Experimental study on mechanical behaviour of fiber-reinforced clayey sand

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ABSTRACT
Experimental investigations and modeling of unconfined compression strength of fiber-reinforced clayey sand under static loading were conducted in this paper. The investigations include three aspects. First, a series of unconfined compression tests were carried out on specimens with different fiber and moisture contents. The effect of fiber and moisture contents on unconfined compression strength (UCS) and E were studied and analyzed.
The results show that fiber insertion in clayey sand, cause an increase in UCS. Other results show that in moisture contents optimum and higher, the fiber insertion in clayey sand soil causes an increase in E and Role of fibers on the increasing of E in optimum moisture content is more sensible.
Second, a function was introduced to describe UCS. The UCS was expressed as a polynomial power function of fiber and moisture content. Third, a function was introduced to describe E. The E was expressed as a linear power function of fiber and moisture content.

RÉSUMÉ
Ce document offre des études expérimentales et modélisation du sable argileux renforcé par des Fibres sous chargement statique dans le cas de compression uniaxial. Ces enquêtes comprennent trios aspects. Tout d'abord, une série d'essai de compression simple ont été effectués sur des matériaux avec différents valeur de Fibre et de teneurs en eau. L'effet des contenu de Fibre et de la teneur en eau sur la compression axial et le module d'élasticité (E) ont été établis et analysés.
Les résultats montrent que l'insertion de fibres dans l'échantillon provoqué de plus en plus la résistance de l'échantillon. Autres résultats montrent que dans le cas de la teneur en eau optimum et supérieur, l'insertion de Fibres dans les échantillons de sable argileux provoque une augmentation de E et le rôle des Fibres sur l'augmentation de E on teneur en eau optimale est plus sensible.
Deuxièmement, une fonction a été introduite pour décrire la résistance de l'échantillon. La résistance de l'échantillon a été exprimée comme une fonction puissance polynôme de la teneur en Fibres et de l'humidité. Troisièmement, une fonction a été produite pour décrire le module élasticité (E). dans ce cas, E a été exprimé comme une fonction linier de la teneur en Fibres et de l'humidité

1. INTRODUCTION

In recent years, more and more geosynthetic materials have been introduced as engineering materials and widely applied in earthquake and geotechnical engineering. Geofiber is one of many types of synthetic materials being used to enhance engineering properties of soils by providing extra resistance of shear and tensile stress. Soil reinforced with geofiber can be considered as a composite material. Studies on mechanical behavior of soils with geofiber reinforcement are comparatively new when compared to other research fields. Various investigations on soils reinforced with short geofiber have been conducted by some researchers and manufactures.

The roots of surface vegetation contribute to the stability of slopes by adding strength (Wu et al., 1988; Ekanayake and Phillips, 2002; Greenwood et al., 2004; Danjon et al., 2007). Monotonic loading in shear box tests, consolidated and drained triaxial compression tests have shown that shear strength is increased and post-peak strength loss is reduced when discrete fibers are mixed with the soil (Gray and Ohashi,1983; Maher and Ho, 1994; Yetimoglu and Salbas, 2003; Ibraim and Fourmont, 2007, among others). The important influence of fibre orientation on the mechanical response of fiber reinforced soils has been experimentally investigated in tests with controlled orientations of fibers (Palmeira and Milligan, 1989; Micha1owski and Cermak, 2002). Triaxial compression tests under drained and undrained conditions indicate that the shear strength parameters of the soil-fibre mixture (i.e. Φ′ and c′) can be improved significantly (Ahmad et al, 2010). Direct shear tests suggest that fibre inclusions introduce an apparent cohesion intercept to the soil in the dry state, which remains almost unchanged by an increase in water content. The peak friction angle was expressed as a function of the relative density of sand for both reinforced and unreinforced cases (Lovisa et al, 2010). Triaxial compression and extension tests show that the shear strength increases due to the fibers in triaxial extension test was significantly smaller than the strength increases in the triaxial compression test for both undrained and drained loading conditions (Chen, 2010). Unconfined compression tests and suction indicate that fiber insertion in the cemented soil, causes an increase in unconfined compression strength and the voids/cement ratio is a good parameter in the evaluation of the unconfined compressive strength of the fiber-reinforced and unreinforced cemented soil (Consoli et al, 2010). Loading tests results that the cross polypropylene fibers can be considered as a good earth reinforcement material especially at fiber content of 0.5%. (Abuel-Maaty, A.E, 2010). Laboratory and some in situ pilot test results (Al Refeai, 1991; Zornberg, 2002; Consoli et al., 2007, 2009; Singh Chauhan et al., 2008) have led to encouraging conclusions concerning the potential use of flexible fibres for the reinforcement of fine granular materials providing an artificial replication of the effects of vegetation. Monotonic loading in triaxial compression tests have shown that For a particular soil, reinforcement, loading conditions and confining pressure, an optimum sand layer thickness exists which gives the maximum benefit. The provision of thicker sand layers will not lead to further improvement in the performance of the system (Unnikrishnan,.Rajagopal and Krishnaswamy., 2002). Cyclic loading in triaxial tests have shown that shear modulus of reinforced soil is significantly affected by multiple factors such as fiber content, confining pressure and loading repetition and as well as shear strain .Shear modulus of fiber-reinforced soil increases with increasing of fiber content and confining pressure, and decreases with increase of loading repetition (Li and Ding., 2002; Li., 2003). Studies on liquefaction resistance of reinforced soils have shown that the fiber inclusions increase the number of cycles required to cause liquefaction during undrained loading (Noorany and Uzdavines, 1989; Maher and Woods, 1990; Krishnaswamy and Isaac, 1994).

This study aims to investigate the effect of random distribution of polypropylene fiber on strength of clayey sand. The effect of different contents of fiber and moisture on unconfined compression strength (UCS), and also interaction of fiber and moisture (the role of moisture content in relation to the effect of fiber on UCS and vice versa) are studied and analyzed.

2. EXPEIMENTAL PROGRAM AND PROCEDURES

The experimental program was carried out in two parts. First, the geotechnical properties of the soil and fibers were characterized. Then a series of compression tests on both the fiber-reinforced and unreinforced samples under different moisture contents were carried out as discussed below.

2.1. Materials

The soil used in this study was clayey sand and was obtained from the bed of a dried river in the region of Kermanshah, west of Iran. The results of the characterization tests are shown in Table 1. This soil is classified as clayey sand (SC) according to the Unified Soil Classification System.

Monofilament polypropylene fibers were used throughout this investigation. The fibers were 6 mm in length and 0.023 mm in diameter, with a specific gravity of 0.91, tensile strength of 500 MPa, elastic modulus of 7.4 GPa and linear strain at failure of 80%. The fiber content χ used in the experiments was 0, 0.5, 1 and 1.5% by weight of the dry soil.

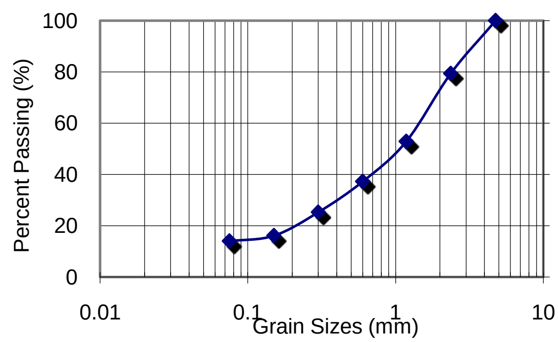

Figure 1. Grain Size Distribution

Table 1. Physical properties of the soil

Characteristic	Value
Sand content	86%
Clay & Silt content	14%
Liquid limit	28%
Plastic limit	11.5%
Specific gravity	2.68
Optimum moisture	8.5%

2.2. Methods

The unconfined compression tests were conducted on samples with three different moisture contents of 6.5%, 8.5% (equal to optimum moisture) and 10.5% with different dry density obtained from Proctor compaction test (20.45, 21,44 and 20.9 kN/m^3 , respectively). Cylindrical samples with 37 mm in diameter and 80 mm height were used. The fiber-reinforced and unreinforced compacted soil specimens were prepared by hand-mixing dry soil, water and polypropylene fibers (when appropriate).

The tests were conducted using an unconfined compression apparatus followed the ASTM code D2166-87. The rate of displacement adopted was 1 mm/min. Soil specimens were prepared in four groups with different geofiber content χ 0, 0.5, 1 and 1.5% in three different moisture contents 6.5, 8.5 and 10.5% . It should be mentioned that the unconfined compression tests were carried out for moisture content 8.5% until strength reached reinforcement in behavior of soil after maximum strength its maximum value. Whereas, tests was continued after peak of curve in moisture conents 6.5 and 10.5% to assessment the effect of reinforcement in

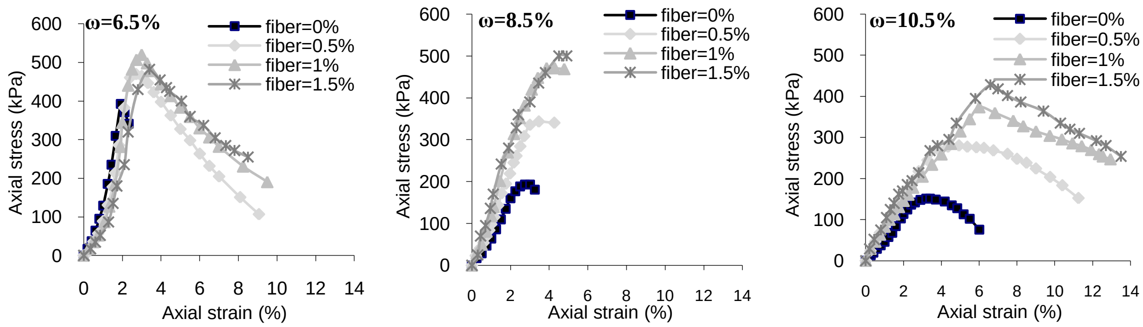

Figure 2. Axial stress vs. axial strain for different fiber content

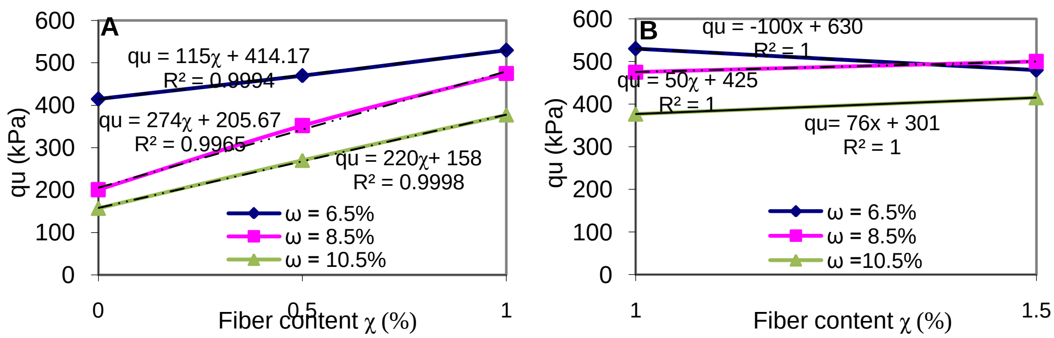

Figure 3. UCS vs. fiber content for different moisture content

behavior of soil after maximum strength. to its maximum value. Whereas, tests was continued after peak of curve in moisture contents 6.5 and 10.5% to assessment the effect of reinforcement in behavior of soil after maximum strength.

3. EXPERIMENTAL RESULTS

3.1. Effect of the fiber content in UCS

The results from various unconfined compression tests on samples with different fiber content for different moisture content (ω) are shown in Figure.2. It can be observed that the fiber insertion in clayey sand soil causes an increase in UCS.

The other point can that be seen in Figure 2. is difference in behaviour of reinforced and unreinforced samples after peak of strength curve. In moisture content 6.5% after peak, unreinforced sample was ruptured, whereas in reinforced samples the rupture was not seen. It can be conclude that the fiber insertion causes that ductility of soil increasing and abrupt failure in soils with low moisture content is fade. In moisture contents 8.5% and 10.5% after peak of strength curve it was seen that the strength loss was reduced when discrete fibers was mixed with soil. The results from the mentioned tests are re-plotted in Figure 3. to show the variation of UCS as a function of the fiber content It can be readily seen that role of fibers on the increasing of UCS in optimum moisture content is more sensible than other moisture contents for low fiber contents in soil (approximately 1%), but when fibers are gradually increased, this role is more significant in moisture content more than optimum. It noted that although in high fiber contents in soil for moisture content more than optimum as compared to other moistures, the role of fiber in increasing of UCS is more, but this increasing is negligible. So it can be conclude that in engineering designs for increase of factor safety of performance of fiber, in optimum moisture content, fibers added to soil.

Another feature can be seen in Figure 3. is the small rate of increasing of UCS due to increasing of fiber content for samples with low moisture content. It seems that in low moisture contents, fibers do not have sensible role in increasing of UCS.

3.2 Effect of the fiber content in E

To determine the effects of the fiber content in E., first elasticity modulus calculated from the slope of stress-strain in Figure 2. Results from the mentioned tests are re-plotted in Figure 4. to show the variation of E as a function of the fiber content. It can be readily seen that in moisture contents optimum and higher, the fiber insertion in clayey sand soil causes an increase in E, whereas in moisture content lower than optimum, causes an decrease in E. It can be conclude that the fiber insertion causes that ductility of soil in moisture content lower and higher than optimum increasing and decreasing, respectively.

Another feature can be seen in Figure 4. is that role of fibers on the increasing of E in optimum moisture content is more sensible than other moisture contents. So it can be conclude that in engineering designs for increase of efficiency of performance of fiber, in optimum moisture content, fibers added to soil.

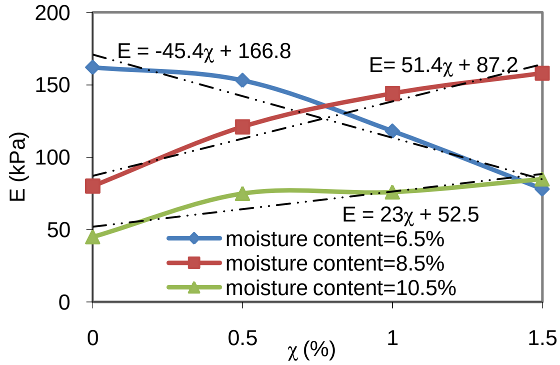

Figure 4. E vs. fiber content for different moisture content

3.3. A constitutive relation of unconfined compressive strength

In this paper, a model was introduced to estimate UCS. The UCS in the model was assumed to be a polynomial power function of moisture content (ω) and fiber content (χ) and is given in the following form:

$$q_u(\chi,\omega) = a_0[(1+\chi)^{a_1}(\omega)^{a_2}]^2 + a_3[(1+\chi)^{a_1}(\omega)^{a_2}] + a_4 \quad (1)$$

Where a (i = 0 …4) = constitutive coefficients are in kPa except a_1 and a_2 that are dimensionless.

Multiple-step graphical methods can be used for convenience of calibrating constitutive parameters in Eq. 1. First, constitutive coefficients a (i =1, 2) using Figures. 5a-5b are determined. These Figures are used for illustration of variables impacts on the UCS. This fact is consistent with the relation introduced in Eq.1 in which the changes of UCS were described by a power function with one variable when other variables are given. The data analysis in Figures 5a-5b show that the average values of the UCS change with ω and χ in a power function $q_u = 3362\omega^{-1.04}$ and $q_u = 246(1+\chi)^{0.755}$ reapectively.

Finally, coefficients a_0, a_3 and a_4 in Eq. 1 were determined. First, variable X was defined as multiples power function of moisture content (ω) and fiber content (χ) and is given in the following form:

$$X(\omega,\chi) = (\omega)^{a_2}(1+\chi)^{a_1} = (\omega)^{-1.04}(1+\chi)^{0.775} \quad (2)$$

Substituting Eq. 2 into Eq. 1 gives the UCS in term of variable X. Therefore, Eq. 1 is defined in the following expression:

$$q_u(X) = a_0X^2 + a_3X + a_4 \quad (3)$$

For convenience of calibrating coefficients a_0, a_3 and a_4 in Eq. 3, Fig. 5c can be used. Fig. 5c shows the UCS as a function of variable X. As we observe, UCS is as a quadratic function based on variable X that is consistent with the relation introduced in Eq.3. Using Fig. 5c the coefficients a_0, a_3 and a_4 were determined and Eq. 3 is renewed in following form:

$$q_u(X) = -14298X^2 + 7158X - 380 \quad (4)$$

Substituting Eq. 2 into Eq. 4, Eq.4 is renewed in the following form:

$$q_u(\chi,\omega) = 14298[(1+\chi)^{0.775}(\omega)^{-1.04}]^2 + 7158[(1+\chi)0.775(\omega)-1.04]-350 \quad (5)$$

Eq. 5 represents the established model for description of UCS. The model in Eq. 5 can be applied to design of roadbeds, highway slopes or foundations and etc if the same composite materials are employed.

3.4. A constitutive relation of elastic modulus

In this paper, a model was introduced to estimate E. The E in the model was assumed to be a power function of moisture content (ω) and fiber content (χ) and is given in the following form:

$$E(\chi,\omega) = a_0(1+\chi)^{a_1}(\omega)^{a_2} \quad (6)$$

Where a (i = 0 …2) = constitutive coefficients are in kPa except for a_1 and a_2 that are dimensionless.

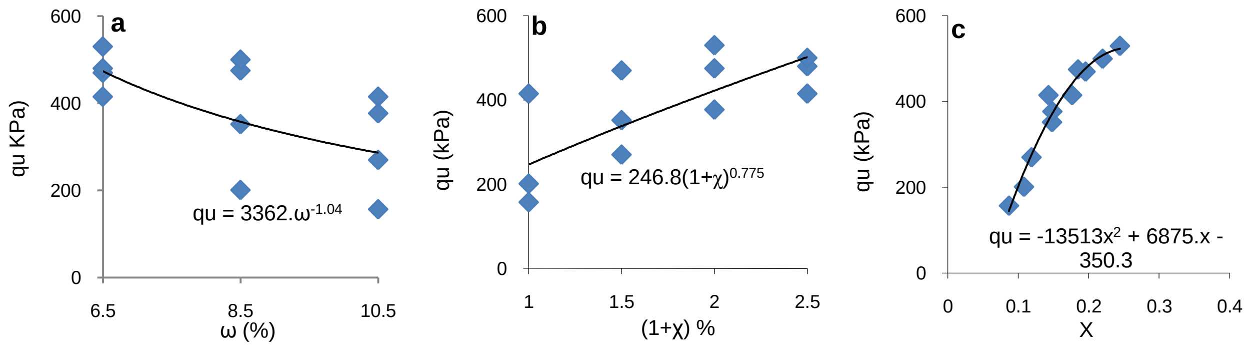

Figure 5. UCS vs.(1+χ), ω and X

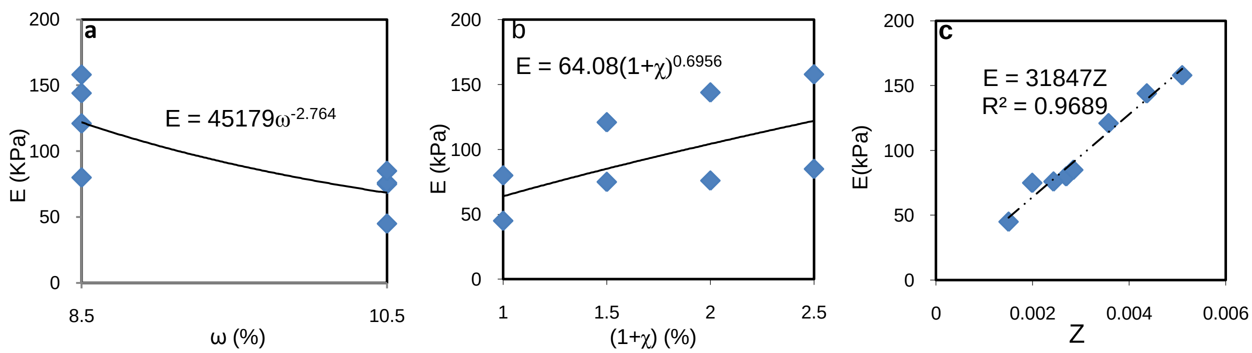

Figure 6. E vs.(1+χ), ω and Z

Multiple-step graphical methods can be used for convenience of calibrating constitutive parameters in Eq. 6. First, constitutive coefficients a (i =1, 2) using Figures. 6a-6b are determined. These Figures are used for illustration of variables impacts on the E. This fact is consistent with the relation introduced in Eq.1 in which the changes of E were described by a power function with one variable when other variables are given. The data analysis in Figures 6a-6b show that the average values of the E change with ω and χ in a power function $E = 45172\omega^{-2.764}$ and $q_u = 64(1+\chi)^{0.695}$ reapectively.

Finally, coefficient a_0 in Eq. 6 was determined. First variable Z defined be a function of product of multiples power functions of moisture content (ω) and fiber content (χ) and is given in the following form:

$$Z(\omega,\chi) = (\omega)^{a_2}(1+\chi)^{a_1} = (\omega)^{-2.764}(1+\chi)^{0.695} \quad (7)$$

Substituting Eq. 7 into Eq. 6 gives the E written in term of variable Z. Therefore, Eq. 6 is defined in the following expression:

$$E(Z) = a_0 Z \quad (8)$$

For convenience of calibrating coefficient a_0 in Eq. 8 can be using than Figure 6c. Figure 6c shows E as a function of Z variable. As we observe, E is as a linear function based on variable Z that is consistent with the relation introduced in Eq.8. The using Figure 6c coefficient a_0 were determined and Eq.8 renewal in following form:

$$E(Z) = 31847Z \quad (9)$$

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Substituting Eq. 7 into Eq. 9, Eq.9 renewal in following form:

$$E(\chi,\omega) = 31847(1+\chi)^{0.695}(\omega)^{-2.764} \quad 10)$$

Eq. 10 represents the established model for description of E. The model in Eq.10 can be applied to design of roadbeds, highway slopes or foundations and etc if the same composite materials are employed.

4. SUMMRY AND CONCLUSIONS

From the data presented in this paper the following conclusions can be draw.

- The fiber insertion causes an increase in UCS in the clayey sand.
- The fiber insertion causes an increase in E for moisture contents optimum and higher, whereas in

moisture content lower than optimum, causes an decrease in E

- The fiber insertion causes that ductility of soils with low moisture content increasing and abrupt failure in these soils is fade but do not have sensible role in increasing of UCS.
- Strength loss is reduced when discrete fibers are mixed with soil.
- In optimum moisture content for low fiber contents in soil (approximately 1%), fibers have the most effect on increasing of UCS and this effect is more significant in moisture content more than optimum when fibers were gradually increased.
- Role of fibers on the increasing of E in optimum moisture content is more sensible than other moisture contents.
- In engineering designs for increase of factor safety of performance of fiber, in optimum moisture content, fibers added to soil
- In this research two models were represented to estimate UCS and E as functions of moisture and fiber content on clayey sand soil under monotonic loading that provides a convenient and useful tool for analysis of static behavior of fiber-reinforced soil and its applications to engineering design.

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