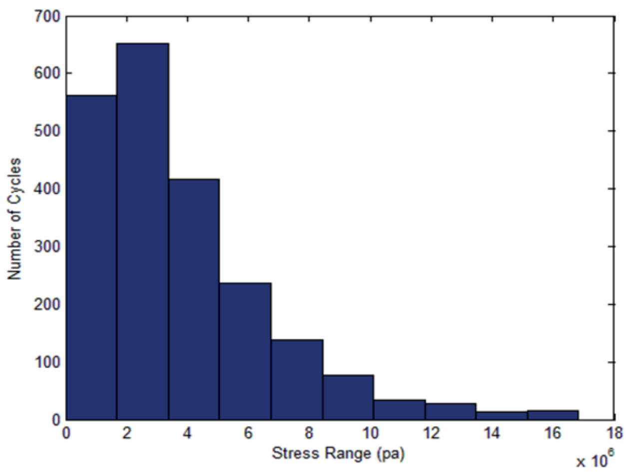

Figure 13. Tension Cycle Counting at the first mode riser in Marine state 1

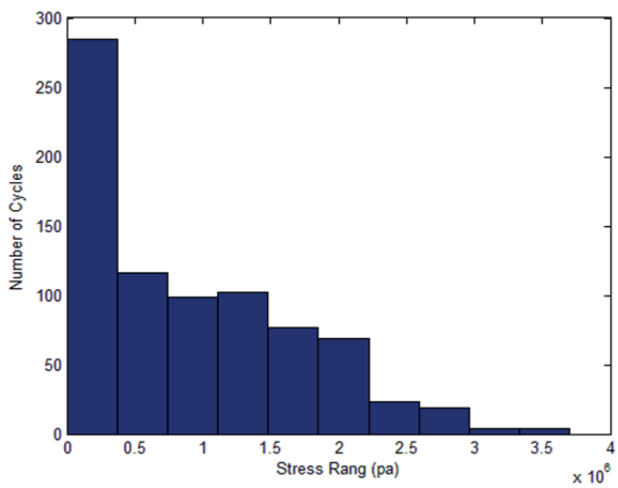

Figure 14. Tension Cycle Counting at the first mode riser in Marine state 2

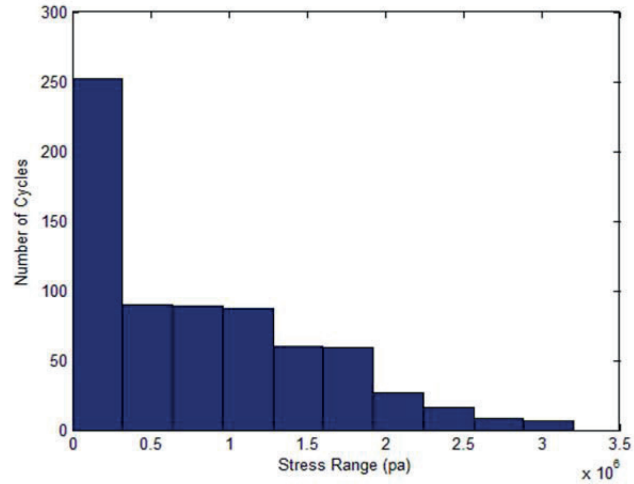

Figure 15. Tension Cycle Counting at the first mode riser in Marine state 3

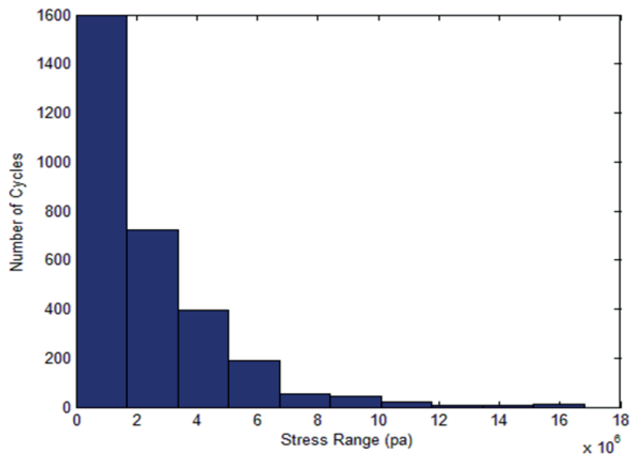

Figure 16. Tension Cycle Counting at the second mode riser in marine state 1

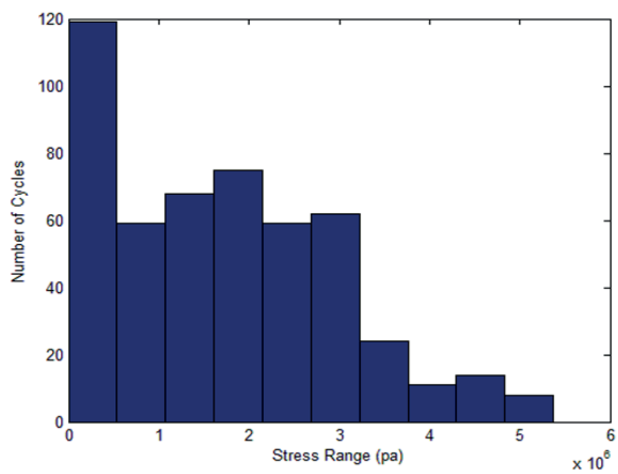

Figure 17. Tension Cycle Counting at the second mode riser in marine state 2

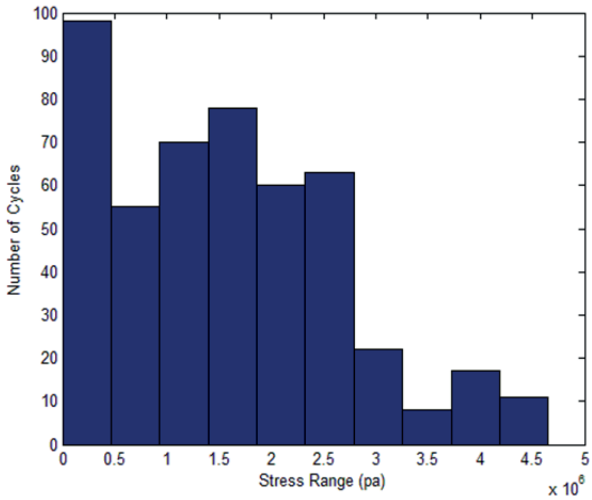

Figure 18. Tension Cycle Counting at the second mode riser in marine state 3

$$Useful\ life = \frac{1}{Total\ damage}$$

$$Useful\ life\ of\ riser\ \text{first mode} = \frac{1}{0.02236491} = 44.7\ years$$

$$Useful\ life\ of\ riser\ \text{second mode} = \frac{1}{0.01321463} = 75.67\ years$$

Table 3. Estimation of the useful life of structure against fatigue failure in the first mode

Workspace

Name ▲	Value	Min	Max
Damage	[7.0069e-07...	3.9420e-09	7.0069e-07
i	3	3	3
LifYear	[45.2549,6.9...	45.2549	8.0441e+03
TotDamage	0.0224	0.0224	0.0224
YearDamage	44.7129	44.7129	44.7129
YearlyDamage	[0.0221,1.43...	1.2431e-04	0.0221

Conclusion

In this study, the platform was modeled in two states in ANSYS software. In the first case, the riser with double-ended joint was modeled along with a footstool. In the second case, the jacket platform was modeled with all elements, which, the using of clamp fittings as part of the jacket platform components, has restrained the riser in two levels of -12 and -44 at a depth of 61 m. In the Aqwa ANSYS software using the finite element method which is specific to the calculation of hydrodynamic forces, the structure was analyzed in the irregular waves of time histories. In the history of time for the irregular waves, the Jansowap theory was used in a thousand seconds with a time interval of 0.2s in three different sea conditions in the study area. The series of time history obtained from the irregular waves along the X-axis of riser were entered to the Structural ANSYS software, and the stress of each riser was calculated. Finally, the stresses extracted from the Structural ANSYS were used to calculate the damage of each model, coded in the MATLAB software as the load counting process. These tensions were introduced as inputs in MATLAB software and ultimately counted the tension cycles, which the results of counting extracted the amount of fatigue damage in the structure. This difference in the life of risers stated the amount of clamping connections to the riser. Finally, due to mounting the riser at two levels of -12 and -44 and a depth of 65m, in the South Pars region (Phase 7), the oscillatory vibrations caused by the wave force and the vibrational force generated by the vortex The impact on the riser considerably reduced, and this tension reduction will increase the riser life.

It is suggested that if the platforms is in the South Pars region, which are part of the deepest Persian Gulf regions, instead of two clamps connecting to the platform of jacket razors, three clamps are considered, that are effective in gradually reduction of vibrations and accumulate fatigue.

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