Swell And Compressibility of Fiber Reinforced Expansive Soils

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Abstract - This paper presents an experimental study evaluating the effect of polypropylene fiber on swell and compressibility of expansive soils. The initial phase of the experimental program includes the study of the effect of polypropylene fiber on maximum dry density (MDD) and optimum moisture content (OMC) with different fiber inclusions. Static and dynamic compaction tests have been conducted on an expansive soil sample with different percentages of 0%, 0.5%, 0.75%, and 1% polypropylene fiber additions (by dry weight of the soil). The second phase of the experimental program focuses on the compressibility and hydraulic characteristics of the soils. The unreinforced and reinforced specimens have been prepared statically and the swell and compressibility behavior of the samples have been analyzed. Finally it is concluded that mitigation of expansive soils using polypropylene fiber might be an effective method in reducing the swell potential and compressibility of subsoils on which roads and light buildings are constructed.

Keywords: expansive soils, polypropylene, compaction, compressibility, swell potential.

I. INTRODUCTION

Expansive soils which include montmorillonite-rich clays, over- consolidated clays and shales are problematic soils found in many parts of the world (Nelson and Miller, 1992). They may cause serious problems in the behavior of light buildings associated with the seasonal cycles of wetting and drying. Moisture variations play important role in the swell-shrink potential of soils, and are dependent on climate, permeability of soil deposits, temperature, groundwater, vegetation, drainage and manmade water sources [9],[13].

There has been a growing interest in recent years in the influence of chemical modification of soils which upgrades and enhances the engineering properties. The transformation of soil index properties by adding chemicals such as cement, fly ash, lime, or combination of these, often alter the physical and chemical properties of the soil including the cementation of the soil particles. Especially use of lime admixture has proved to have a great potential as an economical method for improving the geotechnical properties of expansive soils [2],[3],[14],[10]. Rao, S. M and Shivananda, P. (2005) has examined the compressibility behavior of lime-stabilized soils [4]. According to Gordon and McKeen, (1976), cement and lime show different behavior in soil stabilization [6]. Cement contains the necessary ingredients for the pozzolanic reactions, whereas lime can be effective only if there are reactants in the soil.

Recently there is a growing attention to soil reinforcement with different types of fiber. However, there is limited research done on fiber reinforcement of fine grained soils particularly its effect on swelling, consolidation settlement, hydraulic conductivity, and desiccation characteristics. In this experimental investigation, the aim was to study the effect of polypropylene fiber reinforcement on the improvement of physical and mechanical properties of a clay sample obtained from an expansive clay deposit in Famagusta, North Cyprus. The experimental program was carried out on compacted soil specimens with 0%, 0.5%, 0.75%, and 1% polypropylene fiber additives, and the results of one-dimensional swell and consolidation tests are discussed. Despite the difficulties encountered in representative specimen preparation due to random distribution of fiber filaments, it is observed that there is a future prospect in the use of this environmental friendly additive for soil mitigation.

II. LITERATURE REVIEW

Reference [11] studied the behavior of lime-fiber stabilized soils, concluding the improvement in compression and shear strength, swelling and shrinkage. The addition of fiber is observed to transfer the failure characteristic of soil from brittle to ductile failure. Tang, C., Shi, B., Gao, W., Chen, F., Cai, Y. (2007) investigated on the effect of fiber and cement inclusions on unconfined compressive strength, shear strength parameters, stiffness and ductility of soil specimens. The combined effect of fiber and cement have been observed to improve these properties, and fiber usage to impede the formation of dessication cracks [11]. Abdi, Parsapajouh, and Arjoman (2008)'s work on fiber reinforced soils substantiates the previous findings that consolidation settlements, swelling and dessication crack formation reduce substantially. They have also concluded that the hydraulic conductivities increased slightly by increasing fiber content and length [12]. Viswanadham, Phanikumar, and Mukherjee (2009) examined swelling behavior of geofiber-reinforced soils, using fibers of different aspect ratios and observed a reduction in heave. The swelling pressure was the maximum at low aspect ratios at both the fiber contents of 0.25% and 0.50%. Finally, the mechanism by which discrete and randomly distributed fibers restrain swelling of expansive soil was explained with the help of soil–fiber interaction [6]. Effect of freeze and thaw cycles on the strength behavior of expansive soils reinforced by polypropylene fiber has been studies by Ghazavi and Roustaie (2010). In cold climates freezing and thawing of the expansive soils is the main problem. Once the soil freezes most of its properties including permeability, water content, stress–strain behavior, failure strength, elastic modulus, cohesion, and friction angle will change accordingly. A method of static compaction is used for preparing samples with different percentages of polypropylene fiber to overcome the difficulty in sample preparation Finally, they have reported that an increase in the number of freeze–thaw cycles results in the reduction of unconfined compressive strength of clay samples by 20–25% [7].

III. MATERIALS AND METHODS

A. Soil

The soil that is used in this research has been obtained from the Eastern Mediterranean University campus in North Cyprus. The physical properties of the soils are as depicted in Table I. The high plasticity index indicates high swell potential, the most problematic soil type under light structures. Identification, description, and classification of this type of soils are based on preliminary assessment of their mechanical properties based on the Atterberg limits analysis. According to Nelson and Miller (1992) the soil used in this study has a high swell potential [1].

B. Polypropylene Fiber

The polypropylene fiber used in this study is the most commonly used synthetic material due to its low cost and hydrophobic and chemically inert nature which does not allow the absorbtion or reaction with soil moisture or leachate. The other properties are the high melting point of 160°C, low thermal and electrical conductivity, and high ignition point of 590°C. The physical properties also include the specific gravity of 0.91, and an average diameter and length of 0.06 mm and 20 mm respectively.

C. Sample Preparation

All the test specimens were compacted at their respective maximum dry density (MDD) and optimum moisture content (OMC), corresponding to the values obtained in the Standard Proctor compaction tests in accordance with ASTM D698-91. This is achieved by statically compacting the reinforced and unreinforced soil by applying the right amount of energy needed to reach to MDD at OMC. The static compaction is applied in a modified CBR instrument. To prepare unreinforced samples, water is added and the soil is statically compacted after 24 hours of mellowing. To obtain reinforced samples, the fiber is added after the mellowing time and blended in a mixer.

TABLE I. PHYSICAL PROPERTIES OF THE STUDIED SOIL

Property	
Specific Gravity	2.56
Gravel (>2000 μm), (%)	0
Sand (75-2000 μm), (%)	8
Silt (2-75 μm), (%)	40
Clay (<2 μm), (%)	52
Liquid limit, (%)	57
Plastic limit, (%)	28
Plasticity index, (%)	29
Linear shrinkage, (%)	20
Optimum moisture content, (%)	24
Maximum dry density, (kg/m^3)	1497
Soil classification(USCS)	CH

IV. RESULTS AND DISCUSSIONS

In order to assess the effect of random fiber inclusion on swelling, consolidation settlement, and hydraulic conductivity, oedometer tests were conducted according to ASTM D2435-96.

A. Effect of polypropylene fiber on swell potential

To investigate the swelling characteristics of unreinforced and fiber reinforced specimens, one dimensional swell tests were carried out. Samples were statically compacted in consolidation rings at optimum moisture obtained from Standard Proctor content in consolidation rings of 50 mm inner diameter and 19 mm of height. The samples were left under a low surcharge of 7 kPa and full swell was measured. Specimens of different fiber inclusions have been swelled until the increase in free swell with time became marginal. Figure 1 presents the free swell response in percent swell (ΔH/H0) with respect to logarithm of elapsed time in minutes for different fiber percentages. The results show an increase of swell with 0.5% and 0.75% fiber content and a sudden reduction with 1% fiber content. According to Ghazavi and Roustaie (2009), a reduction in swell percentage has been obtained with 3% of polypropylene fiber and an enhancement of swell percent with 1% and 2% of polypropylene fiber. Sample size is a factor which can influence the swell percentage of the soil samples [7]. As Loehr, Axtell, Bowders (2000) pointed out, samples of 10.2 cm showed reduction in swell percentage versus time with the increase of fiber content and, the same soils have been tested with dimension of 6.4 cm which indicated an increase in swell percent of the soil specimens [8].

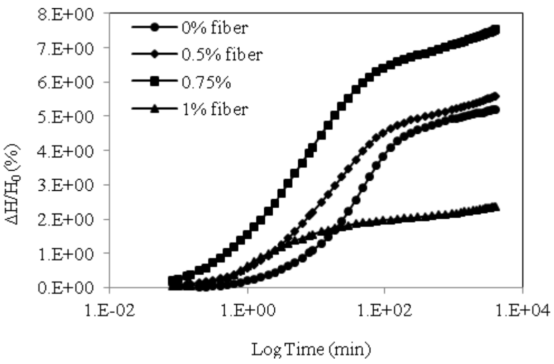

Fig. 1 : Percent swell of soil specimens versus log time with different polypropylene fibers.

Fig. 1 shows the swell percentage versus logarithm of time relationship for different fiber contents. The primary swell (s_w%), secondary swell and the primary swell times (t_s) are summarized in Table II. The results reveal that there is a marked reduction in primary swell potential with the increase in fiber inclusion. The secondary swell, which is the amount of swell beyond the completion of primary swell, has also been reduced with the increase of fiber content.

B. Compressibility Characteristics

The effect of polypropylene fiber on compressibility properties of expansive soils has been investigated by use of one-dimensional consolidation test. Consolidation pressures up to a maximum of 1568 kPa have been applied during the process. Table III indicates the results of this experiment in which a considerable reduction in the compression and rebound indices can be observed with the increase in fiber content. Expansive soil used in this study with high swell potential, was also highly compressible experiencing a noticeable reduction in volume change. Figure 2 gives the results of consolidation tests on increasing fiber contents as time versus logarithm of pressure. A distinct improvement can be observed on the compressibility of the soil which has been mixed with 1 % polypropylene fiber.

TABLE II. PRIMARY AND SECONDRY SWELL OF THE FIBER REINFORCED SPECIMENS

Fiber Content (%)	**Primary swell (%)**	**Time of primary swell, t_s (min)**	**Secondary swell (%)**
0	150	4.4	0.9
0.5	80	4.6	0.8
0.75	50	6.3	0.6
1.0	6	1.6	0.4

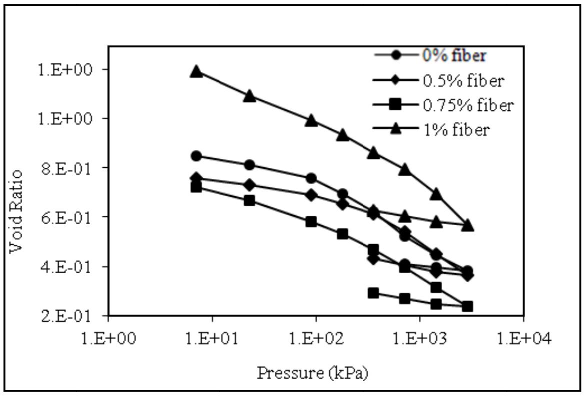

Fig. 2 : Void ratio versus effective consolidation pressure.

C. Hydraulic Conductivity

The hydraulic conductivity of the soil has been determined indirectly from the consolidation test results under low stress ranges. In pavement design, lower stress ranges are important for analysis since it is the surface soil that is in contact which the main layer of the pavement. The hydraulic conductivity of unreinforced and reinforced soils has been obtained using Equation 1.

$$k= c_v \; m_v \, \gamma_w \qquad (1)$$

Where *k* is the saturated hydraulic conductivity, c_v is the coefficient of consolidation, m_v is the coefficient of volume compressibility, γ_w is the unit weight of water. The results show variations of hydraulic conductivity with different fiber content, as presented in Figure 3. Comparing the k obtained for 0-200 ranges of stresses reveals that the addition of 0.5% and 1% fiber reduced the hydraulic conductivity. With 0.75% fiber content an appreciable increase in hydraulic conductivity is observed. Despite the inconsistency in the results, due to random distribution of fiber in soil matrix, there is a tendency for hydraulic conductivity to increase with the increase of fiber content.

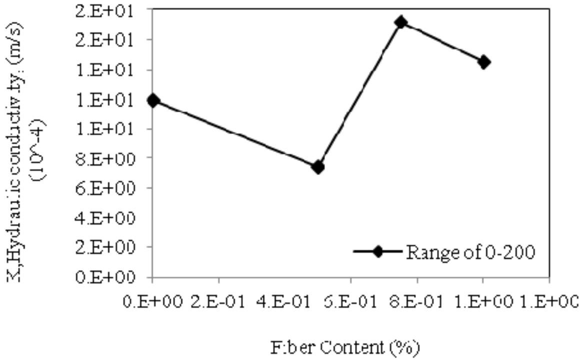

Fig. 3 : Hydraulic conductivity of low range stresses versus fiber content.

TABLE III. CONSOLIDATION PARAMETERS

Fiber content	Compression index (C_c)	Rebound index (C_r)	Preconsolidation pressure	Swell pressure
0%	0.317	0.131	830	200
0.5%	0.265	0.088	199	80
0.75%	0.230	0.058	505	68
1%	0.186	0.046	120	40

V. CONCLUSIONS

This study demonstrates the influence of polypropylene fiber on swelling, compressibility and hydraulic conductivity of expansive soils. The results indicate that primary swell and secondary swell percentages decreased considerably with increase in fiber addition. The time of primary swell, however increased with 0.5% and 0.75% fiber, while a marked reduction occurred with 1% fiber. The same behavior is observed in compression index results. Hydraulic conductivity shows another erratic behavior, increasing with 0.75% fiber, whereas with 1% a reduction in three fold occurs. It can be concluded that there is a potential for use of polypropylene fiber to reinforce expansive soils. 1% fiber content is suitable for the soil in this study to have low amount of swell, compressibility, and hydraulic conductivity. However, further research is required to substantiate these conclusions.

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