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Investigation of Contact Layer «Foundation Grill – Ground Base» Soil Structure Damage and Its Regeneration by Crimping

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Abstract. The paper discusses the numerical modelling results of contact layer «foundation grill – ground base» soil structure damage effect by frost penetration - ground thawing processes. Another part of investigations focuses on contact layer regeneration by crimping for building mechanical safety ensure during the construction and in operation process. Contact layer regeneration is made of cement mortar by injection technology. This method is applicable for construction of combined foundations and deep-grid pile foundations. The paper presents the results of additional ground base deformations and soil structure damage value dependences. The investigations help to establish the crimping organizational and technological parameters, which could include grill-plate in joint work with the ground base more efficiently. Attained results was patented and used in 22-storied buildings construction process in Tyumen, Russia. The geotechnical monitoring confirms the validity of the research.

1. Introduction

It is known that water-saturated clay soils are highly trainable by freezing. In the process of freezing and then thawing, the soil strength significantly reduces, its compressibility increases, which affects the geotechnical structures deformation and the operational reliability of buildings and constructions [1-20]. Settlements take place by thawing of the frozen soil that has significant values [7]. Typical heaving soils by freezing are lake-glacial formation (sandy loam, loam, clay), fine and dusty sands, post-glacial marine sediments and loamy varieties of water-saturated moraine sediments [2].

The foundations settlement can be divided into components [8], given in the equation (1):

\[ S = S_{\text{comp}} + S_{\text{decomp}} + S_{\text{SU}} + S_{\text{SSD}} + S_{\text{expl}} \] (1)

where: \( S_{\text{comp}} \) – is settlement as a result of compaction of soils with undisturbed structure by stress increasing resulted from the external load; \( S_{\text{decomp}} \) – is settlement connected with the decompression of the upper layers of the soil, lying below the foundation pit bottom, due to the reduction of stresses by the soil excavation; \( S_{\text{SU}} \) - is settlement as a result of soil uplift from under the foundation pit by the plastic deformation increase; \( S_{\text{SSD}} \) – is settlement of soil structure damage; \( S_{\text{expl}} \) – is settlement because of ground base stress-strain state changes by the exploitation.
2. Soil structure damage of the ground base

The first three components of settlements \( S_{\text{comp}}, S_{\text{decomp}}, S_{\text{SSD}} \) the most depend on the ground base pressure, its heterogeneity, depth and type of foundations. They can be defined by numerical and analytical calculations. Settlements, developing in building’s exploitation process \( S_{\text{exp}} \), may depend on the change of the ground-water line position, on the possible soil weakening by underground works, on the dynamic effects and different geodynamic processes (karst, landslides, earthquakes).

Let us consider the fourth term – the settlements of soil structure damage \( S_{\text{SSD}} \). Under the soil structure damage we understand a violation of the natural structure of soils because of external influences, which is characterized by a decrease of physical and mechanical characteristics, changes in the consistency of the soil, increasing compressibility, decreasing resistance to shear. External influences in this case can be considered the following [8, 11]:

- meteorological effects (freezing and thawing, softening and swelling by exposing of precipitation, drying and shrinkage);
- groundwater influence (hydrostatic and hydrodynamic pressure, mechanical and chemical suffusion);
- dynamic influence from construction machines, impacts on the bottom of foundation pit;
- rough violations of technology in the operation works.

It is practically impossible to establish the value \( S_{\text{SSD}} \) by calculation, but at the same time, based on the construction experience; it can be comparable with the value of the maximum settlements of the foundation \( S_f \) and even exceed it. Therefore, we should preserve the natural structure of the soil by operation works by organizational, technological and structural-technological methods.

If soil structure is damaged or the “zero cycle” works are supposed to be done in the winter (intersession) period, we should provide measures to ensure that the foundations are in working conditions. For combined foundations efficiently collaboration of the raft foundation with ground can be achieved by crimping the contact layer of cement mortar (RF patent 2572477) [9].

3. Problem statement

Let us consider the option of a combined foundation for a detached building in winter. Suppose that the excavation of the foundation pit, piling and preparatory works rough violations were made such as freezing of the foundation (figure 1). While constructing the foundation the ground base was frozen, and the processes of heaving were implemented. Recent researches show that thanks to the cementing action of ice in the pores, the mechanical properties of frozen soils are ten times higher than the properties of non-frozen or thawed soils. Thus, we should talk about the minimum foundation settlements at low temperatures before thawing of the ground base.

Pchelintseva A. M., Orlov V. O., etc. established the position that deformations by thawing, as a rule, corresponds to the deformations of frost heaving [3, 8]. On this basis we will calculate the value of the relative deformation of the heave \( \varepsilon_f \), equal to the deformation of the thawing \( \varepsilon_{th} \) or settlements by thawing \( S_{th} \) (\( S_{th} \) – the settlement of the ground base condition by the action of its own weight of the thawing soil), that is, we obtain equality \( \varepsilon_f = \varepsilon_{th} = S_{th} \).

Numerical modeling of organizational and technological measures to restore the contact layer "foundation grill-ground base " by its pressing is fulfilled to identify patterns of their impact on the effectiveness of the inclusion of grill-plate foundation in the joint work with the ground base, as well as their impact on the deformation of the foundation and the operational qualities of the building constructions.

The Hardening Soil model [21-23] describes the soil base with the following characteristics::

\[ E_{S_0}^{\text{ref}} = 18000 \text{kN/m}^2; \quad E_{\text{red}}^{\text{ref}} = 18000 \text{kN/m}^2; \quad E_{\text{ur}}^{\text{ref}} = 51000 \text{kN/m}^2. \]

Reinforced concrete grillage plate with a width of 31 m and a thickness of 1.0 m unites piles with a length of 10m with a step of 6m (junctions are rigid). The design scenario included the main stages of the foundation and the
construction of the building frame. Uniformly distributed loads are applied to the floor slabs, the total pressure on the base is \( p = 200 \, \text{kPa} \).

Let us consider the problem of construction of the foundation, basement, first floors of the building, performed in the winter on a frost-free low-compressible ground base. When the grill is being built, the injectors are being installed. They are necessary for the subsequent pressing of the contact layer, which is carried out after thawing of the base, accompanied by subsidence processes and a decrease in strength and deformation characteristics. The stability of the foundation by thawing of soils is provided by piles (figure 1).

A series of numerical modellings with variation of the deformation modulus and width of the structural contact layer \( H_i \) was carried out to identify the regularities of the influence of the reduction of deformation characteristics in the contact layer on the final building settlements. The decreasing of soil deformability in the contact layer is considered in the range from 15% to 95% of the initial characteristics (\( E_{50}^{\text{ref}} = 18000 \, \text{kN/m}^2 \)).

The average settlement of the foundation on a homogeneous ground base without reducing the characteristics is \( s = 140 \, \text{mm} \) (figure 2). It is identified that the decrease in deformation characteristics by 15÷40% in the contact layer of different width causes the foundation settlements increase to 25% (180 mm). With a further decrease in the deformation modulus by 45÷95%, the settlements increase sharply to 40% \( (s = 217 \, \text{mm}) \) at \( H_i = 500 \, \text{mm} \), and to 150% at \( H_i = 2000 \, \text{mm} \). It should be assumed that foundation settlement will increase with the load perceived by the slab of foundation, that is, with decreasing the combined pile-slab foundation coefficient \( \alpha_{\text{CPSF}} \) [24-31].

Considering the problem mentioned above, using a method of restoring the contact layer by crimping it. To determine the influence of organizational and technological parameters of the pressure testing on the final foundation settlement, a series of numerical experiments with varying the soil deformation characteristics in the contact layer was carried out. The value of the pressure of crimping testing was taken in the range of 25÷100 kPa, step of 25 kPa. The pressure testing is assigned after the foundation erection when transferred to the ground base no more than 40-60 kPa \((0.2p - 0.3 \, p)\). The graphs of the obtained dependences are shown in figure 3.
4. The theoretical significance

In all these cases, the organization of crimping (restoration) the contact layer allows to include the foundation grill in collaboration with ground base, providing the deformation of the foundation within the framework of normative values.

Let consider, for example, the graph shown in figure 3b, with the thickness of the soil structure damaged layer $H_2=1000$ mm. So, with a $E_{50}^{ref}$ decrease of 15-70% the recognized settlements should be achieved by using a minimum pressure of crimping $p_{cr}=25$ kPa (0.125p), and, for example, with a decrease of $E_{50}^{ref}>70\%$ using $p_{cr}=100$ kPa (0.5p). With increase of thickness soil structure damaged layer ($H_i=500÷2000$ mm) while reducing $E_{50}^{ref}$ for more than 70%, settlements decrease should be achieved by increasing the pressure $p_{cr}≥100$ kPa.

On the basis of the revealed regularities it was found that when reducing the deformation characteristics by 50–60% in the contact layer with a width up to 1.0–1.5 m, recognized foundation settlements should be achieved by the pressure $p_{cr}=0.125p÷0.5p$, organized at the early stages of construction ($≤0.2 p÷0.3 p$), where $p$ is pressure on the ground base. It should be noted that after thawing of the base foundation, soil structure damaged soils under the influence of load and its own weight are gradually compacted, that leads to their deformation characteristics increasing.

5. Practical significance

These recommendations were tested during the construction of 22-storey monolithic frame buildings in Tyumen city and proved the correctness of theoretical calculations. The necessity to implement the measures was due to the violation of the natural soils structure in the contact layer.
because to the movement of construction machines, the impact of groundwater and freezing of the ground base.

Current creation of measures to restore the contact layer "foundation grill-ground base" allowed to maintain the stability of the combined foundations (CF), erected in the winter on soils heaving in freezing and subsidence during thawing without stopping the building process. The measures included the injection of cement mortar through injection pipes into the cavities formed under the band grillages and into the cavities of the preparation from the rubble, performed after thawing of the soil, accompanied by subsidence processes.

During crimping not more than 5-7% of the final load was implied on the foundation (about 15-20kPa). Buildings at the time of the work had no more than 2...3 floors of the frame, the backfilling of the pit hollows was performed. At the initial stages stability of CF was provided by piles.

Crimping work was performed using a screw mortar pump Putzmeister S5 EV with the possibility of supplying ready-mix under the pressure of 2.5MPa and a capacity of up to 40 l/min. Pressure line for control equipped with pressure gauges. During the works, the discharge pressure of the solution is taken in the range of 20÷30 kPa, which allows the cement spreading in the voids and cavities. As a mortar, a fairly thick mixture of water and cement with W/C=0,6 and the addition of an aqueous mortar of sodium silicate ((Na₂O(SiO₂)n) in the amount of 2% by weight of the mortar was used.

By regenerating contact layer "foundation grill-ground base" should be applied to the organizational and technological schemes of execution of works, presented in figure 4. The injectors are arranged in increments of 2-3m, with the radius of the projection zone is 1-1,5m.

![Figure 4](image)

In the absence of groundwater (figure 4A), the first step is to fill the voids along the perimeter of the foundation grill (I step). Then filling of cavities under the central part of the grillage (II step) with movement from edges to the center is carried out. Created along the perimeter of the impermeable "veil" serves as an obstacle to the spread of the grout injected in the second step. This allows increasing the crimping pressure effect and the quality of performed work.

In the presence of groundwater in the level of the foundation, work should be organized according to the second scheme (figure 4B). The regeneration of the contact layer is performed with movement from the center to the edges, which allows to "squeeze" the water outside the building spot. After central part pressing (figure 4B, 1), parallel pressing of adjacent parts is performed (figure 4B, 2-4).

6. Summary
The marked method can effectively eliminate the effects of subsidence heaving soils by their thawing, and also can eliminate the effects of soil structure damage caused by meteorological influences, effects of groundwater dynamic influence of mechanisms and builder's errors in the process of ground excavation, which in its turn ensures the full inclusion of the foundation grill in the works with ground base.

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