



Effect of freeze–thaw cycles on unconfined compressive strength of fine-grained soil treated with jute fiber, steel fiber and lime

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ABSTRACT

This paper presents an attempt about the effect of freeze–thaw cycles on unconfined compressive strength (UCS) of fine grained soil (low-plasticity silt) treated with jute fiber, steel fiber and lime. The stress–strain behavior (post-peak strength, strain hardening, ductility, brittleness index, resilient modulus) of the stabilized soil has also been discussed due to the treatment effects. An extensive laboratory study has been carried out conducting UCS tests under the freeze–thaw cycles of 0, 1, 2 and 3. The mixture proportions of the stabilizers were 2%, 4%, 6%, 8% and 10% for lime and 0.25%, 0.50%, 0.75% and 1% for both of the jute and steel fibers. Considering the UCS performances together with cost–benefit advantages, the effective dosage rates of stabilizers were separately found as 4% for lime, 0.75% for jute fiber and 0.25% for steel fiber. The combinations including these effective rates have been further investigated on the UCS performance and stress–strain behavior under freeze–thaw cycles. The study results that the UCS value of native soil has been performed best due to the combination of effective stabilizer rates all together (i.e., 4% lime + 0.75% jute fiber + 0.25% steel fiber). In this effective combination, the UCS value of native soil increases from 220 kPa to 1330 kPa for non-freeze–thaw cycle, from 205 kPa to 1300 kPa for one freeze–thaw cycle, from 156 kPa to 1100 kPa for two freeze–thaw cycles and from 114 kPa to 900 kPa for three freeze–thaw cycles. The other stabilizer combinations also show good contributions to UCS of native soil. As for the stress–strain responses, the inclusions due to the jute fiber alone in terms of post-peak strength, strain hardening, and ductility are better than the ones of steel fiber and lime at all freeze–thaw cycles. The combination of effective stabilizer rates all together offers a brittleness index with good ductility as well. In regard to the performance of resilient modulus, it is exhibited well by the combination of 4% lime + 0.25% steel fiber. The results obtained from the study are fairly promising to employ jute fiber, steel fiber and lime against freeze–thaw resistance.

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1. Introduction

Soil stabilization has been one of the best ways to improve the effectiveness of subgrade soils for a long period. The goal of this paper is to investigate the effect of freeze–thaw cycle on the strength and stress–strain characteristics of fine-grained soil (low-plasticity silt) treated with jute fiber, steel fiber and lime under different freeze–thaw cycles. Chamberlain (1981) discussed that the fine-grained soils (especially silts) in the frosty sites generally present poor performance as subgrade, subbase material or as a foundation supporting layer under structures, because of their frost-susceptible nature. In recent years, discrete fibers have been added and mixed into the soils to enhance the strength behavior of soils (Gullu and Hazirbaba, 2010; Hazirbaba and Gullu, 2010; Mandal and Murti, 1989; Prabakar and Sridhar, 2002). Li et al. (1995) described that there have been significant increases in shear strength, durability and plasticity of a cohesive soil after reinforcement with discrete fiber. Cai et al. (2005) report that

the fiber significantly contributes to the stress–strain behavior, strain-hardening and ductile failure characteristics of reinforced soils. Despite numerous past works, the studies on the use of fiber for improving the durability and strength of soil stabilized with lime, jute fiber and steel fiber have still been observed less. The previous works are also insufficient due to the effect of the freeze–thaw cycle (see Hejazi et al., 2012 for the review in detail). Hence, an attempt stabilizing the fine grained soil (i.e., silt) with jute fiber, steel fiber and lime was introduced in this paper.

Lime stabilization is one of the initial methods utilized to improve strength over the long term. It has substantially become in the practice of civil engineering like footings, roadbeds, embankments and piles. When the lime is mixed with soils, it leads to improve a lot of engineering characteristics of soils. Many investigators discovered that the strength behavior of soils significantly increases after lime treatment (Esna-Ashari and Jafari, 2012; Locat et al., 1996; Narasimha Rao and Rajasekaran, 1996). The study of Bell (1996) shows that soils treated with lime experienced distinctive increases in optimum water content, while considering a decrease in maximum dry density. It is noted that the solid cementation bonds between soil particles, added

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by lime-soil responses, may resist the forces applied efficiently, which often led to the decrease of compressibility of marine soils (Rajasekaran and Narasimha Rao, 2002). On the basis of the investigations with extensive soils, it is indicated that both swell rate and swell pressure decrease to zero using the lime admixed to soils (Al-Rawas et al., 2005; Du et al., 1999). The stabilizations with the lime studied in the past works exhibit enhancement characteristics of soils. This performance of soil + lime stabilizations could be extended by adding the jute and steel fibers for the strength development and the brittleness behavior with good ductility. It is reported that jute as an environmental-friendly fiber could be used for soil stabilization in pavement engineering (Hejazi et al., 2012). Gosavi et al. (2004) report that nylon fibers and jute fibers together increase the CBR of treated soil by about 50% of that of native soil. Aggarwal and Sharma (2010) used different rates (0.2–1%) of jute fiber with different lengths (5–20 mm) to stabilize soil, and the result is that jute fiber decreases the maximum dry density of compacted soil while it increases the optimum moisture content. An increase of more than 2.5 times of the native soil of CBR value is obtained with the jute fiber having 10 mm length and 0.8% dosage rate. A different study on the mortar strength shows that the jute fibers are effective for improving the cohesive strength between mortar and block, and the mortar strength (Islam and Iwashita, 2010). As for the steel fibers, they can improve the soil strength, but this improvement requires more investigation by comparing with the other fibers (Ghazavi and Roustaei, 2010; Gray and Al-Refai, 1986; Murray and Farrar, 1988). Ghazavi and Roustaei (2010) recommend that polypropylene fibers are preferable to steel fibers in cold climates, where soil is affected by freeze–thaw cycles.

For the regions where the temperature changes to below zero °C, water in the soil voids turns to ice particles with the procedure known as freezing. In the case of above zero °C, it is known as thawing. In such places, soils are subjected to freezing and frosting heave in the winters, and thaw settlement and weakening in the springs. This freeze–thaw cycle could adversely impose a huge modification of soil characteristics on the cold place countries annually (Sheng et al., 1995; Simonsen and Isacsson, 1999; Watanabe, 1999). Since a huge number of studies indicate the dangerous effects of the freeze–thaw cycles on the engineering properties of fine-grained soil (Qi et al., 2008; Sheng et al., 1995; Simonsen and Isacsson, 1999; Wang et al., 2007; Zhang et al., 2004), an effort of the soil treatment under the effect of freeze–thaw cycle could provide a good contribution in practice. This study investigates the use of jute fiber, steel fiber and lime as the soil stabilizers for treatment of a fine-grained soil (low-plasticity silt) conducting unconfined compressive strength tests at different freeze–thaw cycles. The stress–strain behaviors have also been discussed for the contribution to the brittleness index and resilient modulus. The study is believed to be beneficial for improving the engineering characteristics of silt employed for the stabilization in practice.

2. The experimental program

2.1. Material

The soil used in this study is a fine-grained soil with low plasticity and is classified as ML-type material (silt) according to the Unified Soil

Classification System (USCS). The engineering properties of soil are given in Table 1. The maximum dry-unit weight and optimum water content of silt, found from the modified proctor tests following the procedure of ASTM D 1557, are 19 kN/m³ and 18%, respectively. The particle size distribution of the soil having a mean size (D_{50}) of 0.02 mm is shown in Fig. 1. As for the materials of fibers, Fig. 2 presents the jute and steel fibers used in the study. The jute fiber has been supplied from the carpet industry as a waste material. It has the length of 20–40 mm and the diameter of 1 mm with the specific gravity of 1.7. The steel fiber used is 35 mm in length and 5.5 mm in diameter with the specific gravity of 7.85. Mix proportions of both of the steel fiber and the jute fiber were 0.25%, 0.50%, 0.75% and 1.00% by dry weight of soil. The dosage rate of the steel fiber was limited to 1% due to its high cost in industry. Here, it can be noted that the fiber rate larger than 1% is not efficient and economical for the soil treatment (Fletcher and Humphries, 1991). In regard to the lime, it is a quick lime used at the stabilizer rates of 2%, 4%, 6%, 8% and 10%.

2.2. Testing procedures

The soil was tested in seven treatments with and without freeze–thaw cycles: (1) in its natural state (no treatments), (2) with jute fiber, (3) with steel fiber, (4) with lime, (5) with jute fiber and lime, (6) with steel fiber and lime, and (7) with jute fiber, steel fiber and lime. The experimental program, conducted by the unconfined compressive strength (UCS) tests, is given in Table 2. The rates in the stabilizer combinations (i.e., soil + J.F. + lime, soil + S.F. + lime, soil + J.F. + S.F. + lime) in Table 2 have been determined from the separate performances of the stabilizers. All the samples prepared for the testing were around 55 mm in diameter and 110 mm in height conforming to a minimum of 2:1 height to a diameter ratio. The water content of all the testing treatments was adopted as 18% of native soil, which was determined by the modified proctor test. The samples were compacted following the modified proctor energy (ASTM 1557, 2007) to the dry unit weight, which is being a minimum of 95% of the maximum dry unit weight of natural (native) soil (i.e., silt). All tests in the experimental program of this study have been carried out for unsoaked conditions (i.e., prevention from the direct contact of water by providing an adequate drainage condition) on the basis of the recommendations from previous studies (Gullu and Hazirbaba, 2010; Hazirbaba and Gullu, 2010). No curing conditions were tested through the study due to conservative side and time saving.

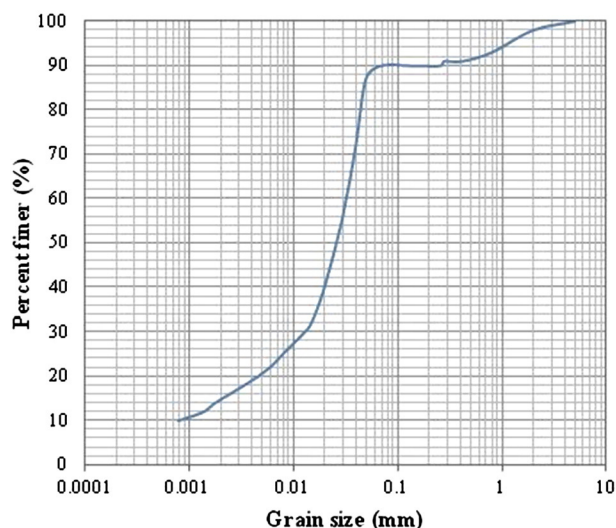


Fig. 1. Particle size distribution of soil.

Table 1
Index properties of soil used in the study.

Property	Value
Specific gravity	2.72
Liquid limit	37
Plastic limit	25
Plasticity index	12
Maximum dry unit-weight (kN/m ³)	19
Optimum moisture content (%)	18
USCS classification	ML

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