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Research paper

Analysis of Main Oil Pipeline Stress-Strain State During the Overhaul Operations

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Abstract

The work is devoted to the actual problem of modernization and overhaul repairs of main pipelines sections after the structure individual elements exploitation period. Relevant spiral-seam pipes damages depending on the corrosion of the metal adjacent to the spiral seam and the pipeline insulation type were investigated. An analysis of the technological process features of connecting the pipeline existing parts with the newly parts was carried out. Factors that may lead to exceeding the permissible stresses and deformations of the steel main pipeline structure under the influence of non-operating loads and affect the reliability of the structure as a whole were detected. Evaluation and calculation of the steel main pipeline stress-strain state parameters with operational loads during the damaged pipeline area replacement were carried out in the article.

Keywords: *main oil pipeline, overhaul operations, reliability, stress-strain state.*

1. Introduction

The stress-strain state of main pipelines constructions during the installation work on overhaul repairs execution is significantly different from the operational one. The tensile stresses from the pressure of the fluid being pumped are absent, but instead there is a bend of the main pipeline area, which creates stresses both tension and compression.

Installation works are carried out at the end of the main pipeline construction individual elements life. An integral characteristic part of the structure state during such works execution is the significant vertical displacement of the pipeline. They are caused by the need to ensure the technological process of docking and welding of existing parts with newly packed ones.

The study of the actual stress-strain state in order to provide the permissible stresses and deformations levels of the main pipeline steel structure under the influence of non-operating loads is an important factor in structure reliability assessing.

2. Analysis of recent research and publications

Presently, the operating stress-strain state of the steel pipeline structure is mainly calculated [1, 2, 13, 14], thus sufficient attention on the main pipeline state under non-stationary operational conditions is not given. Recently, attempts to assess the reliability of main oil and gas pipelines have been made [3…6].

2.1. The purpose of the paper

The aim of the article is the main pipeline stress-strain state parameters analytical establishment during the pipeline part replacement works execution.

3. Basic material and results

The object of the overhaul repair with pipes selective replacement is the section of the main oil pipeline Lisichansk - Kremenchuk. The length of the steel main oil pipeline section, which should to be replaced, is 632 m and it is an underground linear part. The external pipeline diameter is $D_{ex} = 1020 \text{mm}$, the pipeline wall thickness – $\delta = 9 \text{mm}$. The pipeline is made of steel grade 12G2C. The main oil pipeline area is located in the swamp area. In this area seasonal groundwater level lifting and lowering throughout the year can be traced, which has a negative impact on the main oil pipeline itself and directly on its isolation state.

The part of the pipeline to be replaced was made from a spiral-seam pipe. Characteristic damages of such spiral-seam pipes depend on corrosion of the metal adjacent to the spiral seam and the type of the pipeline insulation. In this case, a film insulation that has worse properties than a bitumen was used.

A special diagnostic was performed to determine the overhaul and replacement requiring area. Such diagnostic included the oil pipeline cleaning from paraffin residues, determination of the minimum pass diameter, with the help of magneto-scan devices and ultrascope to determine the damage to the body of the pipe (internal and external defects, their spatial arrangement) and damage to the welds. On the basis of these results, a decision to the main oil pipeline overhaul with the selective pipe sections replacement was taken.

Lysychansk - Kremenchug main oil pipeline belongs to the third category of main pipelines. The main pipeline lowering to the pipe top is taken at least 1 m, which is due to the requirements for the optimal transfer regime and the substances being pumped properties. The trench width at the bottom is not less than $1.5D_{ex}$ [7,8].

Fig. 1: The process of the main oil pipeline new section installation by the pipe-laying machine D-355

To the complex of machines, mechanisms and vehicles used during overhaul repair of the main oil pipeline section with a selective pipes replacement included three medium power pipe-layers D-355 (Fig. 1). The maximum load that can be lifted by the D-355 pipe-layer on the operating radius of 1.22 m is 92 tonnes, and on the operating radius of 2.5 m – 47.8 tonnes.

To ensure the technological jointing conditions of the main pipeline replaced section with the existing pipe, a free length of the pipeline up to 100 m is required. This is due to the considerable dimensions of the pipe cross-section and the pipe dead load. At the extreme point of the main oil pipeline new part, under the installation conditions, it is necessary to reach a rotation angle equal to 0 and to lift the free end of the pipeline over the existing part by 20 cm using three pipe-layers. They are used to achieve the parallelism of the new and existing parts of the main pipeline in a vertical plane, that is, the console part, under its own weight, is distorted and becomes parallel to the existing main oil pipeline (Fig. 2). Therefore, installation motions will be considered moving the new part of the pipeline at the jointing point of 1.2 m. From the length of 100 m of the main oil pipeline free part due to the considerable length of the raised part and a significant pipeline structure load, three pipe-layers D-355 raise only part of the pipeline, the length of which is 85 m.

Taking into account all of the above requirements, a strain scheme of the new pipeline structure part installation position was determined (Fig. 3).

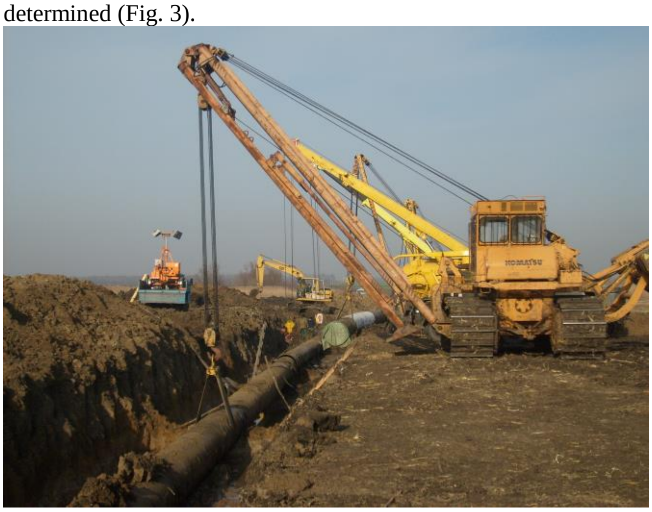

Fig. 2: Main oil pipeline new section installation

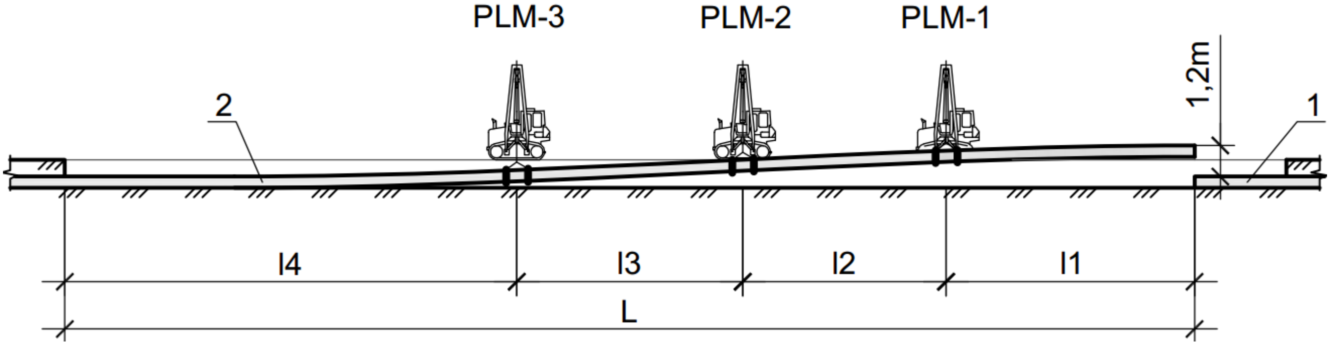

Fig. 3: Installation position scheme of the main oil pipeline structure new section:1 - the existing part; 2 - new part

According to the installation position scheme of the pipeline part during its installation a design deformed scheme [9] was formed (Fig. 4)

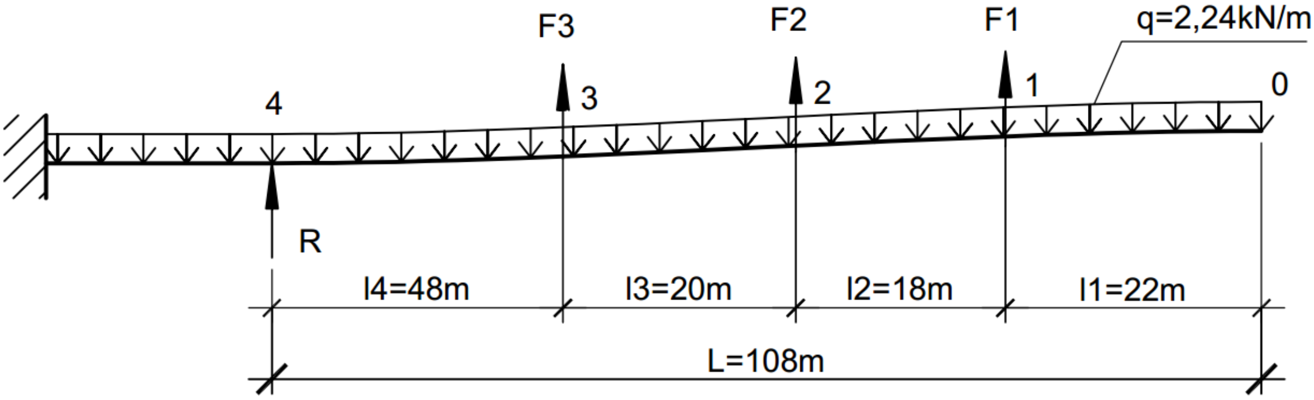

Fig. 3: Design scheme of the main oil pipeline structure during the overhaul repair

The following prerequisites for calculation were adopted:

- the rotation angle at the end of the pipeline console section, which will be connected to the existing part (point 5) equal to $\varphi_5 = 0$;
- the vertical displacement of the pipeline console section end in point 5 is $f_5 = 1.2\,\text{m}$;
- a part of the pipeline area, which is based on the ground (from point 0 to point 1) is equal to 15 m;
- rotation angle and displacement in point 1 are equal to 0, $\varphi_1 = 0,\ f_1 = 0\,\text{m}$.

The first two conditions were mathematically taken into account after the successive integration of the pipeline curved axis equation.

Curved axle beam equation on a section 4 – 5 is equal to:

$$EI \cdot \frac{d\varphi_{4-5}}{dx} = -M = \frac{q \cdot x^2}{2} - R \cdot x - F_1 \cdot (x - l_1) - F_2 \cdot (x - l_1 - l_2) - F_3 \cdot (x - l_1 - l_2 - l_3). \tag{1}$$

Equation of displacements on a section 4 - 5 in the general form:

$$f_{4-5} = \frac{1}{E \cdot I}\left[\frac{x^2 \cdot \left(4R \cdot x - q \cdot x^2 + 4F_1 \cdot x - 12F_1 \cdot l_1 - 12F_2 \cdot \Sigma l_2\right)}{24}\right] - \frac{1}{E \cdot I}\left[\frac{\left(12F_3 \cdot \Sigma l_3 - 4F_2 \cdot x - 4F_3 \cdot x\right) - 12M_0 \cdot x^2}{24} + c_4 \cdot x + c_{44}\right]. \tag{2}$$

Rotation angle equation at the end of the main pipeline console section is equal to (point 5):

$$\varphi_5 = \frac{1}{E \cdot I}\left[\frac{R \cdot L^2}{2} - \frac{q \cdot L^3}{6} + F_1 \cdot \left(\frac{L^2}{2} - l_1 \cdot L + \frac{l_1^2}{2}\right) + F_2 \cdot \left(\frac{L^2}{2} - \Sigma l_2 \cdot L + \frac{\Sigma l_2^2}{2}\right) + F_3 \cdot \left(\frac{L^2}{2} - \Sigma l_3 \cdot L\right) + \frac{\Sigma l_3^2}{2} - M_0 \cdot L\right] = 0, \tag{3}$$

where $\cdot L$ – the pipeline length to be lifted; l_1 – the distance between the point on the pipeline, the first being detached from the trench bottom to the first pipe-layer machine; l_2, l_3, l_4 – the distance between pipe-layer machine PLM-1, PLM-2, PLM-3, respectively; $\Sigma l_2 = l_1 + l_2$; $\Sigma l_3 = l_1 + l_2 + l_3$.

Equation of displacements at the end of the main pipeline console section is equal to (point 5):

$$f_5 = \frac{1}{E \cdot I}\left[\frac{L^2 \cdot \left(4R \cdot L - q \cdot L^2 + 4F_1 \cdot L - 12F_1 \cdot l_1 - 12F_2 \cdot \Sigma l_2\right)}{24}\right] - \frac{1}{E \cdot I}\left[\frac{\left(12F_3 \cdot \Sigma l_3 - 4F_2 \cdot L - 4F_3 \cdot L\right) - 12M_{0 \cdot L^2}}{24} + c_4 \cdot L + c_{44}\right] = 1.2\text{m} \tag{4}$$

where $c_4 = -F_1 \cdot \frac{l_1^2}{2} - F_2 \cdot \frac{\Sigma l_2^2}{2} - F_3 \cdot \frac{\Sigma l_3^2}{2}$; $c_{44} = \frac{1}{6}\left(F_1 \cdot l_1^3 + F_2 \cdot \Sigma l_2^3 + F_3 \cdot \Sigma l_3^3\right).$

The impossibility of such additional conditions made it necessary to determine the stresses values, which were created by the first and second pipe-layer machines as reaction stresses. This precondition is in line with the installation technology: the first and second pipe-layer machines are stationary; they provide main pipeline lifting and its maintenance in the required position.

The stress in the third pipe-layer machine was taken for the dynamometer displays during the fixing of the pipeline part in a technologically necessary position.

After the displacements at the console section end of the main pipeline (4) a displacements graph of the main pipeline axis during the installation operation was calculated (Fig. 5).

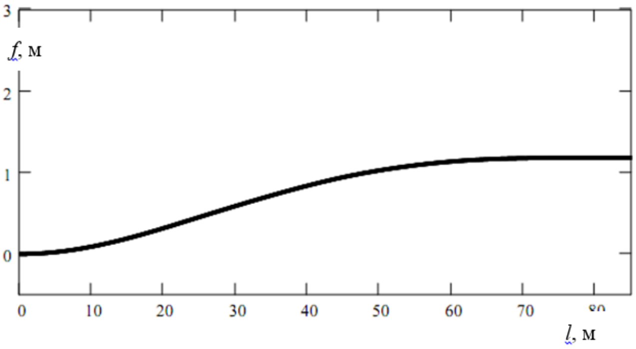

Fig. 5: The displacement of the main pipeline axis during the installation operations

The maximum bending moment (Fig. 6) occurs at the point 1 – the main pipeline lifting point from the trench bottom. It is equal to $M_{\max} = 1510 \text{kN}\cdot\text{m}$. Accordingly, the maximum stresses occurring in the main pipeline are equal to $\sigma_{\max} = \dfrac{M_{\max}}{W} = 279 \text{MPa}$.

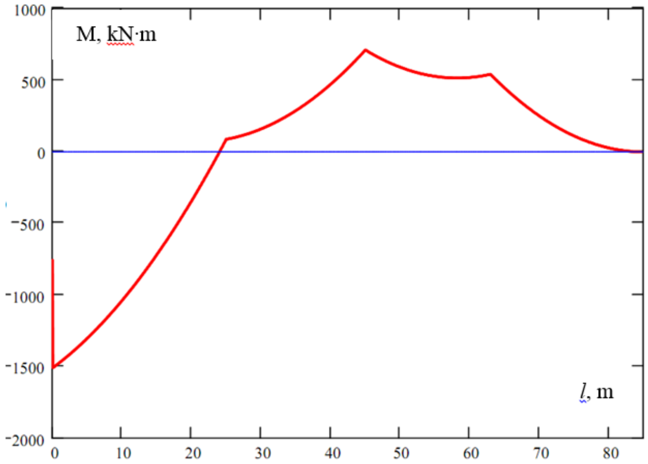

Fig. 6: Bending moments distribution diagram in the main oil pipeline due to the installation operations

4. Conclusions

As a result of the stress-strain state assessment of the main oil pipeline section during its part replacement operations, it was established that the maximum pipeline installation load stresses reach values of 81% of the steel yield strength.

In view of this, it was concluded that deviations from the technological scheme of installation (shortening the length of the assembly area, increasing the load from pipe-layer machines, changing their location) could lead to stresses exceed the tensile yield strength of steel and affect the reliability of the structure as a whole.

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