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Experimental and numerical study of reinforced clay behavior by short vegetal fibers Application for the calculation of the solid waste landfill

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ABSTRACT: The aim of this paper is the study of the reinforced clay behavior, with an experimental laboratory tests. The considered clay is reinforced by the short vegetal sisal fibers. Many experimental studies have been developed and have shown that reinforced clay by synthetic or vegetal fibers makes late cracks over a wetting path. An experimental study with simple compression, a brazilian tensile and deflexion clay beams tests are engaged. In this paper, an effect of density of fixed length fibers is presented. Also, numerical calculation of clay layer deflexion used in covering of the solid waste landfill is accomplished. Testing results indicate that moduli in compression and tension are different for this several tests. In order to determine the effect of fibers reinforced tensile layer behavior, the bimodularity behavior is examinated across the tensile (brazilian or flexure) and compression tests. It is showed that these properties significantly influence this structure behavior. However, it is not available to translate directly the last interpretation to the solid waste landfill problem, while retaining an elasticity assumption.

1 INTRODUCTION

Many civil engineering structures such as caps of waste landfills, embankment slopes, dams core are constructed with clay soils. In this kind of structures, the clay mass is submitted to tensile strength. Tensile stresses may result from settlement, from desiccation induced by shrinking-swelling cycle or from an other particular solicitations. The understanding of the tensile behavior of clay soils is more and more important to control the development of cracking of clay. In a particular case of caps of waste, when the cracking is developed, in clay liner of a landfill, a water infiltration through solid waste is caused. The settlements of solid waste, occurred due to water infiltration. This deformation is advanced along time causing settlement's evolution.

In this paper, an experimental study of clay-tensile behavior is developed. An application choice, is the calculation of reinforced layer used for solid waste landfill localized at 70 km east of Tunisia at Nabeul. It is assumed that the reinforced clay can be seen as a continuum medium, obtained as a superposition of several continua : unreinforced clay and random continua fibers. In several recent soil retentived techniques, a technically feasible and economically viable alternative is to mix the soil randomly with local materials such as vegetable fibers. In tunisia, the "Alfa fibers" probably serve as inclusions, in order to increase the shear strength of the medium. However, the treatise fibers with its characteristics are not still easily available. That's why we consider a "Sisal fibers", as an example, with known identification parameters. It is important to signal that another kind of fiber such as metallic, rubber, glass fibers and polypropylene monofilament or mesh elements exists. A large number of investigations have looked into the effect and the contribution of mix polypropylene and natural fibers (Jones and Mckinley 2001). Other techniques are used to ameliorate the tensile characteristics of soils such us geotextiles and geosyntetics materials. In order to use local products, fiber reinforced technique is studied.

This paper contains a description of tensile tests as Brazilian, tensile-flexure and compression tests. These tests are carried out on reconstitute soil clay provided from Nabeul city (in Tunisia). The observations from different tensile strength tests carried out on clay consolidated form are described.

2 EXPERIMENTAL STUDY

2.1 *Material preparation*

Natural soil was dried then crushed. After, the dry soil was sieved on sifter with diameter 2 mm, pulverized and mixed to appropriate proportions of fibers. The dried clay specimens are mixed at 33 % ± 0.1% corresponding to optimum normal water content. The soil was placed in tightly covered pan and allowed to cure for 48 hours minimum. The soil is tested unreinforced and reinforced with a sisal fibers at different fibers contents level of 0.1 %, 0.3 % and 0.5 % by mass. Characteristics of soil and sisal fiber used in this study are summarized in table 1.

The specimens (diameter = 10.16 cm, height = 20.32 cm) were formed by compacting statically soil-fiber mixture with Standard Proctor compaction energy. A maximum dry density of 13.7 kN/m^3 is almost reached. Then, the specimen were covered and allowed to cure for 48 hours to allow for distribution an homogenous of moisture.

Table 1 Different characteristics of soil and fibre.

Characteristics	
% < 0.080 mm	98
Liquid limit LL (%)	98
Plasticity index Ip	49
W_{opt} (%)	33.0
$\gamma_{d\,opt}$ (kN/m^3)	13.7
Mechanical properties of fibre * :	
Tensile strength (MPa)	580
Ensile Modulus E_t (for 6 % of strain) (GPa)	18

* Khosrow G. et al. (1999).

For more precision in interpretation of test results, the accuracy of the measurement of material properties w_{opt} ± 0.1% and $\gamma_{d\,opt}$ ± 0.2 KN/m^3 are chosen.

Compressive test, flexure test and Brazilian test were conducted according to NF P18 - 406, P18 - 407 and P18 - 408 respectively using a testing machine in displacement control at a steady rate of 0.032 mm/s until failure of the specimen occurris. Axial load is measured by dynamometric ring range of 5 KN.

For deflection test, prismatic samples (4x4x16 cm) were obtained from cylinder bloc (diam 10.16cm, Height 20.32 cm) compacted statically on the same energy cited above (photo1).

The layout used for deflection test and compression test after deflection are shown in photo 2 (a and b).

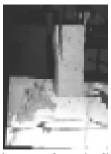


Photo 1. Cubic cutting specimen for deflection test.

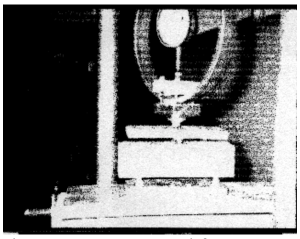


Photo 2a . Layout used for deflection test.

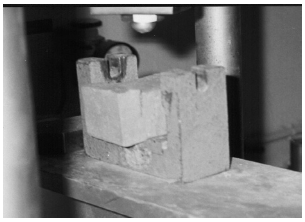


Photo 2 b. Layout used for compression (after deflection test).

2.2 *Experimental procedures*

The random reinforcing capacity of the fibers (with length=3cm), was considered by studying their effects on the tensile and compressive strength on compacted clay by different methods : tensile Brazilian test, flexure test and compressive test.

Brazilian test :

Figure 1 shows that fiber reinforcement increases ductility of soil but littly tensile stresses. We note that unreiforced specimens would often fall into two parts at the failure strength. However the two parts of reinforced specimens remained attached.

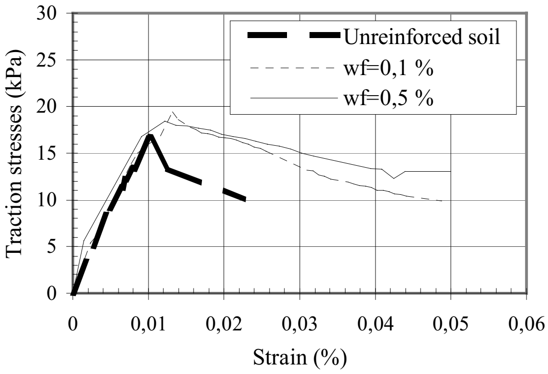


Figure 1. Tensile stress-strain curve for Brazilian tests.

Deflection test :

Tensile stress derived from deflection tests are resumed on table 4b. After deflection failure, the two cubic parts are submitted to compression tests. Figure 2 shows the average experimental values presented with curves of compression stress for each fibre content. We note an improvement of compression stress for reinforced soil.

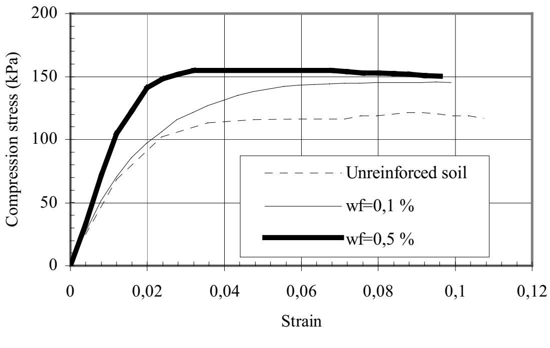


Figure 2 Stress-strain curve for compressive tests on cubic specimens (tests after deflection failure).

A comparison between shape and specimen's size for cylindrical and cubic compressive tests in figure 3, shows that as soon as compression stress "Rc", the rigidity of cubic specimen is higher than that of cylinder specimen. For concrete the usual coefficient ($Rc_{cylinder}/Rc_{cubic}$) is equal to 0.83 for 20 to 30 MPa class. It can be higher for concrete with high resistance, this is due to the enlacement (2 for cylinder and 1 for cubic) and not because of the shape of the specimen (cylindrical or cubic) ,(Dreux & Fiesta 1999).

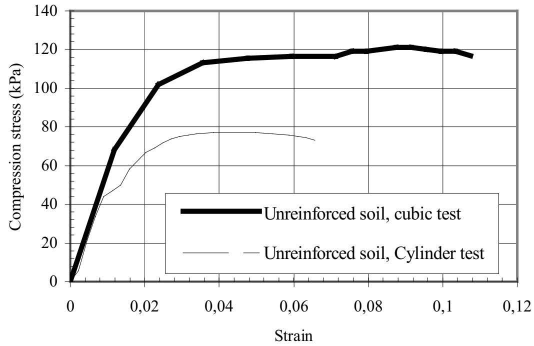


Figure 3. Influence of the specimen shape on the compression strength of the soil.

Compressive test :

Typical stress-strain curves for compression cylindrical specimens of 10.16 x 20.32 cm are shown in figure 4.

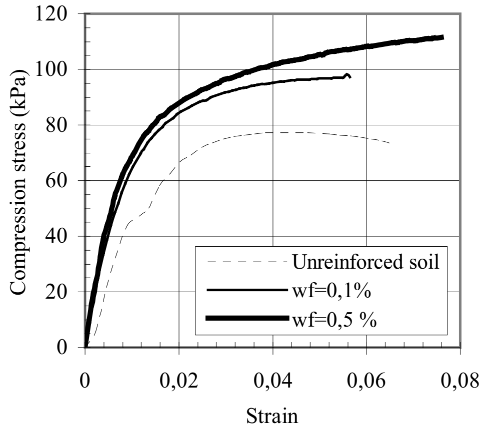
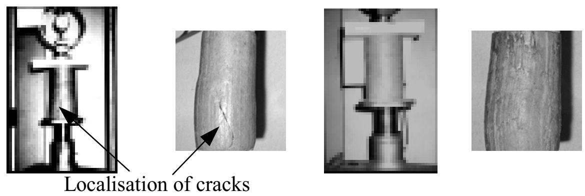


Figure 4 Stress-strain curve for standard compressive tests

Tests showed that sisal fiber increases the maximum failure compressive strength. We note that inclusion of fibers reduces the amount of cracking at Failure State. Photo 3 shows the cracks of unreinforced (a) and 0.1 % reinforced specimen (b) but there are no cracks for 0.3 and 0.5 % reinforced specimens (c and d).



(a)unreinforced specimen | (b) 0.1% fiber content | (c) 0.3% fiber content | (d) 0.5% fiber content

Photo 3 – Dissipation of cracks at failure state.

We note that tests with 0.3 % of fibre content are conducted in parallel but certain dispersion on results is noted, this is due probably to heterogeneity especially in water content preparation sample and than in dry density. This is must be confirmed with other tests.

2.3 *Tests results*

Modulus of deformation in tension tests "E_t" and in compression tests "E_c" are determined for different states of reinforcement upon different techniques.

For tensile brazilian tests, E_t is determined from equation (1), E_c are determined according to equation (2) (Olivier M. 1994). Tensile stress for brazilian test is calculated by equation (3).

$$E_{traction} \cong \frac{P}{\Delta H\, h}(\nu + 0.27324) \qquad (1)$$

$$E_{compression} \cong \frac{0.6366\ P}{\Delta V\, h}(\nu + 3) \qquad (2)$$

$$R_t = \frac{2P}{\pi\, dh} \qquad (3)$$

Where P= axial load; ΔV= vertical displacement ; h=length of specimen; ΔH= horizontal displacement; d= diameter of specimen; and ν= poisson ratio (taken equal to 0.35).

For deflexion tests, E_t is determined according to equation (4) and tensile stress from equation (5).

$$E_t = \frac{1}{f_{max}} \frac{P_f\, l^3}{16\ a^4} \qquad (4)$$

Where l = 106.3 mm, P_f=Failure axial load (daN); f_{max} =maximal deflection (mm), a= side of beam equal to 40mm.

$$R_t = 100 \times (0.25\ F) \qquad (5)$$

where F= axial load (daN); R_t (kPa) (NF. P18-406).

For compression tests, the moduli are measured as the slope of linear portion of the stress-strain curves at 0.2 %.

Table 2 indicates the moduli of deformation obtained from tensile Brazilian and the standard compression tests for different reinforced portion's fibres.

Table 2. Compressive modulus (E_c) from Brazilian and standard compression test.

Fibre content	Brazilian	Compression cylinder	and cubic specimen
%	Ec (MPa)	Ec (MPa)	Ec(MPa)
0.0	2.5	3	10
0.1	6.5	10	19
0.5	8.5	13	16

We note that for compression Modulus, the cubic compressive test gives the most modulus compression than cylinder specimen used compressive one. Brazililian tests under estimated this latter.

For brazilian test, we note on table 3 that the two moduli (E_t and E_c) are different. This test provides a tension modulus grater than deflection traction test (table 3). We think that this difference is noted because the tests are interpreted differently and because these properties are determined on different initial state of specimen. Infortunately, this variability is difficult to control.

Table 3. Tensile module for deflection test - Tensile (Et) and Compressive (Ec) moduli for Brazilian test.

Fibre content	Deflection test	Brazilian Test		
	Et	Et	Ec	Et/Ec
%	(MPa)	(MPa)	(MPa)	
0.0	1.6	0.5	2.5	0.2
0.1	1.2	2.0	6.5	0.3
0.5	1.9	2.5	8.5	0.3

Stimpson & chen (1993) found that a ratio of tensile to compressive modulus is (0.3 – 0.7) for halite, granite and limestone and attribute this ratio to bimodular behavior of rock material. In general, for clays of low tensile, the bimodularity behavior is observed. For inactive clay stabilized with Portland cement, the modulus in compression is greater 7.5 to 11 once than modulus in tension (Krishnayya et al. 1974). The same behavior is observed on reinforced clay soil with ratio of (0.2 – 0.3). This variability is also due to differences of water and dry density between specimens. However the results from the different fibres content and different initial water content and initial dry density are regarded as comparable and provide reasonable evidence for the nearly compressive stress. In fact figure 5 shows that the 0.1 % reinforced soil is more dense (w_o= 33.8 % and γ_d= 13.8 kN/m^3) than 0.3% reinforced soil (w_o=35.9 % and γ_d= 13.3 kN/m^3) and reachs more compression stress.

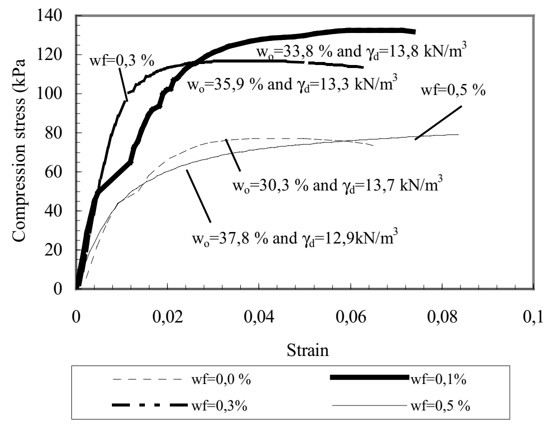


Figure 5. Compressive stress versus strain for different initial conditions.

The variability of initial state (w_o; γ_d) versus compressive modulus secant is illustrated by figures 6-a and 6-b. We note that compression modulus decrease with moist soils and increase with dense soil

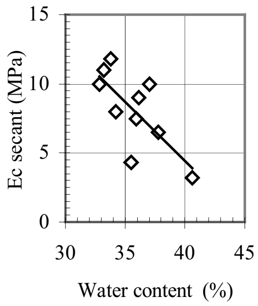


Figure 6a. Compressive stress versus water content

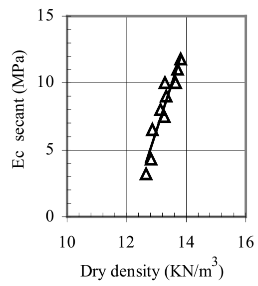


Figure 6b. Compressive stress versus dry density.

A comparison between compression and tensile stresses at failure state are indicated in tables 4.

Table 4a. Compression stress derived for standard compression test

Fibre content	Compression Stress (Cylinder)	Compression Stress (Cubic)
%	R_C (kPa)	R_C (kPa)
0.0	76	120
0.1	100	140
0.5	115	150

Table 4b. Tensile stress derived for the two tests : tensile Barzilian and deflexion test.

Fibre content	Brazilian test	Deflexion test
%	Rt (kPa)	Rt (kPa)
0.0	18	97
0.1	20	100
0.5	19	114

The brazilian test provides a tensile stress lower than the one determined for deflexion test.

3 APPLICATION TO LANDFILL WASTE

The development of the finite element method has made it possible to analyse the landfill structure. Such analysis can lead to evaluate the real contribution of fibers in reducing effects of tensile stresses when deformation is imposed to landfill structure by waste settlements. A numerical stress solution which considers the difference between compression and tensile moduli, is researched, when the waste layer is deformed in compression (settlements) (figure 7). The deflexion layer, is simulated with fixed gradient of modulus, which is increased progressively according to x. The results (figure 8) indicate that the bimodular, has a big influence in clay behavior.

In order to compare and to evaluate this effect, some results of tensile test (tensile brasilian test) and of compression test are used for interpretation of numerical stress solution. This interpretation is typically based on a several assumptions: isotropic linear elasticity of waste materials, bimodular elasticity of clay. Because of the difficulty in leading distinctly the comparison between calculation and laboratory experience results, ratios r_c and r_t are only used where r_c and r_t are respectively:

$$r_C = \frac{(\sigma_{xx})_c}{R_c} \quad \text{and} \quad r_t = \frac{(\sigma_{xx})_t}{R_t} \qquad (5)$$

$(\sigma_{xx})_c$, $(\sigma_{xx})_t$ are respectively calculated compression (negative) and tensile (positive) stress (the dimensions part of waste solid structure are = 5m*1m, the thickness of clay layer is equal to 0.4 m. R_c, R_t are respectively measured compression and tensile stress. Figures 8 shows that, for four sections S_1, S_2, S_3 and S_4, the $(r_t)_{wf=0.5\%}$ is greater than $(r_t)_{wf=0\%}$ in the majority of finite elements which are in traction. But, it'is not the case of compression where fibers contribution (for compression) is not significant.

Nevertheless, these results conduct to be careful in interpretation, to lead to some confusion. In fact, this tensile ratios are defined to considering a calculated elastic strain. Therefore this R_t value correspond to this after elastic phase.
Hence, the elastic-plastic approach will have to be investigated.

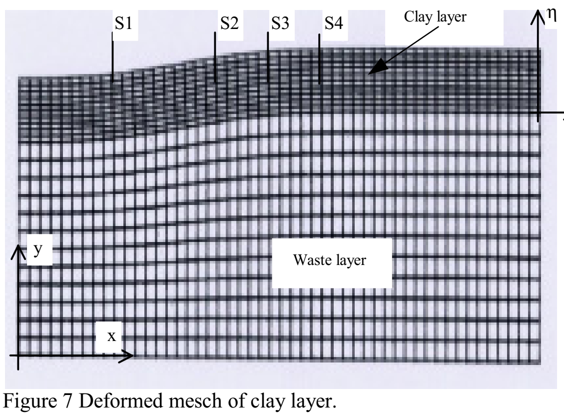


Figure 7 Deformed mesch of clay layer.

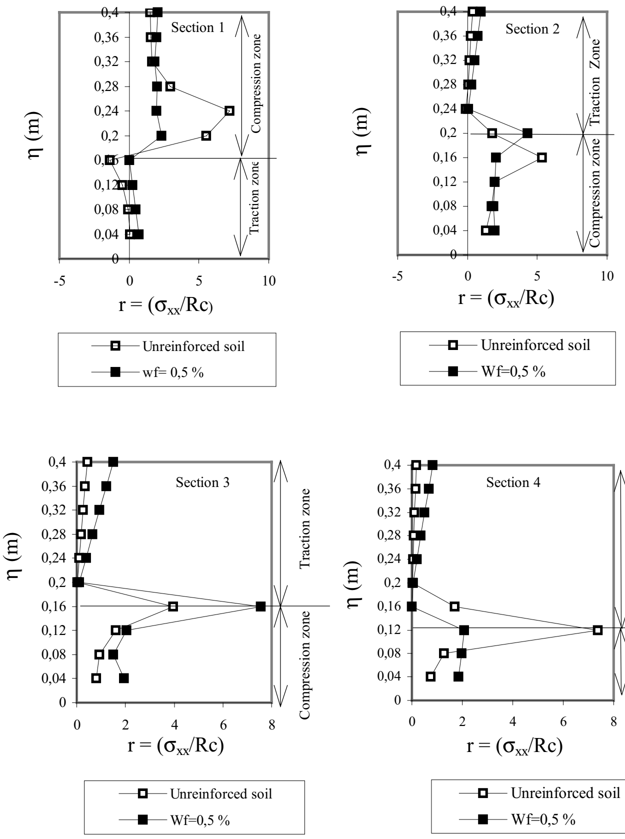


Figure 8. calculated and experimental stresses ratios for (S_1, S_2, S_3,S_4).

4 CONCLUSION

The variation of measured a modulus of deformation and tensile strength between and within varying test methods are found. Flexual tests were attempted using the same device of strength concrete samples with an appropriate range of forces (<5 KN). It is clear that the measurement of tensile strength is significantly dependent on the tensile testing method. It may be concluded that indicative values of the Brazilian test, may be derived from compressive strength using the relationship tensile strength = 0.2*compressive strength. These confirm well-known relationships that have been demonstrated by other authors (Stipson & chen 1993). The finite element calculation of real structure leads to more confirm the good effect of fibers on the tensile resistance than the experience results obtained from short specimens.

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