Comparative Strain-Stress State Analysis of the Pipeline During the Construction of the Trunk Line Underwater Passage by the Directed Drilling Method

I V Ivanova¹, M A Ramzaeva¹, M R Teregulov¹

¹Pipeline Transportation Department, Samara State Technical University, Samara, Molodogvardeyskaya str., 244, 443100, Russia

E-mail: natka_1589@mail.ru; teregulovmroil@gmail.com

Abstract. The article is devoted to the determination of the stress-strain state of the section of the underwater crossing of the main pipeline using the Ansys software package. The paper proposes a method for calculating the stressed state, taking into account the deformation of the cross-section of the pipeline during pulling through. This technique makes it possible to estimate bending stresses in the pipeline arising from changes in the geometry of the pipeline in accordance with the well profile depending on time. This approach makes it possible to assess the stress-strain state of the pipeline along the entire length of the pull-through section.

1. Introduction
Ensuring the stable operation, reliability and safety of oil pipelines is one of the priority tasks in their construction and operation of any pipeline system.

From the point of view of the operational reliability of the oil pipeline, crossings over natural and artificial barriers can be referred to areas with an increased risk of exploitation.

The increased risk of the operation of any underwater crossing in comparison with the main part of the main pipeline is determined not so much by the likelihood of an emergency situation, but by large environmental problems and economic costs to eliminate its consequences. The terms of liquidation of failures at the PPMN are many times higher than those for the onshore part of oil pipelines, and their repair in terms of complexity and costs is comparable to the construction of a new section. At present, the system of PJSC "Transneft" operates over 1,400 PPM with a total length of about 3,000 km (including floodplain areas) [4].

The NNB method is gaining more and more popularity in the construction of underwater crossings. The NDB technology allows to carry out construction work in a wide range of hydrogeological conditions, with minimal volumes of excavation of the earth's surface, which is one of the fundamental advantages of this method along with its economic feasibility compared to the trench method.

The NDB method also has its drawbacks, and the main one is the deformation of the pipeline cross-section during pulling through.
2. Materials and methods

The main purpose of the work was to calculate the VAT of the pipeline during the pipeline pulling through. The assessment of the impact of changing the geometry of the pipeline in accordance with the well profile, depending on the time.

At the moment, in the system of PJSC Transneft, there is a main governing document defining construction methods and design standards for an underwater crossing using the directional drilling method:

- RD-91.040.00-KTN-132-18 “Construction of underwater crossings of oil pipelines using directional drilling” [1-3].

The main formula for determining the stress-strain state of the pipeline is the formula for the maximum stresses in the pipeline at the approach section to the well (section of the section, which is located on roller supports before entering the well), which must satisfy the condition:

$$\sigma_{\text{max}} = \frac{T_{\text{max}}}{E} \cdot \frac{E \cdot D_{\text{min}}}{2 \cdot \rho_{\text{min}}} \leq K \cdot R_{\text{s}}$$

where: $\sigma_{\text{max}}$ - the value of the maximum stress in the pipeline, MPa;

$T_{\text{max}}$ - the maximum value of the traction force required to move the pipeline string on the section of the descent track, kN;

$E$ - modulus of elasticity of steel, MPa;

$D_{\text{min}}$ - the minimum value of the pipeline bend radius, determined depending on the tracing of the descent path and the placement of supports, m;

$\rho_{\text{min}}$ - outer diameter of the pipeline, m;

$F$ - cross-sectional area of the pipe, m²;

$R_{\text{s}}$ - standard resistance of the pipe metal; the minimum value of the yield point according to the certificate for pipes is taken, MPa;

$K$ - generalized coefficient, taking into account the operating conditions of the pipeline and the combination of loads, $K = 0.75$.

According to the results of the calculation using the above technique, the stress values are in the permissible range, and the resulting stresses do not exceed the permissible values.

The disadvantage of this technique is the determination of the maximum stress in the pipeline only in the approach section. The method does not calculate bending stresses arising in the pipeline when it is pulled through.

In the course of the literature review of the problem, it was revealed that the problem of finding the stress-strain state of a pipeline during the construction of an underwater crossing by the directional drilling method in the process of pulling it through remains unexplored. To solve it, numerical modeling by the finite element method in the Ansys software was used.

3. Results

The Ansys software implements the inverse problem of finding the loads acting on the pipeline by shaping the profile of the well drilled by the directional drilling method in the Ansys Static Structural environment [6].

As part of the work, an algorithm for analyzing the stress-strain state of a pipeline is proposed, the main principle of which is to change the planned-height position of the pipeline points in accordance with the well profile, depending on time.

At the initial stage of modeling, material properties are set in the Engineering Data window in accordance with the initial data for the calculation.

At the next stage, a geometric model is built using the SpaceClaim graphic designer. The geometric model is a pipeline 443720 mm long, 820 mm in diameter and 16 mm thick. Along the length of the pipeline, at the same distance from each other, cross-sections are located, on which the boundary conditions are imposed. The distance between the cross sections is selected in accordance with the
required analysis accuracy. An additional goal of the analysis is to find the optimal number of points to ensure the required accuracy of the result.

To reduce the calculation time, it is proposed to use a shell model instead of a solid model, since it allows to reduce the calculation time due to the fact that the calculated grid of the pipeline wall will be one layer of cells instead of several repeating layers, depending on the calculated grid spacing.

The construction of a computational mesh for a geometric model is the main and most important stage of the analysis, since it is the quality of the mesh that affects the accuracy of the results. Ansys is based on the finite element method (FEM). FEM is based on the creation of a system of differential equations, where each equation belongs to its own node or cell (the defining element for creating a system of differential equations depends on the type of analysis). Equations in common nodes / cells have the same solution. The size of the system of differential equations depends on the step of the computational grid. An electronic computer (ECM) solves the resulting system of equations proceeding from the specified boundary conditions [5].

For the analysis of structural deformable models, only a regular rectangular mesh is used; the presence of tetrahedrons and mesh errors is not allowed.

In this case, the Sizing function for the entire body volume and the FaceMeshing function for the outer surface of the pipeline were used to create a mesh. The calculated grid spacing is 10 cm.

![Figure 1. Calculation geometric model grid of the pipeline.](image)

At the next stage of the simulation, the boundary conditions are specified in the Setup window. Since the inverse problem of finding the applied loads and tested stresses was solved depending on the change in the planned elevations of the cross-sections of the pipeline in accordance with the well profile, the problem in the Ansys software was solved using the Displacement function.

The Displacement function allows you to define the displacement of the pipe cross-section along any axes. During the analysis, the movement along the Z axis was set, the movements along the X, Y axes, in order to find the stresses directly in the process of changing the geometry of the pipeline in accordance with the well profile, it was decided to neglect.
To unload data on the displacement of various cross sections, the information data obtained from the drawing was adapted. The adaptation of the data was carried out in an Excel spreadsheet editor with the construction of the dependence of the horizontal-height position of each investigated cross-section on the location along the length of the pipeline.

To simulate the geometry of the underwater crossing section, according to the design drawing, the well profile was divided into 3 sections:
1. Curved section from the beginning of the well to the lowest mark of the well
2. Straight-line section with the lowest well mark
3. Curved section from the lowest elevation of the well to the end of the well

For the two curved sections, using the trend line function in the Excel table, an approximating function was selected (Figure 2; 3). Based on the values obtained using the approximating functions, an array of tabular data was created, which is the initial data for setting the boundary conditions.

Figure 2. Finding the approximating function for the 1-st curved section of the trunk line underwater passage using adapted source data.

\[
y = 3\times10^{-6}x^5 - 0.0002x^3 + 0.0052x^2 - 0.0601x + 0.3198 - 1.757x + 1.5244
\]

\[
R^2 = 0.9999
\]
Figure 3. Finding the approximating function for the 2-nd curved section of the trunk line underwater passage using adapted source data.

The investigated cross-sections were chosen at equal length intervals on the assumption that the pipeline moves uniformly in the well.

In the window of the Displacement function, the change of the horizontal-height position of cross-sections along the Z axis is set in accordance with the table values. In the Graph window, on the basis of the entered table values, a graph of the movement of a point depending on time is formed (Figure 3; 4).

Figure 4. Schedule of changes in the planned altitude position for 1 point out of 44.

Figure 5. Schedule of changes in the planned altitude position for 14 points out of 44.
This operation is repeated for all cross-sections analyzed (Figure 6).

![Figure 6. Introduction of boundary conditions.](image)

To take into account in the calculation of the dead weight of the pipeline, the direction of the gravitational acceleration \( g = 9.81 \text{ m/s}^2 \) in the negative direction of the Z axis is set using the Acceleration function.

The analysis results are a video fragment and a data array unloading with the values of the maximum and minimum stresses at each calculation step.

![Figure 7. Results of analysis of the stress-strain behavior with a distance between cross sections of 10 m.](image)

In the considered case, the highest bending stress is 260.7 MPa, which is higher than the value calculated by the standard method. The most dangerous stressed section is located on the lower generatrix of the pipeline at a distance of 130 m from the well start point (Figure 7).

In order to assess the optimal number of points per unit length of the pipeline, to ensure the accuracy and productivity of the calculation, a comparison of the distances between the cross sections of 20 m, 10 m, 5 m was performed.
The distance of 20 m between the cross-sections does not provide the required accuracy of the analysis results (Figure 8). The pipeline material begins to bend between the cross-sections under consideration in an attempt to compensate for geometry changes and resulting loads. In reality, this does not happen, therefore, it is necessary to choose a more frequent arrangement of the analyzed cross-sections along the length of the pipeline.

Results of analysis of stress-strain state with a distance between cross-sections of 5 m have similar results with an analysis where cross-sections are considered along the entire length at a distance of 10 m. But the higher the density of cross-sections along the length of the pipeline, the higher the complexity of the analysis, due to the need to work with a large amount of data.

Thus, the most optimal distance between the investigated cross-sections is 10 m.

4. Conclusion
From the obtained and presented results, the following conclusions can be drawn: the disadvantage of the existing technique is the determination of the maximum stress in the pipeline only at the approach site. The existing methodology does not calculate bending stresses arising in the pipeline when it is pulled through. The proposed methodology evaluates the stress-strain state of the pipeline along the entire length of the well profile. The modeling algorithm presented in the paper allows to estimate the stress-strain state of the pipeline by solving the inverse problem, based on the known design data of the route profile. Also, in the work, the optimal distance between the points of the pipeline section was determined to ensure optimal accuracy and calculation performance.

5. References
[1] SP 36.13330.2012 Main pipelines Updated version of SNiP 2.05.06-85* Approved 25.12.2012 (Moscow: Gosstroy RF: FAU "FTS") 2012 p 92
[2] RD 91.040.00-KTN-132-18 2018 Main pipeline transport of oil and petroleum products Construction of underwater crossings of oil pipelines Requirements for organization and implementation (PISC "Transneft")
[3] RD 75.200.00-KTN-012-14 2018 Main pipeline transport of oil and petroleum products
Crossings of main pipelines through water barriers. Design standard PJSC "Transneft"

[4] Nikolaev N N 2015 Stress-strain state and stability of curves of inserts of aboveground and underground sections of the pipeline *Oil and gas*

[5] Burkov P V, Chernyavsky D Y, Burkova S P, Konan A 2014 Simulation of pipeline in the area of the underwater crossing IOP Conference Series: E and Env Sc

[6] The Ansys Help reference program as part of the Ansys PC