

Interaction of the augercast micropiles with permafrost

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Abstract. Owing to the current extensive exploration of the continuous permafrost zone which takes up no less than 25% of the entire land area and over 60% of the territory of the Russian Federation, the necessity arises to search for innovative construction technologies in view of bases and foundation engineering carried out in the cryolithozone.

The article studies one of such technologies, i.e. the pile foundations built on permafrost employing the cement grout injection into the pre-drilled hole. The article reveals the investigation findings pertaining to the interaction of micropiles with permafrost. The investigation objective is to determine the mechanical and thermophysical properties of interaction for the micropile cement body with permafrost.

Within the scope of the investigation presented herein a series of tray tests of the scaled augercast pile models in permafrost was carried out to assess their ability to withstand static pressing loads simultaneously measuring the temperatures in depth, as well as proceeding with the laboratory testing of mechanical and thermophysical properties of the injected cement grout, and thermal engineering calculations to determine the nature of thermal interaction of the micropiles with permafrost.

Obtained are the values of the load-bearing capacity of the augercast piles and resistance of frozen non-saline soils to sustain the shear over the adfreeze surface with the cement body of the augercast piles; generated are the graphs of the temperature fluctuations in the course of the cement grout consolidation. The strength values for the cement body of the augercast piles built in permafrost are recorded. The time required to ensure the cement grout hardening to prevent its freezing is estimated; the temperature required for the cement grout used for injection is also determined.

In consequence of the investigation, the recommendations are provided with respect to the augercast piles construction in the cryolithozone.

1. Introduction

Construction in the cryolithozone is currently carried out mainly according to the principle I [1], when the foundation soils are kept in a frozen state during the construction and the entire service life. Preservation of soil in the frozen state in the construction of foundations is a complex geotechnical task, the solution of which is impossible with classical foundation methods. Today, in permafrost the



pile foundations have gained an advantage over others methods. When using them, the need to develop a natural soil in a foundation pit is excluded, which is difficult to perform due to the harsh natural conditions of the terrain and the difficulties with excavation of strong frozen ground.

By the method of immersion in the permafrost soil, the piles are divided into slurred, boring, dipping and driven cast-in-place piles, as well as screw piles. One of the most common of immersion is the slurred method. However, all these technologies are quite difficult to apply when it is necessary to strengthen foundations on permafrost soils.

The thawing of the foundation soils during the operation of the building leads to a decrease in the bearing capacity of the piles, which is why it is required to perform the reinforcement. From this it follows that in the construction and reconstruction of buildings and structures in the cryolithozone there remain questions connected with the need to study new types of pile foundations [2].

The question arises of the rationality of the application of various types of piles depending on the purpose and engineering geological and cryological conditions with the aim of increasing the technical and economic efficiency and reducing the construction time. In this connection, active development and approbation of new methods of operation of pile foundations in frozen soil is underway. Also, technologies used on thawed soils are adapted. These technologies include grout-injected piles.

Grout-injected pile solutions of structures that arise when replacing drilled ground with a pre-prepared mixture of cement. An example of a device can be considered in feeding a cement mixture into a wellbore face through a hollow drill rod under pressure. The technology is applicable for strengthening foundations, as well as for devices of self-pile foundations.

This technology is used to strengthen the foundations of civil and industrial buildings, buildings located on a subsidence ground, when constructing enclosing structures. Such a foundation reinforcement technology is actively used in specific conditions of cramped construction sites. The technology of reinforcing foundations does not require the use of large-sized equipment and excludes large volumes of excavation. In addition, reinforcements with the help of drilling pile piles can be carried out on those sites that are distinguished by problem geological conditions: thermokarst, taliks, etc.

The most striking example of the advantage of reinforcing drill piles is the speed with which the foundation is strengthened. In addition, the foundation is strengthened with the use of computer test equipment, which allows achieving a high degree of structural reliability.

Now in the cities located in the permafrost zone, construction is increasingly being carried out near the existing building. In this case, the erection of a new building exerts not only a mechanical effect on the foundations of buildings of the existing building, but also a thermal effect, which in turn leads to thawing of the foundation soils, uneven deformations and even emergency situations. The use of grout-injected piles will reduce not only the mechanical, but also the thermal impact on the foundations of existing buildings when they are reinforced by a smaller amount of mortar than slurred piles.

2. Grout-injected pile technology

The technology consists in drilling a well with washing, as a rule, with a liquid cement mortar ($w / c = 0.7 - 1.0$) and subsequent injection of a dense cement mortar ($w / c = 0.4-0.6$). The washing cement slurry removes the drilling mud from the well, penetrates the surrounding root of the pile, improves it, strengthens the walls of the drilling hole against collapse, and creates a smooth transition between the pile body and the ground. Thus, depending on the properties of the soil, it is possible to increase the diameter of the manufactured pile to a double diameter of the drill bit. The surface of the walls of the grout-injected piles turns out to be uneven and due to this, their good adhesion to the ground is ensured. Rules of installation of micropiles regulated by State Standard 57342-2016/EN 14199:2005 [3].

One of the types of grout-injected piles are augercast micropiles, the main element, which is a hollow auger. The construction of the auger consists of several parts: a tubular screw rod, a coupling, a centralizer, a drill bit, a base plate, washers and nuts (Fig. 1).



Figure 1. General view of a set of augercast micropile

At the present time, augercast micropiles have not been widely used in the areas of permafrost. Basically, this is due to the need to recruit the strength of the injected composition in the conditions of negative temperatures of the enclosing soil massif and the difficulties encountered in the process of their construction. However, in articles [4][5] was described that according to the research, the process of erection of micropiles in permafrost soils is not different from the usual. One of the most significant objects with the use of foundations from augercast micropiles is the construction of wind turbines for power supply of the research base named "Scott Base" in Antarctica.

3. Research methods

To study the possibility of using augercast micropiles in permafrost soils were carried out the tray tests of the scale models of piles with static loads with parallel measurement of soil temperature around them. Tests to determine the compressive strength of cement hardened at negative temperatures. Physical, thermophysical and mechanical characteristics of the soil in the tray were determined, and were conducted a series of thermal engineering calculations was performed in the program Frost 3D Universal.

The general view of the tray test is shown in Fig. 2.



Figure 2. The general view of the tray test of the pile model

The temperature during the process of the pile assembly was determined with the help of thermometric braids, located along the depth of the tray with a sensor pitch of 100 mm. The microsphere arranged in frozen soil was aged for 28 days in order to further compare the strength of the pile body with the cubic strength of cement hardening at a negative temperature. The vertical static load on the pile model was set by the hydraulic press steps before reaching a conditional stabilization of 0.2 mm for each day of observation, in accordance with GOST 5686-2012 [3]. The test was stopped when the pile was at least 25 mm thick and the pile deformities increased three-fold compared to the previous stage. The load value was calculated using formula (1):

$$F = RA + R_{af}A_{af}, \quad (1)$$

R – pressure on the frozen soil under the lower end of the pile, kPa;

A – pile support area, m^2 ;

$R_{af,i}$ – resistance of the frozen soil or ground solution to the shear along the lateral surface of the pile freezing within the i -th layer of the soil, kPa;

$A_{af,i}$ – surface area of the freezing of the i -th layer of soil with the lateral surface of the pile, m^2 ;

The load on the model of micropile with a auger diameter of 30 mm and a length of 600 mm was 48 kN. The test was carried out by loading steps equal to 10 and 20% of the starting value.

The tray was filled with medium-sized sand, density 2.12 g/cm^3 , humidity 17% and frozen at minus 3°C .

Table 1. Physical and thermophysical properties of the soil

Soil name	$W, \%$	$\rho, \text{g/cm}^3$	$\rho_d, \text{g/cm}^3$	$\rho_s, \text{g/cm}^3$	$e, \text{u.s}$	$S_r, \text{u.s}$	$\lambda_{th}, \text{w/mK}$	$\lambda_t, \text{w/mK}$	$C_{th}, \text{J/m}^3\text{K}$	$C_t, \text{J/m}^3\text{K}$
Medium-sized sand	17.0	2.12	1.81	2.65	0.46	0.78	2.42	2.87	2.94	2.32

Then tests of cement hardened in a freezer with parallel temperature measurement were carried out. Cubes of cement were kept in the freezer for 7-28 days and tested on a press to determine the compressive strength (Fig. 3).



Figure 3. Testing a cube of cement for compression

Based on the results of laboratory studies of thermal engineering characteristics of soils, as well as tray test of pile model, was carried out a computer simulation of the thermal interaction of augercast micropile with frozen soil. In the heat engineering calculation, the initial condition for the cement material-the temperature equal to 12°C -was used to describe the process of heat transfer from the pile cement body to the frozen ground. The heat release due to the hydration process was not conditionally taken into account. The initial data accepted in the calculation is given in Table 1. The simulation was carried out for different soil temperatures (minus 1, 2 and 3°C) for determining the freezing time of the cement of the body of the drilling pile pile and the defrosting radius. The design area was chosen similar to the tray in which temperatures were measured. The general view of the thermal engineering model is shown in Figure 4.

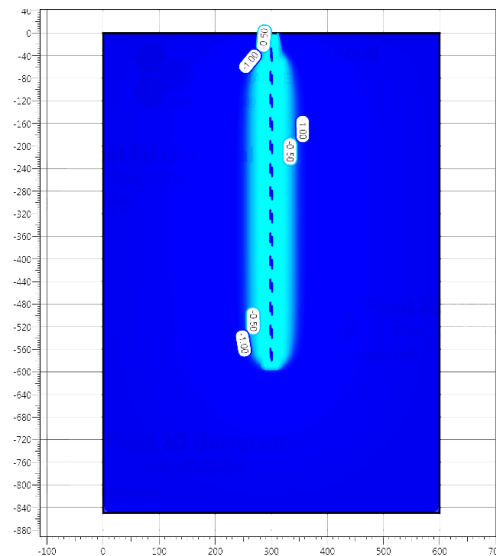


Figure 4. The general view of the thermal engineering model

4. Research results

According to the results of the tray test of the augercast micropile model, it was found that the draft for the 48 kN load was 10.7 mm. This means that its load-bearing capacity corresponds to the calculated on SP 25.13330.2012 [1] as for the drill pile. However, according to [6], the test was carried out before the pile was failure. Figure 5 shows the graph obtained during the static squeeze test. Elastic deformations were 3.98 mm, plastic deformations were 6.69 mm.

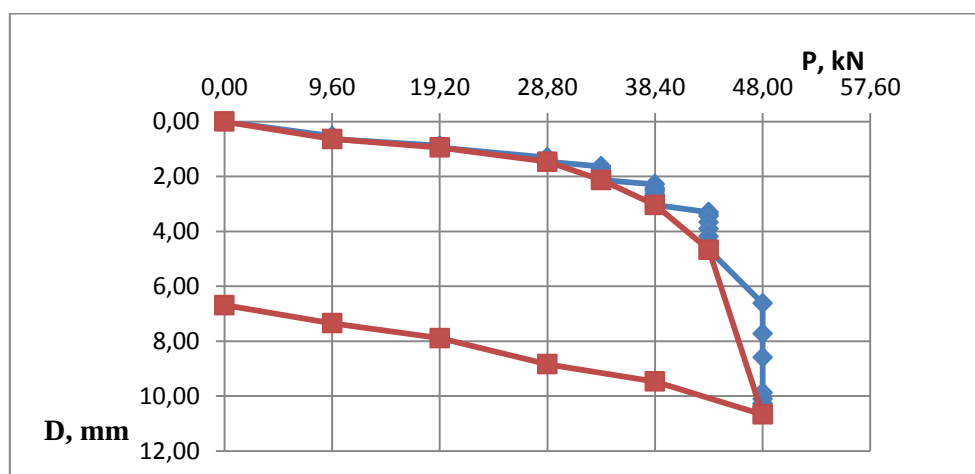


Figure 5. Graph of dependence of the draft of the micropile on the load

Figure 6 shows the graph of the strength of cement collected in the freezer from the time of hardening. The strength gained by the cement cubes at minus 3 °C for 7 and 28 days differs by 17% and is less than 10% of the brand strength. As is known, this is due to the fact that the water needed for the hydration process of the cement freezes at a negative temperature. Also, the degree of cement strength set at a negative temperature is affected by its volume, since the time to its full freezing increases, and the amount of heat released during hydration increases.

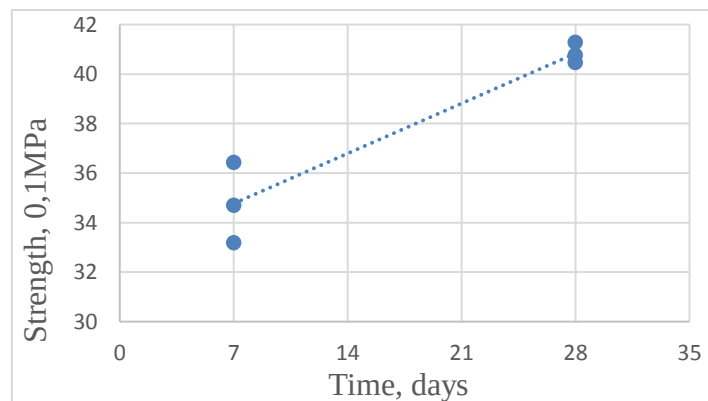


Figure 6. Strength of cement, collected at a temperature of minus 3°C

However, as seen in the graph (Fig. 6), the time of hardening of cement at negative temperatures affects its strength not significantly. From the graph (Fig. 7), it can be concluded that during the hydration of cement at low temperatures a small amount of heat is released, which cannot have a significant effect on the thawing of frozen ground around the micropile.

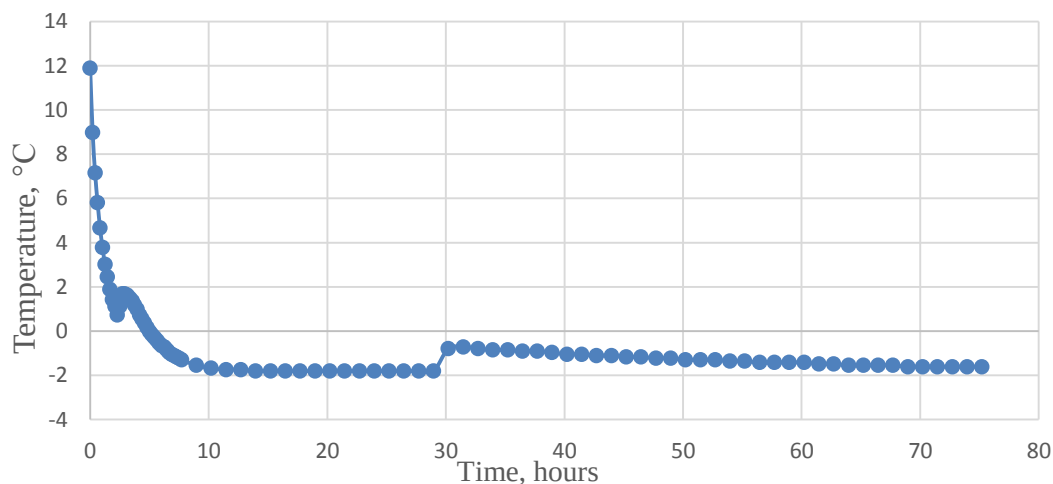


Figure 7. Temperature change in cement at a negative temperature

The temperature of the cube of cement falls below 0 °C after 5 hours after the beginning of hardening (Figure 6), the water in the pores passes into the solid phase and, consequently, the hydration process ceases. To set a higher cement strength value, additives accelerating hardening and lowering the freezing point of Tbf cement should be used.

Further, within the framework of the study, a heat engineering calculation was carried out. To describe the process of heat transfer from the pile cement body to the frozen ground, the initial condition for the cement material - a temperature equal to 12 °C was used.

Heat release due to the hydration process was not conditionally taken into account, since it is evident from the graph (Fig. 7) that the amount of heat of ordinary cement released during hydration in the conditions of negative outside air temperatures is not significant.

Simulation was carried out for the temperatures of frozen soil (minus 1, 2 and 3 °C) to determine the freezing time of the cement of the body of the augercast micropile and the defrosting radius. The design area was chosen similar to the tray in which temperatures were measured. The general view of the thermal engineering model is shown in Figure 4.

As can be seen from the graph (Fig. 8), the temperature in the pile drops below zero degrees after 10 hours from the moment of its device and stabilizes over the next 14 hours.

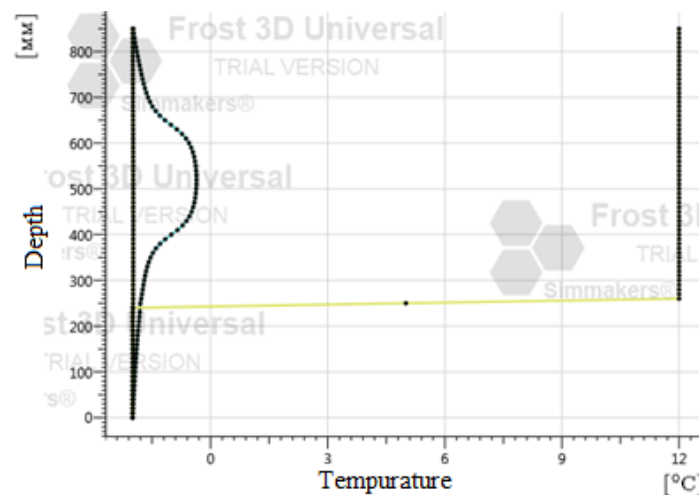


Figure 8. The temperature distribution in the heat-engineering model of the tray at different times (the initial moment, 10 and 24 hours after the pile arrangement)

Radii of thawing and freezing time of thermal engineering models of drilling-injection micropiles at different temperatures are presented in Table 2.

Table 2. Radii of thawing and freezing time

Soil name	Temperature, °C	Radii of thawing, mm	Freezing time, h
Medium-sized sand	-1	47	27
	-2	41	25
	-3	35	24

According to the results of heat engineering calculations, it can be concluded that the amount of heat transferred from the warm cement slurry to the frozen soil is not significant. Thickness of the thawed zone at a temperature minus 1 °C does not exceed the value of the double diameter of the pile cement body. The temperature of frozen ground near this zone is also not significantly increased and returns to its natural state 27 hours after the pile structure.

5. Discussion

The main parameters influencing the radius of thawing of the soil around the pile and the freezing time of the cement are the temperature of the injected solution and its volume (the radius of the pile cement body), respectively.

The strength set of the pile cement body influences its further bearing capacity, therefore, to ensure the cement strength set at the negative temperatures of the enclosing soils, it is necessary to use chemical additives to lower the freezing temperature of cement and accelerate its hardening. The cement slurry recipe should be installed depending on the temperature of the permafrost and ambient air, as well as on the properties of the cement [7].

In this case, the question arises of the migration of salts from the cement body of the pile to frozen soil, which can lead to salinization of frozen soils, and as a consequence to the loss of the bearing

capacity of the base. From this it can be concluded that the amount of additive should not lower the temperature of the beginning of freezing of the soil lower than the natural temperature of permafrost.

The current regulatory and technical base in Russia [1] does not recommend the use of various chemical antifreeze additives in the construction of foundations and foundations on permafrost soils. However, this issue has not found sufficient study and as a result can be revised.

Also, the value of the calculated shear resistance along the lateral surface of the pile cement body with frozen soil should be studied in more detail. Tests for determining the shear for drilling pile injections should be carried out on specially prepared samples. Cement mortar must be poured at a negative temperature in a special ring located on a frozen soil sample, as described in [8].

The use of chemical additives and the provision of hardening of cement at negative temperatures of the surrounding soil massif will lead to additional heat generation due to the hydration process. Therefore, in heat engineering calculations it will be necessary to take this heat into account.

6. Conclusions

When setting up the augercast micropiles is used with cement mix without the use of chemical additives (antifreeze and accelerating hardening), complete hydration of the cement is not provided due to freezing of water. Due to this, there is no strong heat release and accordingly thawing of the ground around the micropiles is not significant.

The strength of the frozen cement material is significantly lower than the brand strength (about 10%) obtained under normal hardening conditions. At the same time, as the hardening time increases from 7 to 28 days, the strength increases by only 17%.

Bearing capacity of micropiles is commensurable with the bearing capacity of slurred piles of the same diameter.

The installation of pile foundations from augercast micropiles can be used in areas of permafrost so as to strengthen the foundations of existing buildings or as basic foundations for lightly loaded structures.

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