Features of fatigue processes occurring in restored welded joints of offshore fixed platforms

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Abstract. There are significant offshore oil and gas resources on offshore and oceanic shelves in Russia, which are developed using offshore fixed platforms. These platforms work in adverse conditions and are subjected to extensive structural deterioration characterized by enormous stress from environmental, which leads to problems when extending the life of offshore platforms, and in particular to assessing the life of repaired welded joints of platforms. Currently, there is insufficient information about the resource of a repaired connection differs from a new one or not. Based on the conducted experimental studies, the author discovered the location of points in the restored welded joint, for which there is the greatest risk of cracking. The causes of cracks in the restored welded joint are combinations of unfavorable factors: the presence of a stress concentration zone, the presence of a heat-affected zone with reduced ductility characteristics and the effect of high residual stresses.

1. Introduction

Oil and gas are produced under difficult environmental conditions in which the equipment is exposed both to the product being extracted [1-7] and to external influences from wave, vibration, corrosion, temperature and many other influences [8-15].Russia has significant offshore oil and gas resources located on offshore and oceanic shelves. Mining is performed actively on the shelves of the Caspian Sea, the Baltic Sea, Sakhalin and other regions. Our country has accessed to existing and developing offshore oil and gas deposits of the Black Sea in the last years; where the mining is produced by using offshore hydraulic structures, which are called offshore oil and gas production facilities (OOGPF). The facilities are offshore fixed platforms (OFP) consist of frames type for different purpose (figure 1). Offshore fixed platforms are used actively by Norway, Azerbaijan, Iran, several countries of Persian Gulf, China, Brazil, the United States and other countries.

Offshore fixed platforms (OFP) are subjected to extensive structural deterioration since they are working in poor sea conditions characterized by enormous stress from environmental.

What is most important fact is that the age of some platforms in use in the world exceeds 30 years. In this regard, the issues of assessing the residual resource of OFP and its extension are importance. Resource assessment of repaired welded joints of OFP is one of the most important issues. Currently, there is insufficient information about the resource of a repaired connection differs from a new one or not; so that in most cases a calculation of the resource is based on diagrams of fatigue for new welded joints because there is no specialized regulatory documentation.
An experimental study was carried by author to address the issue of the resource (or all these words were tired long-term) led to the emergence in the OFP of the conditions of primary and repeated fracture, which should be confirmed by a theoretically substantiated process of crack development in the restored welded joint and an explanation of the difference from the new one.

2. Methods and materials
Destruction mechanism of repaired welded joints is closely linked with accumulation damages in surrounding area. Experimental installations (EI) were built, on which tested primary and secondary destruction of repaired welded joints for research that issue. For greater compliance, geometrically similar samples with similar loading conditions and materials which having similar mechanical characteristics were used, namely, welding materials providing similar values of tensile strength, E4903-P according to ISO2560-2009, providing a tensile strength of the welded joint equal to 420 MPa (60915.85 psi) were used. Pipes made of material according to DIN 2393-1994 RSt37-2 were used as a column model, and steel pipes (from 9MnSi5) were used to model the waist pipe. The diagram of the experimental installation is shown in figure 2.
The sequence of the experiment was as follows. From the high pressure pipeline with compressed air, the test was carried out to the module for monitoring the values of the experimental pressure, in which it was reduced to a predetermined value set in the control module of the experiment. Then the 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. The indicated force under the control of the switching unit developed sequentially along the vertical axis in different directions. This load created alternating stresses in the studied welded joint (WJ). The joint was repaired when a crack appeared (figure 3). Holes with a diameter of 8 mm were drilled at the ends of the crack. Then the welded joint was brought to destruction again.

![Experimental welded joint during repair.](image)

**Figure 3.** Experimental welded joint during repair.

### 3. Result

Previously, only a clear crack was repairing at the points with the highest stress concentration, however, in the process of loading, in addition to the weld itself, significant stress values formed in the metal of the structural elements (the pipes themselves). These stresses also caused the development of cracks not in the welded joint, but in the metal of the pipes. After the repair of the weld, the damages already existing in the base metal of the pipe continued to develop, and moving along the most favorable planes in areas with a maximum stress concentration, they pass into the weld along the fusion line between the weld metal and the base metal, which was established experimentally. If we ignore certain values of the number of cycles and stresses, we can distinguish the following stages of the development of cracks in the base metal. At the first stage, insignificant microcracks occur in the zones of maximum stress, extending deep into the metal to a depth of approximately 0.1-0.3 mm. A duration of this stage can be approximately determined as 35-40% of the total number of cycles. At the second stage, the depth of these cracks increases, new foci of crack nucleation appear, they merge with microcracks formed at stage 1, but their depth does not exceed 1 mm. A duration of this stage is approximately equal to 20-25% of the total number of cycles. At the third stage, the initiation of new crack sources occurs, the depth of previously obtained cracks increases and approaches to 2 mm. A duration of this stage can be approximately determined as 15-20% of the total number of cycles. At the fourth stage, crack growth occurs cutting, the duration of this stage is approximately 5-15%, and at the 5th stage, the cracks go to the opposite surface.

In addition, one of the possible reasons for the development of cracks in the restored weld, according to the author, may be the presence of a heat-affected zone that has undergone structural and phase changes during the repair process. As you know, this zone is mixed. Directly adjacent to the weld metal is a section that includes a fusion line, on which the formation of weld crystals with a length of several grain diameters takes place. The second section is called the «overheating-section»
(temperatures are about 900-1300 °C). Heating steels to these temperatures leads to a decrease in ductility and increase in hardness. The length of this depends on the type of welding, its linear energy and the length of stay at temperatures above 900 °C. So for manual electric-arc welding with a linear welding energy of 5 kJ / cm, a heating duration of over 900 degrees equal to 18 seconds, this zone is 0.3 mm. The overheating-section is followed by sections of complete and incomplete recrystallization, with a length of 0.3-1 mm under the conditions considered above, which is characterized by a reduced ductility. In the welding process, the largest deformations develop in all three sections and the greatest structural transformations occur. In welded joints of carbon steels, a change in hardness occurs in the direction perpendicular to the weld. The maximum hardness values are achieved in the weld metal, then they gradually decrease and reach the minimum values in the base metal. A slightly different nature of the change in mechanical properties is found in low alloyed steels. An area with high hardness and low ductility is adjacent directly to the seam. Hardness decreases in areas of complete and incomplete recrystallization. As the experiments conducted by the author showed, in almost all cases, the destruction occurred along the fusion line of the weld and the base metal (figure 4). The author can attribute this nature of crack propagation only due to the action of the heat-affected zone and the mixed structural of the metal caused by this phenomenon.

![Crack](image)

**Figure 4.** Crack of the restored welded joint.

During welding, the weld metal and the base metal near the weld are heated to high temperature and expand. In the case of repair work, this expansion is prevented by the cold metal of the weld part that has not undergone reduction and the base metal. Due to the plasticity, the repair zone takes the form corresponding to the repair area. The metal tries to shorten when be cold. But the surrounding cold metal prevents compression. As a result, residual stresses occur. The width of the zone of residual stresses for both carbon and low alloyed steel, with a thickness of the welded elements from 10 to 25 mm, is 50-60 mm. Under these conditions, the transverse component of residual stresses is less than the longitudinal. The initial residual stresses reach the yield strength of the weld material. These stresses, combined with stresses from an external load, cause plastic deformation, which leads to a change in the field of residual stresses.

In the welded joints considered in this paper, the places of stress concentration and high residual stresses are combined with the heat affected zone. In contrast to stress concentration, which affects only the stage of initiation of a fatigue crack, factors such as residual stresses and HAZ (heat affected zone) determine the crack propagation. In this case, the properties of the metal of various zones (weld metal, HAZ metal and base metal) are expressed using the corresponding crack resistance characteristics. It was experimentally established that tensile stresses contribute to the development of cracks. Residual stresses manifest themselves ambiguously at various load levels, which is associated with their unequal value, depending on the magnitude of the load. At variable stresses in the range from the fatigue limit to the yield strength, residual stresses significantly affect fatigue resistance. Soin [12-15] it was proved that when calculating the magnitude of the stress intensity factor, the magnitudes of the stresses from the external load should be summed with the values of the residual stresses.
4. Conclusion
In the author’s opinion, it is a combination of these three unfavorable factors, namely, the presence of a stress concentration zone that multiply increases the nominal stress values, the presence of a heat affected zone with reduced ductility characteristics and the effect of high residual stresses under the actual operating conditions of the offshore platform, taking into account the shape of the applied load, create conditions for development of fatigue cracks in the direction of points No. 3 and No. 7 (see figure 5) and in the region of the heat-affected zone mainly along the alloy line of fusion.

Figure 5. The layout of the points.

We emphasize once again that in all the experiments performed by the author, cracks originated at the junctions of the weld to the base metal in the zone of stress concentration along the edges (in rarer cases in the middle) of the weld, where the tensile residual stresses are maximum.

References
[1] Guseynov C S et al 2010 Methodological recommendations for developing a strategy for the development of offshore oil and gas fields Intellectual Property Patent No 10-281 of August 2, 2010 (Moscow: Rospatent)
[2] Guseynov C S 2012 The development of hydrocarbon resources of the Arctic Ocean is the immediate and urgent prospect Drilling and Oil magazine 1
[3] Bär F and Overmeyer T C 2013 Approaches for determination and reduction of non-productive times of drilling rigs for deep wells Logistics Journal
[4] Yuan Z, Schubert J, Esteban UC, 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 applicationsSociety of Petroleum Engineers - SPE/EAGE European Unconventional Resources Conference and Exhibitionpp865-70
[6] Starokon IV, Golovachev AO and Nadyrov R I 2019 Methods for Increasing the Fatigue Life of Repaired Welded Joints of Offshore Oil and Gas Facilities IOP Conf. Ser.: Earth Environ. Sci. 27 032090
[7] Starokon IV and Golovachev AO 2019 Method of Determining the Sizes of Corrosion Defects of Elements of Marine Oil and Gas Industrial Constructions on the Basis of Data on Temperature Contrasts IOP Conf. Ser.: Earth Environ. Sci. 272 032089
[8] 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 Hydroge
[9] Pudlo D, Flesch S, Albrecht D and Reitenbach V 2018 The impact of hydrogen on potential underground energy reservoirs Geophysical Research Abstracts 20
[10] Hagemann B, Rasoulzadeh M, Panfilov M, Ganzер L and Reitenbach V 2016 Hydrogenization of underground storage of natural gas. Impact of hydrogen on the hydrodynamic and biochemical behavior Environmental Earth Sciences 20 595–606
[11] Reitenbach V, Ganzér L, Albrecht D and Hagemann B 2015 Influence of added hydrogen on underground gas storage: a review of key issues Environmental Earth Sciences 73 6927–37
[12] Boersheim E C, 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

[13] Panfilov M, Reitenbach V and Ganzer L 2016 Self-organization and shock waves in undergroundmethanation reactors and hydrogen storages Environmental Earth Sciences 75(4) 313

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

[15] Ganzer L, Reitenbach V, Pudlo D, Albrecht D, Singhe AT, Awemo KN, 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