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EFFECT OF THE FIBERS TYPE ON IMPROVING THE BEARING CAPACITY OF CLAYEY SOILS

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Abstract- Stabilization of suitable soil local materials is a proper engineering solution to reduce construction costs. Soil stabilization is changing one or more soil properties using the mechanical and chemical instruments, so that the soil materials gain favorable engineering properties after implementing them. The main goal of this research is investigation of the effects of various polymeric fibers on the geotechnical and physical properties of clayey soils taken from different depths. In the present research two types of glass and polypropylene fibers with sizes of 38 and 50 mm and different weight percentages are mixed with clayey soil. The uniaxial compressive strength and direct shear tests are performed in this research. The obtained results showed value of parameters such as cohesion (c) and internal friction angle (φ) with increasing FRP increased. In the soils and consequently increased compressive strength especially the tensile strength of the clayey soils. Among the obtained results one could refer to the high effect of polypropylene fibers with respect to glass fibers in increasing the soil bearing capacity.

Keywords: Glass Fibers, Polypropylene Fibers, Soil Reinforcement, Clay Soil, Compressive Strength, Shear Strength

I. INTRODUCTION

Soil as the most important construction material and as the main support for the structures has been under focus of attention of mankind. But due to its weak shear strength and lack of strength against tensile forces, researchers have always been after increasing the load bearing capacity, strength and also improving its properties and 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 in improving and stabilizing the soil layers, in addition to increasing the load bearing capacity, shear strength and reducing its settlement, is used for stabilizing the surface beds, road backfilling and pavements.

Application of auxiliary elements in improvement and modification of soil engineering properties has long been under focus of attention by mankind. Today the efficiency and ability of soil reinforcement method in providing proper applicable solutions in various projects have caused that this method 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. Glass wool is comprised of very tiny glass fibers used for various cases for example as the thermal insulator.

Production and incorporation of polymeric materials as modern materials in the civil engineering has become widespread during the last three decades. By production of polypropylene and glass fibers the technology of soil stabilization was evolved and their application became more 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.

Today, various methods have become widespread for investigating and analysis of soil stabilization with different materials. Various researchers have published many articles and performed research for presenting more optimal methods. Among them one could refer to the studies done by [1, 2] concerning application of the herbal fibers in soil reinforcement and increasing shear strength of sand and kaolinite in triaxial test under static loading. [3, 4, 5] have investigated the effect of polypropylene fibers on the mechanical behavior of sandy soil utilizing the CBR, uniaxial and direct shear tests.

The [6] presented a model for soil and fiber behavior at the shear zone utilizing direct shear test. In [7] during experimental studies performed by direct shear instrument and building the physical model of a reinforced soil retaining wall which was backfilled by beach sand reinforced with aluminum shells, concluded that implementing these elements increases the sand shear strength and the amount of this increase depends upon the properties and percentage of the reinforcing elements.

The [8] investigated effects of utilizing 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. The [9] demonstrated the positive effect of fibers on the specimens' shear strength through performing triaxial tests on sand specimens reinforced with fibers.

The [10] presented a criterion for failure of the sand reinforced with steel and polyamide fibers, based on the laboratory research and theoretical investigations. The [11] is performing uniaxial and triaxial tests studied the effect of adding some 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.

The [12] investigated the effect of low percentage fibers in stabilizing the clayey and sandy soils which resulted in increased soil compressive strength. The [13] is utilizing rubber fibers, attempted to reinforce granular soils and found a relationship between the fibers' aspect ratio and shear strength. In [14] adding 10-20% cement, could 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. The [15] investigated the effect of soil reinforcement with separated fibers on the clayey sand soils, in which they implemented the seismic wave propagation test.

In the present research attempt is made that first investigate the mechanical properties of two soil specimens taken from the study area utilizing particle-size distribution (gradation), Atterberg and direct shear tests. Then, with respect to the performed studies using the available articles and behavior characteristics of different fibers, the polypropylene and glass fibers were selected for soil specimens.

Finally, considering the obtained results from variation in the shear strength, soil cohesion, internal friction angle and compressive strength of soil specimens reinforced with different percentages, the most optimal fiber percentage was determined. The algorithm given in Figure 1 indicates the process of advancement in the present study.

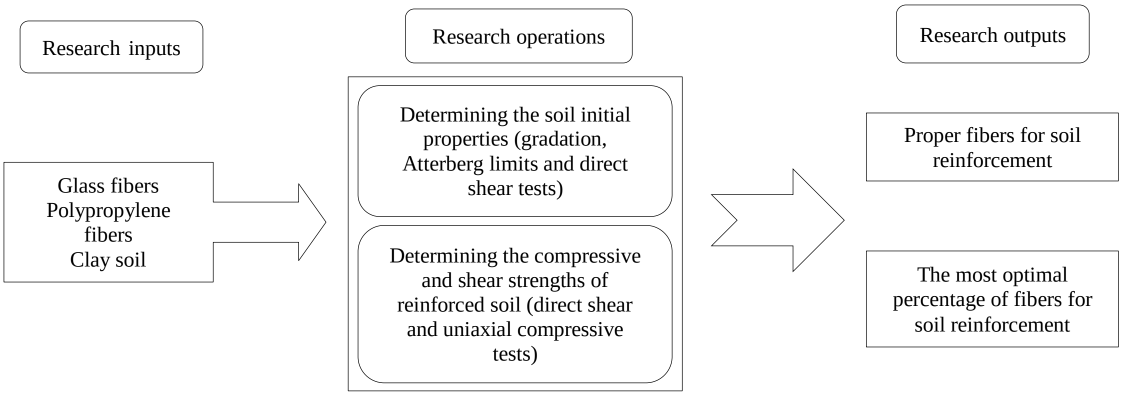

Figure 1. Algorithm for performing stages of the present research

II. GENERAL GEOLOGICAL CONDITIONS AND SOIL LAYERS WITHIN THE STUDY AREA

Tabriz city in Iran is located within Alborz zone and follows its governing tectonic regime. Formation of Tabriz plain and sedimentation in it and creation of tectonic structures which are manifested as fractures and faultation, are in accordance with this system. Tabriz plain is surrounded from the north by Oun-Ebne-Ali Mountains and from the south by Sahand igneous heights and the corresponding pyroclastic sediments. The reverse performance of Tabriz northern fault with northward slope has caused collapse of its southern part. Erosion due to the entrance of large rivers has caused sedimentation of eroded materials with large thicknesses in the plain. With respect to the river origins from the south and east of Tabriz plain and the east-west extension of the plain, moving towards west one should expect smaller particle sizes. Although Azerbaijan region is very diverse with respect to the stratigraphy and has large temporal extension, and as Tabriz plain is surrounded with extensive outcrops from Gambrian rocks up to now, but the rocks and sediments within Tabriz city do not possess significant temporal extension and their constituent units belong to the Cenozoic and quaternary periods (Figure 2) [16].

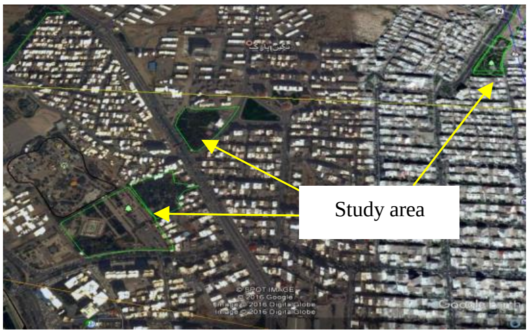

Figure 2. The study area

III. MATERIALS AND METHODS

In this research, two clay soil specimens taken from 8 and 12 m depths are utilized (Figure 3). The gradation curve is estimated according to ASTM D421 and ASTM D422 standards as seen in Figures 4 and 5. The diagrams show that the undisturbed clay soil specimens taken from 8 m depth is of CH type, also the undisturbed clay soil specimen taken from 12 m depth is of CL type. The Atterberg limits values according to ASTM D4318-95a standard for the 8 m depth clay soil specimen (Figure 4) are 54 and 39 for the liquid limit and plasticity index, respectively, and for the 12 m depth specimen the liquid limit (Figure 5) and plasticity index values are 40 and 25, respectively.

Figure 3. Specimens taken from the drilled boreholes

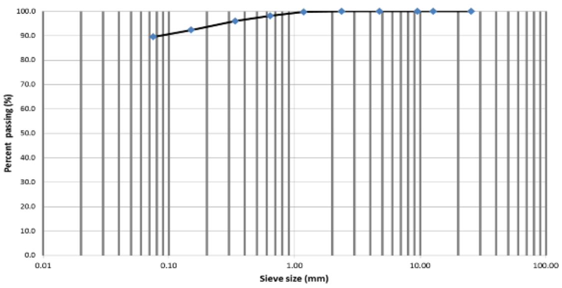

Figure 4. Grain size distribution for 8 m depth soil specimen

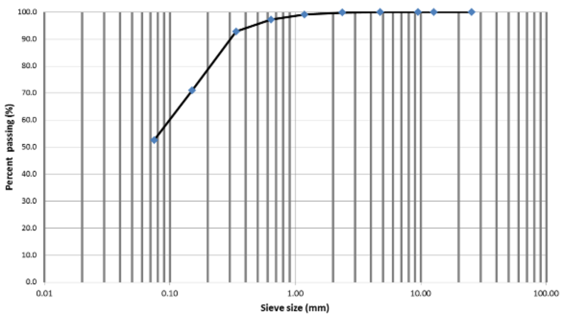

Figure 5. Grain size distribution for 12 m depth soil specimen

The polypropylene fibers in the present research are among relatively new thermoplastic ones which have widespread application in the construction industry. The chemical formula of this polymer is shown in Figure 6. The properties of this substance are close to those of high density polyethylene. Except for the sponge-like plastics, this polymer is the most light-weight thermoplastic which is available in commercial form [17].

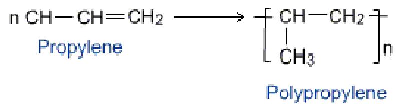

Figure 6. Polypropylene fibers [17]

Its strength against abrasion, scratch and fatigue is generally better than polyethylene or polyester, but is lower than PVC and acrylics. The surface stiffness of polypropylene fibers as Table 1 is excellent, also their tensile strength is greater than that of high density polyethylene. The moisture absorption of PP fibers is very good and the bending strength and resistance against impact are high. They possess very good resistance against different chemical substances. For example, the water solutions of mineral salts and all acids and alkalis with high concentrations and temperatures do not affect this material. Proper mixture and lack of conglobation during making the specimen causes an acceptable uniform distribution of PP fibers in the laboratory specimens [17].

Table 1. Polypropylene fibers characteristics [17]

Characteristics	Value	Unit
Appearance color	White and Black	-
Fiber type	PP 100%	-
Specific gravity	0.91	(g/cm+)
Diameter	23-35	Micron
Tensile strength	400	MPa
Melting range	165	Degree (0 °C)
Tenacity	3-5.2	Grams/Denier
Cut length	38 and 50	mm
Resistance to acids and alkalis	High	-
Resistance to salts	High	-

With respect to the above issues, the main reason for utilizing polypropylene fibers in soil stabilizing, is their long time preservation in the soil, also strengthening the locations which are parallel to the failure plane, as a plane which possesses the fracture potential. Glass fibers are made of very tiny glass fibers with constant dimeter and unlimited length. Glass fibers could be produced in dimeters ranging from 5-28 Microns (Figure 8). The initial raw materials including silicate, soda, clay soil, lime stone, boric acid, fluorspar or different metal oxides are mixed together which form the glass and it is melted in the oven and flows along a straight-line path towards divider. The glass fiber properties including the tensile strength, Young modulus and chemical insolubility are directly measured using the fibers. The other properties like dielectric constant, dielectric loss coefficient, volume/surface resistivity and thermal expansion are obtained from the glass which is formed into a bulk and annealed. Other properties such as density and refractive index are measured in both forms of fiber and bulk samples [18, 19, 20].

Figure 7. Glass fibers [18]

Table 2. Glass fibers characteristics [18]

characteristics	Value	Unit
Fiber diameter	17-19	Micron
Fiber length	3-50	mm
Young modulus	35 GPA	-
Elasticity modulus	1/5 GPA	-
Moisture content	< 0.3	-
Loss of ignition	< 0.5	-
Surface treatment	Good for resin concrete and plaster	-

One of the oldest tests for determining the shear strength of cohesive consolidated soils is direct shear test. To analyze the soil stability problems such as the compressive capacity, slope stability and lateral pressure acting on the soil retaining structures, it is necessary to well understand the shear strength nature. Direct shear test is a test for determining the soil shear strength. In this research also direct shear test was performed using the controlled strain method according to ASTM D3080 standard.

The uniaxial test is a rapid method for determining the undrained strength of cohesive soils. This test is used for those soils where their cohesion to prepare stable specimens, which preserves their strength after removing the confining pressure like clays and cemented soils, is enough. Silty, sandy or lump and cracked soils and pits could not be tested using this method. In the uniaxial test, a specimen of the intended soil is subjected to uniaxial load in controlled strain condition until reaching failure and its strength is calculated based on the total stress induced in the specimen at the moment of failure. In this research, uniaxial test was performed according to ASTM D2166-66 standard. The specimens in this experiment could be undisturbed, rebuilt or manufactured in laboratory with intended compaction percentage & moisture content [21].

In the present research in order to perform direct shear and uniaxial compressive tests and for investigating the effect of adding polypropylene fibers and glass fibers to clay soil specimens taken from 8 m (CH) and 12 m (CL) depths, first the fibers are mixed with different percentages and at each stage the experiments are performed. Addition of fibers to the soil specimens is stage-wise, so that first, 1 wt% of fibers is added to the soil specimen and using the test results, changes in the shear and compressive strengths are recorded.

At the next stage, 2 wt% of fibers is added to the specimen and again changes in the soil strength are measured and this is continued till addition of further fibers would result in increased compressive and shear strengths. At a stage of experiment, where addition of fibers causes decreased soil strength with respect to the previous stage, i.e. when addition of more fibers would negatively impact the soil strength, the experiments are terminated and the maximum shear strength and compressive strength values corresponding to the recorded fibers percentages are determined. These experimental stages are repeated for polypropylene and glass fibers of 38 and 50 mm sizes and for each stage the optimal percentages of fibers are determined.

IV. RESULTS

A. Results from Uniaxial Compressive Strength

First the experiment was performed on the clay soil specimens without fibers and the results demonstrated that in this case the soil specimen taken from 8 m depth with an area of 11.34 cm^2 has 1.898 kg/cm^2 strength corresponding to a maximum strain of 34.21%, the soil specimen taken from 8 m depth with an area of 19.63 cm^2 has 2.406 kg/cm^2 strength corresponding to a maximum strain of 30%, the soil specimen taken from 12 m depth with an area of 11.34 cm^2 has 3.895 kg/cm^2 strength corresponding to a maximum strain of 35.52%, and the soil specimen taken from 12 m depth with an area of 19.633 cm^2 has 3.507 kg/cm^2 strength corresponding to a maximum strain of 34%. This test was first performed on the soil specimen taken from 8 m depth with 38 mm polypropylene fibers. So that first the soil specimen was reinforced with different fibers percentages and the uniaxial compressive strength test was performed and recorded at each stage. Initially, addition of fibers to the soil specimen exhibited increased compressive strength. These tests were continued till the soil specimen reinforced with 10% fibers caused decrease in the compressive strength. At this stage, soil reinforcement was terminated and the soil specimen taken from 8 m depth and reinforced with 9% polypropylene fibers exhibited greatest compressive strength.

In continuation the same soil specimen taken from 8 m depth was reinforced with 38 mm glass fibers and the results of uniaxial compressive strength tests were recorded at each stage. Reinforcement with glass fibers at each stage caused increased compressive strength in the soil specimen so that the result of test performed on the soil reinforced with 7% fibers exhibited reduced compressive strength with respect to that of the previous stage (reinforcement with 6% fibers). As shown in Figure 8, the clay soil reinforced with 6% of 38 mm glass fibers, exhibited the greatest compressive strength. Increasing the percentage of reinforcing fibers added to clay soil is done with respect to soil compressive strength results and for making comparison between them up to the moment where increase in the strength is observed.

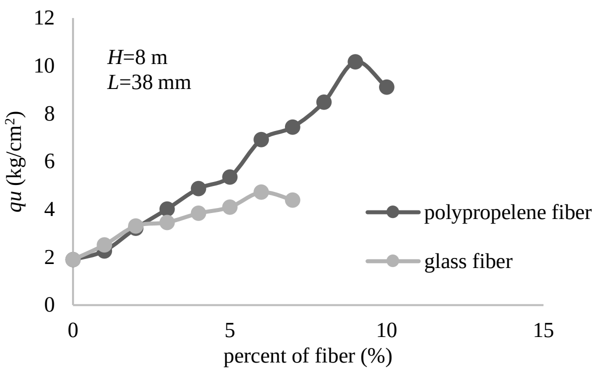

Figure 8. Changes in the maximum compressive strength of 8 m depth clay soil with 38 mm fibers percentages

In continuation, the clay soil specimen taken from 8 m depth and reinforced with 50 mm fibers is tested. First the clay soil specimen is reinforced with different polypropylene fibers percentages and at each stage the tests are performed. The recorded stage-wise results of performed tests concerning reinforcement of clay soil, shows increased compressive strength up to the 8% fibers reinforcement. But continuing with 9% and 10% fibers caused decrease in the compressive strength. Therefore at this stage, the experiment on the 8 m depth soil specimen reinforced with polypropylene fibers was terminated and addition of 8% fibers was selected as corresponding to the greatest compressive strength. Once again the same clay soil specimen was tested with 50 mm glass fibers. As shown in Figure 9, the clay soil specimen exhibits increase in the compressive strength up to 6% fibers, and adding 7% glass fibers caused reduced compressive strength. Therefore, addition of 6% of 50 mm glass fibers was selected as corresponding to the greatest obtained compressive strength.

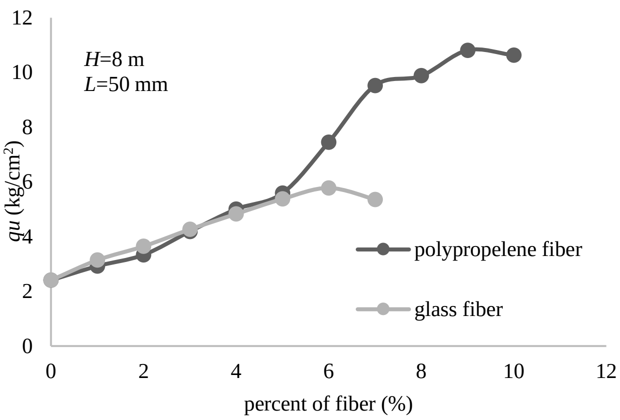

Figure 9. Changes in the maximum compressive strength of 8 m depth clay soil with 50 mm fibers percentages

The performed tests on the soil specimen taken from 8 m depth, are repeated in the same way for the soil specimen taken from 12 m depth to observe the results of reinforcing this soil specimen. Therefore first the 12 m depth soil specimen is reinforced with different percentages of 38 mm polypropylene fibers and uniaxial compressive test is performed on the specimens.

Soil reinforcement with different fibers percentages was continued stage-wise and always increase in the compressive strength was observed. This process was continued till a reduction in the soil compressive strength was observed with 8% fiber reinforcement. At this stage of the tests performed on the soil specimen reinforced with polypropylene fibers were terminated and a 7% fiber reinforcement was selected as corresponding to the greatest compressive strength. The results of uniaxial compressive strength for 12 m depth soil specimens reinforced with different fibers percentages also demonstrated increased compressive strength. So that reinforcement with 10% fibers caused reduction in the compressive strength. As shown in Figure 10, soil reinforcement with 9% and 38 mm polypropylene fibers resulted in the greatest compressive strength.

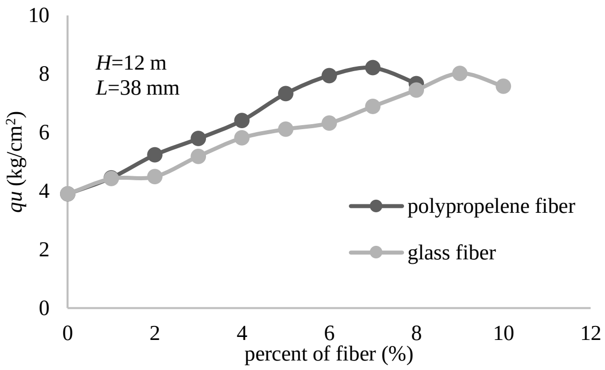

Figure 10. Changes in the maximum compressive strength of 12 m depth clay soil with 38 mm fibers percentages

In continuation reinforcement of clay soil taken from 12 m depth with 50 mm fibers was performed, the results of stage-wise uniaxial compressive strength tests could be seen in the following figure. First the soil is reinforced with 50 mm polypropylene fibers. In experiments no. 1 to 7 corresponding to the 12 m depth clay soil specimens with 1-7 percentages, the results of adding polypropylene fibers showed increase in the compressive strength of clay soil, so that adding 6% fibers exhibited greater compressive strength, and at stage 7, adding 7% fibers caused reduced compressive strength of reinforced clay soil. Therefore at this stage the test performed on the 12 m depth specimen reinforced with polypropylene fibers is terminated and adding 6% fibers corresponded to the greatest compressive strength. In the same way, the soil specimen now was reinforced stage-wise with 50 mm glass fibers and with different percentages and uniaxial compressive strength test was performed on the soil specimen at each stage. In experiments 1-10 corresponding to the clay soil reinforced with 1-10% fibers, addition of glass fibers at each stage resulted in the increased clay soil compressive strength, where addition of 9% fibers corresponded to the greatest compressive strength and at the 10th stage, adding 10% fibers caused reduced compressive strength of reinforced clay soil. Therefore at this stage as shown in Figure 11, the experiment on the 12 m depth specimen reinforced with glass fibers was terminated and addition of 9% fibers was selected as the one which corresponded to the greatest compressive strength.

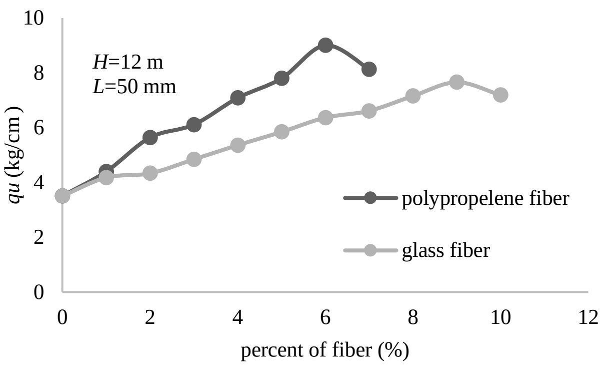

Figure 11. Changes in the maximum compressive strength of 12 m depth clay soil with 50 mm fibers percentages

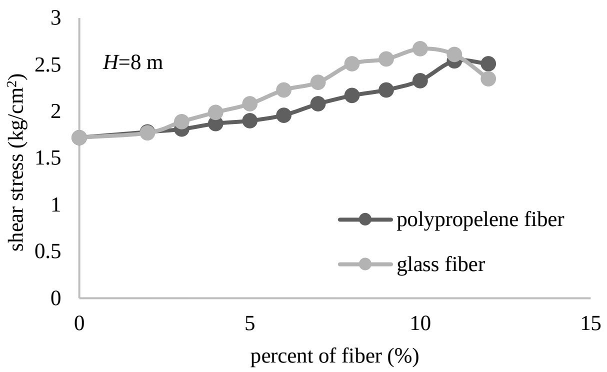

Figure 12. Changes in the cohesion of 8 m depth clay soil specimen with fibers percentages

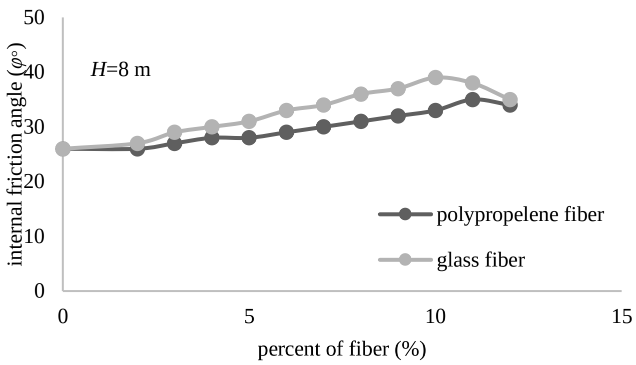

Figure 13. Changes in the internal friction angle of 8 m depth clay soil specimen with fibers percentages

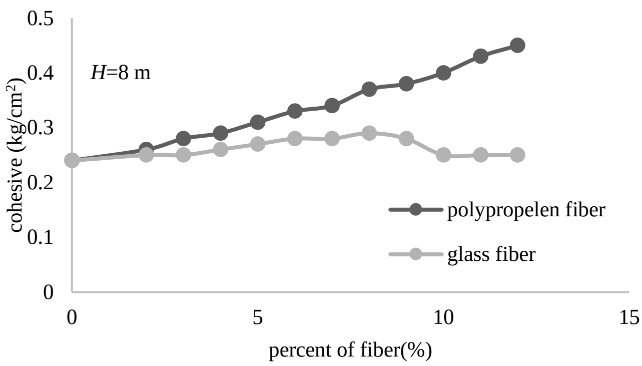

Figure 14. Changes in the shear strength of 8 m depth clay soil specimen with fibers percentages

B. The Results of Direct Shear Test

The performed direct shear tests to investigate the effects of polypropylene and glass fibers on the shear strength, internal friction angle and soil cohesion were similar to those of the uniaxial compressive tests. So that fibers with different percentages were added to the soil and the parameters of shear strength, internal friction angle and cohesion of reinforced soils were measured. This was continued up to the stage where the positive effect of adding fibers to the soil was diminished. By this procedure, first the soil specimen with 8 m depth was reinforced with 1-12% polypropylene fibers and the results were investigated. As shown in Figure 12, the effect of soil reinforcement on increasing the soil cohesion and internal friction angle is observed. Addition of fibers is continued till in investigating the results, the increase in soil shear strength becomes obvious. By increasing the fibers up to 12%, the shear strength increased but at 12% addition a reduction is seen in the shear strength and the test is terminated. Therefore addition of 11% fibers is selected as the appropriate fibers percentage for this soil specimen reinforcement. Also the soil specimen taken from 8 m depth with glass fibers percentages of 1-12 was tested and the results were investigated. As shown in Figure 13, the effects of soil reinforcement on increasing the soil cohesion and internal friction angle could be observed. Addition of fibers up to 8% resulted in increased soil cohesion but further increase resulted in reduced cohesion. Also adding more than 10% fibers caused reduced internal friction angle in the soil. Adding fibers continued till the results exhibited increased shear strength in the soil. By adding fibers up to 12% there was increase in the shear strength but at 11% there was reduction in the shear strength and the test was terminated (Figure 14). Therefore adding 10% fibers was selected as the appropriate percentage for reinforcement of this soil specimen.

In continuation, the 12 m depth soil specimen was reinforced with polypropylene fibers percentages of 1-12 and the test results were investigated. As shown in Figure 15, the effects of soil reinforcement on increasing the soil cohesion and internal friction angle are observed. Addition of fibers is continued till an increase is observed in the shear strength test results. By addition of fibers up to 12% there was increase in the shear strength but at 12% fibers addition a reduced shear strength was observed and the experiment was terminated.

Therefore addition of 11% fibers was selected as the appropriate fibers percentage for reinforcing this soil specimen. Also the 12 m depth soil specimen was reinforced with glass fibers percentages of 1-12 and the test results were investigated. As shown in Figure 16, the results the effects of soil reinforcement on increasing the soil cohesion and internal friction angle are observed. Addition of 9% fibers resulted in increased soil cohesion and internal friction angle and higher percentages caused reduced cohesion and internal friction angle in the soil. Addition of fibers continued till there was an increase in the soil shear strength. Adding fibers up to 12% caused increase in the shear strength but addition of 10% fibers caused reduced shear strength and the experiment was terminated (Figure 17). Therefore adding 9% fibers was selected as the appropriate fibers percentage for reinforcement of this soil specimen.

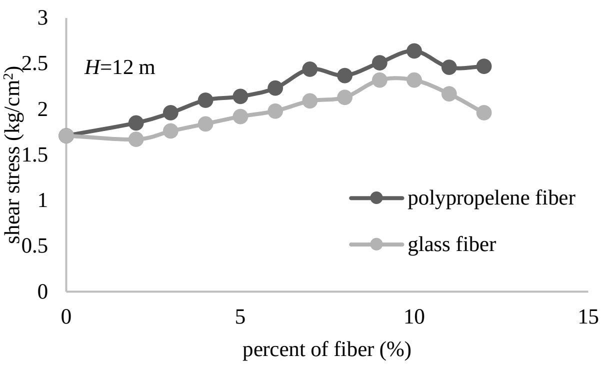

Figure 15. Changes in the cohesion of 12 m depth clay soil specimen with fibers percentages

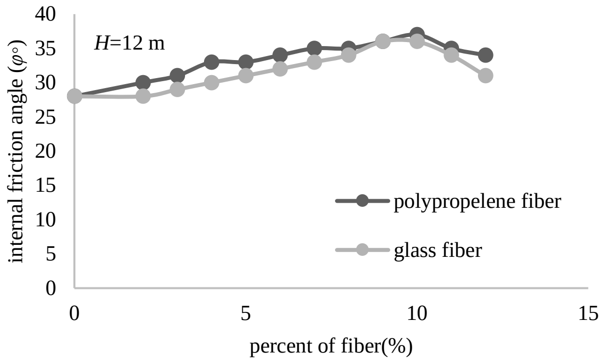

Figure 16. Changes in the internal friction angle of 12 m depth clay soil specimen with fibers percentages

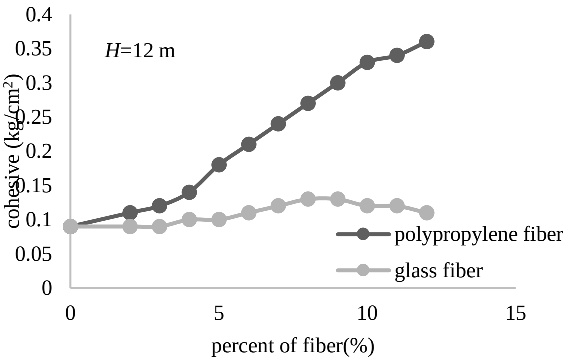

Figure 17. Changes in the shear strength of 12 m depth clay soil specimen with fibers percentages

V. CONCLUSION

In this research the 38 mm polypropylene fibers and 50 mm glass fires were used for clay soil reinforcement taken from 8 and 12 m depths. To investigate the effects of soil reinforcement with these fibers, the uniaxial compressive strength and direct shear tests were implemented. Analyzing the corresponding diagrams of these test results, the following are extracted:

1. The presented diagrams exhibit the results obtained from uniaxial compressive strength and direct shear tests corresponding to the clay soil shear strength parameters. The 8 m depth soil specimen has a cohesion of 0.24 Kg/cm^2 and internal friction angle of 26 degrees and the 12 m depth soil specimen has a cohesion of 0.09 Kg/cm^2 and internal friction angle of 28 degrees. The specific weight of 8 m depth soil specimen is 1.96 gr/cm^2 and the moisture content percentage is 27.2. Also the specific weight of 12 m depth soil specimen is 2.01 gr/cm^2 and the moisture content percentage is 24.8.

2. The results obtained from the tests indicate high performance of glass fibers in increasing soil load bearing capacity, so that the compressive soil strength corresponding to 8 m depth is increased up to 2.5 times and that of the 12 m depth soil specimen is increased twice. Also the results obtained from direct shear strength show that addition of these fibers increases the shear strength of the clay soil more than 1.5 times. Furthermore the test results demonstrated excellent performance of polypropylene fibers in increasing the soil load bearing capacity, so that the soil compressive strength in the 8 m depth soil specimen has increased up to 5 times and that of the 12 m depth soil specimen has increased up to 2 times. Also the results obtained from direct shear test show that addition of these fibers caused increase in the clay soil shear strength up to 2 times.

3. The results indicate that presence of polypropylene and glass fibers among the soil particles causes increased continuity between soil particles. Utilizing glass and polypropylene fibers increases the soil shear and compressive strengths, but in comparison, polypropylene fibers have significant effect on increasing the soil strength and could also be used for increasing the load bearing capacity, excavations stability, and stabilizing earth slopes, also they could be easily used for strengthening the loose soil around the underground structures. As fibers with 38 mm and 54 mm sizes had similar impact on soil reinforcement, the 38 mm size was selected as the optimal one.

Compare the results of the experiments in this study, with results Coreia et al. [5] that soil reinforcement with polypropylene fibers have, indicate that increasing the compressive strength of the present study because of the mixing of samples and test method optimal results are identical to the fibers added to the samples obtained. Which tested under laboratory conditions and soil type can affect the results.

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