Checking the saturation on sandy tropical soil samples in laboratory using the seismic waves

Contrôle en laboratoire de la saturation d'échantillons de sols sableux tropicaux à l'aide des ondes sismiques

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ABSTRACT

The classic triaxial compression test is very useful in Soil Mechanics for assessing the parameters of rigidity and strength of the soil under laboratory conditions. Generally, this test consists on applying to the cylindrical sample of soil and all around uniform pressure σ_3 to confine the sample, which is the same as σ_2 and an increasing axial pressure σ_1 to failure, after saturation and consolidation.
In conducting triaxial tests on soil samples it is important to guarantee the total saturation of the samples, to simulate the most adverse moisture condition of the soil that can arise in situ.
There are various methods for assessing the saturation of the samples in the triaxial test. Conventionally, this verification is done at the end of each pressure increment, setting up the Skempton B parameter of pore water pressure.
The main objective of this paper is to show that it is possible to assess the level of saturation by measuring the velocity of seismic compression waves "P" using ceramic piezoelectric transducer ("bender / extend elements" - bending / compression elements). Waves are induced and transmitted through the soil probe during the test. The value of B can be correlated with the velocity of the P wave (V_P). In the search of reference values both B and V_P must be investigated to the condition of complete saturation. In this paper, the conventional classic process of saturation will not be discussed.

RÉSUMÉ

L'essai triaxial classique de compression est couramment utile pour déterminer les paramètres de rigidité et de résistance des sols en laboratoire. Cet essai consiste à appliquer, en premier lieu, une contrainte de confinement isotrope sur l'échantillon, ensuite après saturation et consolidation, la contrainte axiale est augmentée jusqu'à atteindre la rupture. Il est primordial de garantir la saturation totale des échantillons de sols, lorsque soumis à des essais triaxiaux, pour simuler l'état d'humidité le plus défavorable du sol qui peut surgir in situ. Il existe diverses méthodes pour évaluer la saturation des échantillons lors d'un essai triaxial. Conventionnellement, à la fin de chaque incrément de pression, on mesure le coefficient de Skempton B de pression interstitielle.
Le but essentiel de ce papier est de montrer la possibilité d'évaluer le niveau de saturation par la mesure de la vitesse des ondes de compression sismiques « P » en utilisant un capteur piézoélectrique en céramique. Lors de l'essai les ondes sont induites et transmises à travers la sonde de sol. La valeur du coefficient « B » peut être corrélée à la vitesse V_P de l'onde « P ». A partir des références les valeurs de B et de V_P doivent être examinées à la condition de saturation totale. Dans ce papier, la condition de saturation classique ne sera pas discutée.

1. INTRODUCTION

Realization of triaxial tests for mechanical characterization of materials for application in various geotechnical engineering works is current practice in Mozambique. For a research study several laboratory tests were carried out to evaluate tropical soils characteristics from the south of Mozambique to use in roads construction. Two locations where road rehabilitation works were running was selected to the experimental program by suggestion of some experts in road engineering and also because of the distinction of two types of materials from these borrows.
The soils from these borrows were identified and are summarized in the tables below. The sample called EN-206 is described and classified as poor graded sand with some silt, while the EN-MG sample is a very silty sand with some clay of considerable plasticity. The samples are summarized in the Table 1 and their sieve distribution shown in the Figure 1.

These two soils were compacted at three conditions: one at its maximum dry density, and other two samples compacted at the optimum moisture content more or less 2%, (w_{op} -2% and w_{op} +2%). Figure 2 represents the three soil conditions used in triaxial tests.

Table 1: Soil Properties

Sample	% Fines	γ_s (kN/m^3)	e_0	w_L (%)	w_P (%)	Classi. ASTM	Classif. AASHTO
EN-206	16	26,9	0,32	NP	NP	SP-SM	A-2-4-(0)
EN-MG	36	27,7	0,46	36	24	SM	A-7-6-(1)

The compaction curves for two soils analysed are plotted in Figures 3 and 4, and the optimum moisture content and maximum dry unit are presented. Compaction test was performed using Modified Proctor according to the Portuguese norm LNEC – E 197 – 1966, used in Mozambique and it is in the same line with regional standards, including the SATCC (Southern Africa Transport and Communications Commission) prescribed in the "Standard Specifications for Road and Bridge Works", September 1998.

The triaxial tests were done in the traditional triaxial cell equipped with high accuracy instrumentation for displacement measurement (LDT's - Local Displacement Transducer and LVDT's - Linear Variable Displacement Transducer").

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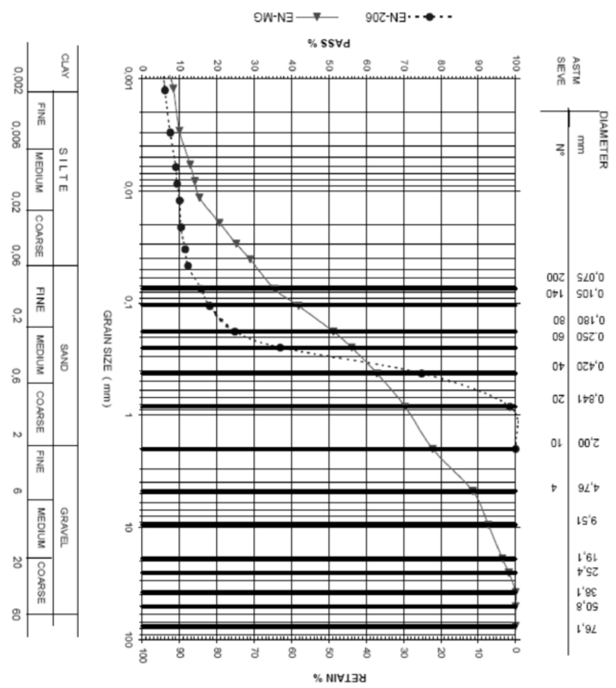

Figure 1: Particle size distribution for two soils tested (ASTM sieves)

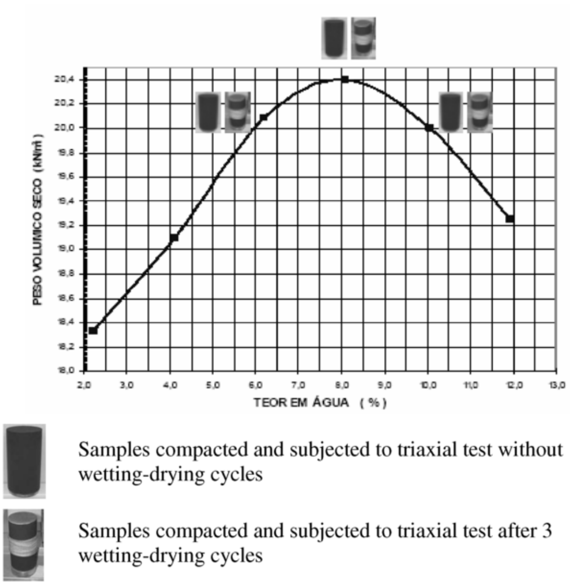

Figure 2: Schematic representation of experimental program for triaxial cyclic tests

In order to simulate the seasonal effects on the landfill, some samples were subjected to the wetting and drying cycles. The process of wetting and drying of the samples is well detailed in Chembeze and Viana da Fonseca (2006).

2. SATURATION PROCESS

In this study, saturation process was done by combination of two methods: increasing the cell and back pressure, and measuring B parameter, and by vacuum method to improve the expelling of air from the voids. This saturation procedure was adopted because the traditional process was too slow, and even with high pressure saturation could not be achieved. Also, the time to finish the experience was limited. To stud the use of seismic waves to control the saturation process, velocity of compression waves, V_P, was measured and compared with reference values of wave propagation velocity in water. To measure the compression waves, ceramic piezoelectric transducer (bender/extender elements) were used. The Bender Element system enables easy measurement of compression waves of soil at small strains in a triaxial cell.

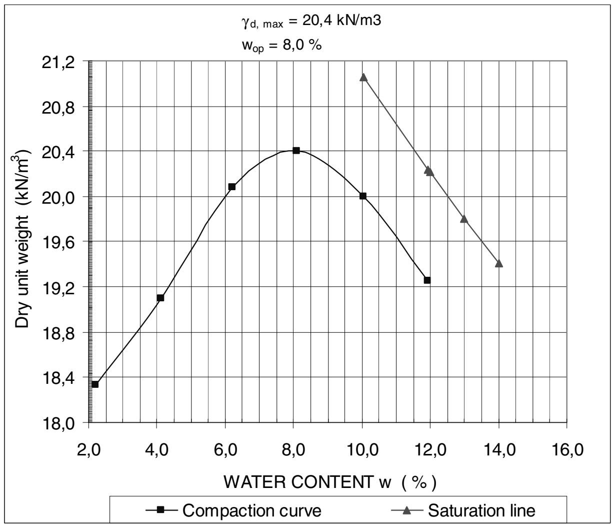

Figure 3: Compaction curve for EN-206 sample

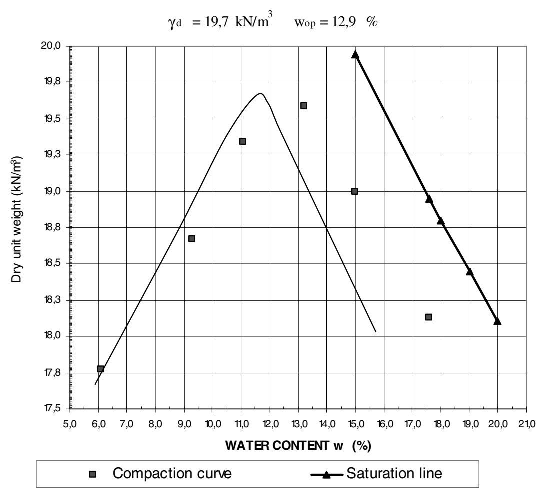

Figure 4: Compaction curve for EN-MG sample

During this process, samples were subjected to a small isotropic consolidation to avoid damage of the sample structure.

At full saturation stage, V_P according to the literature is approximately 1500 m/s.

Normally the verification is done at the end of each pressure increment, setting up the Skempton B parameter of pore water pressure.

This parameter is determined from the values of confining pressure and pore pressure before and after application of a rapid increase that pressure and maintaining closed drainage line. With the expression (1) B parameter can be calculated:

$$B = \frac{\Delta u}{\Delta \sigma_3} \tag{1}$$

where Δu is excess of pore pressure (the pressure difference before and after the change of the loading conditions) read immediately before increase cell pressure σ_3, which for loading isotropic is equal to $\Delta\sigma_1$.

The following figures shows the equipment set up used to carry out this study.

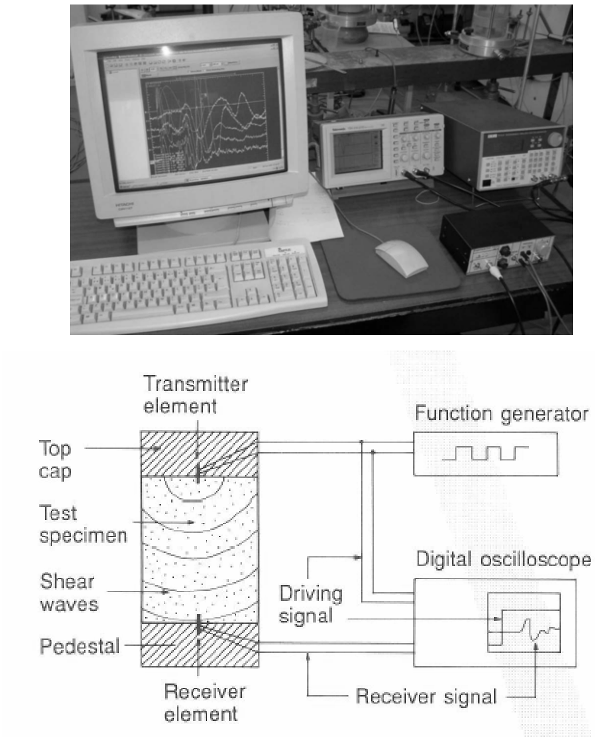

Figure 3: Equipments used to measure seismic waves with respective schematic set up and functioning process

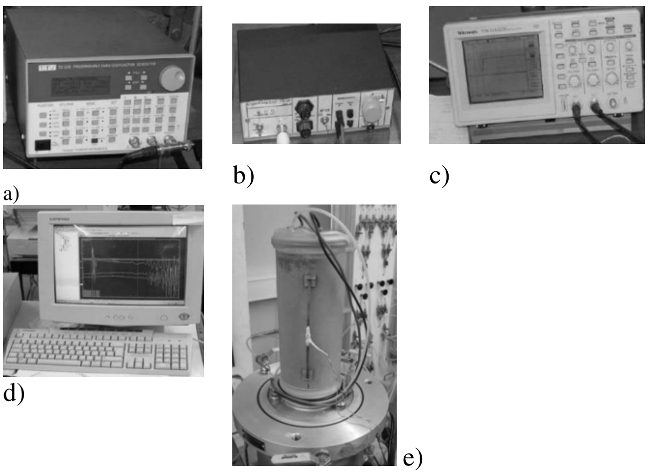

Figure 4: Components of system to measure seismic waves

a) Function Generator

b) System Controller with sign amplifier

c) Digital Oscilloscope connected to computer

d) Computer connected to data acquisition system

e) Sample instrumented with bender elements

Theoretically the soil is fully saturated when the parameter B is equal to 1, because of the very low compressibility of water in the pores. In practice, however, values more than 0.90 depending on the type of soil are acceptable. If the criterion for saturation is the control of parameter B, Black and Lee (1973) consider different categories of soils for this control.

Instead of using the traditional process of B value (for eg. about 0.97, in granular soils), will be more realistic and warrantable to determine a value B according to the properties of soil and loading conditions corresponding to drained or undrained condition. It is important to take in account that a degree of saturation below 100% will have a significant role in the response of pore pressure, particularly in undrained tests, while for 99% degree of saturation, the soil will have a behavior like if it was fully saturated in drained loadings, if the test is conducted at very low speeds. For soft soil, according to Black and Lee (1973), value of B for a degree of saturation of 100% is 1.0 while the value of B = 0.97 to get a degree of saturation of about 98%. It is commonly accepted that we can easily get a B = 0.97 in soft soil, but is not guaranteed that the soil is 100% saturated.

In hard soils, the value of B at saturation can be significantly less than 1.0, it is accepted values above 0.90 for very hard soils (whether compact or structured).

So, to study the levels of saturation of currents soil, the following categories considered:

- Soft soil: soft clays normally consolidated;
- Medium soils: slightly overconsolidated clay, compacted clay and silt;
- Hard soils: hard overconsolidated clays, medium sands;
- Very hard soil: hard clay, very dense sand, consolidated soil under high effective stress, soil with cementing agents, even the open structure.

For those soils, Table 2 shows typical values corresponding to its almost complete saturation

Table 2. Values of B for typical soils on or near the fully saturation (Black and Lee, 1973)

Soil Category	Saturation (*S*)		
	100%	99,5%	90,0%
	B Value		
Soft	0,9998	0,992	0,986
Medium	0,9988	0,963	0,930
Hard	0,9877	0,69	0,51

Practically, S less than 100% is acceptable since successive equal increments of confining pressure, results in differences of equal values of B within the range of values presented above. The consolidation pressure should be constant at each increment. If the pore pressures responds with increasing values with increasing of confining pressure in for successive values of these, it means that the sample is not saturated (Wissa, 1969).

Other way to check the saturation (if it is possible to measure accurately the volume), is by observation carefully the tendency of water to enter into the sample when the backpressure increases. If the sample is saturated, the volume of water that enters into the sample is equal to the measured volume inside the cell.

For the type of samples available for this study (particularly the sandy-silty soil), it was verified that the integrity of the sample should be affected by way the test is conducted, mainly during saturation-consolidation. Traditionally, the saturation is done before consolidation, however, has been noted that this way inducts significant expansion to the soil sample. So, the alternative way was used to reverse the process, first was done slightly consolidation, and then saturation, this process known as saturation "dry way" in opposition to the traditional process well-known as "wet".

So, the process of saturation-consolidation followed the steps:

- isotropic consolidation (K0 = 1.0 - typical value for compacted soil);
- saturation up to Skempton B value over 0.90 VP (velocity of compression seismic waves transmission through the sample "P") over 1500m/s.

After saturation process finish, the sample is subjected to consolidation and loading to the failure. It will not be discussed on this paper more details can be found in Chembeze, S. (2006).

For two soils related to this study, the results are shown in next figures. It can be seen that, the B parameter increases while V_P increases. For sample EN-206, the value of B maintains constant although the wave velocity increases. If the sample stay long time in the saturation process, B value maintain constant, but water in the sample go to stage of more stability that allows increasing of velocity, so the structure of soil gets news rearrange.

B values are about 0.95 and it can be explained according to Black and Lee studies described before.

For the sample EN-MG, values of B are bear 1.0, it means the saturation process is more effective and evident. It is explained taking in account the type of soil (considerable clay content).

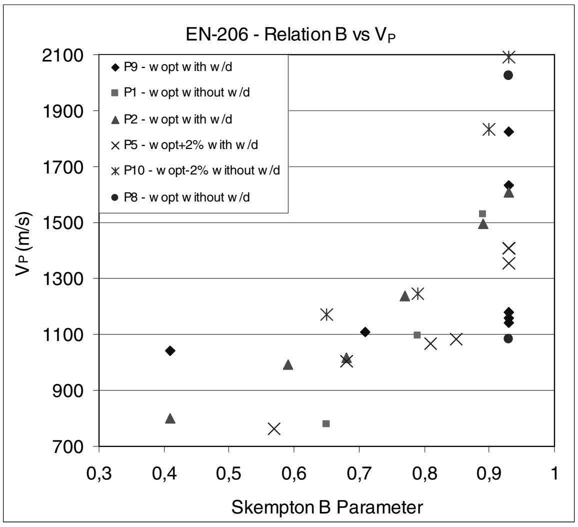

Figure 4. Evolution of de B versus V_P for EN-206 sample

3 CONCLUSIONS

The monitoring of the saturation process, using the seismic waves, revealed in this experimental program as very importance step in this stage. The type of soil has significant influence in the way how the waves are transmitted through the sample. For example in the sample EN-MG witch the content of clay is more than in sample EN-206, the results in the graphic are more consistent. The soil structure permits the transmission with low noise and the results are more "clear".

It can be in the future a good tool to "check" the saturation process of soil samples in the triaxial tests. If B parameter is not useful in the experience, it is possible to reduce the time used to measure it. Although it is relatively fast and easy to implement, this method involves and requires knowledge of good experimental and theoretical level.

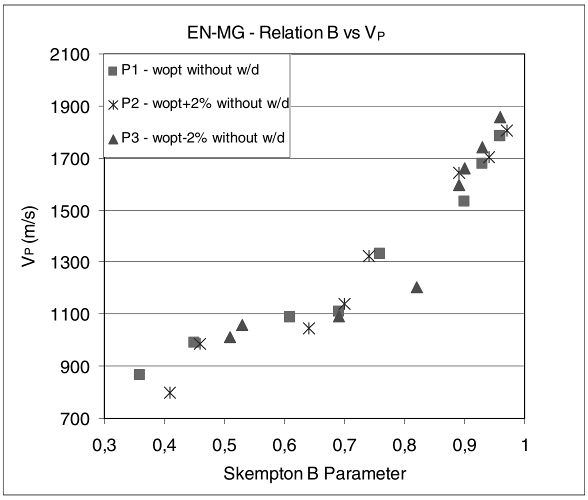

Figure 5. Evolution of de B versus V_P for EN-MG sample

With a good implementation of these methods of measurement seismic waves, we can establish a correlation between their results with those results form conventional classic methods (normally they take long time) to evaluate the saturation using the Skempton parameter B, allowing in this way to obtain quickly some geotechnical parameters necessary to the projects. This method can be in the future, one way to reduce logistic costs and time of classic tests, today considered by many almost as "irreplaceable".

More studies in this subject are recommended, so it is small part of o very great and complex experimental program that needs a very large investigation with specific equipment.

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