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DETERMINATION OF THE FREEZING EFFECT ON UNCONFINED COMPRESSION STRENGTH AND PERMEABILITY OF SATURATED GRANULAR SOILS

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ABSTRACT: Artificial ground freezing usage gradually rises in civil engineering applications as a soil supporting system. However, many unknown fundamental parameters have been still waiting discovery, especially for granular soil. Granular soil can not carry its own weight during unconfined conditions. If water turns to ice that locates in the soil pores, it proceeds as a cementitious material. First step of design phenomena is to identify the material properties in geotechnical engineering. Within this scope, unconfined compression tests (UCC) and permeability tests are performed on frozen granular soils subjected to 1, 3 and 7 day-freezing periods to observe time effect. Experimental procedure are applied totally on 12 sand and gravel type of specimens with saturated cases after freezing application in the CDF/CIF freezing thawing machine. Stress - strain behaviors, ultimate load capacities and permeability of specimens are determined. This method will be used while taking undisturbed granular soil samples from the construction site.

Keywords: Artificial Ground Freezing, Granular Soils, Unconfined Compression Test, Permeability

1. INTRODUCTION

Soil supporting system is an essential component for geotechnical engineering in many soil projects. Undergoing applications are such as laterally loaded piles, retaining walls and sheet piles, braced cuts for deep excavations and NATM or classic tunnel boring methods for tunnel constructions. All of them require dewatering if ground water table creates a risk in the site. Artificial ground freezing (AGF) presents easy, safety, eco-friendly and economical (without initial cost of machines) solution and dewatering as well.

Many researchers have studied artificial ground freezing and its effects on the soil properties. However, limited study have been found in the literature about fundamental mechanical properties such as unconfined compression strength and permeability of saturated frozen granular soils under normal conditions. Unconfined compression test application on the unfrozen granular samples are impossible having to avoid the dispersion of solid particles along the lateral direction according to without confining pressure around the soil media. However, triaxial test can be applied to the granular samples after difficult sample preparation with using vacuum and gradually pressure increment as a cell pressure. Another methods of UCC tests and triaxial tests have been performed inside the modified cold state cells that regulates the environmental temperature at constant value according to undergoing studies. But, proposed approach involves the basic UCC test while room temperature effects to frozen specimens. Evaluation the results of easy and useful undisturbed sampling method without any modified cooling cell is purposed within this study.

Reference [1] presents that mechanical properties of frozen soil depends directly on water content. On the other hand, it is inversely proportional with the increase of consolidation pressure and sand content according to experimental results. Reconstituted soil samples that consist of silty - clay (inorganic clay of medium plastic) and sand (grain size ranged between 0.42 and 0.074 mm) mixtures were used during these tests. Sand content changes between 0, 10, 20, 30 and 50% of the total weight of solid material. Cylindrical specimens have 3.5 cm in diameter and 7 cm in height were used after subjected to 25, 50, 200 and 400 kPa consolidation pressures. Specimens were placed in the freezing chamber having a -14 ºC temperature for 24 hours freezing period. Reference [2] gives that the specimens were prepared at higher dry density having more uniaxial compression strength than lower ones at the same strain rate and temperature for saturated frozen soils as a result of cohesion according to result of given equation in the paper. Remolded silty samples are used. Maximum (1.111) and minimum (0.503) void ratios were kept at constant temperature in freezing cabinet. They preferred the Eq. (1) as a function of strain - temperature according to investigations on the saturated frozen silty soil with different parameter ranges between -2 to -15 ºC and 1.10^{-6} to 7.10^{-4} s^{-1}, temperature and strain values, respectively.

$$\sigma_f = \sigma_o^{'} \, (\theta/\theta_0)^i (\dot{\varepsilon}/\dot{\varepsilon}_0)^m \quad (1)$$

Where; θ_0 is reference temperature, θ is negative temperature, σ_f is axial compression strength, $\acute{\varepsilon}$ is strain rate, $\acute{\varepsilon}_0$ is reference strain rate and m is the parameter changes due to dry density and temperature of samples. Reference [3] shows that ductile deformation type occurred at low water content in partially frozen soils. On the other hand, brittle type of failure was seen on frozen soils that have high water content. Residual compressive strength of frozen soils are independent of their dry unit weight at a particular temperature. However, it increases with decreasing temperature according to peak. Compressive strength observation was studied on saturated fine grained frozen samples with respect to the water content, dry unit weight and temperature parameters. Reference [4] indicates that some of the following practical advantages and disadvantages within the compressive strength observation under the effect of strain rate for both confined (-6 ºC to -10 ºC) and unconfined cases (-2 ºC to -15 ºC) of artificially frozen sand samples. Perfectly end platen preparation are not necessary for frozen soils. Soft platen material can eliminate the minor irregularities after freezing. Relatively short frozen cylindrical shaped samples can be used during strength determination after core drilling from construction site. Compatible platen usage reduces the stiffness of the test system and makes difficult to control test parameters.

In the AGF phenomena, free water that moves in the soil voids turns to ice as a cementitious material. So, concrete like material is obtained easily. But, many factors affect the artificial ground freezing applications in the site. For example, freezing duration, amount of given energy, used machine capacity, location of construction site as a function of weather temperature, construction period, cooling liquid and sizes of circulation pipes. In this study, effect of soil type and freezing duration on the uniaxial bearing capacity and permeability of saturated frozen granular soils were studied.

2. MATERIAL PROPERTIES

Gravel and sand type of soil materials were used during experiments. First of all, fundamental geotechnical tests were performed. Figure 1 shows the grain size distribution curve as a result of sieve analysis. Physical properties of soil samples represent the common values of poorly graded granular materials as shown in Table 1.

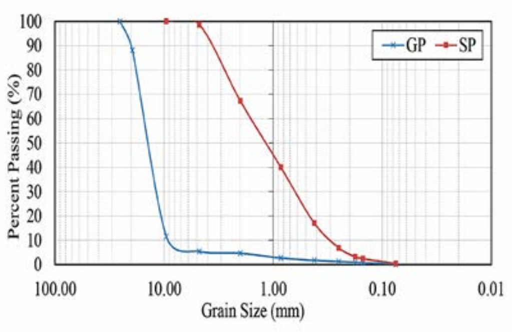

Fig. 1 Grain size distribution curve for samples

Table 1 Soil properties

Soil	I	II
Specific Gravity	2.54	2.58
Gravel (%)	94.60	1.30
Sand (%)	5.20	98.30
Silt & Clay (%)	0.80	0.40
D_{10}	9.10	0.30
D_{30}	11.00	0.62
D_{60}	15.00	1.60
C_u	1.65	5.33
C_c	0.89	0.80
Void ratio (e)	0.94	0.54
Type of Soil	GP	SP

Permeability is used to understand the water flow in soil media. This physical property affects the bearing capacity, settlement, shear strength and liquefaction potential of construction area. Proper dewatering process requires if ground water flow exists. Capacity of discharge increments also makes the removing of water difficult. In this case, AGF presents the useful dewatering technique even eliminating the seepage. Table 2 gives the common coefficient of permeability values [5].

Table 2 Coefficient of permeability values [5]

Soil Type	k (cm/sec)
Clean Gravel	1.0 - 100.0
Coarse Sand	1.0 - 0.01
Fine Sand	0.01 - 0.001
Silty	0.001 - 0.00001
Clay	Less than 0.000001

3. EXPERIMENTAL PROCEDURE

Cylindrical specimens, 70 mm in diameter and 130 mm in height, were used. Six specimens were selected for unconfined compression tests and the others were used for permeability tests as shown in

Fig. 2. Solid particles were placed without any compaction energy by using gravitational energy. Then, freezing process was applied after saturation. First, unfrozen specimens were kept at -10 ºC during 1 day before the tests as pre-freezing period. Then, specimens were removed from molds with hydraulic machine.

Fig. 2 Unfrozen gravel and sand specimens

Freezing of soil particles with lateral displacement under anisotropic and known principle stress is expected situation during both natural and artificial freezing process. However, freezing experiments are generally realized with eliminating displacement by using molds in the laboratory [6]. Accordingly, frozen specimens show volumetric expansion along the longitudinal direction from the top surface. Surface was levelled with spiral grinding machine as shown in Fig. 3.

Fig. 3 Surface levelling of expanded part

The prepared specimens were kept at constant temperature as -15 ºC in a CDF / CIF freezing thawing machine during 1, 3 and 7 days as shown in Fig. 4. In spite of the apparent abundance of published experimental data on frozen soil behavior, some questions has not been answered, yet [6]. Some of them are such as unconfined compression strength and permeability change according to under thawing effect at room temperature after short term freezing periods.

Fig. 4 CDF/CIF freezing thawing machine

Six samples were subjected to axial compression force with 1.0 mm/min loading rate to perform the unconfined compression test. Load rate was selected higher than normal value within the scope of eliminating the quick thawing process. Plexiglas were used at the top and at the bottom caps at -15 ºC. Stress and strain values were collected with using Utest data acquisition system as shown in Fig. 5. Other six samples were used to perform permeability tests. Constant head permeability tests were performed at 300 mm constant head. Amount of water was collected simultaneously during 30 minutes for each specimen as shown in Fig. 6. Coefficient of permeability values are calculated according to these values.

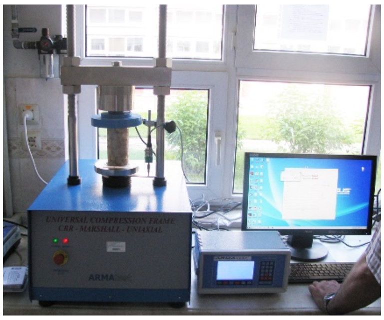

Fig. 5 Unconfined compression test device with data acquisition system

Fig. 6 Permeability test device

4. RESULTS

Soil is known as heterogeneous material that consists of solid particles, air and water. So, unexpected stress and deformation behavior can occur inside the soil phases. Arrangement of particles is less important for frozen soil according to cementitious ice formations. Fine grained soil has more stress and strain capacity than coarse grained soil according to the results of unconfined compression tests as shown in Fig. 7. Unconfined compression strength values of poorly graded gravel specimens are determined as 1.64, 2.92 and 3.49 MPa for 1 day, 3 days and 7 days freezing periods, respectively. On the other hand, strength values are obtained as 2.94, 3.04 and 5.13 MPa during same periods for poorly graded sand specimens. Compressive strength of frozen samples increases with increasing time up to 7 days. Strain rates are approximately similar for sandy specimens. However, it is inversely proportional with increment of freezing period for gravel type of soils. Curves of both 3 days specimens and 1 day specimen of sandy soil are similar. Lower strength and higher strain values of 1 day gravel sample rises from partially freezing of solid particles and ice lenses.

All of the frozen specimens are started to thaw around 5 minutes as a result of constant head permeability tests on the frozen samples. If the freezing time increases, permeability of frozen sandy specimen decreases. However, coefficient of permeability value is inversely proportional with freezing time, unexpectedly. Coefficient of permeability of granular sample is about 5 times greater than the other one. Permeability test results of the samples are shown in Fig. 8.

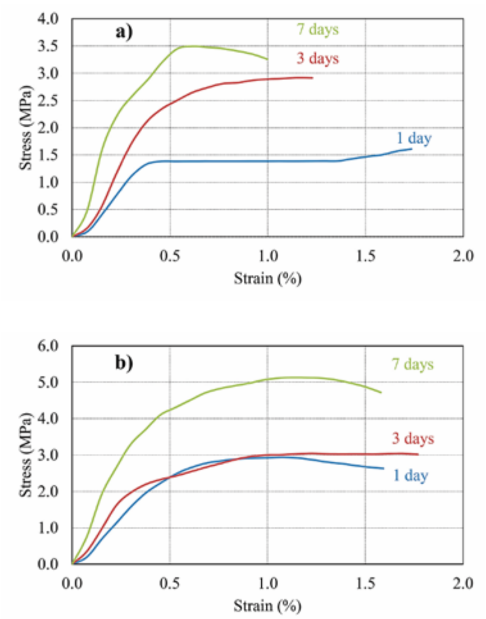

Fig. 7 Stress - strain behavior of frozen granular specimens, a. Poorly graded gravel, b. Poorly graded sand

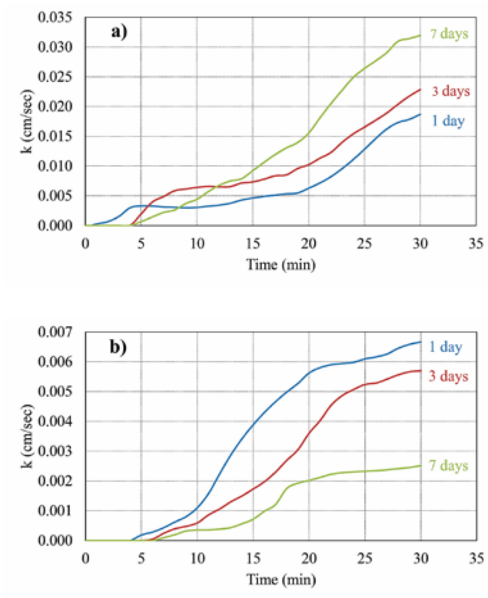

Fig. 8 Change in coefficient of permeability for frozen granular specimens, a. Poorly graded gravel, b. Poorly graded sand

Observed failure modes at the end of the compression tests are completely different for gravel and sand type of samples. Vertical cracks are occurred on the frozen gravel surfaces as shown in Fig. 9a. On the other hand, horizontal cracks are formed on the sand type of specimens as shown in Fig. 9b. All of the failure models are similar to concrete type of brittle material rather than soil like material. However, finer graded frozen soil material has more ductility than the coarser one.

Fig. 9 Failure mode and observed cracks on the samples a. gravel sample, b. sandy sample

Bursting behavior can occur on the frozen samples under very fast or slow loading rate [5]. If loading rate is too slow, ice turns to water - ice mixtures. If loading rate is too fast, frozen soil sample easily disperse due to the lack of cohesion or any finer material. Bursting phenomena was observed on the trial specimen under fast loading rate with using concrete compressive test machine as shown in Fig. 10.

5. CONCLUSION

In this study, experimental analyses of twelve saturated frozen granular samples are examined with 1 day, 3 days and 7 days freezing time effect. The change in unconfined compression strength and coefficient of permeability values are presented. Based on the results, the following conclusions may be drawn:

Both brittle and ductile deformations and different strain values can be observed under same loading conditions according to the degree of water freezing in the pores or amount of fine material. Strength and deformation varies by the using area of the artificial ground freezing in the geotechnical projects.

Compressive strength of frozen samples increases with increasing time up to 7 days. Strain rates are approximately similar for sandy specimens. However, it is inversely proportional with increasing freezing time for gravel type of soils.

Fig. 10 Bursting formation under fast loading rate

All of the frozen specimens are started thawing around 5 minutes. If the freezing time increases, permeability of frozen sandy specimens decreases. However, coefficient of permeability value is inversely proportional with freezing time, unexpectedly. Coefficient of permeability for granular sample is about 5 times greater than the other one.

Presented values can be used for modelling of geotechnical projects both using finite element software and theoretical calculations as well.

6. ACKNOWLEDGEMENTS

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