Calculation Substantiation of the Optimal Anchoring Length of the Working Reinforcement of Precast-Monolithic Piles in the Cryolithozone

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Abstract. The subject of research is the development of rational types of foundations in permafrost. This article is proposed use of prefabricated monolithic piles, providing for a combination of drilling and bored methods of pile foundations. The computational substantiation of the anchoring length of the working reinforcement of precast-monolithic piles under the influence of tangential forces of frost heaving has been carried out. Mathematical modeling of the joint between the prefabricated part of the pile and the monolithic part was carried out in the Ansys software.

1. Introduction
The harsh climatic conditions of the Republic of Sakha (Yakutia), including the continuous distribution of permafrost soils, as well as the seasonality and complex transport scheme for the delivery of building materials, require the development of rational types of foundations. According to the group of authors, the thickness of the permafrost in the region of Yakutsk averages 250 - 350 m, the average annual temperature of the soil varies from - 0.5 to - 2.7 ° C for sandy loam and from - 1 to - 4 ° C for loam [1].

2. Relevance
The use of permafrost soils as bases according to principle I, that is, with the preservation of the frozen state of the base soils during construction and the entire period of operation, pile foundations, arranged mainly by the drilling and bored method, are most widely used [2]. However, the above-mentioned pile foundations have a number of significant disadvantages: for drilling piles - the high cost of the pile, a large amount of drilling work, the possibility of pile bulging in heaving soils, etc.; for bored piles - a large volume of drilling operations, increased material consumption, lack of reliable methods for quality control of the pile shaft, especially in the active layer, where water-ice phase transitions occur, the need for electric heating of the upper part of the pile during work in winter, etc.

Based on the foregoing, the authors have developed a combined method for constructing pile foundations in permafrost soils [3, 4]. The authors note that the most rational type of foundations for low-rise construction are precast-monolithic piles, which provide for a combination of drilling and bored methods for constructing pile foundations [5].
The precast monolithic pile consists of two parts (Fig. 1). The upper part is made of a pre-fabricated reinforced concrete structure with reinforcing outlets, the lower part is monolithic, arranged in a layer of permafrost. In the active layer of the pre-drilled well, the upper prefabricated reinforced concrete part of pile 1 is installed with reinforcement outlets for reliable fastening to the lower monolithic part of the pile 2. Inventory clamps (conductors) are used to secure the pile 1 in the design position. The lower part of pile 2 in a layer of permafrost is poured with concrete, the strength class of which is taken according to calculations. The wellbore in the active layer is filled with non-porous soil.

![Figure 1. Precast monolithic pile: 1 - prefabricated part with reinforcement outlets; 2 - monolithic part.](image1)

![Figure 2. Design diagram of the pile.](image2)

Given the complex transport scheme for delivering materials to remote areas of the Republic of Sakha (Yakutia), where the cost of transporting each kilogram of building material ultimately significantly affects the cost of erecting buildings and structures, it becomes necessary to calculate the optimal anchoring length for working reinforcement of precast-monolithic piles.

### 3. Theoretical part

The length of anchoring should be calculated under the most unfavorable operating conditions of the pile, that is, under the influence of tangential forces of frost heaving. The design diagram of the pile is shown in Figure 2, where: \( \tau_{fh} \) is the calculated specific tangential force of frost heaving, kPa; \( d_{th} \) - standard depth of seasonal thawing, m; \( b \) - width of the precast part of the pile, m; \( R_{sh} \) - design shear resistance of frozen unpopulated soils, kPa; \( D \) is the diameter of the monolithic part of the pile, m; \( x \) is the length of the lower monolithic part of the pile at which the frost heaving forces are equivalent to the calculated values of the force holding the foundation from buckling, m.

The basic anchorage length of the reinforcement is determined by the formula [6]:

\[
l_{0,an} = \frac{R_{sh}A_s}{R_{bond}u_s}
\]  \( \text{(1)} \)
where $A_s$ and $u_s$ are the cross-sectional area of the anchored reinforcement bar and the perimeter of its section; $R_{bond}$ is the design adhesion resistance of reinforcement to concrete, taken uniformly distributed along the length of the anchorage and determined by the formula:

$$R_{bond} = \eta_1 \cdot \eta_2 \cdot R_{bt}$$

(2)

here $R_{bt}$ is the design resistance of concrete to axial tension, $\eta_1$ is a coefficient that takes into account the effect of the type of reinforcement surface, $\eta_2$ is a coefficient that takes into account the effect of the size of the reinforcement diameter.

According to the set of rules of SP 25.13330.2012, the stability of foundations to the action of tangential forces of frost heaving of soils should be checked the condition [7]:

$$\tau_{fh}A_{fh} - F \leq \frac{\gamma_c}{\gamma_n}F_r$$

(3)

where $\tau_{fh}$ is the calculated specific tangential force of frost heaving; $A_{inf}$ is the area of the lateral surface of freezing of the foundation within the estimated depth of seasonal thawing of the soil; $F$ is the calculated value of the force holding the foundation from buckling; $\gamma_c$ - coefficient of working conditions; $\gamma_n$ is the coefficient of reliability for the purpose of the structure; $F_r$ is the calculated value of the force that keeps the foundation from buckling.

The length of the anchorage of the working reinforcement must be taken not less than the base length of the anchorage of the reinforcement, calculated by formula (1) and the length of the lower monolithic part of the pile $x$ (Fig. 2), at which the frost heaving forces are equivalent to the calculated values of the force holding the foundation from bulging $\tau_{fh}A_{fh} - F = \frac{\gamma_c}{\gamma_n}F_r$.

4. Practical significance

The substantiation of the estimated length of anchoring of working reinforcement is considered on the example of pile foundations for an individual residential building in Yakutsk. The working reinforcement of the prefabricated part of the pile is adopted in accordance with RM 2-77 and consists of four reinforcement with a diameter of 20 mm, class A400, transverse reinforcement with a diameter of 8 mm, class A240 with a step of 100 mm at a distance of 2.6 m from the upper end of the pile, below - 200 mm [8]. According to laboratory studies, the soils are represented by sands of medium size. The standard depth of seasonal thawing is 2.9 m, the specific tangential force of frost heaving is $\tau_{fh} = 90$ kPa, the calculated resistance of frozen soils to shear along the ground $R_{sh}$ depending on their temperature is from 252 kPa to 265 kPa. According to the calculations performed, the length of the lower monolithic part of the pile $x$ (Fig. 2), at which the frost heaving forces are equivalent to the calculated values of the force holding the foundation from bulging $\tau_{fh}A_{fh} - F = \frac{\gamma_c}{\gamma_n}F_r$.

Considering that the depth of foundation is determined depending on the loads transmitted on the pile from the overlying structures, for high-rise buildings with heavy loads on the pile, the savings in reinforcement will be significant, since in the lower monolithic part of the pile, reinforcement is needed only for anchoring.

The numerical implementation of the model of the joint between the precast part of the pile and the monolithic one is performed in the Ansys software package. Due to the symmetry of the problem, 1/4 of the pile is considered. Since the longitudinal reinforcement is mainly used for tensile loads, the transverse reinforcement was not taken into account in the calculations. The concrete behavior was described by the Menetrey-William model [9] with the specified characteristics for B25 concrete. The BISO model (Bilinear Isotropic Hardening) with the specified characteristics of the A400 class reinforcement was used for the reinforcement. The model consisted of two types of finite elements: a twenty-node finite element SOLID186 for concrete and a linear finite element of the REINF264 type for reinforcement [10]. The nonlinear calculation was performed by the asymmetric Newton-Raphson method, since dilatation is taken into account in concrete.
Figures 3 and 4 show the equivalent stresses and relative deformations at the junction of the precast part of the pile with the monolithic one and in the zone of reinforcement-concrete contact. Pile failure is determined by the divergence of the global Newton-Raphson solution. In our case, with the specific tangential frost heaving forces $\tau_{fh} = 90$ kPa, the von Mises maximum equivalent stresses at the pile junction and in the reinforcement-concrete contact zone absolutely converge and equal 7.92 MPa, the maximum relative deformations are 0.1 mm, which proves the strength constructions.

5. Conclusion
The use of precast-monolithic piles as foundations of buildings will make it possible to achieve a significant economic effect: an increase in the bearing capacity of foundations by increasing the area of lateral freezing and the area of the end in the lower monolithic part of the pile, a significant increase in resistance to the effects of tangential forces of frost heaving (the lower monolithic part gives the precast-monolithic pile in the shape of an inverted bolt and thereby reliably fixes the pile in a layer of permafrost soils), reducing the cost due to saving material and technical resources, improving the quality of construction (the upper part of the precast-monolithic pile is manufactured in the factory,
undergoes a thorough acceptance control, respectively in the active layer, where reinforced concrete structures are most susceptible to destruction, high-quality material is installed without cavities and cracks, which cannot be guaranteed with the bored method of constructing pile foundations).

6. References

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