# Ensuring Hardening of Cement Injecting Mortar at the Installation of Grout-injected Micropiles in Permafrost Soils

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**Abstract**. The article deals with the problems of grout-injected (bored) micropiles application in the conditions of permafrost soils. This technology is widely applied in many countries, but the complexity of using the bored micropiles in the conditions of the North lies in ensuring curing of injection mortar when being influenced not only by the negative temperatures of permafrost soil, but also by the negative ambient temperatures. Considering the fact that large-scale development of the Arctic districts of Russia has been initiated, the results of researches in this field are very relevant. For the first time in Yakutsk the technology of the grout-injected micropiles installation has been tested in the amplification of the National library building foundation conducted according to "YakutPNIIS" institute recommendations. The obtained positive results indicate the possibility and effectiveness of their application in the repair of buildings, as well as in the construction of facilities. The article presents the results of the development of injection cement mortars compositions with various additives and the kinetics of their hardening, their approbation in production conditions. The analysis and discussion of the received results confirm that the grout-injected micropiles installation technology in the permafrost conditions can be widely used, promoting an increase in efficiency of new construction and capital repairs of buildings and constructions.

## 1. Introduction

Feature of permafrost soil as foundations of buildings and engineering constructions is the dependence of their properties on temperature. With temperature increase durability of soil of the basis decreases, and deformations increase. Therefore if the sizes of buildings and constructions allow, then usually the basis is used by the principle I – preservation of soil of the basis in a frozen state during construction and operation of a building. Deterioration in soil conditions has demanded development of various geotechnical actions, including use of the pile bases of various designs. As the bases generally since 50s driven cast-in-situ reinforced concrete piles of square section are used. However, a number of new types of bases, including grout-injected micropiles, bored and screw piles used on objects with difficult soil conditions has appeared in recent years.

In this regard grout-injected piles which characteristic is the possibility of their production in any soil conditions, on any construction sites are of the greatest interest. Grout-injected piles unlike bored piles have large flexibility ($l/d$ = 80-120) and small diameter ($d$ = 120-250 mm) [1]. It is boring pile

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with a diameter less than 350 mm arranged by an injection of fine-grained concrete mix or cement mix in a borehole including via cored screw [2]. For the first time grout-injected piles (GIP) have been offered by Italian firm "Fondedile" [3, 4]. However, mass application of grout-injected micropiles in Europe has begun in the middle of 80s of the last century [5].

For the first time in Russia the high efficiency of a way strengthening of foundations and bases by grout-injected piles has been shown (further GIP) at reconstruction of the State Tretyakov gallery [6]. The basis was amplified by the system of grout-injected vertical piles with a diameter of 150 mm and inclined with a diameter of 190-243 mm, placed in chessboard order on both sides of strengthened bases with a step of 1,0 - 1,5 m.

Grout-injected piles with a diameter of 150 mm 19-20 m long have been successfully applied to stabilization of foundation draft of building in Moscow [7]. It is possible to carry out strengthening's of foundations without developing ditches and without breaking natural structure of soil of basis by means of grout-injected piles. The equipment used to GIP installation doesn't create dynamic influences. Besides, such equipment is small-sized and can be also installed both in inhabited or production room, and in its substructure. For this reason in the last 10-15 years grout-injected piles have begun to apply widely in Russia [8 - 16] including in conditions of permafrost soil distribution [17].

The analysis of literature shows that practically all the researches are directed to carry out bearing ability of grout-injected micropiles by testing them in field conditions. It is established that supply of cement mortar to a well under a pressure in thawed soil surrounding a pile creates an intense zone, condensing it therefore. There is a sinking of a pile and significant increase in friction on a side surface of a pile. For example, by data [15], increase in soil density next to a single pile after a solution injection, made to 8,8%, increase in bearing ability of piles on a side surface up to 80%, under the lower end up to 20%.

The bearing ability of piles generally depends on soil conditions, but also considerable impact on it will be exerted by quality of cement trunk formation of micropiles in soil. There is lack of data on studying of quality of cement trunk formation. It is noted in work [13] that because of a long break between spudding and injection compaction the dense injection cement mortar given through a bar and outlets of a drill bit couldn't squeeze out the hardened drilling mud fluid mixed with soil. Thus, a key indicator of quality at injection is full replacement from a well of boring slime by cement mortar at achievement of maximum pressure of 4-6 MPa, including by so-called "dynamic compaction".

There aren't enough data on the characteristic of injection cement mortar in the analyzed articles, however, the quality of cement trunk formation of micropiles, and eventually, the bearing ability of piles will depend on correct selection of composition of cement mortar in many respects. Cement mortar is used for installation of grout-injected piles on the published data. For example, at "Titanium" piles installation as drilling mud fluid cement mortar with W/C=1, and for injection with W/C=0,4 [12], with W/C=0,5-0,7 [14] is used. At "Atlant" piles installation as drilling mud fluid cement mortar with W/C=1 and as injection – cement mortar with W/C=0,4-0,6 [12] is also used. The first experience of application of grout-injected micropiles in permafrost soil is described in [17] where injection mortar with lower water cement relation of W/C = 0,34 was used. Such low W/C value is caused by need of providing curing of cement mortar at the negative temperatures characteristic of permafrost soil.

Negative temperatures considerably reduce rates of hydration hardening of cement and final durability of piles material. The intensification of solutions hardening at the minimum violation of permafrost mode and salinity of adjacent layers of permafrost soil is necessary for ensuring the required durability of injection solutions.

Cement mortar with W/C=0,6 for installation of grout-injected piles which meets the requirements imposed to injection mortars is usually recommended to apply. However rates of hardening of cement mortar at W/C = 0,6 on Portland cement of PC 400-D0 considerably decrease even at temperature minus 1°C. At 28-day age durability of samples hardening at temperature minus 1$^{o}$C is only 76% of branded. Average temperatures of soil on piles length (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 hardening the composition of above-stated mortar doesn't provide the required durability without intensification of cement mortar hardening.

Earlier pilot studies have studied influence of complex anti-freezing additives on kinetics of injection cement mortar hardening at a temperature minus $4^0$C. It is established that introduction in mortar mix of superplasticizer S-3 in 0,5% number of cement mass allows to lower W/C from 0,6 to 0,34 when maintaining the same mobility of mix (OK = 12 cm). It is also established that at introduction of anti-freezing components (sodium nitrite (SN), sodium chloride (SC) + SN) in 1,5 to 3% number of cement mass together with superplasticizer S-3 (0,5% of cement mass) the mobility of mortar mix in 12 cm (GOST 5806), is provided at W/C values = 0,30 … 0,34, that is at superplasticizerr combination with anti-freezing additives the synergetic effect was observed.

The first experience of grout-injected piles use in permafrost soil serves strengthening of the basis and tape foundations of the RS(Y) National library building in Yakutsk City. Sixteen-year operating experience after building reconstruction and also experience of GIP application on different objects in Yakutsk have shown a deposit of soil on stabilization of the basis, the development termination that indicates efficiency of application of grout-injected micropiles in areas of permafrost soil distribution. The defining factor of ensuring reliability of this technology in permafrost soil is correct appointment of injection mortar structure developed taking into account specific soil conditions of construction site and features of installation technology of injection micropiles.

The purpose of this work is ensuring hardening of injection mortar at micropiles installation like "Titanium" on experimental platform of LLC "GeoTekhnical Sistems" on the territory of Rotational camp of KS-2 "Yarynskaya" in Yamalo-Nenets autonomous region.

For goal achievement it was necessary to solve the following problems:

- to investigate in vitro kinetics of hardening of injection cement mortar at various temperatures characteristic of permafrost soil;
- to pick up optimum structure for approbation under production conditions and to study technological properties of cement mix and physical mechanical properties of hardened mortar.

## 2. Research technique

Basic data at selection of injection mortar composition are the technology of grout-injected micropiles installation and permafrost soil conditions in which they will be formed. In the studied technology micropiles installation is carried out by means of small-sized, mobile drilling equipment and tubular screw bars "TITANIUM". Work has to be performed by crew from two links: the first link serves the drilling rig, the second link is engaged in preparation of cement injection mortar.

The distinctive feature of studied technology and type of micropiles "Titanium" consists of that combined metal design performs at the same time three functions:

• first, the bar is boring tool equipped with suitable to soil type with the lost crown on a pile tip;
• secondly, along with drilling through a hollow bar (pipe) and a crown with openings cement mortar moves that it allows to fill a borehole from below;
• thirdly, the bar serves as reinforcing element of grout-injected micropile increased from a surface by means of connecting couplings to the necessary length.

"TITANIUM" shell part are drill bit, tubular screw bars (further TSB), connecting couplings and centralizers.

TSB spudding equipped by drill bit with openings is carried out with simultaneous giving in a pipe cavity of compressed air under the pressure up to 7 bars for replacement of boring slime from a well bottom. Upon termination of driving of each bar, the trunk of the well is studied by giving of rotator of boring machine up-down. There is TSB building further and the cycle is repeated before achievement of design mark. Then the well trunk is carefully studied with a purge, and the boring shell rises on 2 – 3 cm over a face. The cement injection mortar of specially picked up structure prepared in RM-750 mortar mixer moves by NB-160/6,3 mortar pump with a speed of 40 … 50 l/min. on a hollow bar "TITANIUM" through openings in a crown before full replacement of drilling mud fluid and slurry

filling, i.e. to an exit of pure cement injection mortar from the mouth of the well. Forcing of solution is made at rotation of bars (dynamic pressure testing). Further the steel pipe in the top part of the well on design mark is established by blockage, it is fixed by means of basic directing ring. After process completion of piles production, if necessary, in the top part of micropiles solution is added and the support plate of a pile is welded.

This technology of micropiles installation can be used in any climatic conditions, including North conditions according to TU 5264 - 001 - 31357109 - 2016 "Tubular screw bars "TITANIUM" and completing elements to them. Specifications" the temperature conditions of shell application "TITAN" hesitates from + $40^0$C to minus $60^0$C. However so far there is no experience of use of technology of grout-injected piles like "Titanium" in permafrost soil. The complexity of development of this technology consisted of surface high module compositions of cement mortar providing the set speed of curing of injection mortar in contact with permafrost soil are required. In these soil conditions and at this technology of micropiles installation it is possible to provide the set properties of solution by means of chemical additives and at obligatory respect for technological properties necessary at mortar compaction (mobility, viscosity, water separation).

For the beginning of works on experimental checks of injection mortar composition data of engineering-geological researches necessary for his selection (type of soil, its temperature, soil physical characteristic) were absent therefore the decision on conducting pilot studies of mortar curing in two modes has been made: at high negative temperatures of soil minus 0,1 … $1^0$C and at low negative temperatures of soil minus 4 … 5°C.

For development of preliminary composition of cement injection mortar pilot studies have been carried out in laboratory. For laboratory experiments Portland cement of CEM I 42,5 B GOST 31108-2016 (JSC PO "Yakutcement") was used. The characteristic of cement is provided in table 1 and 2.

**Table 1.** Chemical-mineralogical composition of clinkers.

| Clinker manufacturer | $C_3A$, % | $C_3S + C_2S$, % | MgO, % | $CaO/SiO_2$ |
|---|---|---|---|---|
| JSC PO "Yakutcement" | 6,64 | 77,24 | 2,76 | 2,67 |

**Table2.** Characteristics of cement.

| Cement type, class, subclass (supplier) | Standard Consistency cement paste, % | Grinding fineness of cement by specific surface area, $m^2/kg$ | Beginning of solidification terms, min | Uniformity of change of volume, mm (expansion) | Compressive strength of cement simple, MPa, at the age of, days | |
|---|---|---|---|---|---|---|
| | | | | | 2 | 28 |
| CEM I 42,5 B (JSC PO "Yakutcement") | 26,75 | 357 | 135 | 1,0 | 25,5 | 49,0 |

For preparation of mortar the water meeting the requirements of GOST 23732-2011 is used.

For ensuring technological properties of injection mix and also ensuring the set rates of mortar curing used the following chemical additives:

- supersoftener for concrete and construction solutions "Poliplast SP-1" (SP-1, S-3) by TU 5870-005-58042865-05, manufacturer is LLC "Poliplast-Uralsib";
- anti-freezing admixture sodium formate technical (SF) of Chinese production.

The choice of complex antifrosty SF + SP1 additive is proved by the fact that depending on change of temperature of permafrost soil it is possible to regulate an anti-freezing component of additive.

Preparation of injection mortar mix was made by means of industrial mixer for preparation of construction solutions from ready dry mixes. Speed of mixer rotation is 960 $min.^{-1}$.

Determination of technological properties of injection mortars are executed by standard methods: flow test, density and water separation in accordance with GOST 26798.1-96, viscosity of mix with the help of VBR-1 viscometer in compliance [18].

Samples cubes with sizes of 70,7x70,7x70,7 mm for determination of physical mechanical properties of cement injection mortar were made of prepared cement mixes. Each series consists of three samples.

Control samples were stored in the camera of normal and moist storage (environment temperature is 20±2°C, environment humidity is 95%) and have been tested at the age of 28 days. The studied samples hardened in the freezer at two temperature conditions characterized for permafrost soil: temperature from minus 0,1 to minus 1°C in the first camera, in the second one from minus 4 to minus 5°C was maintained. The varied factors were in the SF complex additive + 0,7% SP1 a dosage of anti-freezing component. The constant consumption of SP1 super softener in quantity 0,7 % from cement mass has been established by preliminary experiences from a condition of flow test ensuring of mix at low V/C = 0,32÷0,36, necessary for providing GIP installation rate of curing of mortar set by technology: not less than 20 MPa in 7 days, not less than 30 MPa in 28 days. In this regard the studied samples have been tested aged 7 and 28 days, besides the samples hardening at negative temperatures were tested aged up to 56 days.

Definition of physical mechanical properties of cement injection mortar was made in compliance of GOST 5802-86.

## 3. Results and discussions

All samples used for experiment are made of mix with required technological properties except for an indicator of conditional viscosity. As preliminary experiments have shown according to conditional viscosity at W/C = 0,32÷0,36 it wasn't succeed to receive the value of viscosity established by STO NOSTROYA [17] 30 sec. though flow test of mixes made from 230 to 238 mm.

Influence of hardening temperature of samples and W/C on durabilities of injection mortar with additive 3% SF + 0,7% of SP1 at the age of 28 days is shown in figure 1.

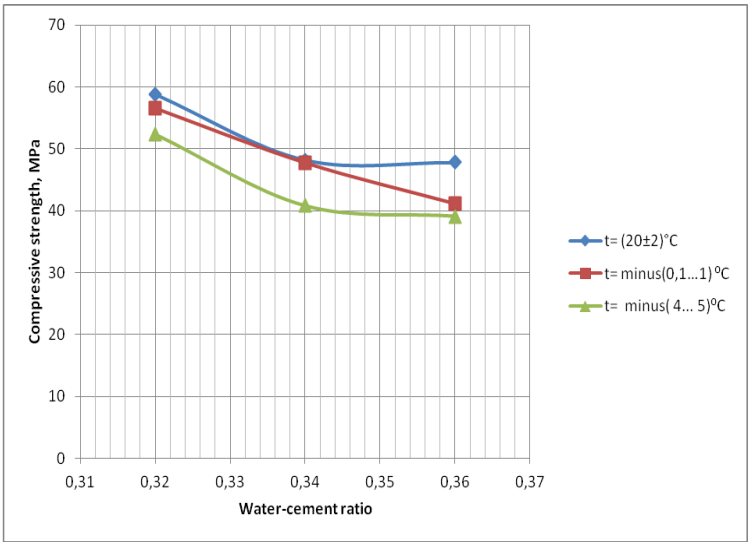


**Figure 1.** Dependence of durability on compression of injection solution with additive 3%SF +0,7% SP1from temperature of curing and W/C.

The schedule analysis shows that character change of samples durability hardening in normal and moist camera at 20±2°C and samples hardening in freezer at temperature from -4 to - 5°C are identical. Fluctuation of W/C from 0,34 to 0,36 has no significant effect on durability of injection mortar. However when mortar curing at negative temperatures characterized for permafrost soil,

durability goes down approximately on 10 MPa. Somewhat different character has change of durability of injection mortar hardening in freezer at temperature from - 0,1 to - 1°C. Solution durability in this case decreases directly proportionally to increase of W/C from 0,32 to 0,36.

A set of mortar durability is presented in the form of charts (figure 2). The analysis of obtained data shows that the rate of hardening demanded for GIP installation both in 7 days, and in 28th days is provided. On the basis of it compositions of injection mortar have been recommended for approbation under production conditions.

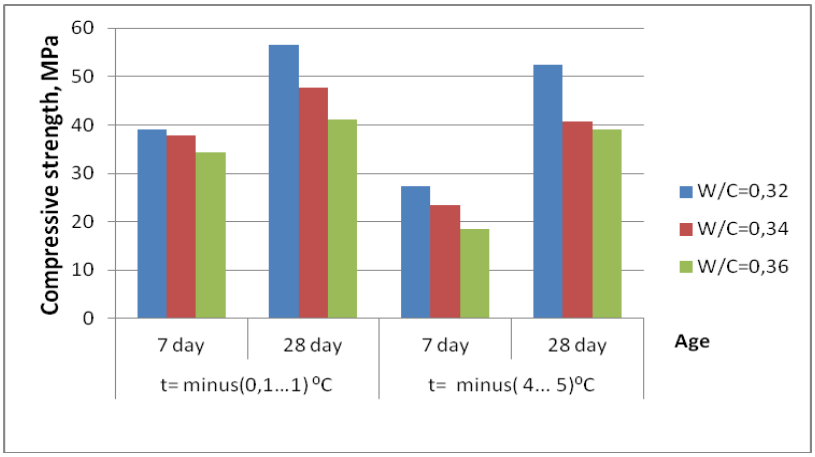


**Figure 2.** Compressive strength of injection mortar with additive 3%FS + 0,7%SP-1 at ages 7 and 28 days.

In contact with permafrost soil by means of complex anti-freezing additives point out results of different researches on efficiency of ensuring hardening of cement injection mortars [17,19,20]

## 4. Conclusion

On the basis of obtained experimental data for natural approbation the composition of cement injection mortar on Portland cement of CEM I 42,5: C/W = 2,94 (W/C = 0,34) has been recommended with SP1 super softener with expense of 0,7% of cement consumption and anti-freezing additive 3% SF (sodium formate) of cement mass.

By experimental works it is established that cement injection mortar on the basis of Portland cement of CEM I brand 42,5 B GOST 31108-2016 (JSC PO "Yakutcement") with use of complex SF + SP1 additive with low water cement relation (W/C=0,34), capable to harden at low negative temperatures characterized for permafrost soil. The developed structure has sufficient survivability for forcing to the well, fast terms of hardening, practical lack of water separation.

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