Results of the experimental study of the fatigue characteristics of the repaired welded joint of the marine stationary oil and gas producing platform

C Teodoriu¹, I V Starokon² and Ch S Guseynov²

¹ The University of Oklahoma, 660, Parrington Oval, Norman, OK, 73019-0390, USA
² National University of Oil and Gas «Gubkin University», 65, Leninsky Prospekt, Moscow, 119991, Russia

Abstract. Offshore stationary platforms are actively exploited in the world. The lifespan of some of these platforms exceeds 20 years. Such a significant period of operation leads to the fact that the platforms are exposed to various loads for a long time, causing alternating stresses and, as a result, fatigue damage, including fatigue cracks in welded joints and the base metal of the platform. When fatigue cracks are identified, defect joints are repaired commonly using welding techniques. However, the duration of the subsequent operation of such repaired welded joints is not currently known. The authors conducted an extensive experimental study to understand the life span of welding repair technologies. This approach was for the first time used to repair the welded joint of a platform located in the White Tiger. White Tiger is the Vietnamese offshore oil field, located 200 km east of Ho Chi Minh City on the shelf of the South China Sea. The result of this study was the fatigue diagram and its equation, which were first obtained by the authors.

Email: starokon@mail.ru

1. Introduction

Fixed offshore platform, commissioned more than 20 years ago, are still operated in the world. In connection with this significant period of operation during which the platform was exposed to various loads that cause alternating stresses and as a result the fatigue damage, the problem of estimation of residual resource of welded joints of offshore platforms after repair becomes extremely urgent. In accordance with Russian Federal law No. 116 "On industrial safety of hazardous production facilities" [1] after 20 years of operation the platform should be subjected to comprehensive technical diagnostics, based on which part of the welded joints with unacceptable defects should be repaired. To confirm the reliability of such repaired joints, residual resource calculation must be made in the framework of the preparation of the conclusions of industrial safety expertise. In preparing these opinions, the resource of welded compounds of the platform is determined from various conditions (for corrosion rates, compliance strength, etc.), including assessment of the resource for each welded joint based on the conditions of the fatigue life under the action of cyclic loads [2, 3]. The residual resource of the long maintained welded joints of platforms differs from a recently commissioned. However, determination of the impact of variable stresses on such elements is possible only by defining in any way the limit of endurance of these elements [4, 5]. In this article, we will talk about the experimental method of determining the fatigue limit of welded joints of offshore platforms on the example of the technology of repair, designed for the repair of the platforms on the field "White tiger"
Many authors have investigated the problems of metal fracture in the oil and gas industry [8, 9], including for tubular joints in sea and land conditions [10, 11, 12].

2. Results and discussion
In the case under consideration during the survey, on one of the platforms installed at the White Tiger field, cracks were revealed (Figure 1) at the joint section of the column with a diameter of 2000 mm and a horizontal pipe-shaped element with a diameter of 1000 mm. The wall thickness of the column is 38mm.

Figure 1. Crack discovered during the survey of the offshore platform

The crack has the form described in [7] and formed in the transition zone from the weld to the base metal and subsequently developed during operation along the fusion line. After the crack circled the horizontal element, its top continued its development into the base metal of the column wall.

To stop the development of the crack, it was decided to weld the crack itself and install a reinforcing pad on the wall of the column. It should be noted that when using arc welding to repair supports with a wall thickness of 38 mm, there is a high probability of the formation of cold cracks in the heat-affected zone, which is caused by the high cooling rate of the surrounding base material. When welding structures with such a significant wall thickness, it is recommended to preheat to reduce the cooling rate, but when welding under water in limited conditions of the caisson, it is extremely difficult to perform heating. To exclude heating during welding of low alloy steels, the following technological method was used. Before welding, a layer of austenitic metal was deposited on the welded edges, then the welded edges were welded together. This technique allows you to create a buffer layer of limy austenitic material, which reduces the likelihood of cracking during welding. The welding itself was carried out by the so-called dry method. For this, a caisson was used, i.e. a special chamber filled either with air (for depths up to 20 meters) or with a mixture of helium and oxygen at depths greater than 20 meters, in which, regardless of depth, a partial oxygen pressure of 29.4 kPa is maintained. In this case, the welder is also placed in this sealed chamber. The experience of using this technology shows that welded joints made in this way do not differ in quality from those made under ordinary atmospheric conditions. At the same time, the caisson should be hermetically adjacent to the structural section being repaired under water and be spacious enough for welders to work in it.

Remedial works of the resulting crack were carried out in the following sequence. The crack was either welded or, if a through hole was formed, which had to be sealed, a plug was introduced in the form of a curved plate of small thickness, the second was welded to the pipe wall with an angular seam in a wet way. Since the plug is not part of the supporting structure, the use of a wet welding
method is acceptable. For welding, austenitic electrodes of the SoufTouch brand were used. It should be borne in mind that the repair of the supporting structure of oil platforms is allowed only by dry method. After welding the crack, a reinforcing pad was installed outside of the column. Then, the lining was assembled at the tack in the caisson and the sections of the column surface 30–40 mm wide were cleaned, adjacent to the end of the lining along its entire contour to a metallic luster. Then, a buffer layer along the contour of the patch is deposited on the surface of the support body by austenitic electrodes. The junction of the buffer layer to the end of the lining is cleaned to remove slag inclusions and prevent the formation of pockets. After that, the main fillet welds are welded. To ensure a smooth transition from the weld to the base metal, the external contour of the weld must be treated with an abrasive tool. The presence of austenitic weld support on the surface of a pearlite body can contribute to an increase in the rate of electrochemical corrosion. To prevent corrosion at the repair site, it is necessary to carry out a protective painting of the welding zone and install protectors.

To assess the resource of the welded joint, repaired as described above, an experiment was designed and conducted. Experimental installations were built in such a way that a welded joint is mimicked in the laboratory scale and cyclic loaded until a crack is observed. The laboratory scale setup consists of a 7” inch vertical pipe to which a 4” horizontal pipe is welded. The weld is first inspected to show that is free of defects and then cyclic loaded using a hydraulic cylinder controlled by a computer until the first crack is observed. Once the crack is measured, the crack is repaired, and the cyclic loading is restarted until a new crack is detected.

![Figure 2. The photo of the experimental setup](image)

An algorithm implemented in the LabVIEW software package was used as a control module. The experiment was carried out as follows. From the high-pressure pipeline with compressed air, a retraction was conducted to the module for monitoring the values of the applied force. In this module, the pressure which controls the force applied to the welded joint was decreased to a predetermined value set in the control module of the experiment. Then, pressure entered the switching unit of the experimental load vector. And then it entered the pneumatic cylinder in which it was transformed by virtue of a certain value, which, under the control of the switching unit, developed sequentially along the vertical axis in different directions. This load created a destructive experimental moment in the studied welded joint. The general installation diagram is shown in Figure 3. The author carried out numerical and analytical modelling of the stress state of welded joints of the offshore platform located at the Black Sea fields. As a result of modelling, it was found that under various conditions of wave action, the maximum amplitude of alternating stresses is in the range from 50 to 90 MPa.
The results of the experiment are shown in Table 1.

Table 1. The number of cycles $N$ obtained from the experimental study of the resource of the restored welded joint

| Stress amplitude, MPa | Number of cycles, $N$ | The resulting $N$ indicating the magnitude of the variance |
|-----------------------|-----------------------|---------------------------------------------------------|
|                       | Sample №1 | Sample №2 | Sample №3 | Sample №4 | Sample №5 | Sample №6 | $N \pm \Delta x$ |
| 90                    | 81538     | 75557     | 74514     | 79348     | 77516     | 73243     | 76953±4964 |
| 51                    | 1041861   | 1167943   | 1324561   | 1287892   | 1165742   | 1216567   | 1200761±160142 |

The calculation of the endurance limit was carried out by the method of D.I. Goltseva [10] according to the formula:

\[
\sigma_R = \frac{1}{2} \sqrt{(\sigma_1^2 N_1 - \sigma_2^2 N_2)/(N_1 - N_2)},
\]

As a result, the endurance limit of 47 MPa was calculated. However, the endurance limit obtained as a result of experiments must be correlated with the actual operating conditions of the welded joints of the offshore platform in the conditions of the shelf. In [10,11], the following main parameters were identified that should be taken into account: the ratio of sample sizes to real objects, roughness, asymmetry of stress cycles, residual stresses, and other factors. Using this technique, we compare the obtained experimental result with a real welded joint.

Table 2. Results of processing the experimental endurance limit of a welded joint, taking into account real conditions of operation on the shelf

| Name of the parameter | Result |
|-----------------------|--------|
| The limiting amplitude of the first main stress, $\sigma_{1a}$ | 90,3 |
| Residual stress asymmetry coefficient, $R_{res}$ | 0.65 |
| Tensile stress coefficient, $\beta_1$ | 0.1 |
| Compressive stresses coefficient, $\beta_2$ | 0.4 |
| Normal stress coefficient, $\beta_3$ | 0.12 |
| Endurance limit, $\sigma_e$ | 47 |
| Endurance limit based on actual operating conditions, $\sigma^{act}_e$ | 15 |

1-other values are given in the work [7].
After the necessary calculations, we obtain the endurance limit of 15 MPa, and the slope of the fatigue curve \( m = 3.6 \). Calculation in accordance with the Baskvin equation made it possible to determine the \( N_G \) fracture point at the level of \( 3.1 \times 10^7 \) cycles. The approximating equation of the fatigue curve and the value of \( N_G \) are calculated in the Wolfram software package. As a result, the following equation was obtained:

\[
\sigma_a = 224,395 - 12,1201 \cdot \ln(N),
\]

(2)

where: \( \sigma_a \) - amplitude of alternating stresses acting in a welded joint; \( N \) - number of cycles.

The fatigue diagram of the restored welded joint by the repair method developed at the White Tiger deposit was built as shown in figure 4.

**Figure 4.** Fatigue diagram of reconditioned welded joint repaired according to the repair technology developed during the repair of the offshore platform at the White Tiger field

Analyzing it, we can say that the value of the endurance limit according to the results of an experimental-analytical study turned out to be higher than for a new compound, but the dependence of the amplitudes of the alternating stresses on the number of cycles shifted to the right, which indicates that the destruction of the compound repaired by this method will occur later than described in the technology of welding cracks with the installation of crack traps.

3. Conclusions

An experimental setup was built to simulate the fatigue of welded joints commonly used for offshore structures.

The experimental investigations have shown that the number of cycles to failure are in the range of 77000 cycles for 90 MPa induced stress and 1.2 million cycles at a stress level of 50 MPa.

Using the experimental data a new equation was derived to assess the fatigue resistance for the White Tiger field selected platform.

The value of the endurance limit according to the results of an experimental-analytical study turned out to be higher than for a new compound, but the dependence of the amplitudes of the alternating stresses on the number of cycles shifted to the right.

**Acknowledgement**

The authors would like to thank the Technical University of Clausthal for the laboratory support offered for the experimental investigations.
References

[1] Bär F and Overmeyer T 2013 Approaches for determination and reduction of non-productive times of drilling rigs for deep wells *Logistics Journal* 7 2192-9084

[2] Topchiev A 2020 Design and monitoring of oil and gas industry facilities based on the use of ultra-light aviation and digital technologies *ICMSIT 2020 Journal of Physics: Conference Series* 1515 042030 IOP Publishing doi:10.1088/1742-6596/1515/4/042030

[3] Bezkorovayniy V, Bayazitov V and Bobov D 2018 Management of the Design and Construction of Offshore Oil and Gas Facilities with Bim Base *IOP Conference Series: Materials Science and Engineering* 463 (4) 042056

[4] Reitenbach V, Ganzer L, Albrecht D and Hagemann B 2015 Influence of added hydrogen on underground gas storage: a review of key issues *IOP Conference Series: Environmental Earth Sciences* 73(10) 6927–37

[5] Hagemann B, Rasoulzadeh M, Panfilov M, Ganzer L and Reitenbach V 2016 Hydrogenization of underground storage of natural gas. Impact of hydrogen on the hydrodynamic and biochemical behavior *IOP Conference Series: Environmental Earth Sciences* 20 595–606

[6] Efimenko L A, Elagina O Yu and Kapustin O E 2017 Equipment for determining the carbon equivalent of low-carbon pipe steels of a new generation *Welding production* 10 3-7.

[7] Lukyanov V F, Rogozin D V and Gritsykhin V A 2011 Repair of metal structures of offshore drilling and oil production platforms *Vestnik DGTU* 9(60) 1630-1636

[8] Yuan Z, Schubert J, Esteban U, Chantose P and Teodoriu C 2013 Casing failure mechanism and characterization under HPHT conditions in south texas *Society of Petroleum Engineers - International Petroleum Technology Conference 2013, IPTC 2013: Challenging Technology and Economic Limits to Meet the Global Energy Demand* vol 3 pp 2207-17

[9] Teodoriu C 2012 Selection criteria for tubular connection used for shale and tight gas applications *Society of Petroleum Engineers - SPE/EAGE European Unconventional Resources Conference and Exhibition* pp 865-70

[10] Starokon I 2019 Methods for solving the problems of extending the resource of offshore stationary platforms *Journal of Physics* 1399 055087

[11] Starokon I and Ermakov A 2019 Assessment of jacket-type platform stress state in corrosion environment *Materials Science and Engineering* 700 012018

[12] Giotis T, Pavlou D and Belibassakis K 2019 Flexural dynamic behavior of submerged cylindrical structures under wave loads *IOP Conference Series: Materials Science and Engineering* 700 012022