Section 1.01 Methodology for assessing local overloads of elements of fixed offshore platforms with corrosion defects based on data on temperature contrasts: results of physical modeling

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Abstract. Today, offshore oil and gas fields are being developed in the world using stationary offshore platforms. Offshore platforms are corrosive during operation. As a result of this effect, cavities or crack-like defects are formed in the platform elements, which are stress concentrators and can cause a critical overload of the platform elements. In order to prevent such a situation, it is necessary to identify dangerous corrosion defects in a timely manner. The author set up a physical experiment, which consisted in the creation of artificial corrosion defects of the V-shaped form, followed by the action of intense heat flows on them. On the basis of the formulas obtained by the author, a practical solution to the problem is given, which makes it possible to determine the size of corrosion damage and, from temperature contrasts, to calculate local overloads in the elements of the offshore platform.

1. Introduction
The Russian Federation is actively developing offshore oil and gas fields using offshore stationary platforms. It should be noted that the extraction of oil and gas resources is generally carried out under difficult conditions, during which the structures are exposed to various influences both from the environment (temperature, vibration, etc.) [1-6], and from the side of the pumped product [7-15]. According to Federal Law No. 116 "On Industrial Safety of Hazardous Production Facilities" [1] offshore stationary platforms are among the hazardous production facilities. Hazardous production facilities (HPF) are such facilities during the operation of which there is a significant risk of an emergency. Accidents at fire hazard facilities can lead to fires and emergencies, resulting in significant casualties among platform personnel and significant environmental damage. It should be noted that Russia has a large number of offshore stationary platforms built back in Soviet times. For a long time, these platforms were operated in extremely adverse environmental conditions. These conditions include both the effect of loads (ice, wave, etc.) and various effects. One of the most aggressive actions in marine conditions is corrosion [16, 17]. Corrosion can cause both surface corrosion, in which caverns form, and through corrosion (Figure 1.).
2. Materials and Methods

It should be noted that the corrosive effect causes a significant local concentration of stresses, including those exceeding the permissible nominal values. It is very important that if through damage is easily detected and rejected during a comprehensive technical diagnosis, then elements such as caverns are often impossible to detect visually in time due to general corrosion damage to platform elements by a continuous layer of surface corrosion or the presence of paint residues. Corrosion defects in the form of caverns begin to spread from the surface into the depths of the surface of the element of the offshore platform and can spread in different directions, usually taking a shape close to conical or cylindrical with uneven edges.

Corrosion defects are especially dangerous if they are crack-like and have small radii of fillet at the end. At the end of these defects, a local overload zone is formed (also called stress concentration). In this zone, the values of the current rated loads increase significantly. Overload of platform elements in the presence of such defects can exceed the nominal almost double. And in some cases, depending on the shape of the defect, this overload can more than double. The calculation of the local stress concentration is carried out according to the formulas:

\[ K_x = \frac{1+\eta \alpha_0}{2\eta} + \frac{1-\eta \alpha_0}{2\eta} \left( \frac{\sqrt{\pi}}{2} \left( \frac{L}{R(\delta-H)} + \eta \pi - \pi \right) \right), \tag{1} \]

\[ K_\theta = \frac{\pi \eta + 2(1-\eta) \sin \frac{\theta}{2} \frac{\alpha_0}{\pi}}{\eta \left( \pi - \frac{\theta}{2} (1-\eta) \right) \left( \pi - \frac{\theta}{2} (1-\eta) \right)}, \tag{2} \]

where \( K_x \) and \( K_\theta \) – stress concentration factors in the longitudinal and annular directions; \( R \) – the radius of the structural element of the offshore platform; \( \delta \) – wall thickness of the structural element of the offshore platform; \( L, \theta, H \) – length in the longitudinal direction, angular size in the annular direction and the depth of the defect; and values \( \eta \) and \( \alpha_0 \) are calculated from the formulas:

\[ \eta = \frac{\delta-H}{\delta}, \quad \tag{3} \]

\[ \alpha_0 = 3 - 2 \frac{3^{\eta-1}}{2^{\eta}}. \tag{4} \]
Based on the above considerations, we calculate stress concentration factors for typical corrosion defects of structural elements of the offshore platform for various ratios of wall thickness, angular dimensions, and depth of the corrosion defect. The results are shown in Table 1.

**Table 1.** Values of stress concentration factors on an example of an element with a diameter of 530 mm and with a wall thickness of 12 mm for various parameters of corrosion defects with a maximum depth of 3 mm

| Depth of corrosion defect \( H, \text{ mm} \) | Length of corrosion defect \( L, \text{ mm} \) | Angular defect size \( \Theta, \text{ angle degrees} \) |
|---|---|---|
| 10  | 15  | 20  | 25  | 30  | 35  | 40  | 50  | 60  | 10  | 20  | 45  | 135 | 160 | 170 |
| \( K_z \) values of longitudinal stresses | \( K_{\Theta} \) values of ring stress factors |
| 1   | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.3 | 1.1 | 1.1 |
| 2   | 1.4 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.4 | 1.5 | 1.5 | 1.5 |
| 3   | 1.6 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.4 | 1.5 | 1.5 | 1.5 | 1.5 |
| 4   | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.5 | 1.5 | 1.4 | 1.5 | 1.5 | 1.4 |

The data given in table 1 convincingly prove the possibility of the formation of such zones with local overloads on the platform elements, which can lead to the destruction of its individual elements and, as a result, an emergency with significant casualties. In this regard, it is necessary to develop methods that could timely identify these dangerous defects. One of these methods, according to the author, is the method of thermal diagnostics. However, despite the fact that this method has been used for many years in various industries (aviation, rail transport, etc.), at present, with respect to offshore platforms, such a technique is absent.

Thermal imaging (thermal imaging diagnostics, thermal diagnostics, etc.) is a universal way of obtaining various, more detailed information about the object of study. During the operation of complex technical devices and products, the processes of heat release, absorption or transfer of thermal energy occur. This allows for technical diagnostics based on the thermal (thermal) control method using the same devices, which are called thermal imagers. Thermal imagers are used in a wide variety of fields - from scientific research and medical examination to industrial plants and nuclear energy. The thermal imager, as a universal measuring device, can be used to solve urgent problems of diagnostics, monitoring, non-destructive testing and energy inspections.

To develop this technique, the author put an experiment. A professional TESTO 885-1 thermal imager was chosen for the experiment. This thermal imager has a high temperature measurement accuracy and has proven itself in scientific and industrial temperature measurements. Some technical characteristics of the TESTO 885-1 thermal imager are shown in Table 2.
Table 2. Some technical characteristics of the TESTO 885-1 thermal imager

| Parameter name             | Parameter value                                                                 |
|----------------------------|---------------------------------------------------------------------------------|
| Measuring range            | -30...+100°C; 0...+350°C; 0...+650°C (switchable)                               |
| High temperature measurement| +350...+1200°C (not in connection with the telephoto lens)                         |
| Accuracy                   | ±2°C, ±2% of m.v.                                                              |
| Emissivity                 | 0.01; 1                                                                         |
| Accuracy for high temperature range | ±2°C, ±2% of m.v.                                                   |

Samples were made from steel pipes. In these samples, V-shaped holes of various diameters and depths were drilled. These holes simulated the most dangerous type of corrosion caverns, in which the maximum stress concentration values arise. A diagram of these imitation holes is shown in Figure 4.

![Figure 4. Scheme of drawing holes simulating corrosion defects on an experimental sample in the form of a tube](image)

These holes were filled with iron oxide Fe$_2$O$_3$. And then an iron oxide layer 1 mm thick was deposited over the entire surface of the sample [18, 19, 20]. These samples were exposed to heat fluxes (Figure 5) with different densities and for a certain time (heat flux power).

![Figure 5. The experimental sample under the influence of heat fluxes](image)

3. Results
With the help of a special construction heat gun, creating a powerful heat flux, an experimental sample with holes simulating corrosion cavities was exposed to high intensity heat fluxes. Almost immediately, a difference was noted in the formation of temperatures in the zones simulating corrosion defects and in the zones of pure metal (Table 3). From the data given in Table 3, it becomes obvious that in the zones simulating corrosion defects the temperature rises much faster than in the zones of defect-free metal.
Table 3. The results of the inspection of the corrosion state. Experiment Results. The diameter of the hole simulating a corrosion defect is 6 mm. Hole depth 4.5 mm

| Duration of exposure to heat flux, \(c\) | 0 | 15 | 30 | 45 | 60 |
|-----------------------------------------|---|----|----|----|----|
| Heat flow dynamics (W/(s\(m^2\)))     | 0 | 1040 | 968 | 895 | 822 |
| Defect-free surface temperature, \(^\circ\)C | 28 | 34 | 36 | 38 |
| Temperature in the defect zone, \(^\circ\)C | 28 | 46 | 52 | 55 | 59 |
| Temperature contrast                    | 0 | 0,30 | 0,35 | 0,35 | 0,36 |

The general results of experiments, which make it possible to relate the geometric dimensions of "V" - modeling holes and their volume, with the density of heat fluxes and temperature contrasts are given in Table 4.

Table 4. Dependence of the defect contrast on its depth (average values are indicated based on the results of 6 experiments)

| Equivalent volume of "V"-shaped defect, mm\(^3\) | Dynamics of heat flux impact \(D\), W/(s\(m^2\)) |
|-----------------------------------------------|-----------------------------------------------|
| Diameter and deepening of a hole simulating a corrosion defect | 1040 | 968 | 895 | 822 |
| \(\varnothing8\times1,5\) | 25 | 0,27 | 0,29 | 0,29 | 0,30 |
| \(\varnothing8\times3\) | 50 | 0,30 | 0,35 | 0,35 | 0,36 |
| \(\varnothing8\times4,5\) | 75 | 0,33 | 0,37 | 0,36 | 0,38 |
| \(\varnothing6\times1,5\) | 14 | 0,24 | 0,26 | 0,27 | 0,27 |
| \(\varnothing6\times3\) | 28 | 0,26 | 0,28 | 0,28 | 0,29 |
| \(\varnothing6\times4,5\) | 42 | 0,27 | 0,29 | 0,29 | 0,29 |
| \(\varnothing4\times1,5\) | 6 | 0,20 | 0,19 | 0,18 | 0,20 |
| \(\varnothing4\times3\) | 13 | 0,22 | 0,23 | 0,22 | 0,23 |
| \(\varnothing4\times4,5\) | 19 | 0,24 | 0,24 | 0,25 | 0,27 |

The author considered that the rate of formation of temperature contrast depends on the volume of \(Fe_2O_3\) in the body of the pipe metal. Since the projection area of a corrosion defect can be visually estimated using a thermal imager, knowing the volume of \(Fe_2O_3\) in the body of the pipe metal, it becomes possible to calculate its depth. A corrosion defect can be represented either in the form of a cone with uneven edges, or a "V" defect - shaped, which is more dangerous in terms of local overload values. The depth of this defect \(H\) can be determined by the formula:

\[
H = \frac{0.00463937 \cdot D^2 - 8.70561 \cdot D + 132.525 \cdot C^2 + 1432.5 \cdot C + 3748.46}{3.14 \cdot r^2},
\]

where: \(H\) is the depth of the defect; \(r\) - radius of the defect; \(D\) - dynamics of heat flux, defined as the product of heat flux density \((\Delta Q)\) on its duration \((\Delta t)\); \(C\) - temperature contrast;

4. Conclusions

The article shows that the identification of corrosion defects in the form of caverns with a high degree of efficiency is possible using the method of thermal diagnostics. It should be noted that the danger of corrosion defects in the form of cavities is that they create a local overstressed state. In the range considered in this article, with a defect depth of 4 mm, it exceeds the rated load by 1.6 times, depending on its direction. But in some cases, it (depending on the shape of the corrosion defect) such defects can create a local overload that is twice the nominal one. Therefore, the identification of the size of corrosion defects in the form of cavities using the method of thermal diagnostics is a highly effective and promising method.

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