Freeze-thaw behavior of fine grained soils subjected to surcharge loads

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ABSTRACT: In cold climate zones, the shallow foundation soils layered below many civil engineering constructions such as highways, railways, irrigation channels are subject to freezing-thawing cycles under surcharge loads. In this study, to represent such soils the freeze-thaw tests have been carried out for the situation where a surcharge load is applied on the specimens in addition to the traditional method where there is no load on the specimens. The experiments have been conducted on a fine-grained soil specimens prepared by the dynamic compaction under standard proctor energy. In the experiments conducted per the traditional method the unconfined compressive strength values of samples were determined after 1, 5 and 10 freeze-thaw cycles. Then the freeze-thaw experiments were repeated while a load representing 25% of these values was on the samples. The freeze-thaw resistances of the samples were determined by both methods. It was observed that the freeze-thaw resistance values of soils under a surcharge load were less than those found by the traditional method.

1 INTRODUCTION

Soils in predominantly cold climate zones are subject to freeze-thaw at least once in a year. This phenomenon affects negatively some of the engineering properties such as water content, bearing capacity and permeability of fine-grained soils. When fine-grained soils are subject to freezing, ice particles are formed at the largest pores first where the freezing point is highest;, subsequently, water in the smaller pores freezes (Erol 2007). The volume increase by the freezing of the water forms new pore cells in the fine grain soils and consequently the shear strength of the soil is decreased to a large extent. This is likely to cause certain damages in several superstructure elements such as highways, railways, earth fills and irrigation channels.

In the design and construction of structures in the zones, which remain seasonally below 0^o C, the mechanical properties of the soil, which will be subject to this thermal situation, need to be known (Cruzda & Hohmann 1997). In most of the studies conducted on the engineering properties of soils subjected to the freeze-thaw cycles, some additives and fibers have been used (Zaimoğlu 2010; Yarbaşı et al. 2006; Hazirbaba & Gullu 2010; Ghazavi & Roastaie 2010). Also, most of the studies in the literature have been conducted on fine-grained soils, which have not been subjected to any surcharge load. However, in cold climate zones the soils layered below the many civil engineering structures such as highways, railways, irrigation channels are subject to freezing-thawing cycles under the load of these superstructures.

The purpose of this study is to compare the freeze-thaw behaviour of fine grain soils under surcharge loads with the situation where they are not subject to any surcharge load. Therefore, this study was performed in two phases. In the first phase, freeze-thaw experiments were conducted in accordance with the traditional method on specimens prepared in the laboratory (in a situation not subjected to loads) and the freeze-thaw resistances (i.e., grain losses after freeze-thaw cycles) and their unconfined compressive strengths have been determined at the end of the 1^{st}, 5^{th} and 10^{th} cycles. In the second phase a load representing 25% of the unconfined compressive strength was applied uniformly on the specimen. The freeze-thaw experiments were repeated under this load. The results of the experiments have been compared and discussed.

2 MATERIAL AND METHODS

The clay soil used in the study has been obtained from the Erzurum-Oltu area. Some engineering proprieties of the clay soil have been given in Table 1 and the grain size distribution curve in Figure 1.

Table 1. Some properties of clay used in tests

Properties	Value
Specific Gravity, G_S	2.67
Liquid Limit, w_L (%)	83
Plastic Limit, w_P (%)	34
Plasticity İndex, I_P (%)	49
Optimum Water Content[1], w_{opt} (%)	32.7
Max. Dry Unit Weight[1], γ_{kmax} (kN/m^3)	12.8
Unconfined Compressive Strength[2], (kPa)	136.3
Soil Class[3],	CH

[1]Obtained from standard Proctor test.
[2]Obtained from samples that were compacted in optimum water content.
[3]Determined based on USCS soil classification system.

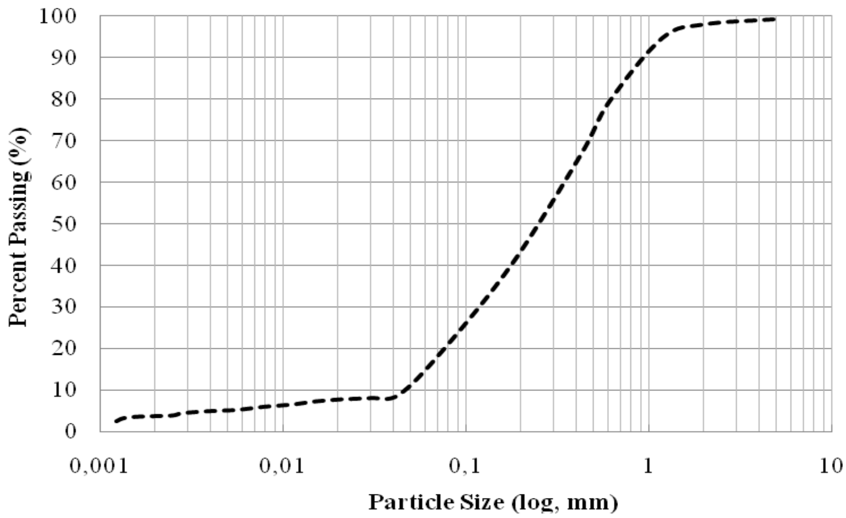

Figure 1. Grain-size distribution curve of the soil

The clay soil used in the study was sieved through a mesh with 0.425 mm opening size and was dried in a stove at 105 ± 5 °C for 24 hours. To determine the optimum water content and the maximum dry unit weight of the soil standard compaction test was carried out according to ASTM

698. The weights of test specimens were measured by preparing cylindrical samples with 38 mm in diameter and 76 mm in height at optimum water content and maximum dry unit weight. To avoid changes in the water contents, the samples were wrapped with aluminum foil (Kvǽrnǿ & Ǿygarden 2006). Furthermore, in order to prevent the aluminum foil from sticking to samples, a small quantity of vaseline was spread on the foil (Qi et al. 2008; Gullu & Hazirbaba 2010) and the specimens were placed in a full automatic freeze-thaw cabin.

In the literature there are several studies under the topic of freeze-thaw that used various numbers of cycles, temperatures and time periods (Liu et al. 2010; Hazirbaba et al. 2011). In this study the number of freeze-thaw cycles were selected as 1, 5 and 10, the temperature was -20 ^{o}C for freezing and +25 ^{o}C for thawing and the waiting period at each temperature was 6 hours (Ghazavi & Roastaie 2010). The specimens were not taken out of the freeze-thaw cabin during the experiment. At the end of each freeze-thaw cycle the related specimens were taken out from the freeze-thaw cabin and after removing the pieces that break off they were weighed. Then their unconfined compressive strength was determined according to ASTM D 2166 (Figure 2). The loading speed in the unconfined compressive strength tests was selected as 0.8 mm/min (ASTM D 2166). The amount of dead load corresponding to 25% of the unconfined compressive strength determined at the end of each cycle was applied uniformly with the help of a special mechanism on the cylindrical specimens that are previously prepared. Specimens were thus placed in the automatic freeze-thaw cabin (Figure 3). The freeze-thaw experiments were carried out while the specimens were loaded. At the end of each cycle the freeze-thaw resistances of the samplespecimens were determined. For the reliability of the results, each of the cycles was repeated on 4 replicate specimens and their average was used in the evaluations.

Figure 2. Unconfined compression testing device

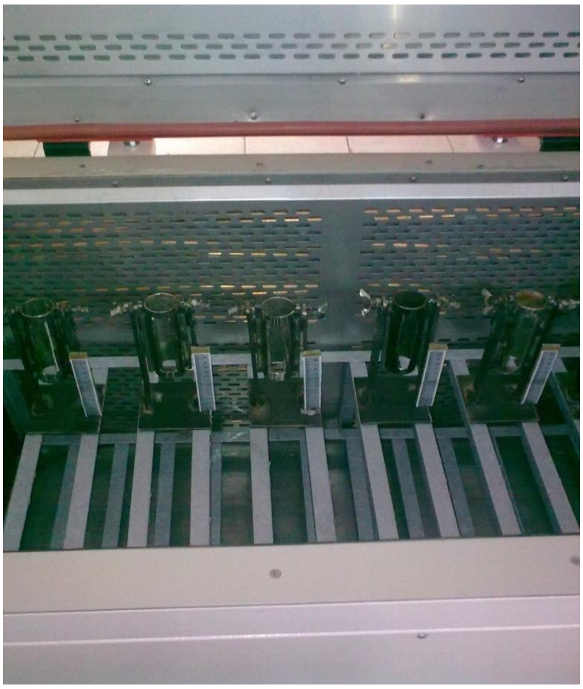

Figure 3. Freeze-thaw test under load (Special loading mechanisms and automatic freeze-thaw test cabin)

3 FINDINGS AND DISCUSSION

The freeze-thaw resistance obtained at the end of each cycle in the freeze-thaw experiments in each phase (i.e., under load and without load application) is shown in Figure 4. The unconfined compressive strength of the specimens at the end of the determined cycles and the load values corresponding to 25% of these strengths are given in the Table 2.

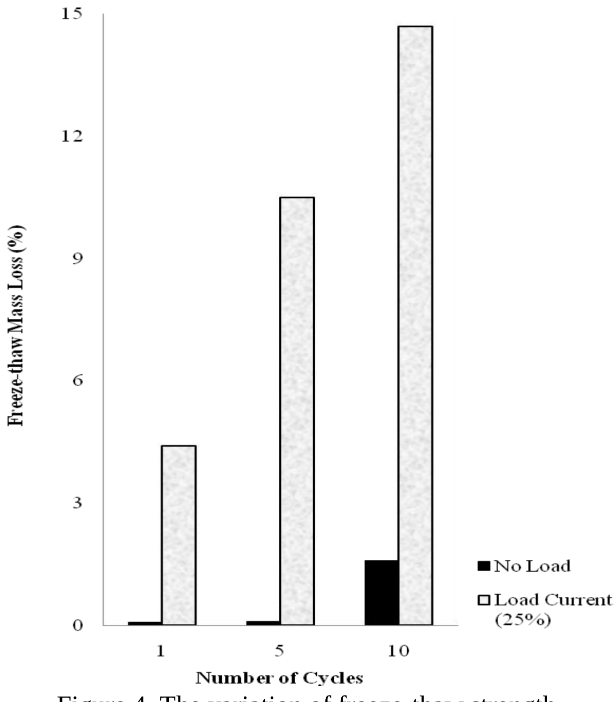

Figure 4. The variation of freeze-thaw strength

At the end of the freeze-thaw cycles, the lowest grain losses found from Formula 1 shows that freeze-thaw resistances of the specimens are the highest (Taşpolat et al. 2006). Freeze-thaw resistances of the specimens shown in Figure 4 are expressed as percentage of freeze-thaw grain losses. The grain losses of the specimens after freezing and thawing (FTG) have been calculated as follows:

$$FTG(\%) = \frac{IW - FTAW}{IW} * 100 \quad (1)$$

Where;
IW: Initial weight of samples,
FTAW: Weights of samples after freezing and thawing.

Table 2. Unconfined compressive strengths and maximum loads

Number of Cycles	Maximum Load (P_{max}, N)	Maximum Load Percentage (%25 N)	Unconfined Compression Strength (kPa)
0	154.4	38.6	136.3
1	83.4	20.85	73.5
5	48.9	12.23	43.1
10	20.0	5	17.6

When Figure 4 is studied, a decrease in freeze-thaw resistance is observed with the increase in the number of cycles both during experiments conducted on specimens carrying surcharge loads as well as in the traditional methods (Ghazavi & Roastaie, 2010; Wang et al. 2007). While there is not a major grain loss after the 1, 5 and 10 freeze-thaw cycles for the specimens tested by the traditional methods, the mass losses decreased approximately 4%, 11% and 15% respectively for the loaded samples. In other words the freeze-thaw resistances of specimens subjected to surcharge loads displayed a major decrease compared with the specimens in the traditional methods. It is thought that this is caused by the separation of soil grains due to the force of the water that is transformed into ice in the pores as well as the increase of pore volume (Wang et al. 2007).

On the other hand, as seen Table 2, the increase in the number of cycles decreased the unconfined compressive strength value approximately 87% (i.e., from 136.3 kPa to 17.6 kPa) in the freeze-thaw experiments carried out by the traditional method. As cracks have been observed on the specimens tested under surcharge loads, unconfined compressive strength tests could not been conducted.

4 CONCLUSIONS

In this study, a series of freeze-thaw experiments were conducted on the specimens of a clay soil.. Some of the specimens were subjected to surcharge load and some were not. The following general conclusions are obtained from the tests.

- The freeze-thaw resistances of specimens subjected to loads exhibited a major decrease in comparison to those tested using the traditional method, i.e., without load.
- Increasing number of cycles caused a decrease in the unconfined compressive strength in experiments carried out by the traditional method.

The freeze-thaw behaviour of soils under different loading and experimental conditions is not well-known yet. Therefore, from the perspective of providing a solution to different engineering issues, conducting similar research on other soil classes in future studies is considered to be useful.

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