On the analysis of the stress state of a pipeline’s bend by its height position

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Abstract. When underground laying, the pipeline bends in accordance with the terrain under the influence of its own weight and an overlying layer of soil. The article provides calculations of the radius of curvature of the pipe and its comparison with the allowable one. Thus, it can be seen from the above calculations that the obtained radii are less than the minimum permissible radius of curvature. Calculations showed that the radii in the horizontal and vertical planes are acceptable.

1. Introduction

When underground piping, the pipeline bends in accordance with the terrain under the influence of its own weight and an overlying layer of soil. The nature of the bending depends on the degree of fit to the bottom of the trench, the bending stiffness of pipe and the mechanical properties of soil. During the operation, the pre-bent state of pipeline changes under the influence of weight and pressure, products of temperature difference, subsidence of the base. The analysis of the stress state of pipeline’s bend during the installation and operation according to its height position is of interest. There are works (1), (2) in which similar studies are carried out considering the features of the terrain.

2. Methods and materials

In the methodology for calculating the stress in a bent pipeline, which is considered below, it is determined by the formula:

\[ G_i = \frac{E_k \cdot D}{2} \cdot y'' \]  \hspace{1cm} (1)

where \( D \) is the outer diameter of pipe, \( E_k \) is the modulus of elasticity; \( y'' \) is the approximate value of the curvature of the axis of pipe at a point.

The second derivative in an arbitrary cross section of the pipeline \( y'' \) will be determined by the array \( \{X_i, Y_i\} \) (Fig. 1) of measurements of the altitude of the points of the upper generatrix of the pipeline. At the same time, we approximate the known curve of the bend of the axis \( Y_f(x) \) by polynomials.

With simultaneously determined distances between space elements,

\[ \bar{Y}_m (x) = a_0 + a_1x + a_2x^2 + \ldots + a_nx^n \]  \hspace{1cm} (2)

the deviation measure of which from the table function \( Y_f(X) \) is written according to the least squares method:
\[ S = \sum_{i=0}^{n} \left[ \tilde{Y}_m(x_i) - f(x_i) \right]^2 \]  

(3)

Here, \( n \) is the number of measurements taken of the altitude position of the upper generatrix.

The approximation by polynomial (2) is not carried out “rigidly” by the measured points, since in the latter case the curve will describe well only the axes of pipeline, and the second arbitrary ones can very significantly, even up to the sign, differ from the true values.

The degree of polynomial (2) is assumed to be uncertain in advance and selected from the condition of least mean square deviation of the two subsequent polynomials between themselves. As we know (3), (4) is a condition corresponded to the smallest deviation of the selected polynomial from the unknown approximate function \( Yf(x) \).

With such a choice of the polynomial degree, the condition \( m-n \) holds, the bending curve does not pass strictly through the measured points.

The latter circumstance seems natural, given that the measured values are not absolutely accurate and were obtained with some error.

We formulate the criterion for determining the degree of polynomial (2), considering the desired polynomials and function \( Yf(x) \) as elements of the normalized Hilbert function space \( L_2[0, x_n] \) with the norm

\[ \| \tilde{Y}_m(x) \|_2 = \sqrt{\int_{x=0}^{x_n} \tilde{Y}_m(x)^2 \cdot dx} \]  

(4)

calculate the sequence of differences of polynomials

\[ \delta Y_m(x) = \tilde{Y}_m + l(x) - Y_m(x) \]  

(5)

at \( l = 2,3 \) until at some \( m = m^* \) the first sharp local or “blurred” minimum of difference norms is found (Fig. 2)

\[ \| \delta Y_m(x) \|_2 = \sqrt{\int_{x=0}^{x_n} \left( \tilde{Y}_m + l(x) - Y_m(x) \right)^2 \cdot dx} \]  

(6)

Figure 1. Measurement of the height position of the axis of pipelines

The appearance of a minimum is confirmed in Ref. 4 on a large amount of experimental material. The norms of differences (6) correspond to the mean-square deviation of two polynoids from each other and are simultaneously determined distances between elements of space \( L_2[0, x_n] \).

The dependence of the norms of the differences on the degree of the polynomial with a “blurred” (1) and a sharp local (2) minimum ...

In connection with the described selection of the optimal degree of polynomial (2), we can suggest that its second derivative will be close to the actual curvature of the axis of pipeline. The degree of this
proximity is checked by comparing the experimentally measured bending stresses on models and natural pipelines with theoretical values calculated by the formula (7).

The main parameters of pipeline that determine technical solutions for the technology of construction and operation are: pipe diameter, working pressure, pipe wall thickness, mass 1 kg of pipe length, characterizing the moment of inertia of the section, buoyancy of the pipe, necessary loads per 1 m of length, pipe deflections that cause stress state.

In direct proportion to the stiffness of pipes are the ability of pipeline to elastically bend and occupy a certain position with respect to the profile of trench’s bottom.

3. Results

A pipeline of any diameter and purpose has curved sections in horizontal and vertical planes, which makes it necessary to bypass various obstacles, terrain and transitions through natural and artificial obstacles. Turns are carried out by elastic bending (free) or by cooking curved pipes.

The radius of elastic bending is calculated from the strength conditions of the metal pipe by the formulas:

\[ R_{\text{hor}} \geq \frac{Ed_o}{4\sigma_b} \] (7)

– in the horizontal plane

\[ R_{\text{con}} \geq \frac{3 Ed_o}{5 \sigma_b} \] (8)

– in a vertical plane on a convex relief

\[ \sigma_b = 0,15 \frac{Pd_o}{\delta} - a_t E \Delta t \pm \psi_t \frac{C}{K_r} R_2' \] (9)

– bending stress.

where \(d_o\) – pipe outer diameter; \(P\) – pipe working pressure; \(\delta\) – pipe wall thickness; \(a_t\) – coefficient of linear expansion of metal pipes; \(\Delta t\) – design temperature difference; \(\psi_t\) – coefficient of compressive (tensile) stresses; \(C\) – pipeline category coefficient; \(K_r\) – reliability factor; \(R_2'\) – standard resistance of metal pipes.

\[ R_{\text{hor}} = \frac{2,1 \cdot 10^6 \cdot 72}{4 \cdot 900} = 42000cm = 420m \] (10)

\[ R_{\text{con}} = \frac{3}{5} \frac{2,1 \cdot 10^6 \cdot 72}{900} = 10080cm = 100,8m \] (11)

\[ R_{\text{exp}} = \frac{1}{2} \frac{2,1 \cdot 10^6 \cdot 72}{900} = 84000cm = 840m \] (12)

| Table 1. To the calculation of the standard resistance of the metal [5] |
|-----------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| E, kgf/ cm²     | \(d_o\), cm | \(\delta\), cm | \(\sigma_b\), kgf/cm² | \(d_i\), cm | \(a_t\), 1/°C | \(\Delta t\), 0°C | \(\psi_t\), \% | \(C\) | \(K_r\) | \(R_2'\), kgf/cm² |
| 2,1 \cdot 10^6  | 72        | 1         | 900       | 70        | 12 \cdot 10^6 | 50         | 0,4       | 1       | 105       | 3300       |

Given the flexibility of the soil, the minimum allowable radius of curvature of the elastically curved section at \(P = 30\) kgf/cm² is:

\[ R_{\text{min}} \geq \frac{Ed_o}{2[1 + 0,15 \frac{Pd_o}{\delta} \pm (1 - \beta) a_t \Delta t - \beta \frac{Pd_o}{4\delta}]} = 490m \] (13)

where \(\beta\) is the coefficient considering the decrease in stresses.

By changing the length of the curved section during its transverse movement.
\[ \beta = \frac{1 + 5m^2}{1 + \frac{15}{16} m^2 \eta^2} = 0.06 \]  

(14)

where \( m \) is the slope coefficient of trench; \( \eta \) is the ratio of the deflection of the pipe to the length of the curve. [5]

4. Conclusion

Thus, it can be seen from the above calculations that the obtained radii are less than the minimum permissible radius of curvature. Calculations showed that the radii in the horizontal and vertical planes are acceptable.

References

[1] Kolosova N M, Mikheeva O V and Shmagina E Yu 2016 To the analysis of the pressure state of the bending of the pipeline in the high position *Techn. Regulat. in transp.construct.* 16

[2] Dusaeva A S and Mikheeva O V 2016 Quality control of operation of the linear part of the pipeline *Trends in the development of construction, heat and gas supply and energy supply Mater. of the int. sci. and pract. Conf. ed F K Abdrazakova* pp 96–8

[3] Mikheeva O V and Dusaeva A S 2016 To the question of quality control of operation of the linear part of the pipeline *Agricult. J.* 10 69–71

[4] Mikheeva O V, Kolosova N M and Shmagina E Yu 2016 The interaction of the underground pipeline under the influence of longitudinal movement *Techn. Regulat. in transp. construct.* 1(16)

[5] Mikheeva O V, Kolosova N M and Illichyova I A 2014 Prediction of the structural reliability of the pipeline *Techn. Regulat. in transp. construct.* 4(8) 58–62

[6] Ovchinnikov I I and Ovchinnikov I G 2012 Mechanics of structures with damage: nonlinear models and methods for determining the durability of structures operating in aggressive environments *Bull. of the Central Reg. Branch of RAASN* 120–7

[7] Ovchinnikov I G 1995 Thin-walled structures under conditions of corrosion wear”, *Calculation and optimization* (Dnepropetrovsk: Publ. House of the Dagestan State Univer.) 192 p

[8] Frank-Kamenetsky D A 2008 *Diffusion and heat transfer in chemical kinetics* (Moscow: Intellect)

[9] *Official website of the group of companies ZAO Orengroup* Retrieved from: http://www.orenburgpm.ru/

[10] *Official website of company Ariel Plastkomplekt* Retrieved from: https://www.arielplast.ru/files/pdf/Arielplast_PE_fittings_publication.pdf

[11] Orlova S S 2016 Evaluation of the operational reliability of pipelines transporting waste water *Agrar. Sci. J.* 3 59–62

[12] Orlova S S, Pankova T A and Kochetkov A V 2016 A differential study of the kinetics of corrosion processes in pipelines transporting waste water *Hydrotechn. construct.* 4 30–6