OIL AND GAS TRANSPORTATION AND STORAGE

Influence of installation elastic bending on stress-strain state of pipeline aboveground passages in mountains

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The experiment-calculated methods of diagnosing stress-strain state of the pipeline aboveground beam passages are shown. By the example of pipeline aboveground passage in the Carpathians the influence of installation elastic bending on its stress-strain state was studied.

Aboveground passages because of various natural and artificial obstacles (rivers, ravines, irrigation channels etc.), as well as dug-up sections of underground pipelines for performance of repair works, belong to especially responsible sections of main oil and gas pipelines. Every such section consists of straight and curved elements (pipes).

In many cases on passages through obstacles of relatively small width they use beam passages without compensation of longitudinal strains and without special bearings on the edges. A characteristic feature of such passages is their hypersensitivity to daily and seasonal air temperature fluctuations, to changes in the pipeline operating mode, to subsidence of bearings and seismic motion effects on adjacent underground sections.

The stress-strain state (SSS) is one of the main parameters determining strength, tenacity and operation reliability of both open sections and the whole linear pipeline portion. The strain state must be determined and analyzed both at the pipeline design and construction phases and during pipeline operation.

It should be noted that determination of the pipe material SSS is an important element of diagnosing of the general technical condition of main pipelines [1], forecasting of strength and endurance of their linear portion [2], taking of a decision on the possibility to continue safe operation or the necessity to perform maintenance and repair works and constructive implementation thereof

The necessity to determine strains in the pipeline wall at the operational phase arises mostly on the so called “potentially dangerous sections” which are operated in difficult conditions and are affected by significant loads related to change in their estimated spatial arrangement.

Fig. 1. Overall view of aboveground passages of “Druzhba” oil pipelines through the Oriava river

The internal pressure is one of the main loads whose effect on pipelines is estimated at the design stage during determination of the wall width. Circular and longitudinal normal stresses arise under the effect of the internal pressure in the pipe wall material.

In accordance with the current standards [3], circular stresses are calculated on the basis of the membrane theory of cylindrical shells according to the well known from strength of materials (structural resistance) “boiler” formula. The value of longitudinal stresses stipulated by the internal pressure mostly depends on the structural layout of the section and its securing conditions and can make up from 30 to 50 % of circular stresses.

As distinct from stress components which depend on the internal pressure and to some extent can be regulated during operation by means of their variation, it’s sufficiently difficult to affect tress components resulted from other loading factors. It relates, first and foremost, to normal and tangent stresses arising in pipeline crosscuts, which are interconnected with internal efforts by longitudinal and lateral forces, bending and rotation moments and are resulted from operation of the pipeline section as the framework.

Occurrence of these stresses is mostly stipulated by deviations of the pipeline longitudinal axis from the designed location during construction or operation.

If the bent axis of the pipeline section is a plane curve, then in the general case such section is under the effect of plane bending, and two main internal force factors arise in the pipeline crosscuts: longitudinal force and bending moment. As to the lateral force, during its effect as the secondary internal force factor is mainly neglected g analysis of the pipeline stress-strain state. In case of a spatial section, the rotation moment arises in its crosscuts as well.

As regards strength calculation, the aboveground pipeline section constitutes in some cases a multiply statically indeterminate system. That’s why determination of internal force factors is related to evaluation of static indeterminacy of structure, which requires study of a geometrical side of the problem – strains of the pipeline axis as the framework. In addition, interaction of the pipeline with the ground on the underground sections adjacent to the aboveground passage must also be taken into account.

The specificity of static analysis of aboveground pipelines is determined, first and foremost, by the peculiarities of the structural layouts and operation conditions and mostly depends on the availability of intermediate bearings, expansion bend and large-curve pipes (offsets).

The passages laid on the mountain slopes feature arising of high longitudinal stresses in the pipe walls, which are related to excessive elastic pipe bending as a result of grading during construction of oil pipelines.

In order to control the stress-strain state of potentially dangerous aboveground sections of "Druzhba" oil pipelines sections, they use experiment-calculated approaches taking into account the main requirements and recommendations of current normative documents [2, 3].

Fig. 2. Destruction of the mounting group of the second oil pipeline support D = 720 mm

Global stresses existing in the pipe metal are determined by the calculation method according to the linear elastic mathematical model taking into account the results of measurement during on-site surveys of actual lengths of bearings, deflection arrows of initially linear sections, pipe wall width and temperature, metal hardness, bearing loads. Therewith, it is accepted that the oil gravity is $\gamma_{н} = 8,76$ kN/m^3, pipe steel elasticity module is $E = 2{,}0 \cdot 10^5$ MPa, specific weight $\gamma_{ст} = 8{,}76$ kN/m^3, and the temperature-related linear expansion ratio is $\alpha_t = 1{,}2 \cdot 10^{-5}$ 1/°C.

The value of the operating pressure on the controlled section is determined based on the results of measurement of the pressure on the neighboring pump stations taking into account the elevation differences and hydraulic friction losses.

As a temperature drop they take the difference between the measured pipe temperature and the pipe temperature during installation, which is established on the basis of the logs of the works performed on the pipeline route: closure of welded joints and laying of the sections adjacent to the aboveground passages into the trench.

The calculation model according to which an aboveground pipeline is considered a multiple covering stringer with unstrained edges of the cross section being under the effect of the internal pressure, lateral localized forces and distributed loading and longitudinal force is taken as the basis of the mathematical model. Interaction of a pipe with the ground on the sections adjacent to the aboveground passage is presented using the model of an ideal elastic-plastic body. The force method is used for disclosure of the system static indeterminacy. In order to determine displacements, an aboveground section is broken up into finite rectilinear elements. The longitudinal axis geometry is assumed discretely by the coordinates of junction points.

For the purpose of calculation using the personal computer of aboveground pipeline beam passages in relation to diagnosing of the stress state and strength evaluation during operation, the programs in the TURBOPASCAL language were developed. The results of measurements of the relevant aboveground passage parameters during on-site surveys and the information received during study of the engineering design documentation serve as the basis for formation of the output data.

Fig. 3. Overall view of of the first (along the oil flow) bearing after repair.

The abovementioned experiment-calculated method was used to investigate effect of the installation elastic bending on the stress-strain state of the structural elements of the aboveground passages of the “Druzhba” oil pipelines laid on the Carpathian slopes. Performance of these investigations is continuation of the works [4–6] which are carried out by the specialists of the Research Laboratory of the National University “Lviv Polytechnic” and the Branch “Oil-Trunk Pipelines “Druzhba” of PJSC “Ukrtransnafta” and which are intended for creation of methods to monitor the technical condition of aboveground passages of main oil pipelines.

As an example let’s study the results of analysis of the stress-strain state of the aboveground passages of the “Druzhba” oil pipelines through the Oriava river in the Carpathians which for a long time were operated subject to undersigned overloading of bearings.

The aboveground passages of both girders of oil pipelines were constructed according to the balk structure with two intermediate concrete supports located not far from the passage edges (Fig. 1). On the edges the pipelines lean directly against the ground.

The right side of the river is sufficiently rash, open, with the height of about 5 m. From this side the route crosses a mound coming to the river with the slope of about 5°. According to the design the trench bed slope relative to the horizontal aboveground section makes up 0.051. The left side is flat with the angle of elevation from the river of about 2°, and the trench bed slope 0.021. Covering of both slopes is designed by the elastic bending.

The aboveground passage of the “Druzhba-2” oil pipeline was constructed using weldless pipes 720 × 10 mm, steel grade “Ц” CP, operating pressure 2 MPa.

According to the certificates of these pipes, the least value of liquid limit equals 370 MPa, and the strength limits are 510 MPa. The total length of the aboveground pipeline is L = 34.4 m, and the girder lengths (along the oil flow) accordingly make up $l_1 = 4$; $l_2 = 22.4$; $l_3 = 8$ m.

After long-term operation (33 years), destruction of the rear cap and mounting group was revealed up to the riser of the second (along the oil flow) U-shaped concrete support (Fig. 2) installed in 1961 during construction of the “Druzhba-2” oil pipeline. The aboveground section of the “Druzhba-2” oil pipeline was laid onto this support in August 1969.

As a result of this destruction a clearance between the rider and the bottom of oil pipeline with the diameter of 529 mm was formed, which brought to increase of the girder from 22.4 to 31.4 m (8 m from the support to the ground edge plus 1 m of the gap between the trench bed and the pipe bottom). Therewith, the pipeline with the diameter of 720 mm was partially supported by the destructed mounting group.

Analysis of the results of visual inspections and measurement of the elevation points of the top generatrix of both aboveground pipelines allows making of the following conclusions.

The main reason for destruction of bearing elements of the supports of the abovementioned objects is their overloading by the forces giving rise to elastic bending of the pipe in the vertical plane as a result of essential elevation of the support points over the designed height during construction of the "Druzhba-2" oil pipeline. It is evidenced by the downshift of the pipeline rider with the diameter of 720 mm connected with destruction of the mounting groups in relation to the initial position after the installation one of about 180 mm.

Destruction of the support as a result of gradual development of cracks occurred during a long period of time and began with breakage of welded joints made of the elbow of the cap sills to which the base plates of aboveground pipeline frames were welded. Growth of cracks can be explained first of all by seasonal changes of the pipe temperature with increase of the loading affecting the support at extreme temperatures, especially during stoppage of oil pumping.

The existing bending in the first support with upward crown in the aboveground pipeline with the diameter of 720 mm pointed at essential overloading of the first support which in two weeks brought to destruction of the console corbel of the right along the oil flow concrete riser of this support.

In order to renew the bearing capacity of the supports, the top part of the concrete risers was implanted by the metal with the width of 12 mm, the destructed concrete girders were replaced by the metal ones taken from the pipe and channel beam which were installed below the previous location of the concrete girders (Fig. 3), which allowed significantly decreasing of operating loads onto the supports. The result of measurements of the loading onto the girder of the first and the second supports of the pipeline with the diameter of 720 mm showed that they made up accordingly 90.5 and 99.0 kN.

Comparison of the main parameters of the aboveground passage of the "Druzhba-2" oil pipeline before destruction of the supports and after repair is given in the table, and the relevant curves of the bent axis of the second girder is shown in Fig. 4. The Table also shows the results of calculations for the rational variant corresponding to equality of the largest values of the bending stresses in bearing cross sections, in the middle of the second girder and absence of the pipe elastic bending in the adjacent underground sections.

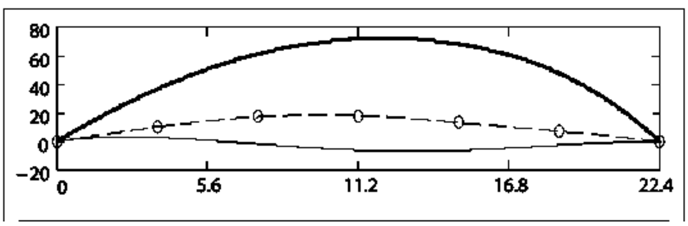

Fig. 4. The curve of the bent axis in the vertical plane of the second girder of the aboveground passage of the pipeline with the D = 720 mm (points-experimental data, solid lines based on the calculation results: heavy line – before destruction, thin line – after repair)

Analyzing the obtained results (Table, Figure. 4), we see that the bending arrow of this girder is an essential influencing parameter of the stress state of the aboveground passage with two intermediate supports and absence of bent elements on the second girder. It should be noted that according to the design the second girder of the abovementioned passage is rectilinear.

Table

State	Supporting forces, kN		Excessive elevation on the supports, mm		Bending arrow, mm		Stress, MPa	Position of dangerous crosscut
	R_I	R_{II}	Δ_I	Δ_{II}	estimated	actual	$\max \sigma_з$	
Before destruction of the support	121.6	225.1	90	219	-72	—	194.4	II support
After repair	90.5	99.0	11	9	6	-18	90.2	I support
Rational	93.1	89.9	-6	-8	26	—	43.6	I–II

A relatively small downward bending arrow and sufficiently small values of maximal bending stresses is characteristic for rational technical condition of such aboveground passage. The crown of the bent axis of the initially rectilinear second girder is indicative of overloading of the supports and excessive stress of the pipeline in the supporting crosscuts. The maximal bending stresses before beginning of destruction of the mounting groups are 4.46 times larger than their values in comparison with the rational variant, after reconstruction they decreased by 2.15 times.

As it was mentioned, the excessive overloading of the second mounting group of the oil pipeline with the D = 720 mm resulted from excessive elevation of the supporting points in relation to the designed height became the main reason for its destruction. The Table gives the values of excessive elevation of the supporting points in the intermediate supports in relation to the straight line connecting the pipeline supporting points at the beginning of the adjacent underground sections.

The difference between the experimental and calculated values of the bends on the second girder after repair (Fig. 4) can be explained by initial deviations from the straight line related to performance of the erection welded joints, as well as to the creep resulted from the long-lasting effect of high level of bending stresses. The mountain-shaped pipes from which the oil pipeline is constructed have the valley depth of up to 2 mm.

Based on the survey results it was established that essential negative deflection arrows (100–200 mm) also exist on some aboveground passages of such type with two intermediate supports and initially designed rectilinear second girder, and the maximal estimated total longitudinal tension stresses determined taking them into account are close to the minimal liquid limit. Although despite long-term operation of the pipeline (42 years) no signs of destruction of the mounting groups were revealed here.

Fig. 5. Overall view of the mounting group of the oil pipeline with the D = 720 mm, whose frame is leaned onto the riser and girder.

It can be explained by location of the essential portion of the supporting frame immediately above the riser (Fig. 5), and, correspondingly, the girder mounting group undergoes considerably lesser stresses as compared to location of the frame only above the girder, as we can see it in the case of the investigated aboveground passage (see Fig. 3). In addition, it should be noted that on this section of the route the oil pipeline is operated under relatively low pressures (< 1.5 MPa).

So, the existing pipeline installation elastic bending in the vertical plane on some aboveground passages of the "Druzhba-2" oil pipeline related to essential elevation of the supporting points in excess of the designed height gives rise to significant overloading of the supports and overstress of pipes in the supporting crosscuts.

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