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Research Article

Analysis of the Variations in Shear Strength of Reinforced Soil with Randomly Distributed Typha Fibers

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Abstract

Geotechnical engineers has always strived to evade the manipulation of the environment by using and developing natural and artificial soil reinforcements which are not friendly with constructions and uploading. At one hand, utilization of natural fibers due to the factor of accessibility, adaptability with the environment and their reasonable costs of production has drawn attention and on the other hand the special feature of Typha in absorbing heavy metals has dedicated a noteworthy role for this plant in the environmental studies. The aim of this study is to investigate the efficacy of Typha fibers, a type of natural fiber, on the variations of the shear strength and changes in plasticity of the reinforced soil. In order to have a better perspective regarding the mechanism of the efficacy of fibers on the shear strength of soil, direct shear test was conducted on the samples of the reinforced soil in different weight percentages of fibers and in normal stresses of 100, 200, and 300 (kpa). Findings showed that addition of fibers to soil bring about increase in the level of cohesion and the friction angle of soil. With the increase in the stresses, vertical displacement variations will decrease. Increase in the percentage of the fibers reduces the plasticity of the sample along the shear plate which leads to the increase in the shear strength of soil.

Keywords: *Reinforced Soil, Natural Fiber, Shear Strength, Direct Shear Test, Clay.*

1. Introduction

Having adequate information regarding the strength of soil is essential in all issues related to the stability of it including design of the foundation, retaining walls and dams. Measurement and determination of the strength of the soil are of the complicated issues in soil mechanics, especially for adhesive soils that are highly important and practical for soil stability (Lambe, 1951). Soil strength in different parts of its behavioral curve that is presented by the Failure Criterion has different titles including tensile strength, shear strength and compressive strength. Yet, we can say that the shear strength of soil is the main factor in determining the properties of soil. The shear strength of soil is the internal strength on its surface unit, in other words, it is the strength that soil can enjoy inside itself to fight against slips and failures along any plate. It is obvious that the matter of shear strength is applicable for issues of soil stability including uploading and stability of slopes, gable roofs and the effective vertical pressure on the structures holding the soil. Utilization of the fibers has taken place in several methods and the random distribution has yielded acceptable results. Various studies have been conducted with regards to the utilization of these fibers in a random distribution or placing them in a special layer (Maher and Gray, 1990; Lawton *et al*., 1993; Benson and Khire, 1994; Oliver and El-Gharbi, 1995; Consoli *et al*., 2002; Ghavami *et al*., 1999; Kaniraj and Havanagi, 2001; Michalowski and Cermak, 2002; Consoli *et al*., 1998; Mesbah *et al*., 2004; Saran, 2010; Singh. 2011-2012; Singh *et al*., 2011; Sivakumar Babu and Vasudevan, 2008; Vildal, 1969 and Zare, 2006). These studies, mostly, investigated different types of sandy soils or other layered soils reinforced by artificial fibers. They also examined the reinforcement of clay. In this study, the effects of Typha fibers are examined on the shear strength of the clay.

Gharooni and Kazem (2010) ran a series of tests on different types of soils and fibers and discovered that depending the type of fiber, an efficient commixture percentage is obtained in which the commixture percentage, fibers had the most strength effects on soil. It was concluded that the reinforced soil by natural fibers has much more strength compared to the soil which was not reinforced. The main effect of the commixture of fibers in soil is its effect in the shear strength of the sample. These fibers can have direct effects due to the involvement of fibers with soil seeds and consequently the effective pressure of seeds on the adhesion and internal friction angle of the mixture bring about variations on the shear behavior of the sample. With regards to the tests conducted on the shear strength, it can be assumed that commixture of these fibers with soil can lead to an

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increase in the ductility of the sample and changes behavior of the soil, despite the reduction of cohesion, from the fragile state to a plastic condition.

One of the techniques of soil reinforcement is to commixture it with fibers, strip and swarf of materials. Mixture of these elements with soil creates a mixed environment in which involvement of flexible material (elements of reinforcement) or seeds of soil improve the strength and plasticity of the soil in different directions. Studies on the application of fibers in soil reinforcement have been conducted and increase in the shear strength of the mixed sand with artificial fibers in a triaxial test under static uploading has been reported (Lee et al, 1973). Density and CBR experiments on the mixture of the broken sand which was reinforced by Polypropylene fibers showed that the application of the fibers, while it increases the needed energy for reaching a specific density, will increase CBR (Hoare, 1982). The triaxial test on the Kaolinite reinforced by natural fibers showed that the application of fibers increases the undrained strength of soil (Andersland and Khattak, 1977). (Gary and Ohashi, 1983) introduced a model for the behavior of soil and fibers in the shear area by doing direct shear experiments. (Dean and Freitag, 1986) examined and reported the positive effects of Polypropylene fibers on the clayed sand by doing uniaxial tests. (Arenzic and Chowdhury, 1988) during the experimental studies with the direct shear device and developing the physical model of a retaining wall of reinforced soil which the dam behind it was beach sand reinforced with Aluminum flakes concluded that the application of these elements will increase the shear strength of the sand and the level of increase is contingent upon the percentage of the reinforcement elements. (Benson and Khire, 1994) examined the effects of Polyethylene strips in the variations of shear strength and the strength of sand and discovered that addition of Polyethylene swarf to soil will increase the CBR, shear strength and the reaction coefficient of sand bed. (Ranjan et al., 1996) reported the positive effects of fibers on the shear strength of the samples by doing triaxial test on the sand samples reinforced by fibers. (Michalowski and Zoba,1996) introduced a criterion for the failure of sands that were reinforced by metal fibers and Polyamide based on experiments and theoretical studies. (Wang et al., 2000) examined the effects of adding some polymeric chips to soil and the improvement of the mechanical behavior of clayed sand soils by doing uniaxial and triaxial tests. They concluded that the addition of these fibers, apart from the increase in the shear strength of samples, improves their plasticity. Observations during experiments showed that existence of the elements in soil creates several shear areas in samples to the point that several strips or shear areas will be created. This behavior can have a direct role in the volumetric strain of the sample due to dilation in all shear areas. (Shewbridge and Sitar,1989) reported that the diameter of the shear strength increases with the increase of the percentage of the elements and this can prove to be effective in the increase of the volumetric strain.

2. Materials and Methodology

2.1 Soil

The clay used in this study was provided from the clay mines of Hamedan Province (Iran). In order to get the engineering features of the soil, experiments were taken place based on the following standards: ASTM D 421-58, ASTM-D 2487, ASTM D 4972-01, ASTM D584-87 ASTM D 698, ASTM-D4318-87 and the results are shown in Table 1 and Fig. 1. A series of XRD experiments were also conducted on the desired sample the results of which are shown in Table 2.

Table 1 The Mechanical Features of the Clay

Characteristics	Value
Specific Gravity	2.64
Liquid Limit(%)	31
Plastic Limit(%)	21.9
Plasticity Index(%)	9.1
Shrinkage Limit(%)	10
Classification	CL
Maximum Dry Density(kN/m^3)	17.62
Optimum Moisture Content(%)	18.84
Activity(A)	0.44
PH	8.4

Table 2 The Results of the X-ray Diffraction

Characteristics	Value
SiO_2	63.98
Al_2O_3	23.9
CaO	1.37
Fe_2O_3	0.67
K_2O	0.6
MgO	0.2
Na_2O	<0.1
TiO_2	<0.1
MnO_2	<0.1
SO_3	0.08
SrO	0.07
Loss on Ignition	8.72

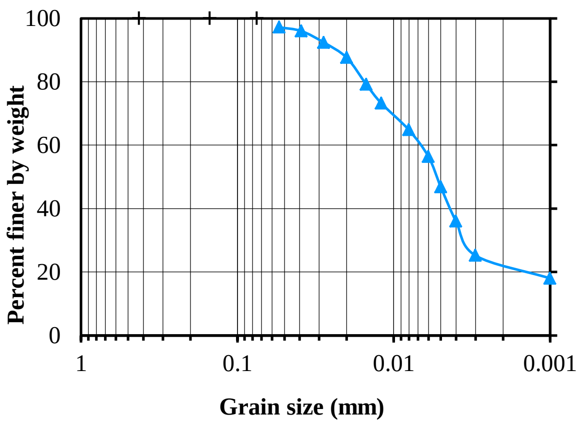

Fig.1 The Aggregation Curve of the Soil

2.2 Fibers

The Typha plant mainly grows around lagoons, lakes, swamps and sweet waters all around the world. This plant also grows in both northern and southern regions of Iran. In this study, the flowers of Typha, brown and tan in color, are used. Figure2 shows the fibers utilized and Table 3 shows the features of the fibers used in this study. In Fig. 3 the effects of the percentage of the fibers in the increase of the plasticity index and liquid limit of soil are demonstrated.

Fig. 2 Fibers Used in the Study

Table 3 Specifications of Fibers

Type	Typha
Length	15-30 mm
Diameter	35-50 µm
Specific Gravity	0.41 – 0.65
Colour	Brown and tan

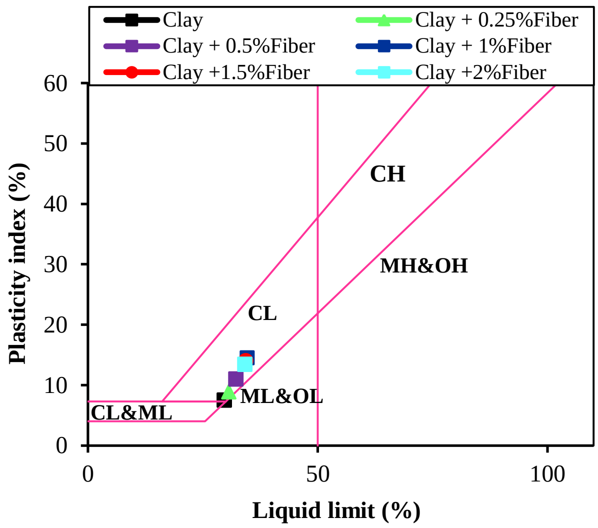

Fig. 3 Variations in the plasticity index and liquid limit of the Reinforced Soil

3. Method of the Creation of Samples

In order to build each sample, the amount of soil, water, and the necessary fibers is calculated based on the geometrical features, density of the sample and the weight percentage of fibers is weighed. To have a better commixture, first the soil is moistened a little and the fibers were added. Then the moisture is increased by the addition of water so as to reach the optimal moisture level of fiber and soil for each percent of fiber with the aim of achieving a homogeneous mixture. Then this mixture is efficiently condensed in the formats related to each experiment. The direct shear format was a cube with dimensions 100×100(mm) and the samples were tested and condensed based on the standard ASTM D 698. In order to develop a consistent density, the method of reduced density was used (Ladd, 1978). Therefore, even if some parts of the soil moisture is absorbed by the fibers but with the increase of the energy of density, all samples were efficiently prepared and condensed in the special weight. In this method, with the gradual decrease of the diameter of the condensed layers in each phase, the consistent density is achieved in the sample in all the height.

4. Data Analysis and Results

The scope of this research is limited to the examination of the efficacy of Typha fibers on the parameters of strength, condensability, and plasticity of the soil. In order to highlight the effects of fibers on the strength of soil, experiments have been conducted on the special maximum weight. The strength parameters were tested by the direct shear experiment under the stabilized drained condition based on the standard ASTM-D 3080-98. Dimensions of the shear box were 100×100×30(mm), the normal stresses were 100, 200, 300 (kpa) and the shear speed of the samples was 0.6(mm) per minute. Since the amount of water extraction is important during the reinforcement and application of the shear force to the shear box of the direct shear device, therefore, some experiments have been conducted to achieve the adequate consolidation time. Findings showed that the most appropriate time is 20 minutes and averagely 98% of consolidation will take place during this time.

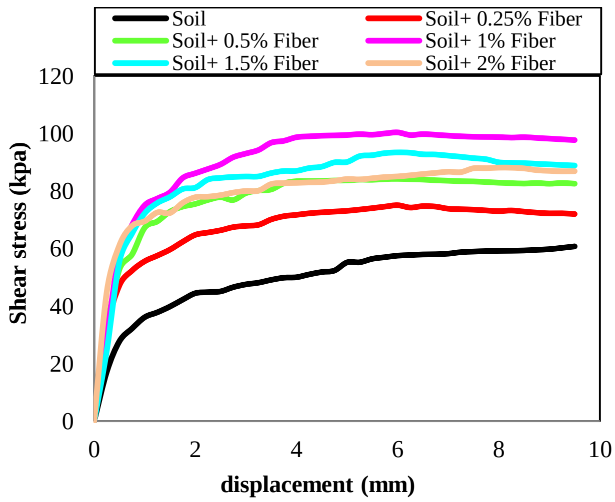

Fig. 4 Shear stress - displacement relationships (*different Percentages ,100 kpa normal stress*)

Fig. 4 to 6 shows the stress- displacement graphs of soil in different percentages of the mixture of soil and fibers. According to the results, with the increase in the percentage of the fibers the shear strength of the reinforced soil is increased and during the experiment the vertical displacement to horizontal displacement variations are decreased thanks to the increase in the percentage of the fibers.

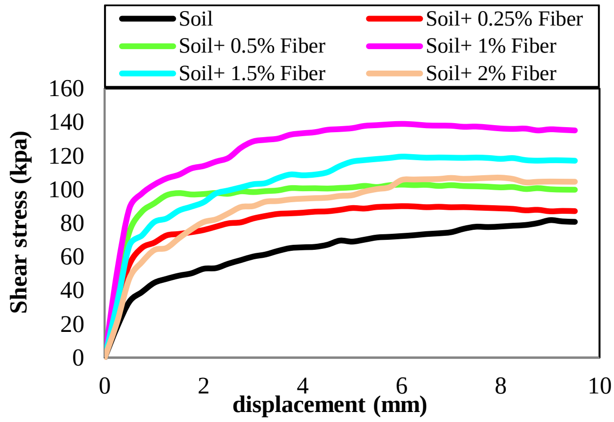

Fig. 5 Shear stress - displacement relationships (*different Percentages ,200 kpa normal stress*)

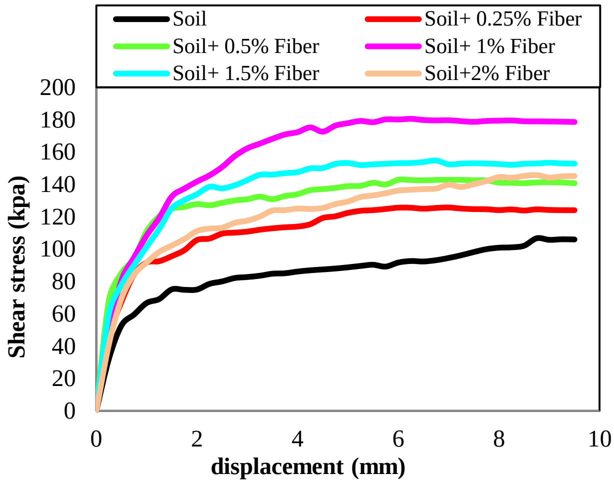

Fig. 6 Shear stress - displacement relationships (*different Percentages ,300 kpa normal stress*)

In all three normal stresses, with the increase in the percentage of fibers the shear stress is increased and with the increase of the applied normal stresses the shear stress had significant increase and the curves of the reinforced soil in percentages of 0.5 and 2 were close to each other. As a result of the displacement between soil particles with fibers in higher percentages, soil particles will be replaced with fibers and the increase in the fiber percentage leads to the reduction of the shear strength of the reinforced soil. Although with the increase of fiber percentage we have a reduction in the shear strength of the reinforced soil, soil strength is highly increased compared to the condition without fibers. Based on the curves obtained from the admixture of fibers and soil, the maximum shear stress graph based on the vertical stress is achieved. Variations of the Cohesion coefficients and the internal friction angle with variations of fiber percentage are shown in Fig. 7.

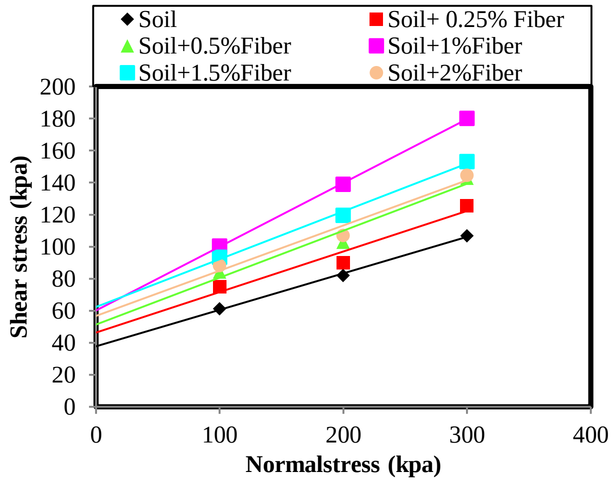

Fig. 7 Variations of the Cohesion and the Internal Friction Angle of the Reinforced Soil

Fig. 7 shows that with the increase in the number of fibers in the sample, the final shear strength of the reinforced soils will be increased. Structure of Typha fibers is multi-branch. When it is mixed with soil, the fibers take positions in different angles and levels and develop an intermingled structure and bring about noticeable changes in the parameters of the soil. On the other hand, the parallel structure of graphs indicate that the variations of the position angle has no significant effect on the friction angle since the failure posh were almost parallel to each other and have effects only on the shear strength of the soil.

The shear strength in the reinforced and non-reinforced soil for clay has a range of plasticity after which changes become critical. The changes of shapes in 5, 10, and 15 percent for different percentages of fibers in different normal stresses are demonstrated in figures 8 to 10. The coefficient of the strength increase is defined as follows:

$$\frac{\Delta\tau}{\tau_0} = \frac{\tau_f - \tau_0}{\tau_0}$$

Where, τ_0 = shear strength of unreinforced soil,
τ_f = shear strength of reinforced soil.

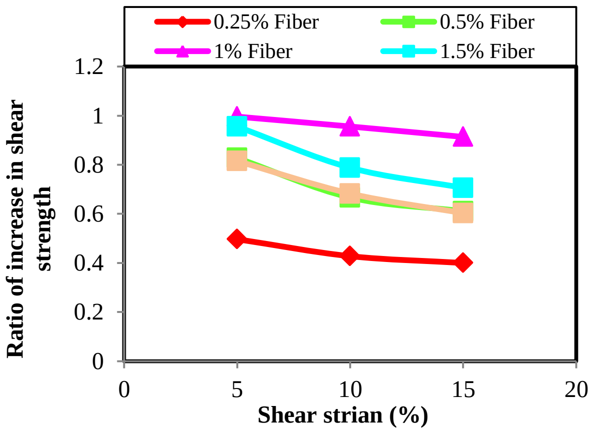

Fig. 8 Relationship between ratio of increase in shear strength and shear strain (*different percentages and the normal stress of 100kpa*)

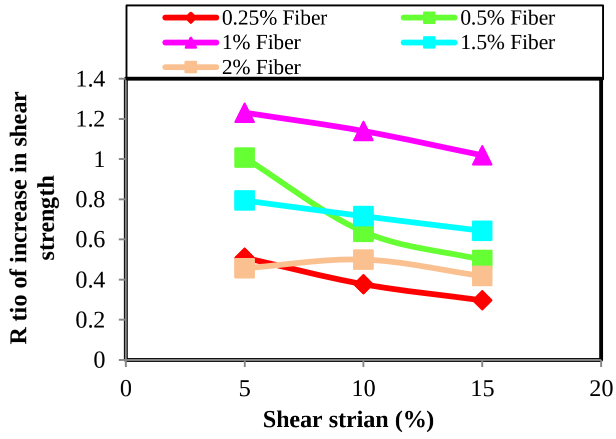

Fig. 9 Relationship between ratio of increase in shear strength and shear strain (*different percentages and the normal stress of 200kpa*)

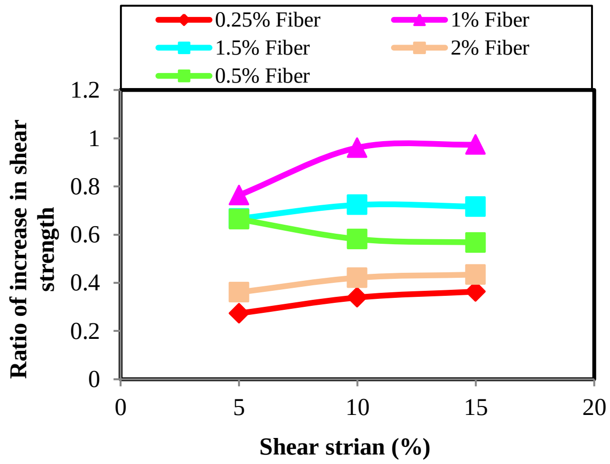

Fig. 10 Relationship between ratio of increase in shear strength and shear strain (*different percentages and the normal stress of 300kpa*)

With respect to the findings, we can say that the reinforcement fibers increase the shear strength and also increase the plasticity of the reinforced samples in soil. The ratio of increase in the shear strength undergoes a reduction with the shear flexibility in low stresses. It, however, rises with the increase of the normal stress. Increase of the shear strength values have been reported in other studies (Gregory and Chill, 1998; Maher and Ho, 1994; Nataraj and McManis, 1997).

Conclusions

The purpose of this study was to examine the effects of fibers on the shear strength of soil. To this end, a rather weak soil sample was tested and the following results obtained:

Results of the direct shear experiment showed that the fibers increase the shear strength of soil under the upload of 100 kpa and 200 kpa to 64% and 68% respectively.

In the overload 300 kpa the shear strength variations are about 70% compared to the condition without fibers. This indicates that with the increase of normal stress, the fibers and the soil will be much more involved that results in an increase in the shear strength value of the soil.

Examination of the components of the soil and fibers in different percentages and under different uploads showed that most of these variations were the change between 100 to 200 kpa in the admixture of soil with 1 % of fiber.

Addition of fibers to the soil, the other fabricated samples do not follow the compulsory shear area which is the distance between the two formats and this region is changeable depending on the fibers.

By adding 0.25 percent fibers to the soil we observe 22% variation in the level of cohesion of the soil and this amount is equal to 7 % for the internal friction angle. The maximum increase of the soil cohesion is equal to 66% and this is 49% for the internal friction angle.

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