RESEARCH PAPER

Method for determining technological parameters to repair pipeline with out-of-spec curvature

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ABSTRACT

When performing in-line inspection of trunk pipelines, line pipe sections are detected with curvature exceeding the values required by specifications. To prepare a repair work project that entails bringing the pipeline into the standard conditions, it is necessary to determine the technological parameters of the repair. The corresponding technique is known for cases of moving an initially straight pipeline. The authors of the paper have developed the method for determining the technological parameters to repair pipeline with out-of-spec curvature of the axis. The method is based on simulation of pipeline deformation with the initial curvature of the axis, taking into account the actual operating conditions of the pipeline and in-line inspection data. Examples of calculations of repair technological parameters and stress-strain state of pipeline sections with out-of-spec curvature are given. The simulation results confirm the possibility for applying this method to assess the technological parameters of repair, the length of trench excavation, the size and limits of the pipeline additional burying or lifting, and to determine the stress-strain state of the pipeline section under repair during and after repair work.

Key words: Pipeline, out-of-spec curvature radius, technological parameters of repair, calculation of stress-strain state.

INTRODUCTION

The underground pipeline axis may acquire an out-of-spec curvature during its construction and operation. The reasons for this are detailed in [1]. Sections with out-of-spec curvature are detected during in-line inspection pigging (ILIP) with the navigation system.

Under the impact of geological conditions, the pipeline axis bending radius may change, including its decrease. Welded joints of sections in the zone of minimum bending radius may have technological welding and corrosion flaws, the propagation of which can lead to the metal fracture. The decision to repair the pipeline is taken with regard to the curvature radius, the geology of the pipeline corridor, the presence of weld joint defects and potential damage from loss of pressure tightness of the weld joint.

To repair a line pipe section with a curved axis and bring the pipeline to the design position, the following actions are used:

- replacing the section with a bend by pre-fabricated bent branch
- changing the pipe section position depending on the bend direction (additional burying or lifting and soil embedding under the pipeline section with bent in the vertical plane)
- relaying a line pipe section with bent in the vertical and horizontal planes.

The repair methods used involve moving a filled pipe that has a significant initial curvature of the axis. The work is performed with a stop of product transfer without emptying the pipeline. At that, the force required for pipeline movement is significantly affected by the internal pressure and temperature difference, which may be less under repair conditions than during operation. During the repair work, to ensure their safety, it is necessary to assess the stress-strain state (SSS) of the pipeline section being repaired. To confirm

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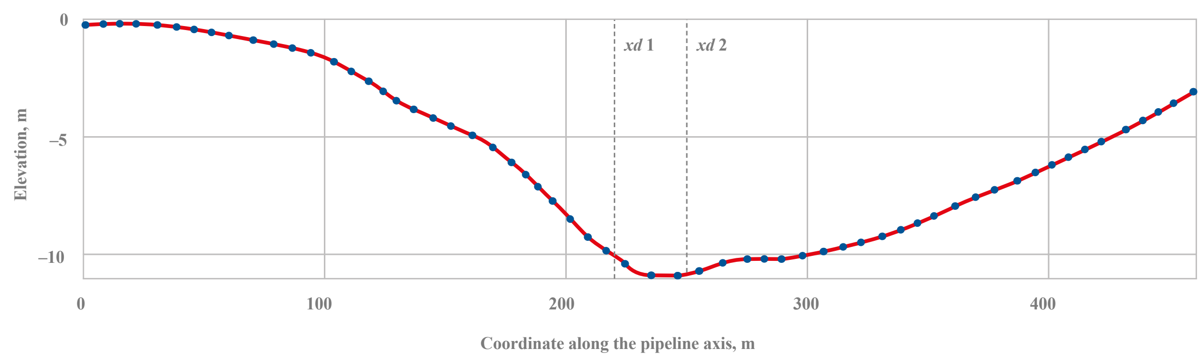

Figure 1. *Profile of the curved pipeline elastic base: ●●● – profile per ILIP data; ▬ – spline approximation; xd1, xd2 – step limits.*

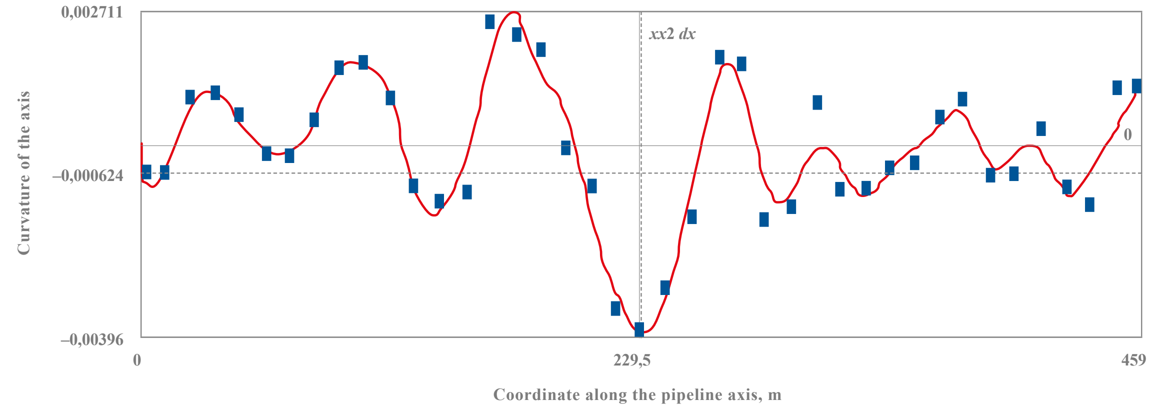

Figure 2. *Pipeline axis curvature: ▬ – design curvature; ●●● – curvature per ILIP data; xx2·dx – repaired section.*

the effectiveness of repairs, such an assessment is required when operating loads are applied at the end of repair activities and pipeline backfilling.

A method is known for determining the technological parameters of repair, when moving an initially straight pipeline [2]. The authors of this article have developed the method to determine technological parameters for repairing underground pipeline sections with out-of-spec curvature of the axis.

This method is based on simulating the pipeline deformation with the initial curvature of the axis, takes into account the actual operating conditions of the pipeline and the results of ILIP, and is relevant for all repair techniques mentioned above.

The sequence of calculations

The sequence of calculating the technological parameters to repair a pipeline section with out-of-spec bend radius is as follows.

Using the measured curvature of the section and double integration, the profile of the curved elastic base (elevation position) of the pipeline is determined and calculated elevation position is compared with ILIP data.

Using the relaxation method [3], the contact problem of pipeline deformation is solved under the impact of loads from the weight of the backfill soil and the own weight of non-emptied pipeline. This takes into account the axial force from the internal pressure and temperature difference during operation and repair. The parameters of the design model depend on the pipeline diameter and wall thickness, its burying depth, and the physical and mechanical properties of the backfill and base soil. The calculated curvature of the axis is determined, and a bending stress distribution diagram is plotted. The pipeline curvature detected by ILIP is compared

[1] SP 36.13330.2012. Trunk pipelines. Current version of SNiP 2.05.06-85* (with Amendments # 1, 2).

with the calculated curvature and, if necessary, the calculated parameters of the model are refined to obtain the maximum data match.

To bring SSS to the design parameters, the limits and values of the pipeline additional burying or lifting are determined. For this purpose, the problem of the pipeline deformation on a curved elastic base under the action of operational loads and impacts is solved. The profile of this base is formed taking into account the necessary position, vertical height and length of additional burying or lifting. This section is defined as a 'step' in the initial profile. The position, limits, length, and height of such a 'step' are determined. The SSS of the pipeline section that is completely backfilled after repair is determined, and verification of strength state conditions per SP 36.13330.2012[1] is performed, when operating loads are applied.

In order to monitor the pipeline SSS during the repair process under previously determined parameters of additional burying or lifting, the problem of the excavated section deformation under the weight of non-emptied pipeline, internal pressure, temperature difference and loads from the pipelayers is solved. Thus, the calculation determines the length limits of the repaired section, the loads of the pipe-laying machines and their placement parameters.

Calculation model

Deformation of the pipeline on an elastic base is described by the differential equation:

$$EJy^{IV} + Ny'' + ky + \lambda\dot{y} + \rho\ddot{y} = 0,$$

where EJ – bending stiffness of the pipeline, MPa/m^4;

y – vertical displacement of the pipeline, m;

N – axial load, N:

$$N = S - \frac{EFd}{\frac{2}{\gamma} + 1},$$

S - equivalent axial load in the cross-section of the pipeline:

$$S = \left(\alpha E \Delta t + 0.2\sigma_{hs}\right)F,$$

α – linear expansion coefficient of steel;

E – Young's modulus of steel, MPa;

Δt – temperature difference, °C;

σ_{hs} – hoop stress, MPa;

F – cross-section area of the pipe, m^2;

l – oil pipeline span over the karst hole (pothole diameter), m;

d – elongation of the section:

$$d = 0{,}5\int_l y'^2\,dx,$$

$$\gamma = \sqrt{\frac{\pi D c_{x0}}{EF}},$$

D – pipeline outer diameter, m;

c_{x0} – generalized coefficient of shear strength of the soil, MPa/m;

λ – damping coefficient, MPa/s;

$k = c_{y0}D$:

c_{y0} – generalized coefficient of compression strength of the soil:

$$c_{y0} = \frac{0{,}12E_s}{\left(1 - \nu_s^2\right)\sqrt{D}},$$

E_s – soil deformation modulus, MPa;

ν_s – coefficient of soil transverse deformation;

ρ – line mass, kg/m:

$$\rho = \frac{q_{pl} + \gamma_s D\left(h_0 - 0{,}39D\right)}{g},$$

q_{pl} – line mass of pipeline filled with oil, MPa/m;

γ_s – specific weight of soil, MPa/m;

h_0 – distance from the pipe axis to the top of backfill, m;

g – gravity acceleration, m/s^2;

A structurally nonlinear (with a variable boundary) contact problem of a pipeline interaction with a curved ground base is solved by the relaxation method [4] using the computer mathematical software MathCAD. The method of finite differences with a constant pitch is applied to sample the initial continuum problem with respect to spatial coordinate. A three-ply difference scheme is used to sample with respect to the time variable.

Example of calculation

Below, the results are shown of the calculation based on the developed method for the oil pipeline section with the following parameters: outer diameter – 1220 mm, wall thickness – 16 mm. Operational pressure – 4 MPa, temperature difference – 30°C, taken pipeline burial depth – 1 m, specific weight of backfill soil – 1700 kg/m^3.

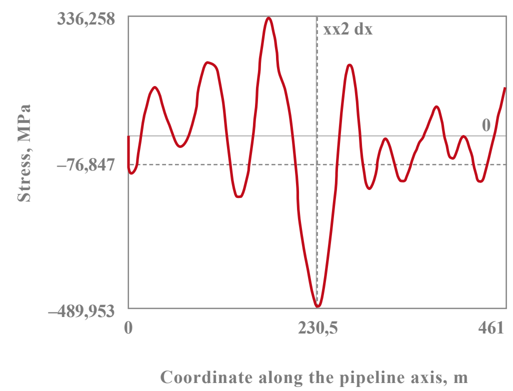

Figure 3. Bending stress distribution diagram: – *calculation data.*

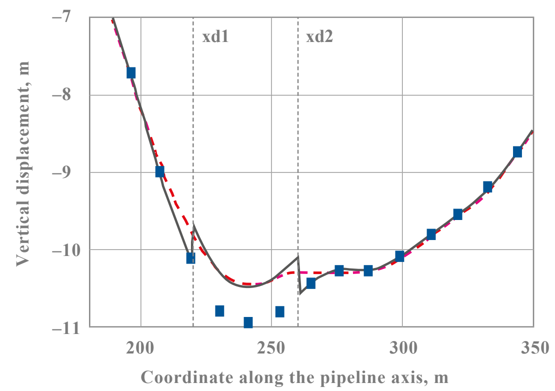

Figure 4. Elastic axis of the oil pipeline section after excavated pipeline laying on the soil v-block: – *elastic axis,* – *profile per ILIP data;* – *spline approximation.*

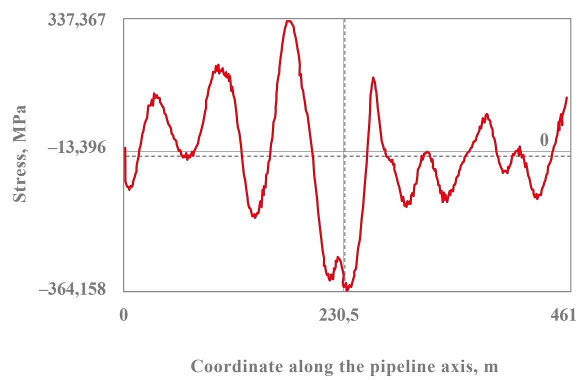

Figure 5. Bending stress distribution diagram after excavated pipeline laying on the soil v-block: – *calculation data.*

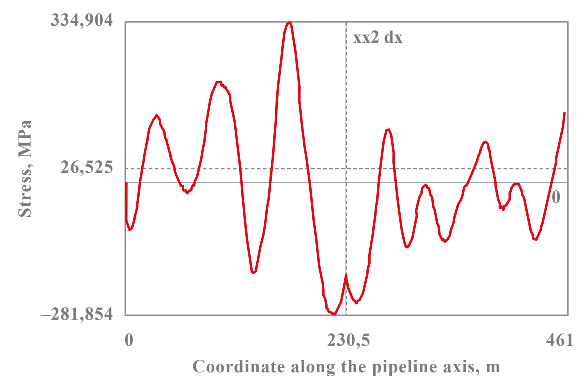

Figure 6. Bending stress: – *calculation data.*

Calculation of repair parameters is performed for the pipeline lifting option. The profile of the considered curved elastic base (elevation position) of the pipeline is shown in Fig. 1.

The result to solved contact problem of the pipeline deformation on the curved pipeline elastic base under vertical loads from backfill soil weight and weight of non-emptied pipeline itself is shown in Fig. 2.

A bending stress distribution diagram is shown in Fig. 3.

Vertical displacement and limits of the pipeline lifting are determined from the condition of stress reduction to the design level after full backfill. Fig. 4 shows the pipeline elastic axis after laying on the 'step' (soil v-block) 0.5 m high within the limits $xd1 - xd2$ and backfilling.

Bending stress distribution diagram after excavated pipeline laying on the soil v-block 0.5 m high and backfilling is shown in Fig. 5.

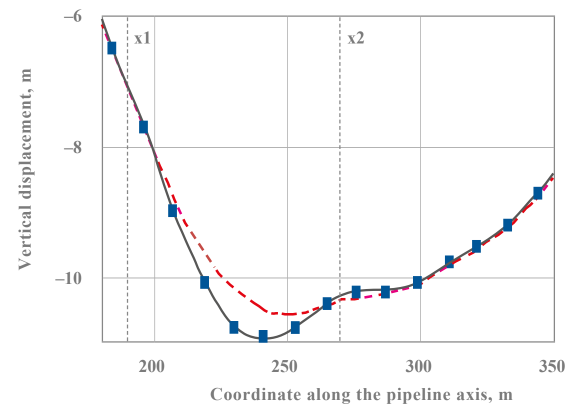

Figure 7. Elastic axis at pipeline displacement and limits of the repaired section: – *elastic axis,* – *profile per ILIP data;* – *spline approximation.*

Calculation per SP 36.13330.2012 for operational loads and impacts demonstrates the fulfillment of the strength state conditions for a new position of the pipeline after repair.

The limits of the repaired section $x1 - x2$ and the hook load of the pipelaying vehicle at vertical displacement 0.6 m upwards are determined from the condition of stress limitation at pipeline movements.

Internal pressure at movement is 0 MPa, temperature difference is 10°C.

Fig. 6 illustrates the bending stress at load applied by the pipelaying vehicle.

The pipelaying vehicle load is applied in the point with coordinate $xx2$. Maximum bending stress at pipeline movement does not exceed 0.7 of the pipe metal yield stress. The necessary hook load of the pipelaying vehicle is 19 tons. It should be noted that it substantially depends on the axial load in the pipeline.

The elastic axis at pipeline displacement and limits of the repaired section are shown in Fig. 7.

Findings

In order to determine the technological parameters to repair sections of underground pipelines with out-of-spec curvature, the method based on simulating the deformation of the pipeline with the initial curvature of the axis has been developed, which takes into account the actual operating conditions of the pipeline and the data of in-line inspection. The simulation results confirm the possibility of using this method for estimating technological parameters of repair, length of the trench excavation section (the limits of the repair section), values and limits of pipeline additional burying or lifting, determining SSS of the repaired pipeline section during repair work execution and after its completion.

Competing interests

The authors declare that there is no competing interest regarding the publication of this paper.

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