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KİLLİ ZEMİNLERİN MÜHENDİSLİK ÖZELLİKLERİ ÜZERİNDE FİBERLERİN ETKİSİ

INFLUENCE OF ADDING FIBERS ON ENGINEERING PROPERTIES OF CLAYEY SOILS

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ABSTRACT

Recently, research into alternative materials and methods has been ongoing with the goal of creating cutting-edge solutions for building earth structures. In circumstances when other alternative materials are employed, improving the soft soils used for these structures, such as the subgrades of highway embankments, might be essential for implementing sustainable and cost-effective applications. In order to examine the utilization of Polypropylene (PP), Copolymer (CP), and Virgin Homopolymer Polypropylene (VHP) fibers to stabilize two separate high and low-plasticity clay soils, comprehensive laboratory studies have been conducted. To estimate how these mixes would behave during earthquakes, a variety of soils and the aforementioned fibers were created in the lab. The engineering features of these combinations were then studied. Investigations were conducted into the engineering behaviors of the samples as well as the results of the compaction, unconfined compression, CBR, and cyclic triaxial testing. The results of the laboratory study are presented in this work, with a focus on the usage of alternative materials that produce stronger soils during earthquakes, which has positive economic and environmental effects.
Keywords: *Fibers, Dynamic and Static Mechanical Properties, Clayey Soils, Soil Improvement Methods*

1. INTRODUCTION

Due to the lack of natural resources, there is a necessity to shift from extraction to regeneration by converting our economy from linear to circular. There is a need to implement techniques that let nature regenerate soils, boost biodiversity, and replenish the soil with biological resources. The majority of the construction resources are lost after usage or pollute the environment. Besides, the economical cost of using synthetic materials increases the cost of the project too. Therefore, there must be a turn point to start resembling natural systems if we switch to a regenerative paradigm. In nature, there is no waste. Natural systems have self-regenerated over billions of years. As population increasing day-by-day and human demands changing as well, transportation plays a role of critical importance. With respect to the fact that highways are the most common and the most advanced means of transport compared to other transportation systems in most countries, great attention should be paid in the design and construction process.

Materials for the pavement, base, subbase, and embankment are obtained from borrow pits. The biggest contributors to overall cost during construction are excavation, material loading, and transportation expenses. The soft soil is removed and replaced with a gravel or crushed rock fill layer in the traditional method of construction. It has recently been discovered that using existing soil is the most cost-effective method, thus it is essential to stabilize and enhance the soil's engineering features in order to meet the requirements for highway projects (Şenol et al., 2003).

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It should be highlighted that several studies have been conducted in an effort to provide various stabilization techniques for in-situ soft soils for embankments. The use of chemical additives for stability, prewetting, compaction management, moisture control, soil reinforcement using geosynthetics, surcharge loading, and thermal treatments are a few of these treatment techniques (Sridharan and Gurtug, 2004). All methods mentioned above have disadvantages such as being expensive and also not being effective all the time. Therefore, new methods are still being investigated aiming at improving the engineering properties of embankments' soft soils (Puppala and Musenda, 1998).

In recent years, vast experimental investigations carried out with the scope of finding the possible effects of natural and synthetic discrete fibers on problematic soft soils (Viswanadham et al., 2008). According to previous researchers' investigations, it has been found that shear strength of fiber-reinforced soils mostly affected by amount of fibers and also friction between fiber and soft soil. Ziegler et al. (1998) claimed that tensile strength of soft soils increases by adding fiber to the plain soil. Besides, it can be seen that the effects of using different types of randomly oriented natural and synthetic discrete fiber materials on the improvement of soft soils have not studied thoroughly yet (Ziegler et al., 1998). The purpose of this short paper is to study the investigation of the efficiency of using three different type of fiber on compaction and cyclic behavior of soft soils during earthquakes.

2. ENGINEERING PROPERTIES OF SOILS AND FIBERS TESTED

2.1 Index Properties Of Soils

The Atterberg tests' findings indicate that Soil-I has more plasticity than Soil-II does. Moreover, wet sieve tests reveal a negligible quantity of coarse dirt in both soil samples, and hydrometer analysis reveals that Soil-I has a larger clay content than Soil-II. Then, compared to Soil-II, compaction tests on Soil-I provide higher dry unit weight and optimum water content. Table 1 contains a list of all test results. According to the Unified Soil Classification System (ASTM D2487), Soil-I and Soil-II are categorized as CH and CL soil types, respectively.

Table 1. Engineering properties of soil samples

Properties of soils	Soil I	Soil II
LL (%)	78	41
PL (%)	28	23
PI (%)	50	18
Gravel (%)	0	0
Sand (%)	3	2
Silt (%)	27	53
Clay (%)	70	45
USCS class	CH	CL

2.2 Physical Properties Of The Fibers

Poly fibers used in engineering are manufactured from virgin homopolymer polypropylene (VHP), polypropylene (PP), and copolymer (CP) fibers. Actually, they are structural materials that were investigated through test outcomes of engineering investigations conducted in the USA in the 1960s. The most popular synthetic materials used primarily for concrete reinforcement are the fibers already mentioned. All of the aforementioned fibers, as depicted in Figure 1, are used in concrete applications in accordance with ASTM C-1116 "Standard Specification for Fiber Reinforced Concrete and Shotcrete" in order to prevent concrete cracking brought on by plastic and settlement shrinkage that takes place prior to initial set. All fibers are made up of twisted network fibers that fibrillate, producing high-performance systems for reinforcing concrete. The greatest level of long-term durability, structural improvements, and efficient secondary/temperature crack management are all provided by these extra-sturdy fibers. The physical characteristics of the fibers employed in this study are listed in Table 2.

3. EXPERIMENTAL PROGRAM AND TESTING PROCEDURE

Experimental program was performed at the Soil Mechanics Laboratories of Işık and Istanbul Technical Universities. First of all, three different fibers used in the experimental program were cut to the same length (6 cm). Then, both clayey soils mixed with 0%, 0.25%, 0.5% and 0.75% of fiber contents by weight. Totally twenty-eight mixtures consisted of two different soils and three alternative materials were then prepared using standard compaction effort (ASTM D698) and maximum dry unit weight and optimum water content of each mixture were obtained.

(a) (b) (c)

Figure 1. (a) Polypropylene, (b) Copolymer, and (c) Virgin Homopolymer Polypropylene fibers.

Table 2. Physical properties of fibers used in the experimental program

Properties of materials	VHP & PP	CP
Color	White	Gray
Form	Fibrillated Fiber	Monofilament Fiber
Acid/Alkali	Excellent	Excellent
Resistance Specific	0.91	0.91
Gravity Tensile	570	758
Strength (Mpa)	6.19	6.19
Length (cm)	70	45

The ASTM D2166 method to unconfined compressive strength is used to determine the ideal mix design for the soil mixes. From each initial combination of compacted soil-alternative material, at least five cylindrical samples with varying water contents are immediately put through an unconfined compression test. The next stage is to generate soil samples with the maximum dry unit weight and optimum water content based on the results of the compaction tests. The CBR test is used to assess the shear strength of the compacted materials at the maximum dry density and the ideal water content (ASTM D1883). For the aforementioned combination employing the high and low plasticity clays, the results of the compaction, unconfined compression, and CBR testing are presented in Tables 3 and 4, respectively.

Table 3. Results of compaction, unconfined compression and CBR tests for CH type soil

No	Description	ω_{opt} (%)	$\gamma_{d\text{-}max}$ (kN/m^3)	q_u (kN/m^2)	CBR (%)
1	Plain Soil (CH)	27	15.04	171	11.06
2	99.75% CH+0.25% PP	26	14.60	255	15.71
3	99.5% CH+0.5% PP	25	14.50	275	16.92
4	99.25% CH+0.75% PP	25	14.50	317	19.03
5	99.75% CH+0.25% CP	26	15.20	236	16.92
6	99.5% CH+0.5% CP	26	15.00	320	19.57

7	99.25% CH+0.75% CP	26	14.80	331	20.59
8	99.75% CH+0.25% VHP	16	16.80	335	20.07
9	99.5% CH+0.5% VHP	18	16.10	306	17.14
10	99.25% CH+0.75% VHP	23	15.60	279	16.21

Table 4. Results of compaction, unconfined compression and CBR tests for CL type

No	Description	ω_{opt} (%)	$\gamma_{d\text{-}max}$ (kN/m^3)	q_u (kN/m^2)	CBR (%)
1	Plain Soil (CL)	26	15.32	177	12.06
2	99.75% CH+0.25% PP	26	14.70	257	15.71
3	99.5% CH+0.5% PP	25	14.50	276	16.93
4	99.25% CH+0.75% PP	25	14.50	317	19.02
5	99.75% CH+0.25% CP	20	15.10	265	14.15
6	99.5% CH+0.5% CP	23	15.34	281	16.59
7	99.25% CH+0.75% CP	18	15.41	377	19.57
8	99.75% CH+0.25% VHP	23	16.10	288	16.79
9	99.5% CH+0.5% VHP	23	15.10	215	15.20
10	99.25% CH+0.75% VHP	24	15.00	209	14.34

As another step of experiments, soil samples are prepared in accordance with their maximum dry unit weight and optimum water content. Once all samples were prepared, they were put on a cyclic triaxial apparatus (ASTM D5311M). Then, de-aired water was percolated from the bottom through the top of the specimens for at least three sample volumes. A back pressure of 100 kPa was applied prior to the B-value check to ensure saturation. Specimens were then isotropically consolidated to an effective confining stress (σ'_{3c}) of 30 kPa. Once the consolidation stage ended, cyclic loading was applied with a constant frequency of 1.0 Hz and cyclic stress ratio (CSR) equal to 0.2, where CSR=q_{cyclic}/(2. σ'_{3c}). Continuous records of axial strain, axial stress and excess pore pressure were obtained during the cyclic phase. All experiments continued at least until the pore water pressure became equal to the initial confining pressure of the sample (i.e. 30kPa), which is considered as initial liquefaction. It should be noted that clays can experience some softening, but they do not reach zero effective stress. In fact, there is the term cyclic softening that tries to capture the response of clay-like soils to cyclic loadings. Figures 2 and 3 illustrate the results of cyclic triaxial tests for all soil mixtures.

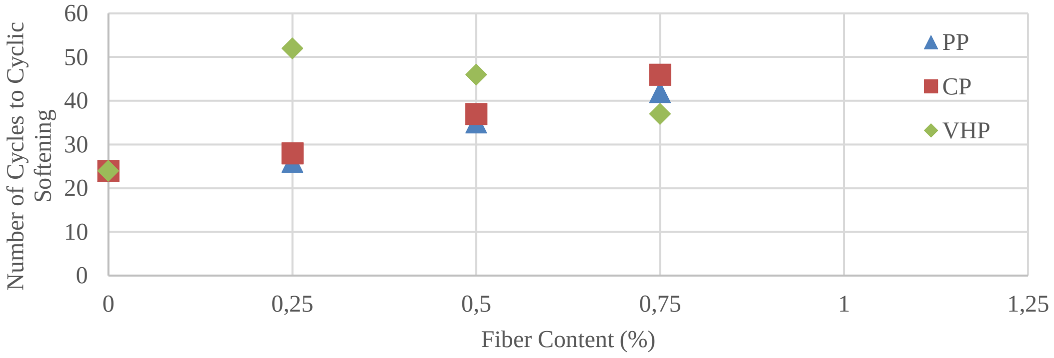

Figure 2. Number of cycles to initial liquefaction versus fiber content for CH type soil.

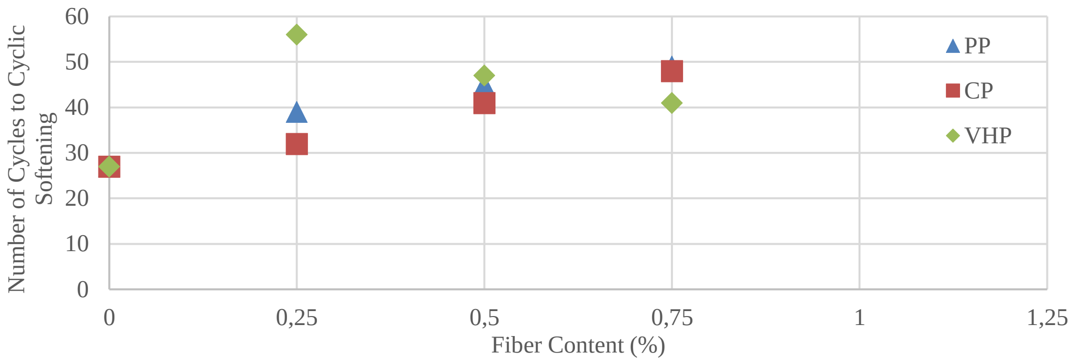

Figure 3. Number of cycles to initial liquefaction versus fiber content for CL type soil.

4. CONCLUSIONS

This study examined the effects of virgin homopolymer polypropylene (VHP), polypropylene (PP), and copolymer (CP) fibers with fiber concentrations of 0%, 0.25%, 0.50%, and 0.75% on the treatment of low and high plasticity clays. The use of subpar on-site materials may become feasible as a consequence of the research's findings, which might also result in cheaper building costs. The results of this experimental investigation lead to the following conclusions.

The addition of all three types of fibers to both CL and CH soils leads in an increase in strength and California Bearing Ratio (CBR) values, as shown by the results of the unconfined compression and the CBR tests on all combinations. It should be mentioned that the observed behavior of the rise in fiber content of utilized fibers displays two separate phases. In other words, strength increases for both clayey soils when the amount of PP and CP fibers in the blended soil is 0.25 percent. Then, as the amount of mixtures of clayey soils with both the abovementioned fibers rise, this enhancement gets even better. On the other hand, addition of VHP fiber increases the strength of both CH and CL types of soils with the largest increase at 0.25% and this improvement in strength and CBR decreases with higher VHP ratios.

According to the results of cyclic triaxial tests and from clays' cyclic softening aspect, it can be found that adding VHP fiber causes higher number of cycles to liquefaction for both CH and CL types of soils compared to the other fibers and therefore, result in strengthening the plain soils for liquefaction (cyclic softening) phenomena. With respect to the results of cyclic triaxial tests, it is found that adding all three types of fibers to both clayey soils lead to increasing the number of cycles to liquefaction. It should be noted that as the amount of CP and PP fibers increase from 0.25% to 0.75%, both mentioned fibers' resistance to liquefaction shows increasing trend, while the addition of VHP fiber from 0.25% to 0.75% result in decreasing resistance to liquefaction. In fact, the compression between the outcomes of both clayey soils exhibit a very little effect on the type of soil, passing from CH to CL type of soil. This can be explained by the fact that both plain soils (without any fiber content) showed approximately the same behavior and therefore, both clay soils' mixtures also exhibited more or less the same behaviors.

With respect to the results of all tests conducted on high and low plasticity soils, it can be inferred that the highest strength of the clayey soils was obtained when adding 0.25% of VHP type of fiber for CH and 0.75% of CP for CL types of clayey soils. In next investigations, it is predicted that clayey soils can be combined with VHP fiber and other alternative elements like fly ash and lime to create stronger soil combinations.

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