Measures to limit subsidence of underground oil pipeline in insular permafrost

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Abstract. In this paper optimal solutions to limit the subsidence of underground oil pipeline in insular permafrost are proposed.

1. Introduction

The advance of Russian oil and gas companies on the Asia-Pacific Region markets requires development of new fields and construction of gathering and trunk pipelines in Eastern Siberia and the Far East. Most of these areas are characterized by vast zones of insular permafrost that has an adverse effect on the stress-strain state of underground structures. Therefore, this fact should be taken into account in pipeline design and construction.

The insular permafrost is characterized by discontinuous occurrence of permanently frozen layer of small thickness and temperature close to 0 ˚C. Therefore, such a negative process as thermokarst is a rare case. In addition, as oil pipelines operate under positive temperature, which is conditioned by the need to reduce oil viscosity by heating, frost heaving is also not distinctive.

Soil settlement that occurs during formation of thawing halos represents a real threat to pipeline operation in insular permafrost conditions. To ensure safe operation of underground oil pipeline under these conditions, it is necessary to undertake a complex of actions to limit the subsidence of oil pipeline.

The goal of this research is to propose optimal solutions to limit the subsidence of underground oil pipeline laid in the frozen soil of different properties: thawing rate and depth of thawing halos [1].

2. Materials and methods

There are several technological concepts to limit the subsidence of pipeline in the permafrost environment: use of various types of thermal insulation, removal of icy soil from the trench, application of expansion joints (doglegs) and soil thermo-stabilizers. Nowadays, to ensure safe operation of underground oil trunk pipeline in insular permafrost, Russian pipeline engineering companies use polyurethane foam heat insulation and supplementary polystyrene heat insulation laid in the trench, as well as replace frozen soil by dry soil in the trench [2]. The choice of the definite engineering solution is based on soil settlement modeling and should meet pipeline strength requirements.

The choice of the measures that limit the severity of pipeline subsidence rests on the calculation of ultimate stress limit occurred within the subsidence area. The design ultimate stress limit of pipe steel is determined according to [3]. The magnitude of stress caused by internal pressure and temperature difference is deducted from this value. The ultimate stress defines the maximum pipeline subsidence.

The most intensive subsidence-induced stress occurs between frozen soil and thawed soil, as well as in permafrost areas characterized by different properties. Being the most dangerous, these zones are considered in calculating maximum allowable subsidence according to the method proposed in [4]. The pipeline is regarded as a restrained beam, and pipeline deflection is determined. Stress-induced deflection that corresponds to ultimate one is the maximum allowable subsidence of pipeline which is calculated by the following formula (1).

$$S_{\lim} = \frac{6 \cdot \sigma_{\lim}^2 \cdot I}{r^2 \cdot q \cdot E}, \quad (1)$$

where, S_{lim} – the maximum allowable subsidence;
σ_{lim} – stress limit;
I – centroidal moment of inertia;
r – pipe radius;
q – pipeline load;
E – modulus of elasticity.

According to [1], the soil settlement occurs due to thawing of ground ice and soil compaction caused by pipeline and backfill weight. The assumption that soil settlement occurs due to ice thawing only has been accepted. This assumption allows calculating the maximum allowable depth of soil thawing at given thawing rate by the following formula (2).

$$H_{\lim} = \frac{S_{\lim}}{A}, \quad (2)$$

where, H_{lim} – the limit depth of thawing halo;
A – thawing rate.

Calculating the depth of permafrost thawing under the pipeline is done by the method proposed in [1], which is based on the solution of the soil heat equation. The depth of thawing halos is determined for bare pipes, preinsulated pipes and pipes with supplementary insulation. The obtained values are compared with the maximum allowable depth of thawing halo. If the calculated thawing halo exceeds the maximum allowable depth, it is necessary to replace frozen soil by dry soil in the trench. In this case, the depth of soil to be replaced is determined by the difference between design and the maximum allowable depth of thawing halo.

The next step is to calculate the cost of measures aimed at minimizing subsidence of a pipe section (11 meters). Based on the calculation results, the optimal engineering solution (an action or set of measures) is selected. The chosen solution should guarantee allowable subsidence of underground pipeline at the lowest cost.

The choice of measures that limit the subsidence of underground oil pipeline was made in accordance with described algorithm. The pipeline specifications were as follows: outer diameter – 720 mm, wall thickness – 8 mm, internal pressure – 6.0 MPa, oil temperature – 30 °C. The modes of pipeline construction in permafrost characterized by different characteristics were examined. Based on the data [5-7], the depth of thawing halos is assumed to be from 3 to 11m, thawing rates – from 0.1 to 0.4, which corresponds to soils of second and third subsidence categories.

3. Results and discussion

According to the data [8], the optimal measures to limit the subsidence of underground oil pipeline in permafrost were selected (table 1).

Table 1. Measures to limit underground oil pipeline subsidence.

Depth of thawing halo (m)	Thawing rate			
	0.1	0.2	0.3	0.4
3	Bare pipe	Factory-insulated pipe	Factory-insulated pipe + 0.6m soil replacement	Factory-insulated pipe + 0.8m soil replacement
5	Factory-insulated pipe	Factory-insulated pipe + 0.9m soil replacement	Factory-insulated pipe + 1.5m soil replacement	Supplementary insulation + 1.0m soil replacement
7	Factory-insulated pipe	Supplementary insulation + 0.6m soil replacement	Supplementary insulation + 1.1m soil replacement	Supplementary insulation + 1.4m soil replacement
9	Factiry-insulated pipe + 1.0 m soil replacement	Supplementary insulation + 1.9m soil replacement	Supplementary insulation + 2.5m soil replacement	Supplementary insulation + 2.8m soil replacement
11	Supplementary insulation + 0.6 m soil replacement	Supplementary insulation + 2.2m soil replacement	Supplementary insolation + 2.8m soil replacement	-

4. Conclusion

Based on the obtained results, it is possible to draw a conclusion that the selected measures could guarantee the allowable subsidence of underground pipeline in all examined soils, except if thawing rate is greater than 0.3 at thawing depth being more than 9 m. Under these conditions, soil replacement is difficult to carry out due to the technical limitations of excavation equipment. In this case, construction of above-ground pipeline can be recommended.

References

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