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Analysis on technological features of pile foundations construction in frozen and seasonal thawing soils

A Montayeva¹, A Zhussupbekov², V N Kaliakin and S Montayev⁴

¹PhD Student, Department of Civil Engineering, L.N. Gumilyov Eurasian National University, 2 Satpayev Street, Nur-Sultan, Kazakhstan

²Professor, Department of Civil Engineering, L.N. Gumilyov Eurasian National University, 2 Satpayev Street, Nur-Sultan, Kazakhstan

³Professor, Department of Civil & Environmental Engineering, University of Delaware, Newark, Delaware 19716, 360 Dupont Hall, USA

⁴Professor, Department of Civil Engineering, Zhangir Khan West Kazakhstan Agrarian Technical University

E-mail: asmontay@gmail.com

Abstract. This article assesses the more productive methods for thawing seasonally frozen soils. The most rational and progressive method of thawing seasonally frozen soils involves putting antifreeze additives into the soil. New goals and objectives for the development of pile foundation construction technology in seasonally frozen soils in northern and central regions of Kazakhstan is presented.

1. Introduction

The construction of a building or other structure in wintertime is a laborious process. Consequently, many companies slow down or pause the construction process in winter due to frozen soils that precludes the fabrication of foundations. However, rapid industrial development and constant population growth in Kazakhstan necessitate year-round construction of buildings and other structures. There is thus a need for the new scientific methods that ensures construction of during wintertime.

When carrying out construction work in winter, the most important stage is the arrangement and selection of foundation type. Difficulties in arranging the foundation in winter are associated with the following factors:

- The development of pits and trenches in frozen ground require the use of powerful excavators, which result in additional financial costs;

- The laying of monolithic concrete foundations requires the pouring of water; at freezing temperatures this results in the freezing of the concrete. Therefore, it is not always possible to perform work, especially in high negative temperatures;

- The need for heating a concrete structure using the convection method or electric heating through reinforcement laid in the foundation, which increases the complexity of the work and the energy costs.

Therefore, the most efficient method for the construction of buildings and other structures during wintertime is the use of prefabricated foundations made at the factory. The study aims to establish the possibility of using anti-freeze additives to eliminate soil freezing during the installation of pile foundations in winter.



At the outset of the present study, a body of previous work related to this topic was reviewed.

Previous studies [1-2] have shown the results of technology that improves the properties of permafrost soils by thawing it with chemical reagents. Frozen soils have been thawed by injecting concentrated aqueous solutions of salt to the soil. The results showed that anhydrous liquefied and gaseous chemicals are capable of actively thawing ice and protecting thawed soils from subsequent freezing.

The possibility of using chemical reagents for thawing frozen soils, in particular gravelly-sandy soils, by pouring forth into the soil without applying external pressure [3]. However, the rate of filtration of a chemical reagent in the soil decreases sharply.

The use of pile foundations in winter is associated with the following problems:

- In practice, the use of bored piles is a proven technology. However, the installation of bored piles requires a preparatory stage involving drilling. This is very difficult when the soil is frozen;

- The driving reinforced concrete piles into frozen soil have low efficiency and a high risk of destruction of the concrete protective layer;

- The installation of a screw foundation in frozen soil is characterized by a substantially greater amount of energy and requires the use of special mechanized equipment.

The technology of constructing pile foundations in permafrost and seasonally frozen soils is associated with additional construction processes, which increase the complexity and duration of the effort. In some cases, when the depth of frozen soil does not exceed 0.5–0.6 m, construction companies use powerful mechanical hammers and vibratory hammers to reduce additional operations. However, such pile driving techniques increase the likelihood of collapse of the pile head. The destruction of the pile head, in turn, leads to the potential seepage of water into the pile foundation.

The main aggressive factors that negatively affect reinforced concrete foundations are soil type, groundwater, and cold weather [4]. Physical damage during the installation of driven piles in frozen soils can also be caused by use of more powerful hammers. Such damage can lead to the corrosion of the reinforcement, which leads to the loss of bearing capacity of the pile foundation.

When choosing methods for driving piles in seasonally frozen soils, special attention must be paid to the thickness of the frozen soil. The thickness of frozen soil is the main criterion for choosing specific method for driving piles.

2. Engineering geological investigations of design area

Based on an engineering and geological survey, the following soil profile was identified at the design area:

- a) Soil-plant layer, the thickness of layer 0.2 m, bulk soil: dark brown loam, solid consistency, mixed with wood and soil. Layer thickness: 0.4 / 1.2 m.

- b) Brown loam from solid to stiff plastic consistency, with seams of fine sand saturated with water. Layer thickness: 2.6 / 6.2 m.

- c) Sand of polymictic composition, medium density, saturated with water. Layer thickness: 0.7/1.3 m.

The base under the piles is multi-colored clay loam from solid to semi-solid consistency. The total capacity of the wells with a depth of 15.0 m was not opened. The opened thickness of layer is 8.8 / 10.8 m. The soil has the following characteristics: density= 1.92 g/cm³, cohesion = 26 kPa, angle of internal friction = 18°, deformation modulus = 5.3MPa.

Groundwater in the study area was found at a depth of 2.7 to 3.5 m. Absolute elevations of the steady-state level are 345.15 to 346.75 m. The distribution of groundwater has is sporadic. The aquifer is confined to a layer of variegated sands, in clay soils to lenses and layers of sand.

The groundwater is unconfined. Under natural conditions, the groundwater level is subject to seasonal fluctuations: an expected maximum rise in groundwater level during the flood period is in early May, whereas the minimum level is expected in January and early February. The maximum groundwater level in the spring should be expected to be 1.5 m higher than the previously recorded level during the survey. In terms of chemical composition, groundwater contains sodium sulfate-

chloride, with a salinity of 4121/7201 mg / L, hard, and medium-mineralized. The pH of the medium is neutral.

According to laboratory data, the soils in the design area are non-saline (GOST 25100). Above the established groundwater level they have low to medium sulfate aggression to concrete of W4-W8 grades on ordinary Portland cement, not aggressive to concrete on sulfate-resistant cement, and have medium chloride aggression to reinforced concrete structures (SP RK 2.01-101-2013). The corrosive activity of soils in relation to carbon steel is high.

3. Analysis of current situation of pile foundations construction in winter season

The following methods are considered to be traditional technologies for piling in seasonal frozen soils:

- The shock method is used with a frozen layer thickness of up to 0.3 to 0.5 m;
- The vibration shock or indentation method is used by installing leader wells using a drill to the entire depth of freezing with a frozen layer thickness of 0.6 to 2.0 m;
- Special preliminary warming of piling places with heat-insulating materials in order to prevent soil freezing;
- Methods for thawing a layer of frozen soil.

A review of the current state of practice of pile foundations in seasonal frozen soils allowed us to establish that with a greater depth of freezing, the accuracy of driving piles can sharply decrease. In addition, the inclination probability of piles from the design position is up to 10-15 cm, which is not an acceptable value. Practical observations of piles driven into the frozen soil layer have also shown that in more than 90% of cases, the body of the pile is damaged by the hammer blows.

In addition, the strain rate in a seasonally frozen layer usually decreases with increasing depth and distance from the soil-pile boundary, and a change in the strain rate by three to four orders of magnitude can occur in a seasonally frozen layer [5]. Such a large change in the strain rate can have a significant impact on the performance of piles that are loaded in a cross-direction its effect should be taken into account.

It has also been established that frozen soil can transform the system of piles and the surrounding soil from a plastic state into a brittle one. Therefore, the behaviour of soil must be taken into account when designing pile foundations in cold regions.

The results of research work [6-7] have shown that before designing or constructing any buildings in winter, the penetration depth, freezing index, and frost susceptibility of the foundation soil must be taken into consideration.

Traditional methods for thawing soils include electric heating with the help of special device and immersion of piles in pre-steamed wells of permafrost soils. However, our analysis of traditional methods of thawing permafrost and seasonal frozen soils showed them to be rather complex and typically costly. To prevent soil freezing after thawing, there is a need for the new scientific approaches that are technologically advanced, effective, and of low cost.

4. Proposed methodology for soil thawing in winter

The following antifreeze reagents for thawing frozen soils are proposed:

- Calcium chloride (CaCl), which generates heat;
- Sodium chloride (NaCl), which absorbs heat;
- A corrosion inhibitor that protects against destruction of material surface on which the antifreeze reagent is applied (Figure 1).



Figure 1. General view of an antifreeze reagent.

To conduct scientific site and experimental work, the foundation ditch at the construction site of a school was chosen. This site is located between A16 and A34 Streets in the city of Nur-Sultan, Kazakhstan. Reinforced concrete foundations with C5-30 model were chosen for this project. At the time of the scientific and experimental work, the outdoor temperature at the site was -18 to -20°C. The depth of soil freezing was 0.8-1.2 m.

Before beginning the experiments, certain preparatory work was performed. This consisted of determining the depth of frozen soil and organizing site fencing with special portable racks interconnected with special ribbons of bright colour (Figure 2).

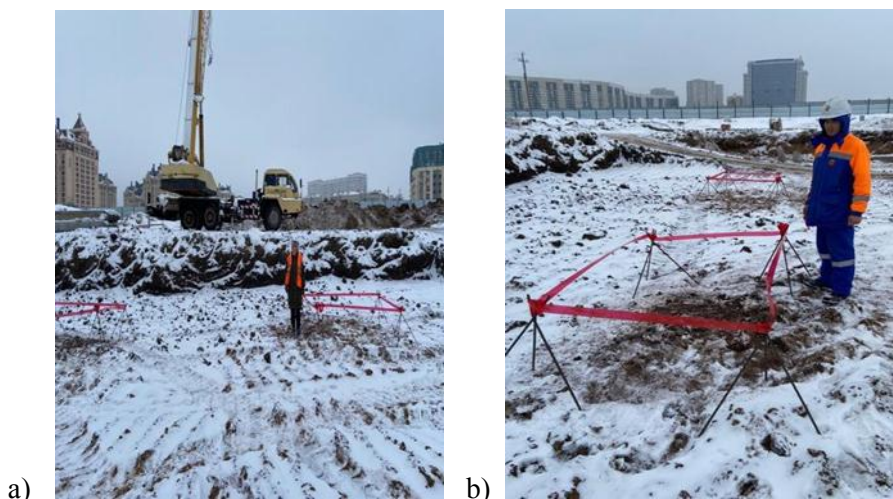


Figure 2. Organizational and preparatory work for testing the antifreeze reagent for thawing soil for the installation of a reinforced concrete pile foundation in Nur-Sultan, Kazakhstan.

The next stage of the experimental work consisted of choosing the method of applying the antifreeze reagent into the soil. Two different methods were chosen so as to allow for a comparative analysis:

- 1) A dry method of applying a reagent to the surface of the soil;
- 2) A wet method of applying reagent to the surface of the soil consisting of the reagent mixed with water.

In the dry method, the reagent was introduced onto the frozen ground surface in its natural form (loose granules) with a thickness of 1.0 to 1.5 cm.

In the wet method, a previously prepared aqueous solution of water to reagent, in a ratio of 1:1, was applied to the surface of frozen soil (Figure 3).

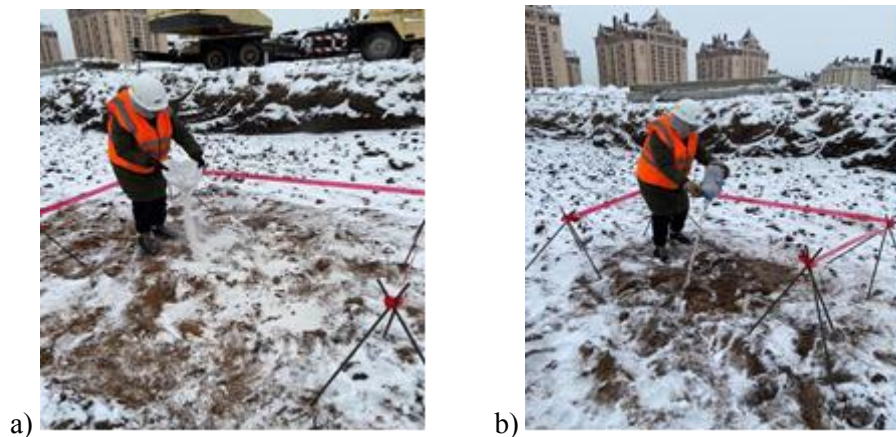


Figure 3. Applying reagent to the surface of frozen soil in two ways:
a) dry method b) wet method

After the reagent was introduced into frozen soil for 7 days, its effect on thawing frozen soil was monitored. In result of such monitoring, the following patterns were established:

- On the next day in both cases, the surface layer of frozen soil thawed to a depth of 5-7 cm. However, in the case of the dry method, reagent granules on the soil surface remained undissolved;
- On the fourth day after application, the thawing in the soil by the wet method reached a depth of 75-80 cm. With the dry method, the depth of thawing only reached 15-17 cm;
- On the seventh day after application, a continuation of the thawing process with the wet method was observed, reaching a depth up to 1.5 m. With the dry method, the thawing process slowed significantly.

5. Method for estimating the load bearing capacity of pile foundation by static loads

Load bearing capacity tests were carried out according to the requirements of GOST 5686-2012 “Soils”. Test piles were installed in two different places. First one was driven into the ground where antifreeze reagent had been applied in the wet form. The second pile was installed into frozen soil.

The field tests were carried out when the piles came to rest, 10-16 days after driving into the ground. The piles were tested by using different types of soil protection methods. In the first case, driven piles were covered by dry sawdust in order to protect the pile from freezing. The thickness of the sawdust layer was 0.5 m. In the second case the reagent was used in an aqueous form (Figure 4).

The depth of thawed zone was determined by drilling the ground and by the speed of driving. As the tested piles were driven in two different zones, the range for both piles was different (first pile was driven into the ground where antifreeze was applied; another pile was driven into the frozen ground).

The load was applied to the piles through an Enerpac CLS2006 185-ton hydraulic jack that is pumped up to the loading platform from beam systems. A total weight of hydraulic jack, which is connected to the Enerpac P462 pumping station, is 150.0 tons. The applied load was recorded by a load cell digital dynamometer as part of the connected SLT2 monitoring system. The pressure is fixed by a manometer with a division price of 20 atm (kgf / cm²) to 1000 atm (kgf / cm²) of the MA100VU100 type.

The displacements of each pile were recorded by four digital electronic transducers (027DG1, 027DG2, 027DG3, 027DG4) that were connected to the monitoring system SLT2. The SLT2 static load test monitoring system is specially designed to monitor the static load tests and present data in accordance with Eurocode 7. This system makes it possible to monitor the static load test from a distance of up to 25 m, thus avoiding any potentially hazardous situations due to the heavy applied loads.

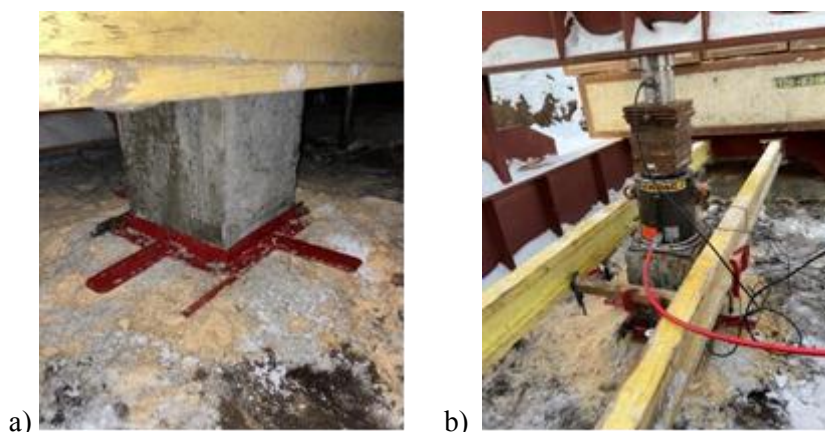


Figure 4. Testing piles for bearing capacity using different antifreeze methods
a) SLT using antifreeze reagent b) SLT using sawdust

Piles were tested with static stepwise increasing loads. The first four steps consisted of 104 kN (40 atm) per step. This was followed by 52 kN (20 atm) and was then brought to 728 kN (280 atm) for pile No. 455, and to 520 kN (200 atm) for pile No. 134.

With a maximum applied load on pile No. 455 and 134, their displacements were 3.99 and 16.65 mm, respectively.

The piles were unloaded in steps, with observation of elastic deformations at each step every 15 minutes. After complete unloading to 0 kN, observations of elastic displacements were made for one hour, taking data every 15 minutes.

6. Results of static load tests using different methods of soil thawing

A static load test (SLT) was performed on two piles. The first pile was in sawdust. Sawdust is used as an artificial soil while testing the piles in winter. The second pile was protected with antifreeze reagent. The results of SLT using sawdust at the fixed settlement 5.5 mm attained a maximum load 520 kN. The results of SLT using an antifreeze reagent at the fixed settlement of 5.5 mm, attained a maximum load 670 kN (Figure 5). These results are explained by the fact that sawdust decreases the adhesion of the soil to the pile. Consequently, the bearing capacity drops. The antifreeze reagent, on the other hand, helps to thaw the frozen soil and protects the soil from freezing in its natural form.

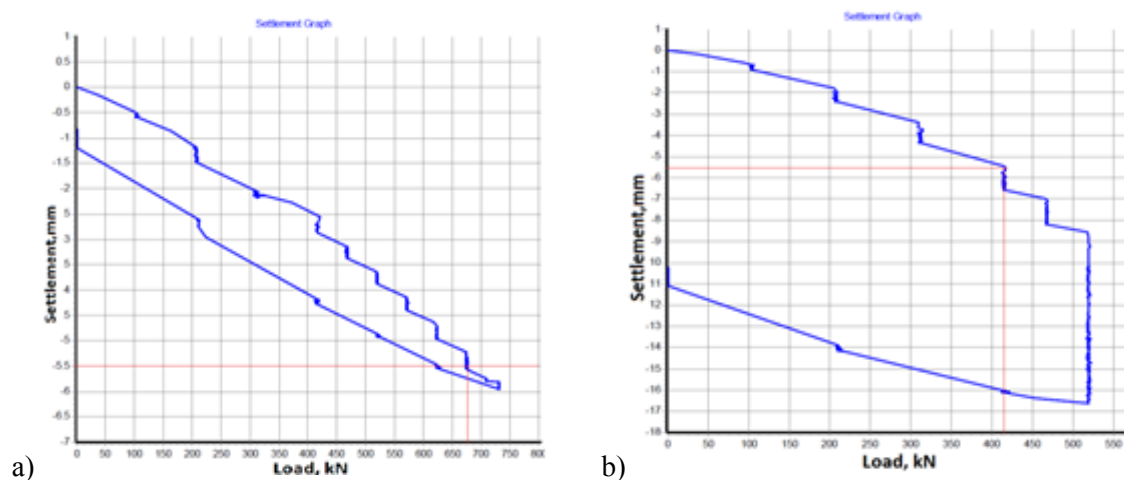


Figure 5. Results of SLT.
a)SLT with antifreeze reagent b) SLT with sawdust

7. Conclusions

1. The possibility of using the antifreeze reagent to eliminate frozen soil during the installation of driven piles during winter in the city of Nur-Sultan, Kazakhstan has been established;
2. Simple methods have been proposed that are easily carried out in the field and do not require significant labour and financial costs;
3. It has been found the use of the wet method is the most effective when the outdoor temperature more than - 20 C, since this method provides deeper thawing of soil;
4. It has been found if the depth of frozen soil is no more than 50 cm, it is possible using the dry method of reagent, which does not require the preparation of a special aqueous solution;
5. Implementation of the proposed method of thawing frozen soil provides the potential for high productivity driving of reinforced concrete piles without the risk of their destruction. At the same time, there is no need to use more powerful (and thus more expensive) hammers for driving piles in frozen soils.
6. It has been established that the static load test, used in conjunction with antifreeze reagent, helps to obtain bearing capacity data during winter that is more accurate than without the reagent.
7. It has been identified that during the static load test, antifreeze reagent on frozen soil decreases its compressibility. This phenomenon is very important for pile installation in winter.

References

- [1] Zakharov A E 2001 The study of temperature fields in frozen soils in contact with hardening mortar layers. Scientific conf. (Saint Petersburg State University of Architecture and Civil Engineering).
- [2] Nevzorov A L, Krieger E V, Sakharov I I, Zakharov A E, Paramonov V N, and Kudryavtsev S A 2004 Assessment of soil deformation associated with freezing and thawing. Foundations and Foundations: Theory and Practice. Interuniversity thematic proceedings. pp 34-140
- [3] 1977 Guidance on the technology of physico-chemical strengthening of freezing and thawing soils. Stroyizdat (Moscow).
- [4] Zoran B, Gordana T, Ćurčić N D, and Jelena S 2015 Damage of Concrete and Reinforcement of Reinforced-Concrete Foundations Caused by Environmental Effects Procedia Engineering. 117 pp 411-418
- [5] Wenping F, Zhaohui J Y, and Tiecheng S 2019 Ground freezing impact on laterally loaded pile foundations considering strain rate effect Cold Regions Science and Technology 157 pp 53-63
- [6] Zhussupbekov A, Shakhmov Z 2015 Experimental investigations of freezing soils at ground conditions of Astana, Kazakhstan. Sciences in Cold and Arid Regions, 7(4) 0399–0406. DOI: 10.3724/SP.J.1226.2015.00399.
- [7] Zhussupbekov A, Eun C S, Shakhmov Z, and Tleulnova G 2018 International Journal of GEOMATE, 2018 15 pp 85-90