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Unconfined compressive strength and post-freeze–thaw behavior of fine-grained soils treated with geofiber and synthetic fluid

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ABSTRACT

This study focuses on a relatively new non-traditional stabilizer (synthetic fluid) used in conjunction with geofiber to improve the strength characteristics of a low-plasticity fine-grained soil. The investigation is based on unconfined compressive strength (UCS) tests. An efficient geofiber dosage was determined for the soil; treating it with geofiber only for the dosage rates varying from 0.2% to 1% by weight of dry soil. The individual contribution of the geofiber and synthetic fluid to the UCS gain was studied through testing each additive independently with the soil. Additionally, UCS tests were conducted on soil samples treated with geofiber and synthetic fluid together. All experiments were conducted for both unsoaked and soaked sample conditions. Strength developments were also investigated under freezing and thawing conditions. The treatment results are discussed in detail in terms of UCS and stress–strain response of the UCS test. The results demonstrate that the use of geofiber with synthetic fluid provided the highest UCS improvement (170% relative gain) in unsoaked samples when compared with the other treatment configurations. On the other hand, the synthetic fluid, when used alone, caused a relative decrease of 21% in the UCS of untreated soil in soaked conditions. The use of geofiber with synthetic fluid performed better in terms of the UCS under freezing and thawing conditions, while the synthetic fluid alone under the same conditions performed inadequately. The stress–strain responses of the soil treated with geofiber and synthetic fluid in terms of post-peak strength, strain hardening, and ductility were better than that of treated with synthetic fluid alone. Finally, the resilient modulus for the various treatment configurations was estimated from the UCS results. The findings indicate that the investigated soil stabilization technology appears to be promising for sites that can be represented by unsoaked conditions (i.e., where adequate drainage and unsaturated conditions can be ensured).

1. Introduction

A non-traditional soil stabilization technology in which geofiber and synthetic fluid (a liquid stabilizer) are used to improve locally available fine-grained soils in Interior and Western Alaska was investigated through an extensive testing program. In the first phase of the investigation, the California Bearing Ratio (CBR) performance was the basis for evaluation and analyses. The results from the first phase of the research are presented in Hazirbaba and Gullu (in review). This paper is a follow-up effort to Hazirbaba and Gullu (in review) and presents the results from the second phase of the investigation. The primary objective of the research described in this paper was to investigate the freeze–thaw strength and stress–strain characteristics of fine-grained soils improved through the use of randomly-oriented discrete-polypropylene geofiber and synthetic fluid.

Fine-grained soils, especially encountered in Interior Alaska, are not desired as subgrade, subbase material or as a foundation supporting layer under buildings due to their frost-susceptible nature. They are prone to significant ice segregation with higher moisture conditions (Chamberlain, 1981). The use of geofiber and liquid stabilizers separately to improve various soils has been researched to some extent. However, the research on the combined use of the two additives for stabilizing and improving cold region soils, particularly fine-grained soils, is very limited (Hazirbaba and Gullu, in review; Hazirbaba and Connor, 2009). The majority of available literature on the use of geofiber deals with cohesionless or granular soils. Typically, adding geofiber to cohesionless or granular soils improves the shear modulus, liquefaction resistance and particle interlocking, and increases load bearing capacity (Freitag, 1986; Arteaga, 1989; Maher and Ho, 1994). It has been reported by various investigators that addition of geofiber to soil increases the peak strength (shear, compressive, and tensile) (Gray and Ohashi, 1983; Gray and Al-Refeai, 1986; Maher and Ho, 1994; Ranjan et al., 1996; Webster and Santoni, 1997). Previous studies showed that the improvement of the engineering properties with the inclusion of geofiber depends on

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various parameters such as type, length, content, orientation and aspect ratio (length/diameter) of the geofiber, and natural soil properties. Al-Refeai (1991) found that for fine and medium sand no appreciable increase in the stiffness of the sand was gained by using fibers longer than 51 mm. Stabilization of sands with the geofiber contents greater than 2% by dry weight of soil presented no added benefit (Ranjan et al., 1996). A laboratory study by Ahlrich and Tidwell (1994) indicated that monofilament and fibrillated geofiber types were not effective in stabilizing a high-plasticity clay, while both geofiber types at 0.5% dosage rate enhanced the properties of a sandy soil. However, Kumar et al. (2006) reported that the unconfined compressive strength of clay and clay–sand mixtures increased with the addition of geofiber. Tingle et al. (1999) recommended using a geofiber content between 0.6% and 1%, and they reported that a geofiber content of 0.8% is sufficient to ensure a strain hardening behavior. Maher and Gray (1990) noted that randomly-oriented geofiber has a primary advantage of the absence of potential planes of weakness that can develop parallel to oriented reinforcement. A comparative study by Lawton et al. (1993) revealed that geofiber reinforced soils require some amount of deformation before the strengthening benefits can be seen. Ranjan et al. (1996) studied the relationship between soil grain size and the geofiber-bond strength, and found that finer sand particles had significantly greater geofiber-bond strengths than coarser grained soils. Kaniraj and Havanagi (2001) reported that the inclusion of geofiber increased the strength of cement-stabilized fly ash-soil samples and changed their brittle behavior to ductile behavior.

As for the non-traditional fluid stabilizers, Scholen (1992) described five different groups: electrolytes, enzymes, mineral pitches, clay fillers, and acrylic polymers. Oldham et al. (1977) reported that polymer resin was more effective than asphalt, cement, and lime with sandy materials and provided the greatest increase in unconfined compressive strength. Rauch et al. (2002) studied the use of three liquid stabilizers; an ionic stabilizer or electrolyte, an enzyme, and a polymer product, with five high-plasticity clay soils to measure the improvement in soils in terms of reduced plasticity. They found that the only effective reduction in plasticity occurred with the ionic stabilizer in sodium montmorillonite. Santoni et al. (2002) performed tests on a silty-sand material with traditional (cement, lime, and asphalt emulsion) and non-traditional stabilizers (polymers and tree resin). The results indicated that the strength gain in the soil treated with non-traditional additives was much quicker than that treated with traditional stabilizers. Newman and Tingle (2004) used emulsion polymers for soil stabilization of airfields and found that all of the polymers increased the unconfined compressive strength after 28 days of cure time for both wet and dry conditions.

The present research effort investigates the use of randomly-oriented discrete-polypropylene geofiber and synthetic fluid as an alternative non-traditional stabilization method with a fine-grained soil. In particular, the stress–strain characteristics and freeze–thaw performance of treated and untreated soil samples were studied for various contents of the additives through an extensive experimental program that consisted of unconfined compressive strength (UCS) tests and freeze–thaw tests.

2. Experimental program

2.1. Material

The soil used for this study is a fine-grained soil and referred to as Fairbanks silt. Basic soil index properties of the silt are given in Table 1. It is a low-plasticity silt and is classified as ML-type material according to the Unified Soil Classification System. The particle size distribution was determined by hydrometer analysis and is shown in Fig. 1. The mean size (D_{50}) was measured as 0.03 mm. The maximum dry-unit weight of Fairbanks silt was found to be 1713 kg/m^3 at the optimum water content of 12%.

Table 1
Index properties of the silty soil.

Property	Value
Specific gravity	2.73
Liquid limit (%)	26
Plastic limit (%)	24
Plasticity index (%)	2
Maximum dry density (kg/m^3)	1713
Optimum moisture content (%)	12
USCS classification	ML

The geofiber used was discrete 51-mm long and 2-mm wide tape type polypropylene geofiber. Polypropylene material was chosen based on its availability, resistance to ultraviolet degradation, chemical stability and reasonably high strength characteristics (Fletcher and Humphries, 1991). The index properties of the geofiber are listed in Table 2. The geofiber dosages investigated were: 0.2%, 0.375%, 0.5%, 0.625%, 0.8%, and 1% by dry weight of the soil sample. The dosage in this study was limited to 1% due to the greater costs of geofiber at higher dosages.

The synthetic fluid used in this investigation is colorless (clear and bright) with a specific gravity of 0.863 and a viscosity index of 70. The index properties of the synthetic fluid are given in Table 3.

2.2. Testing program and procedures

The soil was tested in four treatment configurations: (1) in its natural state (no additives), (2) with geofiber, (3) with synthetic fluid, and (4) with geofiber and synthetic fluid together. Both unsoaked and soaked conditions were investigated. The target water content for the tests at natural soil moisture with no additives and for those with geofiber treatments was selected as 12%, which was the optimum moisture content of untreated soil determined by modified Proctor energy. As for the treatment with synthetic fluid only, and with geofiber and synthetic fluid together, the target water content was kept at 6% to: i) represent the *in situ* conditions, as the *in situ* water content for Fairbanks silt was measured to be about 6%, and ii) minimize the need for additional water in soil improvement especially for cold region applications. The synthetic fluid content in the treatments (configurations 3 and 4) was selected as 4% by dry weight of soil as recommended by Hazirbaba and Gullu (in review). The geofiber dosage was varied from 0.2% to 1.0% for the treatment that involved geofiber alone (configuration 2) and kept constant at 0.5% when used in combination with synthetic fluid (configuration 4). Addition of geofiber beyond 1% was not considered as dosages larger than 1% usually present an uneconomical mix (Fletcher and Humphries, 1991).

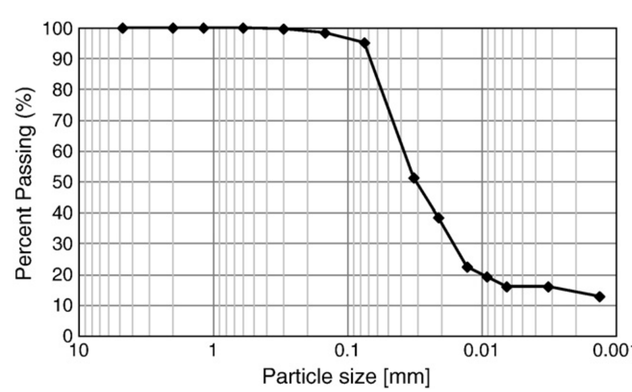

Fig. 1. Grain size analysis of Fairbanks silt.