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Application Experience of Bored Micropiles in the Conditions of Permafrost Soil

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Abstract. Results of pilot studies executed when strengthening foundation and tape bases of architecture monument – the building of National library of the Republic of Sakha (Yakutia) in Yakutsk are given. The article presents data on the kinetics of hardening of cement mortar with a complex additive NN+S-3 at low temperatures of permafrost soils. It is shown that the rate of hardening and strength of the solution greatly depend on the dosage of antifreeze component. A feature of the technology was also to determine the strength of cement mortar, with which possible pressure testing of the well. The strength of the mortar for re-injection should be not less than 10 MPa and not more than 20 MPa. The device technology of bored micropiles in permafrost soil is approved by the contractor – the Yakut branch "Svratka", Czech Republic. The received results indicate an opportunity and efficiency of micropiles application in conditions of permafrost soil.

Introduction

For the first time bored piles have been (BP) offered by the Italian firm "Fondedile" [1, 2]. However, mass application of bored micropiles in Europe has begun in the middle of 80s of the last century [3]. The technology of bases strengthening and constructions bases by bored micropiles widely develop in Germany, England, France, Italy, Sweden, Finland. In present time such piles are widely applied in the USA, Canada, Malaysia, etc.

In Russia these piles were applied since the beginning of 1990s [4-7]. For the first time in Russia high efficiency of strengthening way by bored piles of bases and foundations has been shown at reconstruction of the State Tretyakov Gallery. The basis was amplified by system of bored vertical piles with a diameter of 150 mm and inclined with a diameter of 190-243 mm, the strengthened buildings placed in chessboard order on both sides with a step of 1,0 - 1,5 m. Piles were buried in rather kept limestones, reinforced by a spatial framework of ten types. More than 750 piles were installed in total [4].

The bored piles with a diameter of 150 mm with a length of 19-20 m were established from the floor level of the cellar [5] have been successfully applied to stabilization of foundation draft of the building in Moscow.

The technological line on BP device applied in Russia consists of small-sized SBA-500, SKB-4, SBU-300 ZIV, UGVK-150 drilling rigs, NB-30 grout pumps, NGR 120/40, the mortar mixers turbine type RM-500, RM-750, SO-48, mud cleaner installation CSGU-2, reception capacities and grout splitters [3].

Piles can be reinforced by single reinforcing cores, welded frameworks, rigid fitting in the hire form of ferrous metals or metal pipes. Fittings of piles can be uniform at all length or combined. In uniform soil it is allowed not to reinforce the lower part of trailing piles [8]. For the prevention of deviation of a framework from a well axis clamps are put on it.

Strengthening of bases and foundations of deformed buildings is one of important questions in ensuring recovery of operational characteristics of buildings and constructions and extensions of their service term. It is considered that the most vulnerable in buildings operated in areas of permafrost soil distribution are basis soil which when thawing leads to uneven deformations of a building. It is confirmed with operating experience of stone houses in Yakutsk built till 1914. There were more than 40 stone buildings in Yakutsk by 1917 [9]. All these buildings have been built on rubble tape bases with depth of laying from 1,5 to 2,5 m, i.e. the same bases as in the European part of our country have been applied. Such solution of bases didn't consider feature of properties of permafrost soil. Because of mass deformation of buildings owing to soil thawing of bases from 1914 to 1925 in Yakutsk stone buildings weren't built. Need of ensuring stability of buildings in use for areas of permafrost distribution, has forced builders to look for new constructive decisions. All subsequent solutions of bases have been directed to preservation of permafrost soil border in building use. Now the majority of buildings and constructions are designed on piles with aired underground less often on base plates on soil with a device of system of cooling systems from pipes and channels arranged under a plate.

By the end of the 20th century old stone constructions couldn't save including the first one-storey stone building of voivode office (1702). Since the end of the 90s of the last century a lot of work on preservation and restoration of not numerous historical and cultural monuments began to be carried out. Example, Preobrazhenskaya, Nikolskaya, Bogoroditskaya churches, Trinity Cathedral, two-storey buildings of Hierarchal rooms (nowadays building of Museum of Local Lore), Treasury building (nowadays museum of West-European art), building of vocational school and building of library (nowadays building of National Library of the Republic of Sakha (Yakutia) of A. S. Pushkin).

Various special technologies at restoration and strengthening of foundations, bases, of brick walling, etc. have been developed by JSC YakutPNIIS at restoration of old buildings from which it is possible to distinguish for the first time applied the technology of bored micropiles device in the conditions of permafrost soil distribution.

Experience of ensuring curing of cement concrete in permafrost soil is studied and fulfilled on the example of bored piles with a diameter not less than 500 mm. The specified technology has found broad application in Yakutia where from 1996 more than 50 buildings of civil appointment are built till present. Adaptation feature of the known technology of bored micropiles device to permafrost soil conditions consists of ensuring curing of cement and cement and sand solutions in boring driving of small diameters (less than 200 mm).

For experimental check of technology of bored piles device in natural conditions has been chosen an object: "Restoration of the building of National Library of A.S. Pushkin". The project of strengthening of foundation and bases of restored building executed by GUP YakutPNIIS, bored piles device of small diameter through a body of tape base has provided. Similar piles have been designed for the first time for conditions of permafrost soil. The contract organization – LLC PKF "V. R. Shelts" has concluded the contract for micropiles device with Czech firm "Zakladani group" having experience of similar micropiles device in Czech Republic.

Wells were drilled by small-sized machine on caterpillar course of Czech production of MSV 741/20 brand with torque 120 kHm. Pneumatic blows were created by compressor with a productivity of 10 m/min with the minimum pressure of 1,0 MPa.

Cement mortar was prepared in grout mixer of activation action. Forcing of cement mortar was made by CLIVIO pump (Italy) with maximum pressure of 10 MPa with operated pumping out speed.

Thick-walled pipes Ø70 x 12 mm applied as fittings. The pipe of each micropile consists of three sections with threaded connections: the first – 2 m long has welded spiral Ø fittings of 5 mm, a step of 70 mm; the second – with a smooth surface 3 m long; the third – 3 m long, punched with rubber cuffs through 0,5 m.

Lowering of a pipe to the well was made by means of drilling rig after screw removal. Separate sections of pipe were docked as follows:

- by means of drilling rig with preservation of tilt angle of a bar the first (lower) section fell to previously drilled wells and it was fixed by means of special fascinating device;

- by means of threaded connection the second section joined to the first and it was released to well, and fixed by fascinating device over the well at distance 0,3÷0,5m;
- by described technology the third (last) section joined to the second.

Complexity of bored piles device technology in permafrost soil is connected with the fact that area in which there is a curing of solution (concrete) has negative temperature. Negative temperatures considerably reduce rates of hydration curing of cement and final durability of piles material. The intensification of solutions curing at minimum violation of permafrost mode and salinity of adjacent layers of permafrost soil is necessary for ensuring the required durability of injection solutions. The solution of this problem will allow to use bored piles and in areas of permafrost soil distribution.

Besides ensuring curing of cement mortar at negative temperatures of permafrost soil technology feature consisted of durability determination of cement mortar at which pressure testing of well is possible. Additional injection of well is necessary for ensuring full filling of well with solution after shrinkage of cement mixes in micropile body and full filling of annular space. Preliminary experiences have been established that demanded solution durability on technology for repeated injection has to be not less than 10 MPa and no more than 20 MPa. At higher durability of cement mortar in conditions of permafrost soil the rupture of cement mortar and filling of formed shrinkable cavities doesn't occur.

The additional injection of well was made from below top through a full-hole pipe fitting by means of an injector with a double tampon. Forcing of mix was carried out on micropile height through everyone 0,5m. In the process of injection were controlled the mortar flow and pressure. Injection at each level was considered finished at achievement of pressure of 2 MPa.

Research Technique

The purpose of development of injection solution compositions for the piles device in permafrost soil is definition of a ratio of its components providing the following characteristics:
- workability of grout mix corresponding to the accepted way of bored piles device;
- achievement by solution of required durability at each technological stage.

Taking into account the accepted technology of bored micropiles device, mobility of cement mortar has been appointed equal 12 cm on a cone of StroyTHNIL with a water separation of cement mortar no more than 2%.

Soil of bases is presented within an active layer bulk and clay (loams and sandy loams) by soil, lower are sands dusty to averages. Their distinctive feature in comparison with soil on a vacant part of platform are high ice content and difficult cryogenic structure characteristic of depths 3-8m, with maximum values of total humidity 0,95-1,01humit on marks 4-5m - directly under the bottom of foundation. Streaks, ice nests, ice in the form of crusts are found in the lower part of brick walls and in the destroyed rubble masonry of the top layers of bases. Material ice content of bases is dated for weathered sandstones and layers of limy and sand solution.

Soils are characterized by low values of temperatures, typical for the built-up central part of Yakutsk, from minus 4,3 to minus 5,9^{0}C at a depth of zero annual amplitudes. Temperature of soil is the main factor defining for development of injection solution composition. Cement mortar with the complex component NN ($NaNO_2$, an antifreeze component) + S-3 (the effective concrete plasticiser) is used in this regard for bored piles device. Portland cement of PC 400-D0 brand is used in experiences, released by JSC PO "Yakutcement" (R_3 = 24,7MPa, R_{28} = 39,0MPa).

Mobility of cement mortar was defined in 15 min. after mixing water in accordance with GOST 5802-86. Workability keeping on time, solidification kinetics were studied at negative temperatures.

The samples of 7x7x7 cm in size made from cement mortar compounds with complexes of components after keeping in the conditions of underground camera at a temperature of external environment minus (3,8 … 4,2)^{0}C were tested for compression in given periods. Control samples for establishment of branded durability of injection solution hardened in the camera of normal solidification (t_{av} = 20±4^{0}C, W = 90 ± 5%) conditions to 28-day age.

Temperature condition of underground laboratory provides change of temperature in the period of all term of keeping of samples at the level of minus 4±0,2^{0}C and creates conditions for kinetics observations of cement mortar curing during the long period (to 90 days).

Results of Selection of Cement Mortar Composition

For bored piles device is usually recommend to apply cement mortar with W/C = 0,6 which meets requirements imposed to injection solutions. However rates of curing of cement mortar at W/C = 0,6 on a local Portland cement of PC 400-D0 considerably decrease even at a temperature minus 1°C. At 28-day age durability of samples hardening at a temperature minus1^{o}C makes only 76% of branded. Average temperatures of soil on length of piles (2-10 m) in the conditions of Yakutsk, for example, change ranging from minus 3 to minus 10^{0}C. In such temperature condition of curing composition of above-stated solution won't be able to provide the required durability without intensification of cement mortar curing.

Further experiences have been directed to studying of influence of complex antifreeze additives on kinetics of injection cement mortar curing at a temperature minus 4^{0}C. It is established that introduction to grout mix of S-Z superplasticizer in number of 0,5% of cement mass allows to lower W/C from 0,6 to 0,34 at preservation of the same mobility of mix (OK = 12 cm).

It is also established that at introduction of antifreeze components (HH, HX+HH) in number from 1,5 to 3% of cement mass together with superplasticiser S-3 (0,5% of cement mass) mobility of grout mix in 12 cm, is provided at W/C = 0,30 … 0,34.

At complex research of antifreeze additive NN + S-3 changed quantity of antifreeze component from 1,5 to 3% of cement mass, leaving a dosage of plasticizing S-3 component to constant equals of 0,5% of cement mass. The choice of specified temperature is caused by conditions of experimental ground.

The works which are earlier performed in YakutPNIIS, on studying of influence of maintenance of antifreeze component in concrete mix on migration of salts in soil, it has been defined that at a consumption of sodium nitrite of 3% of cement mass increases salinity of soil slightly, without exceeding the allowed norm [10]. In real researches the optimum dosage of antifreeze component of complex additive NN + S-3 was established by studying of kinetics of cement mortar curing. The received results are presented in Table 1.

Table 1. Kinetics of cement mortars curing at temperature minus 4°C.

Additive quantity [% of cement mass]	Compression capacity[MPa] in age [days] (reciprocally in % of brand durability)			
	7	14	28	90
1,5 %NN+0,5%S-3	7,1 / 19	14,2 / 38	16,6 / 44	18,0 / 48
2,0 %NN+0,5%S-3	14,4 / 34	27,0 / 65	46,5 / 112	56,7 / 136
3,0%NN+0,5%S-3	10,0 / 24	21,0 / 50	41,2 / 102	51,6 / 123

Apparently, from the Table 1, rates of curing and durability of solution considerably depend on a dosage of antifreeze component. So, at introduction of 1,5% of NN rates of curing are insufficient for achievement of required durability, even in 90 - daily age durability of cement mortar has made only 48% of branded. Introduction of 2% and 3% of sodium nitrite has provided at the 28th daily age durability respectively 46,5 and 41,2 MPa that is higher than branded and design durability of solution. At the same time introduction of 2% of NN is more effective on all terms of durability control that is caused by chemical interaction of cement with antifreeze component. Similar results have been received in the works that are earlier performed by us when studying kinetics of concrete curing with complex antifreeze additives at negative temperatures [11]. The increased content of antifreeze additives can bring to increase in porosity of concrete owing to a moisture mass transfer.

Results of Working off Technology of Injection Micropiles Device

Preparation technology of solution on construction site was fulfilled in grout mixer of activation action (480 rpm, volume of 300 l). The general duration of batch preparation made 10-12 min.

Density of grout mix has made 2000 kg/m^3, mobility – 12 cm on a cone of StroyTHNIL, W/C = 0,34.

It is experimentally established that recommended composition of cement mortar at working grout mixer keeps working mobility within 2 hours.

Test of mix № 2 is prepared at the device of the first experimental micropile (ES1), test of mix № 3 – at the device of the second experimental pile (ES2).

The data provided in Table 2 confirm suitability of cement mortar for devices of bored piles. At the 28-days age, the strength of samples keeping in the conditions of underground camera higher than strength of control samples hardened in the camera of normal solidification at 12-15%. Later this have been confirmed by field tests of the experimental piles. Analysis of the kinetics of hardening of cement mortars also shows that the re-grouting of the micropiles should be done on 5-6 day, when the strength of the solution is less than 10 MPa and not more than 20 MPa.

Table 2. Kinetics of cement mortars curing.

№ of sample grout	Samples durability [MPa] in age [days] hardening at minus 4^{0}C				Brand durability [MPa]	Brand of cement mortar
	1	3	7	28		
2	-	5,5	18,3	36,7	31,9	M300
3	3,1	-	23,1	34,4	30,7	M300

The same composition of solution has performed works on injection of rubble masonry of tape base.

On construction site the technology of bored micropiles device is approved and the production schedules on their device in permafrost soil are developed. 15-year operating experience of renovated building of National Library of the Republic of Sakha shows that rainfall of the building was stabilized. It specifies efficiency of bored micropiles application for strengthening of the bases and the tape bases. Projects of bases and foundation strengthening with the help of bored micropiles are also realized on the following objects of Yakutsk: “Reconstruction of a house with “Yunost” shop”, “Reconstruction of a house with “Raduga” shop”, projects of bases and foundation strengthening of buildings of High School № 8 (nowadays High School № 1) on 32, Lenin Avenue, and the Yakut psychoneurologica dispensary in Yakutsk are prepared.

Conclusions

Providing curing of injection cement mortar with complex chemical additive at low temperatures of soil in bored piles (micropiles) of small diameter opens opportunities for introduction of new effective type of pile base as for strengthening of bases and foundation of deformed or reconstructed buildings, and also for new construction at small loads of bases in areas of permafrost soil distribution.

Tests results of skilled bored piles of different length, in various soil conditions and at different temperatures (for example, temperature of soil under end faces of piles differ on 1^{0}C), testifies to reliability of accepted technology of micropiles device in permafrost soil.

Fifteen-year operating experience of National Library building of the Republic of Sakha (Yakutia) in Yakutsk after strengthening of the bases and tape bases, and also experience of application of BP on other objects is pointed out efficiency of bored micropiles application in areas of permafrost soil distribution.

On the basis of performed works the production schedules on bored piles device in permafrost soil are developed.

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