IOP Conference Series: Materials Science and Engineering

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IOP Conf. Series: Materials Science and Engineering **753** (2020) 052025 doi:10.1088/1757-899X/753/5/052025

The Combined Method of Arrangement of Pile Foundations in the Permafrost Zone

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Abstract. The subject of the study is the development of rational types of foundations in the permafrost zone. The use of a combined method of arrangement of pile foundations, which provides for a combination of drilling and bored methods and seasonal cooling devices (SOU), is proposed. The greatest efficiency of using combined piles can be obtained when designing shallow foundations that are most susceptible to the effects of tangential forces of frost heaving and when calculating which not only the bearing capacity of the piles, but also the resistance to these tangential forces is taken into account. The Frost 3D software package performed mathematical modeling of the dynamics of the temperature field of the soil mass. The use of combined piles as building foundations will allow to achieve a significant economic effect: increase the bearing capacity of foundations, reduce its cost, reduce construction time, save materials and improve the quality of construction (the upper part of the combined piles is manufactured in the factory, undergoes thorough acceptance control, respectively, in the active the layer where the reinforced concrete structures are most susceptible to destruction, a high-quality cancer-free material is installed wines and cracks that can not be guaranteed when the process device bored pile foundations).

1. Introduction

The territory of the Republic of Sakha (Yakutia) is located in the zone of continuous distribution of permafrost soils, whose thickness reaches 600 m [1]. In the Yakutsk region, these indicators reach 250–350 m, the average annual temperature of soils varies from –0.5 to –2.7 ° C for sandy loam and from –1 to –4 ° C for loam [2].

It should be noted that the whole north of Yakutia is forced to live on seasonal provision of goods, in the summer during short northern navigation, construction materials can be transferred by water and in winter by road along the winter road, which opens by the end of December and closes in mid-April [3]. Severe natural and climatic conditions, the continuous spread of permafrost soils and a complex transportation scheme for the delivery of materials determine the search and development of rational types of foundations.

2. Theoretical part

According to table 6.2 SP 25.13330.2012 “Foundations and foundations on permafrost soils. Updated edition of SNiP 2.02.04-88 »reinforced concrete structures located in a seasonally thawing soil layer and subjected to alternate freezing and thawing in a water-saturated state with a design temperature of outside air below -40 ° C must have a concrete class of compressive strength not lower than B35 , frost

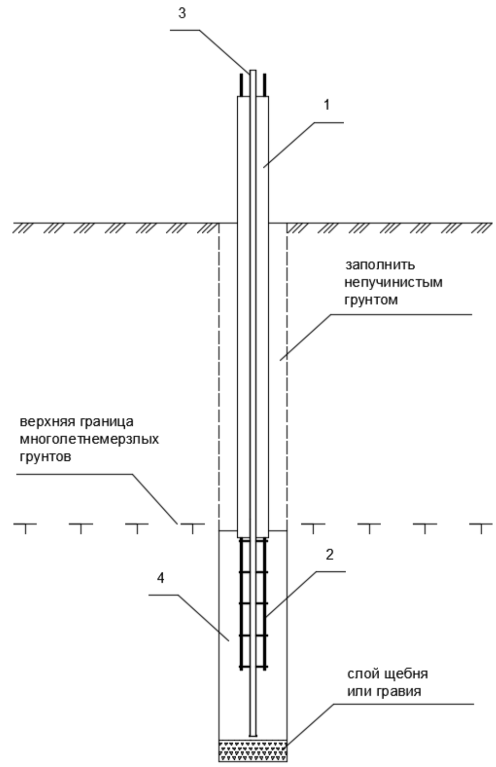
resistance not lower than F400 and water resistance W10 [4]. Therefore, for drilling and bored piles, which are used as foundations for stone buildings and structures, expensive concrete with the required characteristics for the entire length of the pile is used, although according to the set of rules these characteristics are necessary only for the seasonally thawing layer.
Also, according to the mandatory application P SP 25.13330.2012, it is necessary to determine the temperature coefficient γt by the formula

$$\gamma_t = 1{,}15(1 + \nu^2) - 1{,}61\nu\sqrt{\ln\frac{\tau}{\nu}},$$

which is influenced by the duration of the building's operation τ and the coefficient of variation ν, which depends on the depth of the foundations and the temperature of the soil of the base. With high-temperature soils and a shallow depth of foundation, this coefficient tends to zero and even takes a negative value, which leads to an increase in the length of piles and an increase in the cost of construction. It should be noted that in the old SNiP 2.02.04-88 * "Foundations and foundations on permafrost soils" this coefficient was increasing and equal to 1.1 [5].

3. Practical significance

Based on the foregoing, it is proposed to use a combined method of arrangement of pile foundations, providing for a combination of drilling and bored methods and seasonal cooling devices. In the active layer, where the greatest damage to the foundation structures occurs due to alternate thawing and freezing of soils, prefabricated (100% quality control before immersion) prefabricated reinforced concrete piles with an embedded metal pipe with a plugged bottom part, the length of which should reach the bottom of the drilled well, are installed. Figure 1 shows a diagram of a combined pile. The device consists of a prefabricated reinforced concrete pile 1 with reinforcing outlets 2, which are necessary for reliable fastening with the lower monolithic part of the pile 4. A metal pipe 3 integrated in the prefabricated reinforced concrete pile 1 is necessary for installing a heating element to create normal conditions of concrete hardening in the lower monolithic part of the pile 4 and, after the concrete has set, for the injection of refrigerant in order to restore the temperature regime and cool the soil mass around the pile.



Fugure 1. Combined pile pattern

Before installing the prefabricated part of the reinforced concrete pile 1, a layer of crushed stone or gravel is laid on the bottom of the pre-drilled well to prevent the concrete from the monolithic part of the pile 4 from contacting the permafrost soil under the lower end of the pile. Next, with the help of a crane, a precast reinforced concrete pile 1 is installed in the design position, fixed on the conductors and the lower part of the pile 4 is concreted in the layer of permafrost soils, the wellbore in the active layer is filled with non-porous soil. After that, the heating element 5 is immersed in the metal pipe 3 and connected to a current source, while at the boundary between the assembly and the monolithic part of the pile, a heat-insulating plug 6 is installed to create a thermal circuit in the lower monolithic part of the pile (Fig. 2). After the concrete has set, the heating element 5 and the heat-insulating plug 6 are removed from the metal pipe 3, a plug with a nipple 7 is welded in the upper part of the metal pipe 3, and refrigerant is pumped through the pipe, as a result of which the pile will be a "cold pile" with a vapor-liquid cooling device, which will lead to more intensive cooling of the adjacent soil mass, a reduction in the technological break for restoring the calculated values of the temperature of the soil of the base, and a reduction in the construction time In the course of development, as well as a subsequent decrease in the temperature of these soils and a significant increase in its bearing capacity (Fig. 3).

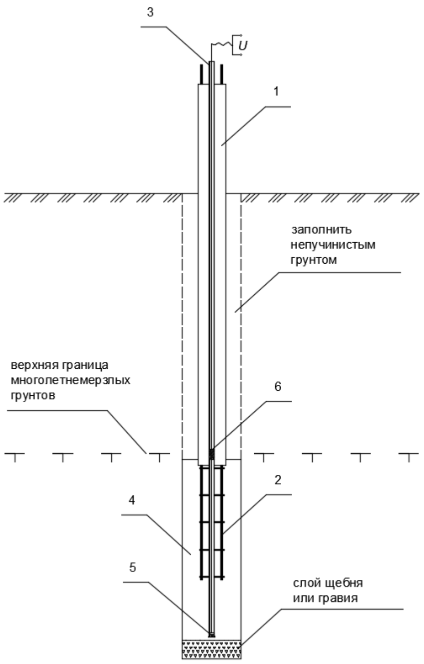


Figure 2. Heating element.

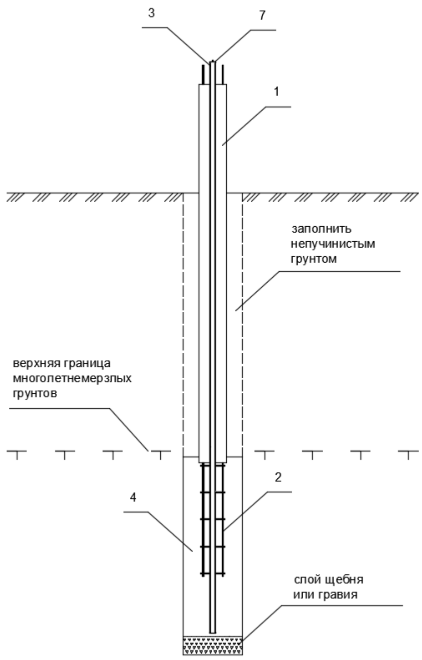


Figure 3. Combined pile with a vapor-liquid Seasonal-cooling device.

The Bearing capacity of such piles is defined as the sum of the bearing capabilities due to the freezing forces along the side surface of the pile and at the end. An increase in the bearing capacity of piles in comparison with traditional drill-driving piles is achieved by increasing the lateral freezing area and the end area in the lower monolithic part of the pile, as well as lowering the temperature and significantly increasing the bearing capacity of the base soils as a result of the operation of the vapor-liquid cooling device. The greatest efficiency of using combined piles can be obtained when designing shallow foundations that are most susceptible to the effects of tangential forces of frost heaving and when calculating which not only the bearing capacity of the piles, but also the resistance to these tangential forces is taken into account. In most cases, due to the fact that the pile does not withstand the impact of these tangential forces, the length of the pile is increased, which leads to a significant increase in the cost of the construction of foundations. The lower monolithic part gives the combined pile the shape of an inverted bolt and thereby reliably fixes the pile in a layer of permafrost soils and significantly increases resistance to the tangential forces of frost heaving.

According to the data of a group of authors, lowering the temperature at the base of objects with hanging piles to design values that provide sufficient bearing capacity of foundations can only be obtained by forced cooling methods [6]. The work of H.R. Khakimov [7], S. I. Gapeev [8, 9], V.I. Makarov [10-14], S.S. Vyalov [15, 16], N.G. Trupak [17, 18], G.F. Biyanov [19], E.A. Bondarev [20, 21], F.S. Popov [22], S.P. Shkulev [23], G.A. Raspopin [24], B.V. Bakholdin [25], Filippovsky S.M. [26], Zhang R.V. [27], Kuzmin G.P. [28] et al.

Mathematical modeling of the dynamics of the temperature field of the soil mass adjacent to the combined piles was performed using the Frost 3D software package, which allows one to obtain scientifically based forecasts of the thermal regimes of permafrost soils under the thermal influence of pipelines, production wells, hydraulic and other structures taking into account soil thermal stabilization.

The calculations were performed with the initial data, including information on the material composition of the soil mass, on the thermophysical characteristics of each layer, thermometry data, and parameters of the cooling columns. The missing data were obtained from published reference and scientific literature.

In the table. 1 shows the average monthly values of air temperature, wind speed; and in the table. 2 - field data of temperature changes along the depth of the soil mass.

Table 1. Monthly average air temperature, wind speed.

Options	**January**	**February**	**March**	**April**	**May**	**June**
T_a, **°C**	-42.6	-35.9	-22.2	-7.2	5.8	15.4
υ_a, **m/sec**	1.4	1.5	2.0	2.8	3.4	3.3
Options	**Jule**	**August**	**September**	**October**	**November**	**December**
T_a, **°C**	18.7	14.9	6.2	-8.0	-28.3	-39.5
υ_a, **m/sec**	3.0	2.8	2.6	2.5	2.0	1.3

Table 2. Field temperature data for the depth of the soil mass in mid-September.

z, m	0	1	2	3	4	5	6	7	8	9
T, °C	4,18	3,15	1,67	0,62	0,14	-0.05	-0.32	-0.62	-0.83	-0.99

Table 3. Thermophysical properties of soils.

Name of indicator	Index	Measure	I	II	III	IV
			Fine sand	Fine sand	Sand medium size	Fine, slightly saline sand
Numbers of the EGE			1	2	3	4
Total weighted soil moisture	*Wtot*		0.19	0.26	0.25	0.31
Dry soil density	*Pf*	kg/m ^{3}	1500	1500	1580	1360
Volumetric heat capacity of thawed soil	C_{th}	$\frac{MJ}{m^3 K}$	2,33	2,78	2,86	2,66
Volumetric heat capacity of frozen soil	C_f	$\frac{MJ}{m^3 K}$	1,76	1,98	2,04	1,94
Freezing temperature	T_{bf}	^oC	-0.25	-0.2	-0.2	-0.3

As an experiment, we simulated the operation of a seasonal cooling device in the form of a vertical thermal stabilizer built into a combined pile for a period of time from September 20, 2019 to April 4, 2021, i.e. the total duration of the experiment is 3 years. The time step of calculations is 30 days. The Frost 3d program automatically turns on and off the thermostabilizer depending on the temperature of the outdoor air and the soil mass adjacent to the thermostabilizers. In the course of the experiment, bushes of two thermostabilizers built into combined piles were considered. In the created computer model, four geotechnical elements are distinguished, the characteristics of which are given in Table 3. The upper parts of the combined piles installed in the active layer are reinforced concrete with a cross section of 30 x 30 cm and a length of 3 m, the lower parts are reinforced concrete with a diameter of 65 cm and a length of 5, 5 m. It should be noted that the upper part of the pile, towering 1.2 m long above the surface of the earth, is included in the boundary conditions of the condenser part of the thermostabilizer. The distance between the piles is 1300 mm, the laying depth is 8.5 m. The calculated values of the temperatures of the surrounding soil massif are given below. Figure 4 shows that before the work on cooling the soils, the talik zone was at a depth of 6 m and the temperature of the soils at a depth of zero annual amplitudes was -0.9 ° C.

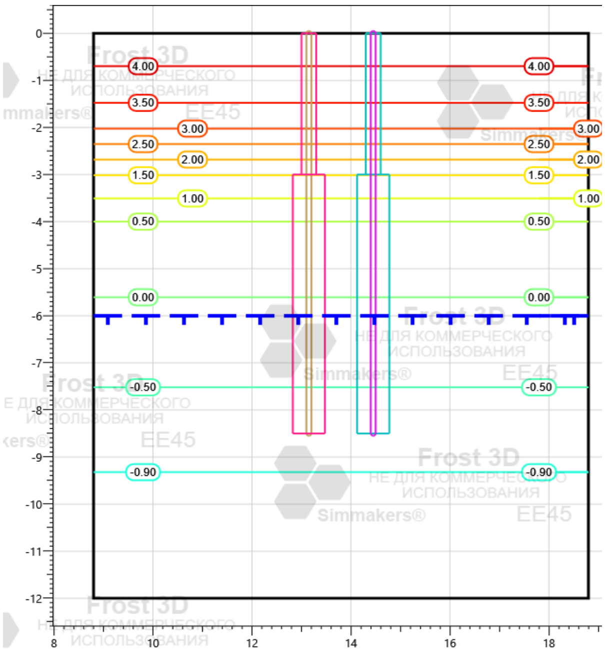


Figure 4. Temperature distribution on 20.09.2019 0:00:00.

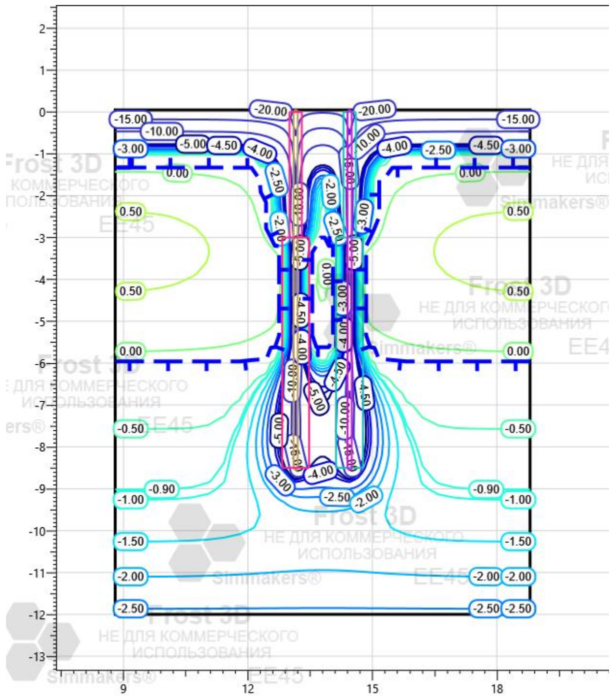


Figure 5. Temperature distribution on 19.11.2019 0:00:00.

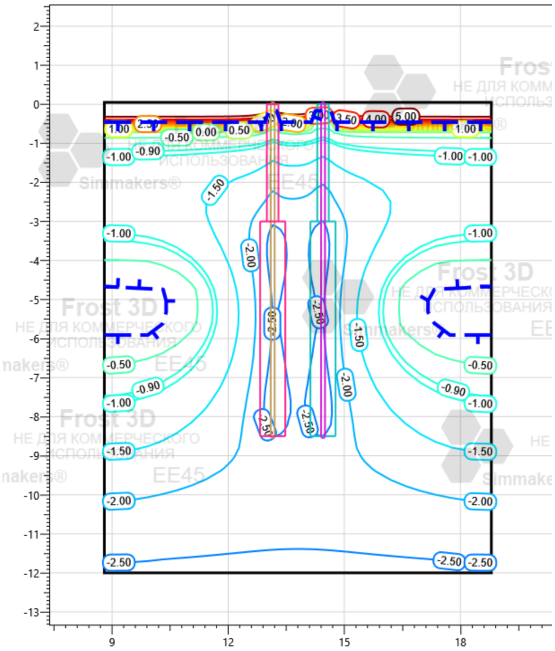


Figure 6. Temperature distribution on 16.06.2020 0:00:00.

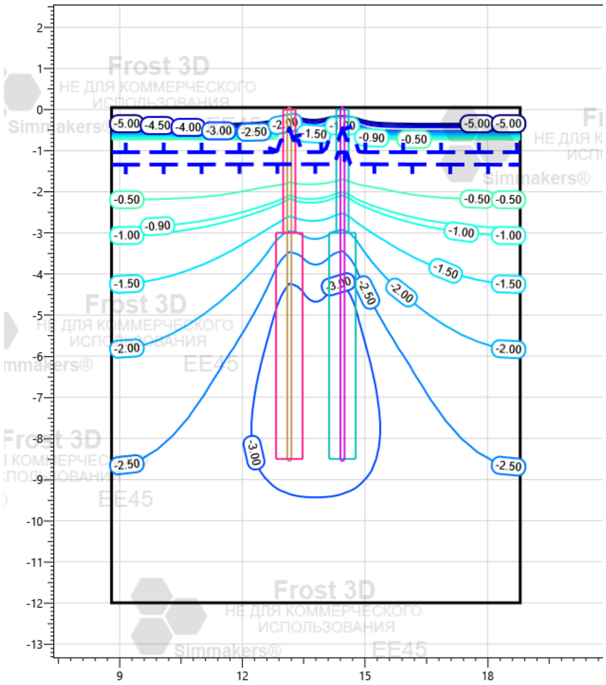


Figure 7. Temperature distribution on 08.11.2021 0:00:00.

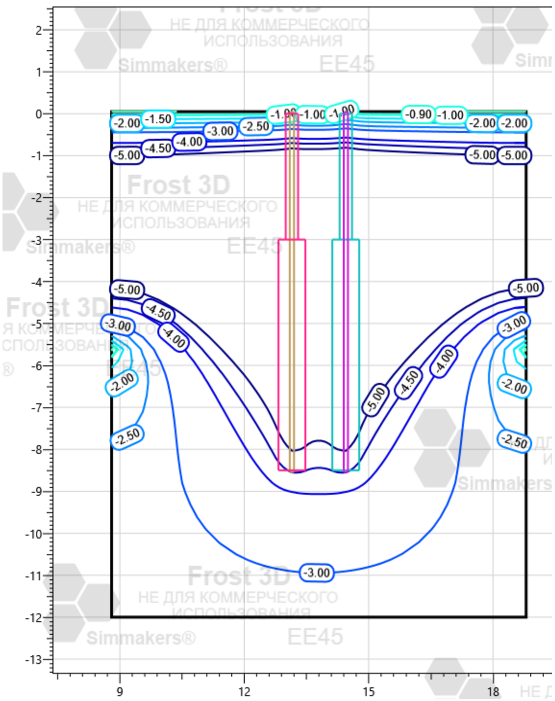


Figure 8. Temperature distribution on 12.05.2021 0:00:00.

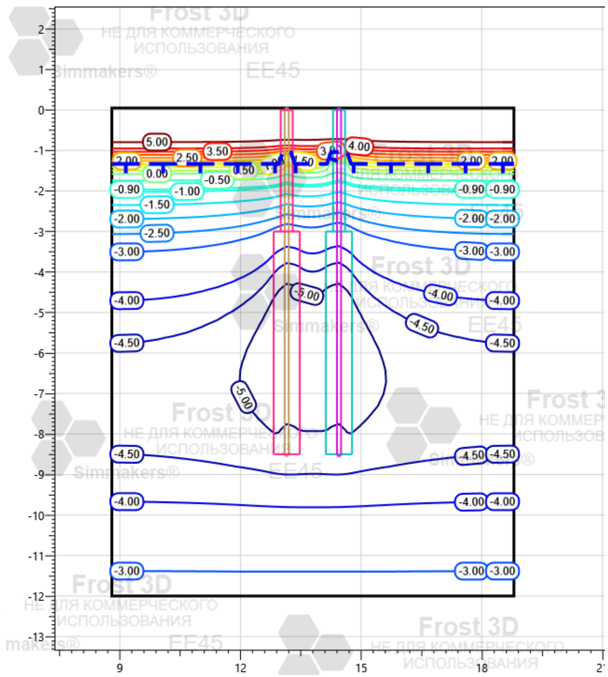


Figure 9. Temperature distribution on 04.09.2022 0:00:00.

With the onset of stable negative outside temperatures, thermostabilizers are included in the operation, which is subject to Figure 5, where it is shown that the freezing front goes from top to bottom as a result of exposure to ambient air and from heat stabilizers. Moreover, in the middle part of thermostabilizers, the freezing front moves more slowly than at the end due to the presence of the talik zone. The power of the talik zone decreases with each month of operation of thermostabilizers and by the end of the second year of cooling, the talik zone disappears (Fig. 9). Due to the thermal inertia of the soil, the phase transition front advances even after the thermal stabilizers stop (Fig. 7). In summer, an adjacent soil mass thaws as a result of exposure to a positive ambient temperature. The temperature at a depth of zero annual amplitudes is in mid-November for the first year of operation of the thermal stabilizer - 1.8 ° C, the second year - 2.2 ° C and the third year - 3.8 ° C. The figures show that the rate of temperature change for the frozen zone is greater than for melt. The nature of the temperature changes in the upper layers of the soil is greatly influenced by heat transfer with the surrounding atmospheric air. It is clearly seen in all the figures that the temperature distribution over the depth is nonmonotonic, which is explained by the thermal inertia of the cooled soil and the nature of the change in the temperature of the atmospheric air. It is also necessary to keep in mind that when the soil mass is cooled by bushes of thermal stabilizers, there is a large accumulation of cold in the soil mass and, accordingly, these soils are less susceptible to the positive outside temperature in the warm season.

4. Conclusion
The use of combined piles as building foundations will allow to achieve a significant economic effect: increasing the bearing capacity of foundations, reducing its cost, reducing construction time, saving materials and improving the quality of construction (the upper part of the combined pile is manufactured in the factory, undergoes thorough acceptance control, respectively, in the active the layer where the reinforced concrete structures are most susceptible to destruction, a high-quality cancer-free material is installed wines and cracks that can not be guaranteed when the process device bored pile foundations).

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