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# RISK ASSESSMENT IN SUBSEA PIPELINES FOR THE CASPIAN SEA CONDITIONS

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**Abstract**

*The article presents the results of studies conducted on the analysis of risks in the underwater pipelines of the Azerbaijan sector of the Caspian Sea. For the study, the results of long-term observations of the state of the state of underwater pipelines and the opinions of experts in this field were collected. Based on the analysis of these data, the most characteristic situations were identified that, to one degree or another, led to the loss of pipeline performance and the need for repair and restoration work.*

*It was found that the main hazards for subsea pipelines in the Caspian Sea are external and internal corrosion. Pipelines floating, damage at pipe junctions, vibrations, damage from falling foreign objects, and wave impacts in the coastal strip. For the listed main and other rarely observed situations, quantitative risk assessment was carried out using the Boston Cube method. The results of the assessment showed that the greatest risk is associated with external corrosion.*

**Keywords:** hazards, risk, risk analysis, risk assessment, list of failures, external corrosion

## I. Introduction

Azerbaijan has more than 70 years of experience in laying and operating underwater pipelines in the Caspian Sea. After the signing of an oil contract for the development of the deep-water part of Azeri-Chirag-Gunashli in 1994, the design and intensive construction of new underwater pipelines began, ensuring the transportation of products from offshore fields to onshore terminals by using cutting edge technology. Within the framework of the project for the development of the Shah Deniz gas condensate field, new underwater communications are in operation and are being built currently. In connection with the prospect of expanding the Southern Gas Corridor project, increasing the capacity of TANAP and TAP, using the resources of Turkmenistan and Kazakhstan, underwater pipelines are becoming even more relevant.

At present, the issues of industrial safety of oil and gas facilities, including underwater pipelines, are given paramount attention. The solution of these issues is closely related to the analysis and assessment of risks based on various existing methods that are actively used in international practice. Moreover, in foreign practice, an underwater survey of structures is also carried out necessarily on the basis of a quantitative risk assessment and recommendations on which elements of the structure should be given special attention during the inspection.

When analyzing and assessing risks, various graphical schemes, diagrams and output tables are used, e.g., risk matrices are built, where potential hazards are ranked by frequency and degree of danger. In this case, the opinions of experts are taken as a basis and the correlation of the considered danger into one or another cell is, generally speaking, subjective in accordance with the experience and intuition of specialists. To increase the reliability of this procedure and the degree of objectivity of the final decision on the expected risks, recent studies often use the methods of fuzzy set theory and fuzzy logic.

## II. Methods

During the operation of subsea pipelines monitoring is periodically carried out based on the preparation of an inspection plan [1] in order to identify damage and assess the strength resource. The sample has been described at the Figure 1.

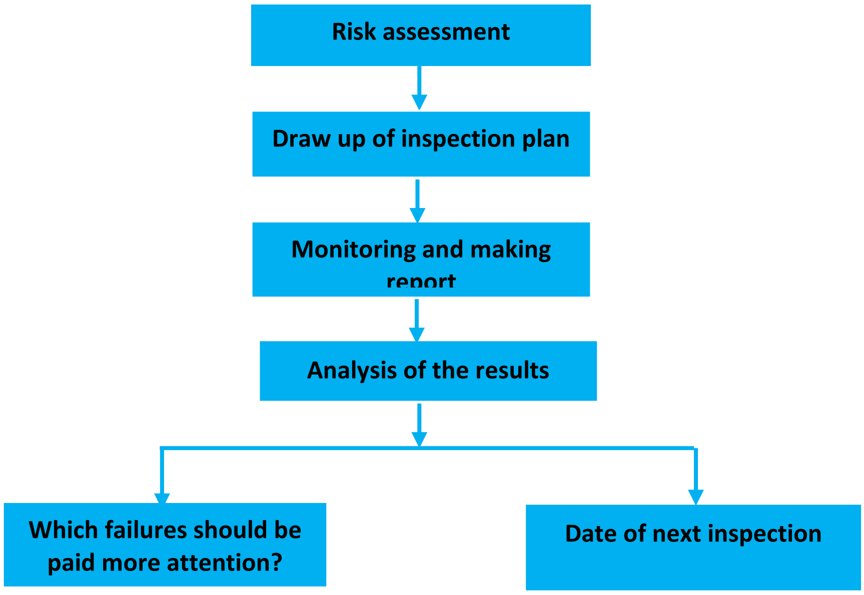


**Fig. 1:** *Example of inspection plan*

The Fig.1 shows a risk analysis and assessment should be carried out before conducting a survey. There are various methodologies for conducting a quantitative risk assessment [2-4], of which the Boston Cube method [1] was applied in this article and includes the following sequential steps.

**Step 1**. A list of possible situations is compiled that can lead to a loss of pipeline performance. Based on the analysis of data collected over many years of experience in the operation of subsea pipelines and based on the opinions of experts in this field for the conditions of the Caspian Sea, 15 items were included in the list of failures:

1. Damages in the connections
2. External corrosion
3. Internal corrosion
4. Surfacing pipelines
5. Vibrations
6. Damages from fishing
7. Wave loads
8. Current loads
9. Technological mode violations
10. Blockage of the pipeline
11. Destruction of the concrete pavement
12. Landslides of sea soil
13. Earthquakes
14. Mechanical damages from anchors
15. Damages in the raiser

**Step 2**. For each item presented in Step 1, 3 calculation parameters are calculated: the frequency of occurrence of the situation, the hazards level and the possibility of detection. The frequency is determined by the statistics of damage, accidents or repair and restoration work on underwater pipelines. The hazards level is assessed by experts and here the potential damage from the consequences of the situation that has arisen is taken as a basis. Regarding the parameter of detection level, the assessment of this parameter is based on the level of provision with the necessary special apparatus and means for conducting an inspection of underwater pipelines. All three calculated parameters are evaluated at 3 levels (H- High, M - Medium and L - Low level, respectively 3, 2 and 1 points).

**Step 3.** The final risk for each item in Step 1. is estimated as the product of the estimates for all 3 calculated parameters and the Boston Cube (3-dimensional risk matrix) is built. Thus, the value of the final risk ranges from 1 (1x1x1) to 27 (3x3x3).

We will illustrate the implementation of the above sequential procedure using the example of the point related to external corrosion. Many years of experience in the operation of subsea pipelines in the Caspian shows that this is the most common situation. Therefore, the frequency of occurrence of this situation can be estimated at the maximum level (3 points). The degree of danger can also be rated at 3 points, since corrosion defects can lead to very serious consequences (leaks, pipeline rupture, oil spills, etc.) and potential damage can reach very large sizes). As for the calculated parameter characterizing the possibility of detecting the situation, Azerbaijan (SOCAR) currently has a special vessel for underwater inspection of oil and gas facilities, equipped with special equipment. Also, special diving groups can be involved in underwater surveys. But, the remaining difficulties in carrying out these works, the level of possibility of detecting external corrosion in subsea pipelines under local conditions can be assessed as an average level (2 points).

Thus, the final value of the risk for the situation associated with external corrosion can be estimated as 3x3x2 = 18 points. Similarly, totals were obtained for the risks associated with all considered situations (List of failures, Step 1.) and are presented below in the Table.

## III. Results

**Table:** *Results for risk assessment*

| Results for risk assessment | | | | | |
|---|---|---|---|---|---|
| № | Situations | Frequency | Hazards level | Detecting level | Risk |
| 1 | Damages in the connections | 3 | 3 | 1 | 9 |
| 2 | External corrosion | 3 | 3 | 2 | 18 |
| 3 | Internal corrosion | 2 | 3 | 1 | 6 |
| 4 | Surfacing pipelines | 1 | 3 | 3 | 9 |
| 5 | Vibrations | 1 | 3 | 3 | 9 |
| 6 | Damages from fishing | 1 | 1 | 1 | 1 |
| 7 | Wave loads | 1 | 3 | 1 | 3 |
| 8 | Currents loads | 1 | 3 | 1 | 3 |
| 9 | Technological mode violations | 1 | 2 | 2 | 4 |
| 10 | Blockage of the pipeline | 1 | 3 | 1 | 3 |
| 11 | Destruction of the concrete pavement | 2 | 2 | 1 | 4 |
| 12 | Landslides of sea soil | 1 | 3 | 1 | 3 |
| 13 | Earthquakes | 1 | 3 | 1 | 3 |
| 14 | Mechanical damages from anchors | 1 | 3 | 1 | 3 |
| 15 | Damages in the raisers | 2 | 2 | 3 | 12 |

# IV. Discussion

Analysis of the obtained results for risk assessment in subsea pipelines of the Azerbaijan sector of the Caspian Sea showed that out of 15 typical situations taken for consideration, the greatest risk is associated with external corrosion. The lowest risk is rated for damage from fishing. The results of all the obtained assessments can be said to agree quite well with the assessments of experts from among scientists, leading specialists and risk analysts in offshore oil and gas facilities and, in particular, underwater pipelines. However, the experts' opinions are based primarily on their experience, intuition, and are, generally speaking, subjective in nature, and the level of confidence in these estimates can be increased using the opinions of several experts individually or by a group of experts. Risk assessment for subsea pipelines according to the above Boston Cube construction procedure assumes ranking for design parameters at 3 levels (High, Medium and Low level). But this very ranking and correlation of the frequency of occurrence of a situation to one level or another, especially in conditions of uncertain and insufficient information, is subjective. Decision making under such conditions is based on fuzzy reasoning, and carrying out logical operations with them and formulating a fuzzy logical conclusion can be described quite well from the standpoint of fuzzy set theory [5,6].

Let us illustrate the possibility of applying the methodology of fuzzy sets to estimating the parameter of the frequency of occurrence of a situation in a pipeline that can lead to a loss of pipeline performance. The frequency of occurrence of the situation is assessed at 3 levels (low, medium and high levels) and the question arises what is meant, for example, by low frequency. We formalize this imprecise definition from the point of view of the concept of a fuzzy set.

As is known, an arbitrary fuzzy set C can be represented as a set of ordered pairs {MF_C (x) / x}, where MF_C (x) is a membership function. This function expresses the degree of belonging to a fuzzy set C and is defined on the interval [0,1]. A value of 0 indicates the absence of membership, and 1 indicates a complete belonging to a fuzzy set. The set x defines the scope of reasoning.

The parameter "The frequency of occurrence of a situation" in the theory of fuzzy sets can be characterized as a linguistic variable [5], which in turn depends on three fuzzy variables: "Low frequency"; "Medium Frequency" and "High Frequency". The reasoning area for this linguistic variable, using the example of an underwater pipeline, will be based on the following considerations. The long-term experience of operating underwater pipelines shows that typical situations can be identified that can lead to failures in their work: external corrosion, internal corrosion, ascent of pipelines, damage to connections, vibration, damage from anchors of shipping vessels and trawls of fishing vessels and other situations. Each of these situations occurs with a certain frequency, that is, as a percentage of the total sample size (the number of situations that occurred).

Based on this, the reasoning area for the notion "The number of events" for each situation can be set on the set [0; 100]. The membership functions for each linguistic term (low, medium, and high frequency) are given in trapezoidal and triangular form, and the resulting distribution is shown in the Figure 2.

We will set the values of the belonging function on the line [0; 1] according to the following rules.

For correlation to fuzzy set C-"Low frequency":

$IF\ \ 0 \le x \le 5, MF_C(x) = 1.00;$

$IF\ \ 5 < x \le 10, MF_C(x) = 0.50; IF\ \ 10 < x \le 100, MF_C(x) = 0.00.$

For correlation to fuzzy set C - "Average frequency":

$IF\ \ 0 \le x \le 10, MF_C(x) = 0.00\ ; IF\ \ 10 < x \le 15, MF_C(x) = 0.125;$

$IF\ \ 15 < x \le 50, MF_C(x) = 1.00;$

$IF\ \ 50 < x \le 100, MF_C(x) = 0.00.$

For correlation to fuzzy set C-"High frequency":

$IF\ \ 0 \le x \le 50, MF_C(x) = 0.00;$

$IF\ \ 50 < x \le 60, MF_C(x) = 0.40;$

$IF\ \ 60 < x \leq 100, MF_C(x) = 1.00$

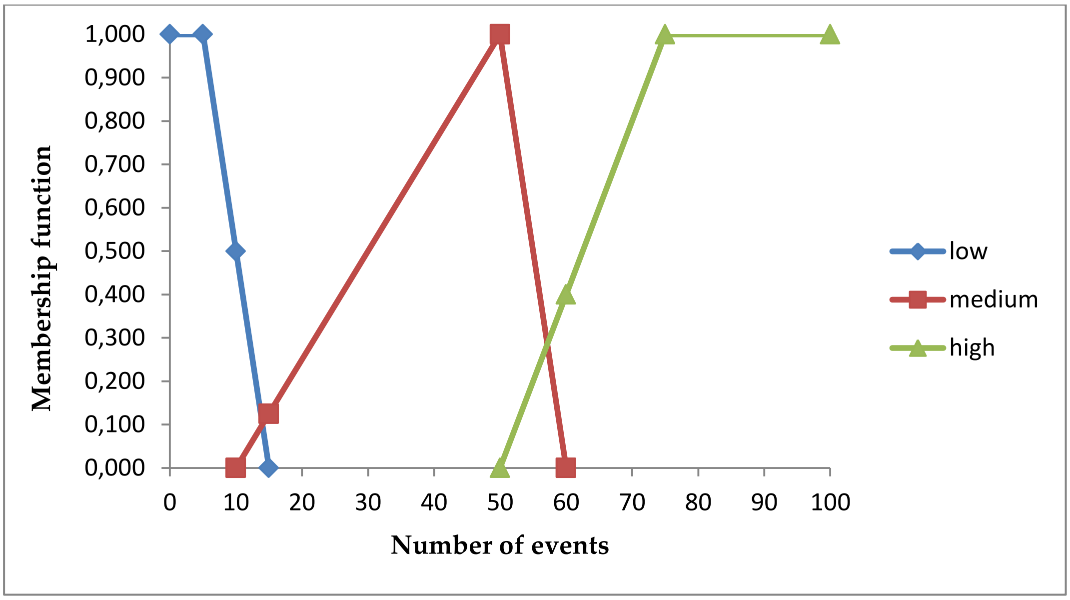


**Fig. 2:** *The distribution of values of membership function for the linguistic variable "frequency of the situation"*

As can be seen from the figure, if any situation, leading to some extent to the loss of performance of the underwater pipeline, is observed with a frequency of 15%, then it can be attributed with a membership degree of 0 to a low frequency, and with a value of 0.125 - to an average frequency. The situation that occurs with a frequency of 60%, with a membership degree of 0.40, can be correlated with a situation with a high frequency, and with a value of 0, with an average frequency. At the intersection of lines for different frequencies, when choosing how to characterize the current situation, we can compare the corresponding values of the membership function and correlate the situation under consideration to a category with a higher degree of membership.

Regarding the other two parameters as the degree of danger of the situation and the possibility of identifying it, then, similarly to the procedure carried out above, you can also formalize these two fuzzy concepts and construct the corresponding membership functions for them. At the final stage of risk assessment, we must set the rules to establish a fuzzy logical conclusion about the degree of risk for each situation under consideration. Here we will operate with the values of the membership function constructed for each linguistic term.

Let us dwell in more detail on obtaining expert estimates when applying the Boston Cube method and comparing the estimates obtained using other methodologies. It should be noted here that the main idea in the risk assessment methodology is that risk assessment can be complicated only if the information collected about the object (process) under consideration is insufficient. Therefore, it is recommended to start with a qualitative risk assessment based on available process data. Risk assessment begins with risk identification (HAZID), for example, according to the WHAT-IF method. You can then move on to other analysis methods such as CHECKLIST-ANALYSIS, HAZOP, FAULT TREE ANALYSIS (FTA) or BOWTIE charting. In all these listed methods, the opinions of experts are decisive.

The quantitative assessment of risks proposed in the work using the Boston Cube method assumes the availability of sufficiently extensive information about the object. With regard to subsea pipelines in the Caspian Sea, such information exists on the basis of statistics on accidents, their reasons for carrying out repair and restoration work, and based on the results of earlier expert assessments. These data allowed us to compile a list (List of failures) of 15 previously observed situations typical for the conditions of the Caspian Sea that led to the loss of performance of the subsea pipeline during the assessment. At this stage, we take as a basis the frequency of occurrence of the situation, that is, of all the observed situations, the selected 15 are the most common. However, when ranking the frequency (high, medium or low), the expert makes a decision, which, generally speaking, is somewhat subjective, for example, if the corrosion situation was observed with a frequency of 0.2, then by what criterion to relate it to a low, medium or high level.

Here, the expert can use, in our opinion, data analysis methods (rank classification, cluster analysis), which we did not use in this work. We only propose in this article, as one of the possible solutions, the adoption of the fuzzy inference methodology. On the other hand, the objectivity of an expert assessment can be somewhat increased when ranking the situation under consideration, using a team of experts when making a decision. It is also possible to conduct a comparative analysis of the results of the analysis and risk assessment by other methods. Thus, the result of obtaining the maximum risk for subsea pipelines associated with external corrosion is in good agreement with the results of estimates using the Event Tree analysis method.

At present, the safety issues of industrial facilities, including strategically important offshore oil and gas facilities and related underwater pipelines, are of paramount importance. The solution of these issues is also closely related to the analysis and assessment of risks, starting from the design stage and further during the construction and operation of these facilities.

Safety issues also include environmental risk assessment. Subsea pipelines are characterized by an oil spill situation due to damage at the joints, corrosion defects, leaks, pipe breaks, etc. Here, the methodology of the Boston Cube can also be applied to assess the risk of environmental pollution. In this case, the frequency of occurrence of damage and the manifestation of defects leading to spillage of the product can be taken as the first design parameter in this case. As the second parameter, it is advisable to consider the potential volume of spilled oil, and the third parameter may be, for example, the parameter of the sensitivity of the environment to the situation that has arisen. The latter parameter can be ranked depending on the wave and wind regime in the area, the presence of underwater currents, proximity to the coast and so.

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