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Influence of adding polymeric fibers on engineering properties of clayey soils

Influence de l'ajout de fibres polymères sur les propriétés techniques des sols argileux

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ABSTRACT: Nowadays alternative materials and techniques are constantly being investigated within the scope of developing innovative solutions for the construction of earth structures. Improvement of the soft soils for the structures such as subgrades of highway embankments and shallow foundation soils can be critical for implementing sustainable and economical applications, especially for cases where other alternative materials are used. In this research, extensive laboratory experiments have been performed to investigate the use of Polypropylene (PP), Copolymer (CP) and Virgin Homopolymer Polypropylene (VHP) fibers in order to stabilize two different high and low plasticity clay soils. Various soil and mentioned fiber mixtures were prepared in the laboratory and the engineering properties of these mixtures were observed with the aim of predicting their behavior under heavy loads. The compaction, unconfined compression, CBR and cyclic triaxial tests were conducted and related engineering behaviors of the samples were investigated.

RÉSUMÉ : Aujourd'hui, les matériaux et techniques alternatifs font constamment objet d'enquête dans l'objectif de développer des solutions novatrices pour la construction de structures en terre. L'amélioration de sols mous pour les structures comme les sous-couches des accotements d'autoroutes et les sols de fondation superficielle pourrait être cruciale pour l'implémentation d'applications soutenables et économiques, particulièrement là où d'autres matériaux alternatifs sont utilisés. Dans cette recherche, de nombreuses expériences en laboratoires ont été menées pour analyser l'utilisation de fibres de Polypropylène (PP), de Copolymère (CP) et de Polypropylène Homopolymère Vierge (VHP) dans le but de stabiliser deux sols argileux différents, l'un de forte et l'autre de faible plasticité. Des sols variés et des mélanges de fibres mentionnés ont été préparés dans le laboratoire et les propriétés d'ingénieurs ont été observées à fin de prédire leur comportement sous forte charge. Les tests de compactage, de compression non confinée, de CBR et de triaxiaux cycliques ont été menés et des comportements mécaniques associés des échantillons ont été étudiés.

KEYWORDS: Compaction; Unconfined Compression; CBR; Cyclic Triaxial.

1 INTRODUCTION.

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.

The embankment, subbase, base and pavement materials are provided from borrow pits. During construction process; excavation, loading and transportation costs of the material are the most important factors for the total cost. In the conventional way of approach, the soft soil is removed and replaced by gravel or crushed rock fill layer. Recently, it is found that using existing soil is the most economical way, and hence, it is inevitable to stabilize and improve the engineering properties of the soil to satisfy the necessary criteria for highway constructions (Senol et al., 2003).

It should be noted that, significant number of experiments have been performed with the aim of developing different treatment methods to stabilize in-situ soft soils for embankments. These treatment methods contain stabilization with chemical additives, prewetting, controlling compaction, moisture control, reinforcing the soil using geosynthetics, surcharge loading and thermal methods (Sridharan et al., 2004). All methods mentioned above have disadvantages such as 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 et al., 2002).

In recent years, vast experimental investigations were performed to find the possible effects of natural and synthetic discrete fibers on problematic soft soils (Viswanadham et al. 2008). Previous researchers got to the conclusion that strength

characteristics of fiber-reinforced soils, consisting of randomly oriented discrete fibers, mostly related to fiber contents and fiber-surface friction along with the strength of both soil and fiber. 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 effects of using different types of randomly oriented natural and synthetic discrete fiber materials on improvement of soft soils have not studied thoroughly yet. Therefore, in this study, the effect of using three different types of fibers on compaction and cyclic behavior of soft soils during earthquakes are investigated.

2 ENGINEERING PROPERTIES OF SOILS AND FIBERS

2.1 Index properties of soils

According to the consistency tests' results it is found that Soil-I has higher plasticity than Soil-II. Besides, wet sieve analysis exhibits limited amount of coarse soil on both of the soil samples and according to hydrometer analysis, clay content of Soil-I is higher than Soil-II. Then, compaction tests performed on Soil-I gives higher dry unit weight and optimum water content than Soil-II. All test results are listed in Table 1. From that point further based on Unified Soil Classification System (ASTM D2487) Soil-I and Soil-II categorized as CH and CL type of soil, respectively.

2.2 Physical properties of the fibers

Poly fibers that made of all Virgin Homopolymer Polypropylene (VHP), Polypropylene (PP) and Copolymer (CP) fibers are engineering products. In fact, they are structural materials that

Table 1. Engineering properties of soil samples

Properties of soil	<i>Soil-I</i>	<i>Soil-II</i>
Liquid Limit (%)	78	41
Plastic Limit (%)	28	23
Plasticity Index (%)	50	18
Gravel (%)	0	0
Sand (%)	27	53
Silt (%)	28	23
Clay (%)	50	18
ω_{opt} (%)	28	22
$\gamma_{dry\ max}$ (kN/m ³)	16.25	15.2
USCS class	CL	CH

were explored by the test results of engineering researches in the USA in 1960s. Mentioned fibers are the most common synthetic materials mainly used with the scope of reinforcing concrete. With respect to ASTM C-1116 “Standard Specification for fiber reinforced concrete and shotcrete” all mentioned fibers, shown in Figure 1, are used in concrete applications in order to inhibit concrete cracking caused by plastic and settlement shrinkage that occurs prior to initial set. All fibers consist of a twisted fibrillating network fiber, yielding high-performance concrete reinforcement systems. These extra heavy-duty fibers offer maximum long-term durability, structural enhancements, and effective secondary/temperature crack control. Table 2 summarizes the physical properties of the fibers used in this research.

Table 2. Physical properties of fibers used in experimental program

Properties of material	<i>VHP & PP</i>	<i>CP</i>
Color	White	Gray
Form	Fibrillated fiber	Monofilament fiber
Acid/Alkali Resistance	Excellent	Excellent
Specific Gravity	0.91	0.91
Tensile Strength (MPa)	570	758
Length (cm)	6	6

3 EXPERIMENTAL PROGRAM AND TESTING PROCEDURE

Experimental program was performed at the Soil Mechanics Laboratory of İ̇sık University and Istanbul Technical University. 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 D698a) and maximum dry unit weight and optimum water content of each mixture

obtained. It should be noted that standard Proctor tests were performed in specially designed Harvard miniature compaction equipment (Figure 2). The compaction mold has an inner diameter of 42 mm and a height of 96 mm. As the equipment is calibrated for standard compaction energy; compaction is applied in three layers with 27 hammer blows each (Senol et al. 2011). Variations in compaction versus molding water content of the prepared samples are plotted in Figures 3 and 4.



a)



b)



c)

Figure 1. a) Polypropylene [PP], b) Copolymer[CP], c) Virgin Homopolymer Polypropylene [VHP] fibers.

The unconfined compressive strength (ASTM D2166) approach is applied to estimate the optimum mix design of the soil mixtures. At least five cylindrical samples with different water contents from each original compacted soil-alternative material mixture are directly subjected to unconfined compression test. As the next step and with respect to the outcomes of compaction tests, soil samples are prepared with their maximum dry unit weight and optimum water content. Shear strength of the compacted materials at the optimum water content and the maximum dry density are determined by using CBR test (ASTM D1883). Results of unconfined compression tests for the aforementioned mixture using the high and low plasticity clays are shown in Figures 5 and 6, respectively. Besides, outcomes of CBR tests are exhibited in Tables 3 and 4.



Figure 2. Modified Harvard compaction equipment used in the experimental program.

As another step of experiments, soil samples are prepared in accordance with their maximum dry unit weight and optimum water content. Once all samples prepared, they were put on a cyclic triaxial apparatus (ASTM D5311M). Then, de-aired water was percolated from 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 $CSR = q_{cyclic} / (2 \cdot \sigma'_{3c})$. 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. 30 kPa), 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 7 and 8 illustrate the results of cyclic triaxial tests for all soil mixtures.

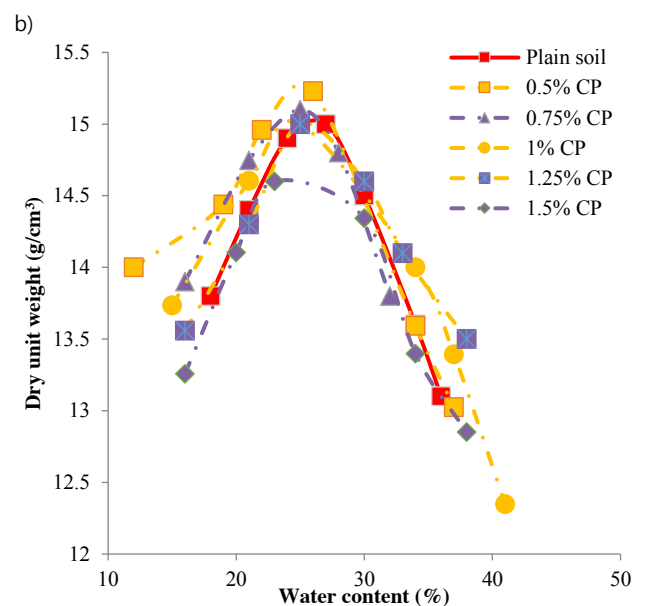
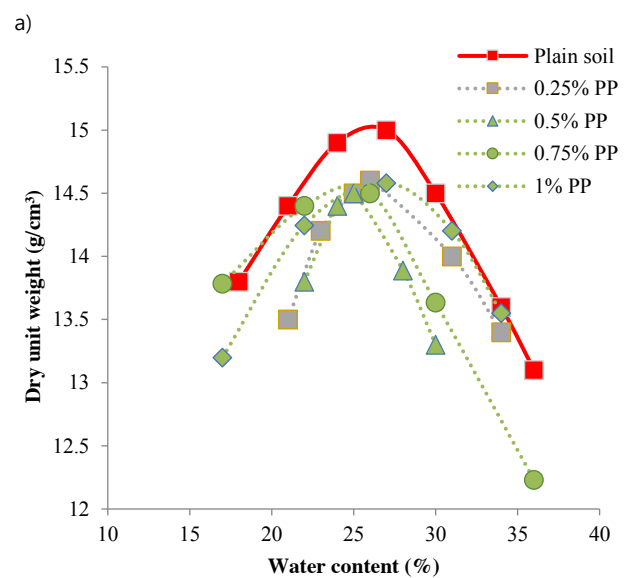
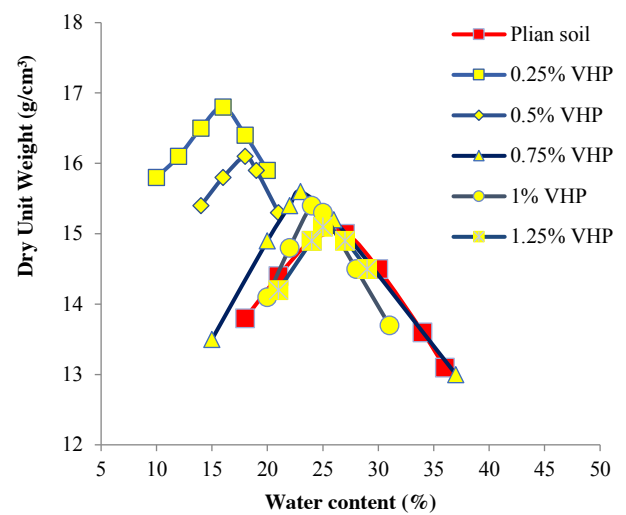
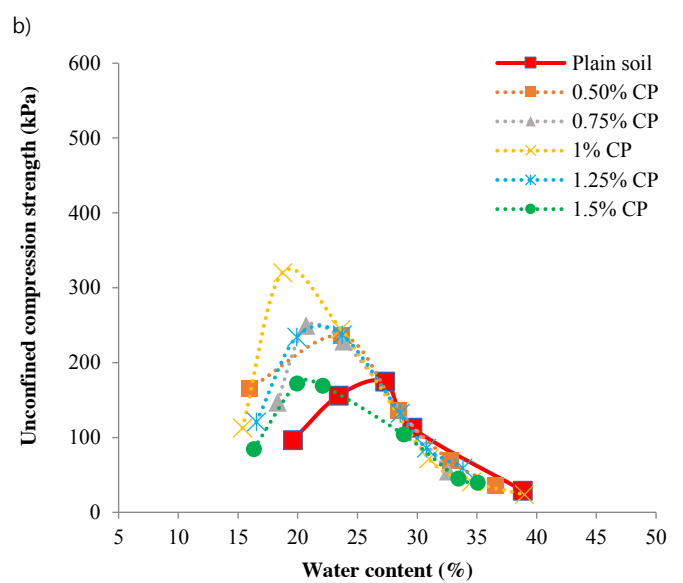
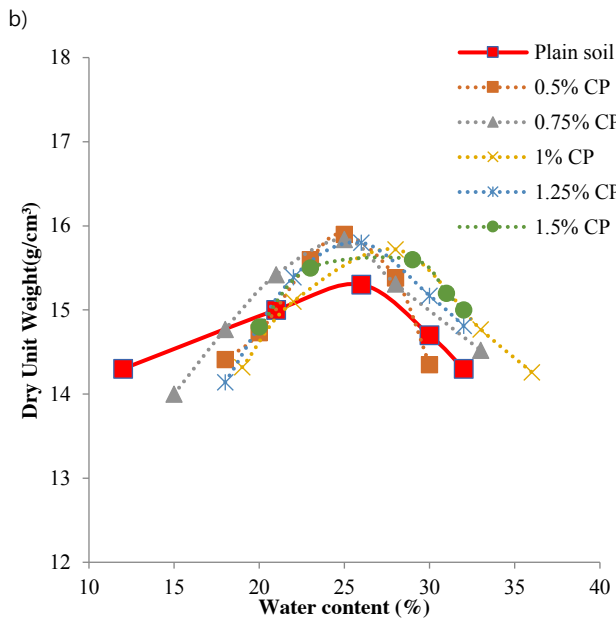
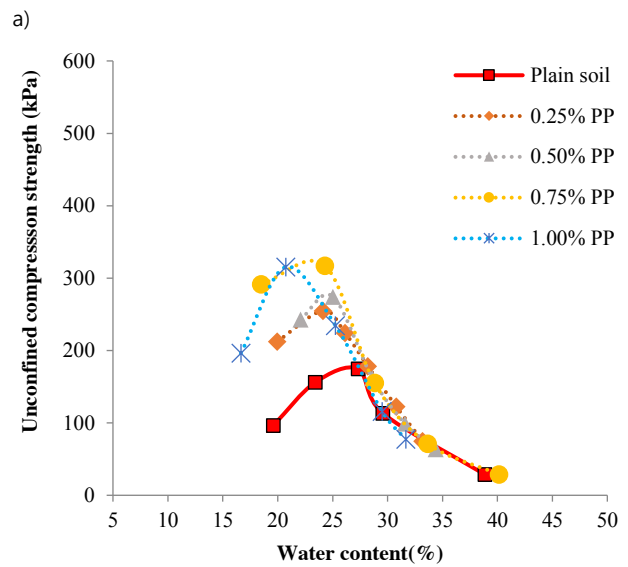
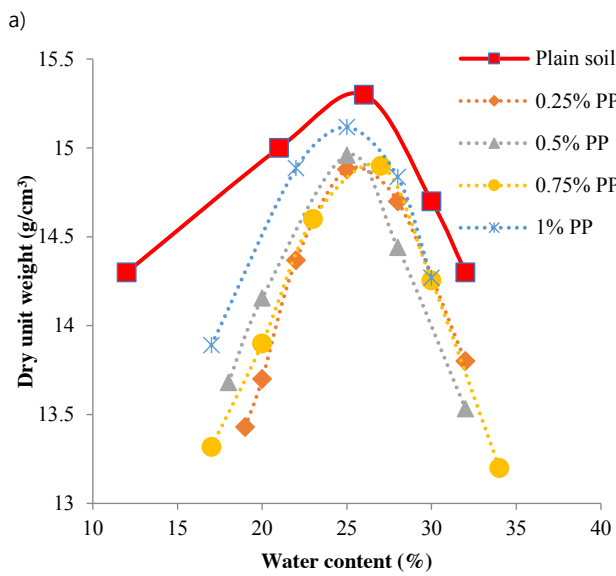
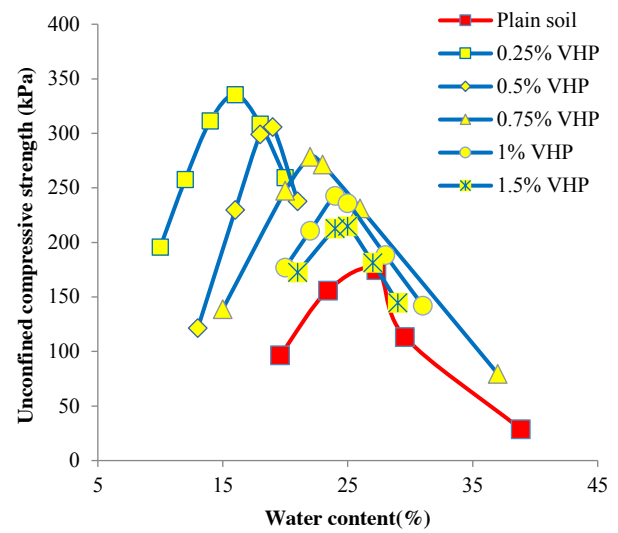
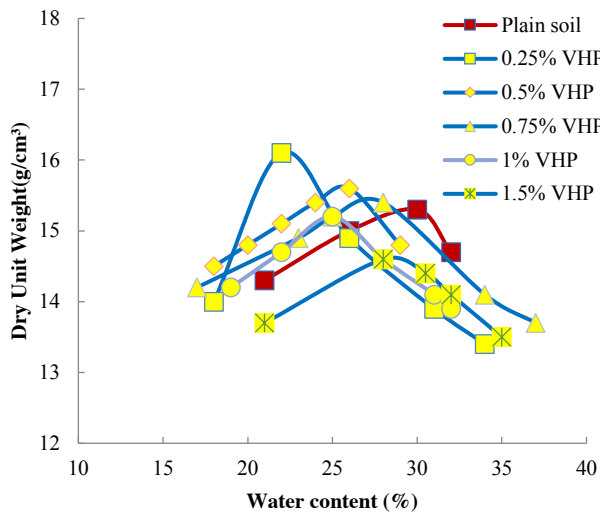
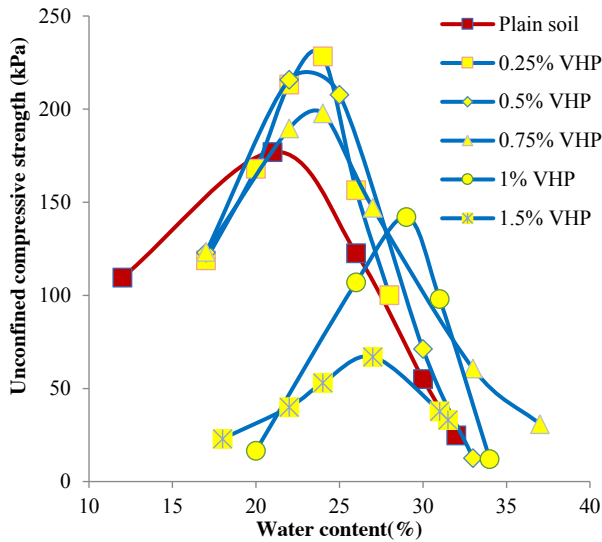


Figure 3. Compaction test results of CH a) Virgin Homopolymer Polypropylene [VHP] b) Polypropylene [PP] c) Copolymer [CP].

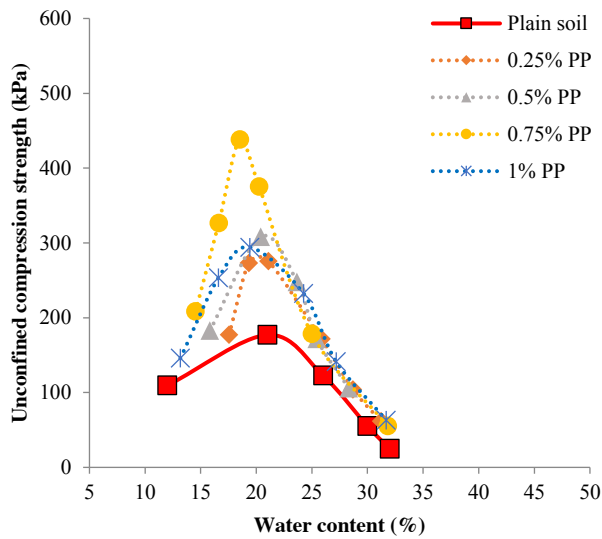


c) Figure 4. Compaction test results of CL a) Virgin Homopolymer Polypropylene [VHP] b) Polypropylene [PP] c) Copolymer [CP].

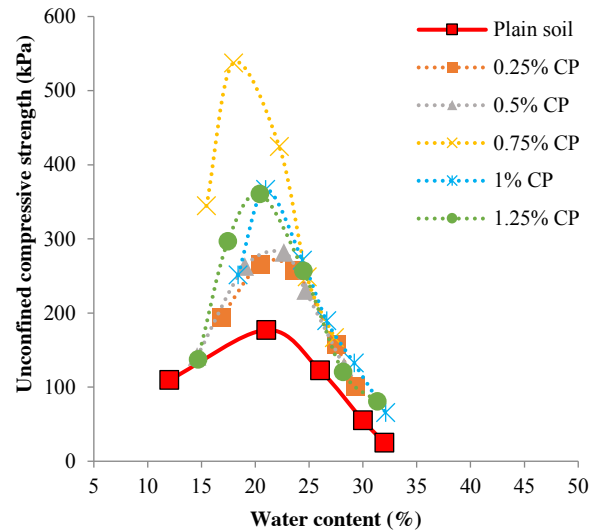
c) Figure 5. Unconfined compression test results of CH a) Virgin Homopolymer Polypropylene [VHP] b) Polypropylene [PP] c) Copolymer [CP].



a)



b)



c)

Figure 6. Unconfined compression test results of CL a) Virgin Homopolymer Polypropylene [VHP] b) Polypropylene [PP] c) Copolymer [CP].

Table 3. Results of CBR tests for CH type soil

Description	CBR (%)
Plain Soil (CH)	11.06
99.75% CH+0.25% VHP	20.07
99.5% CH+0.5% VHP	17.14
99.25% CH+0.75% VHP	16.28
99.75% CH+0.25% PP	15.71
99.5% CH+0.5% PP	16.92
99.25% CH+0.75% PP	19.04
99.75% CH+0.25% CP	16.92
99.5% CH+0.5% CP	19.57
99.25% CH+0.75% CP	20.59

Table 4. Results of CBR tests for CL type soil

Description	CBR (%)
Plain Soil (CL)	12.06
99.75% CL+0.25% VHP	16.79
99.5% CL+0.5% VHP	15.20
99.25% CL+0.75% VHP	14.34
99.75% CL+0.25% PP	15.71
99.5% CL+0.5% PP	16.93
99.25% CL+0.75% PP	19.02
99.75% CL+0.25% CP	14.15
99.5% CL+0.5% CP	16.59
99.25% CL+0.75% CP	19.57

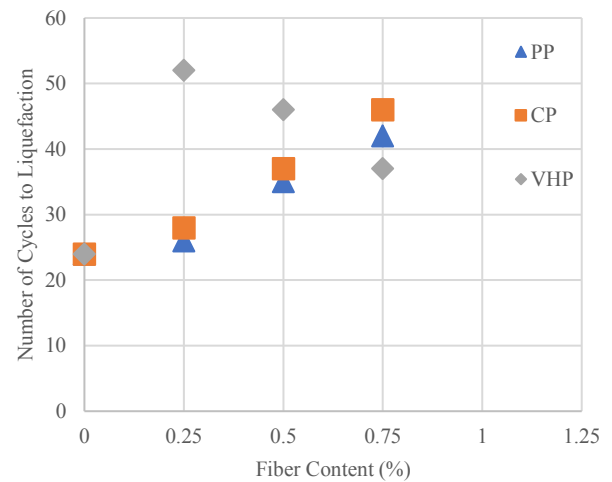


Figure 7. Number of cycles to initial liquefaction versus fiber content for CH type soil.

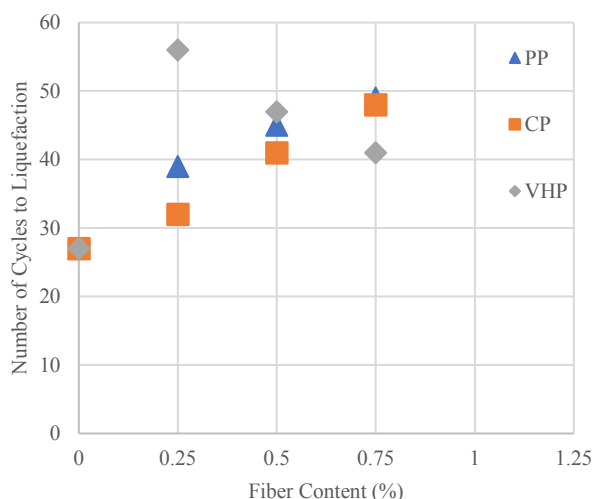


Figure 8. Number of cycles to initial liquefaction versus fiber content for CL type soil.

4 CONCLUSIONS

This paper presents the results of an experimental research on the treatment of low and high plasticity clays using Virgin Homopolymer Polypropylene (VHP), polypropylene (PP) and copolymer (CP) fibers with 0%, 0.25%, 0.50% and 0.75% of fiber contents. The results from this research may lead to significant implications of making the use of marginal on-site materials possible and lowering construction costs. The following can be concluded from this experimental study.

According to the results of unconfined compression and california bearing ratio (CBR) experiments of all mixtures, it can be seen that adding all three types of fibers to both CL and CH soils result in increasing the strength and CBR values. It should be noted that the increase in fiber contents of used fibers exhibits two distinct stages in terms of observed behavior. In other words, for both clayey soils, when the proportion of PP and CP fibers are 0.25% of the blended soil, there is an increase in strength. This improvement increases as the amount of both fibers further increase. On the other hand, addition of VHP fiber increases the strength of both CH and CL types of soils with the largest increase with 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 cause higher number of cycles to liquefaction for both CH and CL types of soils compared to 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 numbers 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 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 of the type of soil, passing from CH to CL type of soil. This can be explain by the fact that both plain soils (without any fiber content) showed approximately same behavior and therefore both clay soils' mixtures also exhibited more or less same behaviors.

With respect to the results of all tests conducted on high and low plasticity soils, it can be inferred that highest strength of the clayey soils obtain when adding 0.25% of VHP type of fiber for both clayey soils. As future studies, it is expected that more strengthen soils mixtures can be obtained by mixing clayey soils

with the mentioned fibers and other alternative materials such as fly ash, and lime.

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