Methods for solving the problems of extending the resource of offshore stationary platforms: case study

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Abstract: Currently, many countries of the world are developing offshore mineral deposits (oil, gas, coal, gold, etc.) Minerals in offshore deposits are being milked using offshore stationary platforms, many of which have exhausted their design life. The extension of the resource of such structures is carried out by conducting their examination of industrial safety. However, an expert carrying out this extension has a number of tasks that have not been resolved to date. One of these tasks is the high statistical variability of the results of a comprehensive diagnostic examination, which does not allow to predict the probability of detection of dangerous defects. Another problem is the lack of a theory that allows one to predict the probability of the occurrence of a wave of high security for an extended service life if no such wave action has been recorded since the start of operation. In the article, the author provides his own solution to these problems.

1. Introduction
There are significant offshore oil and gas resources on offshore and ocean shelves in Russia (figure 1). Mining is performed actively on the shelves of the Caspian Sea, the Baltic Sea, Sakhalin and other regions [3, 9]. 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. Offshore fixed platforms are used actively for mining of oil and gas shelf deposits in the world. For example, approximately 4500 facilities are used in the Gulf of Mexico. Offshore fixed platforms are used actively by Norway, Azerbaijan, Iran, several countries of Persian Gulf, China, Brazil, the United States and other countries. That’s why it’s safe to say that these facilities are widespread and play a key role in mining oil and gas resources on shelf.

Offshore fixed platforms (OFP) are subjected to extensive structural deterioration [4, 5, 6, 7, 8] since they are working in poor sea conditions [1, 2, 3] characterized by corrosion activity, enormous stress from waves and currents.

Here issue of remining life assessment of offshore fixed platforms (OFP) and issue of extension on the basis of effects of the environment take on major importance.
2. The problem of evaluating the results of a comprehensive diagnostic examination in the context of their high statistical variability

As it has been demonstrated in reports [9, 10, 11], different defects (corrosion defects, dents, cracks, etc.) in elements and welds are considered to be a real danger for safe and reliable exploitation offshore platforms (including fatigue defects). In this regard, the industrial safety expert [1], who is extending the life of the offshore platform, has the task of assessing the risk of new dangerous defects. If this can be achieved, it will allow the expert to form a list of compensatory measures such as scheduled repairs, reasonable reduction of the duration between the periods of control checks, installation of reinforcing structures, etc.

Indicator that made it possible to define cracks or other dangerous effect is probability $P(Cr)$, which is in the foundations of statistics and given by formula:

$$P(Cr) = \frac{N}{n},$$

(1)

where $P(Cr)$ - probability of an unacceptable defect (in a survey a year);

$N$ - is the number of identified of unacceptable defects;

$n$ - is the number of comprehensive diagnostic tests performed.

Obviously, than more value of probability of an unacceptable defect then higher likely to occur of such effects. However, statistics of offshore platforms showed that the number of defects found do not followed the mathematic rules of linear, logarithmic and other relationship and have random view. In this case, expert need to have a mathematical parameter, which would access to conclude about possibility of defects based on analysis results of statistics date on detected defects. The parameter may be coefficient of variation $V$, which is a measure sufficient variability of random value and can be a measure of risk assessment. The coefficient of variation is changing from 0 to 100%. At values up to 10%, the probability of detecting dangerous defects is small. The range from 10% to 25% showed that dangerous defects may to be created. Values of a coefficient of variation above 25% indicate that platform are in at particular risk and the probability of detecting dangerous defects is very high [12, 13, 14].

Figure 1. Offshore platform located on the Black Sea oil and gas field.
Examples are given in the table 1. This table depicts the number of unacceptable defects which were identified as a result of the survey on each 100 of welded joints sea platform.

**Table 1.** The number of unacceptable defects on each 100 of welded joints which were identified.

| Zone of OFP       | Years of review comprehensive diagnostic tests performed |
|-------------------|--------------------------------------------------------|
|                   | 1989 | 1994 | 1999 | 2004 | 2009 | 2014 | 2019 |
| Underwater        | 2    | 4    | 8    | 5    | 8    | 6    | 11   |
| Periodic by wetting| 19   | 18   | 23   | 20   | 25   | 19   | 24   |
| Atmospheric       | 9    | 14   | 12   | 16   | 15   | 19   | 17   |

For the decision of this problem, the author invites the following sequence based on reports [12, 13, 14]:

- The average number of identified of unacceptable defects for 100 welds by formula:

\[
N_{cp}(Cr) = \frac{N_1(Cr) + N_2(Cr) + N_3(Cr) + ... + N_n(Cr)}{n}, \quad (2)
\]

where \(N(Cr)\)- the number of identified of acceptable defects for 100 welds by formula in the given year;

\(N_{cp}(Cr)\)- the average number of identified of acceptable defects for 100 welds;

\(n\)- the number of comprehensive diagnostic tests performed during operation;

- Dispersion \(D\) is calculated according to the formula:

\[
D = \frac{\sum [N(Cr) - N_{cp}(Cr)]^2}{n}, \quad (3)
\]

- Standard deviation \(g\) is calculated according to the formula:

\[
g = \sqrt{D}, \quad (4)
\]

- The coefficient of variation \(V\) is the calculated in accordance with the formula:

\[
V = \frac{\pm g}{N_{cp}(Cr)} \times 100 \% \quad (5)
\]

**Table 2.** Probability parameters of emergence defects risk.

| Zone of OFP | The average number of identified of acceptable defects for 100 welds, \(N_{cp}(Cr)\) | Dispersion, \(D\) | Standard deviation, \(g\) | The Coefficient of variation \(V\) |
|-------------|-------------------------------------------------|-----------------|-----------------|-----------------|
| Underwater  | 6,28                                            | 7,63            | 2,76            | 43,95           |
Based on the data in table, it is evident that for underwater zone is high rate of swings number of detected defects in despite of the fewest identified of unacceptable defects compared to atmospheric and periodic by wetting zones; this demonstrates that in underwater zone is a tendency to the formation of dangerous defects and relying on the probability value of their detection is not enough. The statistic variation is little for identified of acceptable defects in atmospheric and periodic by wetting zones, and in this situation the probability value of their detection is enough.

3. Solving the problem of extending the safe life of the offshore platforms

Thus, as mentioned above, different defects are identified in the process of integrated diagnostic survey. A particularly important task for the industrial safety expert is determine the terms of addressing is defects. Achieving this goal lies in the identification stress in the area of possible defects. Clearly, waves actions area cause of extremely factors of stress for offshore platforms. As we known, offshore platforms are calculating on the wave loads actions by 1%, those highest waves may arise in once every 100 years. The nominal height to wave multiplied by appropriate coefficient and calculated wave loads for these waves in accordance with [2, 3, 7] (figure 2).

Theory has not been elaborating to date, which to foretell an appearance of those wave on renewable term for cases if wave with 1% of availability has not arisen since of start exploitation.

Furthermore, waves with less than 1% of availability is enough for occurrence of unacceptable stresses in defects such as cracks. Therefore, obtaining information on probable wave loads and their parameters is a mandatory requirement for determining the degree of danger of defects and the need to eliminate them. It is to this end that author recommends the following approach. According to the Federal Act 116, hazardous production facilities, including of offshore platforms, must be surveyed after 20 years of operation once every 5 years. This interval between surveys can be reduced if it necessary. Accordingly, while assessing the risk of defects should be taken into account the possibility of a wave with of availability from 0.05% to 1%.

Let’s define probability of occurrence of a wave with 1% of availability fora period of exploitation of 5 years if this wave has not arisen since the start of exploitation. For sorting out this problem, we use the properties of the binomial distribution and its particular case the Bernoulli formula [15]:

\[ P_n(m) = \frac{n!}{m!(n-m)!} p^m \cdot q^{n-m}, \]  

**Figure 2.** Graph of the values of the coefficients \( k_i \), which determines the estimated height depending on its availability.
where: \( P_n(m) \) - is the possibility that during \( n \) years wave load with some availability will be \( m \) times; 

\( p \) - the probability of occurrence of a wave load; 

\( q \) - the probability of non-occurrence of wave load for considered availability which calculated by formula:

\[
q = 1 - p,
\]

(7)

Let’s define probability of occurrence of a wave from 0.05% to 1% of availability with interval 0.05%.

Suppose the platform has been being exploited since 1979. Waves of 1% were not observed during the operation of period \( T \). The calculation is carried out at the time of the extension of the resource in 2019. Consequently, the platform has been in operation for 40 years. Since the wave of 1% is provided with an increased value of 0.01 to the value:

\[
p = \frac{1}{100-40} \approx 0.0167
\]

(8)

In accordance to Bernoulli’s formula the possibility of it arising for renewable term life circle equal 5 years will be 0.078.

The possibility of occurrence a wave with availability which is equal to 0.5% (it means with possibility to arise once every 50 years) for the extended safe operation period for 5 years period will be 0.32 and etc. Obviously, the possibility of arising non-safe waves of various security is increasing.

An expert should identify based on knowledges, for example, about cracks parameters or corrosion cavity, which tress concentration factors arise in this defect and how current rated voltages change with a wave of certain security. To modeling actions of wave loads in specialized software systems, it is necessary to determine the force from the wave action at which stresses from the wave of a certain height cause unacceptable stresses in the defect zone. Having determined this value, it becomes possible to establish the minimum permissible wave height, which will not cause overvoltage in the defect zone and determine the probability of its occurrence for an extended service life, thereby substantiating the safety of the operation of the offshore platform.

4. Conclusion

Thus, the article provides a new solution to the main tasks of extending the resource of offshore platforms:

- A reasonable forecast of the probability of occurrence of dangerous defects in conditions of significant statistical variability of the results of a comprehensive diagnostic examination.

- A new solution that allows you to predict the probability of occurrence of a wave that is dangerous from the point of view of safe operation for an extended service life if no such wave action has been recorded since the start of operation.

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