Analysis on the behavior of soils to anti-frost additives

Analyse sur le comportement des sols aux additifs antigel

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ABSTRACT: One of the biggest problems in installing piles in cold season is frozen soil which its depth reaches two meters down in Northern and Central part of Kazakhstan. Frozen ground is hard to excavate and compact due to its thickness, so at the initial stage of driving piles, some difficulties may arise, which sometimes lead to the destruction of piles. The methods that are currently used to drive the piles into the frozen soils are ineffective in terms of economy and time during the construction process. This paper proposes a new approach that allows easily and quickly install pile foundations in winter without using powerful construction equipment that needs additional cost. The results of experiment have shown not only the effectiveness of suggested method but also the possibilities of testing piles for bearing capacity in winter even when it is -20C, - 30C. Moreover, there has been established two different methods using the additives to protect the soil. The findings of this experiment can help the construction process to run all year round without any problems of pile installation.

RÉSUMÉ : L'un des plus gros problèmes lors de l'installation de pieux pendant la saison froide est le sol gelé dont la profondeur atteint deux mètres dans le nord et le centre du Kazakhstan. Le sol gelé est difficile à excaver et à compacter en raison de son épaisseur, donc au stade initial du battage des pieux, certaines difficultés peuvent survenir, ce qui conduit parfois à la destruction des pieux. Les méthodes actuellement utilisées pour enfoncer les pieux dans les sols gelés sont inefficaces en termes d'économie et de temps' pendant le processus de construction.Cet article propose une nouvelle approche qui permet d'installer facilement et rapidement des fondations sur pieux en hiver sans utiliser d'équipement de construction puissant qui nécessite des coûts supplémentaires. Les résultats de l'expérience ont montré non seulement l'efficacité de la méthode proposée mais aussi les possibilités de tester la capacité portante des pieux en hiver même lorsqu'il fait -20C, - 30C. De plus, il a été établi deux méthodes différentes utilisant les additifs pour protéger le sol. Les résultats de cette expérience peuvent aider le processus de construction à se dérouler toute l'année sans aucun problème d'installation des pieux.

KEYWORDS: seasonally frozen soil, chemical additives, freezing depth, pile foundation, antifreeze reagent.

1 INTRODUCTION

Soil softening in winter in order to drive the piles is a common issue due to the lack of effective methods. The current traditional methods of driving piles in winter are quite costly due to additional works and transportation costs involved, and these operations can also may stop or slow down the process of construction. The engineering practices demonstrate that freezing point of soil has been the one of the challenges of pile foundation construction in winter months.

Freezing depth is an important parameter in the geotechnical engineering for planning and designing construction and its applications. The research (Peppin et al.,2008) has proved that freezing point for water in soils is lower than 0 C because the soil particles usually have chemical substances and free energy which affect to its freezing behavior. Moreover, the freezing temperature of saline soil is an important characteristic to consider when researching its freezing mechanism (Xiao,2018). In this research, an equation for determining the freezing temperature is proposed, which includes two major contributing factors: water activity and pore size.

It is important to note that freezing point is differs depending on type of soil and temperature (Shakhmov,2019). The results of study have shown that freezing depth of soil also changes over the years. The authors of study suggest to consider the freezing depth of heaving soils when designing and building the pile foundations.

In cold regions, de-icing technologies are widely used on roads to thaw or move down the ice and snow to keep the safety (She et al.,2016). Adding the salt to the soils has shown its effectiveness in reducing its frost heave (Grechishchev et al.,2001). The several laboratory tests have been carried out to research this important phenomenon. The results presented the decreased indications of freezing point by presence of salt in soils. Moreover, many laboratory tests have shown that the content of salt plays a major role in freezing point of saline soil. In the research (Zhang et al.,2002), the authors claim that the freezing-thawing characteristic of salinized soil is dependent on the type salt. Another study (Wan et al., 2015) tested the soil with salt for the type of soil. The soils with high content of salt and low water can affect differently on the freezing point. The soils with fine particles have a lower freezing point when adding salt than the soils with coarse particles.

There is a research that has shown the investigations of freezing point depression in soils by adding NaCl (Feng et al., 2020). The authors came up to the results that the initial water content has a little influence on freezing point of soil. In addition, it has found that the addition of salt into the soil decreases the water activity. Consequently, this leads to the decrease of freezing point of soil since the salt reduces the total potential of soil water and decreases the molecular interactions.

2 METHODS AND MATERIALS

2.1 *Materials of the experiment*

The soil used in this research was collected from the construction site "Nur-Sultan Hospital" which is located in the capital of Kazakhstan-Nur-Sultan city. To investigate the effect of anti-frosty additives on soils, the mechanical characteristics of soil have been defined at the laboratory of LLP "KGS-Astana in accordance with the requirements existing regulatory documents, instructions and guidelines. According to the total content of easily and moderately soluble salts, according to the requirements of GOST 25100-2011, the soils that make up the survey site is considered unsalted.

The top of the soil layer which is sandy loam have been used for model test. According to the field description, the color of the sandy loam is light brown, the consistency differs from hard to soft-plastic, from depth 1.0 ÷ 3.0 m the loam is water-saturated with clay interlayers up to 20 cm thick. The loam thickness ranges from 1.4 m to 7.8 m. The mechanical and physical properties of the sandy loam are given in the Table 1.

Table 1. Physical properties

№	Indicators	Unit of measure ments	Average values
1	Natural humidity	%	6,74
2	Humidity in the yield strength	%	17,0
3	Moisture at rolling limit	%	14,4
4	Plasticity number	%	2,5
5	Consistency		0,60
6	Soil density	g/cm^3	1,79
7	Density of soil particles	g/cm^3	2,59
8	Porosity coefficient	share units	0,542
9	Moisture degree	share units	0,326
10	Specific adhesion	kPa	44,5
11	Angle of internal friction	degree	26,4
12	Deformation modulus	MPa	39,8

Anti-frosty chemicals were utilized to keep the soil from freezing during the experiment. The deicing composition of the material consists of the following components:

- sodium chloride-NaCl;
- calcium chloride-CaCl;
- corrosion inhibitor;
- sodium formate;
- marble chips;

Marble chips are composed of calcium carbonate which the main component consists of chalk, shells, eggshells. It does not have a melting ability. Salts make up the rest of the PHM components. When dissolved in snow, they produce a brine with a similar composition to seawater. The multicomponent material's melting ability is substantially higher than regular salt, yet its corrosiveness is more than 2 times lower than sodium chloride. Temperatures as low as -30° C can be used. This anti-icing compound is a low-hazard product.

Soil salinization is not caused by the multicomponent composition, regardless of the application technology. There are no allergic reactions to the reagent. Biophilic elements and rust inhibitors are present, and the product is considered safe for soil and construction materials. Also, it contains chemicals that prevent sodium from accumulating in the ground when they are ingested.

As a result, the anti-icing material not only does not increase, but also decreases soil salinity caused by sand-salt mixes and halite. Anti-frosty additives are made up of unique salts that not only melt ice but also protect metal from corrosion. As a result, this anti-icing chemical is 2 times less corrosive to metal buildings than sand or industrial salt. Figure 1.

Figure 1. The anti-frost additives

Plastic was used to create the model piles, which were then printed using a 3D printer. The piles were 10 x 10 mm (cross-section) x 150 mm in length as shown in Figure 2. The plastic has a density of 1.38 g/cm^3.

Figure 2. The model piles made of plastic.

Piles with sizes of 400 x 400 mm (cross-section) x 6000 mm (length) at a ratio of 1:40 were modeled. Driving piles in the lab was done in three separate boxes. The boxes were built of wood and measured 150 mm in length, 70 mm in width, and 250 mm in height as shown in Figure 3.

Figure 3. The process of driving the model pile into the soil in the box.

2.2 *Methods of the laboratory experiment*

The first box was filled with soil, while the second box was filled with soil that had been treated with antifreeze reagent. These two cartons were placed in the freezer for seven days at a temperature of -30 degrees Celsius. At the freezing camera, the first box containing antifreeze reagent was kept and observed for 15 days.

The antifreeze reagent prevented the entire soil in the box from freezing since the soil was soft. The hummer quickly drove the plastic pile in 13 hits. The results are depicted in Figure 4.

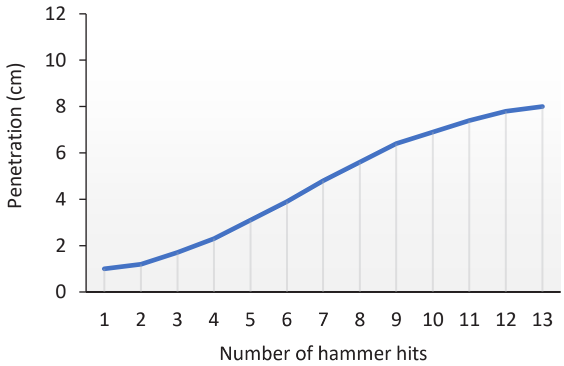

Figure 4. The results of pile driving in the first box.

Furthermore, the piles were static load tested in the freezing camera under various load circumstances as well as steady loads (increasing in steps). The pile's settlements were measured with the ruler. Dumbbells of various weights (1 kg, 2 kg, 4 kg, 5 kg, 6 kg, and 8 kg) were employed as loads. The pile began to settle at 4 kg for 0,1 mm, and by 8 kg, it was completely wavy. Refer to Figure 5.

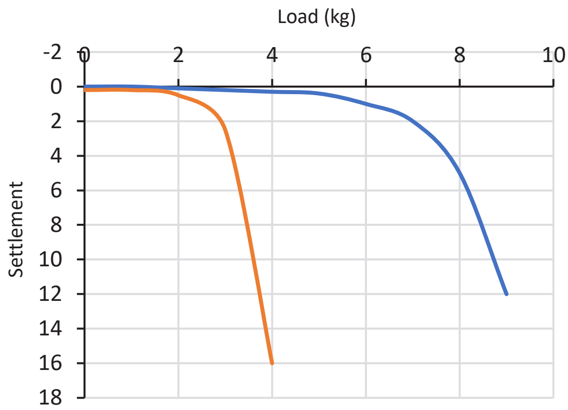

Figure 5. The results of the static load test for model piles.

The static stress test was also performed on the second box, which was kept at room temperature (+18 C). The pile was completely driven in 8 hummer hits. Refer to Figure 6.

The third box was completely frozen since there was no anti frost additives on the surface. After 100 hits and even after boring for 5 cm, the pile could not be driven. A large number of strikes injured the plastic pile's head.

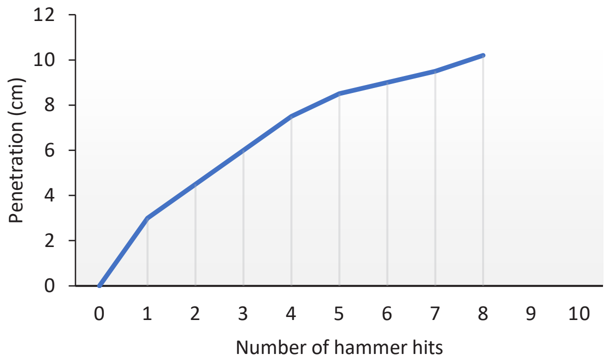

Figure 6. The results of pile driving in the second box.

3 EXPERIMENT AT THE FIELD

The purpose of this experiment is to see the effect of the antifreeze reagent and to monitor whether it thaws the already frozen soil.

At the site experiment (as shown in Figure 7), the ground was already frozen, therefore, the technique of conducting the experiment was slightly different. The outside temperature was -25 degrees Celsius. The antifreeze reagent was applied locally in places of two piles.

The thawed ground was 10 cm deep after 14 days. During the day, it was -27 degrees Celsius, and at night, it was -30 degrees Celsius. The earth was soft and damp on top of the ground. Because there were some thawing effects, it was decided to drive one of the piles without drilling in these spots. The number of impacts on already drilled locations was 198, while the number of hits on thawed ground was 200.

The number of hits was identical in both ways, demonstrating the efficacy of applying antifreeze reagent even in frozen ground.

Figure 7. Driven pile at the construction site.

4 CONCLUSIONS

1. The antifreeze reagent's ability to keep soil from freezing in the winter has been discovered.
2. When the proposed method is used, it results in high productivity driving of reinforced concrete piles with no risk of their being destroyed.
3. Furthermore, if the soil has been protected from erosion, there is no need for extra drilling and more powerful and expensive hammers for driving piles.
5. The usefulness of antifreeze reagent, which facilitates pile penetration into the ground in the winter, was demonstrated by a comparison of two model box tests.
6. During the experiment, the antifreeze reagent's melting impact on already frozen soils was discovered.
7. Because the utilized r had a thawing effect, it was able to test the piles for static load tests during the winter.
8. Piles driven into the soil where the antifreeze reagent was sprayed showed more accurate bearing capacity data during the static load test.
9. The antifreeze reagent has been found to reduce the compressibility of frozen soil.

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