

# Field Studies of Technologies for Reducing Frost Heaving of Line Supports in the Conditions of the Republic of Sakha (Yakutia)

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**Abstract** – Frost heaving of power transmission line supports in regions with permafrost soils directly affects the reliability and uninterrupted operation of power supply systems. The article provides information on the work on field studies of the effectiveness of using anti-heaving coatings and shells “Reline” in application to wooden and concrete foundations of overhead power transmission line supports to reduce the tangential forces of frost heaving of soils in the climatic and geocryological conditions of the Republic of Sakha (Yakutia). During the work, a test site was set up on a heaving site in the city of Yakutsk, 12 cycles of monitoring the altitude position of the support foundations and the temperature regime of the soil were carried out. The obtained results demonstrate the efficiency of using the tested coatings in the conditions of the Republic of Sakha (Yakutia).

The work was carried out by Yakutsk Design Research Institute of Construction and Ural Plant of Polymer Technologies “Mayak” by order of PJSC “Yakutskenergo”.

**Index Terms** – Overhead conductors, permafrost, line supports, frost heaving, anti-heaving coatings.

## I. INTRODUCTION

Operation of overhead conductors in the complex geocryological conditions of the Republic of Sakha (Yakutia) is associated with a number of features and problems, one of which is frost heaving of supports. Frost heaving is caused by freezing and expansion of moisture in a closed volume of soil pores during periods of negative air temperatures. In addition to the expansion of water during freezing, liquid water is drawn to the freezing front, due to which the degree of vertical displacement of the soil can be significantly greater than the volumetric expansion of the freezing water [1–3]. The occurrence of incoming frost heaving creates strong stresses (tangential and normal) aimed at pushing the supports out of the soil volume. Studies show that the intensity of heaving is influenced by many factors, the main ones being the heaving of the soil [4–6], its humidity [7, 8], salinity and content of organic components [9, 10], as well as the freezing rate [6, 11, 12]. The latter factor is especially characteristic of the extreme climatic conditions of the Republic of Sakha (Yakutia), as a result of which frost heaving processes occur faster and more intensively.

For low-load structures, which line supports are, the heaving forces, exceeding the load on the support, change its design position in environment, creating a risk of collapse. The change in the position of the support has both a cyclical nature, with a rise in the cold season and a lowering in the warm season, and a progressive nature, when the height of the support extrusion increases every

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*Fig. 1. PSPP “Reline” anti-heaving polymer coating for piles.*

year.

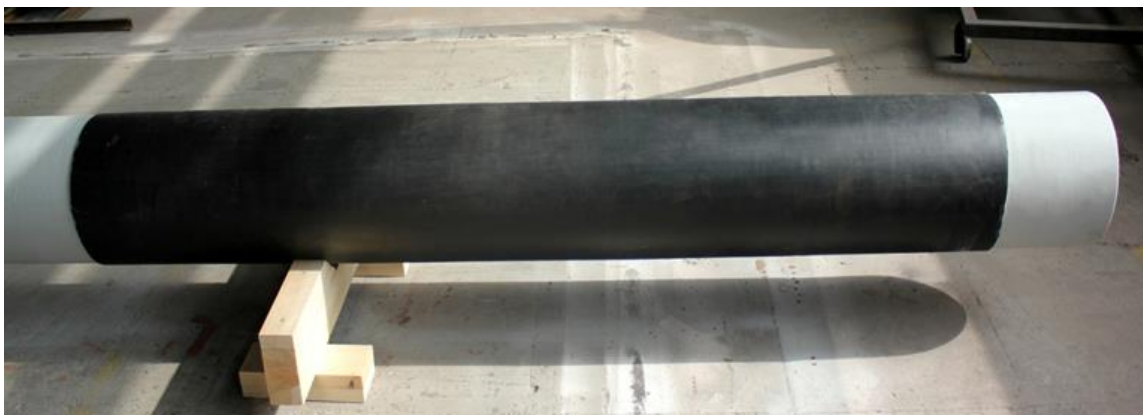
In regions with permafrost soils, deformations of transmission line supports due to frost heaving are widespread, which leads to an emergency situation. Heaving deformations of pile foundations are observed both on thawed and permafrost soils, including low-temperature soils (below  $-2C^{\circ}$ ) [13, 14]. This is confirmed by the results of inspections of overhead power line supports in Yakutsk, showing that one of the main causes of deformations is strong and excessive heaving of the soils of the active layer. At the same time, the average heaving rate of untreated support foundations (footings) in heaving soils is 10 cm/year. The critical heaving value is 50 cm, i.e. the service life of support adjuncts in heaving areas does not exceed 5 years on average. After which either the support collapses and subsequent emergency restoration work occurs, or it is routinely dismantled and a new one is installed. Both the first and second developments entail interruptions in supply and power outages for the duration

of the emergency response or scheduled maintenance on the lines.

Thus, solving the frost heaving problem will not only significantly increase the service life of the foundations of the transmission line supports, directly reducing the costs associated with emergency recovery and repair work, but also reduce the number of interruptions in supply and undersupply of electricity, increasing the overall reliability of power supply systems. This is especially relevant for the conditions of the Far North, where uninterrupted power supplies are very important for life support systems.

Methods for reducing frost heaving forces or anti-heaving measures are divided into three types [15]:

- meliorative, which reduce soil moisture content or prevent its water saturation;
- chemical, examples of which may be soil hydrophobization with binders, lowering the freezing temperature of pore moisture with salt solutions or introducing polymer additives into the soil that compensate



*Fig. 2. OSPT “Reline” anti-heaving heat-shrinkable shell for piles.*

for soil heaving when moisture freezes;

- construction and structural, which consist of increasing the depth of the foundation, adapting the above-ground parts of the structure to heaving deformations and reducing the forces and deformations of heaving.

The last group includes methods for reducing tangential heaving forces by creating a sliding surface on the underground part of the supports.

One of these technologies is the “Reline” polymer coatings and shells developed and produced by Ural Plant of Polymer Technologies “Mayak”.

The PSPP “Reline” anti-heaving polymer coating for piles (Fig. 1) is a protective layer made of modified polymer epoxy material, which after application and hardening creates a durable coating resistant to various impacts.

The OSPT “Reline” anti-heaving heat-shrinkable shell for piles (Fig. 2) is a two-layer sleeve consisting of a heat- and light-stabilized, cross-linked and longitudinally

oriented polyolefin composition and an adhesive sublayer based on modified hot-melt adhesive compositions.

II. METHODOLOGY

The field studies were conducted in order to determine the efficiency of using “Reline” coatings and shells for wooden and concrete foundations of line supports in reducing the tangential forces of frost heaving of soils in the climatic and geocryological conditions of the Republic of Sakha (Yakutia). To conduct the studies, a test site was equipped in an area with heaving soils in the city of Yakutsk.

The methodology and testing were carried out in three stages:

1. Preparatory stage, including:

- conducting engineering and geological surveys at the site of field tests to determine its geological and geocryological conditions;

Depth	EGE	Well section	Description of the soil	Depth of the sole layer, m	Layer thickness, m	Absolute elevation of the layer base, m	Total moisture content fractions of units	Soil temperature, C, on 10.10.2022
1.0	①		Heaving sandy loam with an admixture of organic soil	1,5	1,5	95,15	0,19	+1,3
2.0							0,25	+1,4
3.0	②		Water-saturated dusty sand	3,8	2,3	92,85	0,26	+0,0
4.0							0,27	-0,7
5.0							0,28	-0,9
6.0	④		Sand, fine, frozen, icy	7,5	3,7	89,15	0,31	-1,0
7.0							0,29	-1,1
8.0	③		Frozen sandy loam, icy	9,2	1,7	87,45	0,31	-1,2
9.0							0,32	-1,2
10.0	④		Sand, fine, frozen, icy	10,0	0,8	86,65	0,31	-1,2

Fig. 3. Engineering and geological section of the field test site.

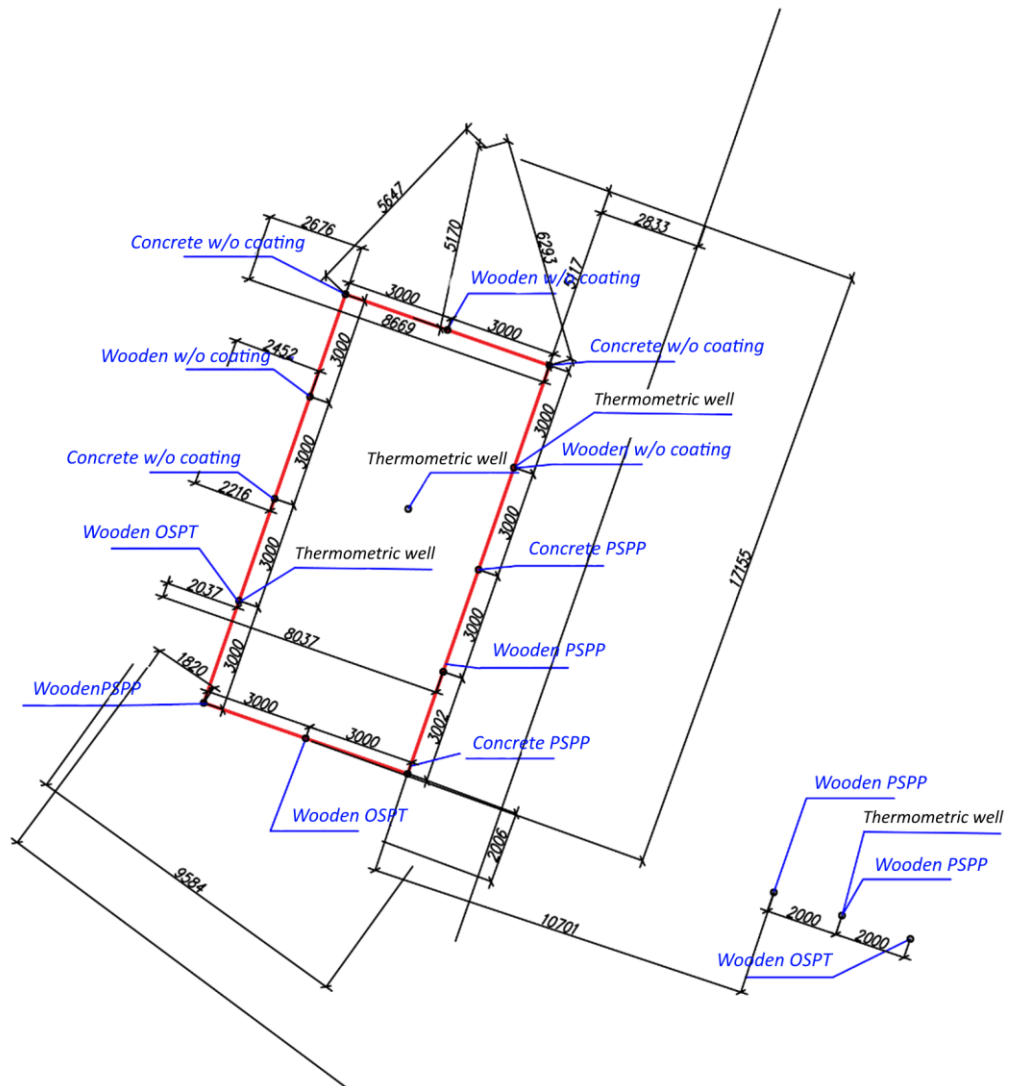


Fig. 4. Layout of the samples of line supports foundations (footings) at the site of field tests.

- selection and description of the test foundations of supports (footings) with options for the design of anti-heaving coatings;
  - normative calculations of footings for bearing capacity and resistance to tangential forces of frost heaving in specific engineering and geocryological conditions;
  - determination of the test load on the foundations;
  - test site equipment sequence;
  - requirements and conditions for conducting tests;
  - program of visual and instrumental monitoring.
2. Stage of visual and instrumental monitoring, including:
- visual survey;
  - instrumental determination of vertical displacements;
  - soil temperature measurements in thermometric wells.
3. Final stage, including:
- processing, analysis and presentation of test results;
  - preparation of a scientific and technical report (upon completion of the experimental part).

Figure 3 shows the results of engineering and geological surveys, showing that the geological section of the site is represented by four engineering and geological elements: highly heaving sandy loam with an admixture of organic matter, silty water-saturated sand, saline icy sandy loam



Fig. 5. The way of fastening the ballast to transfer the test load to the footings.

with an admixture of organic matter and fine, icy sand.

Based on the experience of use in the Republic of Sakha (Yakutia), 2 types of foundations (footings) for line supports were selected as test foundations (footings):

- PT-60 reinforced concrete footing according to series 3.407-57/87;
- wooden footing made of larch according to GOST 9463-2016 [16].

For each footing type, tests are carried out for samples without a special anti-heaving coating and samples with an applied OSPT anti-heaving coating (wooden footing) and PSPP (reinforced concrete and wooden footing) of the Reline series. According to the design documentation for

the construction of various line supports, the typical depth of immersion of the footing into the ground is 4.0 m.

Thus, the following types of footings for transmission line supports were installed:

- PT-60 reinforced concrete footing without anti-heaving coating – 3 pcs.;
- PT-60 reinforced concrete footing with the “Reline” PSPP coating – 3 pcs.;
- wooden footing made of larch without anti-heaving coating – 3 pcs.;
- wooden footing made of larch with the “Reline” OSPT coating – 3 pcs.;
- wooden footing made of larch with the “Reline” PSPP

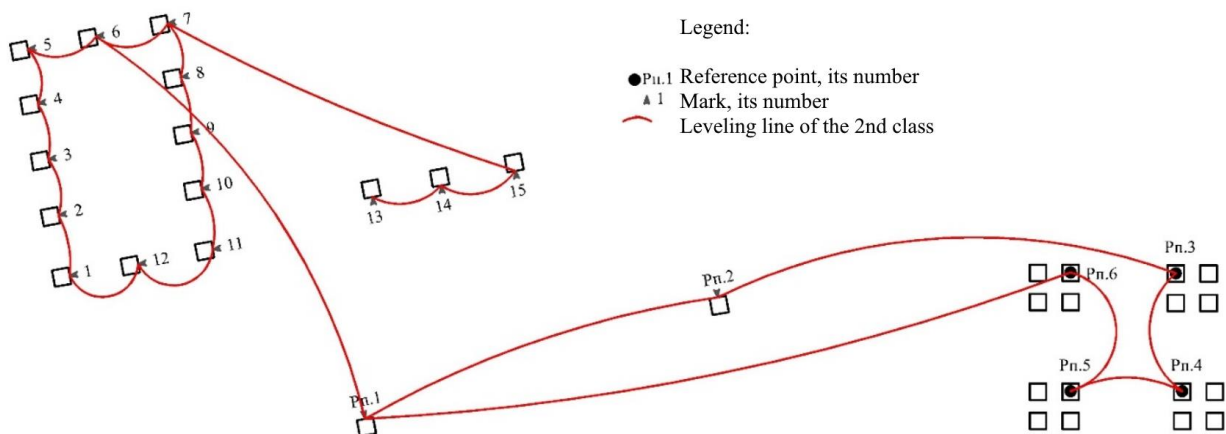


Fig. 6. The layout of reference points and deformation marks.

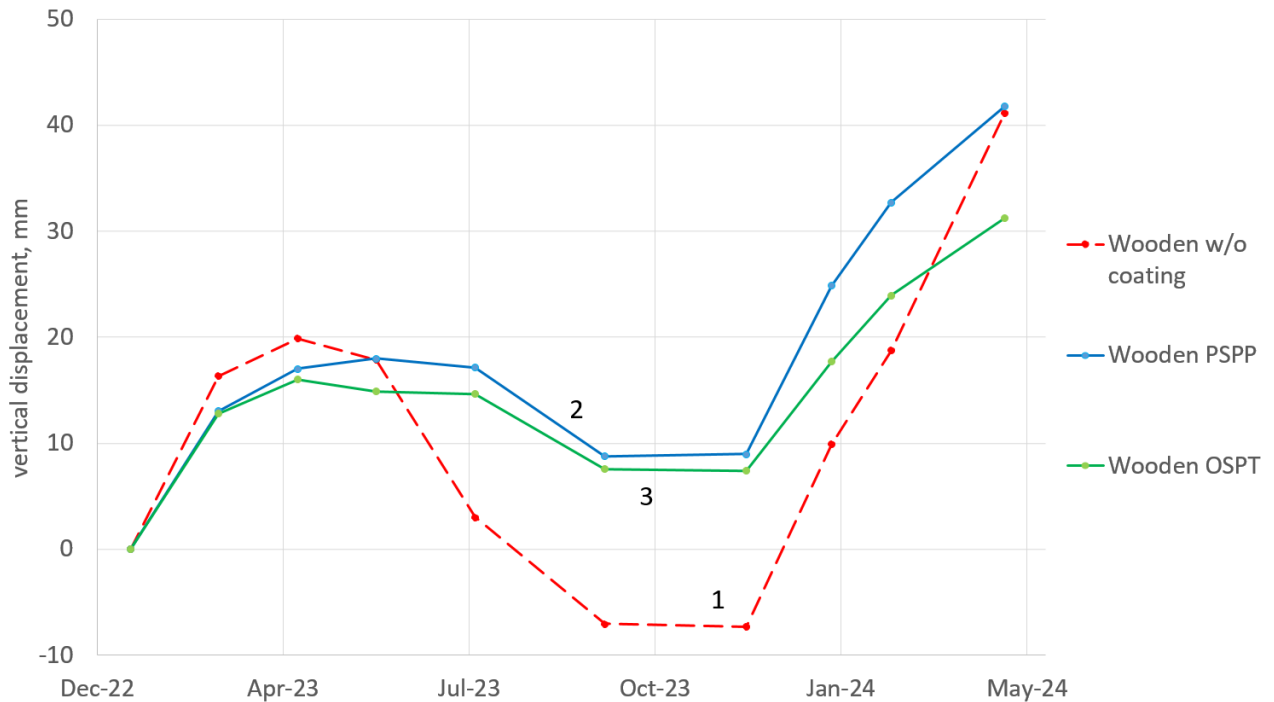


Fig. 7. Averaged data on vertical displacements of larch footings.

coating – 3 pcs.;

The layout of the samples of line supports foundations (footings) at the site of the field tests is shown in Fig. 4. Four thermometric pipes were also installed to monitor the temperature at the depth of the footings:

According to standards, the weight of the tested line supports with associated elements is:

- for a support on a reinforced concrete footing – 0.454 tons;
- for a support on a wooden footing – 0.375 t.

The footings were loaded with corresponding test load using concrete ballasts, the method of fastening the ballast is shown in Fig. 5.

During the preparatory work, PSPP coatings were applied to the tested footings and OSPT “Reline” shells were installed. Anti-heaving coatings were applied taking into account the estimated depth of seasonal freezing of 3.9 m.

The vertical displacements of the footings were determined using the geometric leveling method of class II in accordance with GOST 24846-2019 [17]. The layout of reference points and deformation marks is shown in Fig. 6.

The soil temperature was measured using a multi-zone

digital temperature sensor (MDTS) in accordance with GOST 25358-2020 [18].

### III. RESULTS

In total, 11 cycles of monitoring vertical displacements of the footings and 7 cycles of soil temperature measurements were performed during the field tests from December 2022 to April 2024.

The effectiveness of anti-heaving coatings was assessed based on a comparative assessment of the vertical displacements of attachments with anti-heaving coatings and without coatings.

The comparison of vertical displacements was taken based on the average values for each of the installed groups of the footings - the second cycle (January 12, 2023), performed after the installation of test loading ballasts and stabilization of the vertical position of the attachments, was taken as the zero reading of vertical displacements.

Figure 7 shows the average values of vertical displacements for larch footings. Line 1(a dotted line), corresponds to the average displacement of footings without an anti-heaving coating. Line 2 corresponds to the average displacement of footings with the PSPP anti-

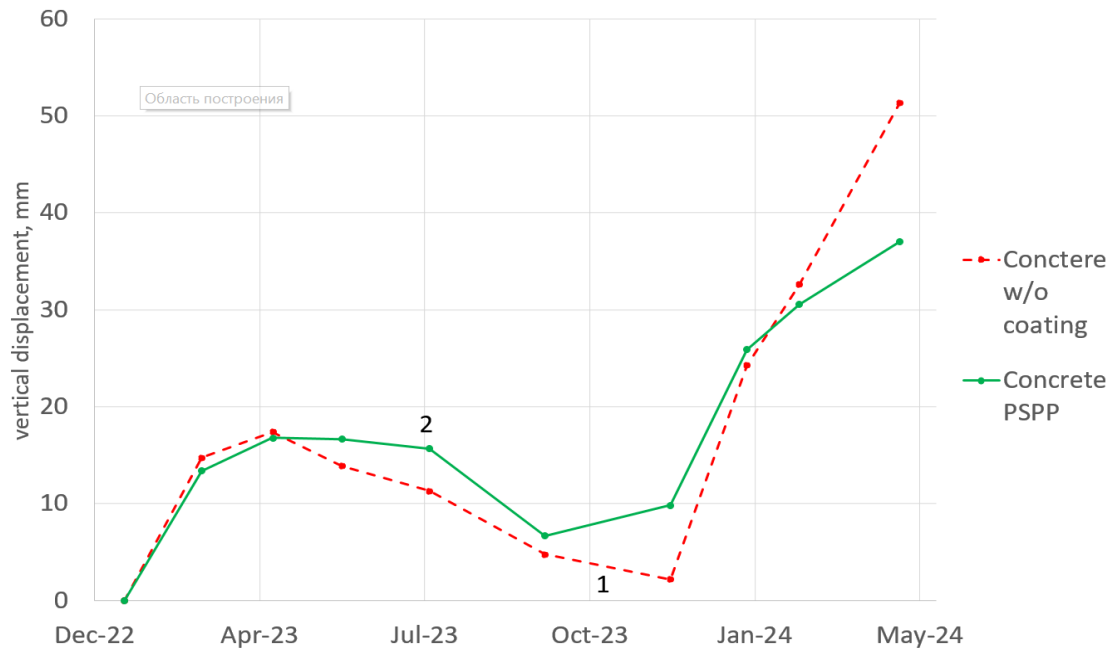


Fig. 8. Averaged data on vertical displacements of concrete footings.

heaving coating, line 3 – the average displacement of footings with the OSPT shell.

Figure 8 shows the average values of vertical displacements for concrete footings. Line 1 (a dotted line), corresponds to the average displacement of footings without an anti-heaving coating. Line 2 corresponds to the average displacement of footings with the PSPP anti-heaving coating.

The effectiveness of anti-heaving coatings was assessed as a percentage for two heaving periods:

- from January 12, 2023 to April 12, 2023, from the moment of stabilization of the vertical position to the peak value of the footing displacement;

- from September 24, 2023 to April 26, 2024, from the beginning of the cold season to the peak values of heaving, based on the data obtained in 2023.

The analysis of the research data is given in Table 1. Since the first heaving period from the moment of site arrangement in January 2023 was only 90 days, the second period, the duration of which is 215 days, provides more complete data.

#### IV. CONCLUSIONS

The obtained results show that in the soil conditions of the test site, the surface heaving soil layer of which consists of sandy loam with an admixture of organic matter with a

TABLE 1. Comparison of Vertical Displacements for Two Heaving Periods

Footing type	January 2023 – April 2023		September 2023 – April 2024	
	Vertical displacement, mm	Reduction of heaving effect, %	Vertical displacement, mm	Reduction of heaving effect, %
Wooden w/o coating	19.88		48.18	
Wooden PSPP	17.03	14.4	33.07	31.4
Wooden OSPT	16.00	19.6	23.70	50.8
Concrete w/o coating	17.41		46.59	
Concrete PSPP	16.77	3.6	30.39	34.8

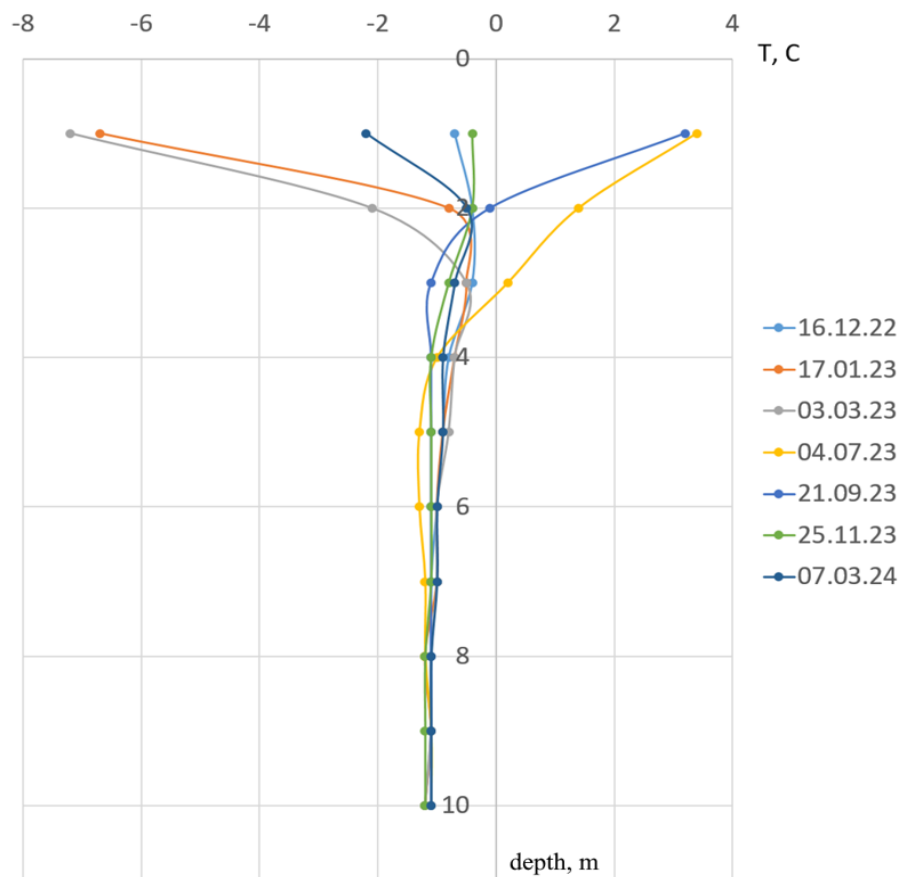


Fig. 9. Results of measurements in a thermometric well in the center of the test site.

total moisture content of 19% to a depth of 1.5 m, and silty sand with a total moisture content of 25–27% to a depth of 4 m, the PSPP coating on average reduces the frost heaving of larch and concrete footings of line supports by 31.4–34.8%, and the OSPT coating reduces the frost heaving of larch footings of line supports by 50.8% during the heaving period from September to April.

Thus, it can be concluded that the results obtained during the field studies allow us to positively assess the effectiveness and confirm the prospects for using the “Reline” PSPP and OSPT anti-heaving coatings in the cryolithozone of Yakutia.

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