

Welded joints of offshore fixed platforms for the extraction of oil, gas and other minerals on shelf

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Abstract. The world is actively developing offshore mineral deposits (oil, gas, coal, steel and other minerals). Offshore fixed platforms are actively used for offshore production. During operation, these platforms are subject to various impacts (wave, wind, etc.), which leads to the occurrence of alternating stresses. Current AC voltages activate fatigue processes in welded joints. Therefore, the knowledge of the peculiarities of the stress state of the welded joints of offshore platforms is the key to understanding the fatigue processes taking place in them. Nowadays various theories offer different understanding of the stresses acting in a welded joint. For example, the strength theory does not take into account the presence of "hot spots" in the welded joint, assuming a uniform distribution of stresses on the welding seam. The influence of static load on the general picture of the stress state in the welded joint was also investigated. As a result of the carried out researches the location of points with the greatest concentration of pressure, influence of thicknesses, diameters and an angle of interface of connected elements is established. The calculations showed that the sharper the angle of connection of the branch to the main pipe, the lower the value of stress concentration coefficients. Stresses acting in the welded joint also increase in case of increase in the diameter and wall thickness of the offshore platform columns. The analysis of the results of the computer model showed that the greatest contribution to the stress state of the platform is the tensile force and bending moment outside the plane, which indicates that the points with the highest stress concentration will be the points located in the direction of the wave beam.

1. Introduction

1.1. Fixed offshore platforms

The world's significant oil and gas resources are located on the sea and ocean shelves. Active production is carried out on the shelves of the Caspian Sea, the Baltic Sea, Sakhalin and other regions, where production is carried out using offshore oil and gas hydraulic structures, which are fixed offshore platforms (SSPs) of various purposes. Offshore fixed platforms are actively used for oil and gas production at offshore fields in the world. For example, in the Gulf of Mexico alone, approximately 4,500 such facilities are used. Fixed offshore platforms are actively used by Norway, Azerbaijan, Iran, a number of Gulf countries, China, Brazil, the United States and many other countries. In other words, it is safe to say that these facilities are widespread and play a key role in the production of oil and gas resources on the shelf.

It should be noted that the extraction of resources, and in particular oil and gas resources, is a



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complex process in which oil and gas production facilities are subject to significant impacts associated with both corrosion, temperature, vibration and product impacts. [1-16]. Therefore, the elements and welded joints of the platforms are in a complicated state during operation. Wave, wind and other loads in the welded joints activate fatigue processes that lead to gradual depreciation. The purpose of the article is to study the peculiarities of the stress state of welded joints of marine stationary platforms, which is the key to understanding the kinetics of fatigue processes taking place in them.

2. Materials and methods

At present, the stress state of welded joints of support blocks of offshore stationary platforms is estimated by the formula:

$$\sigma = \sqrt{\left(\frac{N}{\beta_f k_f L}\right)^2 + \left(\frac{6M_N}{\beta_f k_f L^2}\right)^2}, (1)$$

where: σ – stress in the welded joint; M_N – the moment of force from the total load; N – an equalizing force; L – seam length; k_f – corner seam cathetus.

Thus, it is initially assumed that in the tubular welded connection of the support block of the offshore fixed platform, the stress is distributed evenly over the welded connection. In the course of experiments on fatigue life of these welded joints, the author drew attention to the fact that the primary failure always begins in a certain area, at a point located in the plane formed by the column and branch. It has allowed assuming that at loading by a bend in a welded joint there are zones of non-uniform pressure. Studies of the stress state in this area have shown that the maximum stresses act at points 1 and 5 (see Figure 1). Gradually, the voltage is attenuated and its minimum values are reached in the direction of points 3 and 7 hours. These conclusions are well confirmed by DNVRP-C 203 [1].

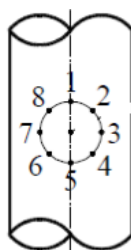


Figure 1. Point layout

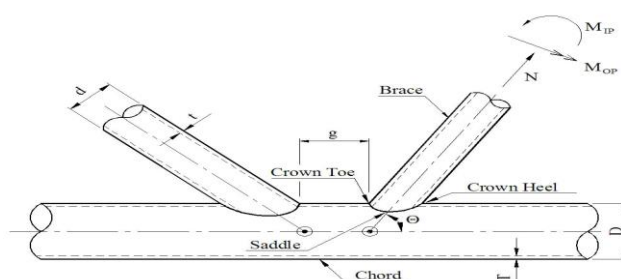


Figure 2. Basic scheme of loads on the welded joint

There is another representation about the stress state of the welded joint in the foreign normative documentation (basic scheme in Figure 2) and nominal stresses are determined from the conditions:

$$\Delta\sigma = \max \left\{ \begin{array}{l} \sqrt{\Delta\sigma_{\perp}^2 + 0,81\Delta\tau_{//}^2} \\ \alpha\Delta\sigma_1 \\ \alpha\Delta\sigma_2 \end{array} \right. \quad (2)$$

where: α - coefficient taken depending on the class of connections in the range from 0.72 to 0.9. In turn, the values of the main stresses should be calculated by formula:

$$\Delta\sigma_{1,2} = \frac{\Delta\sigma_{\perp} + \Delta\sigma_{//}}{2} \pm 0,5 \sqrt{(\Delta\sigma_{\perp} - \Delta\sigma_{//})^2 + 4\Delta\tau_{//}^2}, \quad (3)$$

The above picture is typical for the case of a flat stress state. In this case, the maximum shear stress is located at the site located at an angle of 45°, and the maximum shear stress is determined by the formula:

$$\Delta\tau = \frac{\Delta\sigma_{\perp} - \Delta\sigma_{//}}{2}, \quad (4)$$

This method of calculation is also valid for determining the stress state in the presence of cracks in the welded joint. The basic scheme for determining the stresses in this case is shown in Figure 3 (a) and Figure 3 (b).

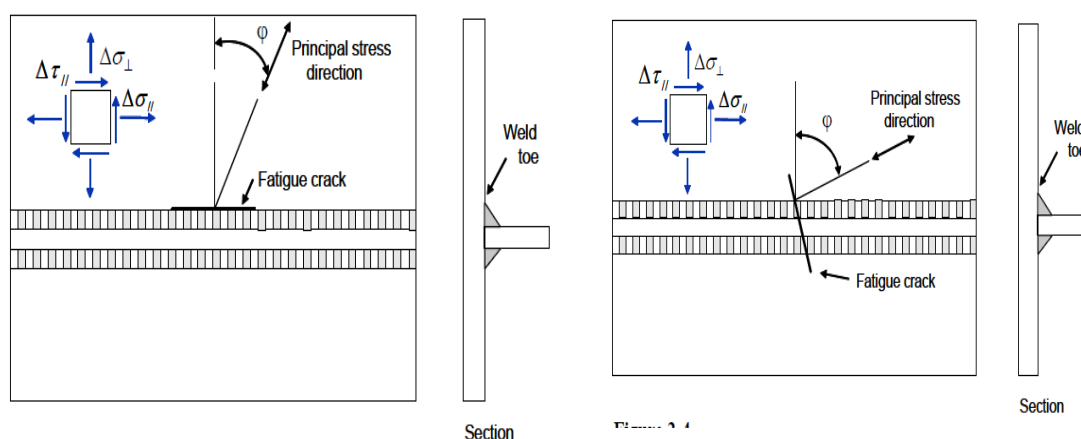


Figure 3 (a) and Figure 3 (b). Principle diagram of stress state and crack position

3. Discussion

3.1. Dependence of stress concentration coefficients on the diameter and wall thickness of the mating elements

The author carried out calculations (connection of pipes 114x114 mm in diameter) for bending conditions in the plane (formed by the column and branch), which showed that there is a double concentration of stresses in points №1 and №5 compared to the nominal values. Under actual conditions, for example, for connecting a column of 720 mm diameter with a wall thickness of 20 mm and a horizontal element of 325 mm diameter with a wall thickness of 12 mm, the stress concentration coefficient will be equal to 3. As the diameter and wall thickness of the connected horizontal elements increase under the same conditions, the stress concentration coefficient at these points will change slightly and is approximately also equal to 3. Thus, with a column diameter of 1080 mm with a wall thickness of 20 mm in connection with a horizontal element with a diameter of 325 mm with a wall thickness of 12 mm, the stress concentration coefficient will be equal to 3.8. At connection of the same column with a horizontal element of 526 mm diameter with a wall thickness of 15 mm, the stress

concentration coefficient will be equal to 4.8 mm. The experimental study clearly indicates the location of points №1 and №5 as points with the maximum values of stress concentration coefficients in the conditions of the experimental destructive moment.

3.2. Location of the points with the maximum concentration of stresses in the welded joint in the real operating conditions of offshore platforms

It is extremely important to consider how the location of the points with the maximum concentration of stresses in the actual operating conditions of the offshore platform will change, not only in terms of one bending moment, but also in terms of static weight stresses (platform elements and equipment) and tensile stresses from the forces acting in the horizontal elements. Partly this question is considered in DNV-RP-C 203 [1]. It is necessary to note that in real conditions of action of the bending moment occurs in the direction of action of wind-wave loading. Accordingly, the position of points with the maximum values of stress concentration changes as well. So the greatest values of concentration of tensions arise in points №3 and №7. These values also become more significant. So at connection of a column in diameter of 720 mm with thickness of a wall of 20 mm and a horizontal element in diameter of 325 mm with thickness of a wall of 12 mm the factor of concentration of pressure will be equal to 7. Further modelling has shown that the change of values of concentration of pressure in this case is caused first of all by change of a thickness of a wall of connected elements. So at connection of a column in diameter of 720 mm with thickness of a wall of 20 mm and a horizontal element in diameter of 525 mm with thickness of a wall of 12 mm the factor of concentration of pressure will be equal to 7, 77. The increase in the wall thickness of the horizontal element up to 14 mm gives the value of the stress concentration coefficient 9.1 In the studies conducted in [1, 14] it is shown that the stress state of the welded joints is influenced by the shape of the welded joints, which varies along the line of coupling of the pipe elements and depends on the angle of inclination of the branch to the waist tube, the ratio of the diameters of the joined elements, the local stress concentration at the point of transition of the weld to the base metal is affected by the radius of rounding of the weld, as well as the value of the welded seam roll and the angle of inclination between the It is necessary to take into account the following requirements: the welded joint has a smooth transition and concave smooth surface (without burns, influxes, contractions, interruptions) with a convexity within the range of 0.5-3.0 mm and a width of not more than 2.5 diameters of the electrode, as well as if it does not have a weld, neprovars, undercuts, craters, etc. If these requirements are not met, a local stress concentration factor should be introduced. The type of loading is of great importance, which determines the position of the hot spots. Calculate the stress concentration coefficients for connecting the elements (diameter x wall thickness) 325x12 and 720x20. We classify the position of hot spots as follows.

Table 1. Dependence of the stress concentration coefficient on the type of loading

<i>Load type</i>	<i>Column</i>		<i>Branch</i>	
	<i>Saddle</i>	<i>Crown</i>	<i>Saddle</i>	<i>Crown</i>
	T- joining			
Axial load applied to the branch (chord ends are rigidly fastened)	11	4	10	2.7
Axial load applied to the branch (chord ends are hinged)	11	5	10	3
Bending moment in the plane of the formed column and horizontal element	-	3	-	3
Bending moment perpendicular to the plane of the formed column and horizontal element	8	-	7	-

The analysis of the computer model of the offshore platform has shown that the maximum values of stress concentration, provided that all the main loading circuits (except for torque in the plane) are in "saddle" points №3 and №7 (see Figure 1), which clearly indicates that the destruction caused by the action of alternating voltages will be located in the points №3 and №7. Consider the influence of

the angle for connections of the type of struts. We investigate the values of stress concentrations when connecting the pipe at angles 300 and 570 at various types of loading.

Table 2. Dependence of voltage concentration coefficient on the type of load and connection angle of the column and branch

<i>Type of loading</i>	<i>Kolumn</i>		<i>Branch</i>	
	<i>Saddle</i>	<i>Crown</i>	<i>Saddle</i>	<i>Crown</i>
off-plane bending moment				
Abutment angle				
30 ⁰	2.3	-	2.5	-
57 ⁰	5.3	-	5.9	-
Axial load applied to the branch (the ends of the chord are fixed rigidly)				
30 ⁰	3.71	3.58	2.92	2.69
57 ⁰	8.5	3.9	6.9	2.69
Axial load applied to the branch (chord ends are hinged)				
30 ⁰	4.24	3.96	2.92	2.99
57 ⁰	9.1	4.6	6.98	2.99

From the obtained values it becomes obvious that the sharper the angle of connection of the branch to the main pipe, the lower the value of stress concentration coefficients. As in the previous case, the character of the hot spots location is preserved, these are points №3 and №7. However, it is not clear how the stress state will change under static gravity loading. The models constructed by the author (with different wall thicknesses and diameters of the elements to be joined, the length and height of the sutures' catheters) under loaded only with static load from weight showed the following picture (see Figure 4), i.e. the most stressed are the points 1 and 5, but the values of stress at points 3 and 7 are only approximately 15% lower. The main combinations of loads create alternating voltages at points №3 and №7, indicating that they will be the most stressed (Figure 4).

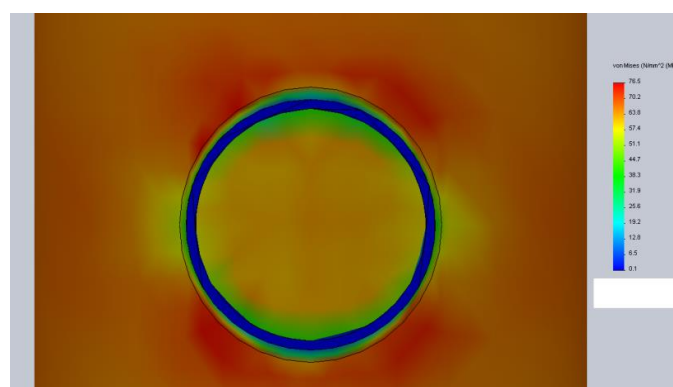


Figure 4. Stress distribution in the welded joint and columnbase metal under the action of weight loads

3.3. Methods of analysis of the stress-strain state of the sea platform on the computer model made in the StructureCAD software package

The authors analyze the stress-strain state of the platform at different combinations of loading, absence and propagation of wind wave load along the X-axis. In view of the complexity of taking into account the mutual influence of numerous mating elements for the study were developed models of the platform in the StructureCAD software package (Figures 5 (a) and 5 (b)), which allowed establishing the main types of load, creating alternating stress in the welded joints of the platform.

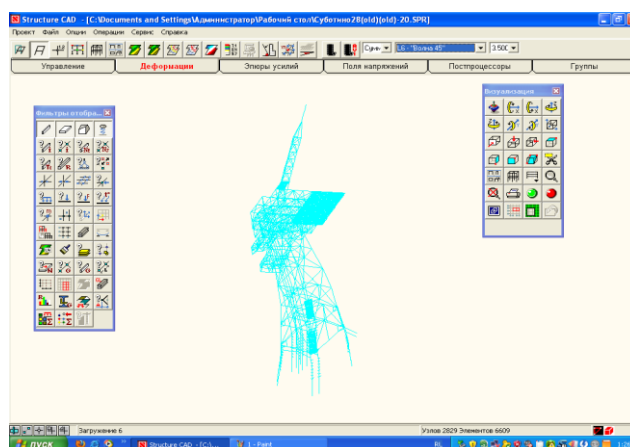


Figure 5 (a). Deformation scheme of the support block at propagation of wind-wave load along the X-axis

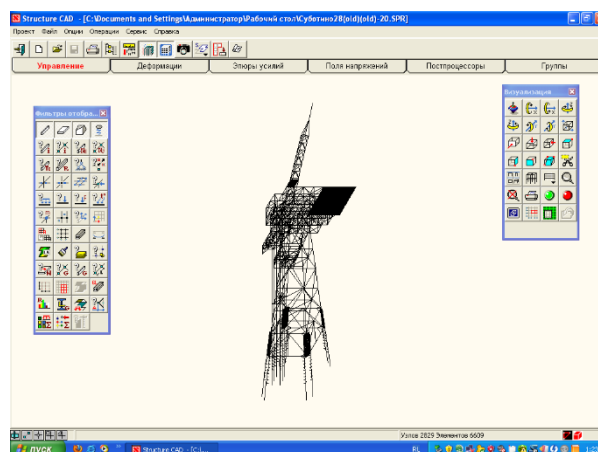


Figure 5 (b). Deformation scheme of the support block in the absence of wind-wave load

The analysis of the computer models of the platforms, which are under the influence of the wind-wave load, has shown that the main types of load, creating an alternating voltage, can include the tensile load on the branch, as well as bending moments acting as a plane and perpendicular to the plane formed by the connection of the column and horizontal elements. The greatest contribution to the stress state of the platform is made by the tensile force and bending moment outside the plane, which indicates that the points with the highest stress concentration will be points №3 and №7.

4. Conclusion

As a result of the carried out researches the location of points with the greatest concentration of pressure, influence of thicknesses, diameters and an angle of interface of connected elements is established. The calculations carried out on the basis of the standard [1] showed that the sharper the angle of connection of the branch to the main pipe, the lower the value of stress concentration coefficients. Stresses acting in the welded joint also increase in case of increase in the diameter and wall thickness of the offshore platform columns.

The author also investigated the influence of static load on the location of points with the highest stress concentration, as a result of which it was established that the most stressful are points №1 and №5, but the values of stress at points №3 and №7 are lower by only about 15%. The main

combinations of loads create alternating stresses at points №3 and №7, which indicates that they will be subject to the highest stress (see Figure 1). It has been established that the main loads producing alternating voltages under the actual conditions of operation of the offshore platform include the tensile load on the branch and bending moments acting both in the plane and perpendicular to the plane formed by the connection between the column and the horizontal elements. The analysis of the results of the computer model has shown that the greatest contribution to the stress state of the platform is the tensile force and bending moment outside the plane, which indicates that the points with the highest stress concentration will be the points in the direction of the wave beam.

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