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EXPERIMENTAL STUDY OF MODEL PILE FOUNDATIONS IN SEASONALLY FREEZING SOIL GROUND

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ABSTRACT: The bearing capacity and settlement of pile foundation were greatly influenced by the temperature variations of soil ground around pile foundation. This paper presented a short report about laboratory static load tests by model precast concrete piles (cross-section 4×4 cm and length of 60 cm) in seasonally freezing soil ground. The depth of frozen soil was 10 cm, temperature -5℃, -10℃, +20℃. There were many factors influencing on pile foundations, such as ice in the ground, low temperatures and moisture of the soil. A series of tests of model piles in seasonally freezing soil ground were carried out, the results of bearing capacity of pile foundations and a settlement were compared. The results of the experiments were shown in charts. By application of numerical modeling the pile and soil base interaction vertical deformation in thermal changes of soil ground, the different settlement of piles. Modeling of thermal conditions of soils in software in accordance with real conditions on the construction site of Kazakhstan, analysis,and comparison of the obtained results ofthe settlement of pile foundations at low temperatures are presented in the paper.

Keywords: Pile, Seasonally, Ground, Bearing capacity

1. INTRODUCTION

The problem of the reliability of construction in freezing soil ground has been studied by many scientists. The most experienced researchers in this project were from Korea [1]-[3].

There were problems of constructions in the seasonally freezing soil which contribute to serious damage for pile foundations. An average monthly temperature was shown in figure 2 indicates that the temperatures from November to March were fallen below zero degrees. It was a frost heave of freezing soil ground, ice in frozen soils and etc., that were quite complex and poorly studied at present.

The question of the impact of depth of soil freezing on the ultimate bearing capacity of pile foundations was not fully described in the standards of Kazakhstan. The variations of freezing depth across Kazakhstan territory were shown in figure 2 [10].

2. DESCRIPTION OF MODELING STAND

The objects of study in this paper were the use model reinforced concrete piles in the frost-susceptible soil.

The upper part of the reinforced concrete pile was located in the seasonally freezing soil and the lower part of the pile was in the area below the freezing soil, non-freezing soil. The subject of the research was the interaction of model pile foundation with seasonally freezing soil at a temperature of +20℃, -5℃, -10℃.

3. LABORATORYEXPERIMENTS

The experiments were conducted in the test chamber.

The metallic chamber has two layers. As the first model soil of an experimental soil (mixture consisting of 70% fine quartz sand and 30% marine clay)was used, as it was typical in the upper part of the geological conditions of the west part of Kazakhstan and the second layer was sand. The height of the first layer was 50 cm, the height of the second layer was 15 cm.

In the geotechnical laboratory of the National University of Incheon (INU, South Korea), the physical and mechanical properties of frozen soils were determined. Mechanical properties determine the behavior of soils under load, as well as to calculate the size of the sediment base and the forecast. The strength index was the ultimate shear resistance, its value in accordance with the Coulomb's law is found by two parameters - the specific cohesion c and the angle of internal friction $\boldsymbol{\varphi}$. At the expense of the cementing effect of the ice containing in the pores the deformation-strength properties of frozen soils were tens and hundreds of times higher than the properties of thawed [11]. Freezing soil temperature T=-5℃, C $= \mathbf{25^o}$, $\boldsymbol{\varphi} = \mathbf{0.26}$ [12]-[19].

3.1 Model Test Box

Laboratory model tests were conducted in a box (Figure 1). The chamber size was 580 mm (length) × 380 mm (width) ×700 mm (height). Four sides of the box were made of steel planks, and covered with term materials [4].

The model test box was braced with angle irons to avoid yielding during soil placement and loading of the model foundation. The inside of the test box was made as smooth as possible to reduce friction with the edges of the model foundation during the application of load [4]-[9].

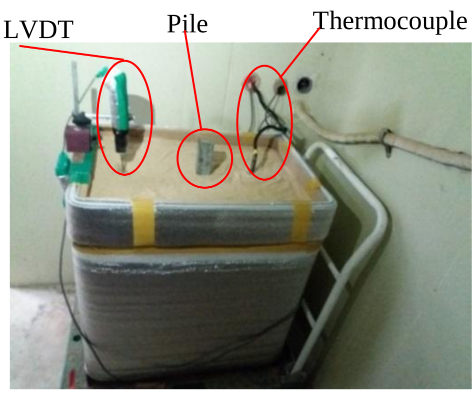

Fig.1 The photo of Model Test Box

3.2 Model concrete piles

Laboratory bearing capacity tests were conducted using a model pile foundation made from the concrete pile with reinforces, with dimensions of 600 mm (length, L) 40× 40 mm (thickness, t). To ensure rigidity, an aluminum plate having the same width as the model foundation was mounted on its top.

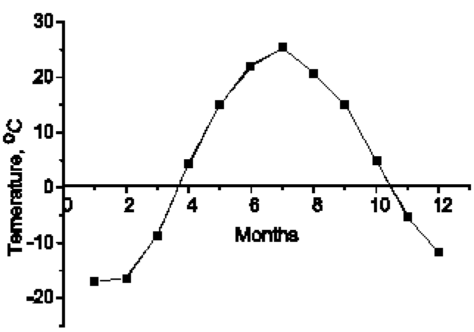

Fig. 2 Graph average temperatures each of months in Kazakhstan

The base of the model foundation was made rough by cementing a thin layer of sand to it with epoxy glue [4].

On the top of the foundation, a hole was made to ensure that the applied centric load during the tests remained vertical [4]. The model piles were kept for 28 days in order to achieve design strength. The allowable design stress in concrete should not be more than one-third of the minimum concrete strength. Model pile foundation was shown in Figure 3.

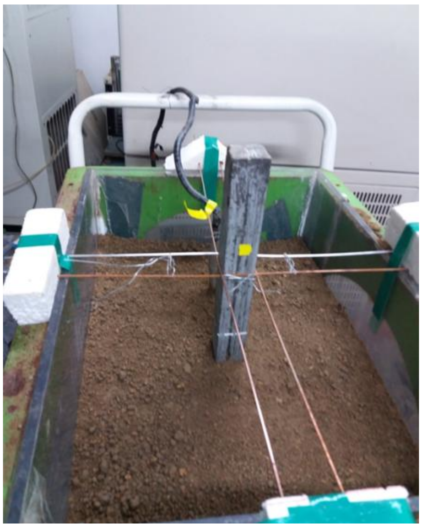

Fig. 3 Model of pile foundation in the Model Test Box (MTB)

Fig.4 Compaction procedure of soil ground

Figure 4 was shown that the preparation of the model soil was made by using each 10 cm layer compaction of soil ground in Model Test Box. A sample from each layer of the soil was taken to determine the density.

3.2.1 Conducting the freezing condition

To obtain frozen soil at temperatures of -5 ℃ and -10 ℃ in the chamber model soils stay in the freezing room (camera) until the temperature reached -5 ℃ and -10℃.

The depth of frozen soil was 14 cm. The temperature was -10℃, the heaving amount of soil ground was 3.1 mm.

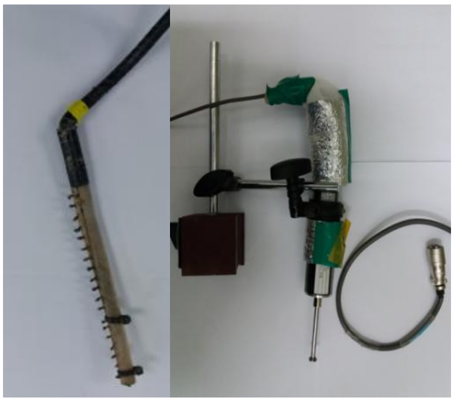

Fig.5Thermocouple T type and LVDT

Thermocouple T type was used to check the soil in chamber each of which is with the depth of 1cm, 2 cm, 5 cm, 10 cm, 18 cm, 19 cm. LVDT was for checking displacement of freezing soil on the laptop each time (Figure 5).

3.3 Conducting the experiments

Three series of experiments were carried out in the conditions of the geotechnical laboratory: the first series was for analysis of the stability of the pile and the interaction of the soil base with the pile on thawing conditions +20°C; the second and the third series were for determining the stability of the pile and the interaction of the soil base with the pile in the freezing soil -5°C, -10°C.

The increase of step-by-step loading of the pile foundations was held. Load step was equal to 0.01 N. The model of the pile foundation was loaded to achieve the total bearing capacity as shown in Figure 6.

Fig. 6 Experimental loading of model pile

3.4 Evaluation heaving soils

The tray with the ground, located in the refrigerating chamber at a temperature of - 10°C, -5 °Cand gradually cooled at the freezing of the upper layers of soil experienced swelling. During experiments every second shot meter readings and T type thermocouples LVDT, measuring the displacement of the soil surface.

The ground was capable of freezing with the side surface of the basement and lifting it due to the forces of frost heaving. Seasonal ground freezing is uneven [11].

Migration of moisture in the freezing ground was largely determined by the nature of freezing (speed, time, etc.). Therefore, migration and freezing were two interrelated processes that determine the intensity and magnitude of the deformation of the frost heave [9].

3.5 Numerical modeling the pile and soil base interaction vertical deformation in thermal changes

Temp/w was a finite element of a software product that can be used to model the thermal changes in the ground due to environmental changes, or due to the construction of facilities, such as buildings [8].

3.5.1 Application of numerical simulation for the calculation of piles in the seasonally frozen ground

Temp/w by presenting procedures involved in analyzing a geothermal problem. This program step-by-step define a problem, solved and analyzed the result. With the help of numerical modeling Temp/w was calculated two cases for determining bearing capacity of pile foundations in seasonally freezing soil ground. The working area was the size of the space available for defining of the geotechnical problem [8].

Case: a) In numerical modeling Temp/w for determining bearing capacity of pile foundation boundary conditions of ground-level T=-10℃ and T=-20℃.

Case: b) Bearing capacity of pile foundation in seasonally freezing soil was applied with ground level T=20℃.

The main reason for numerical modeling Temp/w was to made quantitative predictions compare alternatives; identify governing parameters; understood processes and train our thinking.

The finite element of numerical methods Temp/w was based on the divided small pieces of all construction and reconnecting all parts of construction then predicting the behavior of pile foundations during loads testing. Figure 8 was shown the mesh of soil ground.

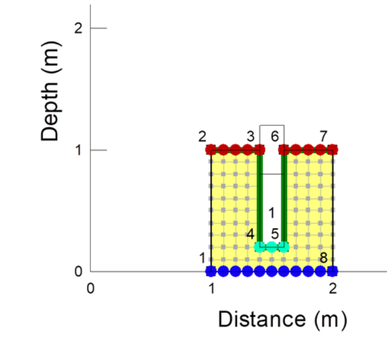

Fig.7 Graph of soil ground mesh

4 EXPERIMENTAL RESULTS

The results of the ultimate bearing capacity of pile foundations with a change of temperatures T=20°C,-5°C, -10 °Cwere presented in Table 1 [5].

Table 1 Results of the experimental test of piles in seasonally freezing soil

Test	L/D (cm)	Temperature, °C	Ultimate bearing capacity q_u, kN/cm^2
1	12	20	8
2		-5	9
3		-10	10.5

Model tests of piles in ordinary and frozen ground conditions showed different results.

In figure 8 presented results of static load, tests were the curves of load and settlement.

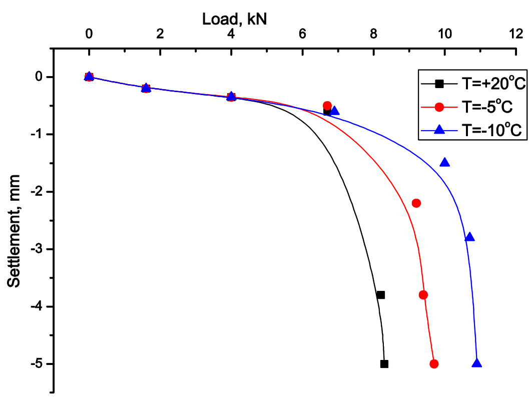

Fig. 8 Graph load-settlement of piles in seasonally freezing soil

The objective of the analysis was to compute the depth of the frozen beneath the surface of the soil of pile foundation after 3 months. The temperatures of soil surface were+10°C, +20°C; -20°Cfor a period 100 days. The ground surface was 3°C at a depth of 1 m.

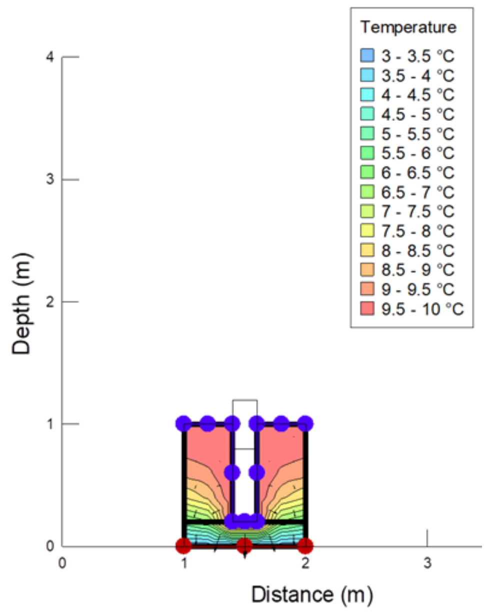

Fig. 9 Graph of ground level change T=10°C and depth

Figure 9 was shown the influence of ground level (T=10°C) on test loading of pile foundations. The settlement was 0.5 mm.

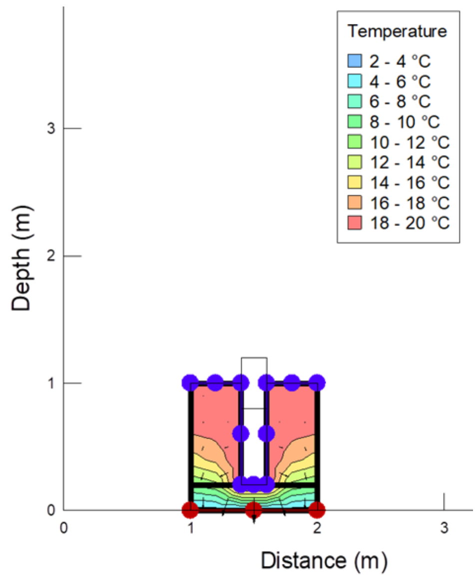

Fig.10Graph of change T=20°C and depth

Figure 10 was shown the changed behavior of pile foundations on test loading for T=20 °C. Settlement of pile foundation was the same for T=10 °C. It was important setting the boundary conditions in these zones as illustrated in figure 9, figure 10, figure 11. The solutions for freezing and non-freezing was identical the material properties for both frozen and unfrozen soils [8].

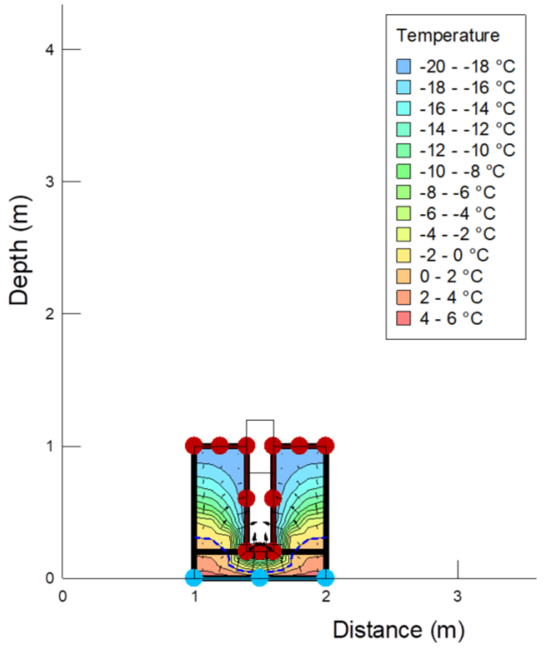

Fig.11Graph between change T=-20℃ and depth

Figure 11 was shown the influence of T=-20℃ on pile foundations. The settlement is 0.7mm.

Figure 12 was shown the frost heaving of soil at a temperature of -5 ℃. Settlement of pile foundation was the same for T=10 ℃ .The measurements were carried out with Thermocouple T type and LVDT at a depth of soil ground 1 cm, 2 cm, 5 cm, 10 cm, 18 cm, 19 cm.

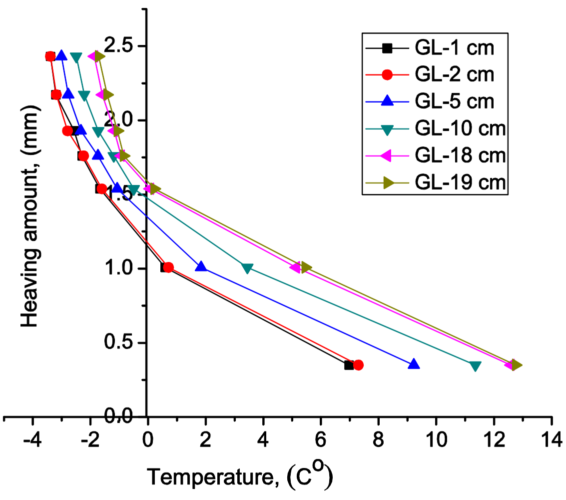

Fig.12 Frost heaving of the soil

The frost heaving of the experimental soil increased by 2.5 mm at a temperatureT=-5℃.

The first experiment was a pile load test in the non-freezing soil, so the settlement was 0.3 mm. The second experiment was a pile load test in freezing soil at temperature T=-5℃, the settlement was 0.5 mm. The third experiment was pile loading in freezing soil at temperature T=-10℃, the settlement was 0.6 mm.

Table 2 Comparison experiment results and numerical analysis of settlement of pile foundations

Temperature, ℃	Settlement, mm	
	Experiment	Numerical modeling Temp/w
-10℃	0,6	0,5
+20℃	0,3	0,28

Comparison results of pile field test, piles in frozen ground conditions showed an increase in the bearing capacity of almost 0.5 times greater than in the same length under normal conditions. This was due to the compression of the piles along the perimeter and the freezing of the soils along the sides in connection with the expansion and the pore pressure that occurs during freezing.

5 CONCLUSION

The purpose of the article was determined the bearing capacity of piles in the seasonally frozen period. Comparison of the bearing capacity and the settlement of 3 piles number No.1, No.2, No.3 in seasonally freezing soil showed that the bearing capacity and the settlement of piles No.2, No.3 in frozen soil increase compared to the bearing capacity and the settlement of pile No.1 in non-freezing soil ground.

At a temperature of -10 ℃, the results of the settlement were shown in the experimental part to be 16% more than the settlement in the results of numerical simulation of Temp/w.

At a temperature of +20℃, the results of the settlement were shown in the experimental part to be 7% greater than the settlement in the results of numerical simulation of Temp/w.

The data of an experiment and numerical studies of the interaction of piles with seasonal soils were important for the understanding of the mechanism of pile foundations in the above ground grounds.

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