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Effects of Glass Fiber Reinforced Polymer on Geotechnical Properties of Clayey Soil

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Abstract

Soil reinforcement can be considered as the combination of two parts. One part is soil for compressive stress capacity and another part is some material such as geosynthetics such as steel belts and fibers for tensile stress capacity. Soil improvement is one of the useful methods to increase the strength parameters of the soil. The main goal of this study is to evaluate the effects of GFRP on the bearing capacity, shear strength, and permeability of clayey soil. For this purpose, the length of GFRP is selected 10 mm and amount of GFRP are 0.2, 0.4, 0.6, 0.8 and 1% that mixed randomly with clay. Mixture specimens prepared using the optimum water content. Bearing capacity of specimens measured by unconfined compressive test and direct shear test. Also, Permeability parameter assessed based on the falling head permeability test. Results of this study showed that with mixing GFRP up to 0.8% increases the clay bearing capacity and flexibility. Although with continuing to add GFRP the bearing capacity decrease, the clay permeability using GFRP is increased.

Keywords: *GFRP, Clayey soil, Angle of internal friction, Cohesion, Permeability*

1. Introduction

Soil as the most important construction material and as the main support for the structures has been under focus of attention of mankind. However, due to the weak shear strength and lack of strength of soil against tensile forces, researchers have always looked after increasing the load bearing capacity, strength and also improving its properties. Therefore, researchers have implemented different methods including the mechanical modification such as compaction, and chemical modification such as stabilization using lime or cement together with application of the reinforced soil idea by implementing the auxiliary elements and with high tensile strength. In this respect, the soil reinforcement method due to low cost, easy execution and its great effect on improving soil properties has been recognized as an appropriate method for soil improvement and modification. Reinforced soil has a structure comprised of two different materials and their simultaneous performance reduces corresponding weakness of each of them. In this idea, the soil bears compressive stresses and reinforcing elements bear tensile stresses. Today, soil reinforcement as an effective and reliable method to improve and stabilize the soil layers. In addition to increasing the load bearing capacity, shear strength, and reducing its settlement, this idea used to stabilize the surface beds, road backfilling and pavements. Application of the auxiliary elements for improvement and modification of soil engineering properties has long been taken attention by mankind. Today, the efficiency and ability of soil reinforcement methods to provide the proper applicable solutions in various projects have lead to find its place in geotechnical engineering. To increase the soil load bearing capacity and its shear strength properties, use of polypropylene and glass fibers has been invented, which increases the probability of enhancing these properties in different conditions. Production and incorporation of polymeric materials as modern materials in the civil engineering has become widespread during the last three decades. By production of glass fibers the technology of soil stabilization was evolved and their application became more

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common, that is because utilizing these products one could alter the soil physical and mechanical properties according to the project conditions and better provide for the project requirements. Various methods have become widespread for investigating and analysis of soil stabilization with different materials. [1]

2. Literature Review

Many researchers have published many articles and conducted studies to presen more optimal methods. Among them one could refer to the studies accomplished by Dean and Fretting [2] have investigated the effect of the polypropylene fibers on the mechanical behavior of sandy soil utilizing the CBR, uniaxial and direct shear tests. Arenzic and Chawdhury [3] during experimental studies performed by direct shear instrument and building the physical model of a the reinforced soil retaining wall which was backfilled using beach sand reinforced with aluminum shells, concluded that implementing these elements increases the sand shear strength which the amount of this increase depends upon the properties and percentage of the reinforcing elements. Benson and Kayer [4] investigated effects of utilizing the polyethylene strips in altering the sand shear strength and stiffness and concluded that addition of polyethylene chips to the soil causes increase in the CBR, shear strength and modulus of subgrade reaction values in sand. Ranjan et al. [5]have demonstrated the positive effect of the fibers on the specimens' shear strength through performing triaxial tests on sand specimens reinforced with the fibers. Michalowsky and Zoba [6] presented a criterion for failure of the sand reinforced with the steel and the polyamide fibers, based on the laboratory research and theoretical investigations. Andersland and Khattac [7] concerned application of the herbal fibers in soil reinforcement and increasing shear strength of sand and kaolinite in triaxial test under static loading. Wang et al. [8] performed uniaxial and triaxial tests studied the effect of adding some the polymeric chips to soil in improving mechanical behavior of the clayey sand soils and concluded that addition of these fibers to soil, while increasing the specimens' shear strength also enhances their ductility. Cai et al. [9] investigated the effect of low percentage fibers in stabilizing the clayey and sandy soils which resulted in increased soil compressive strength. Erdinciler and Ayhan [10] utilized the rubber fibers to reinforce granular soils and found a relationship between the fibers' aspect ratio and shear strength. Sukantasokl and Jamsawang [11] added 10-20% cement to stabilize soft soil which slightly increased its bending strength and then adding fibers to the soil-cement mixture, the test results revealed significant increase in the residual strength. Cristello et al. [12] investigated the effect of soil reinforcement with separated f ibers on the clayey sand soils, in which they implemented the seismic wave propagation test. Main purpose of this study is to evaluate the effects of GFRP on bearing capacity and shear strength of clayey soil. In final, Sahebkaram and Dabiri [13] observed the effects of the several fibers type application on soft soil compared; tests results showed that polypropylene increased the bearing capacity more than other fibers. In continue, materials used and methodology described.

3. Materials and Methodology

To achieve the mentioned purposes, it was necessary to identify the geotechnical properties of materials and the physical features of GFRP. The grading of clay was determined using ASTM D421 [14] and ASTM D422 [15], which is shown in Figure 1. The clayey soil used from Kuye Fereshteh in Tabriz City (Figure. 2). The PH analysis of the clayey soil performed based on ASTM D4972 [16] that is equal 8. As shown in Figure 1, the clay is in accordance with unified classification in group CL. The Atterberg's limits of the clay in study area is PI=22 according to ASTM D4318-95a [17]. Moreover, the values of special weight (Gs) of the clay was determined based on ASTM D854 [18] standard that is equal 2.66. Compaction test was performed on material according to ASTM D 698 [19]. The results of the compaction tests are shown in diagrams of Figure 3. Properties of GFRP applied in this research described in Table 1.

Table 1. Engineering and index properties of GFRP [1]

Items	Specification	Results
Length	12mm	12mm +/- 0.5
		Less than 12mm < 0.2%
		More than 12mm
Diameter	11-15 micron	-
Moisture	< 0.15%	-
Tex	600, 1200, 2400	Mixed
Sizing	saline	100%

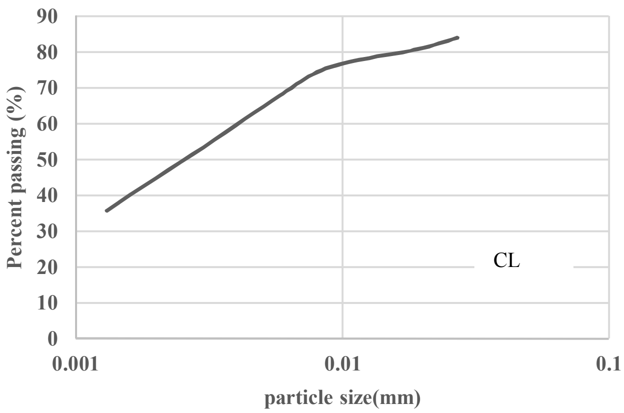


Figure 1. Grain size distribution for soil used in this Study

Figure 2. Position of study area in North east of Tabriz City

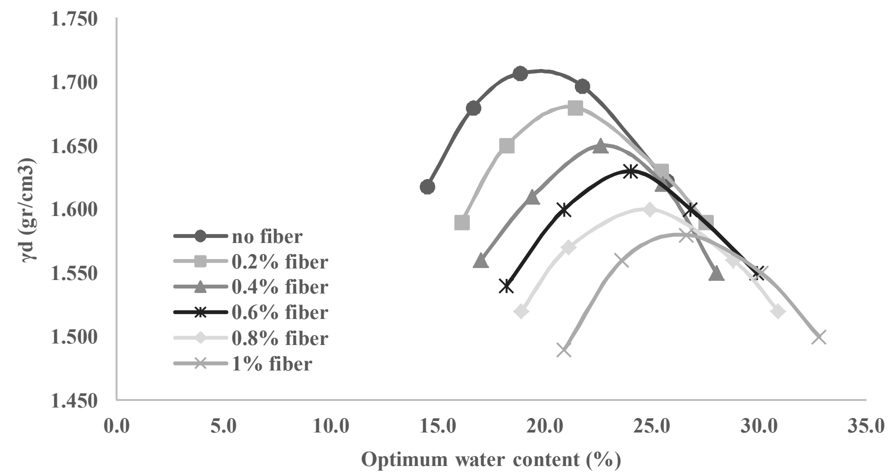


Figure 3. Effects of GFRP on the dry weight values in this study

In the present study GFRP with length 10 mm mixed in soil CL as random reinforcement in amount of 0.2%, 0.4%, 0.8% and 1%. Mechanical and geotechnical properties of soil improvement specimens was measured using a number of laboratory tests include direct shear test based on ASTM D3080 [20]. In this test specimens prepared in 6×6 cm mold at optimum water content. Loading performed with slowly speed (0.05mm/min) with vertical stress equal 0.5, 1 and 1.5 kg/cm2. Unconfined compressive strength test according to ASTM D2166 [21] carried out. In final, Falling Head Permeability Test performed on soil specimens based on ASTM D5084 [22].

4. Tests Results

The results of this study can be expressed as follow:

1. As can be observed in Figure 4 (a, b) effects of GFRP on maximum dry weight and optimum water content of specimens were compared. Accordingly, it can be found that increasing GFRP content in clay leads to, decrease the γdmax and in contrast, water absorption and in other words optimum water content increases. These condition indicates that GFRP causes more flexibility in clay.
2. Deformation and ductility of the clayey specimens mixed with GFRP and prepared for unconfined compressive test can be seen in Figure 5. General test results can be observed in Figure 6. As shown in the diagrams, with increasing the percent content of GFRP up to 0.8% in clayey soil, axial strength of reinforced clayey soil slowly growth.

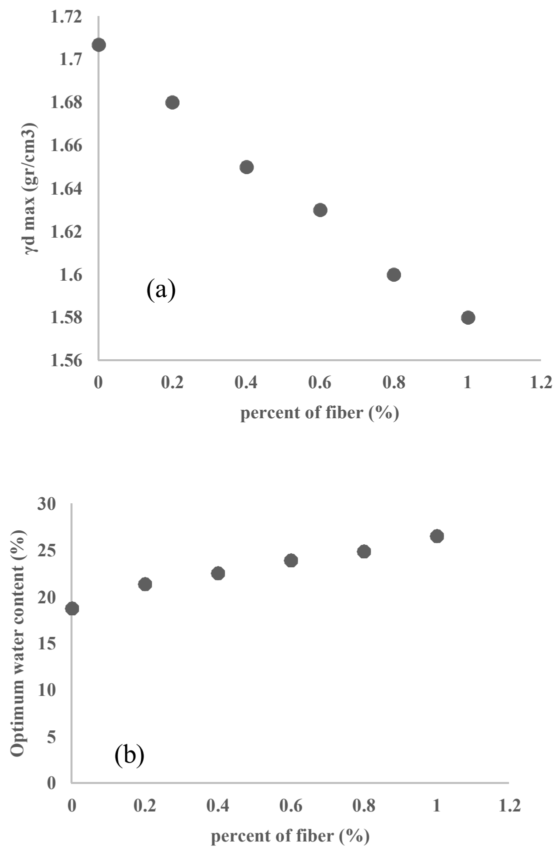


Figure 4. Effects of GFRP on clay: (a) maximum dry weight, (b) optimum water content.

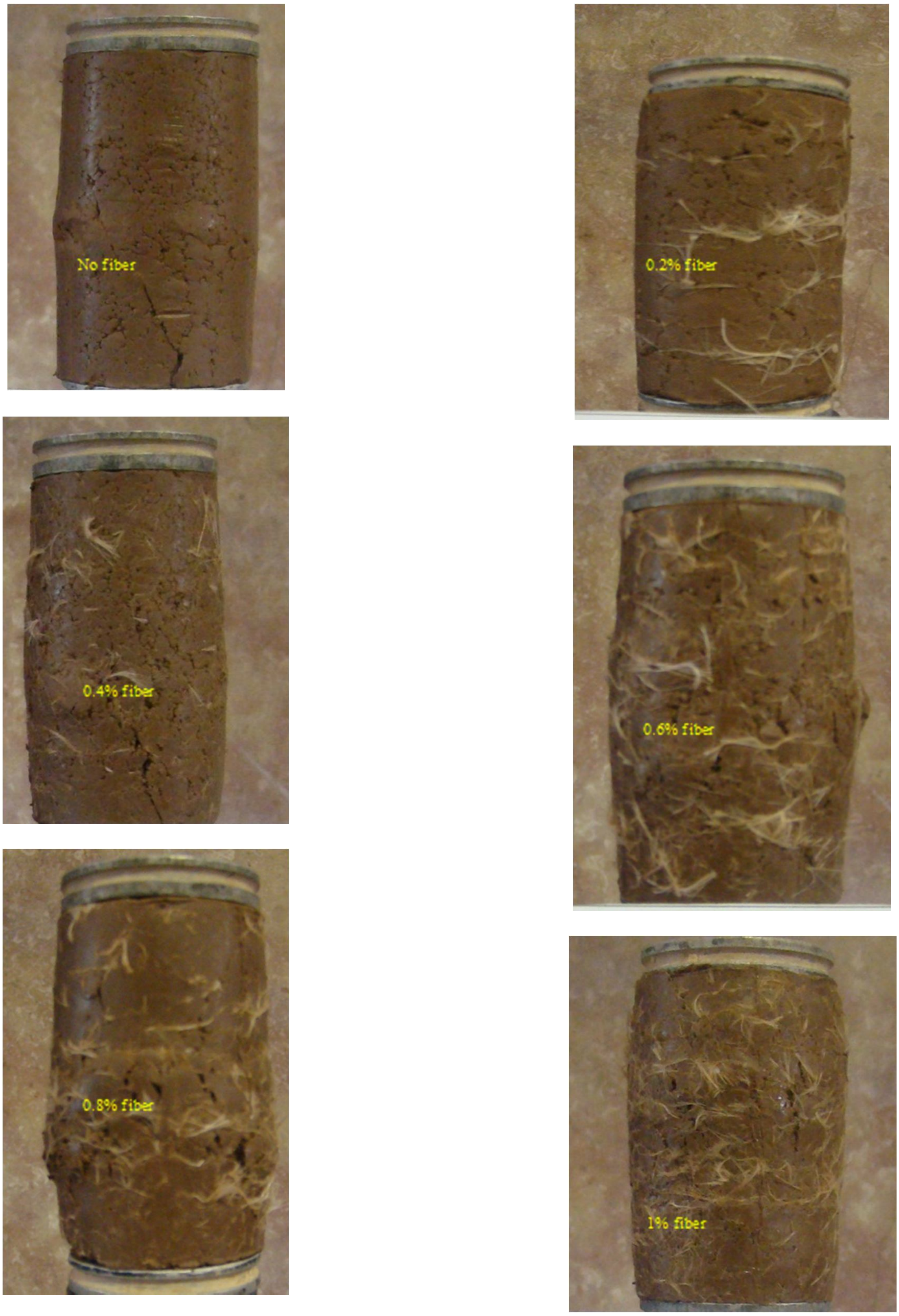


Figure 5. Deformation of clay specimens mixed with GFRP randomly in unconfined compressive test.

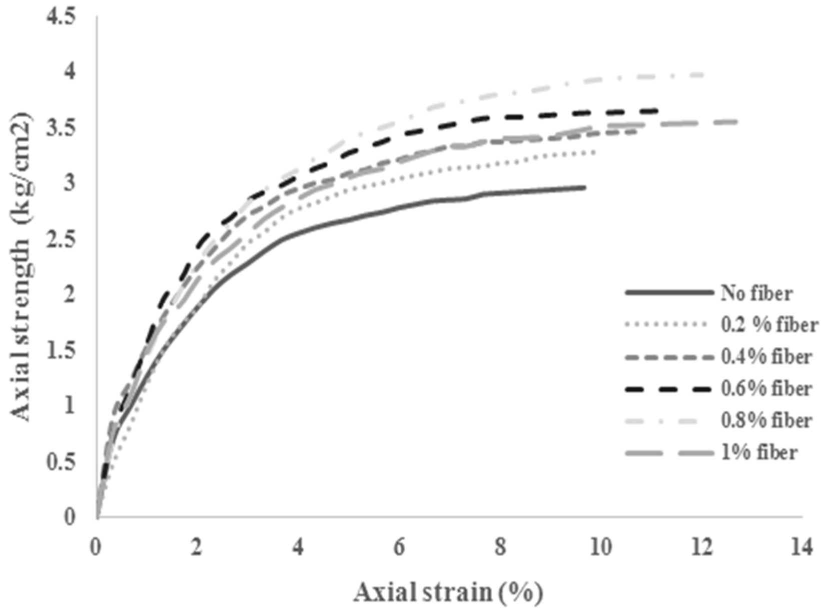


Figure 6. Variation of axial strength versus axial strain of clay specimens mixed with GFRP randomly

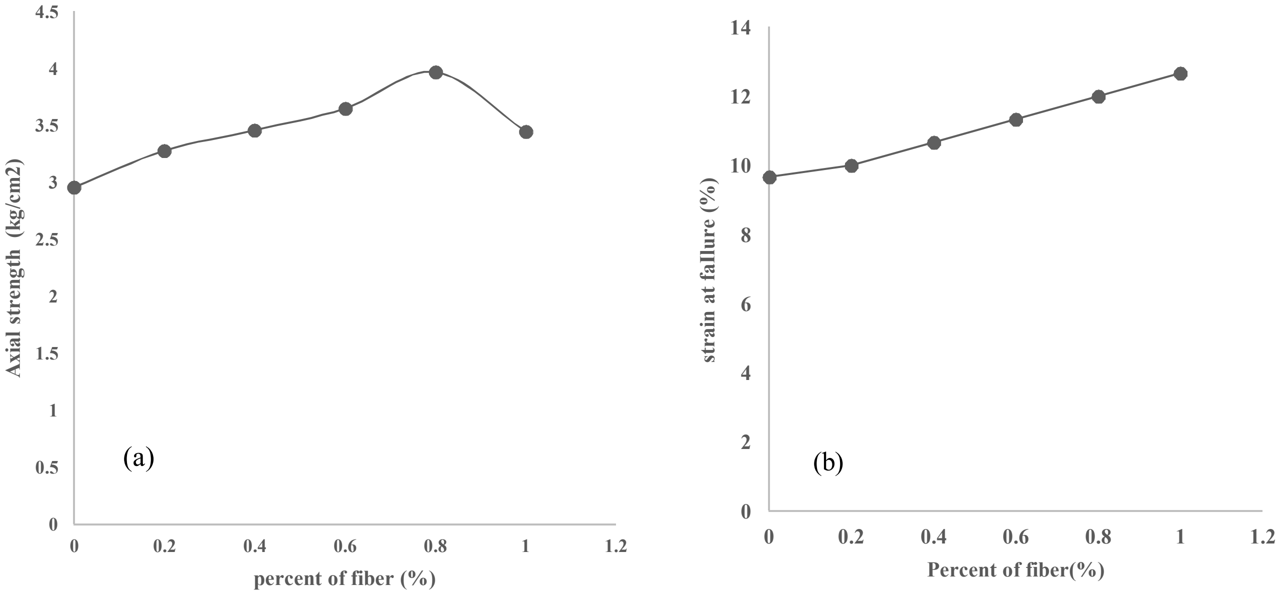


Figure 7. Effects of GFRP on clay specimens: (a) Axial strength, (b) strain at failure

3. Accordingly, Figure 7 ashows that with increasing GFRP content in clay up to 0.8% axial strength reaches to peak value. After that by continuing to add GFRP the axial strength decreases. Although value of strain at the failure in of specimens accordance with Figure 7b which tends to rise at the same time by adding GFRP. This condition explain that flexibility and ductility in clay mixed to GFRP increases.

4. According to Figure 8 (a, b) the axial strength and strain at the failure of the specimens changes based on the versus optimum water content. As regards by adding GFRP in clay axial strength at optimum water content equal to 25% and 0.8% , GFRP has heights value. Although, rate of strain at failure with increasing optimum water content and percent of GFRP at the same time tend to rise.

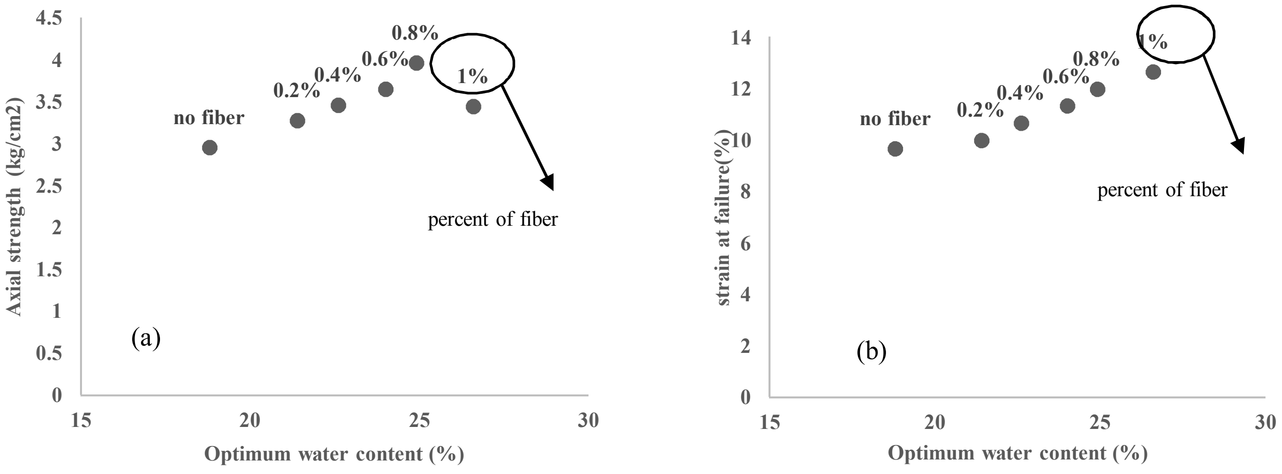
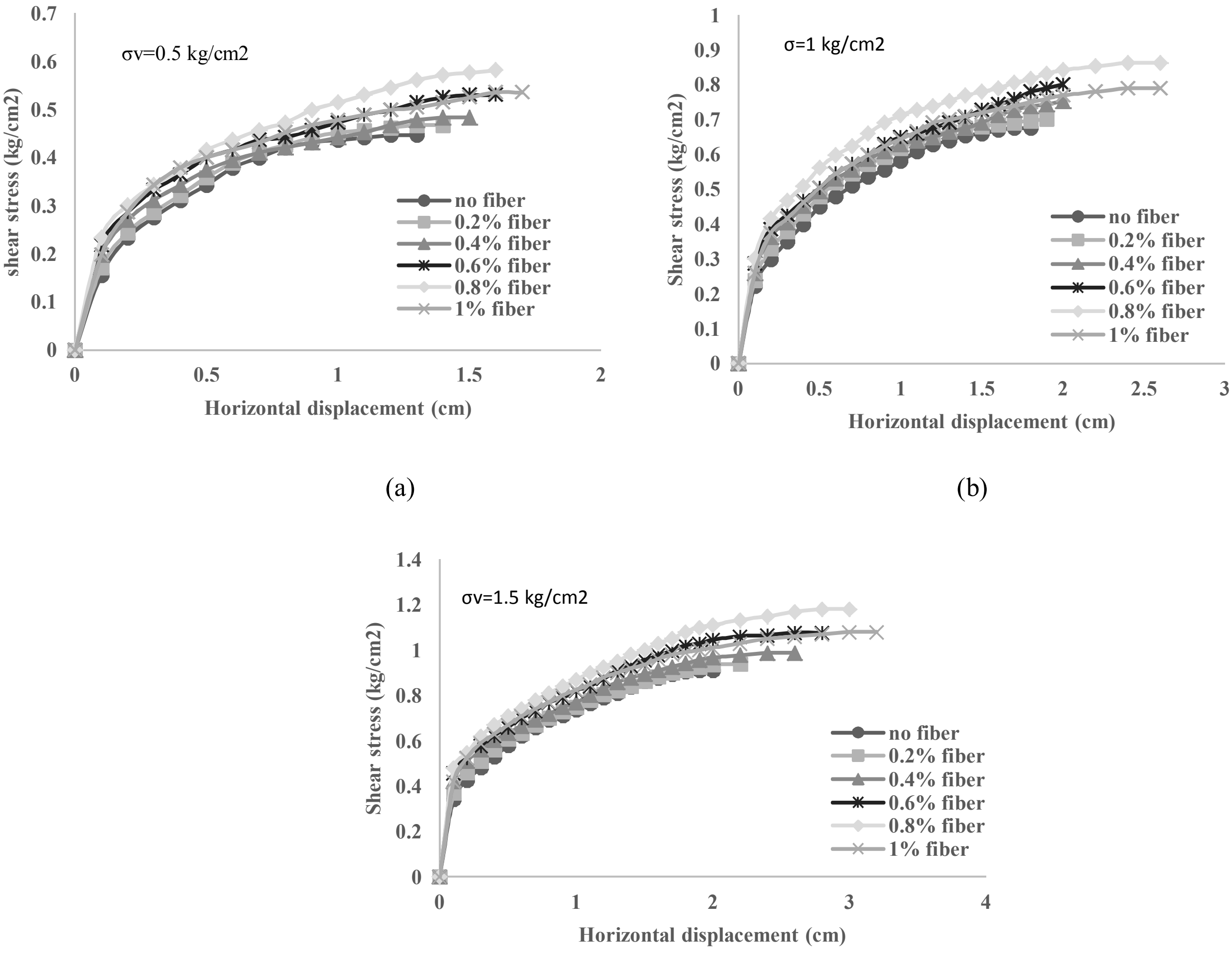


Figure 8. Effects of GFRP on clay specimens: (a) Axial strength versus optimum water content, (b) strain at failure versus optimum water content



(c)

Figure 9. Effects of GFRP on shear stress of improvement clay specimens: (a) σv=0.5 kg/cm2, (b) σv=1 kg/cm2, (c) σv=1.5 kg/cm2

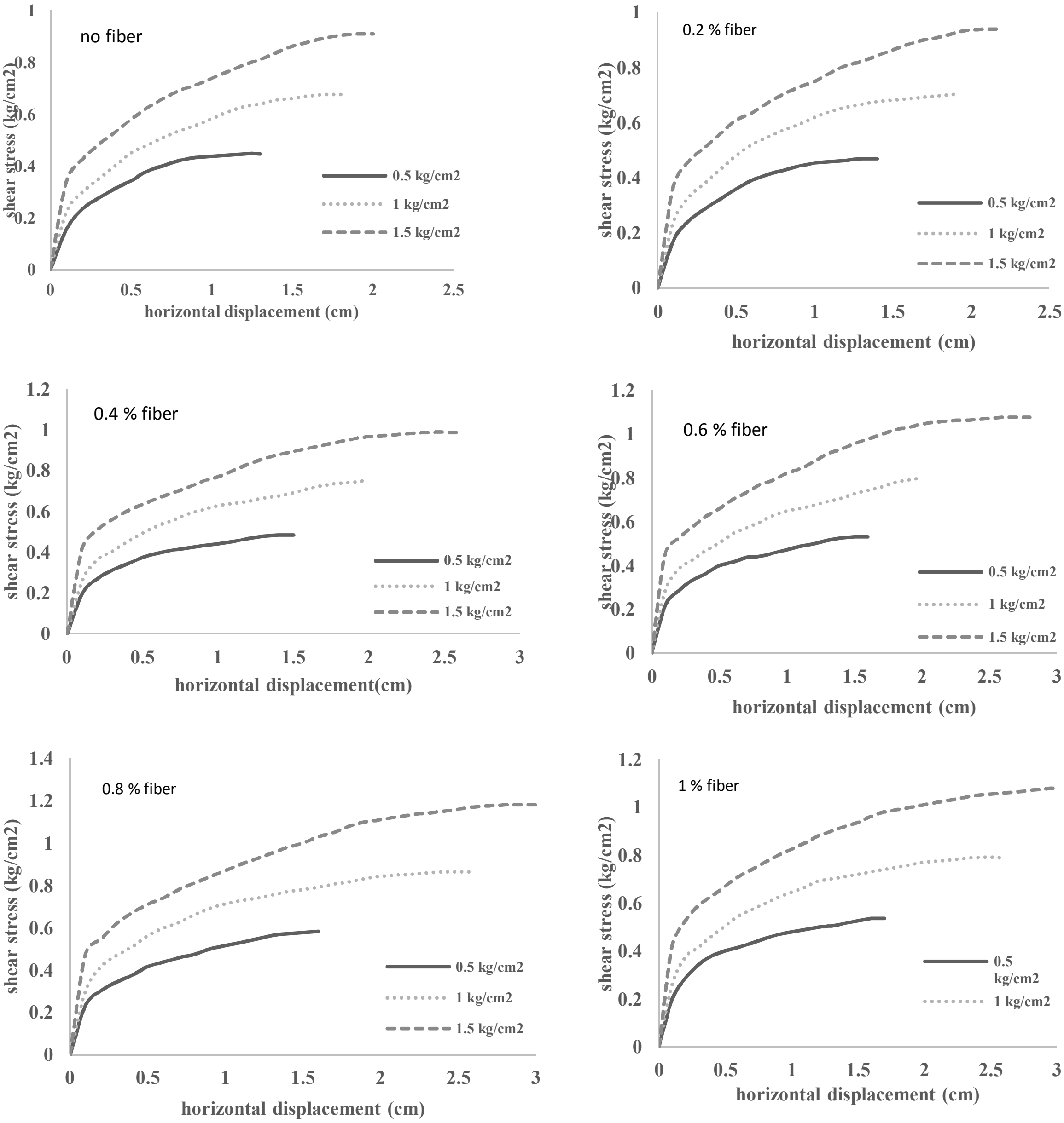


Figure 10. Variation of shear stress versus horizontal displacement of improvement clay specimens mixed GFRP

5. As mentioned the previous parts, in order to determine the shear strength and geotechnical properties of the clay specimens mixed with GFRP. General results can be observed in Figure 9. As regard in equal vertical stress, increasing GFRP up to 0.8% leads to increase shear strength.
6. As can be observed from Figure 10, while GFRP percent reached up to 0.8% the shear strength can be increased. Also, generally with increasing GFRP the horizontal displacement tends to be increased.
7. As can be seen from Figure 11 (a, b), both of the internal friction angle (φº) and the cohesive of specimens have tend to rise with increasing GFRP up to 0.8%. After that, with continuing to add GFRP both of the mentioned parameters are decreased. Similar to this results, Figure 12 (a, b) shows that the increasing of the internal friction angle (φº) and cohesive of improved clay are related to the optimum water content.
8. Figure 13 assessed the effects of GFRP on clay soil. Results showed that by increasing GFRP in clay the permeability is increased. Therefore, it can be explained that GFRP can be used as the drainage for cohesive soils.

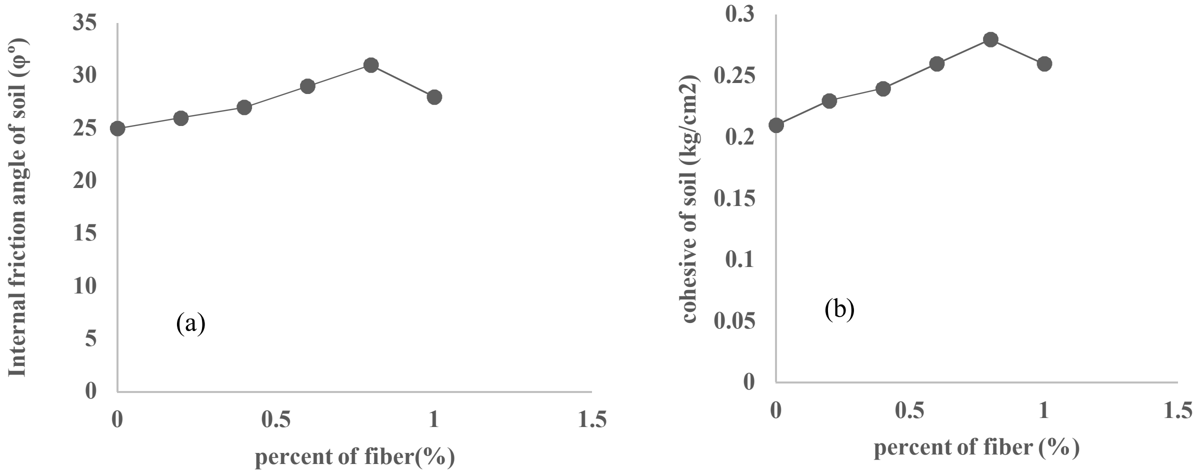


Figure 11. Effects of GFRP on geotechnical properties of improvement clay specimens: (a) internal friction angle (φ), (b) cohesive (C)

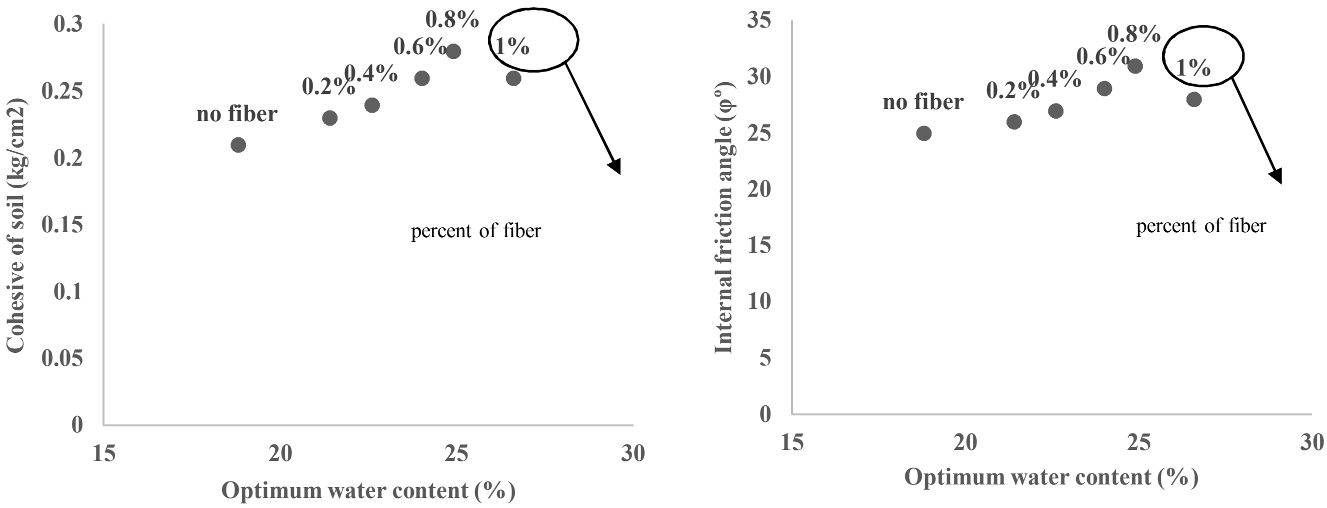


Figure 12. Effects of GFRP on clay specimens: (a) internal friction angle versus optimum water content, (b) cohesive versus optimum water content

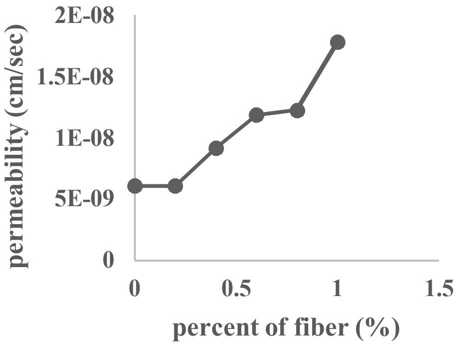


Figure 13. Effects of GFRP on permeability factor of reinforced clayey specimens

5. Conlucions

The main purpose of this study is to investigate the effects of random placement of GFRP using the same itslength on the bearing capacity and the geotechnical properties of clayey soil. The results are expressed as follows:

1. In a fixed length, by increasing the content of GFRP in clay the shear strength parameters tends to be increased.
2. There is direct relationship between the shear strength of soil and weight percent of GFRP. Although the rate of the shear strength in terms of the weight percent of

GFRP decreases, increasing GFRP up to 0.8% can increasethe shear resistance of soil. Furthermore, it is worth mentioning that by adding GFRP the shear resistance is decreased. Consequently, it can be expressed that 0.8% of GFRP is the optimum value of GFRP for improving the clayey soil.

3. Unconfined strength of the improved clay with GFRP showed that: while the amount of GFRP is considered more than 0.8% the resistance capacity is started to be decreased. This is interpreted as the high values of the reinforcements. In other words, amount of reinforcement elements can control the behavior of soil.
4. In this research, it wasobserved that with increasing GFRP in clay behavior of fragility to ductility and flexibility can be changed.
5. Permeability factor is one of the important parameters in drainage performance in subgrade and pavement design. Results showed that with increasing GFRP in clay permeability can be tended to be augmented.
6. Generally, itcan be explained that one of the improvement methods is to add fiber to soil. Also, according to results of this study, it can be argued that improved clay with GFRP has more ductile behavior than the unreinforced one. In other words, the soil behavior change from fragile to ductile and increasing in resistance at the same time are important advantages in improved clay using GFRP.

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