Comparative Analysis of Resource Evaluation Methods on the Example of Welded Connections of Offshore Oil and Gas Facilities Background

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Abstract. The world is actively developing offshore oil and gas fields. Various hydraulic structures are actively used for offshore production. Offshore fixed platforms have become widespread among these hydraulic structures. During operation, these platforms are subjected to various loads and influences, which include wind-wave and ice loads, temperature and vibration-vibrational effects, etc. causing their gradual destruction. Therefore, the determination of the values of the duration of the safe operation of welded joints of offshore platforms from the moment of their operation until the onset of their destruction, which is also called a resource, is a key requirement for ensuring the safe operation of these structures.

1. Introduction
The world is actively developing offshore and onshore oil and gas fields, which play a key role in supplying energy to the population and industrial enterprises in the world. It should be noted that the extraction of these resources is carried out in difficult natural and climatic conditions [1-4]. Offshore conditions are considered especially difficult and unfavorable for the extraction of oil and gas resources [5, 6]. It should be noted that Russia has significant offshore oil and gas resources. The development of offshore fields on the shelves of the Caspian, Baltic, Sakhalin, Black Sea and other regions is underway at a high rate. The development of marine resources is carried out using hydraulic structures, which are also called offshore oil and gas facilities (OOGF). These structures are truss-type fixed offshore platforms (FOP) for various purposes (Fig. 1).
All over the world, offshore fixed platforms are actively used for oil and gas production on the shelf. At present, the total number of such facilities exceeds several thousand, which indicates that these facilities are of great importance in the extraction of oil and gas resources in offshore conditions.

According to clause 3 of the Federal norms and rules in the field of industrial safety "Safety rules for offshore oil and gas facilities" [7], offshore fixed platforms are hazardous production facilities of the offshore oil and gas complex. Facilities of this kind are characterized by a high risk of accidents or incidents during their operation. Accidents occurring at such facilities can have serious consequences for the lives of human personnel operating the offshore platform, and can cause significant damage to the environment and property. To prevent the occurrence of accidents on offshore platforms, in accordance with clause 6 of the “Safety Rules for Offshore Oil and Gas Facilities” [8], design decisions are made based on ensuring strength under load conditions. In this situation, when solving the problem of ensuring the strength of these structures, the priority task for the designer and industrial safety expert is to determine the service life of the welded joints of fixed offshore platforms.

Currently, various methods have been developed for assessing the resource of offshore platforms [9]. Let’s conduct a comparative analysis of the resource values obtained by various methods.

2. Materials and methods
The purpose of the article was to carry out a comparative analysis of various methods for assessing the service life of welded joints of stationary offshore platforms using a practical example.

For a comparative analysis, the Palgram-Weller methods (modernized by V. Sereson and V.P. Kogaev) and the method for assessing the resource of structures by their actual state were chosen. The calculations were carried out on the basis of the data described in the article [13].

2.1. Method №1
In this method, to assess the resource, a study of individual blocks of amplitudes of variable loading, consisting of several stages of loads, is carried out for one year of operation. To assess the service life of a welded joint or the main structural element of an offshore platform, it is necessary to divide the stresses caused by loads of different magnitude into blocks of alternating stress amplitudes. The loading block consists of several stages of loads, each of which causes alternating stresses, which can be characterized by the amplitude of the alternating voltage $\sigma_{ai}$, the number of repetitions of this...
amplitude in the step $v_{i\sigma}$. The total number of repetition cycles of the amplitudes of all levels in the loading block $v_{i\sigma}$ is determined by the formula:

$$v_{i\sigma} = \sum_{i=1}^{r} v_{i\sigma}, \quad (1)\quad$$

With the number of loading blocks $\lambda$, the number of repetition cycles of a certain stress amplitude $\sigma_{ai}$ for the entire operation time will be $n_i$:

$$n_i = \lambda v_{i\sigma}, \quad (2)\quad$$

If the number of cycles to failure along the fatigue curve at the stress amplitude $\sigma_{ai}$ is equal to $N_i$ cycles, then at this amplitude the structure receives a damage fraction equal to $n_i/N_i$. In this case, failure under block loading occurs when the sum of the values of relative damage becomes equal to $\sigma_p$ and the failure condition takes the form:

$$\sum_{i=1}^{g} \left( \frac{n_i}{N_i} \right) + \sum_{i=1}^{k} \left( \frac{n_i}{N_i} \right) = \alpha_p$$

$$(\sigma_{ai} > \sigma_R) \quad (\sigma_{ai} < \sigma_R) \quad (3)\quad$$

Where: $\sigma_R$ is the endurance limit, $\alpha_p$ is the critical degree of material damage corresponding to the moment of fracture or crack initiation and is calculated by the formula:

$$\alpha_p = \sum_{i=1}^{k} \left( \frac{\sigma_{ai}}{\sigma_{max}} \right) t_i, \quad 0,2 \leq \alpha_p \leq 1 \quad (4)\quad$$

Where $k$ – number of block steps; $\sigma_{max}$ – maximum amplitude in the loading block; $t_i$ – a parameter calculated for all steps of the block by the formula:

$$t_i = \frac{v_{i\sigma}}{v_{\sigma}} \quad (5)\quad$$

The $N_i$ value is determined from the fatigue diagram of the platform welded joints, which is described by two oblique lines of the form:

$$\sigma_{ai}^{m_1} N_a = \sigma_R^{m_1} N_r \quad \text{при} \quad \sigma_{ai} > \sigma_R \quad \text{(6)}\quad$$

Where: $N_a$ is the number of cycles to failure for a certain stress amplitude $\sigma_{ai}$; $\sigma_R$, $N_r$-coordinates of the fatigue curve break point; $m_1$ - coefficient characterizing the slopes of the branches of the fatigue curve.

Taking into account dependencies (1), (2), (4), (5), (6), the formula for calculating the service life of a welded joint will take the form:

$$\lambda = \frac{\alpha_p}{\sum_{i=1}^{g} v_{i\sigma} \sigma_{ai}^{m_1} \sigma_R^{m_1} N_r + \sum_{i=1}^{k} v_{i\sigma} \sigma_{ai}^{m_2} \sigma_R^{m_2} N_r}$$

$$(\sigma_{ai} > \sigma_R) \quad (\sigma_{ai} < \sigma_R) \quad (7)\quad$$

Based on the fatigue diagram taking into account the corrosion effect (Fig. 2) given in the document [11, 12], we calculate the service life of the welded joint of the offshore platform.
Taking advantage of the problem given in article [13], we will accept the following initial data for the calculation (Table 1).

**Table 1.** Initial data for determining the service life of a welded joint of an offshore platform.

| Step number | The magnitude of the stress in the welded joint $\sigma_{ai}$, MPa | Amount of the cycles, $n_i$ | Subsidiary parameter $t_i$ |
|-------------|-----------------------------------------------------------------|-----------------------------|---------------------------|
| 1           | 41                                                              | 430                         | 0,000719921               |
| 2           | 30                                                              | 2425                        | 0,004060018               |
| 3           | 20                                                              | 8447                        | 0,014142256               |
| 4           | 16                                                              | 22912                       | 0,038360054               |
| 5           | 12                                                              | 48386                       | 0,081009496               |
| 6           | 10                                                              | 514688                      | 0,861708255               |

Using the methodology described above and the data given in Table 1, we will calculate the resource.

**Table 2.** Estimated values of the resource.

| Damageability, $\alpha_p$ | Endurance limit, $\sigma_f$ | Maximum amplitude value $\sigma_{\text{max}}$ | Breakpoint of the fatigue curve, $N_f$ | Resource, $m_f$ |
|---------------------------|-----------------------------|---------------------------------------------|--------------------------------------|-----------------|
| 0,259                     | 10                          | 41                                          | $1,1 \times 10^4$                    | 3               |
|                           |                             |                                             | 3                                    | 37              |
2.2. Method №2
There are other approaches to resource assessment based on the study of structural changes in the metal of welded joints during their operation [14-20]. These methods include a method based on the principle of “safe operation of an object according to its actual technical condition”. This method has proven itself in assessing the residual life of buildings and structures with defects identified by the results of a comprehensive diagnostic survey. The resource assessment of the object is carried out according to the parameters of the technical condition of the main structural elements, ensuring its reliable and safe operation.

The relative reliability of the structure during operation $J$ and the damage to the structure $\varepsilon$ can be calculated from the dependencies [21, 22]:

$$J = \gamma / \gamma_0,$$

(8)

where: $\gamma$ - actual coefficient of structural reliability, taking into account the existing damage; $\gamma_0$ - standardized coefficient of structural reliability.

$$\varepsilon = 1 - J,$$

(9)

For welded joints of an offshore platform, an assessment scale is used that links the category of the technical condition of the platform and the damage parameters. Each category of the technical condition of the welded joint corresponds to its relative reliability $J$ (or damage $\varepsilon$), the value of which can be adopted in accordance with the normative and technical documentation. To classify a welded joint into one or another category of technical condition, one of the signs that characterize this category is sufficient (Table 3).

| Technical condition category | Description of technical condition                                      | Relative reliability, $J$ | Damage deniability, $\varepsilon$ |
|-----------------------------|------------------------------------------------------------------------|---------------------------|----------------------------------|
| 1                           | Normal serviceable condition. There is no visible damage. There is no need for repair work. | 1                         | 0                                |
| 2                           | Satisfactory working condition. The bearing capacity of the structures is ensured, the requirements of the norms for the limiting states of the II group and durability may be violated, but normal operating conditions are provided. An anti-corrosion coating device is required, the elimination of minor damage. | 0.95                      | 0.05                             |
| 3                           | Not entirely satisfactory, limited working condition. The existing damage indicates a decrease in the bearing capacity. To continue normal operation, repairs are required to eliminate damaged structures. | 0.85                      | 0.15                             |
Unsatisfactory, (inoperative) condition. The existing damage indicates the unsuitability of the structures. Major overhaul with structural reinforcement is required. Before carrying out the strengthening, it is necessary to limit the acting loads. Operation is possible only after repair and reinforcement.

Emergency condition. Existing damage indicates the possibility of collapse of structures. An immediate unloading of the structure is required and the installation of temporary fasteners, racks, props, fences of the hazardous area. Repairs are mainly carried out with the replacement of damaged structures.

According to the data given in article [13], the welded joint considered in the example has been in operation since 1986. Those the amount of damage to the platform welded joint after $t$ years of its operation is determined by the formula:

$$
\varepsilon = 1 - e^{-\lambda t},
$$

where: $t$ - the duration of the WJ operation; $\lambda$ - wear constant, determined from survey data based on changes in bearing capacity at the time of survey, is found by the formula:

$$
\lambda = -\ln J / t_{\mu},
$$

where: $J$ - the relative reliability, $t_{\mu}$ - the service life in years at the time of the survey. The service life of structures before overhaul is determined by the formula:

$$
t_r = \frac{T}{\lambda'}
$$

where: $t_r$ - resource, years; $T = 0.16$, operating environment of structures before the first major overhaul; $T = 0.22$, provided that the structures are operated to an emergency state.

According to the requirements of the NTD [21], it was found that the values $J = 0.95$, and $t_{\Phi} = 24$. Substituting the values in formulas (11-12), it was $\varepsilon = 0.05$, $\lambda = 0.001509$. Substituting these values into the formulas, we get the resource before the first overhaul of 106 years. Note that the obtained resource value is more than twice the value obtained by method 1 and, in the author's opinion, does not correspond to the existing statistics of offshore platforms operation. Also, as a result of the calculation using this method, provided that the considered offshore platform with a 20-year service life is in the 5th category, i.e. its being in a virtually emergency condition (relative reliability $J = 0.65$), the time before overhaul is set to 7.4 years. It is difficult to call such calculation results practically applicable, since there is a significant risk of platform collapse in a storm, which, for example, in the Black Sea, is highly likely to occur in the coming autumn-winter period within one year.

3. Conclusion
Based on the calculations performed, it can be concluded that Method №1 gives results that are closer to the existing statistics of offshore platforms operation compared to Method №2. In addition, the very mathematical apparatus of Method №2 does not allow determining the service life of the platform welded joint from the moment of its commissioning (i.e., design life), since referring the considered
welded joint to the first category (for which $J=1$), the calculation according to the formula (11) leads to the appearance of a zero value, which prevents further calculations. Therefore, Method №2 is applicable for the estimated values of the residual life at the stage of its calculation based on the results of complex diagnostics. The calculation of the residual resource by Method №1 is more laborious, however, according to the author, it will give more accurate results of the resource value.

4. References

[1] Pudlo D, Flesch S, Albrecht D and Reitenbach V 2018 The impact of hydrogen on potential underground energy reservoirs Geophysical Research Abstracts p 20

[2] Panfilov M, Reitenbach V and Ganzer L 2016 Self-organization and shock waves in underground methanation reactors and hydrogen storages Environ. Earth Sci. 75(4) p 313

[3] Reitenbach V, Ganzer L and Albrecht D 2014 Influence of Hydrogen on Underground Gas Storage Research Report DGMK(Hamburg) p 752

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

[5] Yuan Z, Schubert J, Esteban U C, Chantose P and Teodoriu C 2013 Casing failure mechanism and characterization under HPHT conditions in South Texas IPTC vol 3 pp 2207-2217

[6] 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 865-870

[7] Federal Law “On Industrial Safety of Hazardous Production Facilities” of July 21 1997 N 116-FZ http://www.consultant.ru/document/cons_doc_LAW_15234/

[8] Federal norms and rules in the field of industrial safety "Safety rules for offshore oil and gas facilities" Ser. 08. Issue 23. M.: Closed Joint Stock Company Scientific and Technical Center for Research of Industrial Safety Problems p 68

[9] Starokon I V 2019 Methods for solving the problems of extending the resource of offshore stationary platforms J. Phys. Conf. Ser. 1399(5) 055087

[10] Serensen V, Kogaev V P Bearing capacity and strength calculation of machine parts (M) "Mechanical Engineering” 197 p

[11] DNV- RP-C103 2008 Recommended practice. The calculation of the fatigue of naval steel structures (Norway: DNV) p 158

[12] 2A-WSD Recommended practice for planning, designing, and constructing offshore fixed platforms-calculation based on permissible stresses American Bureau of shipping (NewYork) p 132

[13] Gubaidulin R G, Gubaidulin M R, Tingaev A K 2012 Determination of the residual resource of the support block of the offshore stationary platform Academic Bulletin UralNIproekt RAASN vol 1 pp 80–85

[14] Wartkin P P 2006 Marine oil and gas facilities: a textbook for universities Part 1 Design (M.: LLC “Nedra-Business Center”) p 555

[15] Efimenko L A, Kapustin O E, Utkin I U, Ramus A A, Ponomarenko D V, Sevostyanov S P, Ramus R O 2019 Assessment of the structure and properties of repair welded joints of gas pipelines made of steels with increased deformability Weld. prod. vol 12 pp 40-46

[16] Makarov G I, Kapustin O E 2019 Computer methods of calculation and design of welded structures of oil and gas profile using the finite element method Weld. Prod. vol 11 pp 3-9

[17] Starokon I V 2019 Development of theoretical bases of analysis of reliability of marine oil and gas constructions with regard to temperature impact J. Phys. Conf. Ser. 1399(5) 055066

[18] Starokon I V 2020 Problems of evaluating the stressed state of welded joints of offshore fixed platforms of type “Jacket” through the example of the Black sea region Mater. Sci. Eng. C, 860(1) 012022
[19] Lukyanov V F, Rogozin D V, Gritsikhin V A 2011 Repair of metal structures of offshore drilling and oil production platforms *Vestnik DSTU* part 11 vol 9(60) pp 1630-1636

[20] Starokon I V Determination of the endurance limit of structural elements of fixed offshore platforms with accumulated damage based on experimental studies *J. Phys. Conf. Ser.* 1515(4) 042034

[21] Recommendations for assessing the reliability of building structures of buildings and structures by external signs TsNIPromzdaniy, FSUE TsPP (Moscow) 2001 p 100 https://meganorm.ru/Data2/1/4293853/4293853571.pdf

[22] SP 13-102-2003 Rules for Inspection of Load-Bearing Structures of Buildings and Structures FGUP TsPP (Moscow) 2001 p 26 Https://files.stroyinf.ru/Data2/1/4294816/4294816189