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Assessment of strength development and freeze–thaw performance of cement treated clays at different water contents

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ABSTRACT

This paper examines the strength characteristics of Portland cement-treated fat and lean clays (CH and CL) under the conditions of freeze–thaw cycles. Specimens of natural clays were mixed with Portland cement in different percentages of 5% and 10%, in terms of the dry mass of soil using two different water contents of 30% and 50% for CH type of clay soil and 20% and 30% for CL type of clay soil to represent different consistencies and workability of soils. Besides, a group of cement free specimens was prepared and/or a group of specimens was not subjected to freeze–thaw cycles for comparison reasons. All specimens were cured for 7 and 28 days in a humidity controlled room at a constant temperature. After curing, specimens were subjected to a maximum of five cycles of closed-system freezing and thawing. Unconfined compression tests and ultrasonic pulse velocity tests were conducted on the specimens. The results of unconfined compression tests were evaluated in terms of water–cement ratio, curing period and the number of freeze–thaw cycles. Consequently, the compressive strength increased with the cement content increment of the clay specimens. While the specimens with highest cement content showed brittle behavior before freeze–thaw tests, they manifested less brittle behavior after freeze–thaw tests. The highest strength values were obtained in the specimens with low water contents. The compressive strength decreased as the freeze–thaw cycles increased, but cement treatment partially prevented the strength loss in freeze–thaw conditions. Generalized equations of strength development were assessed considering the total water–cement ratio and curing time effects for fat and lean clays that were subjected to 0, 1, and 5 cycles of freeze–thaw tests. In this way, this study showed that clay water–cement ratio hypothesis can be used to analyze the strength development of clays at different freeze–thaw cycles. It was observed that a linear correlation existed between the ultrasonic pulse velocity and the unconfined compression strength values. Furthermore, the plasticity index of the specimens subjected to 5 freeze–thaw cycles showed a decrement for the clay which was highly plastic in its native condition. Finally, with this study it is proven that cement treatment techniques can be preferred to enhance the freeze–thaw durability of fat and lean clay soils.

1. Introduction

The physical and mechanical properties of soils are affected by the freeze–thaw cycles in cold regions. Many geotechnical applications such as embankments, man-made fills, unpaved roads, railroads, and buried structures may be vulnerable to climate changes. Damages and loss of bearing capacity may become the major problems due to freezing–thawing.

The physical properties of the soils such as void ratio, density, hydraulic permeability, and Atterberg limits, and the mechanical properties of soils such as ultimate strength, stress–strain behavior and resilient modulus change in accordance with the freeze–thaw conditions experienced by the soil. Qi et al. (2006) summarized that there are general agreements on the influence of freeze–thaw on physical properties, but the same cannot be said to the influence of the mechanical properties.

Some important properties of fine grained soils subjected to freeze–thaw cycles were researched in literature. The permeability of soil would increase with the enlargement of the pores that are left after the thaw of ice crystals as micro-fissures are enlarged and melted ice in the soil matrix leaves internal large pore spaces; finer particles might move out of large pore spaces during freezing and thawing (Chamberlain et al., 1990). Soil parameters such as the liquid limit may also be changed by freeze–thaw (Yong et al., 1985). Studies by Wang et al. (1995) and Viklander and Eigenbrod (2000), show that freeze–thaw cycles may influence the grain-size distribution, which may induce a change in the plastic limit. In contrast to Yong et al. (1985), Eigenbrod (1996) reported that Atterberg limits were not significantly changed by freeze–thaw.

The freeze–thaw cycles reduce the ultimate strength of soils. All over-consolidated soils exhibit a peak on the triaxial stress–strain curve and this peak is reduced or may even disappear (Graham and

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Au, 1985). Resilient modulus would reduce significantly even by a small number of freeze–thaw cycles (Simonsen et al., 2002). Moreover, these cycles considerably decrease the undrained shear strength which is an important factor in fine-grained soil design (Graham and Au, 1985). Fine-grained soils have a relatively low permeability and during loading they tend to behave as undrained. As a consequence, stability problems in such soils are often controlled by the undrained shear strength. The effect of freeze–thaw on the undrained shear strength has been studied on natural soil specimens as well as laboratory-prepared specimens. It was found that the undrained shear strength decreased significantly for natural clays (Graham and Au, 1985; Leroueil et al., 1991). It was also found that the change was greatest during the first few cycles (Yong et al., 1985).

With regard to the change in physical and mechanical properties after freeze–thaw cycling, different conclusions can be found, sometimes even contradictory. This may be due to the fact that different researchers studied different soils and applied different conditions during freeze–thaw. It is recognized that there is a lack in study on the difference of the same soil at different water contents, on the difference of soil types, as well as on the difference of the freezing conditions. The presence of additives in the reconstituted fine grained specimens provides a different level of contribution as the origin, mineralogy, and structure of the grains vary considerably according to the location of the soil.

The use of additives in optimum amounts may increase the performance of fine grained soils under freeze–thaw conditions. Yarbaşı et al. (2007) showed that, after freeze–thaw cycling, the compressive strength, California bearing ratio, ultrasonic wave, and resonant frequency of lime, fly-ash and cement added soils lead to high freeze–thaw durability when compared to unmodified specimens. Altun et al. (2009) conducted unconfined compression tests on fly ash and cement treated specimens and the results were evaluated in terms of the amount of cementitious material included, curing conditions and the number of cycles. The specimens with high fly ash and cement content had greater strength values. Kalkan (2009) examined the effects of silica fume on the geotechnical properties of fine-grained soils exposed to freeze and thaw and concluded that the stabilized fine-grained soil specimens containing silica fume exhibit high resistance to the freezing and thawing effects as compared to natural fine-grained soil specimens. Jafari and Esna-Ashari (2012) worked on the unconfined compressive strength of lime stabilized clayey soil with waste tire cord reinforcement and stated that the compressive strength and stress–strain behavior of specimens depend considerably on the amounts of both fiber and lime and the contribution of fiber in the strength of specimens increased the number of freeze–thaw cycles. Olgun (2013) optimized lime and rice husk ash amounts for expansive clays under freeze–thaw conditions. Aldaood et al. (2014) investigated the impact of freeze–thaw cycles on the mechanical and the mineralogical behavior of gypseous soils stabilized with lime and observed that gypseous soil samples lose a substantial amount of their strength and became less durable after a limited number of freeze–thaw cycles. Shibi and Kamei (2014) quantified the effect of variable freeze–thaw cycling on the durability of cement-stabilized soils containing bassanite and coal ash and showed the possible use of bassanite in earthwork projects in seasonal frost areas. Güllü and Khudir (2014) presented a novel study on the effect of freeze–thaw cycles on unconfined compressive strength of low-plasticity silt treated with jute fiber, steel fiber and lime. They proposed a combination of effective stabilizer rates all together, increasing the unconfined compressive strength performances together with cost–benefit advantages.

This study examines the strength characteristics of Portland cement-treated fat and lean clays (CH and CL) under the condition of freeze–thaw cycles. Specimens of natural clays were mixed with Portland cement in different percentages of 5% and 10%, in terms of the dry mass of soil using two different water contents for both clay types to simulate the varying workability conditions. The specimens were cured for 7 and 28 days in a humidity controlled room at a constant temperature. After curing, some specimens were subjected to one or five cycles of closed-system freezing and thawing. Then unconfined compression strength tests and ultrasonic pulse velocity tests were conducted on the specimens. The main aims of this study are: i. to investigate the effect of cement content on the strength of different types of clay soils subjected to freeze–thaw cycles; ii. to observe the changes in mechanical properties by providing different physical properties (e.g. clay type, water content, curing period) of soils; iii. to establish the possible strength relationships depending on total water–cement ratio of the test cases considering curing time effects and iv. to examine the possibility of a relationship between the unconfined compression tests and ultrasonic pulse velocity tests.

2. Materials

Two clay specimens in bulk form were taken from a construction work site in Izmir, Turkey. The soils were classified as CH and CL in Unified Soil Classification System (USCS) and they were named as clay A and clay B, respectively. The geotechnical properties of clays are listed in Table 1. CEM 42.5 type of cement that had a specific density of 3.08 g/cm^3 and a specific area of 3960 cm^2/g was chosen for the stabilization. Chemical properties of cement are given in Table 2.

3. Experimental program

3.1. Specimen preparation

Firstly, natural clay soils were dried in an oven at approximately 105 ± 5 °C for 24 h. After the grinding process, dry mass of clay was remolded with water to achieve the desired water content of the samples. Separately, dry mass of cement and water were mixed homogeneously to prepare the cement slurry at water/cement ratio of 0.6. Then, the cement slurry was added into the clay–water mixture, but the duration of mixing process had to be completed in 10 min to prevent hardening of the mixture. In this study, water content is defined as the ratio between the mass of water and the mass of dried soil before the addition of the cement slurry. The cement content is defined as the ratio of the mass of the dry cement to the mass of dried soil. The clay specimens were utilized with two different percentages of cement (5% and 10%) by dry weight of soil and water contents were also ranged between the liquid limit and the natural water content to represent different consistencies and workability of soils. The mixture was placed with 3 layers into standard proctor mold and each layer was compacted with a standard hammer to remove the entrapped air. The specimens were prepared according to ASTM C150 (2012) and ASTM D698 (2012). Specimens that have 38 mm diameter and 76 mm length were taken out with a specimen extruder. The specimens were wrapped air tight with LLDPE film and placed in a moisture room (at 25 °C and r.h. 97%) for 7 and 28 days. In the context of this study, specimens are named with clay type (A or B), water content (W), cement

Table 1
Geotechnical properties of the natural clays used in this study.

Property	Value	
Name of material	A	B
Soil type (USCS)	CH	CL
Natural water content	30	27
Sand (%)	5	22
Silt (%)	20	48
Clay (%)	75	30
Liquid limit (%)	51	36
Plastic limit (%)	19	18
Plasticity index	32	18
Optimum water content (%)	22.3	19.4
Maximum dry unit weight (kN/m^3)	16.3	16.1