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Prevention method of soil freezing during pile driving in winter

Abstract. One of the common challenges of driving piles in winter is frozen soil. The depth of frozen soil reaches two meters in Northern and Central Kazakhstan that made it difficult to build the pile foundations in cold months. In order to prevent the pile distraction, the places of pile installation are usually drilled by drilling machines which takes time and additional cost for preparatory works. In this paper we proposed a new method of preventing the soil from freezing by using an antifreeze reagent. The reagent can also be used to thaw the frozen ground which allows the construction works in winter months. During the static load test, the piles driven into the soil that had been applied with antifreeze reagent have shown more accurate bearing capacity data. The scientific and experimental studies have established that the antifreeze reagent reduces the compressibility of frozen soil.
Keywords: frozen soil, pile foundation, piles, static load test, antifreeze reagent.

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Introduction

Pile driving in winter has its obstacles as the ions of water get crystalized during the long time of sub-zero temperatures making the soil thick and frozen. One of the widely adopted methods of driving piles in winter in Kazakhstan is drilling the frozen depth of pile places. Usually, frozen depth gets to two meters below the ground level. There are many challenges when placing the piles in cold weather. For example, due to the frozen ground, the number of impacts exceeds the requirements for driving the pile. Consequently, due to a lot of hard-driving, concrete piles can develop horizontal cracks. Usually, the head of concrete piles is vulnerable to impacts. The head of a pile usually gets deformed or damaged by the high blow counts. These issues also lead to the penetration of water into the structure of concrete piles. Moreover, when the soil is thick and frozen, piles can be driven out of their accepted location which is not acceptable for pile foundations

It is important to know the methods of foundation piling one needs in cold weather conditions, which might affect not only the structure of pre-cast- concrete piles but also the whole foundation itself.

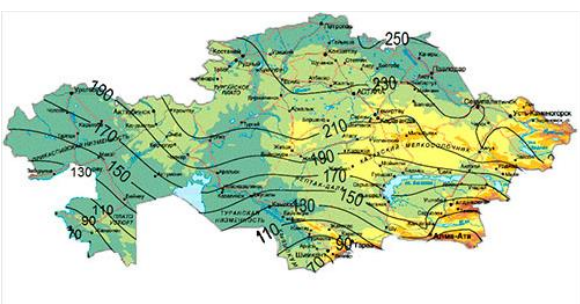

Figure 1. Seasonal frost depth across Kazakhstan

The proposed antifreeze reagent can serve as thermal insulation for the soil when the temperature drops below freezing in the winter months. Moreover, it can provide an ideal condition to drive the piles on the construction site without waiting for the springtime. In order to run the project on schedule, and antifreeze reagent can offer significant advantages in wintertime.

It is important to note that antifreeze reagent can also help to make fewer disturbances to the surrounding area since the ground is unfrozen and does not require any major excavation. Pile foundations can be easily placed in winter without additional and extra costly operations.

There are a lot of studies that investigated the effects of seasonally frozen soils on pile foundations. Authors of research suggest replacing the soil with frost stable material or preventing the soil from freezing since the lenses of ice develop forces in soil ground that affect all parts of the foundation. Pile driving in frozen soil can produce harmful frost actions [1].

The authors of a study [2] point out the problems of seasonal freezing ground on piles of solar power generation. The authors proposed a new approach of rehabilitation to address frost effects on piles as the ground may rise in cold weather which leads to the upward displacement of piles.

Research by Sarsembayeva [3] has shown the effect of de-icing chemicals on seasonal freezing of highway subsoil. The authors stated that removal of snow from road payments (pavements?) by spreading chemical de-icing reagents decreases the freezing point if the water in soils is made to be able to migrate.

The authors of a study [4] proposed a new technological solution that increases the efficiency of pile driving into seasonally frozen soils. The idea is to install a thermal vibrolider on the head of a pile hummer which decreases the density of frozen soil and allows the pile to drive into the frozen soil without drilling or other extra preparatory works.

A new type of pile filed with porous material was suggested by Li and Xu [5]. The authors claimed that this new type of pile decreases the gradient of soil temperature fluctuations. However, the disadvantage of such a solution is that the manufacture of such piles will be very costly. Also, there might be some difficulties in ensuring the quality of the backfill when the piles are driven into the ground.

The authors [6] have done research on the effects of frozen soil characteristics on the bearing capacity and settlement of the pile foundation. In the article, the authors have presented results of static load tests on model concrete piles (how long?) that have been driven into frozen soils with 10 cm freezing depth below the ground at a different temperatures -5C, - 20C.

Sri Sritharan et al. [7] investigated the effects of seasonal freezing of soil on lateral load response of bridge column-foundation, and its interaction and implications with soil. The authors have demonstrated two outdoor column foundation system test examinations during summer and winter at ambient temperatures of 23°C and −10°C, respectively, and have observed significant changes in the column and foundation due to drastic changes in the properties of soil caused by seasonal freezing. The authors noted that the design of pile foundations in seismic areas does not consider the seasonally freezing soil effects.

Another study [8] on modeling the response of cyclically loaded bridge columns into unfrozen and seasonally frozen ground has shown a comparison analysis of soil in warm and cold conditions. The experimental data presented the influence of temperature difference of soil on effective stiffness, maximum moment, moment location, shear demand, and length of the plastic region.

1.1 Sustainability

Considering the climate change impacts, it is important to support the sustainability of environmental, social, and economic domains by reducing waste and using fewer resources during the operations of constriction. Using reagents can be an innovative idea in building a sustainable future by reducing carbon emissions and having a less negative impact on the environment.

Nowadays, energy use in the construction industry is still considered very high. All the heavy machines that are used in construction still depend on fossil fuels.

The number of green buildings and the move to achieve the green building certification is now growing over the world. However, Kazakhstan is still not active in achieving such projects as the USA, South Korea, Japan, and European countries. The term "green buildings" means a practice of building structures and the processes of construction using natural resources that are not only environmentally friendly but also support the quality of life by eliminating negative impacts on the environment.

2. Methods of field work and laboratory research of soils.

The purpose of the research is to see the thermal effect of the antifreeze reagent on soils in negative temperatures in the laboratory and at the construction site during the winter.

In the laboratory of the LLP "KGS-Astana", the mechanical properties of the used soil were identified. The used soil was obtained from the construction site "Nur-Sultan Hospital" which is located in the capital of Kazakhstan -Nur-Sultan city.

Figure 2. Testing the soil for bearing capacity.

Based on the field description of the soils and the results of laboratory tests, the soils were divided into engineering-geological elements (IGE) in the stratigraphic sequence of their occurrence. The followings are the elements of the soil:

IGE-1. Topsoil - tQ_{IV}
IGE-2. Loam - aQ_{III-IV}
IGE-3. Sandy loam - aQ_{III-IV}
IGE-4. Clay - aQ_{II-III}
IGE-5. Fine sand - aQ_{II-III};
IGE-6. Sand of medium size - aQ_{II-III}
IGE-7. Coarse sand - aQ_{II-III};
IGE-8. Gravelly sand aQ_{II-III}
IGE-9. Clay - Pg33

Each allocated engineering and geological element are given specific values of indicators of physical and mechanical properties, given the movement and compression tests by laboratory methods and the consolidation of dredging.

2.1 Experiment in the laboratory.

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In order to obtain comparative results, there have been three different boxes with soils. The first box was filled up with soil without the de-icing chemical reagent, whereas in the second box at the surface of the soil was sprayed the antifreeze regent. Both boxes were put into the refrigerator. The third box was filled up with soil but kept at the room temperature. In order to see the effect of the antifreeze reagent, the model piles were driven into three boxes.

The boxes were made from wood with dimensions of 150 (length) x 70 mm (width) x 250 mm (height). The model piles were made from plastic and printed with 3D Printer (Figure 4). The size of piles was 10x10 mm (thickness) x 150 mm (length). The mass of each pile is 12 mg. The density of the plastic is 1.38 g/cm^3. The piles were modeled from the piles with sizes of 40x40 (thickness) and 600 m (length) in a ratio of 1:40.

Figure 3. Process of filling the box

Figure 4. Model piles made of plastic

The first step to test the antifreeze reagent was the calculation of its consumption. There was a task to calculate the mass of antifreeze reagent needed to prevent soil freezing. In the winter months, chemical additives are usually used to thaw the ice and snow on roads. The study of Kiyalbayev [9] presented the equation for de-icing the roads by chemical reagents. Authors claimed that the main characteristics for the calculation of antifreeze reagent are the density of soil, concentration of antifreeze reagent, and frozen depth of the ground.

Based on his works and equation, the mass of antifreeze regent needed for soil has been calculated. [may have to show the equation] Since the antifreeze reagent is used on top of the soil, the characteristics of sandy loam have been taken into account.

In order to identify the concentration of the reagent, the soil was tested at the refrigerator at different temperatures and concentrations. The results have been presented in Gibb's diagram below (Figure 5).

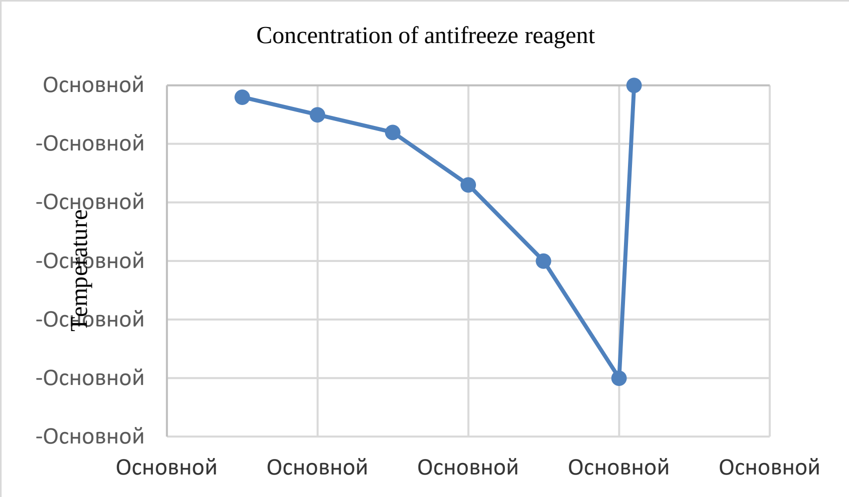


Figure 5. Gibbs diagram for antifreeze reagent

The physical and mechanical properties of sandy loam are known from the geological investigation and presented in Table 1.

Table 1.

№	Thenameofindicators	unitofmeasurements	Limitvalues		Average (normative) values
			min.	max.	
1	Naturalhumidity	%	6,25	8,0	6,74
2	Consistency		0,28	0,81	0,60
3	Soildensity	g/cm³	1,60	2,01	1,79
4	Densityofsoilparticles	g/cm³	2,35	2,80	2,59
5	Porositycoefficient	shareunits	0,385	0,686	0,542
6	Moisturedegree	shareunits	0,256	0,440	0,326

According to the SNiP 23-01-99 (Building codes and regulations), the average temperature of the coldest five days in Nur-Sultan city is -37C. Normative frozen ground depth is 205 cm according to SP RK 2.04-01-2017. From the table, it was calculated the mass of water in 1m³ of soil, which was equal to 37 kg (is this for the water or soil? Your writing is for the soil). It is important to determine the depth of the soil which should be prevented from freezing. In this experiment, the depth was calculated for 10 cm.

The mass of the antifreeze reagent will be equated as below:

$$m_{anti.r.} = \frac{C_{anti.r.} * M_{water}}{100\% - C}$$

$$C_{anti.r} = 25\%\ at\ the\ temperature\ -30\ C$$

$$m_{anti.r.} = \frac{25\% * 37\ kg}{100\% - 25\%} = 12.3\ kg$$

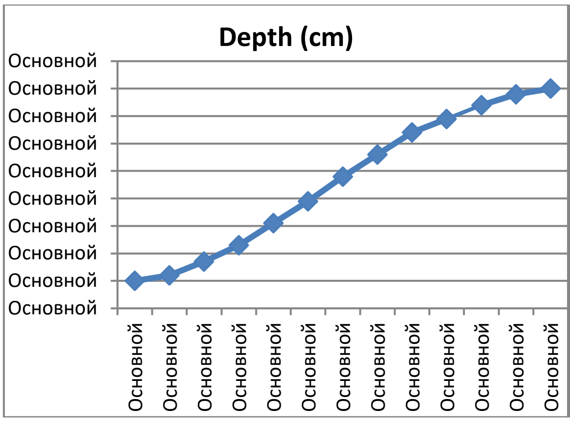
Locally for each pile with the size of 40x40, the mass of antifreeze reagent will be as follows:

$$0,4 * 0,4 = 0,16\ m^2$$
$$12,3\ kg\ * 0,16\ m^2 = 1,79\ kg$$

2.2 Results of laboratory experiment

The first and third boxes were kept and monitored for 2 weeks in the freezing camera. The soil in the first box was unfrozen. The reagent has prevented the soil from freezing. The plastic pile was driven easily by the hammer in 13 hits (Figure 6).

Moreover, the piles were tested for static load in the freezing camera under different load conditions and in constant loads (increasing in steps). The ruler was used to measure the settlements of the pile. As for the loads, the dumbbells were used with different weights of 1 kg, 2 kg, 4kg, 5 kg, 6 kg, and 8 kg. The pile has started to settle from 4 kg for 0,1 mm, and at the first box results of the static load, test can be seen in Figure 7.



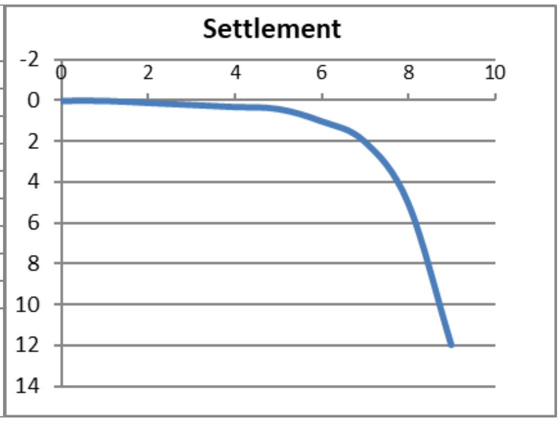
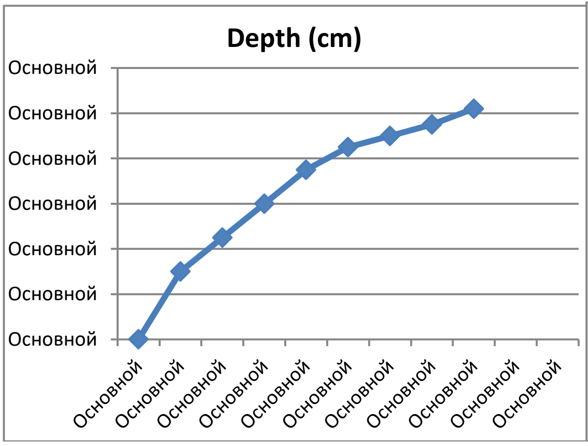


Figure 6.The results of pile driving in the first box (units, please)

Figure 7. The settlement of pile in the first box (put down the unit)

The second box which was kept at room temperature +18 C also was tested for a static load test. The pile was fully driven in 8 hits by hammer (Figure 8). The pile under 8 kg was totally gone into the soil (Figure 9).



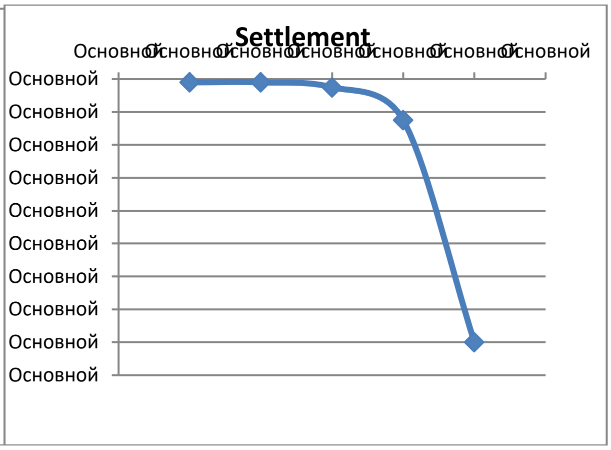


Figure 8.The results of pile driving in the second box.(unit, please)

Figure 9. The settlement of pile in the second box. (unit, please)

The third box which has no antifreeze reagent on the surface was fully frozen. The pile could not be driven after 100 hits and even after boring for 5 cm. The head of the plastic pile was damaged by excessive hittings.

2.3 Experiments at the construction site.

For the construction site during testing, the soil was already frozen and the outdoor temperature was -25 C. Freezing depth was -1.5 m. The chemical additives were applied locally in places of two piles (Figure 10). As the ground was covered by snow, there had been a chance to see other advantages of the chemical reagent. The places of piles where de-icing reagent was put had been monitored for two weeks. The day later, it has been noticed that the snow was fully melted by reagent. Also, there was a thawing effect from the reagent as the depth of unfrozen soil reached 3 cm.

Figure 10. Spreading the antifreeze reagent on top of snow
Figur 11. The pile installation on thawe

After 14 days, the depth of thawed soil had reached 10 cm even if the outdoor temperature was -27 -30 C (which one is the temperature?). It has been decided to drive one of the piles without drilling and the second one into the already drilled hole. The differences in the installation were defined by the number of blows of the hammer. The number of blows on a place where antifreeze reagent was applied was 200 hits, while the pile on the drilled place was driven in 198 hits. Even if the method of driving those two piles was different, the number of hits in the installation was almost similar that showed the effectiveness and profitability of using antifreeze reagent.

Results and discussion

Based on the test results, the antifreeze reagent has shown its effectiveness in protecting the soil in winter. The distinctive aspect of using the antifreeze reagent is the ability to protect the soil (from freezing?) and the simplicity of the method. Many traditional methods are directed to thawing or drilling the places of the piles. From an economic perspective, the method is cost-effective and environmentally friendly. Implementation of the proposed method of protecting the 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 hammers for driving piles in frozen soils.

Moreover, based on the studies, the equation of calculating the mass of antifreeze reagent has been created. Since the consumption of the reagent depends on the density and frozen depth of the soil, it is possible of using less reagent in other regions of Kazakhstan where the winter is not as cold and aggressive.

Conclusion

The experiment results have shown that protecting method of soil from freezing is possible and cost-effective. During the process, it has been also found that the reagent is able to thaw the already frozen ground which makes it a more competitive tool in dealing with frozen soil during pile foundation construction. The main advantages of using reagent are its possibility of driving piles in wintertime without boring and testing them for bearing capacity. Since the chemical reagents keep the soil unfrozen even in cold weather it also decreases the compressibility of the soil. Consequently, there is no need for special equipment with high power that might destroy the heads and the structure of the concrete piles. Moreover, using this new method of preventing the soil from freezing decreases the blow counts, and helps to avoid driving the piles out of their places.

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Қыста қадаларды орнату үшін топырақ қатуының алдын-алу әдісі

Аңдатпа. Қыста қада қағудың қиындықтарының бірі – топырақтың мұз болып қалуы. Мұздатылған топырақтың тереңдігі Солтүстік және Орталық Қазақстанда екі метрге дейін жетеді, бұл суық айларда қада іргетастарын салуды қиындатады. Қадалардың сынуын болдырмау үшін, әдетте мұз болып қалған қабатын бұрғылау машиналарымен бұрғылайды. Бұл дайындық жұмыстары уақытты және қосымша ақшаны қажет етеді. Бұл мақалада біз антифриз реактивін қолдану арқылы топырақтың мұз болып қалуының алдын алудың жаңа әдісін ұсынамыз. Реагентті мұздатылған жерді еріту үшін де пайдалануға болады, бұл құрылыс жұмыстарын қыс айларында жүргізуге мүмкіндік береді. Статикалық жүктемені сынау кезінде антифриз реактиві қосылған топырақта, қадалардың көтергіштік қабілеті дәлірек көрсетті. Ғылыми және эксперименттік зерттеулер антифриз реактивінің мұз топырақтың сығылғыштығын төмендететінін анықтады.

Түйін сөздер: мұзтопырақ, қадаіргетасы, қадалар, статикалық жүктем сынағы, антифриз реактиві.

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Способ предотвращения промерзания грунта в местах забивки свай

Аннотация. Одна из частых проблем при забивании свай зимой — это мерзлый грунт. Глубина мерзлого грунта в Северном и Центральном Казахстане достигает двух метров, что затрудняет строительство свайного фундамента в зимний период. Во избежание разрушения сваи обычно мерзлый слой грунта бурится буровыми машинами, что требует времени и дополнительных средств на подготовительные работы. В данной работе мы предлагаем новый способ предотвращения замерзания почвы с использованием противоморозного реагента. Реагент также можно использовать для оттаивания мерзлого грунта, что позволяет проводить строительные работы в зимние месяцы. Во время испытания на статическую нагрузку сваи, забитые в грунт, обработанный противоморозный реагентом, показали более точные данные о их несущей способности. Научными и экспериментальными исследованиями установлено, что противоморозный реагент снижает сжимаемость мерзлого грунта.

Ключевые слова: мерзлый грунт, свайный фундамент, сваи, испытание на статическую нагрузку, противоморозный реактив.

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