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ANALYSIS OF STRUCTURAL RELIABILITY OF MAIN GAS PIPELINES

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The possibility of future operation of pipelines that are under exploitation is one of the most important issues of the oil and gas industry. Therefore, it is necessary to periodically check (diagnose) the technical condition of pipelines. Taking into account the operating conditions, the thickness losses may occur during the operation period.

The paper investigates the residual operating resources of various elements of the pipeline as a result of diagnostic work, as well as the calculation of the wall thickness of the main gas pipeline with methods based on modern technologies. Both analytical methods and modern software were used during the calculations. A three-dimensional spatial model of the pipeline was created via the software, and the strength and stability of the pipeline under the influence of various forces were calculated. Subsequently, following technical diagnostics of the pipeline, the possibility of further operation of the pipe element was determined.

Keywords: *Allowable stress, design resistance, main gas pipeline, reliability coefficient, strength, yield strength.*

1. INTRODUCTION

Main gas pipelines are complex structures, usually of large diameter, transporting natural gas at high pressures, and are considered hazardous production facilities. Main gas pipelines pass through various geological and climatic zones and fulfil a major function – reliable gas supply to the consumer.

As an integral part of gas production facilities, main gas pipelines have been exposed to several external and internal factors from the moment they are put into operation. Loads and impacts on gas pipelines have a wide range and include gas pressure and temperature, vibration loads on pipelines from compressor stations, wind loads on aboveground pipelines, hydrodynamic loads on underwater passages, etc. These effects cause losses in various elements of the pipeline, especially in the wall thickness of the pipeline. Defects in the welding elements that connect the various components of the pipe (linear section, elbow, transition, etc.) can lead to a reduction in the pipeline's service life or even shutdown the pipeline. In order to keep all these effects under control and to avoid negative consequences, it is important to carry out periodic inspections of pipelines.

Currently, a number of periodic inspection and monitoring methods are implemented in practice to address the stated problems and to increase the structural reliability of the pipelines. Conducted diagnostic measures play an important role in detecting potential hazards that may occur in the pipeline due to the influence of a number of static and dynamic loads. The purpose of carrying out the inspection is to determine the possibility of future operation of oil and gas pipelines [1]–[3].

2. RESEARCH METHODOLOGY

Taking into account the above-mentioned, the aim of the study is to determine the residual operating resources of various elements of the pipeline as a result of diagnostic work. In the studies, the process was modelled using the STAAD.Pro 3D Structural Analysis and Design Software, and the wall thickness of the gas pipeline was determined as a result of mathematical calculations.

The analysis of the state of operation of the studied main pipeline was carried out in the following order.

2.1. Determination of Pipeline Resistance to Tension (Compression)

To determine the structural reliability of the main pipelines in operation, as the first step, the minimum value of the pipe resistance to tension R_1^n and compression R_2^n (tensile strength and yield strength) must be determined [4]–[6]:

$$R_1 = \frac{{R_1}^n \times m}{k_1 \times k_e};\ R_2 = \frac{{R_2}^n \times m}{k_2 \times k_e},$$
$$R = min\{R_1;\ R_2\}, \tag{1}$$

where
${R_1}^n$ – normative resistance, MPa;
${R_2}^n$ – yield strength, MPa;
m – pipeline operating condition coefficient;
k_1, k_2 – reliability factors for material;
k_e – the reliability factor for the purpose of the pipeline.

The values of the coefficient of operating conditions that are used in calculating the strength, stability, and deformation of the pipeline and depend on the category of the pipeline are given in Table 1 [7].

The reliability coefficients for the material depending on the purpose of the pipeline are selected according to Tables 2–4, respectively [8]–[10]:

Table 1. Coefficient of Operating Conditions

Category of the pipeline and its area	Pipeline strength, stability and the coefficient of working conditions when calculating deformation, m
In more important areas, such as inside buildings, compressor stations, underground gas storages, and water passages of oil pipes with a diameter of Ø1200 mm. B	0.60
Water crossings of main pipelines, railway crossings, highways, difficult-to-cross swamps, intersections with compressor stations, pigging launcher and receiver points I və II	0.75
III	0.90
IV	0.90

Table 2. Reliability Factor According to the Material

Pipe specifications	Reliability factor according to the material, k_1
100 % controlled rolling steel and thermally strengthened welded pipelines with the whole process seam safe method	1.34
Double-sided arc welding, rolled and forged seamless pipes with the whole process seam safe method	1.40
Pipes welded from low alloy or carbon steel, 100 % controlled, safe or non-destructive, made by double-sided electric arc welding	1.47
Welded pipes and other seamless pipes of low alloy or carbon steel, double arc welded	1.55

Table 3. Reliability Factor According to the Material

Pipe specifications	Reliability factor according to the material, k_2
Low carbon, seamless	1.10
According to $R_2^n/R_1^n \leq 0.8$ low-carbon and low-alloy straight seam and spiral seam, welded	1.15
Made of high – strength steel $R_2^n/R_1^n > 0.8$	1.20

Table 4. Reliability Factor for the Purpose of the Pipeline

Nominal pipe diameter, mm	Reliability factor for the purpose of the pipeline, k_r			
	For gas pipeline			For oil and oil products
	P≤5.4 MPa	5.4<P≤7.4MPa	7.4<P≤9.8MPa	
Up to 500	1.00	1.00	1.00	1.00
600–1000	1.00	1.00	1.05	1.00
1200	1.05	1.05	1.10	1.05
1400	1.05	1.10	1.15	-

2.2. Determination of the Pipeline Wall Thickness

The calculated thickness δ (mm) of the pipeline, which provides the necessary strength at a given working (standard) pressure P, is calculated using the following formula [4], [5]:

$$\delta = \frac{n \cdot P \cdot D}{2(R + n \cdot P)}, \quad (2)$$

where
P – operating pressure, MPa;
n – reliability factor due to load;
D – external diameter of the pipe, mm;
R – allowable stress for steel, MPa.

2.3. Conducting Technical Inspection Studies of the Underground Main Gas Pipeline – "Astara-Gazimammad" (Azerbaijan)

The main purpose of technical inspection is to identify potentially dangerous sections of the pipeline, assess the degree of danger of defects, determine the priority of dangerous sections and carry out preventive repairs [11], [12].

According to the current technical task:

- Length of the pipeline – L=210 km;
- External diameter of the pipeline – D=1220 mm;
- Design pressure of the pipeline – P_{design}=5.5 MPa;
- Maximum allowable operating pressure – $P_{operating}$ = 1.8 MPa;
- Type of steel – 17Г1С-У [10].

During the technical diagnostics, gauge measurements were performed by using an OLYMPUS 27 MG Ultrasonic Thickness Gauge. Based on the actual data obtained in the studies, the minimum allowable thicknesses corresponding to the existing internal pressure in the pipeline were calculated and compared with the actual minimum thicknesses. Thus, the possibility of safe operation of the gas pipeline was studied on the basis of gauge measurements, minimum thicknesses, and operational loads.

3. RESULTS AND DISCUSSION

The assessment of the safe operating reserves of the studied pipeline was determined, taking into account the surface defects observed as a result of direct measurements. The actual minimum cross-sectional thicknesses were based on the results of the stress calculation under internal pressure.

As a result of the measurement carried out at pressure of P=1.8 MPa at L=187.74th km of the "Astara-Gazimammad" underground main gas pipeline, the wall thickness of the pipeline was determined in different places:

- on the top – 12.18; 12.24; 12.36; 12.45; 12.40; 12.58; 12.65 mm (δ_{min} = 12.18 mm),
- on the side – 11.96; 11.95; 11.80; 11.91; 11.96; 11.93; 11.98 mm (δ_{min} = 11.80 mm),
- on the bottom – 9.85; 9.64; 9.49; 9.19; 9.25; 9.30; 9.38; 9.48 mm (δ_{min} = 9.19 mm).

Also, corrosion pits with a depth of 5÷6 mm and layered corrosion products were found on the side and bottom surface of the pipe.

The calculated value of the required minimum thickness of the pipe cross-section at given conditions is determined:

$$\delta = \frac{n \cdot P \cdot D}{2(R + n \cdot P)} = \frac{1.1 \cdot 1.8 \cdot 1220}{2(260.87 + 1.1 \cdot 1.8)} = 4.6 \text{ mm}$$

As a result of the comparison of the result obtained in the measurement performed on the bottom surface of the pipe (taking into account the corrosion pits) with the calculated value, it was determined that this section of the pipeline was no longer suitable for operation.

3.1. Creating a Constructive Model

The strength and durability analysis of the pipe was performed using the standard STAAD.Pro Connect Edition software (OMAE 2008-57836). STAAD is a popular structural analysis application known for analysis, diverse applications of use, interoperability and time-saving capabilities. STAAD helps structural engineers perform 3D structural analysis and design for both steel and concrete structures. A physical model created in the structural design software can be transformed into an analytical model for structural analysis. Many design code standards are incorporated into STAAD to make sure that the structural design complies with local regulations.

A simple diagram of a simulated main gas pipeline with a diameter of 1220 mm is shown in Fig. 1.

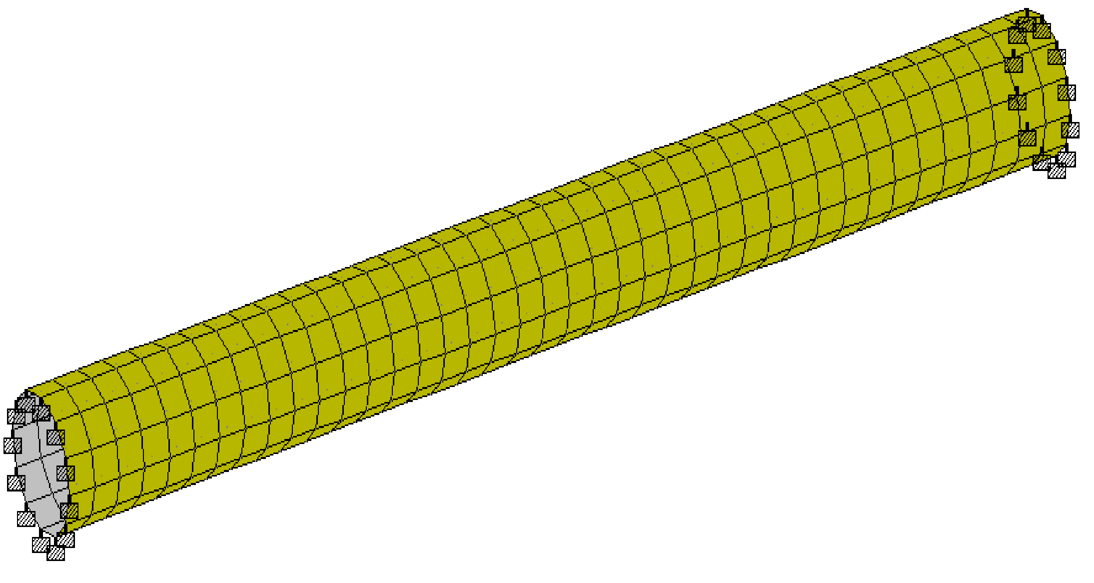

Fig. 1. Simplified model of the gas pipeline.

The characteristics of the steel used at the 187.74th km section of the Astara-Gazimamed underground gas pipeline are given in Table 5.

Table 5. The Properties of the Steel

Indicators	Actual Dimensions
Density, kg/ m^3	7849
Modulus Elasticity, E , MPa	200000
Shear modulus, G , MPa	77220
Poisson's ratio	0.3
Yield stress, MPa	245

3.2. Distribution of Applied Loads

The applied mathematical modelling took into account the operating pressure generated in the pipeline, including the mass of the metal. The load distribution scheme is shown in Fig. 2.

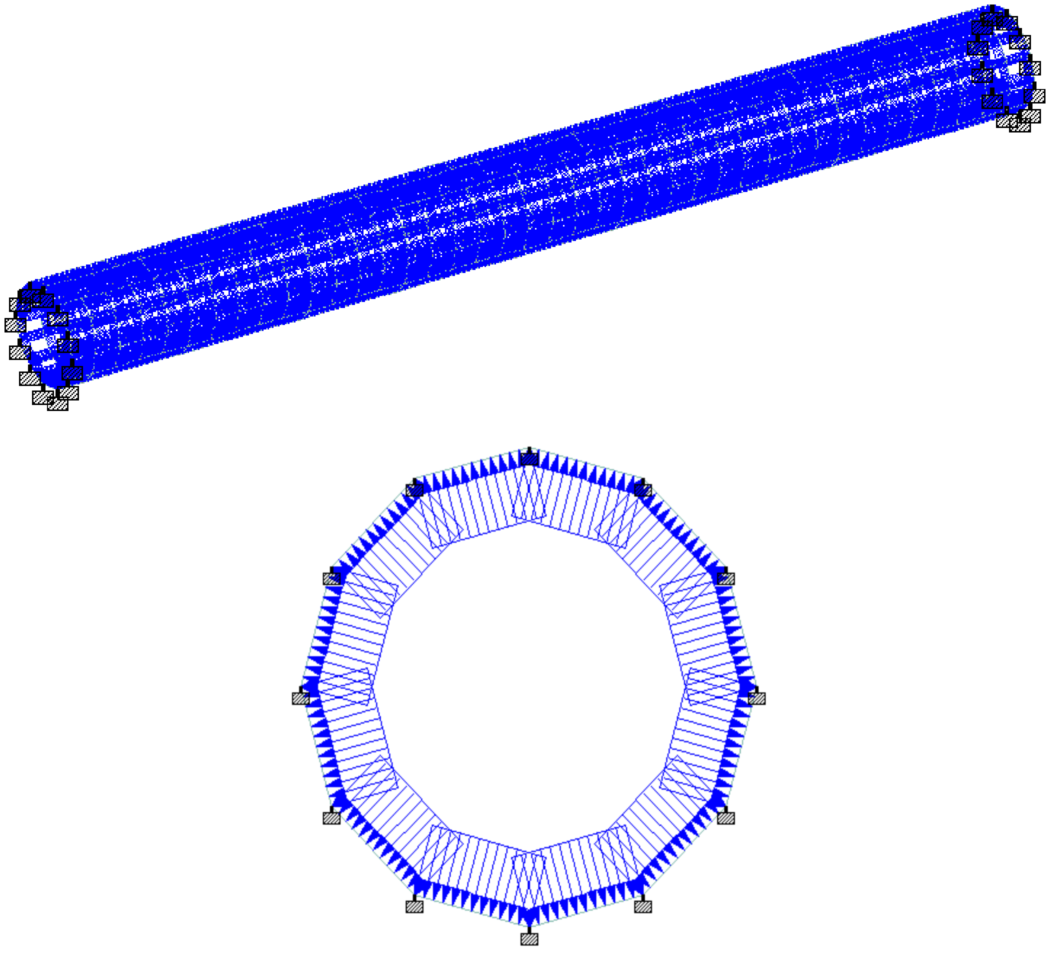

Fig. 2. Distribution of applied loads along the surface of the pipe.

3.3. Determination of the Stress Concentration Zone

It was determined that the maximum value of the yield stress in the pipeline, due to the effect of the applied load combination, was 379 MPa (Fig. 3).

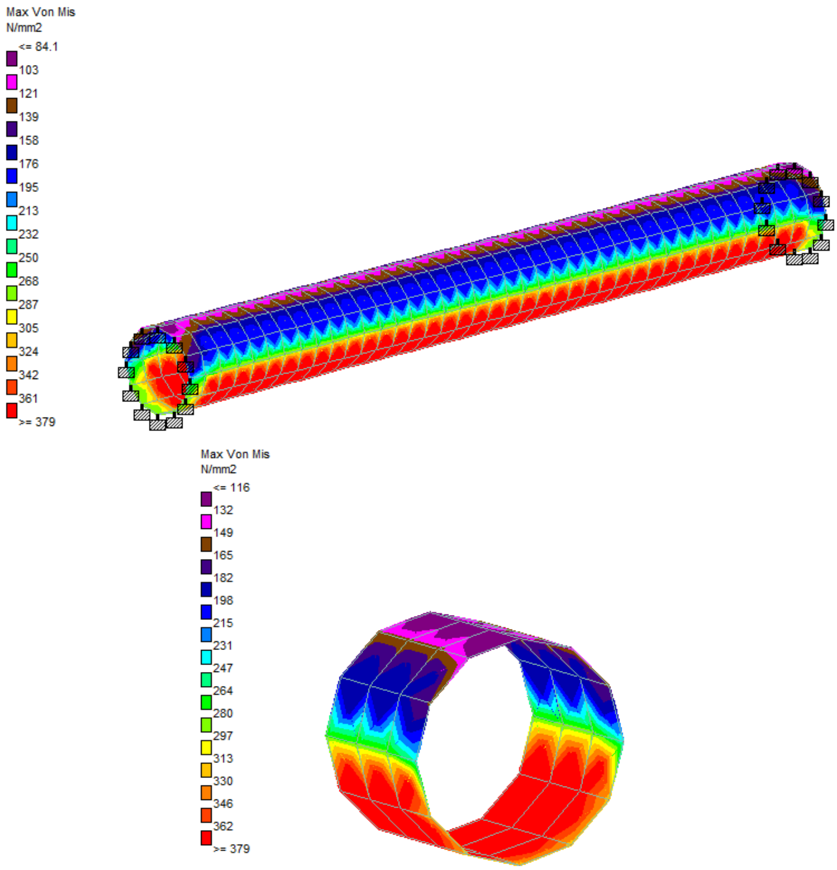

Fig. 3. Evaluation of stress limit generated in pipeline elements.

According to the selected load combination, the colour diagram shows the increase of the yield stress from top to bottom according to the model.

The structural model of the pipe was modelled in the STAAD.Pro software, and analysed taking into account the metal weight and the working pressure generated in the pipe. Since the yield strength on the bottom of the pipeline (379 MPa) is greater than the yield strength (350 MPa) corresponding to the physical properties of the metal, the resulting stress in the pipe is greater than the allowable stress.

4. CONCLUSION

- Defectoscopy was carried out with an OLYMPUS 27 MG ultrasonic thickness gauge on the 187.74th km section of the underground main gas pipeline “Astara-Gazimammad” of the “Gas Export” Department (SOCAR, Azerbaijan).

- During the monitoring process, measurements were taken on the surface of the pipeline in the annular direction, and it was determined that the actual wall thicknesses were 12.18 mm on the top surface of the pipe, 11.80 mm on the side surface, and 9.19 mm on the bottom surface. Since corrosion pits sized 5÷6 mm were found on the bottom surface of the pipe, the actual value of the thickness in this part turned out to be 3.19 mm.
- By comparing the estimated thickness of the pipeline by mathematical calculation with the actual thickness (3.19 < 4.60), it was concluded that the pipeline was unsuitable for operation.
- The structural model of the pipeline was modelled in STAAD.Pro software and analysed taking into account the metal weight and the operating pressure generated in the pipeline. Since the yield stress (379 MPa) is greater than the stress corresponding to the physical properties of the metal (350 MPa), the resulting stress in the pipe is determined to be in excess of the allowable stress limit.

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