Combined influence of seasonal processes of permafrost soils on stress and strain state of underground oil pipeline

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Abstract. The paper simulates the condition of the underground oil trunk pipeline under the combined influence of freezing-thawing processes in permafrost soils. Changes in seasonal temperatures lead to the emergence of processes such as heaving and sinkholes, which affect the spatial position and performance of the pipeline.

The paper presents the calculation of the underground pipeline laying in permafrost with an outer diameter of 520 mm (steel 355 JR), a length of 30 m (depth of 1.5 m), which passes oil temperature 25 °C under pressure of 5 MPa, with the temperature of the outer shell of the pipe 0 °C. Simulation was carried out in SolidWorks using the Simulation package. The stress-strain state and displacements arising from the combined effects of processes in permafrost soils are determined. According to the results of the study, conclusions are drawn about the impact of the combined effects of freezing and thawing processes on the performance of the underground pipeline.

1. Introduction
A large number of oil pipelines is located in the climatic zone characterized by existence of permafrost soils. The distinguishing feature of this type of soils is existence of seasonal soil freezing and melting processes (heaving, collapses, etc.), where each of them as well as several of them combined affect operation of the oil pipelines [1,2,3].

The need for calculation of the stress and strain state under multifactor loading in such conditions is determined, first of all, by specific features of installation and construction of underground pipelines [4,5]. When designing a section, the pipeline breaking point is considered to have a safety factor. However, the design calculation does not allow for consideration of occurring combined loads, which cause the oil pipeline to break. Therefore, testing to assess impact of seasonal melting and freezing processes allows assessment of the most dangerous states of oil pipeline and taking necessary measures in advance.

2. Setting and Method of Solution
This article provides simulation of the stress and strain state of the oil pipeline made of S355JR grade steel (an analogue of 17Г1C) laid underground (depth of coverage is 1.5 meters) that is 30 meters long and has a diameter of 520 mm, 10 mm wall thickness in conditions of permafrost soils, pumping oil under pressure of 5 MPa with a temperature of the pumped oil of 25 °C and temperature of the external coating of the pipeline of 0 °C. Choice of the twisting value is based on the previously carried out test [4] and is equal to 50 Nm.
The simulation was performed in the SolidWorks Simulation software. The static analysis was performed using the final element method. In order to simulate the impact, a diagram of the section squeezed between the permafrost soils with hard pinching on the ends of the pipeline (0 and 30 meters).

3. Calculations and Results
The calculation results are presented in figures 1–5 and table 1.

![Figure 1. Stress and strain state and motion at collapse with heaving without twisting](image1.png)

![Figure 2. Stress and strain state and motion at collapse with heaving and twisting](image2.png)

![Figure 3. Stress and strain state and motion at heaving with twisting](image3.png)
Figure 4. Stress and strain state and motion at emergence of heaving spots without twisting

Figure 5. Stress and strain state and motion at emergence of heaving with twisting

Table 1. The value of maximal stress and motion

| Scenario                                    | Max. stress, MPa | Motion, mm |
|---------------------------------------------|------------------|------------|
| Collapse with heaving without twisting      | 374.9            | 181.81     |
| Collapse with heaving with twisting         | 390.3            | 182.91     |
| Heaving with twisting                        | 115.38           | 1.47       |
| Spots of heaving without twisting           | 90.72            | 9.37       |
| Spots of heaving with twisting               | 101.81           | 8.54       |

The greatest value of stress inside the pipeline wall is observed when there is a collapse on the occurrence route, which is higher than the yield limit of S355JR steel (275 MPa), which allows us to judge of presence of residual plastic strain. The motion between the collapse with heaving and twisting and heaving without twisting is considered to be equal, which allows us to judge of inconsiderable impact of this load (twisting) on the oil pipeline compared to the effect of the collapse.

Value of stress inside the walls of the oil pipeline at combined impact of heaving and other seasonal melting - freezing processes (without collapse) below the yield limit, which corresponds to the permissible loads included at the stage of design. Motion at heaving is inconsiderable (less than 1 cm) compared to the combined effect of soil collapse. When the heaving spots increase, no stress exceeding the yield limit occurs. Possible combination of heaving with other processes (not addressed in the article) can cause failure of oil pipeline operation.
Small values of twisting (50 Nm) at combined loading do not lead to a considerable growth of stress in the oil pipeline wall.

4. Summary
The test results allow for the following conclusions:

- Impact of processes of seasonal changes in permafrost soils makes the pipeline change its position in relation to the original laying;
- The highest stress in the oil pipeline wall and motion in relation to the geometrical position in the soil is caused by soil collapse at combined loading;
- The need in performance of works on selection of a reliable route of the oil pipeline laying and stabilization of the section. When multiple loading areas emerge (including seasonal heaving spots), the operation of the facility preserves. Impact of the collapse with other working processes considerably reduces the operation cycle of the oil pipeline section;
- The need in control of the pipeline position (relative to the original depth of laying) and well equipment for water removal along the pipeline route in the spring and autumn seasons.

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