Physical Modelling in Geotechnics

Stabilization of silty sand with CSA cement under freeze-thaw cycles

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ABSTRACT: The integrity of the infrastructures built on weak soils (e.g., silty sand) can be easily damaged, due to the low quality of soil, such as poor stability, low strength, and easy deformation. In cold regions, the problem of weak soils is further exacerbated by freeze-thaw cycling, as lower temperatures can easily break down the natural soil structure, resulting in reduced soil strength. These soil properties can be improved by exploiting soil stabilization techniques with ordinary Portland Cement (OPC). However, due to the issue of OPC producing a significant amount of carbon dioxide emission, calcium sulfoaluminate (CSA) cement that has a lesser carbon footprint can be used. This study aims to conduct comprehensive laboratory work to assess the effectiveness of the soil stabilization method using CSA cement for the improvement of properties of silty sand. For this purpose, samples were prepared at optimum moisture content using different cement content, 3%, 5%, and 7%. Unconfined compressive strength, and ultrasonic pulse velocity testing were performed on the stabilized soil specimens cured for 3, 7, and 14 days under freeze-thaw cycles. The test results show that the strength of the samples increases with the increase of the cement content, but strength loss can be observed with the increase of freeze-thaw cycles. Overall, the use of CSA as a stabilizer for silty sand would be useful to achieve sufficient strength and meet the requirements subgrade.

Keywords: soil stabilization, calcium sulfoaluminate cement, freeze-thaw cycle, silty sand.

1 INTRODUCTION

In regions with a cold climate, soils undergo cyclic freezing and thawing, which subsequently leads to a change in the structures and properties of the soil. The effect of freeze-thaw cycles on soil, especially on problematic soils, can lead to loss of strength, volume, compressibility, bearing capacity and microstructure. Such soil damage causes the collapse of the infrastructure built on them. This can be avoided by improving soil characteristics with a soil stabilization method. To improve the engineering properties of the soil, the method of chemical stabilization has been considered effective for the soil subjected to cyclic freezing and thawing (Shooshpasha and Shirvani, 2015; Zhang et al., 2019). Several research papers have examined the effectiveness of various additives in improving soil performance by evaluating the mechanical and physical properties of treated soil subjected to freeze-thaw cycles. Among the existing soil additives, ordinary Portland cement (OPC) is the most commonly used. However, in terms of cost and environmental impact, OPC has become less attractive. Therefore, the use of alternatives to replace OPC is currently preferred. For example, calcium sulfoaluminate (CSA) cement can replace OPC, as it has already been studied for soil improvement purposes (e.g., quick repair) by several studies under various conditions. (Subramanian et al., 2018; Vinoth et al., 2018; Subramanian et al., 2019; Moon et al., 2020; Bisserik et al., 2021; Jumassultan et al., 2021). This study aims to investigate the effectiveness of CSA cement treatment to stabilize silty sand subjected to freeze and thaw cycling. To evaluate the performance of weak soil treated with CSA cement, ultrasonic pulse velocity (UPV) and unconfined compressive strength (UCS) freeze-thaw cycle tests were performed.

2 EXPERIMENTAL WORK

2.1 Materials

The material used for this study is natural soil, calcium sulfoaluminate (CSA) cement, gypsum and water. Natural soil used in this study was obtained from an open-cut excavation in Nur-Sultan, the capital of Kazakhstan. The main physical properties of the soil are shown in Table 1. Based on the Unified Soil Classification System (USCS), the soil is defined as a well-graded sand with silt (SW-SM).

Table 1. Physical properties of the soil used in this study.

Property	Value
D_{10} (mm)	0.11
D_{30} (mm)	0.55
D_{60} (mm)	1.8
Coefficient of curvature (C_c)	1.53
Coefficient of uniformity (C_u)	16.36
USCS classification	SW-SM
Plastic Limit (%)	40.35
Liquid Limit (%)	44.31
Plasticity Index (%)	3.96

The CSA cement used as a stabilizing binder in this study is mainly composed of ye'elimite, belite, and gelignite. Previous studies have shown that partial replacement (30%) of CSA cement with gypsum will result in a high initial strength gain in the treated soil (Subramanian et al., 2019). Therefore, 30% of the CSA cement was replaced with gypsum.

Table 2. Standard Proctor Test results.

Cement content	Optimum moisture content (%)	Maximum dry density (kN/m^3)
0%	16.5	1.75
3%	20.8	1.67
5%	21.0	1.62
7%	22.0	1.56

2.2 Sample Preparation

The cement-soil mixture was prepared at an optimum moisture content (OMC) defined from standard Proctor test (ASTM/D698, 2007). The results of OMC and maximum dry density (MDD) are shown in Table 2 for the soil samples with 3%, 5%, and 7% cement contents, which are 20.8, 21.0, and 22.0, respectively. Moreover, the OMC of untreated soil was defined in order to check the effect of cementation. From the obtained results, it can be observed that with the increase of cement content, the maximum dry density decrease, and optimum moisture content increases.

For the preparation of the mixture to make samples, oven-dried soil was used. The prepared mixture was compacted in the mold in three layers. Each layer was compacted 25 times by a hand rammer, and top and middle layers were scarified in order to ensure contact between layer layers. Cement-treated soil samples were prepared in a mold with a diameter of 50 mm and a height of 100 mm. Then, the samples were cured for 3, 7, and 14 days at room temperature.

2.3 Experimental methods

After the completion of the curing period, the soil specimens were placed into the freeze-thaw chamber. The freezing temperature was –20 °C since it is the minimum temperature of the soil in Nur-Sultan, Kazakhstan (Askar and Zhanbolat, 2015), and the thawing temperature was taken as the room temperature (23 °C), based on previous studies (Ding et al., 2018). Freeze and thaw times lasted 12 hours each. The duration of one freeze-thaw cycle was 24 hours. Samples were tested for 1, 3, 5, 7 and 10 freeze-thaw cycles.

After cyclic freezing and thawing, an ultrasonic pulse velocity test (UPV) was performed. The UPV test is a non-destructive test since the test can be repeated several times for the same sample at a different time (Reinhardt and Grosse, 2004). The UPV test is conducted using a portable ultrasonic nondestructive digital indicator tester (PUNDIT), where the test is applied using two transducers with a diameter of 50 cm attached to the surface of samples. Before the start of testing, the device should be calibrated. The pulse velocity values are determined from the pulse traveled along the length of the sample (ASTM/597-09, 2009).

Following the UPV tests, an unconfined compressive strength (UCS) test was conducted to evaluate the mechanical properties of the soil. The UCS test was based on ASTM/2166 Standard (2003). For the analysis of the UCS test results, the average of the results of 3 samples was used in order to get more reliable results.

3 RESULTS AND DISCUSSIONS

Fig. 1 shows the results of UPV testing for 3, 7, and 14 cured samples under cyclic freezing and thawing. It can be seen that with the increase of freeze-thaw cycles, the pulse velocity values decrease. In addition, it can be noted that the UPV value of soil samples with 7% cement content considerably decreased after the 7th freezing and thawing cycle by 80 % (Fig 1. (a)). Such a reduction in the UPV values can be explained by the effect of cyclic freezing and thawing on soil samples. The impact of cyclic freezing and thawing causes the formation of microcracks and an increase in the volume of voids, which leads to a change in the structure of the samples. This will reduce the ability of the sample to transmit ultrasonic pulses.

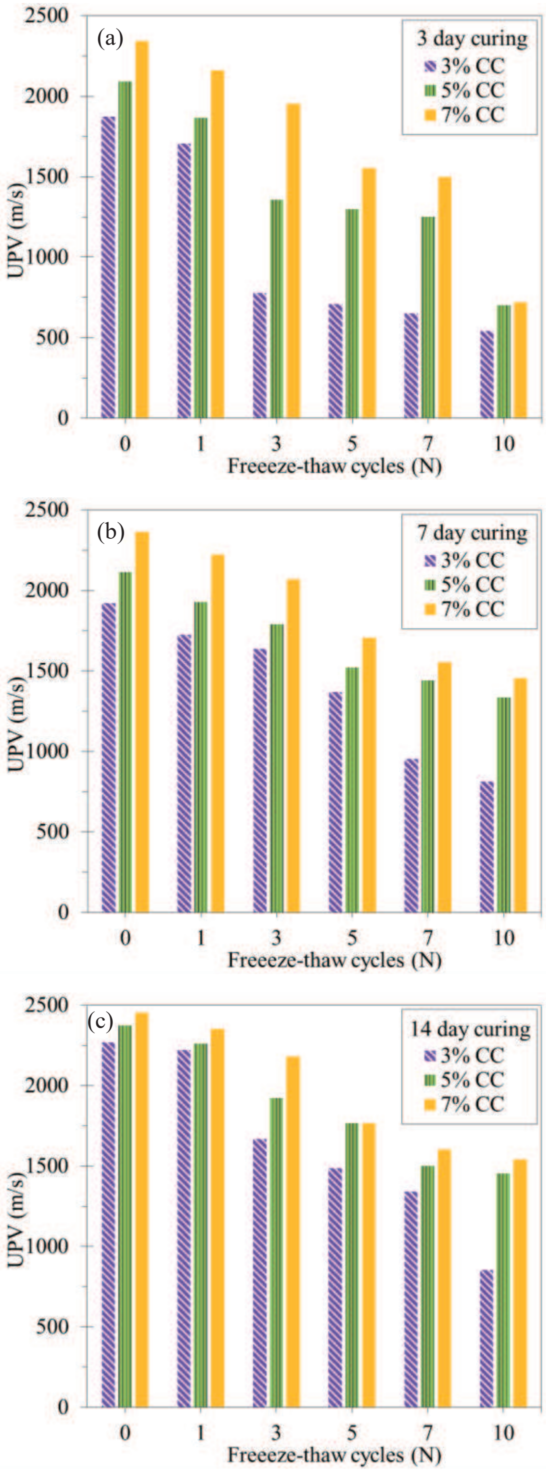

Fig. 1 UPV test results for (a) 3, (b) 7, (c) 14 day cured samples.

Moreover, there is an increase of pulse velocity with the increase of cement content from 3% to 7%. Furthermore, the increase in pulse velocity can be observed with the increase of curing days. For instance, the pulse velocity values increased from 1872 m/s to 2340 m/s, 2090 m/s to 2373 m/s, and 2340 m/s to 2453 m/s, with the increase of curing days from 3 to 14, at 3%, 5%, and 7% of cement content, respectively. Such increase in UPV values can be explained with the effect of cementation. Thus, increasing the cement content increases strength.

Fig. 2 illustrates the results of the UCS test for 3, 7, and 24 days cured cement-treated samples exposed under cyclic freezing and thawing.

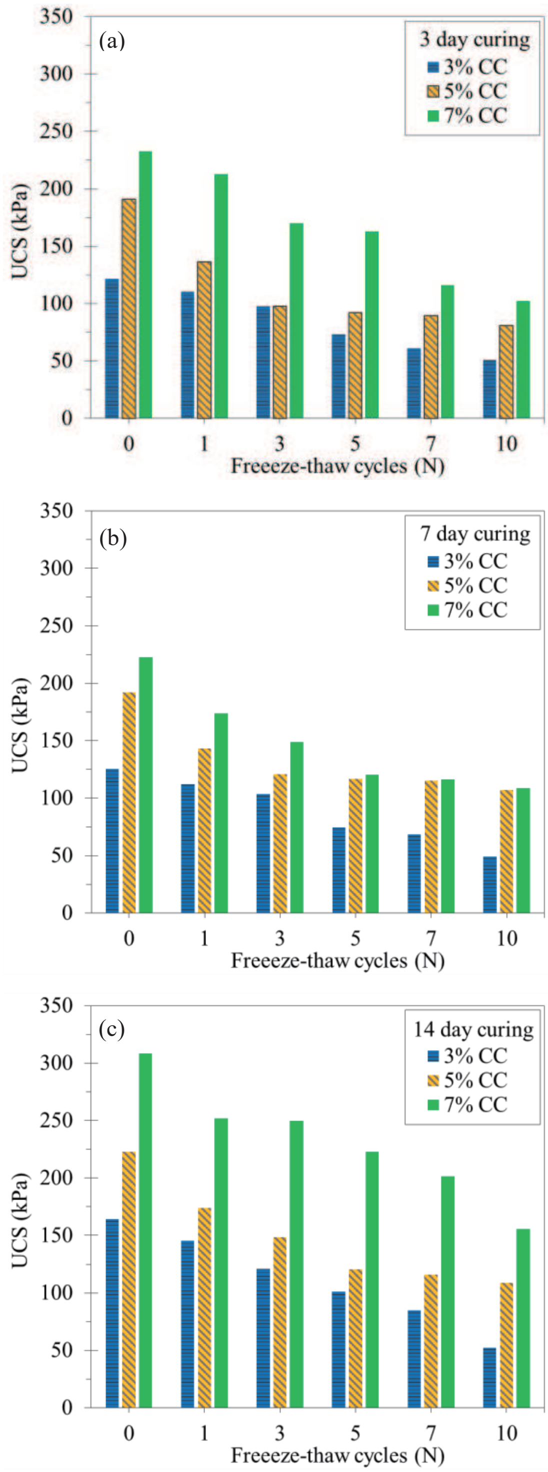

Fig. 2 UCS test results for (a) 3, (b) 7, (c) 14 day cured samples.

The results of UCS tests show the same trend as the results of the UPV test. Loss of strength is observed at all curing periods, with increasing freeze-thaw cycles. The strength values of soil samples without exposure to cyclic freezing and thawing have shown an increase in strength with the increase of cement content and curing days. This can be explained by the cementation of soil, due to the hydration of gypsum and belite in the CSA cement (Glasser and Zhang, 2001).

In addition, exposure to freezing and thawing negatively affects the strength of soil samples. It can be explained by the formation of ice crystals during freezing, which melts after the thawing process that further leads to the shrinkage of soil samples. These results are consistent with the results of previous studies that examined the effect of cyclic freezing and thawing of cement-treated soil samples. (Kamei et al., 2012; Liu et al., 2016; Jumassultan et al., 2021).

4 CONCLUSIONS

This paper is conducted to assess the impact of cyclic freezing and thawing on the mechanical and physical properties of silty sand stabilized with CSA cement. For the evaluation freeze-thaw effect and treating method, UPV and UCS tests were performed. The main findings of the research were:

- By increasing the number of freezing and thawing cycles, the UPV and UCS values decreased for all samples with 3%, 5%, and 7% cement content, and were cured for 3, 7, and 14 days at dry conditions.
- The addition of cement improves the soil performance and with the increase of cement content, the strength values also increase.

In the future, other engineering parameters, such as durability, resilient modulus, and microstructure of soil should be examined with the laboratory testing and numerical simulations to deeply understand the effectiveness of soil stabilization technique applying CSA cement.

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