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Behavior of Cohesive Soil Reinforced by Polypropylene Fiber

Mohammed A. Al-Neami [a], Falah H. Rahil [b], Yassein H. Al-Ani [c*]

[a] University of Technology, Baghdad, Iraq, al_neami74@yahoo.com; 40008@uotechnology.edu.iq

[b] University of Technology, Baghdad, Iraq, 40029@uotechnology.edu.iq

[c] University of Technology, Baghdad, Iraq, yassein.hjm@gmail.com

*Corresponding author.

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KEYWORDS

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ABSTRACT

For any land-based structure, the foundation is very important and has to be strong to support the entire structure. In order for the foundation to be strong, the soil underneath it plays a very critical role. Some projects where the soil compacted by modifying energy is insufficient to achieve the required results, so the additives as a kind of installation and reinforcement are used to achieve the required improvement. This study introduces an attempt to improve cohesive soil by using Polypropylene Fiber instead of conventional kinds used in soil stabilization. Three different percentages (0.25%, 0.5%, and 0.75% by dry weight of soil) and lengths (6, 12, and 18) mm of fiber are mixed with cohesive as a trial to enhance some properties of clay. The results of soil samples prepared at a dry density at three different water conditions (optimum water content, dry side, and wet side) showed that the increase of the percentage and length of polypropylene fiber causes a reduction in the maximum dry density of soils. Soil cohesion increases with the increase of PPF up to 0.5% then decreased. The length of Polypropylene fiber has a great effect on the cohesion of soil and adding 0.5% Polypropylene fibers with a length of 18mm to the soils consider the optimum mix for design purposes to improve the soil. Finally, the soil reinforced by PPF exhibits a reduction in the values of the compression ratio (CR) and accelerates the consolidation of the soil.

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1. Introduction

For any land-based structure, the foundation is very important and has to be strong to support the entire structure. In order for the foundation to be strong, the soil underneath it plays a very critical role. So the soil needs to have proper knowledge about their properties and factors which affect their behavior. The stabilization process of soil helps to achieve the required properties in the soil must be available to use it in the construction work. The soil needs to have proper knowledge about their properties and factors which affect their behavior. The process of soil stabilization helps to achieve the required properties in the soil must be available to use it in the construction work.

The reinforcement consists of incorporating certain materials with some desired properties within other material which lacks those properties [1]. Therefore, the soil reinforcement is defined as a technique adopted to improve the engineering characteristics of soil in order to improve the soil properties such as shear strength, compressibility, density; and hydraulic conductivity [2]. Consequently, reinforced earth is a composite material consisting of alternating layers of compacted backfill and man-made reinforcing material [3]. The primary purpose of reinforcing soil mass is to improve its stability, increase its bearing capacity, and reduce the settlement and lateral deformation [4].

2. Methodology and Experimental Works

I. Soils Used

Three types of natural soil obtained from different places were used to achieve the purpose of this study (Palestine Street, Al-Rubaie Street, and Al-Dora area) in Baghdad province/middle of Iraq. An excavator machine was used to get on the soil samples reaching the required depth (1-1.5m). The surface layer was scraped to remove the topsoil which contains any organic material and small bushes. Then, all soil samples placed in plastic bags, labelled and transported to the Soil Mechanics Laboratory of the Civil Engineering Department – University of Technology for testing. The soil sample was air-dried and pulverized and used to study and specified the effect of Polypropylene fiber on soil properties. The symbols A, B and C are given to express the soils used in this study. Several tests are conducted to concern the geotechnical properties of soils used. The details of physical properties are tabulated in Table 1.

Table 1: Properties of soils used

Index Property	Standard Specification	Index Valve		
		Soil A	Soil B	Soil C
Depth (m)	---	1.5	1	1.5
Specific gravity, Gs	ASTM D 854	2.67	2.70	2.74
Gravel (larger than 4.75mm) (G)%	ASTM D 422	0	0	0
Sand (0.075 to 4.75 mm) (S) %	ASTM D 422	44	13	2
Liquid limit (%)	ASTM D 4318	27	39	54
Plastic limit (%)	ASTM D 4318	16	20	23
Plasticity index (%)	ASTM D 4318	11	19	31
Optimum moisture content (modified) (%)	ASTM D 1557	13	14.5	17
Maximum unit weight (modified) (kN/m3)	ASTM D 1557	19.52	18.8	18.48

II. Polypropylene Fiber (PPF)

Various types of polypropylene fibers are available in the market to differ in their characteristics such as fiber type, length, and diameter. Table 2 and Figure 1 respectively, depict the properties and shape of fiber used in this study. The useful life of this fiber may be as long as 5 years at 121° C, 10 years at 110° C, and 20 years at 99° C. Specially stabilized grades are Underwriters Laboratories-rated at 120° C for continuous service.

Figure 1: Polypropylene Fibers

Table 2: Properties of Polypropylene Fibers Used [5].

Fiber Properties	Values
Fiber Type	Single fiber
Average Length, mm	6,12 & 18
Average Diameter, mm	0.034
Unit Weight, g/cm^3	0.91
Tensile Strength, MPa	350
Young's modulus, MPa	3500
Fusion point , °C	165
Burning point, °C	590° C
Surface area, m^2/kg	250
Elongation, %	24.4
Water Absorption	Nil
Dispersibility	Excellent
Acid & Alkali resistance	Very Good

III. Soil samples preparation and testing program

Three types of Polypropylene fiber (PPF) different in length are used (6, 12, and 18) mm. Each type of PPF is added to the soil in three percentages (0.25, 0.5, and 0.75) %. The weight of fiber adds to the soil can be specified by the equation below, [6] [7]:

$$\rho f = \frac{Wf}{W} \times 100 \quad (1)$$

Where: ρf = ratio of fiber content, Wf = weight of the fiber, gm. W = weight of the air-dried soil, gm.

The soil was mixed with the specified amount of fiber in a good way by using three types of mixer machine as shown in Figure 2. Mixer (1) was used to prepare the samples to have weights of 1 to 1.5 kg. Mixer (2) was used to prepare samples with weights of 1.5 to 5 kg. Mixer (3) was used to prepare samples to have weights more than 30 kg.

Figure 2: Mixers type for soil sample preparation

The testing of soil samples consists of the follows:

1) Conducting of 81 tests to study the effect of PPF on the maximum dry density of soils studied using three fiber lengths (6, 12 and 18) mm with three percent's (0.25, 0.5&0.75) % with three percent's of water content at (95% of maximum dry density in dry, wet and optimum side) for each type of soil (A, B and C).
2) Conducting of 42 tests to study the influence of the PPF on the unconfined compressive strength of soil by using a Maximum dry density and optimum water content with adding of (0.25, 0.5 and 0.75) % with (6, 12 and 18) mm PPF length and to select the pest length and percent of PPF and add it on each soil at (95% maximum dry density in the dry and wet side).
3) After selecting the best length and percentage of PPF (18mm length, and 0.5% weight), a total of 54 samples were tested in the direct shear device at (dry, optimum and wet sides).
4) A one-dimensional consolidation test was conducted on 18 samples to study the impact of PPF on the compression index (Cc), Recompression index (Cr) and coefficient of consolidation (Cv) at dry, optimum and wet sides.

3. Results and Analysis

The testing program is implemented on clayey samples to investigate the effects of Polypropylene fiber (PPF) on the geotechnical properties of such soils. The results of the tests are recognizing into three series. The first is devoted to studying the effect of (PPF) on the compaction characteristics. The second series is divided into three parts; the first one is devoted to studying and designing the suitable length and percentage of polypropylene fiber which need to add for the improvement depending on the results of an unconfined compression test. The second part, focusing on the effect of PPF on the fraction angle of soil samples determined by the direct shear test and the last one includes studying the effect of PPF on the soil consolidation properties. Table 3 depicts the maximum dry density, optimum water content and cohesion of natural three soils (A, B and C) at three water sides of water content (dry, optimum and wet).

Table 3: Maximum Dry Density, Optimum water Content and Cohesion of natural Soil.

Water state	Soil Property								
	Soil A			Soil B			Soil C		
	ρdmax g/cm^3	ω%	c kPa	ρdmax g/cm^3	ω%	c kPa	Pdmax g/cm^3	ω%	c kPa
dry	1.854	7	133	1.786	9.2	369	1.755	12	449
O.M.C	1.952	13	187	1.88	14.5	335	1.848	17	255
wet	1.854	16	86	1.786	18	175	1.755	21.3	135

I. Effect of PPF on compaction characteristics

The modified compacted test is conducted on all soil samples to specify the effect of PPF on maximum dry density in dry, optimum and wet sides of the compaction curve. The results of all tests show that adding PPF to soil samples leads to a decrease in the maximum dry density due to reducing the average weight of the solids unit in the soil and fiber mixture. Also, the results demonstrate that the dry density obtained for all three types of soils at optimum water content, dry side and wet side decreased with the increase of the percentage and length of polypropylene fiber. This reduction is significant when the fill materials need to be lightweight. Figure 3 represents the effect of PPF on dry unit weights.

II. Effect of PPF on shear strength parameters

For both natural and enhanced soil samples, the shear strength of soils used is obtained using unconfined compression tests. This test is a special case of the unconsolidated undrained triaxial test (UU test). The test was performed according to the [8] on all soil specimens before and after adding of PPF (Figure 4) to clarify the effect of this additive on shear strength parameter of soil (cohesion) on a cylindrical specimen with 38 mm diameter and Several unconfined compression tests are conducted by using different percentages (0.25, 0.5, and 0.75) and different lengths of PPF (6, 12, and 18 mm).

The remolded soil samples are prepared in the laboratory-based on the maximum dry density and the optimum water content. The results of all tests are depicted in Figures 5 and 6. To concern the improvement degree occurred in soil samples due to adding of PPF, the enhanced factor is calculated using equation (2) corresponding to the amount of improvement in the undrained compression strength, [9]. As shown in Table 4.

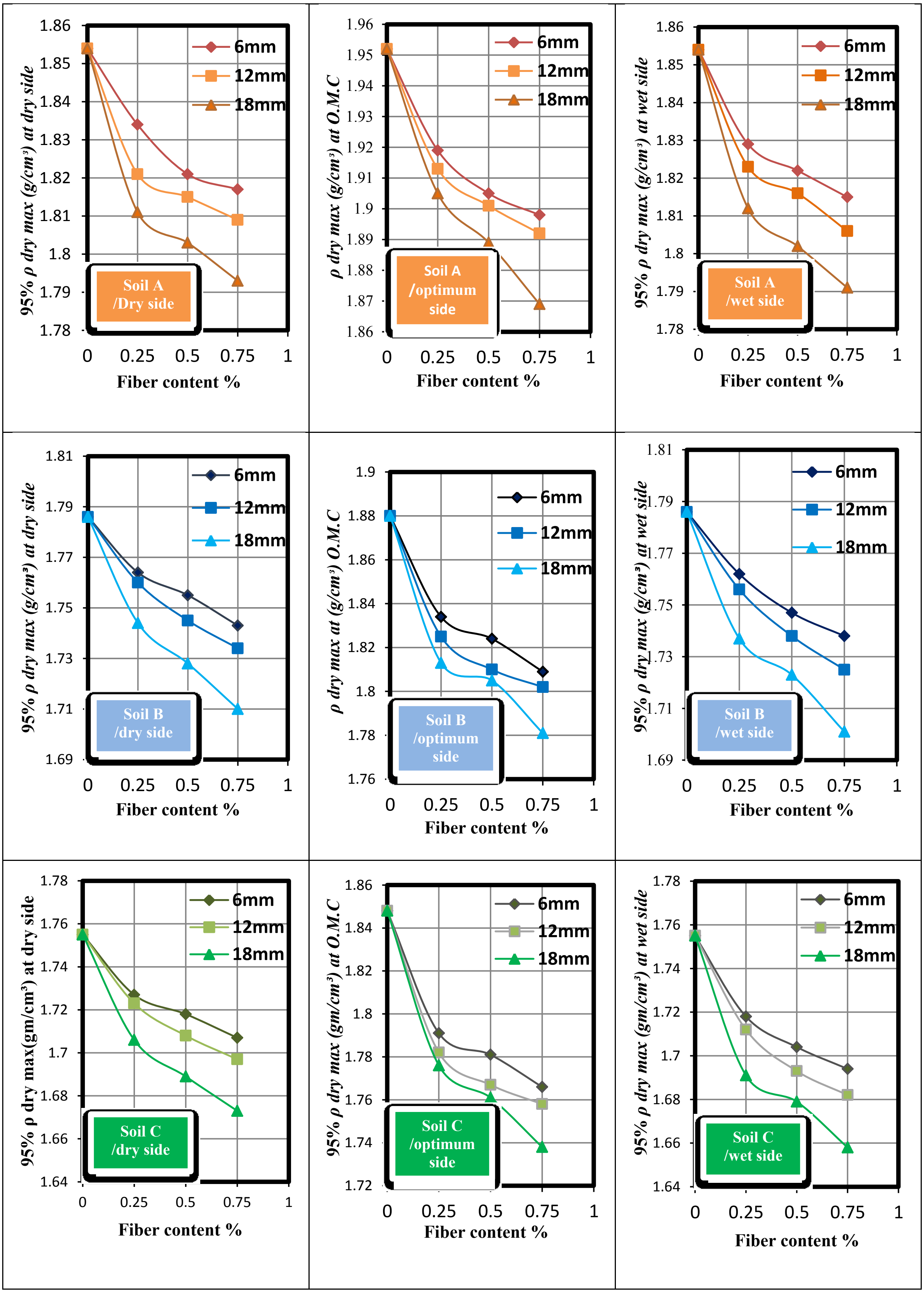
$$I_{UCS} = \frac{q_{UR} - q_{UU}}{q_{UU}} = \frac{q_{UR}}{q_{UU}} - 1 \quad (2)$$

Where:

IUCS: the enhanced factor

q_{UR}: the UCS of fiber-reinforced soil,

q_{UU}: the UCS of unreinforced soil.



76mm in height (L/D = 2)

Figure 3: Relationship between maximum dry density and three (length and percent) of Polypropylene fiber at the dry, optimum and wet side for soils used

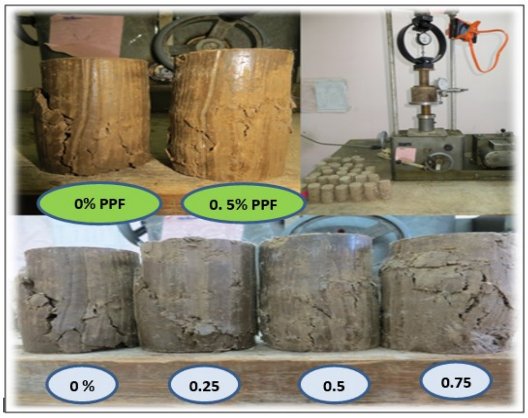


Figure 4. Soil Samples preparation for unconfined test

The analysis of unconfined results demonstrates that the soil cohesion increases when PPF percent increased from 0.25% and 0.5%, respectively due to increasing the physical bonds between PPF and soil surrounding it, but when PPF increased to the percentage of 0.75%, the cohesion is decreased due to decrease the soil unit weight. Also, the length of Polypropylene fiber has a great effect on the cohesion of soil; the increased additive length causes an increase in the soil cohesion due to increase the contact area between the soil and fiber, and therefore the increased adhesion will lead to increase the soil cohesion.

Depending on these results, it can be concluded that adding 0.5% Polypropylene fibers with a length of 18mm to the soils can be considered as an optimum mix for design purposes to improve soil because it gives a maximum value of cohesion when adding to the soil.

I. Effect of PPF on consolidation behavior

Consolidation tests are conducted according to the standard consolidation test, [10] on soil samples (unreinforced soil and reinforced soil with 18mm and 0.5% of polypropylene fiber) to know the effect of PPF on the compression index (c_c), swelling index (c_r), coefficient of volume change (m_v), coefficient of consolidation (c_v), and permeability (k) of soil samples. In this test, a soil specimen is restrained laterally and loaded axially with total stress increments. All the tested samples were prepared under the modified compaction. The relationship between compression ratio and compression index is not a direct relation, and the compression index (Cc) does not represent the compressibility of the soil, [11] mentioned that the compression ratio (CR) is more realistic to find out the compressibility value, which it is;

$$CR = \frac{Cc}{1+e_0} \quad (3)$$

In contrast, the Rebound (Swelling) ratio (RR) is more accurate than the swelling index (Cr), Where;

$$RR = \frac{Cr}{1+e_o} \quad (4)$$

The results shown in Table 5 and Figures 7 to 9, the soil reinforced by PPF exhibits a reduction in the values of compression ratio (CR) and this effect of PPF is important in the controlling the swelling of the soil, and hence the extravagant settlement of structures built on such can be reduced extremely. The coefficient of consolidation increases when the fiber adding in three phases (optimum, dry and wet side), so it leads to accelerating the consolidation of soil. This indicates that the presence of fiber increases the resistance of soil to compress. In general, the c_v increases for all soils under different conditions. Soil C has a higher percentage of increasing at the water content taken in a wet side while soil B achieves a higher value in the percentage of increase in c_v at a water content taken at a dry side. This behavior may be due to the difference in high plasticity for soil samples. Thus, the time required to achieve a primary consolidation decreases for fiber-reinforced soil for a given degree of consolidation and a given drainage path.

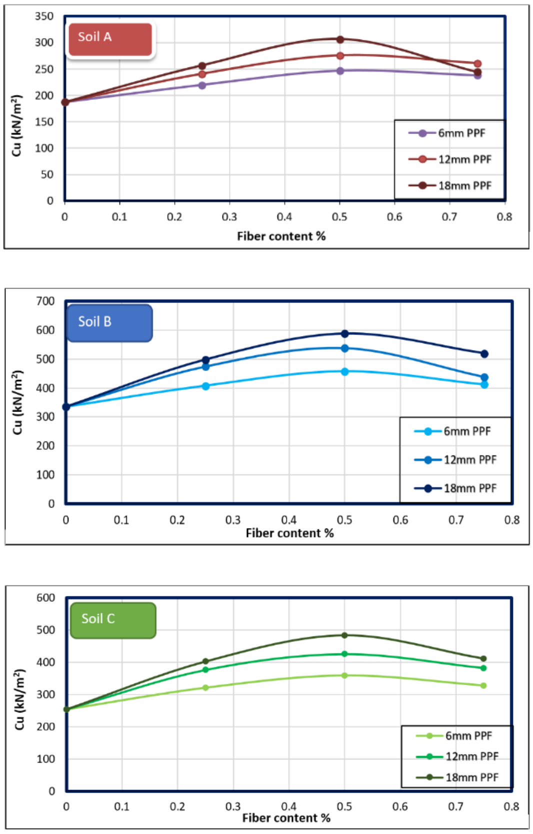
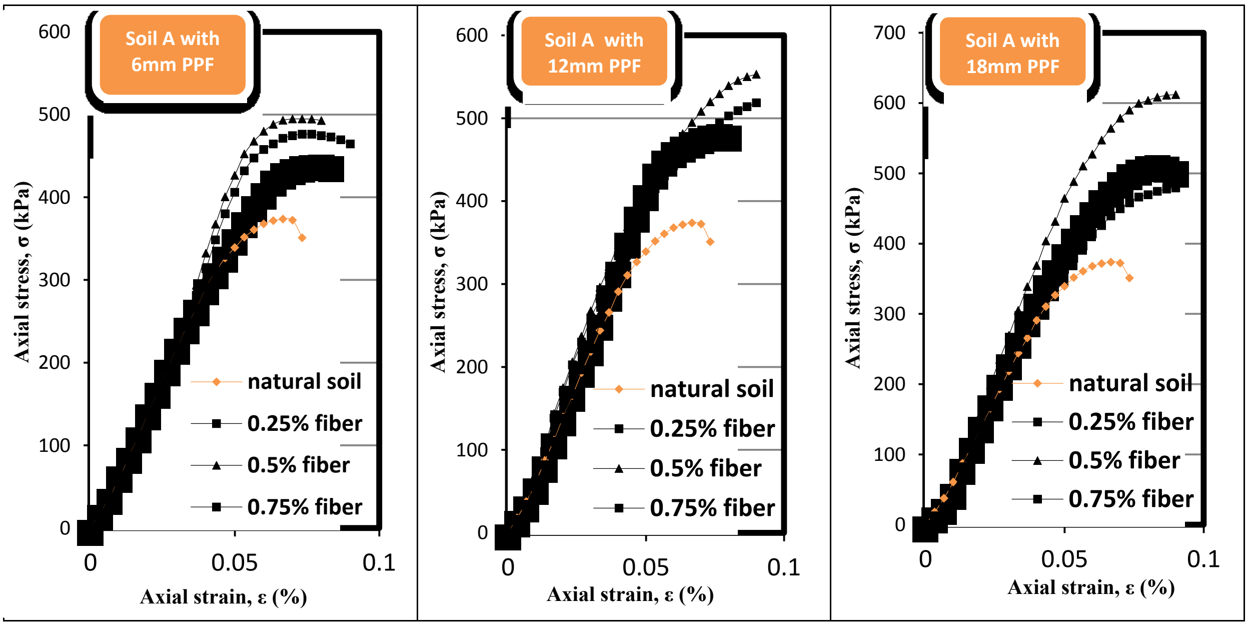


Figure 5: Undrained shear strength variation in different PPF content of soil (A), (B) and (C)



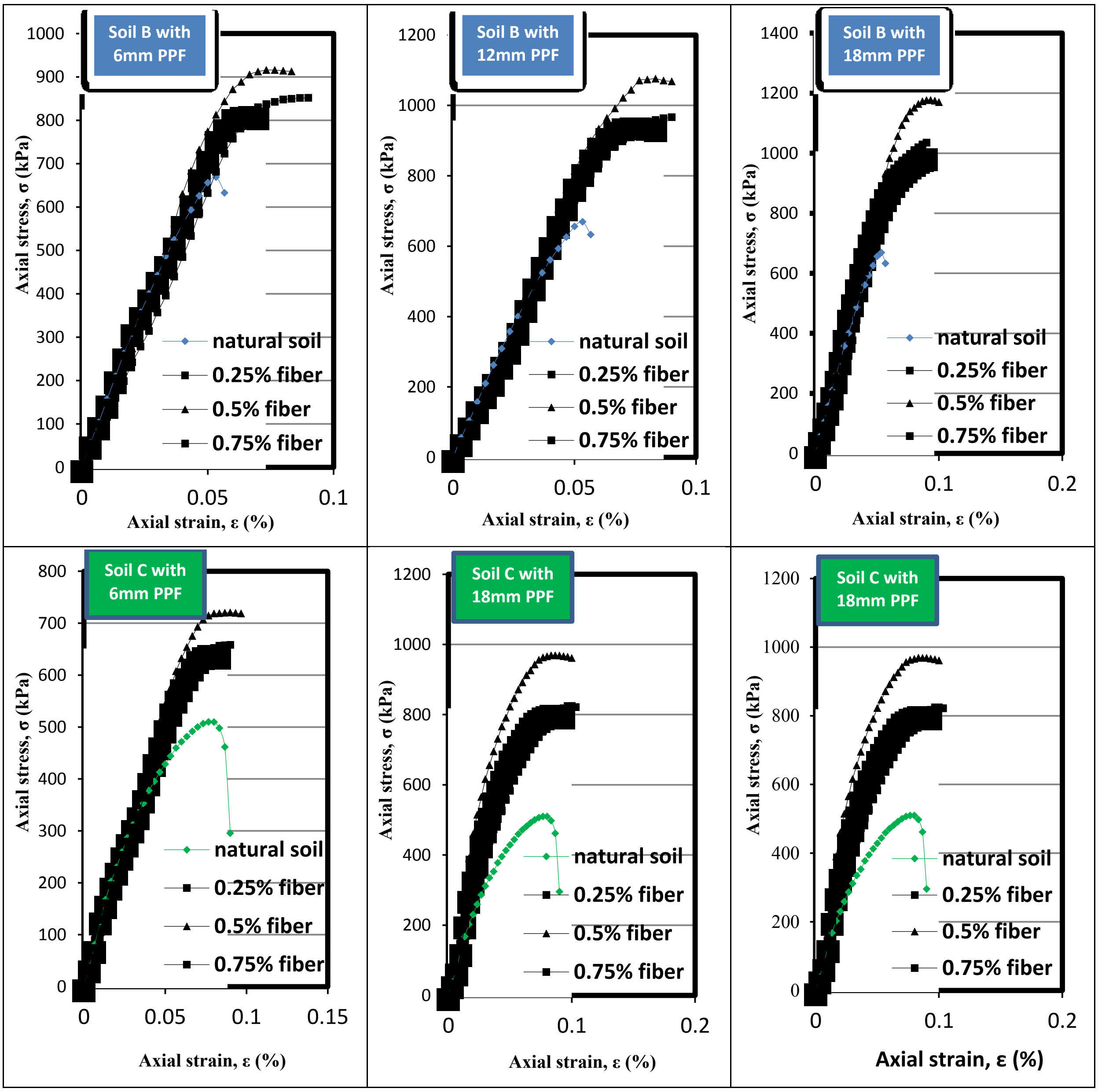


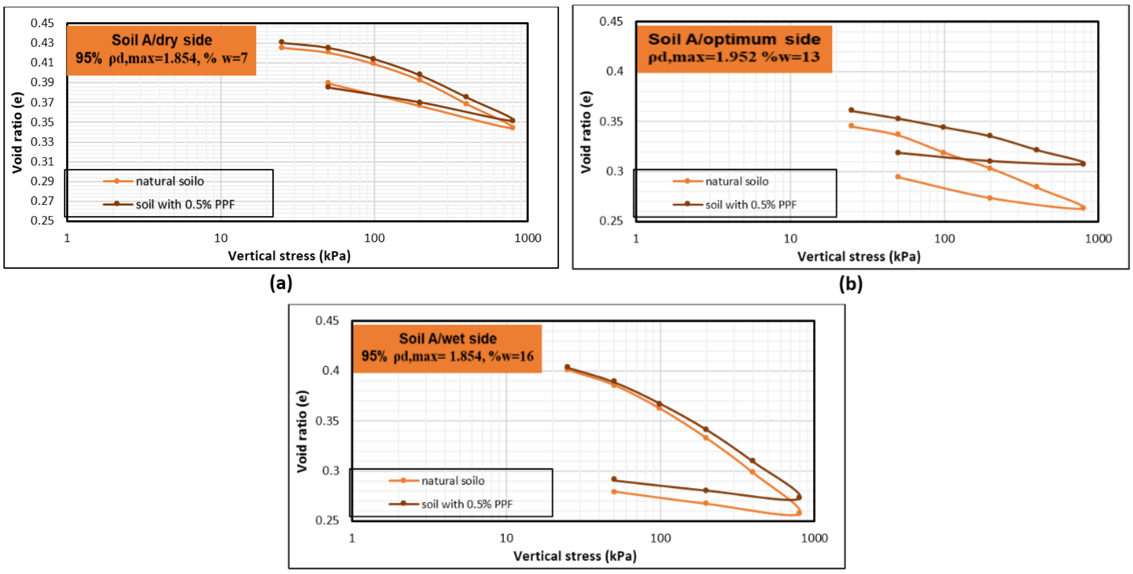
Figure 6: Stress-Strain relationship for soils Used at optimum side with PPF (6, 12 &18) mm

Table 4: Results of unconfined compression tests

soil (A) unconfined test result						
#	side	w%	fiber length (mm)	fiber content %	Cu (kN/m^2)	I_{UCS}%
1	dry side	7	0	0	133	45
2		7	18	0.5	193	
3	Optimum	13	0	0	187	0
4		13	6	0.25	220	18
5		13	6	0.5	247	32
6		13	6	0.75	238	27
7		13	12	0.25	241	29
8		13	12	0.5	276	48
9		13	12	0.75	261	40
10		13	18	0.25	257	37
11		13	18	0.5	307	64
12		13	18	0.75	244	30
13	wet side	16	0	0	86	53
14		16	18	0.5	132	
soil (B) unconfined test result						
#		w%	fiber length (mm)	fiber content %	Cu (kN/m^2)	I_{UCS} %
1	dry side	9.2	0	0	369	68
2		9.2	18	0.5	620	
3	Optimum	14.5	0	0	335	0
4		14.5	6	0.25	408	22
5		14.5	6	0.5	458	37
6		14.5	6	0.75	412	23
7		14.5	12	0.25	474	41
8		14.5	12	0.5	538	61
9		14.5	12	0.75	438	31
10		14.5	18	0.25	498	49
11		14.5	18	0.5	588	76
12		14.5	18	0.75	520	55
13	wet side	18	0	0	175	60
14		18	18	0.5	280	
soil (C) unconfined test result						
#	side	w%	fiber length (mm)	fiber content %	Cu (kN/m^2)	I_{UCS} %
1	dry side	7	0	0	449	76
2		7	18	0.5	791	
3	Optimum`	13	0	0	255	0
4		13	6	0.25	322	26
5		13	6	0.5	360	41
6		13	6	0.75	329	29
7		13	12	0.25	377	48
8		13	12	0.5	426	67
9		13	12	0.75	383	50
10		13	18	0.25	403	58
11		13	18	0.5	484	90
12		13	18	0.75	412	62
13	wet side	16	0	0	135	61
14		16	18	0.5	218	

Table 5: Results of consolidation tests

Index properties		Index value					
Soil A							
Index properties		(unreinforced) soil			(reinforced) soil		
		dry	O.M.C	wet	dry	O.M.C	wet
(eo)		0.4413	0.3692	0.4413	0.4413	0.3692	0.4413
(Cc)		0.0813	0.0693	0.1364	0.0766	0.0454	0.1137
(Cr)		0.0383	0.0346	0.0203	0.0251	0.0090	0.0149
(CR)		0.0564	0.0506	0.0946	0.0531	0.0332	0.0788
(RR)		0.0265	0.0253	0.0141	0.0174	0.0066	0.0103
(av)*١٠$^{-3}$ (m2/kN)		0.1657	0.1565	0.2954	0.1256	0.0889	0.2594
(mv)*١٠$^{-3}$ (m2/kN)	At 200)kPa	0.115	0.1143	0.205	0.113	0.065	0.18
(cv) (m2/year)		28.571	3.439	11.142	30.952	4.352	19.809
(k) (cm/sec)		12.962	1.116	9.011	13.798	1.550	14.067
Soil B							
Index properties		(unreinforced) soil			(reinforced) soil		
		dry	O.M.C	wet	dry	O.M.C	wet
(eo)		0.5117	0.4361	0.5117	0.5117	0.4361	0.5117
(Cc)		0.1506	0.1264	0.1657	0.0979	0.0763	0.0527
(Cr)		0.0715	0.0327	0.0376	0.0194	0.0047	0.0119
(CR)		0.0996	0.0880	0.1096	0.0647	0.0531	0.0348
(RR)		0.0473	0.0228	0.0249	0.0128	0.0033	0.0078
(av)*١٠$^{-3}$ (m2/kN)		0.1814	0.1077	0.2267	0.0982	0.06462	0.1058
(mv)*١٠$^{-3}$ (m2/kN)	At 200)kPa	0.12	0.075	0.15	0.065	0.045	0.07
(cv) (m2/year)		14.50	9.92	11.02	29.08	19.89	24.56
(k) (cm/sec)		6.868	2.937	6.523	7.458	3.532	6.783
Soil C							
Index properties		(unreinforced) soil			(reinforced) soil		
		dry	O.M.C	wet	dry	O.M.C	wet
(eo)		0.5607	0.4826	0.5607	0.5607	0.4826	0.5607
(Cc)		0.2203	0.0960	0.1684	0.0699	0.0554	0.1062
(Cr)		0.0693	0.0320	0.0777	0.0187	0.0067	0.0116
(CR)		0.1411	0.0647	0.1079	0.0448	0.0373	0.0680
(RR)		0.0444	0.0215	0.0498	0.0120	0.0045	0.0047
(av)*١٠$^{-3}$ (m2/kN)		0.2106	0.0741	0.2731	0.078	0.0667	0.1638
(mv)*١٠$^{-3}$ (m2/kN)	At 200)kPa	0.135	0.05	0.175	0.05	0.45	0.105
(cv) (m2/year)		28.52	12.14	17.85	48.42	30.95	40.41
(k) (cm/sec)		15.192	2.395	12.328	9.552	5.495	16.793



(c)

Figure 7: Variation of void ratio with vertical stress for soil (A) prepared at: (a) dry side (b) optimum side (c) wet side, in odometer test

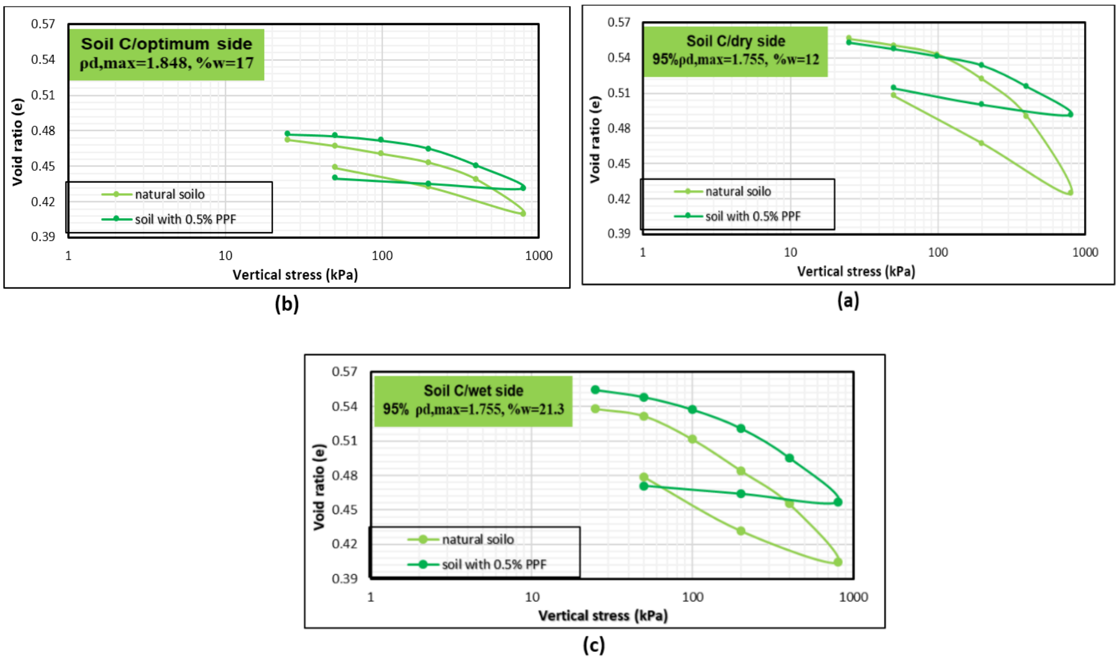


Figure 8: Variation of void ratio with vertical stress for soil (B) prepared at: (a) dry side (b) optimum side (c) wet side, in odometer test

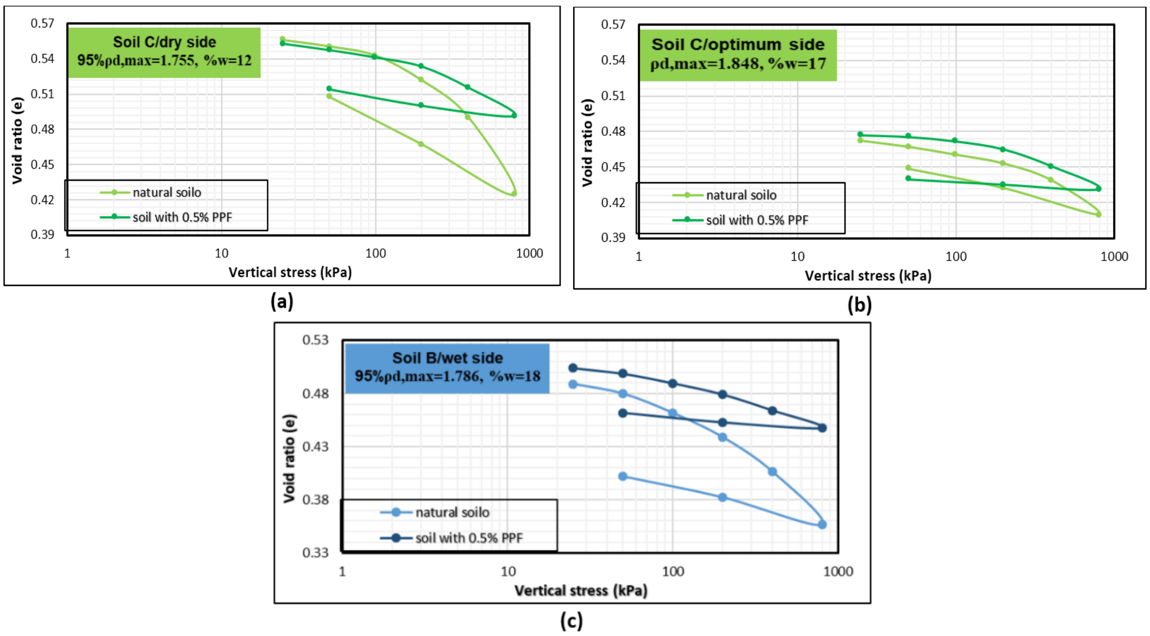


Figure 9: Variation of void ratio with vertical stress for soil (B) prepared at: (a) dry side (b) optimum side (c) wet side, in odometer test

4. Conclusions

Based on the testing results of soil – fiber mixture, the following conclusions can be drawn:

Adding of PPF leads to a decrease the maximum dry density of soils. Dry density obtained for all three types of soils at optimum water content, dry side and wet side decrease with the increase of the percentage and length of polypropylene fiber. Soil cohesion increases when PPF percentage increases from 0.25% and 0.5%, but when PPF increases to the percentage of 0.75%, the cohesion is decreased. The length of Polypropylene fiber has a great effect on the cohesion of soil; the increased additive length causes an increase in the soil cohesion due to the increase the contact area between soil and fiber. Adding 0.5% Polypropylene fibers with a length of 18mm to the soils consider as an optimum mix for design purposes to improve the soil. The soil reinforced by PPF exhibits a reduction in the values of the compression ratio (CR) and this effect of PPF is important in controlling the swelling of the soil, and hence the extravagant settlement of structures built on such can be reduced extremely. The fiber leads to accelerate the consolidation of soil. The coefficient of consolidation increases when the fiber, adding to the soil under different conditions.

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