The Stabilization Ensuring of the Underground Pipelines Design State in the Permafrost Conditions

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Abstract. The article considers one of the possible options for improving the technology of construction of underground pipelines in conditions of permafrost soils, which today is very relevant. The most significant disadvantages of the existing methods of underground laying of pipelines on permafrost soils are the thermal and mechanical impact of the pipeline on the soil base during operation and the occurrence of unacceptable plastic deformations of the pipeline. The purpose of the studies is to prevent or minimize the thermal impact of the pipeline on MMG during operation, and as a result, to ensure stabilization of the design position of the pipeline by preventing unacceptable plastic deformation of the pipeline. The main tasks solved in research: develop a method of laying an underground pipeline that eliminates thermal impact on the containing frozen soil; simulate the underground pipeline laying structure and calculate stress-strain state in the ANSYS software complex, as well as forecast calculation of thermal interaction of the structure on frozen soil in the FROST 3D Universal software complex.

1. Introduction

Underground pipeline laying is mainly used in areas folded with rock or well draining (for example, gravel) soils, which are not subject to thawing of significant sediments. In areas folded with soils with high ice content, ground or above-ground laying is used [10]. However, significant changes in geocryological conditions along the pipeline route are due to the need to apply various laying schemes (often changing along the route), which makes it very difficult to build the pipeline. As a result, structural diagrams and length of pipeline sections are selected taking into account construction technology.

As a result, individual sections of pipelines can be under adverse geocryological conditions, for example, the intersection of sections of routes with the inclusion of ice in the soil base.

Thermal impact of pipelines on permafrost soil (PFS) during operation period is determined by pumped medium temperature. The range of temperature fluctuations along the length of the pipeline is 0... 70 °C or more. The interaction of such a powerful heat source with surrounding permafrost soils leads to a sharp change in thermal and water conditions, the power of the active soil layer, thermophysical properties, activation of subsidence phenomena, etc. [8].

In this regard, the problem of stabilization of underground pipelines is very relevant, especially in the construction of pipelines in conditions of frozen soils [1, 5, 9-11].

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The main tasks solved in research:

- develop a method of laying an underground pipeline that eliminates thermal impact on the containing frozen soil;
- simulate the underground pipeline laying structure and calculate stress-strain state in the ANSYS software complex, as well as forecast calculation of thermal interaction of the structure on frozen soil in the FROST 3D Universal software complex.

2. Simulation models

The authors propose a method of laying an underground pipeline in permafrost soils, the schematic diagram of which is shown in figure 1 [6], the 3D model for further calculations in software complexes is shown in figure 2.

![Schematic diagram of the proposed method of underground pipeline laying at PFS](image)

**Figure 1.** Schematic diagram of the proposed method of underground pipeline laying at PFS: 1 - heat insulation material, 2 - dry peat, 3 - pipeline, 4 - ventilation branch pipes, 5 - polystyrene concrete box; 6 - polystyrene foam box.

![3D-model of the proposed method of underground pipeline laying on PFS](image)

**Figure 2.** 3D-model of the proposed method of underground pipeline laying on PFS: a) section view; b) general view; 1 - heat insulation material, 2 - dry peat, 3 - pipeline, 4 - ventilation pipes, 5 - polystyrene concrete box.

The parameters of the trench correspond to normal gasket conditions, ensuring the use of conventional typical methods of work for linear construction [3,4]. Dry peat 2 is filled into foam polystyrene box 6, pipeline 3 is laid in heat insulation 1, peat 2 is poured and sealed. Using peat as insulation will compensate for longitudinal deformations due to free movement. Peat is an elastically deformable soil and has a low heat transfer capacity (λгр varies 0.06... 0.45 W/(m · deg) with an increase in humidity, respectively), therefore, the heat flow from the pipe practically does not reach the walls of the trench [2]. Within the isolated trench, a constant thermal mode will be maintained, which will allow maintaining the temperature of the pumped product without additional heating during operation [7]. However, a so-called "greenhouse effect" may occur within the proposed structure, for this purpose, it is proposed to use breathing pipes 4 (vent pipes of the IR type) between the pipeline and the wall of the structure. For attachment of the nozzles, it is intended to use a box made of polystyrene concrete 5, since it has the necessary properties for the design: low thermal conductivity, low water absorption, low density and mass, frost resistance, as well as environmental friendliness and economy. The structure is connected to each other by means of a rectangular spike-slot section. Polyurethane glue Ceresit Express ST 84 with the necessary adhesive and strength properties for construction in the northern regions is used to connect and hermetically connect the elements of the polystyrene foam box.

All stud-slot connections and end joints of panels are filled with glue. Geosynthetic material of MEAPLAST-HPH geomembrane is used for waterproofing of the whole structure, which excludes moisture penetration into the structure.
3. Calculation results

After the import into the ANSYS 15.0 software complex of the design model built in the software complex SolidWorks, an analysis of the power effects and loads to which the design is subjected under operating conditions was carried out, these include: weight of trench heat insulation, weight of foam polystyrene box, pipeline weight, weight of soil (peat), weight of pumped product (oil), internal pressure of pumped medium 6.4 MPa, impact from seasonal bundling of soil base, gravity force, temperature effect from pumped medium, snow load, soil temperature. Simulation of thermal and mechanical impact was carried out for a 820 mm diameter main pipeline with a wall thickness of 16 mm, the density of oil is $\rho = 870 \text{ kg/m}^3$, containing soil - loam.

Climatic data of the construction region according to SP 131.13330.2012 are accepted for the Yamalo-Nenets Autonomous District.

According to the results of the stress-strain state (SF) calculations in the ANSYS software complex, the maximum stresses for a pipe with a diameter of 820 mm are 233 MPa, and the maximum stresses in the polystyrene foam box are 0.001 MPa, while the total deformations of the entire structure are no more than 53 mm (figures 3, 4).

**Figure 3.** Field of general deformations of the analyzed structure.

**Figure 4.** Field of total stresses of the analyzed structure.

The FROST 3D Universal software complex allows you to predict in a short time the three-dimensional dynamics of heat fields in the circle of a pipeline of great pro-severity for the entire period of operation, taking into account phase transformations and convective heat transfer.

To calculate the proposed design, FROST 3D Universal took into account the following geometric parameters:

- linear dimensions of the modeling area: 50 × 50 m in the horizontal plane and 9.7 m in depth;
- pipe wall thickness: 16 mm;
- heat insulation thickness of the pipeline: 100 mm;
- thickness of foam polystrol box: 100 mm;
- pipeline length: 50 m.

Thermal forecast calculation was carried out in the period from March 2018 to February 2019, taking into account the thermal impact of the oil pipeline on the soil (figure 5). Results of calculations of soil pouring halos around pipelines are given in Tables 1, 2. figures 6, 8, 10 show the calculated three-dimensional temperature field for a pipeline with a diameter of 820 mm.

The temperature field is represented by a color distribution from -5 °C to +7 °C, where the blue color corresponds to the lowest temperature -5 °C and the red color corresponds to the highest +7 °C. Temperatures above this range are displayed in red and below in blue. The temperature distribution in the section of the calculation area is displayed as isolines.

The results of the simulation make it possible to conclude that this design minimizes the thermal impact of the pipeline on permafrost soil.
Figure 5. 3D Geometry in FROST 3D Universal.

Figure 6. Calculated 3D Temperature Field for Pipeline Diameter 820 mm in March 2018.

Figure 7. Visualization of the temperature field in the section of the design area in the form of temperatures in March 2018.

Figure 8. Calculated 3-D temperature field for pipeline diameter 820 mm in July 2018.

Figure 9. Visualization of the temperature field in the section of the design area in the form of temperatures in July 2018.

Figure 10. Calculated three-dimensional temperature field for a pipeline with a diameter of 820 mm in August 2018.

Figure 11. Visualization of the temperature field in the section of the design area in the form of temperatures in August 2018.
Table 1. Radii of soil penetration around pipelines of different diameter taking into account the proposed method of laying for 2018-2019.

| Month    | Pipe diameter, mm |
|----------|-------------------|
|          | 530   | 630   | 720   | 820   |
|          | Draining radii, m |
|          | 2018   | 2019   |
| March    | 0.815 | 0.835 | 0.77  | 0.78  |
| April    | 0.815 | 0.835 | 0.77  | 0.78  |
| May      | 0.825 | 0.835 | 0.77  | 0.78  |
| June     | 0.825 | 0.835 | 0.77  | 0.78  |
| July     | 0.825 | 0.835 | 0.77  | 0.78  |
| August   | 0.825 | 0.835 | 0.77  | 0.78  |
| September| 0.825 | 0.835 | 0.78  | 0.78  |
| October  | 0.835 | 0.825 | 0.78  | 0.79  |
| November | 0.835 | 0.825 | 0.78  | 0.79  |
| December | 0.835 | 0.835 | 0.78  | 0.79  |
| January  | 0.835 | 0.835 | 0.79  | 0.81  |
| February | 0.835 | 0.845 | 0.85  | 0.98  |

Table 2. Soil penetration radii around 820 mm diameter pipeline without thermal insulation for 2018-2019.

| Month    | Draining radii, m |
|----------|-------------------|
|          | 2018   | 2019   |
| March    | 1.19   | 1.9    |
| April    | 1.19   | 1.9    |
| May      | 1.19   | 1.9    |
| June     | 1.19   | 1.9    |
| July     | 1.57   | 1.58   |
| August   | 1.57   |        |
| September| 1.57   | 1.59   |
| October  | 1.6    | 1.58   |
| November | 1.59   |        |
| December | 1.58   |        |
| January  | 1.9    |        |
| February | 1.9    |        |

The economic efficiency of the proposed method of construction of the considered pipeline was calculated, showing its increase in price by 862510.4 rubles. in relation to the usual method of laying. However, the proposed construction method is effective in the long-term due to the possible occurrence of soil base melting, pipeline sediment and, as a result, its rupture, which will require tens of times more funds to eliminate.

4. Conclusions
A method of laying an underground pipeline has been developed, which allows minimizing the thermal impact on the containing frozen soil during operation and ensuring the design position of the pipeline by preventing unacceptable deformation values.

Due to the fact that oil pumping was carried out in low-temperature mode, progressive melting of the containing frozen soil is excluded. If the structure is damaged, the pipeline will be in an acceptable pouring halo.

The underground piping layout was modeled according to the proposed method and stress-strain state calculation was made in the ANSYS software complex, showing that the maximum stress for a pipe with a diameter of 820 mm is 233 MPa, and the maximum stress in the polystyrene foam box is 0.001 MPa. The maximum strains in the proposed piping scheme are 52.898 mm, which is within the limit of permissible values. The thermal interaction of the pipeline with frozen soil was also calculated in the FROST 3D Universal software complex for diameters of 530... 820 mm, showing that with the application of the proposed scheme for laying the halo, the penetration is practically unchanged. By comparing the results of the calculation of thawing halos using the proposed laying scheme and laying the pipeline in the usual way without using thermal insulation in the FROST 3D Universal software complex, the prevention of progressive melting of the soil base was revealed.

Studies have shown that 3D computer simulations are an effective tool for quantifying geocryological hazards. In particular, the use of the FROST 3D program made it possible to assess the amount of pouring and freezing of soils around the oil pipeline, taking into account the influence of the following factors: the geological and lithological structure of the section, meteorological conditions, the temperature of oil pumped through the pipe, the thickness and type of heat insulation of the pipe and the design features of the trench in which the oil pipeline is located.

5. References
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