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THEME:

INFLUENCE OF THE INCLUSION OF A PERFORATED GEOTEXTILE ON THE SHEAR STRENGTH OF A DUNE SAND

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DEDICATION

To my grandfathers, may Allah have mercy on them, the two men whose wish was for me to reach this day, but fate chooses and the will of Allah is above everything.

To the heart that overflows with the purity of my grandmothers, may Allah prolong their lives.

To my dear father, who has always been by my side to support and encourage me. This work reflects my gratitude and affection.

To my dear mother, whatever I do or say, I will never be able to thank her as I should.

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To my family and loved ones who have given me love and strength and distinguished themselves for their loyalty and generosity, my uncles and aunts and their sons.

I would like to thank my partner "FETIMI SARAH" for her trust and understanding so that we can carry out this project. I wish her more brilliance and success.

Mamanou Rayan

DEDICATION

This dedicates to my grandfather, my Allah has mercy on him to those who supported me my grandfather and grandmother they are a gift from Allah for me.

I give my best dedicate to father for always pushing me To try my best ,and guiding me towards the right path of life.

To my mother, for everything, and I hope one day to be at least half of her character ,she is always the first person, who has supported me and does not skimp on me with her advice,

To my sister and my brothers I wish them success in their studies.

To my aunts and my uncles for help me, I just want to tell you that I appreciate all the hard work you have put in,

To my best friend MAMANOU Rayan,she has all my respect and admiration.

To my teachers wonderful blessings and to all my friends for all that you have given me.

Fetimi Sara

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MAIN RATINGS

Latin letters

GTX: Geotextile

DS: Dune sand

UU: Unconsolidated Undrained test

CU: Consolidated Undrained test

CD: Consolidated Drained shear test

Greek letters

C: cohesion (kPa)

φ: Angle of internal friction of the soil (˚)

σ: Volumetric pressure (kPa)

GENERAL INTRODUCTION

Geosynthetic products are occupying an increasingly interesting position in the world of geotechnics. This is because of the beneficial contribution of such materials with regard to the quality of the soil. Indeed, the constructive provisions are evaluated according to their effectiveness and their costs.

One of the most abundant natural materials in Algeria, especially in the south of the country. The abundance and low price of these materials made geotechnicians and civil engineering partners consider their use. Dune sand is considered an important component in many different fields, such as arts, painting, glass making, as backfill materials, drain, filters, and even in the field of agronomy.

Although sand dune sand is integrated in many fields, it has some physical and mechanical defects that prevent its rational use. In this respect, are namely distinguished the aggressiveness against the ordinary concrete, the lack of compactness and zero cohesion.

The present study aims to contribute to the correction of the physical and mechanical characteristics of this material. The addition of another material is allowed in order to improve the mechanical quality and suitability of dune sand for engineering purposes. This will result in obtaining a new composite material. It can be used in civil engineering, geotechnical, agronomy.... The intrinsic defects of dune sand could, thus, be reduced till to make it acceptable for various uses.

The added material is a perforated geotextile, which is included in the dune sand. Geosynthetics (including geotextiles) have in fact proven their added value on the mechanical stability of various achieved structures.

Methods for correcting the mechanical and physical properties of dune sand, the most important of which are cohesion and friction angle. The triaxisltesting is one of the ways to reach the appropriate goal. This test is carried out on dune sandalone without any addition. Then the same test is repeated, but by forming a composite of one or several layers of geotextile between the layers of dune sand. The worst type of geotextile material is deliberately used, due to its low price.Each time the appearance of this material is changed, by placing holes either square or circular in shape with the aim of economy, and the shape of these holes is also changed in terms of size and diameter as well as in terms of spacing between these holes until reaching acceptable results.

This test can also be done in order to obtain other properties such as hydration ratio and volumetric mass....

The present memory is structured in five mean chapters. The first chapter is a pedagogical subject aimed at popularizing the concepts related to the triaxial test.

In the second chapter, the elementary materials are characterized according to sufficient physical and mechanical information. Also, the composite material is defined.

Chapter 3 includes the results of the tests carried out (presentation, explanation and interpretation). Some test details are transferred and displayed in the appendix.

A bill of quantities and estimate for an example of a linear structure is presented in chapter 4. The comparative analysis between usual materials and innovative materials highlights a good deal of interesting information.

Finally, Chapter 5 is devoted to reminders of the relevant results of the study carried out. It is a conclusion extended to recommendations and perspectives of the subject discussed.

Chapter 1/ OVERVIEW OF THE TRIAXIAL TEST

1.1. INTRODUCTION

The present study concerns, in particular, the handling of the triaxial test. Hence, this chapter is achieved with a view to sufficiently presenting this test. The latter is reputed to be the most analytical and informative of all soil mechanics tests. Indeed, the test in question makes it possible to measure a number of mechanical parameters of the soil such as the angle of internal friction, cohesion, hydraulic conductivity, resistance to compression, compressibility and distortion.

In principle, this test is feasible on natural soils (intact or reconstituted), but for research purpose, it is applied to the DS/GTX compound. The test procedure remains, obviously, the same as the standard.

1.2. PRINCIPLE OF THE TEST

The triaxial test is based on two main steps. The first step consists of preparing a cylindrical specimen of soil, covered with a flexible and impermeable membrane. An arbitrary volumetric pressure (σ_3) is applied, by means of water, to the soil specimen (lateral surface and the two base surfaces).

After a certain duration of applying σ_3, depending on the test protocol, comes a second step of the test. This consists of application of additional stress to the specimen along the vertical axis. The application of this stress continues until it causes specimen shear failure. At precisely the beginning of the failure, the stress value is recorded as (σ_1).

1.3. VARIOUS TYPES OF TESTS

1.3.1. Unconsolidated Undrained test

The Unconsolidated Undrained test is abbreviated as (UU). It is a rapid shear test adapted to fairly common situations encountered in situ.

- **Step 01:** The volumetric pressure (σ_3) is applied to the saturated soil sample from all sides (the two bases and lateral surface). The pressure is applied quickly.This does not allow the sample to be completely drained. The water pressure does not drop to zero (u > 0), This prevents the load σ_3 from moving into the solid skeleton of the soil, resulting in the soil sample not being consolidated.

- **Step 02:**An additional axial stress ($\Delta\sigma$) is applied to the soil specimen. In this case the specimen is not allowed to be drained, and the pore water pressure does not drop to zero (u>0). The axial stress is continuously increased until the specimen fails. This will be the greatest stress the soil sample will have supported. That is, the weakest stress that caused the rupture of the soil specimen. This stress ($\sigma_1=\sigma_3+\Delta\sigma$) is referred as the major principal stress. ($\Delta\sigma= \sigma_1-\sigma_3$) is named deviatoric stress.

1.3.2. Consolidated Undrained test

The Consolidated Undrained test is referred to as (CU). It is a fairly quick test, which follows the following two stages.

- **Step 01:** The volumetric pressure (σ_3) is applied to the saturated soil sample from all sides (the two bases and lateral surface). Provide sufficient time for the soil sample to drain completely. That is until the water pressure drops to zero (u = 0) and the load (σ_3), applied to the soil specimen, moves to the solid skeleton of the soil. Some water is drained, so the soil sample volume is reduced, and this allows the sample to consolidate.
- **Step 02:**The second stage of the test consists of increasing the axial stress according to a speed such that drainage is not possible. The increase in the axial stress, without allowing drainage, leads to an increase in the pore pressure until the rupture of the soil sample is reached. The value ($\sigma_1=\sigma_3+\Delta\sigma$) is recorded.

1.3.3. Consolidated Drained test

The Consolidated Drained shear test is commonly referred to by the abbreviation (CD). It is a long test following its two stages of feasibility. It represents the long-term shear strength characteristics of the soil.

- **Step 01:** A volumetric pressure (σ_3) is applied, as in the case of the UU and CU tests. Drainage of the soil sample (initially and always saturated) is allowed. Drainage continues until the pore pressure is eliminated. All the stress (σ_3) applied to the soil specimen is, therefore, transmitted to the solid skeleton ($\sigma=\sigma'$ and u=0): this is the consolidation. The load transmitted to the solid skeleton of the soil induces its compression. In soil mechanics, this is called settlement.
- **Step 02:** As for the previous test procedures, the second step of the triaxial test consists of applying the additional stress $\Delta\sigma$. This process is applied slowly so as not to induce pore pressure. Drainage occurs continuously while increasing (σ_1). The pore pressure is

always maintained at zero value (u = 0).The loading process is continued until the soil specimen failure is obtained.

1.4. TYPICAL PRESENTATIONS OF TEST RESULTS

The results of the tests carried out according to the triaxial shear are often presented in a graphic format called "Mohr's circles".

Mohr circle is representative of the stress states (σ, τ) applied at a point in the soil medium. Same as for the Coulomb failure curve, a Mohr circle can be represented on the orthonormal plane (σ, τ). In terms of representation of stress states (σ and τ), this coordinate system is called 'Mohr-coulomb plane'. The Coulomb curve (equation $\tau = c + \sigma . tg(\varphi)$) is recognized as tangent to the various Mohr circles of stresses respective of the tests carried out.

A Mohr circle, representative of a triaxial test (figure 1.1), is diametrically bounded on the σ axis by the two values:

- **Minor principal stress**, corresponding to the volumetric stress σ_3.
- **Major principal stress**, corresponding to the axial stress σ_1 at rupture of the tested specimen of soil.

The Mohr circles retained for a graphical representation of the stress states are those best suited to the same tangent. Each triaxial test is considered to be properly carried out (e.g. average of, at least, three similar tests).

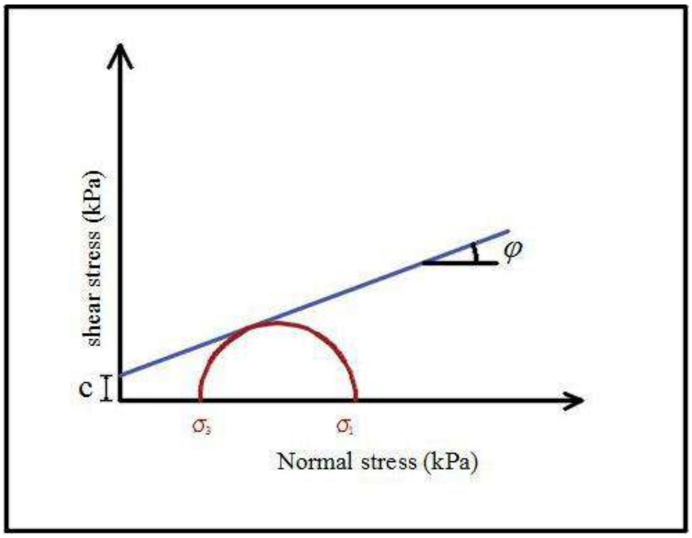


Figure 1.1: Representation of a Mohr stress circle.

The values of the major principal stress (σ_1) are that corresponding to the value of the stress σ_1 at the beginning of the rupture by crushing. It is the maximum compressive strength (σ_1) that the soil can develop while being confined under (σ_3). σ_1 is the sum of the volumetric stress (σ_3) and the deviatoric stress ($\Delta\sigma$): σ_1=σ_3+$\Delta\sigma$.

Figure 1.2 shows the variation of the stress σ_1 developed in the tested sample as a function of its deformation ($\Delta H\ or\ \varepsilon = \Delta H/H_0$), for certain value of σ_3. The maximum stress is retained as being the principal major one reported on the Mohr's circle.

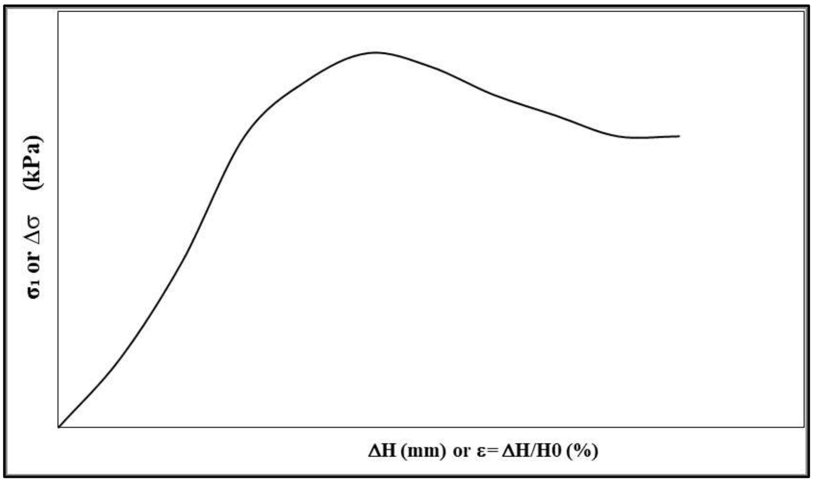


Figure 1.2: Typical Δσ versus Δ*H* relationship.

After several tests carried out (respectively) on several soil samples, at various confinement stresses (σ_3), the curves $\Delta\sigma$=f(ε) and the corresponding Mohr circles are drawn (figures 1.3 and 1.4). The Coulomb curve is, therefore, easily established: it is the tangent to the drawn Mohr circles. The Coulomb curve (failure line) makes it possible to deduce:

- the y-intercept: cohesion (C)
- the slope: angle of internal friction of the soil (φ).

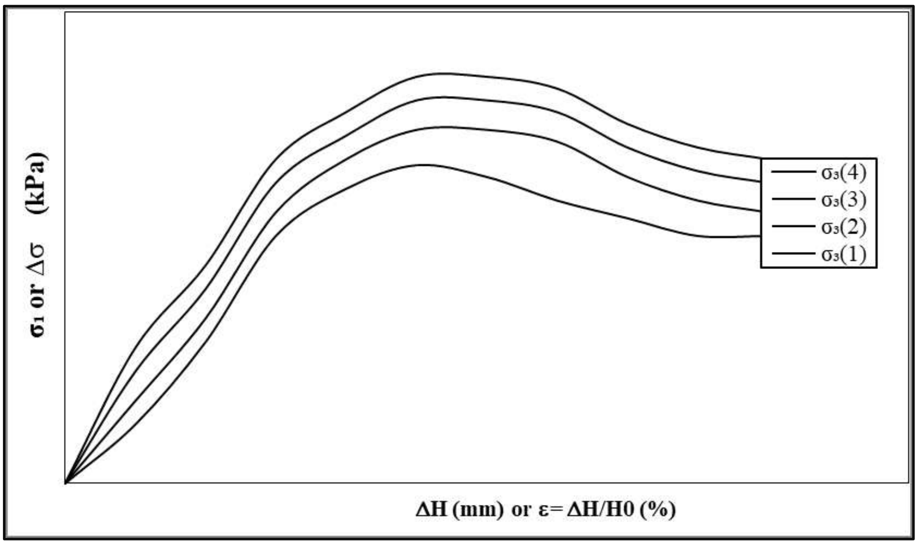


Figure 1.3: Stress-strain representation according to various values of σ_3.

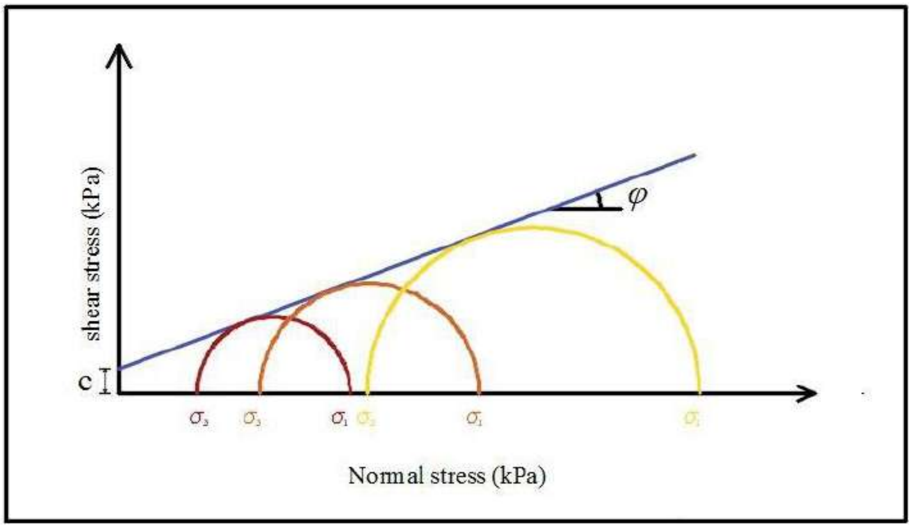


Figure 1.4: Representation of stress states on the Mohr-Coulomb plane.

1.5. CONCLUSION

The triaxial test is renowned for being a powerful experimental tool in the field of soil mechanics. It is a device, indeed, a little complex, but in return, it makes it possible to test the soils in largely analytical ways. The design and handling of this experimentation tool has gone from a mechanical and manual level to a completely sophisticated mode: programmable, computer-assisted and controlled via the Internet.

The device in question is adaptable to measure several parameters of soil: angle of friction (φ), cohesion (C), Young's modulus (E), Poison coefficient (ν), hydraulic conductivity (k), compressive strength (R_C), ...

The test can simulate a variety of conditions, making it relatively representative of site conditions. Similarly, it is achievable on a wide range of materials, whether natural, composite, and/or synthetic. The samples tested are all cylindrical in shape, but many physical characteristics can be varied: dimensions, water content, grain size, level of reconstitution, ...

Chapter 2/ EXPERIMENTATION OF THE USED MATERIALS

2.1. INTRODUCTION

In this chapter, the materials to be experimented are presented. Indeed, the physical and mechanical characteristics of these must be known as precisely as possible. The results of the experiments will surely depend on these characteristics.

The two materials, considered to be elementary, are dune sand (DS) and a geotextile (GTX). The compound of these two materials will be referred to as DS/GTX. Tiaxial tests are carried out within the framework of this chapter according to the standard protocol. The mode of coupling of the two elementary materials is varied for each test. The objective is a convergence towards an optimal arrangement of the composite material.

2.2. PRESENTATION OF THE ELEMENTARY MATERIALS

2.2.1. Dune Sand

The dune sand of Ouargla region is chosen to be object of the planned tests. The latter is particularly chosen regarding its proximity and unpolluted natural state. The summary physical parameters sufficient to characterize the sandy material are designated in Table 2.1.

Table 2.1: Mean Physio-chemical and mechanical characteristics of the used sand [1]

<table>
<tr><th colspan="6">Physical and mechanical characteristics</th></tr>
<tr><th colspan="3">Volumic mass (g/cm^3)</th><th>Sand equivalent (%)</th><th colspan="2">Angle of friction (°)</th></tr>
<tr><td>Loosest state</td><td>Densest state</td><td>Natural state</td><td>E_S</td><td colspan="2">φ</td></tr>
<tr><td>1.25</td><td>1.75</td><td>1.63</td><td>79.17</td><td colspan="2">28.44</td></tr>
<tr><th colspan="6">Percent chemical composition (%)</th></tr>
<tr><th>Insoluble</th><th>$CaSO_4$ $2H_2O$</th><th>SO_3</th><th>NaCl</th><th>$CaCO_3$</th><th>Cl^-</th></tr>
<tr><td>95.99</td><td>2.63</td><td>0.49</td><td>0.046</td><td>1.5</td><td>0.028</td></tr>
</table>

- SO_3: Sulfates
- $CaSO_4,2H_2O$: calcium sulfate hydrate
- Cl^-: Chlore
- NaCl: Sodium chloride
- $CaCO_3$: Carbona

2.2.2. The Geotextile

A Low quality geotextile GTX is chosen to constitute the compound material. The low quality of the chosen GTX concerns the physical characteristics of the material, which translates into low mechanical parameters. This choice is made on purpose to highlight the economic interest of the compound. A better GTX may be considered if the performance of the compound obtained is below the acceptable threshold.

The characteristics of the GTX are chosen directly from the manufacturer. They are listed on the technical data sheet of the product. The material means available at the university departments do not make it possible to verify the authenticity of the values transcribed by the producer. Table 2.2 shows the mean characteristics of the chosen GTX. The latest is designed as (AS10).

Table 2.2: Characteristics of the chosen GTX (AS10) [1]

Designation		**Standards**	**Units**	**Value**
Physical characteristics				
Surface mass		EN ISO 9864	g/m^2	100
Thickness under 2kPa		EN ISO 9863-1	mm	0.5
Mechanical characteristics				
Tensile strength	PD*	EN ISO 10319	kN/m	6
	TD*			7
Puncture resistance CBR		EN ISO 12236	kN	1.00
Pyramidal puncture resistance		EN 14574	kN	0.70
Strain at maximum tensile stress	PD*	EN ISO 10319	%	70
	TD*			90
Dynamic perforation		EN ISO 13433	mm	30
Hydraulic characteristics				
Permeability normal to the plane		EN ISO 11058	m/sec	0.080
Filter opening		EN ISO 12956	μm	90

PD*: Production Direction, **TD*:** Transverse Direction

- **Surface mass:** The Surface mass of a geotextile product (GTX) is the ratio of its mass per unit area. It is generally expressed in (g/m^2). The European standard in force applicable to the purpose of measuring the surface mass of a GTX is EN ISO 9864.
- **Thickness under 2kPa:** The thickness of a GTX sample is the distance between the top face and the underside face. The measurement is often realized under a confining pressure of (20 ± 0.1) kPa. The thickness is referred to a pressure of containment of (2 ± 0.01) kPa. A force of (0.6 ± 0.1) N, for example, can be applied to a circular plate (9.77 mm in diameter), resting on the GTX liner. The thickness of the latter is deduced through the difference in thicknesses before and after inclusion of the GTX.
- **Tensile strength:** Tensile strength test is applicable to most GSY products, in particular GTX. As in the case of steels, the GTX is stretched until it reaches its rupture. The maximum tension force recorded and the corresponding deformation are then noted.
- **Dynamic perforation:** The dynamic perforation test is generally applicable to all geosynthetics. This test is performed with a conical punch falling from a height of 50cm onto the geotextile held between jaws. The diameter of the drilled hole is noted (mm). The larger the resulting hole, the less resistant the GTX is to penetration. The penetration mark of the perforator cone is representative of the reaction of the GTX to mechanical aggressions such as those of direct contact with angular stones.
- **Puncture resistance:** The static punching test (also called CBR test) is, similar to that applied to floors. It consists of pressing a piston, with a flat base, on the GTX material under test. Static puncture resistance is expressed as Newton (N).The parameters obtained from the test are used to characterize the puncture resistance of the material.
- **Pyramidal puncture resistance:** The pyramidal indentation test (PYR) consists of the driving of a pyramid-shaped piston on the GTX material. The obtained results are often used in the characterization of the puncture resistance of the material.
- **Permeability normal to the plane:** The permeability test normal to the plane is similar to that of Darcy practiced on soils. The permeability coefficient is denoted (k_n). It can be measured according to the method known as:
  - constant head permeability when the material is largely permeable
  - falling head permeability when the material is very slightly permeable.

- **Filter opening:** The filtration opening (O_f) is assimilated to the dimension of the largest particle likely to cross the filter. It can be evaluated either by a theoretical approach or by an experimental determination.

2.3. PRESENTATION OF THE COMPOSITE MATERIAL

Dune sand is reputed to have fairly good mechanical characteristics. Nevertheless, its intrinsic defects are unavoidable: unsuitable for compaction and non-cohesive. In a first series of tests, only the sand is examined According to the triaxial test procedure.This makes it possible to recognize the shear resistance characteristics (c and φ) of the sand, although the cohesion is already recognized as zero. Then, other series of tests are carried out by having introduced GTX strips into the sand matrix. The parameter targeted in this analysis is the perforation format of the GTX, in particular the diameter of the perforations of the GTX and the spacing between them.

In the present study, the two materials can be associated in various ways. The resulting compound can be abbreviated as (DS/GTX). The behavior of the latter is, in fact, a function of the physical and mechanical characteristics of the two elementary components.

The test being triaxial, the rupture is recognized to appear in the central part of the soil sample. The rupture plane forms the angle ($\pi/4 + \varphi/2$) with the horizontal. Therefore, the GTX liner will be placed halfway up the tested sample. The installation of the GTX is carried out with care, so as to avoid creasing of the latter or cavities at the (DS/GTX) interface. The test is then carried out in the usual way, hence the deduction of the shear resistance characteristics (C and φ).

Once a first test has been carried out, the location of the GTX can be varied while intersecting the central zone of the sample tested. The figure 2.1 shows the area where the GTX should be introduced. The series of tests can, actually, be resumed by introducing more than one GTX layer. The placement of the GTXs, whatever their number, is landmarked at mid-height of the sample under test.

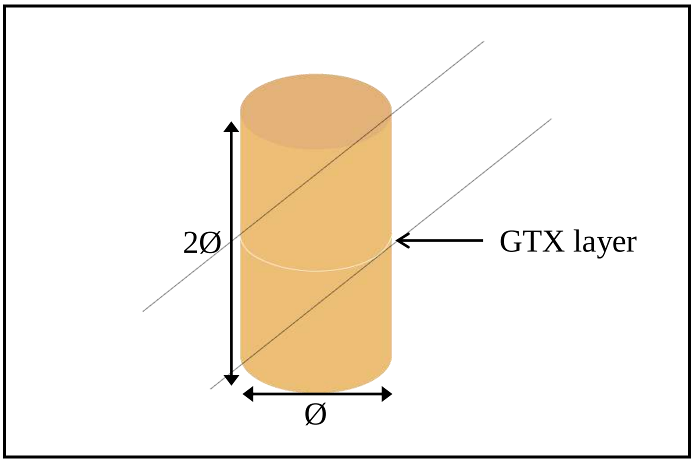
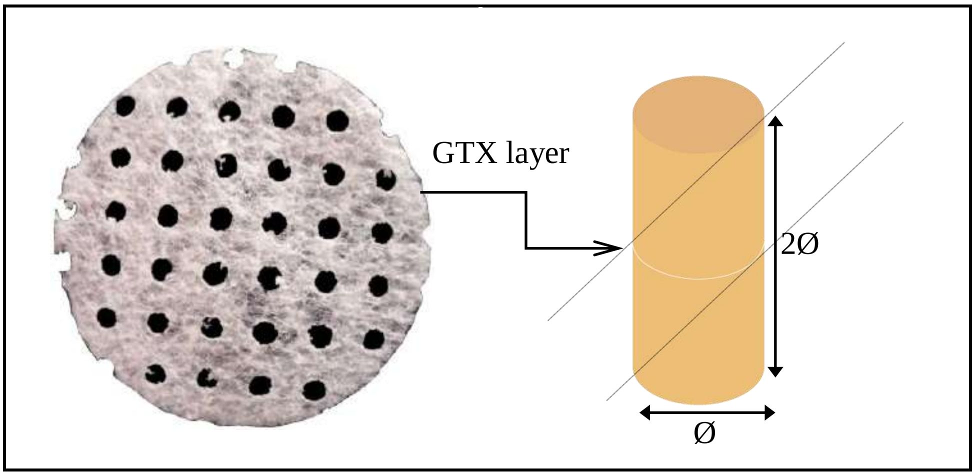


Figure 2.1: Location of the GTX and direction of the rupture plane

Increasing the number of GTX layers is expected to increase the soil strength (in terms of C and φ), but the economics of the compound becomes a disadvantage. An optimal configuration is, therefore, sought so as to satisfy the two conditions: technical and economic.

In order to ensure sufficient crosslink of the (DS/GTX) compound, the same tests can also be performed on sand samples, but by using the geotextile in another form.

That is, the layer of the GTX material is perforated according to a rectangular matrix for which the opening of the pores is made varied, as well as the spacing $\Delta_x = \Delta_y$. The figure 2.2 shows the structure of the established pores, as well as the imprint of the GTX layers to be cut.



The figure 2.2: Example of perforated GTX introduced into the soil specimen

As these holes allow the sand grains to become entangled with the GTX layer and intertwine with each other, the (DS/GTX) friction is expected to grow considerably. If the sand and the GTX are intertwined relatively well. This will give the sand some 'tensile strength'. The latter is, in fact, the resistance of the GTX imprinted with the sand matrix.

Further tests can be carried out on sand and geotextile in various other forms. However, since the time is not enough to conduct all possible tests, only the parameters 'location' and 'format' of the GXT are tested.

2.4. PRESENTATION OF THE TRIAXIAL TESTING PROCEDURE

The triaxial tests are usually performed on saturated soil specimens.-This condition is taken into account in order to simulate the worst case of resistance. For the case of the present study, the tested soil samples are administered in the dry state. This condition is thus considered in order to simulate the real operating conditions of the compound. Almost no water, so no water pressure. The likely test conditions are thus of the CD type.

Stresses applied to soil samples are fully supported by the solid skeleton ($\sigma_1 = \acute{\sigma}_1$and $\sigma_3 = \acute{\sigma}_3$).

The soil samples are prepared in various ways and placed in cells according to the usual procedure. Some of them consist of sand alone without any additives, and some are prepared from a compound of sand and geotextile materials. The mass of the placed soil can be deduced through the difference in the weights of the triaxial cell (before and after filling), which enables the extraction of many physical properties of the soil such as porosity, volumetric weight and the voids ratio.

2.5. CONCLUSION

In this chapter, some mean properties of the dune sand and the (AS10) geotextile are presented. Also, the compound material (DS/GTX) is made explicit. The parameters taken into account as variables in this study are in particular the location of the GTX in relation to the tested sample and the mode of perforation of the geotextile. Neither the time nor the technical means make it possible to investigate many other parameters: water content, density, other forms of perforation, number of GTX lengths, ...

All these parameters are supposed to significantly affect the shear resistance of the composite. There is also the possibility of changing the dimensions of the cylindrical sample in terms of diameter, height or even the shape, and see the influence on the final results.

Finally, the type of GTX used can also be modified in order to assess its impact on the behavior of the compound under shear. The conclusions deduced from the obtained results are associated with the investigated soil. The entire experimental protocol can be taken over another type of soil.

Chapter 3/ RESULTS AND DISCUSSION

3.1. INTRODUCTION

The implementation of any project in the fields of civil engineering and public works requires a sufficient geotechnical description. This chapter presents the results of various tests performed on the materials used in this study. The materials tested are those mentioned in Section 2.2 of chapter 2. This chapter also provides an analysis and interpretation of the results obtained according to the scientific opinion of the authors of the memory.

3.2. PRESENTATION OF THE RESULTS

The results obtained from the carried out tests are grouped in this section. Figure 3.1 relates to the sand test without addition of geotextile. Figures 3.2 through 3.13 are those relating to a single layer of GTX placed at the middle of the tested sandy samples. The geotextile material The GTX included in the sand specimens is perforated with holes (ϕ 2mm), regularly spaced by a distance respectively equal to 5mm, 7mm, 9mm and 11mm.

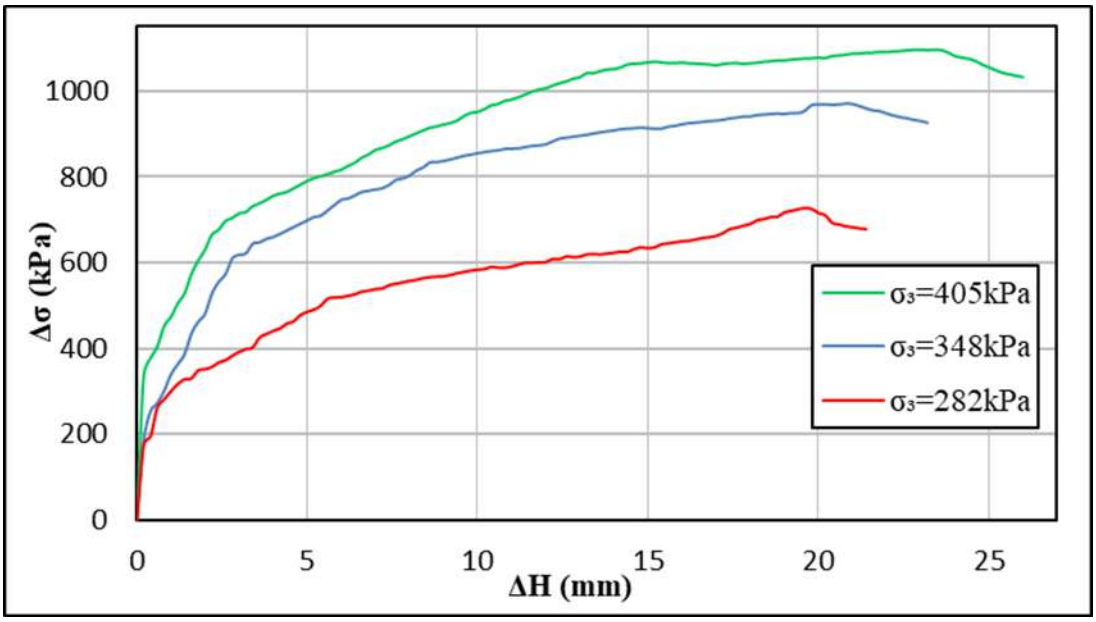


Figure 3.1: Deviator stress versus deformation (sand alone)

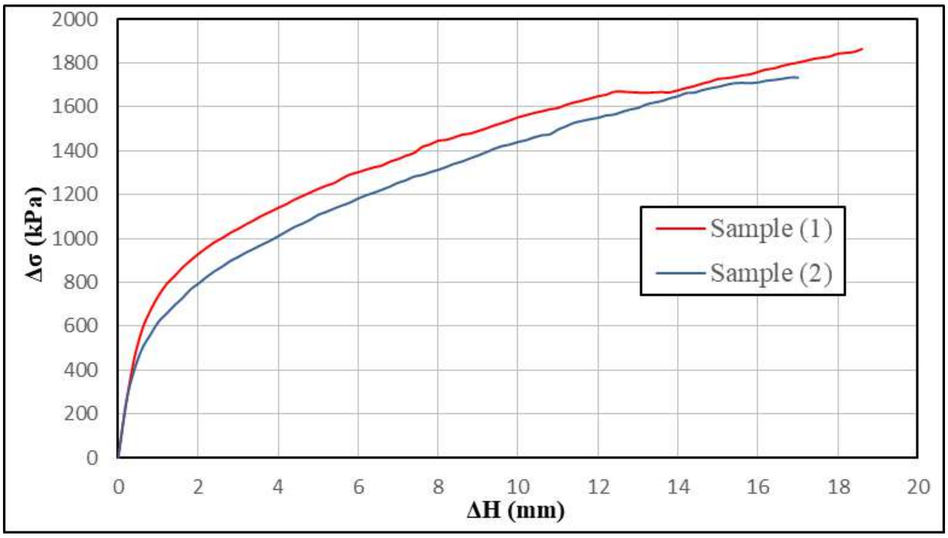


Figure 3.2: DS/GTX (Ø 2 / 5mm); σ_3=350 kPa

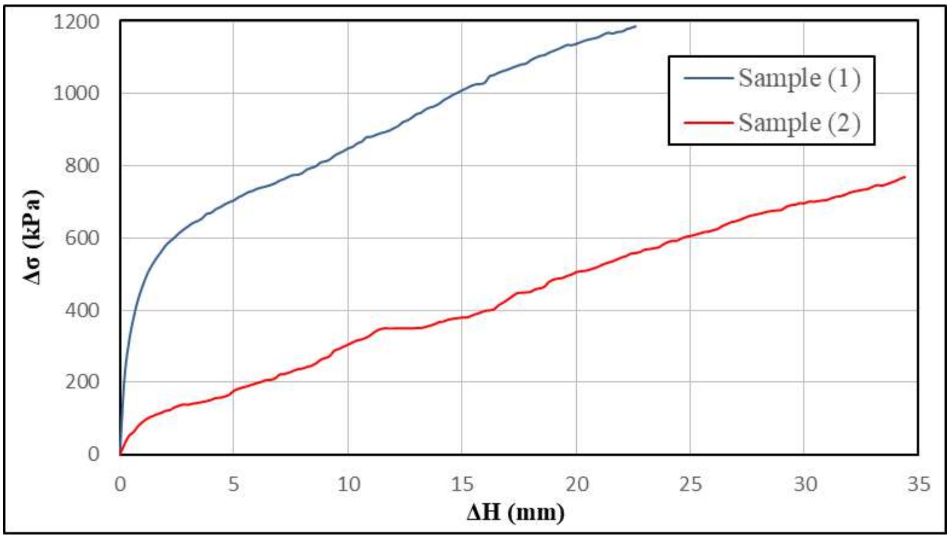


Figure 3.3: DS/GTX (Ø 2 / 5 mm); σ_3=400 kPa

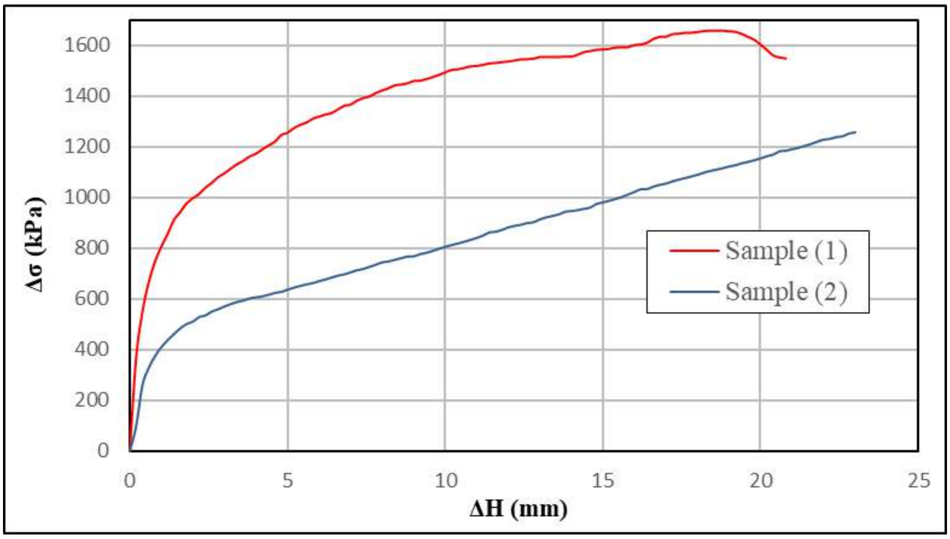


Figure 3.4: DS/GTX (Ø 2 / 5 mm); σ_3=510 kPa

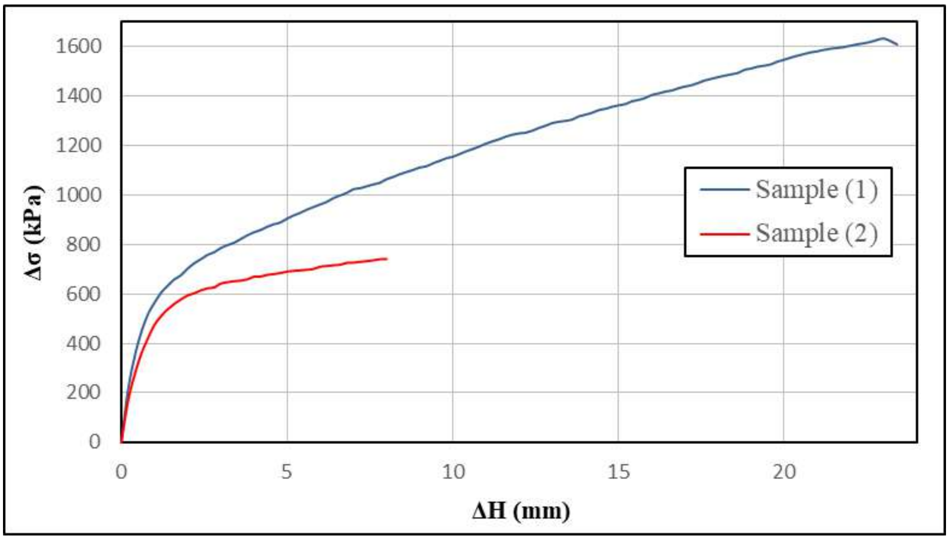


Figure 3.5: DS/GTX (Ø 2 / 7 mm); σ_3=400 kPa

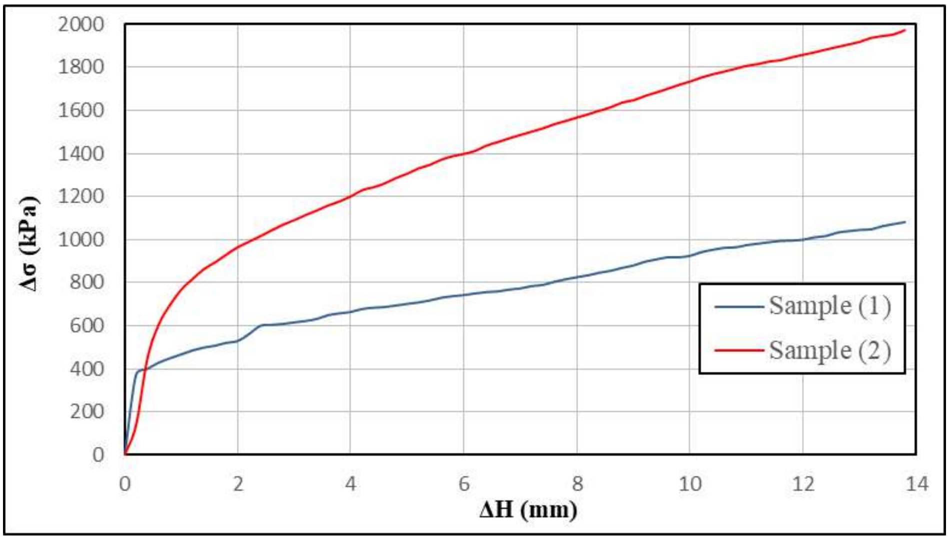


Figure 3.6: DS/GTX (Ø 2 / 7mm); σ_3=570 kPa

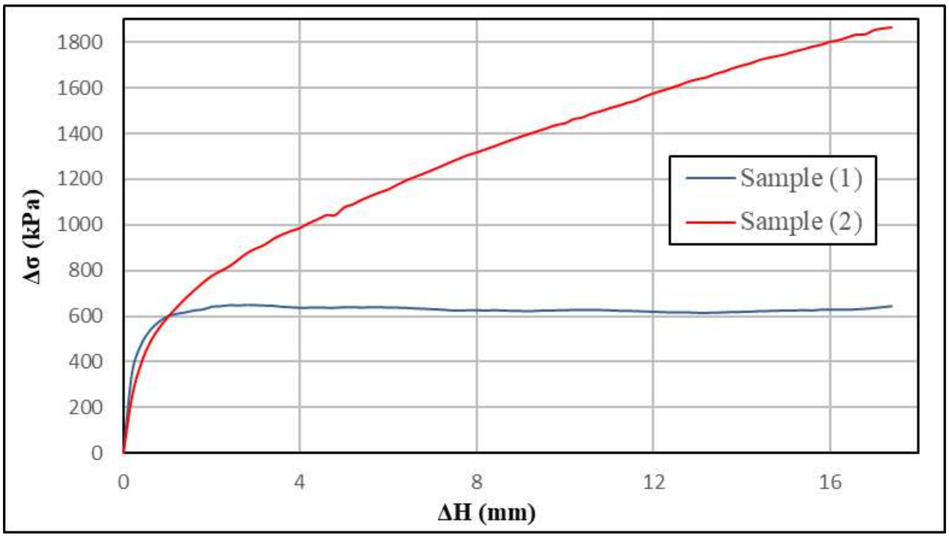


Figure 3.7: DS/GTX (Ø 2 / 7 mm); σ_3=600 kPa

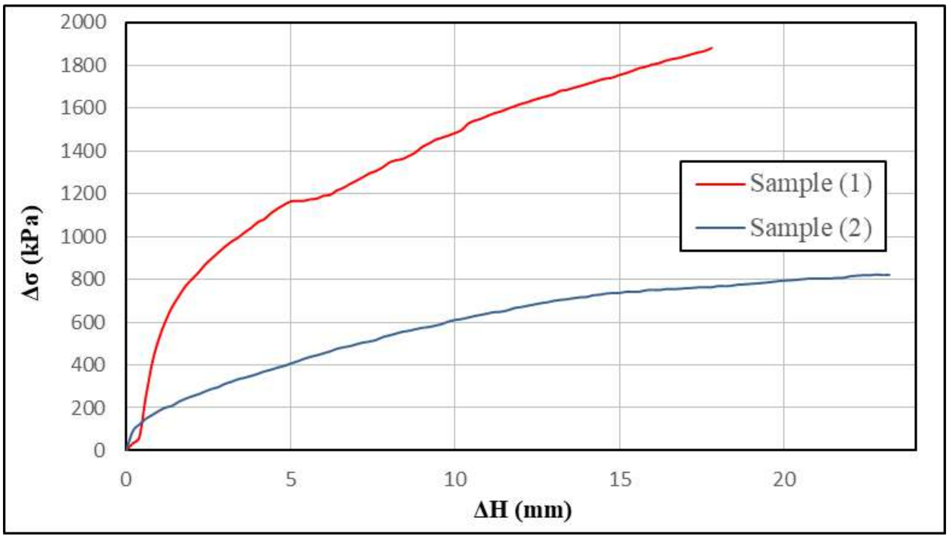


Figure 3.8: DS/GTX (Ø 2 / 9 mm); σ_3=300 kPa

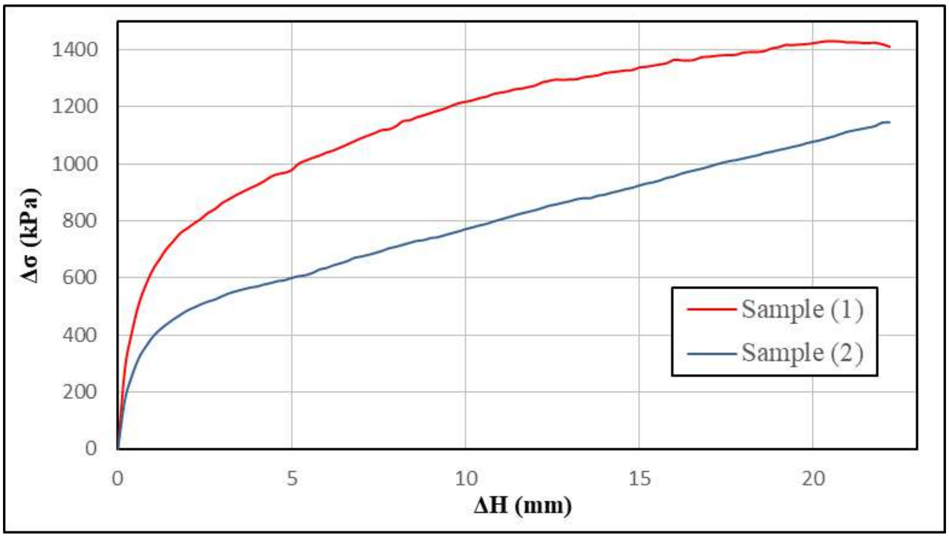


Figure 3.9: DS/GTX (Ø 2 / 9 mm); σ_3=400 kPa

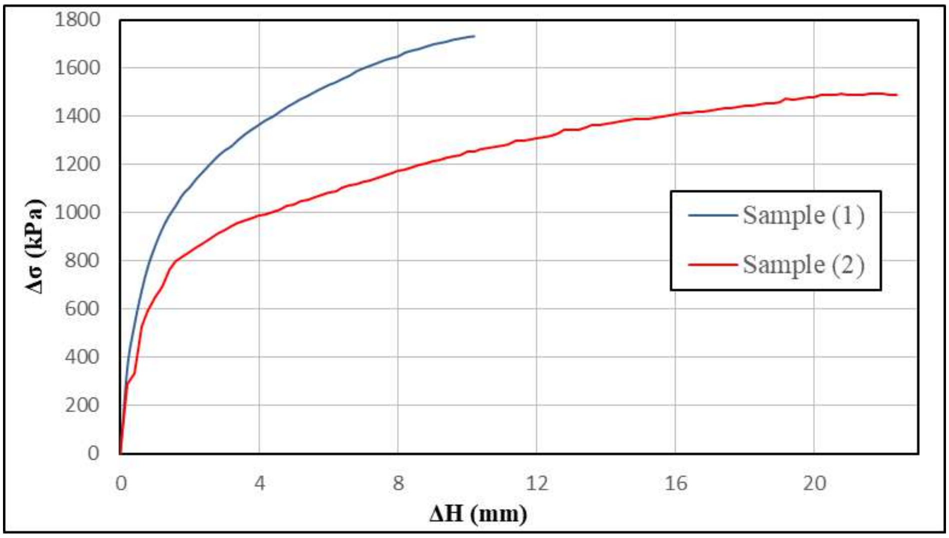


Figure 3.10: DS/GTX (Ø 2 / 9 mm); σ_3=490 kPa

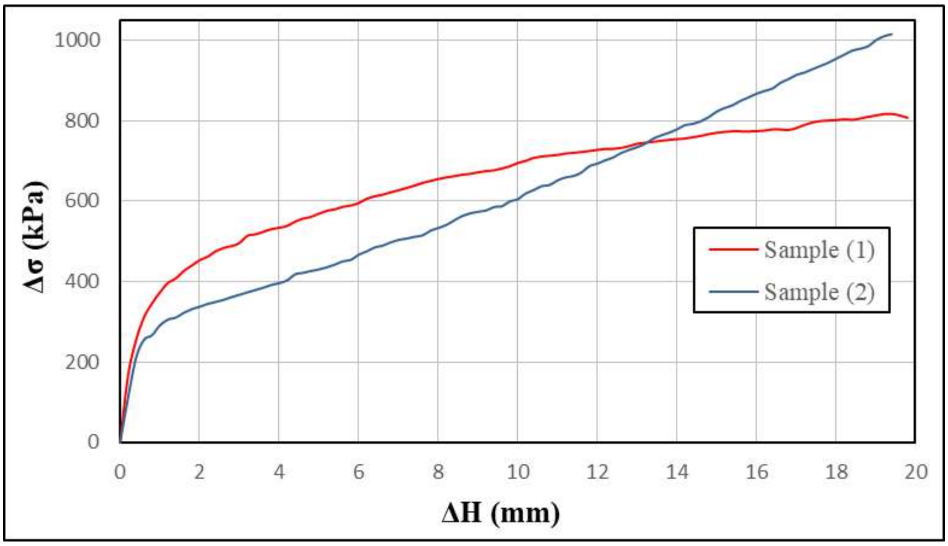


Figure 3.11: DS/GTX (Ø 2 / 11 mm); σ_3=300 kPa

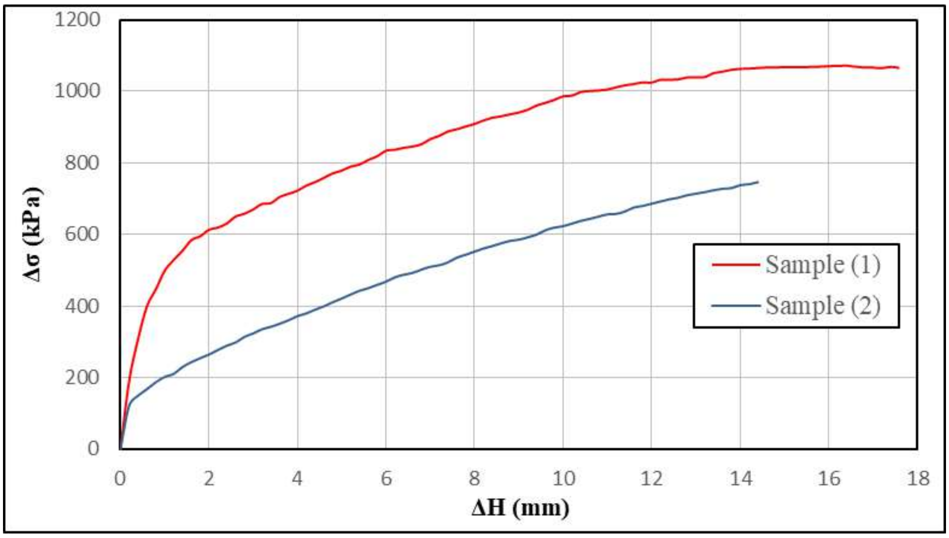


Figure 3.12: DS/GTX (Ø 2 / 11 mm); σ_3=380 kPa

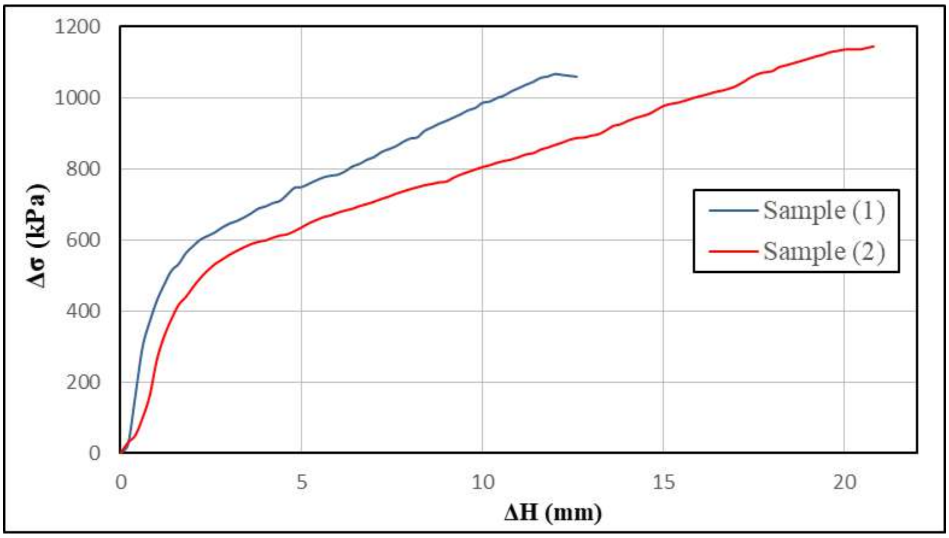


Figure 3.13: DS/GTX (Ø 2 / 11 mm); σ_3=450 kPa

The maximum values of axial pressure of each sample are deduced using the relationship ($\sigma_1 = \sigma_3 + \Delta\sigma$). $\sigma_1$is called major principal stress. It is the maximum compressive stress that the specimen can withstand when subjected to a confining pressure σ_3. Table 3.1 summarizes the σ_3 and σ_1 stresses recorded on the tests performed on the sand alone.

For the DS/GTX specimens, the minors and majors principle stresses are summarized on table 3.2.

Table 3.1: Minor and major principle stresses (sand alone)

Specimens	(1)	(2)	(3)
σ_3 (kPa)	282	348	405
σ_1 (kPa)	999.02	1315.34	1499.8

Table 3.2: Minor and major principle stresses (DS/GTX)

		Sample (1)	Sample (2)
Spacing (mm)	σ_3(kPa)	σ_1(kPa)	σ_1(kPa)
5	350	1587.21	1169.4
	400	2167.39	1766.49
	510	2213.97	2083.61
7	400	1141.54	2034.08
	570	2464.54	1248.26
	600	1651.74	2543.10
9	300	1830.5	1546.15
	400	2181.5	1121.33
	490	1981.21	2223.41
11	300	1123.10	1116.41
	380	1126.17	1451.71
	450	1516	1585.5

After recording of the σ_3 and σ_1 values, the mechanical parameters C and φ are deduced by drawing the Mohr's circles (figures 3.14 to 3.18).

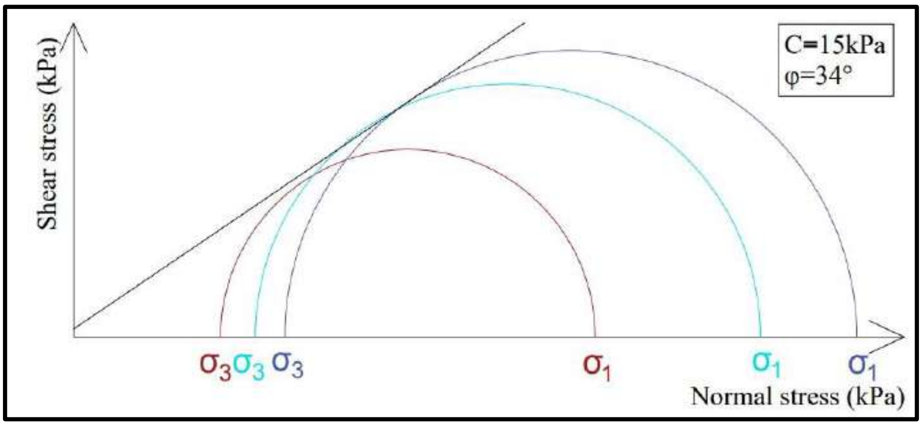


Figure 3.14: Mohr's circles and failure line (sand alone)

For the DS/GTX tests, the Mohr's circles to extracted the values of C and φ are presented in figure 3.14

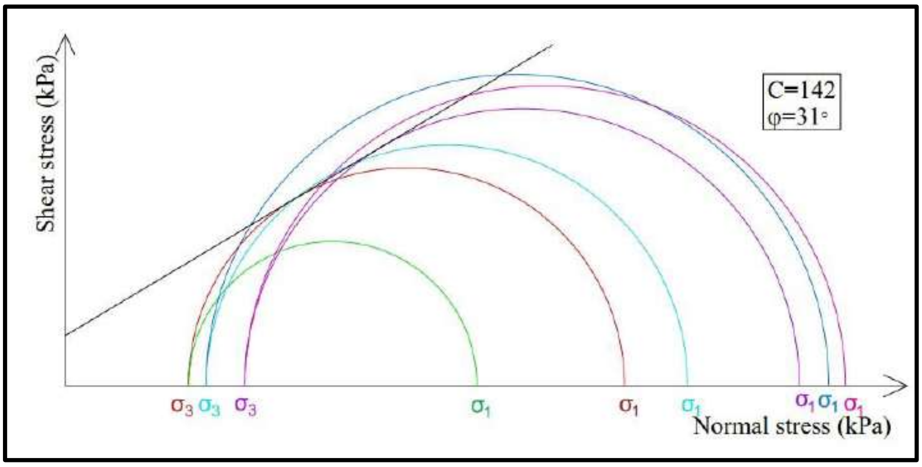


Figure 3.15: Mohr's circles and failure line (DS/GTX – S=5mm)

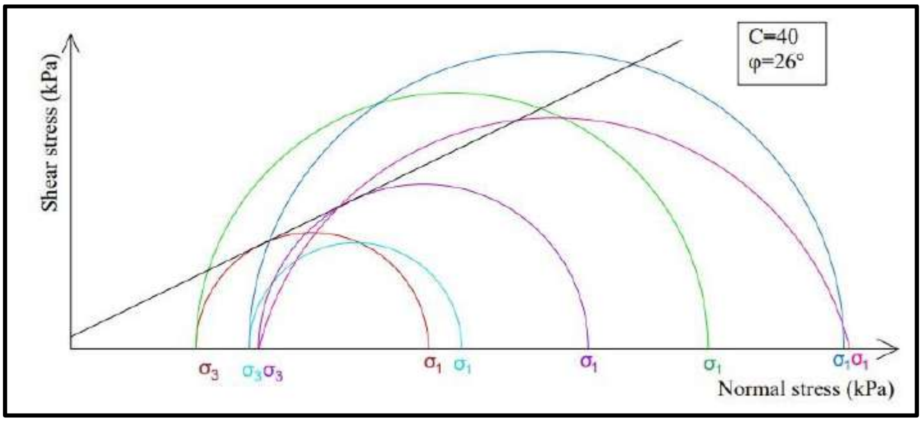


Figure 3.16: Mohr's circles and failure line (DS/GTX – S=7mm)

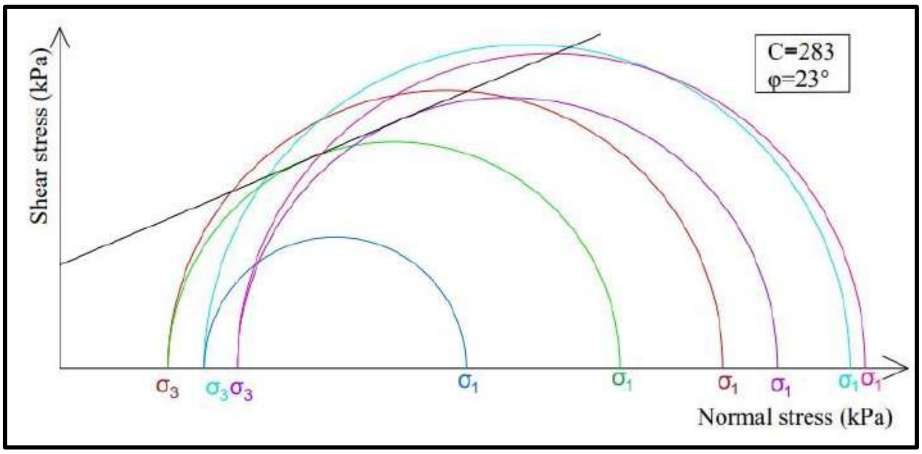


Figure 3.17: Mohr's circles and failure line (DS/GTX – S=9mm)

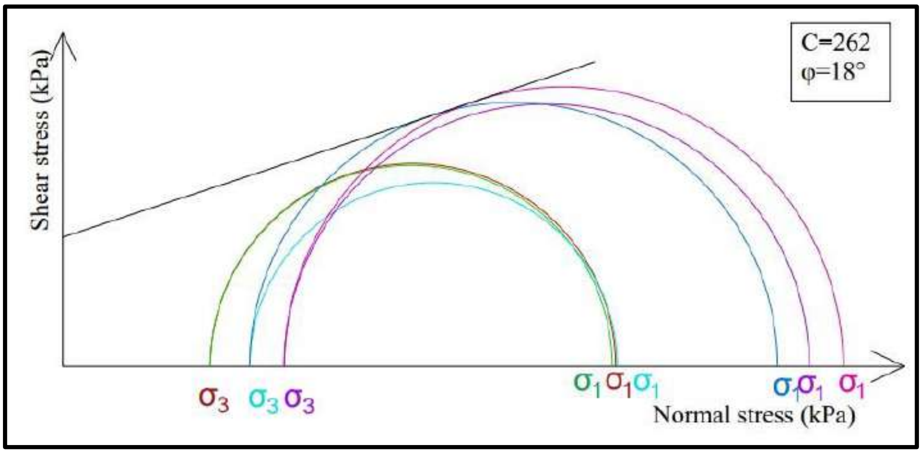
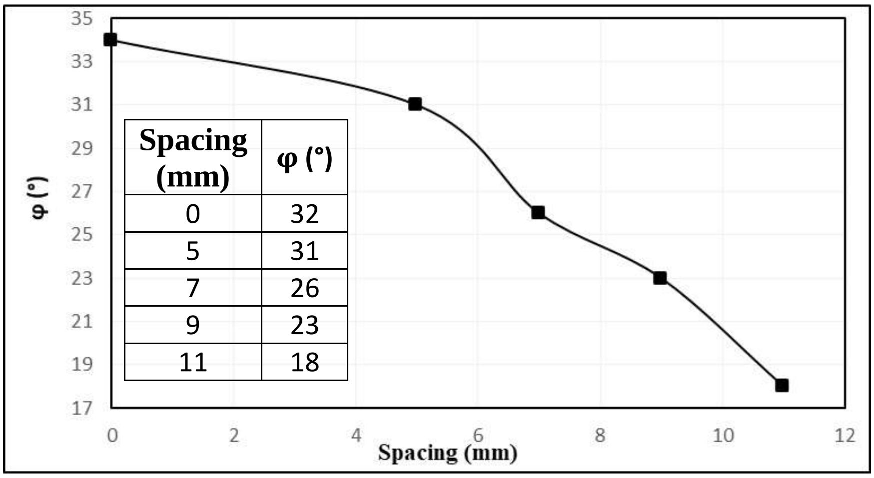


Figure 3.18: Mohr's circles and failure line (DS/GTX – S=11mm)

The φ values were extracted from the Mohr circles shown in the previous figures for all the tests performed, are summarized in figure 3.19:



Spacing (mm)	φ (°)
0	32
5	31
7	26
9	23
11	18

Figure 3.19: The φ versus spacing variation

3.3 PRESENTATION

Figures 3.1 to 3.13 show typical variations of the deviatoric stress as a function of the deformation of the soil specimen. The appearance of the curves tends to express a ductility of the material, except for the case of sand alone, where the peak of the crushing strength is quite clearly apparent.

As for the Mohr circles (figures 3.14 to 3.18), the results are relatively interfered, which makes it difficult to identify the failure line. The latter is deduced after analytical reasoning, which makes it possible to deduce the probable values of C and φ.

The later values (of C and φ) are deduced from all the triaxial tests carried out. The curve in figure 3.19 briefly shows a decrease in φ as a function of the spacing (E).

3.4 INTERPRETATION OF THE RESULTS

The results obtained from the various tests can be interpreted according to the points of view below:

- The angle of internal friction and the cohesion of the sand alone are considered a little high compared to results found in direct shear test reports. This may be due to the small amount of water content attributed to the soil specimens.
- Indeed, it was necessary to moisten the sand slightly (case of all the test specimens) in order to confer 'cohesion', if only fictitious, to successfully make the test specimens. Also, the membrane used in the completed tests provides some sort of retention of test specimens. Furthermore, the low humidification of the soil gave it internal forces of capillary retention, which results in sustained friction.
- The results obtained from the various tests carried out are not very harmonious with each other. As such, several factors can contribute to the appearance of the observed anomalies (circles of Mohr):
    - ⇨ the method of making the samples,
    - ⇨ the condition of the membranes used,
    - ⇨ the centrality of the load applied to the piston
- The decrease in the spacing between the holes tends to prepare for the case of sand alone. The friction decreases when the spacing increases because of the known low friction

between the sand and the GTX used. The greater the spacing, the more the GTX tends to occupy the entire contact surface with the sand.

- The value of the 'sand cohesion' (recognized as artificial) becomes visibly appreciable in the presence of the perforated GTX. The figure 3.20 attests to a localized confinement which manifests itself in 'cohesion' in the representation τ-σ.

Figure 3.20: Clamping of the specimen in line with the perforated GTX

3.5. CONCLUSION

This chapter summarizes the various experimental results obtained from testing of the sand alone and the compound DS/GTX. The GTX included in the sand is regularly perforated in order to ensure a good entanglement.

The examination of the results of the triaxial tests carried out on the sand alone, then on the reinforced sand, demonstrates that the GTX brings a certain 'cohesion' to the sand.

The test conditions significantly affect the results obtained. The condition of the membranes, the method of preparation of the specimens and their positioning must be carefully considered.

At a constant diameter of the holes, the spacing between them decreases the value of the angle of internal friction of the soil. It also seems that the spacing between the perforations of the GTX attributes an apparent 'cohesion' to the dune sand.

Chapter 4/ ECONOMIC STUDY

4.1. INTRODUCTION

The economic estimating or appraisal is an important aspect in the study of any construction project. It enables the project owner to make decisions regarding the costs necessary to complete the project. This estimating depends on many technical, social and functional parameters. This assessment is closely linked to the specificities of the project under consideration. It can even change from one period to another for the same project.

The present chapter aims a presentation of an application example. This relates to a stretch of road of a given length. The cost price of a layer of the compound (DS / GTX) is evaluated in comparison with the same layer made using conventional techniques according to current market rules. Also, the means and techniques implemented, and the temporal aspects are highlighted.

4.2. QUANTITATIVE AND ESTIMATIVE VALUATING

In this part of the study, the sub-base of a road section is considered. This part of the road structure is evaluated (on the one hand) by being constructed with the ordinary materials currently in use, and (on the other hand) made in DS/GTX compound. The two quotes are presented (respectively) in tables 4.1 and 4.2.

The foundation section length taken into account is 6960m. This length is dictated by the quantity of GTX materials that can be transported by a semi-trailer type truck. The loading capacity of such a truck is retained as the reference unit for the work to be performed. This is because it is a key parameter for the progress of work and the evaluation of funding. In table 4.1, the unit prices mentioned relate to the supply of materials from a deposit in the vicinity of the project (distance less than 20 km).

Table 4.1: Quantitative and estimated detection of 6960 m of road carried outby the habitual method

DESIGNATION	U	Qty	U.P. (DA)	T.P. (DA)	Duration	Number of workers
Supply, transport, implementation, and execution of the tuff foundation layer 20 cm thick including extraction, loading, Transport to the place of deposit, leveling of the subgrade, watering and compacting with repair all networks damaged due to excavation work and all constraints of good performance.	m^3	6960	600	4.176.000	The period required to complete this layer of the road is illustrated by planning GANTT. It is estimated at 26 days.	▪ Four truck drivers for transporting and unloading tuff. ▪ Driver grader for spreading tuff. ▪ Driver for the Vibratory compressor for crushing large tuff stones. ▪ Driver for soft cylindrical compressor to compact the tuff. ▪ Driver for the water tank to spray the layer, until reaching the cohesion. ▪ Four workers to provide various services
	Total amount (E.T.)			**4.176.000**		
	TAV 19%			**793.440**		
	Total A.T.I.			**4.969.440**		

Table 4.2: Quantities and estimations of 6960 m of foundation layer made by DS/GTX compound

DESIGNATION	U	QTY	U.P (DA)	T.P (DA)	Duration	Observation
Supplyingof DS	m^3	6960	31.25	217.500	/	▪ The load of sand in a truck with a capacity of $16m^3$, the payment is estimated at 5000 DA.
Spreading theDS	km	6.96	30.000	208.800	7 days	▪ The sand is spread by the machine by 1 km/day, at a price of 2000 DA/day. ▪ Two workers, by hand, adjust the effects of the machine, the payment of each worker 1000 DA/day.
Purchase of GTX	m^2	48720	100	4.782.000	/	▪ Generally from Algiers
Transport of GTX rollers	U	28	(forfeit)	40.000	/	▪ According to AFITEX ALGERIA company, a truck can carry 28 rolls.
Unloading and setting up (deploying)	U	28	600	16.800	7 days	▪ Set in place by machine, 3 rolls per day.
Backfilling GTX with DS layer	km	6.96	30.000	208.800	7 days	▪ The GTX is backfilled with a layer of sand to avoid its movement due to wind or other factors.
		Total amount (E.T.)		**5.545.900**		
		T.A.V. 19%		**1.053.721**		
		Total A.T.I.		**6.599.621**		

4.3. COMPARISON ASPECTS

The comparative analysis of the two tables (4.1 and 4.2) shows some relevant aspects.

1) The amount of road construction with the composite (DS/GTX) is higher compared to the usual method. The percentage increase between the two methods is estimated at 32.8%. The main reasons can be the ones below:

- The first method is based on using tuff material, which is of low cost, considering its availability in the vicinity of the construction project. This contributes, visibly, to the low cost of carrying out the project.
- The second method is based on the implementation of the GTX material. The purchase price of this material is recognized to be the major reason for the high cost of constructing the road. Its purchase price alone constitutes 75% of the total amount of the project.

2) Another potential parameter making the difference between the two implementation techniques is the time factor. In fact, the method based on compound (DS/GTX) is three times faster than the usual method. This is because the two used materials (DS and GTX) are considered ready for immediate implementation.

3) Labor is one of the most important elements in construction projects. It is an indispensable resource in any construction project.

4) A simplistic comparison between the human resources required in the two cases shows, among others, the following aspects:

- The nature of the tuff material generally used in roads construction requires leveling with certain techniques of high accuracy. Therefore, this method depends on skilled and experienced labor commensurate with the work style, especially for machine drivers.
- The second method using (DS/GTX) is a method that does not require special skills or the intervention of a large number of workers. Four to five workers can be enough to run a construction site.

5) The use of machines for carrying out the work also shows distinctive aspects:

- In the usual method (using tuff), each operation is carried out with special machines and each machine has a specific task.
- The ‘DS/GTX’ method does not depend too much on machinery. It only needs a crane and a motor grader.

6) The purchase price of the GTX may be negotiated and, somewhat, reduced or compensated by another service, like any commercial transaction. This is supported by the diversity of suppliers and the competition between them. Also, the means of transport can be diversified given the handy nature of the GTX lots.

7) Unlike the technique based on classical materials, the one using DS/GTX can be implemented anywhere due to the availability of raw materials. This constitutes a key parameter in the socio-economic development policy based on the extension of the road network.

4.4. CONCLUSION

A quantitative estimation is prepared to compare the variables (DS/GTX) and (tuff) for a road of about 6960 m. This amount is governed by the truck's packing capacity of the geotextiles.

The study in question shows that the second method (DS/GTX) is more expensive compared to the first method (tuff). This is due to the higher purchase price of the main component (GTX) that really affects the balance of benefits.

The second method is characterized by the speed of implementation compared to the classic method, the fact that it does not require a lot of effort and equipment. And it can be implemented anywhere for the availability of ready-made raw materials.

The current technique cannot be used in just any region. The availability of compliant materials is, indeed, a primary condition governing this issue. Similarly, many construction machinery and equipment must be moved to the construction site. All these conditions can be against a road construction project.

Finally, the quality and specialization of the workers also make a main difference between the two techniques. Neither the number nor the performance of the workers is required when the compound (DS/GTX) is implemented.

GENERAL CONCLUSION

The study carried out, as part of the preparation for the Master's degree in civil engineering, focuses on the experimental testing of a composite material (dune sand + geotextile).

At the end of this work, some relevant technical opinions are presented. The topics recalled are considered relevant according to the estimation of the authors of this Memory.

In this study, the dune sand material is chosen considering its availability and low price.This constitutes the essential advantage of the adopted approach.

The properties of the materials used (DS and GTX) significantly influence the choice of the tests performed in order to determine their performance.

The triaxial test adopted precisely within the framework of the present study is recognized as one of the most developed mechanical tests. It allows the measurement of many mechanical parameters of the soil: C, φ E,ν, k, ..

Most of these characteristics and parameters can be used to assess soil deformation and/or its bearing capacity.

The results of the present study confirm the reinforcement of the sand by the geotextile material. The latter gives the former a kind of 'cohesion' resulting from the entanglement between the two materials. The angle of friction of the reinforced soil decreases as the spacing between the holes of the GTX increases. The user of such a process is required to optimize between the gain in 'cohesion' and the drop in friction.

Furthermore, some recommendations, in relation to the completed study, can be pointed out.

- The preparation of the specimens (DS/GTX) must be carried out with care and as much as possible in accordance with the standards in force.
- The triaxial tests to be carried out are recognized as being the most important from the point of view of evaluating the mechanical characteristics. Other physical, chemical and

mechanical characteristics of the soil should also be carried out with a view to a fairly complete characterization of the handled material.

Some study topics, complementary to this work, are suggested below. They can be developed in the form of graduation projects or research projects.

- Resume the same test protocol using other types of GTX products.
- Realization of a parametric study varying the physico-mechanical and geometric parameters of the GTX, and the physical (even chemical) parameters of the soil.

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ANNEX

ILLUSTRATIVE PHOTOS OF THE DS/GTX MATERIAL SUBMITTED TO TRIAXIAL TEST

Figure A.1

Figure A.2

Figure A.3

Figure A.1: Failure plan clearly visible during the compression test (DS alone)

Figure A.2: The shear failure is more noticeable at the end of the test (DS alone)

Figure A.3: Distinctive bulge between the two halves of the specimen. (DS/GT: ϕ2-S11)

Figure A.4

Figure A.5

Figure A.6

Figure A.4: Perfectly symmetrical specimen (structure and loading). The perforated GTX offers localized tightening. (DS/GTX: ϕ2-S5)

Figure A.5: Well symmetrical structure and load. The sand tends to overflow at the 'boundary' surfaces (DS/GTX: ϕ2-S7)

Figure A.6: Deformation and appearance of the rupture plane conditioned by the inclination of the piston (DS/GTX: ϕ2-S9)

Figure A.7

Figure A.8

Figure A.9

Figure A.7: Combined deformation between shear and distortion (DS/GTX: ϕ2-S11)

Figure A.8: Two (parallel) planes of shear failure coupled to the distortion of the soil specimen (DS/GTX: ϕ2-S11)

Figure A.9: Membrane accidentally split on the upper part of the specimen. Result: doubly confined area (DS/GTX: ϕ2-S11)

ملخص

رمال الكثبان ثروة طبيعية لكن غير مستغلة في عموم الصحاري، ومنها صحراء الجزائر. تهتم الدراسة الحالية بتقدير إمكانية استعمال هذه الرمال في مجال البناء.
من ضمن الخصائص الذاتية الرئيسية الحائلة دون استعمال هذه الرمال، قلة القابلية للرص، وكذا انعدام التلاصقية.
تقوم الدراسة المنجزة على استعمال جهاز القص ثلاثي المحاور لقياس، أساسا، الخصائص القصية للتربة (C و ϕ). في مرحلة ثانية، تم حشو التربة الرملية بمادة جيونسيجية (GTX) ومنها إعادة اجراء نفس التجارب القصية. أظهرت الدراسة تحسنا ملحوظا فيما جاء عن تلاصقية التربة الرملية المدعمة.
من جهة أخرى، تم تغيير التصميم الهندسي للمادة الجيونسيجية الداعمة للرمل، إلى غاية تعيين الشكل الأمثل للثقوب المحدثة بها، وكذا المسافة الفاصلة بين هذه الثقوب.
بناءا على النتائج المهمة المتحصل عليها، يمكن الانتقال إلى توظيف المادة المركبة في مشاريع واقعية مما سيسمح بتقييمها ميدانيا.
الكلمات المفتاحية: جيو نسيج، جهاز القص ثلاثي المحاور، رمل الكثبان، تدعيم.

ABSTRACT

The sands of the dunes are a natural but untapped wealth in all deserts, including the desert of Algeria. The current study is concerned with estimating the possibility of using this sand in the field of construction.
Among the main intrinsic characteristics that prevent the use of these soils, are the lack of compaction, as well as the lack of compaction.
The completed study is based on the use of a triaxial shear device to measure, mainly, the shear properties of the soil (C and ϕ). In a second stage, the sandy soil was filled with geotextile material (GTX), including re-conducting the same shear experiments. The study showed a significant improvement in the stickiness of the reinforced sandy soil.
On the other hand, the engineering design of the geotextile material supporting the sand was changed, in order to determine the optimal shape of the holes created in them, as well as the distance between these holes.
Based on the important results obtained, it is possible to move to employing the composite material in realistic projects, which will allow its evaluation in the field.
Key words: Geotextile, Triaxial shear apparatus, dune sand, reinforcement

RÉSUMÉ

Les sables des dunes sont une richesse naturelle mais inexploitée dans tous les déserts, y compris le désert d'Algérie. La présente étude porte sur l'estimation de la possibilité d'utiliser ce sable dans le domaine de la construction.
Parmi les principales caractéristiques intrinsèques qui empêchent l'utilisation de ces sols, figurent le manque de compactage, ainsi que le manque de compactage.
L'étude réalisée est basée sur l'utilisation d'un dispositif de cisaillement triaxial pour mesurer, principalement, les propriétés de cisaillement du sol (C et φ). Dans un second temps, le sol sableux a été rempli de matériau géotextile (GTX), notamment en re-conduisant les mêmes expériences de cisaillement. L'étude a montré une amélioration significative de l'adhésivité du sol sableux renforcé.
D'autre part, la conception technique du matériau géotextile supportant le sable a été modifiée, afin de déterminer la forme optimale des trous créés dans ceux-ci, ainsi que la distance entre ces trous.
Sur la base des résultats importants obtenus, il est possible de passer à l'emploi du matériau composite dans des projets réalistes, ce qui permettra son évaluation sur le terrain.
Mots clés: Géotextile, l' appareil cisaillement triaxial, Sable de dunes, Renforcement