Velychkovych Andrii, Andrusyak Andriy, Petryk Ivan
(IFNTUOG, Ivano-Frankivsk)

THE METHOD FOR DETERMINING THE REACTION IN THE ADJUSTABLE SUPPORT OF AN OVERPASS OIL PIPELINE

E-mail: a_velychkovych@ukr.net

ABSTRACT. The article examines the model of a two-section overpass of an oil pipeline in a mountainous area, consisting of an above-ground section modeled as an elastic tubular beam and underground sections interacting with a linear-elastic base. A methodology for determining the support reaction under external influences is developed. The equilibrium differential equations describing pipeline section deformations were solved using the initial parameter method. The edge effect of the stress-strain state in the underground section and its attenuation with distance were identified.

KEYWORDS: oil pipeline, overpass, edge effect, linear-elastic base, stress-strain state.

Consider the model of the two-section overpass of the oil pipeline in Fig. 1, which is built in a mountainous area. The overpass consists of the above-ground section *BC* with the length of $2l$, equipped with the adjustable support *K*, and the adjacent underground sections *AB* and *CD*, which rest on the soil base (placed on the bottom of the trench). The length of the underground sections of the oil pipeline is much longer than the above-ground section. During the construction of the oil pipeline, hot-rolled seamless steel pipes were used.

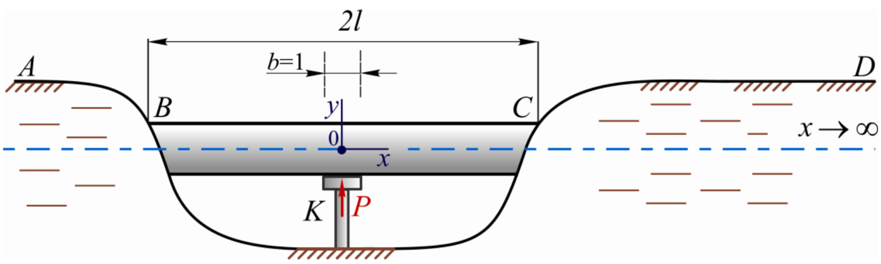

Fig. 1. The model of the two-section overpass of the oil pipeline

The effect of volume forces and operating loads on the support K will cause a reaction P. To assess the behavior of the oil pipeline, it is necessary to have the method of determining the reaction to any external influences (including adjustment of the support, during abnormal changes in the properties of the soil base, etc.).

The above-ground part KC of the structure was modeled with an elastic tubular rod of fixed length, which has support with a one-way connection on the left end (there may be an installation gap δ between the support and the pipe). The underground section CD, lay directly on the natural soil base and loaded from above with backfill soil, was modeled by a semi-infinite beam with an annular cross-section interacting with a linear-elastic base (Fig. 2). Standard operating loads on the oil pipeline consist of the structure's own weight, the weight of the petroleum product filling the pipes, and the standard load from the weight of the soil used to fill the trenches with underground pipe sections. The totality of the listed force influences on the calculation scheme was presented in the form of distributed loads q_i.

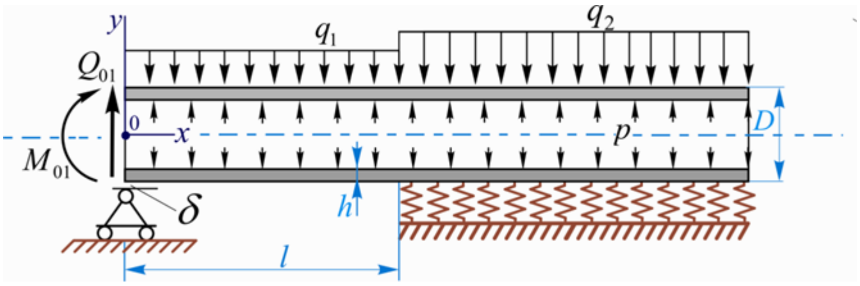

Fig. 2. The scheme for calculating the above-ground overpass of the oil pipeline with the intermediate support

The system of differential equations of equilibrium in displacements, which describe the deformation of the oil pipeline sections, has the following form:

$$EJ_z \frac{d^4 w_{y1}}{dx^4} + q_1 = 0, \quad x \in [0, l); \tag{1}$$

$$EJ_z \frac{d^4 w_{y2}}{dx^4} + Dk_y w_{y2} = q_2, \quad x_2 \in [l, \infty), \tag{2}$$

where w_{y1}, w_{y2} are transverse movements of the above-ground and underground sections of the oil pipeline, respectively; E is Young's modulus of the pipe material; J_z is the axial moment of inertia of the pipe cross-section; D is the pipe diameter; and k_y is the bed coefficient of the soil base.

To obtain the solution of the system of Equations (1) and (2), the method of initial parameters proposed by the authors of the article in their previous publication [1, 2] was applied. As a result, we obtain the following solving equation:

$$\mathbf{A}\vec{\mathbf{X}} + \vec{\mathbf{\Delta}} = 0, \qquad (3)$$

where, respectively, the matrix of coefficients $\mathbf{A}$, the vector of free members $\vec{\mathbf{\Delta}}$ and the vector of unknown static initial parameters $\vec{\mathbf{X}}$ have the form (4).

The solution of Equation (3) gives us the value of the transverse force Q_{01} and the bending moment M_{01} in the middle of the above-ground section, and at the beginning of the underground section are Q_{02}, M_{02}.

$$\mathbf{A} = \begin{vmatrix} 1 & 1 & 0 & 0 \\ l & 0 & 1 & 1 \\ \dfrac{l^2}{2EJ_z} & -\dfrac{2\beta^2}{Dk_y} & \dfrac{l}{EJ_z} & -\dfrac{4\beta^3}{Dk_y} \\ \dfrac{l^3}{6EJ_z} & \dfrac{2\beta}{Dk_y} & \dfrac{l^2}{2EJ_z} & \dfrac{2\beta^2}{Dk_y} \end{vmatrix}, \ \vec{\mathbf{\Delta}} = \begin{vmatrix} -q_1 l \\ -\dfrac{q_1 l^2}{2} \\ -\dfrac{q_1 l^3}{6EJ_z} \\ \delta - \dfrac{q_1 l^4}{24EJ_z} - \dfrac{q_2}{Dk_y} \end{vmatrix}, \ \vec{\mathbf{X}} = \begin{vmatrix} Q_{01} \\ Q_{02} \\ M_{01} \\ M_{02} \end{vmatrix}. \qquad (4)$$

Then, the equations of transverse forces and bending moments for the oil pipeline can be written in the following form:

$$Q(x) = (Q_{01} - q_1 x)H(l-x) + (2\beta M_{02}\eta_3(x-l) - Q_{02}\eta_2(x-l))H(x-l), \quad (5)$$

$$M(x) = \left(M_{01} + Q_{01}x - \frac{q_1 x^2}{2}\right)H(l-x) - \left(M_{02}\eta_1(x-l) + \frac{Q_{02}}{\beta}\eta_3(x-l)\right)H(x-l), \quad (6)$$

where $\beta = \sqrt[4]{k_y D / 4EJ_z}$ is a coefficient, $H(x)$ is Heaviside's function; $\eta_1(x) = e^{-\beta x}(\cos\beta x + \sin\beta x)$; $\eta_2(x) = e^{-\beta x}(\cos\beta x - \sin\beta x)$; $\eta_3(x) = e^{-\beta x}\sin\beta x$.

The support reaction of the oil pipeline is equal to the jump in the transverse force curve that occurs above the overpass support. A characteristic feature of the presented dependences (5), (6) is the wave-like changes in the functions of internal loads at the beginning of the underground section of the oil pipeline with gradual damping when moving away from the edge of this section. We call such an effect the marginal effect of the change in the stress state of the underground section of the oil pipeline, and the length over which this effect has significant manifestations is the length of the marginal effect. The damping of the marginal effect is explained by the presence in Equations (5) and (6) of the functions η_i, which contain the multiplier $e^{-\beta x}$. This multiplier goes to zero if the product βx goes to infinity.

References:

1. Velychkovych, A.; Andrusyak, A.; Pryhorovska, T.; Ropyak, L. Analytical model of oil pipeline overground transitions, laid in mountain areas. *Oil Gas Sci. Technol*. 2019, 74, 65.

2. Dutkiewicz, M.; Velychkovych, A.; Andrusyak, A.; Petryk, I.; Kychma, A. Analytical Model of Interaction of an Oil Pipeline with a Support of an Overpass Built in a Mountainous Area. *Energies* 2023, *16*, 4464.

АНОТАЦІЯ. У статті розглянуто модель двосекційного естакадного переходу нафтового трубопроводу в гірській місцевості, яка включає наземну секцію, змодельовану пружною трубчастою балкою, та підземні секції, взаємодіючі з лінійно-пружною основою. Розроблено методику визначення реакції опори на зовнішні впливи. Диференціальні рівняння рівноваги, що описують деформацію секцій трубопроводу, вирішено методом початкових параметрів. Визначено крайовий ефект напружено-деформованого стану підземної секції та його загасання зі збільшенням відстані.

КЛЮЧОВІ СЛОВА: нафтовий трубопровід, естакада, крайовий ефект, лінійно-пружна основа, напружено-деформований стан.