Comparative analysis of the fatigue characteristics of repaired compounds of the “T” and “K” types of fixed offshore platforms

I V Starokon

Russian state university of oil and gas named by I.M. Gubkin, Leninskiy pr. 65, Moscow, 119991, Russia

E-mail: starokon79@mail.ru

Abstract. The study of the fatigue characteristics of repaired welded joints is an important task to determine their remaining lifetime. At present, there is no methodology that allows calculating the resource of reconditioned welded joints; therefore, industrial safety experts use the diagrams and fatigue equations given in the normative documentation for new joints when extending the resource. It is also not established whether there is a difference in fatigue characteristics depending on the type of pipe joint “T” or “K”. In this regard, the authors conducted research during which a new welded joint was brought to primary failure, and then repaired and brought to repeated failure. Based on these experiments, graphs were constructed that describe the dependence of the number of cycles on the values of the amplitudes of the alternating stresses and a mathematical equation was obtained that describes the fatigue parameters for both “T” and “K” types of welded joints.

1. Introduction

The Russian Federation is actively producing on the shelves of the Caspian, Baltic, Sakhalin and other regions. Mining is carried out using fixed offshore platforms (FOPs), which are widespread and play a key role in the extraction of oil, gas, coal and other resources on the shelf. According to paragraph 3 of the Federal norms and rules in the field of industrial safety "Safety rules for offshore facilities of the oil and gas complex", approved by Order No. 105 of the Federal Service for Ecological, Technological and Nuclear Supervision of March 18, 2014. [1], FOPs are hazardous production facilities of the offshore oil and gas complex, the operation of which is at risk of accidents or incidents. Accidents during the operation of such facilities can have serious consequences for the life of human personnel operating the marine platform, and can cause significant damage to the natural environment and property [1-20]. To prevent accidents on offshore platforms in accordance with clause 6, “Safety Rules for Offshore Facilities of the Oil and Gas Complex,” design decisions are made based on ensuring durability under the influence of loads. Separately, it is necessary to single out the problem of assessing the resource of restored welded joints under the action of the loads characteristic of the field on the shelf. During operation, offshore platforms are subject to diagnosis. Based on the results of this diagnosis, a decision is made about the need to repair defects in welded joints that arose during operation. At the same time, there is currently no information on methods for calculating the resource of such repaired welded joints. The solution to this problem, according to the authors, can only be got by obtaining the fatigue equation obtained on the basis of the experiment.
The focus of this article will be the study of two main types of welded joints of offshore platforms, which received the designation "T" and "K" in the technical literature. A “T” pipe joint is two pipes welded at right angles (figure 1), a “K” pipe joint is a pipe welded together (figure 2) at a certain acute angle (up to 90°). Each of the compounds has its own performance features. In some cases, the T-joint and brace do not have a common nodal connection, because with this method of connection, the magnitudes of the stresses in the assembly slightly increase.

2. Methods
To study the fatigue properties of metal of welded joints of "T" and "K" types, it is necessary to establish differences in their stress state. The determination of the stress state in a welded joint is a difficult task, for the solution of which it is necessary to take into account the mutual influence of many structural elements of the support block. According to the author, to take into account this mutual influence, it is advisable to use the displacement method and the CAD complex for computer-aided design, which allows you to automatically calculate the values of displacements and angular deformations. The authors constructed a digital model of the support block (figure 3) and loaded with the appropriate loads for the project, which allowed us to determine the difference in the values of linear and angular deformations arising in welded joints (table 1). The following load combinations were specified: loads from dead weight, from the weight of equipment and marine fouling, buoyancy of the aquatic environment (combination of loads K1). Then, the load from the wind-wave action (BBH) was added to this load combination. Moreover, to take into account the mutual influence of the elements, the direction of development of the wind-wave load was set both along the X axis (combination of loads K2) and in the direction at an angle of 45° to the axis X (combination of loads K3).
Table 1. The values of the amplitudes of the alternating stresses acting in the studied welded joints without taking into account the static component.

| Load combination | T-joint | Connection brace "K" -type |
|------------------|---------|---------------------------|
| Values of amplitudes of alternating stresses, $\sigma_a$ |         |                           |
| $K_2$            | 50.2    | 81.4                      |
| $K_3$            | 91.2    | 115.1                     |

To solve this problem, experimental installations (EI) were built on which primary and repeated destruction of the restored (repaired) welded joints was carried out. The schematic diagram of the installation is shown in figure 4.

Figure 4. Schematic diagram of the experimental setup.

As it was shown above, the compounds “T” and “K” of types (species) are studied. In order to comply with the similarity of the experiment to the actual object and the conditions of its operation, the following requirements were met:

- applied pipe molds;
- The experimental load was created due to the action of the bending moment;
- used welding materials (E4903-P according to ISO 2560-2009), providing similar values of the tensile strength of the welded joint equal to 420 MPa. As a column model, pipes made of material according to DIN 2393-1994 RSt37-2 were used, and 9MnSi5 steel pipes were used to model the waist pipe.

The experiment was carried out as follows. The high pressure pipeline with compressed air was connected to the module for monitoring the values of the experimental pressure, in which it was changed.
to a predetermined value set in the control module of the experiment. Then, the pressure in the switching unit of the experimental load vector was transformed by virtue of a certain value. The indicated force under the control of the switching unit developed sequentially along the vertical axis in opposite directions, which created an experimental bending moment and alternating stresses in the studied welded joints of "T" and "K" types. When a crack appeared, the joint was repaired. Holes with a diameter of 8 mm were drilled at the ends of the crack. The metal along the crack was chosen with abrasive wheels with a run of not less than 25 mm beyond the visible boundaries of the crack on each side, and welded (figure 5 and figure 6). Then the welded joint was brought to the appearance of a new crack.

![Figure 5. The repaired "T" -type compound.](image)

![Figure 6. The repaired "K" -type compound.](image)

A series of four samples of repaired T-shaped welded joints was tested at the level of amplitudes of alternating stresses of 50 MPa and 90 MPa. The experimental results are shown in table 2. 

**Table 2.** The number of N cycles at various voltage amplitudes obtained experimentally during the test of the repaired T-joint.

| Sample № | Sample № | Sample № | Sample № | Sample № | Sample № | Voltage amplitude $\sigma_1 = 51$ MPa |
|----------|----------|----------|----------|----------|----------|-------------------------------------|
| 1        | 2        | 3        | 4        | 5        | 6        | $\bar{x}$ | $s_n$ | $s_x$ | $\Delta x$ | $X \pm \Delta x$ |
| 40100    | 41400    | 42900    | 43036    | 40648    | 42981    | 41844    | 1304   | 652   | 2073    | 41844 $\pm$ 2073 |

| Voltage amplitude $\sigma_2 = 90$ MPa |
|-------------------------------------|
| 9178 | 8232 | 9652 | 9014 | 9305 | 8965 | 9041 | 474 | 237 | 753 | 9041 $\pm$ 474 |

3. **Result**

As a result, the endurance limit of 43 MPa was calculated.

Using the Klykov technique, we compare the obtained experimental result with a real welded joint. We calculate the limiting amplitudes of the main stresses, the coefficients of the influence of normal stresses, and other auxiliary quantities, taking into account the influence of residual stresses:
Table 3. The results of processing experiments obtained during the test of the repaired T-joint and calculation of the limiting amplitude of the first principal stress.

| $\sigma_1$ | $R_1^{oct}$ | $M_{max}^{oct}$ | $C_1^{oct}$ | $K$ | $a$ | $\eta_1$ | $\eta_2$ | $\eta_3$ | $\sigma_{-1}$ | $\sigma_1^{n}$ |
|------------|-------------|----------------|-------------|-----|----|--------|--------|--------|----------|-----------|
| 90.3       | 0.65        | 2.00           | 0.53        | 1.4 | 0.52| 0.1    | 0.4    | 0.12   | 43.04     | 12.61     |

Designation:
- $\sigma_1$ – a limiting amplitude for the first primary stress;
- $R_1^{oct}$ – an asymmetry coefficient of residual stresses;
- $M_{max}^{oct}$, $C_1^{oct}$, $K$ – auxiliary coefficients

$\eta_1$, $\eta_2$, $\eta_3$ and – an influence coefficient of tension, compressive and bending normal stresses, respectively

$\sigma_{-1}$ – a fatigue range

$\sigma_1^{n}$ – a limiting amplitude for the first primary stress

Thus, as shown by computational and experimental studies, the endurance limit of a T-type welded joint of a type after repair is 12.61 MPa.

Additional points were also obtained at the level of amplitudes of alternating stresses of 35 MPa (the number of cycles before failure 400,000) and 24 MPa (the number of cycles before failure 1,000,000). The graph of the results obtained during the experiments with the repaired "T" compound is shown in figure 7.

Figure 7. Results obtained during experiments with the repaired "T" joint: $\sigma$ - the amplitude of the alternating stresses acting in the welded joint; N - number of cycles.

In the same way, the parameters of the fatigue equation for the "K" compounds were determined. The endurance limit for the restored "K" connection according to the results of processing the experimental data is 13.6 MPa. Graphically, the results obtained during the experiments with the repaired "K" compound are shown in figure 8.
Figure 8. Results obtained during experiments with the repaired "K" joint: σ - the amplitude of the alternating stresses acting in the welded joint; N-number of cycles.

4. Conclusion
The results of the study showed that the value of the endurance limit, as well as the number of cycles for both types of joints studied, are almost the same, from which we can conclude that the σ-1 parameters of FOPs welded joints are determined by the mechanical properties of the material and the type of repair. Based on the experimental studies for the repair technology in the form of welding the cracks and creating crack traps, we calculate the equation:

$$\sigma = 216,915 + 13,9917\ln N,$$

(1)

where: σ - the amplitude of the alternating stresses acting in the welded joint; N-number of cycles.

References
[1] Guseynov C 2010 Methodological recommendations for developing a strategy for the development of offshore oil and gas fields Intellectual Property Patent No 10-281 (Moscow: Rospatent)
[2] Guseynov C 2020 In Arctic - new technical means and technologies for the development of oil and gas fields in long-term freezing deepwater areas IOP Conference Series: Materials Science and Engineering 734 012174
[3] 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
[4] 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 3 2207-17
[5] 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
[6] Topchiev A Design and monitoring of oil and gas industry facilities based on the use of ultra-
light aviation and digital technologies. *IOP Conference Series: Materials Science and Engineering* **734** 1

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

[8] Starokon I 2019 Development of theoretical bases of analysis of reliability of marine oil and gas construction with regard to temperature impact. *Journal of Physics* **1399** 055066

[9] Starokon I, Golovachev A, Nadyrov R 2019 Methods for Increasing the Fatigue Life of Repaired Welded Joints of Offshore Oil and Gas Facilities. *IOP Conference Series: Earth Environ. Sci.* **272** 032090

[10] Starokon I and Ermakov A 2019 Assessment of jacket-type platform stress state in corrosienvironment. *Materials Science and Engineering* **700** 012018

[11] Boersheim E, Reitenbach V and Albrecht D 2019 Summary of an experimental investigation to evaluate potential technical integrity issues in porous UGS containing hydrogen. *EAGE/DGMK Joint Workshop on Underground Storage of Hydrogen* **2019** 1-3

[12] Pfeiffer W and Bauer S 2015 Subsurface porous media hydrogen storage-scenario development and simulation. *Energy Procedia* **76** 565–572

[13] 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

[14] 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

[15] Albrecht D, Reitenbach V 2015 Investigations on fluid transport properties in the North-German Rotliegend tight gas sandstones and applications. *IOP Conference Series: Environmental Earth Sciences* **73** 5791

[16] Panfilov M, Reitenbach V and Ganzer L 2016 Self-organization and shock waves in underground methanation reactors and hydrogen storages. *IOP Conference Series: Environmental Earth Sciences* **75**(4) 313

[17] Reitenbach V, Ganzer L and Albrecht D 2014 Influence of Hydrogen on Underground Gas Storage. *Research Report DGMK-752 73* 6627-937 (Hamburg)

[18] Ganzer L, Reitenbach V, Pudlo D, Albrecht D, Singhe AT, Awemo K N, Wienand J and Gaupp R 2014 Experimental and numerical investigations on CO2 injection and enhanced gas recovery effects in Altmark gas field (Central Germany). *Acta Geotechnica* **9**(1) 39-47

[19] Zolotukhin B and Gayubov 2019 A Machine learning in reservoir permeability prediction and modelling of fluid flow in porous media. *IOP Conference Series: Materials Science and Engineering* **700** 012023

[20] 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