Resource of repaired welded compounds of marine oil and gas structures

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Abstract. The article deals with the assessment about service life of welds for offshore oil and gas facilities. Research covered offshore fixed platforms (OFP) of the core type. It is noted that to date, any studies have not been undertaken on the service life of reconditioned (repaired) OFP welds. Through specialized software systems StructureCAD and SolidWorks, models of offshore platforms were built and maximum amplitudes of alternating stresses acting in welds in the Black Sea were established. As results of the tests and processing observed data, the endurance limits of the repaired welds were calculated, which amounted to approximately 13 MPa (1885.49 psi). We also obtained characteristic points of the dependence of the number of cycles to failure N on the values of the amplitude of the alternating stresses σa. The experiment made it possible to create fatigue diagrams for restored welds of offshore fixed platforms. Using the example of a T-type welded joint, it was shown that the service life of a restored weld is much lower than the service life of a new one.

1. Introduction
The Russian Federation has significant oil and gas resources located at the bottom of the sea. In recent years, our country gained access to existing and promising offshore oil and gas fields in the Black Sea, which are extracted using offshore oil and gas facilities. The oil and gas facilities which are called offshore, where we carry out the processes of mining, transportation, storage and other oil and gas from offshore fields [1-10]. This article focuses on offshore fixed platforms of beam elements type, which were selected as a target of research. Some of these platforms are original from USSR and are over 30 years [10-15]. Offshore oil and gas facilities operate under adverse marine conditions, which characterized by corrosion activity, significant loads from waves, flows and other influences, they are subject for numerous wears. An analysis of their accident rate in recent years has shown that the accident frequency remains high. A significant part of these accidents is associated with fatigue processes of metal structural elements and welds. The fatigue of the material of offshore oil and gas facilities can cause the destruction of individual elements and the loss of the bearing capacity of whole structure. Fatigue factor must be taken into account at the design stage is to ensure the reliable and safe operation of OFP. However, according to the author, the methodology for assessing the service life or fatigue of long-term welds of OFP, does not require taking into account some important conditions that are characteristic of offshore fields and affecting fatigue and processes that arise in connection with these
tasks. Among such tasks, the problem of assessing the service life of repaired (restored) welds should be highlighted separately.

As you know, the welded joints of the platforms according to the results of a comprehensive diagnostic examination undergo repair. To date, it has not been established whether their resource will be the same as that of the new connection, or whether it will be different. Therefore, the author sets the task of studying the service life of restored welded joints and identifying differences in this period compared to new welded joints.

2. Methods
The solution to this problem is based on the experiment, which was to bring the model of the welded joint to the initial destruction and subsequent repair, after which the next destruction is carried out. According to the classification DNV, all welds of OFP, depending on their geometry, can be classified as “T” and “K” types. In the literature, there is such a classification as “X” compounds. However, in reality, the stress state of such “X” compound can be described by a “T” connection. Therefore, this article describes only the experimental results for compounds “T” and “K” types.

The experiment was the following:
The author has developed experimental installations in which the primary (see figure 1) fracture of welded joints was carried out before a crack appeared. After the formation of this crack at a distance of 12 mm from the ends, a crack trap was made, which was a hole with a diameter of 8 mm and was designed to reduce the stress concentration at the crack tip. The metal along the crack was cut at a distance of 30 mm in such a way as to form an imitation of a V-shaped groove of the edges (see figure 2).

Figure 1. The primary crack in the welded joint of the experimental plant.
Figure 2. Welded joint of the experimental plant after repair.

3. Discussion
3.1 Experimental test result
A series on four samples refurbished welded “T” joints were tested amplitudes of alternating stresses of 54 MPa (7832.038 psi) and 90 MPa (13053.40 psi). All models developed for the platform operating conditions in the Black Sea, in conditions of combined wind-wave loading at different angles to the platform. The results are shown in table 1:
Table 1. The number of cycles N to failure obtained during the test of repaired welded joints.

| Voltage amplitude $\sigma_a$, MPa | Model number | Average | Dispersion | Standard error | Confidence interval | The number of cycles to failure, N |
|-----------------------------------|--------------|---------|------------|----------------|-------------------|-------------------------------|
| 1                                 |              |         |            |                |                   | 41857 ± 2205                  |
| 2                                 |              |         |            |                |                   | 9041 ± 961                   |
| 3                                 |              |         |            |                |                   |                              |
| 4                                 |              |         |            |                |                   |                              |

Given that value of voltages which have been obtained at maximum amplitudes have been turned out not enough to build a fatigue chart, additional tests have hold by this method. In the result of additional tests which were undertaken and were processed endurance limits of repaired welded joints have been calculated (about 13 MPa).

The generalized fatigue diagram obtained as a result of the experiments represents the dependence of the number of cycles to failure $N$ on the value of the amplitude of the alternating voltage $\sigma_a$ (MPa) and looks like (figure 3):

![Fatigue diagram of OOGP welded joints repaired using crack welding and cracking technology.](image)

The equation describing fatigue processes for this type of repair has form:

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

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

3.2. Resource assessment of new and refurbished welded joints
For an assessment the service life of welded joints (new and restored), the Weibull and Kogaev theory is widely used. Both of these theories are modernized Palgram-Meyer theory and are well tested in practice.

For evaluation this duration, it is necessary to know the values of the amplitudes of the alternating stresses, the conditions of its loading, and the blocks of the amplitudes of the stresses during the operation period. Besides, it is necessary to know the mechanical properties of welded metal. The initial data necessary for the calculation: wave height with security 1% is 11.2 m, wave length is 149 m, wave period is 10.6 s, sea depth is 30 m, the value of the static component of the nominal tensile stresses in the welded joint is 80 MPa.

For assess the fatigue life of a welded joint, it is necessary to know its stress state, which will allow dividing stresses caused by loads of different magnitude into amplitude variable voltage amplitude blocks for one year of operation [6, 7]. The loading unit consists of several stages of loads, each of which causes alternating voltages, which can be characterized by the amplitude of the alternating voltage \( \sigma_{ai} \), the number of repetitions of the amplitude in the step \( \nu_{ai} \) and load application frequency \( v \). The number of cycles to failure in the fatigue diagram is \( N_i \). With this amplitude, the welded joint receives a fraction of damage equal to \( n_i / N_i \). In this case, the destruction under block loading will occur when the sum of the values of the relative damage becomes equal \( a_p \) and the condition of destruction will take the form:

\[
\sum_{i=1}^{q} \left( \frac{n_i}{N_i} \right) + \sum_{i=1}^{k} \left( \frac{n_i}{N_i} \right) = a_p
\]

(2)

where \( a_p \) – the critical degree of damage to the material corresponding to the moment of fracture or crack initiation and is calculated by:

\[
a_p = \sum_{i=1}^{k} \left( \frac{\sigma_{ai}}{\sigma_{max}} \right) t_i \text{, } 0,2 \leq a_p \leq 1
\]

(3)

where \( k \) – the number of block steps \( \sigma_{max} \) – maximum amplitude in the loading unit [6] – parameter calculated for all stages of the block according to the formula:

\[
t_i = \frac{\nu_{ai}}{v}\sigma
\]

(4)

From this it follows that the durability of the calculated welded joint, expressed by the number of loading units, determined by the formula:

\[
\lambda = \frac{a_p}{\sum_{i=1}^{q} \frac{\nu_{ia}m_1}{R_{Ki}N_{Gi}} + \sum_{i=1}^{k} \frac{\nu_{i\sigma}m_2}{R_{Ki}N_{Gi}}}
\]

(5)

\( \sigma_{Rk}, N_{Gi} \) – coordinates of the point of fracture of the fatigue curve; \( m_1, m_2 \) – coefficients characterizing the slopes of the branches of the fatigue curve, and the remaining values.

We will calculate for the connection "T" type, based on the source data. Total number of wave load cycles per year based on calculation results \( v_{G} \) is 30532411. If \( a_p \) according to the calculation results less than 0.2, then in the calculations should be taken equal to 0.2 [6, 7], since a lower value is not justified by experimental results. In accordance with the regulatory documents DNV we will accept \( m_1=3 \) и \( m_2=5 \).

As a result of calculations the durability of the new weld is 38.7 years. Using obtained diagram of fatigue on figure 3 to calculate the resource of the restored compound.

We will leverage only data which are higher than endurance limit obtained early (13 MPa) due to the fact that there are no data on the slope indices of the right branch of the fatigue curve in the area after its fracture.
Table 2. Characteristics of amplitude variable amplitude blocks in a welded joint of a support block OFP.

| Wave height, h | Amplitude of variable voltage, 6a | The number of cases of amplitude repetition in the block, νi6 | t       | 6i/6max |
|----------------|---------------------------------|-------------------------------------------------|---------|--------|
| 11,2           | 41                              | 430                                             | 1,41·10^-5 | 1,408·10^-5 |
| 9              | 30                              | 2425                                           | 7,94·10^-5 | 5,811·10^-5 |
| 7              | 20                              | 8447                                           | 27,7·10^-5 | 13,49·10^-5 |
| 5,5            | 16                              | 22912                                          | 75·10^-5  | 29,28·10^-5 |
| 4,5            | 12                              | 48386                                          | 158,5·10^-5 | 46,38·10^-5 |
| 3,5            | 10                              | 514688                                         | 168,6·10^-4 | 41,11·10^-4 |
| 2,5            | 8                               | 974097                                         | 31,9·10^-3  | 6,22·10^-3  |
| 1,5            | 7                               | 2421847                                        | 7,93·10^-2  | 1,35·10^-2  |
| 0,5            | 5                               | 7539179                                        | 24,69·10^-2 | 3,011·10^-2 |
| <0,5           | 3                               | 18849092                                       | 62,23·10^-2 | 5,0086·10^-2 |

It is important to know that these values of variable amplitudes which are less than the endurance limit, slightly affect the overall indicators of durability. The value of the fracture point of the fatigue curve according to the results of experiments performed by the author is \( N_G = 3 \times 10^6 \) cycles. As a result of the calculation, it was established, that \( a_p = 0.36, \nu_i6 = 82600 \). Next step of calculation.

Table 3. Characteristics of amplitude variable amplitude blocks in a restored welded joint of an OFP support block.

| Wave height, h | Amplitude of variable voltage, 6a | The number of cases of amplitude repetition in the block, νi6 | t       | 6i/6max |
|----------------|---------------------------------|-------------------------------------------------|---------|--------|
| 11,2           | 41                              | 430                                             | 52,05·10^-4 | 52,05·10^-4 |
| 9              | 30                              | 2425                                           | 29,35·10^-3  | 21,48·10^-3 |
| 7              | 20                              | 8447                                           | 10,22·10^-2 | 49,88·10^-3 |
| 5,5            | 16                              | 22912                                          | 27,7·10^-2  | 10,82·10^-2 |
| 4,5            | 12                              | 48386                                          | 58,57·10^-2 | 17,14·10^-2 |

After holding of all counting we can realize that residual life of the restored welded joint is 6,9 years under the same operating conditions.

4. Conclusion
Thus it was established:
Fatigue diagrams used for new welds cannot be used with this repair method.
The resource of a repaired welded joint by the method described in the article is significantly lower than that of a new joint, which requires a further assessment of the effectiveness of various welding joint repair technologies.
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