نَرْفَعُ دَرَجَاتٍ مِّنْ نَّشَاءٍ وَفَوْقَ كُلِّ ذِي عَلِيمٍ عَلِيمٍ

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ABSTRACT

The behavior of soils reinforced by fibers has been studied by several investigators over the last two decades. Fiber-reinforced soil is becoming a viable soil improvement method for geotechnical engineering problems.

The objective of this project is to present an experimental study on the behavior of silty soil reinforced by organic fibers, conducted in situ triaxial compression tests.

This work contains four chapters:

**Chapter 1** presents the different types of rheological behavior of soils and the influential parameters.

**Chapter 2** describes the different methods of soil stabilization (slopes, river bank, embankment...) by tree roots.

**Chapter 3** presents the triaxial apparatus developed for the study of soil behavior. This device can perform triaxial tests following various stress paths (isotropic drained and undrained, cyclic, proportional to deformation, etc...). After describing the procedure followed for the tests, we expose the different arrangement of fibers in the soil.

**Chapter 4** includes a presentation of the results of the drained and undrained triaxial compression tests performed on the chlef soil from the region of Chlef. It first presents the drained triaxial compression tests performed on samples of plain soil, and the soil reinforced by roots under confining pressures up to 100 kPa. This chapter also concludes with a determination; based on testing, soil characteristics within the study area (modulus of deformation, internal friction angle). These results will be compared to those found in literature in particular soils reinforced by tree roots.

**Key Words:** Compression Triaxial Test, Fiber, Reinforcement, Soil, Undrained, Drained.
الملخص

هذه المذكرة عبارة عن عمل خيبر لدراسة سلوك التربة مدعمة بالألية العضوية تحت تأثير الاحمال المستقرة. في هذا البحث تم دراسة التأثيرات النفعية لتشييح طبيعة التربة باستخدام شعيرات ذات أطوال صغيرة (الفيبرات) موزعة عشوائياً إضافة إلى استعمال جذور شجرة الأكاسيا. وتشمل أربعة فصول:

الفصل الأول: يختص بمراجعة وتحليل البحوث السابقة حول الموضوع.

الفصل الثاني: يتناول معرفة طرق تثبيت التربة (المنحدرات, الركام ..) بالألية والجذور الخاصة بالأشجار.

الفصل الثالث: يتناول شرح العمل والاجهزة المستعملة في التجارب بالإضافة إلى طريقة قياس دقة النتائج المحصلة من هذه التجارب.

الفصل الرابع: يشمل عرض النتائج بواسطة الاحمال الثابتة ومناقشة مدى تأثير الألية والجذور على سلوك التربة.

ظهرت النتائج أن ارتفاع نسبة الألية تقوي مقاومة التربة إلى حد ما إما سلوك التربة المدعمة بالجذور يكون حسب وضعية الجذور إذا كان عمودياً أو أفقياً.

الكلمات الدالة: ضغط ثلاثي المحاور, دعامة, تربة, الألية, التصريف, الجذور.
I. INTRODUCTION

Slope instability is one of the serious geological hazards to most environmentally regions. Significance numbers of failure are reported on residual soil slope and more than 2/3 of slopes movements are shallow sliding with less than 1m depths. Earth slope could be stabilized using reinforcement techniques and bioengineering techniques seem suitable for preventing shallow slope failures. Vegetation plays important roles for slope stability by providing immediate shear strength enhancement and modifying the saturated soil water regime.

Our country knows this problem of slopes and bank instability, the coverage of this natural risk is an integral part concern of public authorities in town and country planning. Landslides know last decades a large increase, the landslide corresponds to a loss of due resistance mainly a surgénération of the pressure of water in the ground.

Recent experimental investigation on fibre reinforcement in sand yielded controversial findings, depending on the method applied. Using shear tests, Yetimoglu and Salbas (2003) found no improvement in the shear strength of the composite compared to pure sand, and Operstein and Frydman (2000) reported an essentially constant angle of internal friction of soil reinforced by roots, but an increase in the apparent cohesion.

However, analyses based on triaxial tests compression revealed and increase in the angle of internal friction of composite (fibre reinforced sand) compared to the untreated granular matrix (Stauffer and Holtz 1995; Consoli et al. 2002). The addition fibres to cohesionless pure sand yielded an increase in the angle of internal friction without any change in the cohesion but when added to cemented sand (with cohesion), the increase in the angle of internal friction went along with a decrease in cohesion (Consoli et al. 2002). Furthermore, it was found that the reinforced effect generally correlates positively with the fibre aspect ratio, and if the aspect ratio and concentration of fibres are kept constant, the composite strength is positively correlated with the length of the fibres (Michalowski and Cermak 2003).

The present study undertaken to examine the influence of fibres and roots on the shear strength of Chlef silty soil area in a recent slide area. The focus is on triaxial testing with a programme including pure soil and soil reinforced by fibre and roots. Consolidated drained and undrained triaxial testing was performed at different confining pressures to assess the effects of fibers and roots on soil stability.
II. RESEARCH METHODOLOGY

1 - INTRODUCTION

During the last decades there has been a pronounced increase in the number of catastrophic events including shallow landslides and erosion processes after heavy rainstorms, particularly in mountainous regions, which has raised public awareness of the hazard [Bezzola and Hegg (2007)]. Slope instability is thus a major concern for all those responsible for the protection of human lives and infrastructure against natural hazards. Consequently, methods to protect slopes against processes of erosion and sliding, and to stabilise those already affected are needed, as are reliable models and ways of estimating and predicting slope stability, and of calculating the factor of safety against failure.

1-1- Triaxial Compression Test

The triaxial compression test is the most widely used technique to determine the shear strength of soils. The apparatus is shown diagrammatically in the (figure6). The sample, which is cylindrical, is tested inside a perspex cylinder filled with water under pressure. The sample under test is enclosed in a thin rubber membrane to seal it from the surrounding water. The pressure in the cell is raised to the desired value, and the sample is then brought to failure by applying an additional vertical stress.

One of the major advantages of the triaxial apparatus is the control provided over drainage from the sample. When no drainage is required (i.e. in undrained tests), solid end caps are used. When drainage is required, the end caps are provided with porous plates and drainage channels. It is also possible to monitor pore-water pressures during a test.

The triaxial compression test is a useful method for obtaining shear strength parameters from undisturbed soil specimens. Currently, there are two types of tests used. They all use the same equipment but vary in procedure and effectiveness.

1-2-Triaxial Test Equipment

The triaxial compression test system housed in the Laboratory of Materials Sciences and Environment (University of Chlef) comprised of many equipment. The important system components are listed below:

- An autonomous triaxial cell type Bishop and Wesley: This cylinder shaped cell held the soil test specimen and pressurized water around it. The top plate allowed a loading piston to penetrate into the cell. The bottom assembly connected pressure transducers and drainage/saturation lines to the soil specimen or chamber water
- Pressure controllers / GDS volume (2MPa).
- **Vacuum Pump**: This was used to pull air out of the soil specimen and deair water.
- **Water Tank**: This cylinder shaped tank was used to hold deaired water.
- **A computer**: A standard IBM-compatible PC ran special software prepared by the manufacturer of the triaxial test system; so that the sensor readings acquisition and test management will be automatic once the soil specimen is conditioned in the test cell.

1-3-Plant Material

1-3-1-Fibre

A fibres root of Acacia pycnantha was used in this study with a mass ranging from 0 % to 30 percent. This fibres was mixed with the chlef soil to get a composites samples comprised of fiber roots.

1-3-2-Root

A compression drained (CD) and undrained (UD) triaxial test is applied in the laboratory to study the soil reinforcement by roots of Acacia pycnantha (Golden Wattle).

1-3-3-Soil

The soil samples used in the present study were derived from weathered sandstone, and were obtained from the region of Chlef in southern Algeria. The Atterberg limits of the portion passing No. 40 sieve are: liquid limit 33.5% and plastic limit 21.07%. The particles have a mean diameter (D50) of 0.06 mm, a minimum void ratio (emin) of 0.70, a maximum void ratio (emax) of 1.12, a uniformity coefficient (Cu) of 37.5, and a specific gravity of 2.65 (ASTM D854). According to the Unified of Soil Classification System (ASTM D2487), the soil is classified as low plasticity silty soil. Figure 1 shows the Particle Size Distribution curve of the soil used in this study.

- **I-4-Grain Size Distribution**: 

  **Sieve Analysis**: 

  Grain size analysis of chlef soil includes three steps: wet sieve analysis (XP P 94-041), the dry sieve analysis (NF P 94-056) and the hydrometer test (NF P 94-057).

  Sieve analysis is conducted by taking a measured amount of dry, well pulverized soil. The soil is passed through a stack of sieves with a pan at the bottom. The
amount of soil retained on each sieve is measured, and the cumulative percentage of soil passing through each sieve is determined. This is generally referred to as percent finer. Soil particles are generally separated into particle-size ranges using a series of sieves: 80 μm; 100 μm; 200 μm; 400 μm; 1mm; 2mm; 5mm; 10mm; 20mm. The size of particles less than 0.08 millimeter (fine fraction) is generally determined by a sedimentation process, using a hydrometer to secure the necessary data.

The main outcome of this test was the grain size distribution curve, which provided percent gravel, percent sand, percent fines (silt + clay), and key particle sizes (D60, D30, and D10).

- **Hydrometer Analysis:**

Hydrometer analysis is conducted on the principle of sedimentation of soil particles in water. In the test 40 grams of dry pulverised soil. A deflocculating agent is always added to the soil. The soil is allowed to soak for at least 16 hours in the solution of Sodium Hexametaphosphate. After the soaking period, distilled water is added, and the soil-deflocculating agent mixture is thoroughly agitated. The sample is then transferred to a 1000-ml glass cylinder. More distilled water is added to the cylinder to fill it up to the 1000-ml mark, and then the mixture is again thoroughly agitated. A hydrometer is placed in the cylinder to measure usually over 24 hour period.

![Soil Classification Curve](image)

**Figure:** Soil Classification Curve of the soil utilised in this study
I-5 - Sample Preparation

The samples were 70 mm in diameter and 70 mm in height with smooth lubricated end-plates. First we put on filter paper pads (drainage hole) to protect them, and then we put a layer of silicone (KS63G) on two bases. After the specimen has been formed, the specimen cap is placed and sealed with O-rings; it was mounted on the base of the triaxial cell. The base platen was lightly coated with a film of thin grease prior to attaching the membrane. The membrane was then sealed to the top loading cap and the bottom platen with O-ring seals. To ensure a good homogeneity of stress and strain in the sample and reduce friction between the sample and the upper and lower bases. Saturation was performed by purging the dry specimen with carbon dioxide for approximately 15 min. De-aired water was then introduced into the specimen from the bottom drain line. Water was allowed to flow through the specimen until an amount equal to the void volume of the specimen was collected in a beaker through the specimen upper drain line. Therefore, to maintain contact between the top loading cap and the load cell a nominal deviatoric stress of about 2 KPa was applied to the sample.

To quantify the important influence of plant roots on shear strength of chlef soil, we performed consolidated-drained and undrained triaxial compression tests with different confining pressures (σ3' = 50, 100, 200, 300, 400 kPa). all samples were prepared on medium dense state (Dr=50%). Two different types of samples were tested: A) pure soil samples and B) composites samples comprised of roots of Acacia pycnantha (Golden Wattle).

III. Experimental Results

1. Triaxial Compression Tests

1-drained compression tests

A) Pure soil

The results of monotonic drained compression tests are shown in Figure (1), we find that the drained shear strength increases with increasing confinement; we note that there was not a peak deviator despite large confinements (fig.1-a). This results from the absence of the peak role of suspended matter in the soil in the increase in soil contractancy phase (Figure 1-b). In Figure 1-IVb shows that the volumetric strains remain in the field contracting despite increasing confinement. Our results are in perfect agreement with those found in the literature (Shewbridge and Sitar 1989; Wu and Watson 1998; Operstein and Frydman 2000; Cazzuffi and Crippa 2005; Wu 2007), for fine soils (silt or clay) the volumetric strains decrease with the increase of confinement ,while sandy soils the volumetric strains increase with increase in the confinement (Michalowski 2008 ).
Figure 1. Curves of Monotonic Drained Triaxial Tests: a) Deviatoric Stress (q) versus triaxial Axial Strain (εp), b) Volumetric Strain versus Axial Strain.

Figure (2-) shows the evolution of secant deformation modulus versus difference confinement. It is found that the deformation modulus decreases sharply with increasing axial strain up to 5% and then stabilizes for all confinements. Figure (2-B) shows the change in modulus as a function of axial strain up to 5%, we note that the modulus increases with increase in confinement, the increase in modulus resulting in increased soil stiffness for large confinements, the same results can be found in Chen et al (2008).

Figure 2:- Curves of deformation modulus versus confining pressure.
**Soil reinforced with horizontal roots**

Figure 3 illustrates the change of the shear strength characterized by the deviatoric stress versus the axial deformation of the fiber-reinforced soil with diameters equal to 3.5 mm and a length equal to 30 mm. It is found that the shear strength gradually from 50 kPa, 75, 95 to 150 kPa for reinforced soil consolidated under an isotropic stress $\sigma_c = 100, 200, 300$ and 400 kPa respectively. Figure 3-b shows the evolution of volumetric strains versus the axial strain, we note that the presence of root in the soil reduces the volumetric strains and therefore contractancy. Figure 3 shows the evolution of the deviatoric stress versus the confining stress, we see the resistance increases almost linearly with an increase of confinement for the plain soil and reinforced soil according to the expressions (1) and (2).

\[
\begin{align*}
\text{Pure soil} & \quad Y = 0.23X + 16.9 \quad (1) \\
\text{Soil root-composites} & \quad Y = 0.20X + 31 \quad (2)
\end{align*}
\]

Figure 3: Response drained of reinforced soil (root diameter = 3.5 mm)

a- Evolution of a deviatoric stress, b-Evolution of volumetric strains.
2- Undrained compression tests

1- a) pure soil

Figure 4 shows the results of compression tests performed on undrained pure soil under a mean effective confining stress $\sigma'c = 100$ kPa. It is found that the undrained shear strength increases with increasing confinement. The deviator stress reached a peak of 18, 44, 60 and 80 kPa and then decreases slightly mobilizing a residual force until the end of shear (Fig. 4). Figure IV-9 illustrates the evolution of pore pressure as a function of axial strain for different confinements, we note that the virgin soil quickly generates water pressure de570, 670, 740 and 820 kPa as after 5% deformation axial; and then there is a stabilization of the water pressure until the end of shear. This rapid increase in water pressure in soil results from the role of fines in the increased volume contracting behavior observed in drained compression tests.

Figure 4: undrained Response of plain soil (a- deviatoric-stress b-Evolution of pore pressure) versus the axial strain.

1- b) soil reinforced with horizontal root

The results of these tests are illustrated in Figure 5. Note that there is not improved soil resistance despite the presence of a number of fibers to a 10% axial strain beyond this limit there is a slight improvement in resistance soil shear reinforced by seven fibers (Fig. 5). Figure 5b shows the evolution of pore pressure as a function of axial strain. A slight decrease in pore pressure with the increase of fiber, the fiber reinforced soil 7 sees its pore pressure stabilized at around 565 kPa, while for the three fibers reinforced soil and virgin soil pressure is stabilized at around 575 and 580 kPa. This decrease in water pressure fiber reinforced soil in 7 of the role of the fibers results in reducing the phase contractancy and therefore the increase in the dilatancy of the soil.
Figure 6 illustrates the evolution of the deviator stress normalized by the axial deformation, we can see the fibers begin to actively participate in improving the soil from 15% axial strain; below this value, the fibers contribute to the improvement of the soil resistance.

![Figure 6](image)

Figure 6: Curve of the normalized stress versus the axial strain.

2- Influence of the fibers on the angle of internal friction

Figure 7 shows the evolution of the internal friction angle as a function of confinement, usually for our tests the results show that the angle of internal friction decreases with increasing confinement. Our results are in perfect agreement with those found in the literature [Tatsuoka et al. (1986); Flavigny (1990), Al Mahmoud (1997), Arab (1998 and 2008)].

![Figure 7](image)

Figure 15-IV: Evolution of the friction angle versus the confining pressure.
Figure 7 shows the evolution of the friction angle based on the number of fibers. Note that the friction angle decreases for soil reinforced with a fiber and then increases again when the number of fibers increases to 3, this increase in friction angle results from the role of fiber in improving the resistance of soil shear.

Figure 7: Evolution of the friction angle depending on the number of roots (fibers).

Additionally, roots have little influence on the friction angle of root-reinforced soils with respect to that of root-free soils (Gray and Ohashi, 1983), and of the shear strength increase of root-reinforced soils with respect to root-free soils is equated to the increase in apparent cohesion (Waldron, 1977; Operstein and Frydman, 2000).
Conclusion

This work was carried out to study the behavior of soil and soil reinforced by fibers and tree roots as mentioned in this study. It consisted of laboratory tests on different loading paths and in different soil conditions.

The position of the roots in the soil plays an important role to improve the shear resistance of the soil. The roots horizontally decrease the volumetric behavior resulting in a considerable increase in shear strength, while the vertical roots rise against the volumetric behavior resulting in an amplification phase contractancy.

Undrained monotonic tests showed the layout and root diameter plays an important role in the undrained shear strength. The soil reinforced by roots arranged horizontally plays no role in improving soil strength, while the roots placed vertically in a manner significantly improve the undrained shear strength. Also, the number of roots plays a role in improving the undrained shear strength.

The results are a very good data base for development and validation of numerical models. It would be interesting at first to test existing models and to determine parameters for soil types and then use finite element codes to study the behavior of structures in sites with a risk of instability.