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Investigation of Frozen Soil Behavior under Unconfined Compression Test

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ABSTRACT: Frozen sand soils are often observed in underground urban and engineering constructions in cold climates. Artificial ground freezing is a soil improvement technique, and soils in coastal areas are mostly comprised of poorly-graded sand with low moisture and temperature. Thus, it is required to explore the effects of different factors on the strength of frozen soils in such areas. In addition, the freezing age required to obtain sufficient strength is studied. The present study investigates sand from the Shorabil Lake shore in Ardabil, Iran, frozen in cold seasons. To evaluate the effects of the soil grain size, sands with gran sizes of 0.15 and 0.25 mm mixed with clay in different ratios were employed. Uniaxial compressive testing was implemented to measure the unconfined compressive strength of ten soil mixtures with four moisture contents. Thus, a total of 40 mixtures were studied at three freezing ages. The stress-strain curves showed strain softening. The specimens had almost the same strength at shorter freezing ages. As the freezing age increased, different stresses were observed due to the clay content; the strength of a specimen with a low clay content remained almost unchanged as the freezing age increased. The specimen with a clay content of 50% and a moisture content of 15% had a strength of 205.5 kPa at a freezing age of 24 h and 283.8 kPa at a freezing age of 72 h. Also, the specimen with a clay content of 10% and a moisture of 15% was found to have strengths of 265.4 and 283.8 kPa at the freezing ages of 24 and 72 h, respectively. Several specimens underwent an up to 36% decline in strength as the sand grain size decreased; however, the trend was still the case, and the specimen with 30% clay showed the highest strength in most cases.

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1- Introduction

In cold regions and in severe cold, the water among the soil particles is frozen. From a material science perspective, frozen soil consists of four parts: solid soil particles, ice, liquid water and gas. Frozen clay can contain liquid water up to -110°C. On the other hand, when ice fills most of the pores, the mechanical behavior of frozen soil will reflect the behavior of ice. The behavior of frozen soil with increased hydrostatic pressure is influenced by a combination of mechanical and thermodynamic effects, the first of which implies the division of stress and the latter on melting and pressure phenomenon [1, 2].

Freezing water increases ice pressure and reduces the cavity pressure. Due to the reduction of water pressure digging on the frozen front, the water moves from the underlying layers to the frozen borders. Even if the soil has no access to shallow water, the pressure of large harmful cavities and movement of water causes vertical contractile cracks to form in the soil beneath the frozen front. As the frozen front moves forward, these cracks are filled with ice. When the ice melts, the cracks become a conduit for the flow of water and the permeability of the soil increases [3-5].

2- Methodology

The used materials are sand and clay with different combinations. Soil specifications are listed in "Table (1)". Sand is mixed with uniform aggregation with 11%, 21%, 31%, 41% and 21% clay and the obtained samples are mixed with moisture content and prepared differently. The aggregation of the samples is carried out according to T27-AASHTO standard. The composition of the soils and grading diagram are in Figure 1.

Table 1. Soil properties consumed in the study.

Soil type	LL	PL	PI	G_s	γ_d
sand	-	-	-	2.65	2.14
clay	33	30	20	2.5	1.8

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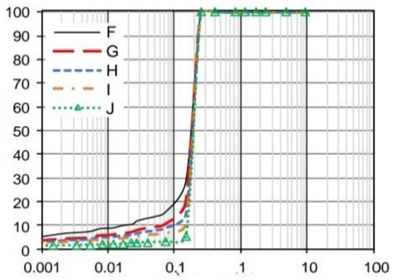
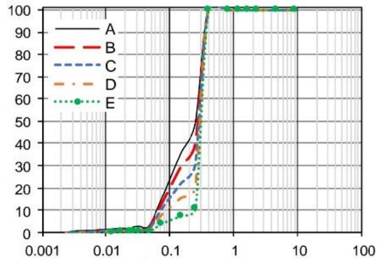


(A)



(B)

Fig. 1. Grain size distribution curves in two combinations A, B.

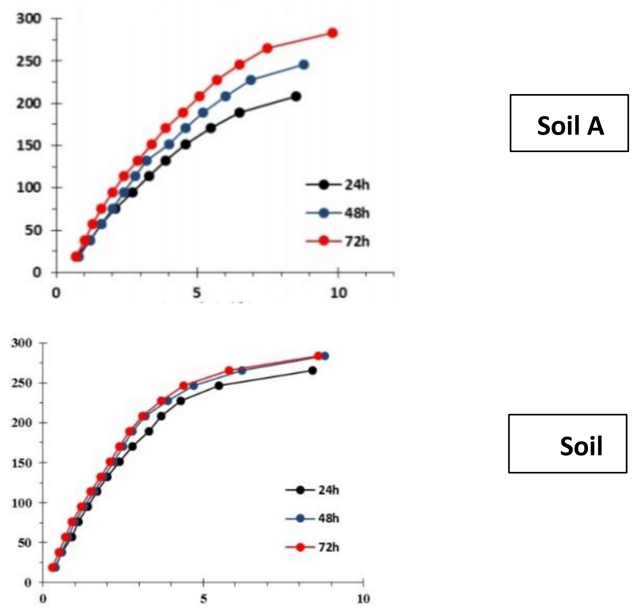


Fig. 2. Effect of freezing time for soil type A and E at 15% moisture content.

In the "Form (1-A)", the aggregation diagram of five types of soils A, B, C, D and E resulting from the mixing of clay with 1.22 mm sand is observed. According to the figure, the straight line in the diagram related to the sand is uniform, which after adding clay, some to the left of the diagram has been curvy and the starting point of this curvature indicates the percentage of clay added. In the "Form of (1-B)" the aggregation diagram of five types of soils F, G, H, I and J, which is the result of mixing with 1.12 mm sand, is also shown in this diagram. In general, a part of the curve is almost direct which is related to sand and the other part is related to clay. In the meantime, it is explained that the sandy soil is uniform in coastal areas. Beside the Shorabil lake, it is observed and it is exposed to frost at temperatures below zero degrees, and we also know the artificial freezing method is used in areas close to surface waters to create a type of temporary soil treatment.

2- 1- Laboratory Model

Due to uniform sand, in moisture less than 8%, the sample does not have sufficient density and is disintegrated. In humidity above 15% due to condensation, water is drained from the end of the sample. Therefore, after mixing with 8%, 10%, 12% and 18% moisture in the form of cylinders with a length to diameter ratio of about 3(this ratio in the uniaxial test standard between 2 and 3(which is specified in Figure 4, prepared and then stored at -22°C for 24 hours. Soil freezing temperature is about -2.0°C in studies and researches. It can vary slightly according to the amount of clay. However, the soil was removed from the mold after 12 hours.

3- Preparation of samples

After placing the samples in the device, the force was applied with a strain rate of 1 min/mm, then the axial stress diagrams were compared to the meeting was drawn. The results indicate that the sample with a combination of 30% clay, in most cases tolerates more stress, the sample with a combination of 10% clay has the minimum stress and then the sample is located with 20% clay. However, in 15% humidity, this rate is disturbed and the sample of 10% clay has the highest stress. It should be noted that the frozen sample is more quickly with less clay and more ice lenses are formed within 24 hours. Nevertheless, at the time of testing, the samples with more clay, less heat transfer and ice lenses melt a slower. Most samples with 10% and 20% clay were crushed within 2 minutes (after removing from the freezer), it is not possible to test on them.

4- Results and Discussion

4- 1- Effect of sand size

By keeping the moisture content and freezing time in soil samples, changes of uniaxial resistance with different percentages of sand were measured and the results are shown in Figure 2. In general, in the bigger size and amount of sand materials, the more upward curves are. In other words, increasing the amount of coarseness increases strain energy and the uniaxial resistance of the sample. As the sand size is smaller, the resistance of the samples has decreased by about 36%. This value, varies by 2% in different samples.

4- 2- Effect of freezing age

According to the experiment results, the resistance of frozen soil samples increases with increasing freezing age. However, the effect of freezing age on samples with high clay percentage is because the lower the amount of sand consumed, the lower the speed of ice lens formation. In soil A, with the highest clay content, the growth of resistance with increasing freezing ages 24, 42 and 22 hours, it is generally known that the amount of sand used increases. However, in the case of the effect of aging, the freezing age decreases so that in E mode, it can be said that the resistance of the sample has remained constant during different days and in A state, the resistance of the sample has gradually increased.

4- 3- Effect of moisture percentage

The increase of the resistance in samples varies according to the freezing period. The more the moisture of the samples increases, the more influential the freezing age is because of the amount of moisture that freezes increases. On the other hand, the larger the soil mixture has a higher specific surface area, the more resistance will be made, and with increasing moisture of this specific surface, in this case, the interaction between soil and ice particles is in the best possible condition, and as a result, the resistance of frozen samples grows more. Increasing moisture in samples containing more sand in the shortest time increases resistance, but in samples with less sand, this process is slow because the amount of frozen water with high clay is lower.

5- Conclusion

The main results of this study are as follows:

1- Stress-axial strain curve in all samples shows strain softening state. In an age of freezing, as the amount of sand increases, the strain energy decreases.

2- As the humidity increases, the number of ice lenses also increases, and because ice is the cause of soil particle adhesion, therefore soil resistance increases.

3- Based on the resistance during different ages of freezing, the higher the soil sample exposed to moisture, the higher the bonding rate. The formation between ice and soil particles increases, and eventually, the existing resistance increases

4- The higher the amount of sand, the faster the freezing takes place, and with the increase in the freezing duration, the more clay samples, the yield. They have better. So that the sample A has the highest clay content, from 212.2 kPa resistance for 24 hours to 2 kPa/223 resistance in the period of 22 hours has arrived (in the highest humidity); in other words, about 36% increase in resistance.

References

[1] D. Chen, W. Ma, G. Li, Z. Zhou, Y. Mu, A long-term strength criterion for frozen clay under complex stress states, Cold Regions Science and Technology, 176 (2020) 103089.

[2] N. Girgis, B. Li, S. Akhtar, B. Courcelles, Experimental study of rate-dependent uniaxial compressive behaviors of two artificial frozen sandy clay soils, Cold Regions Science and Technology, 180 (2020) 103166.

[3] W. Fei, Z.J. Yang, Modeling unconfined compression behavior of frozen Fairbanks silt considering effects of temperature, strain rate and dry density, Cold Regions Science and Technology, 158 (2019) 252-263.

[4] F. Hou, Y. Lai, E. Liu, H. Luo, X. Liu, A creep constitutive model for frozen soils with different contents of coarse grains, Cold Regions Science and Technology, 145 (2018) 119-126.

[5] Z. Zhou, W. Ma, S. Zhang, Y. Mu, G. Li, Experimental investigation of the path-dependent strength and deformation behaviours of frozen loess, Engineering Geology, 265 (2020) 105449.

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