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Measurement of soil suction using soil's resistivity

Estimation de la suction des sols par des mesures de résistivité

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ABSTRACT

During several years, the analyses of geotechnical problems have been dominated by solutions developed in the classical soil mechanics where the soil is considered completely saturated or dry, conditions that make the analyses less complicated. However, in many geotechnical problems, the engineer has to deal with unsaturated soils which properties are complex due to the fact that now two fluids are involved in their performance (water and air). One of the main concepts in unsaturated soils theory is "suction" that can be determined in laboratory or field. In soil science, the soil resistivity has been studied widely to determine the capacity of the soil to retain water, however, in geotechnical engineering has not been taken much advantage of such parameter. The authors of this paper present a study on soil resistivity and its relationship to suction. It is shown how the density, degree of saturation and volumetric water content can affect the resistivity. In addition, the results show that there is not a unique relationship between suction and soil resistivity.

RÉSUMÉ

Par des nombreuses années les analyses géotechniques ont été dominés par des solutions tirés de la mécanique des sols classique, où les sols sont considérés saturés ou secs. Cependant, actuellement l'attention est tournée ver des solutions plus complexes que permettent de prendre en compte les trois phases présent dans les sols. Un des concepts les plus importants est la suction du sol, qui peut être mesurée sur le terrain ou en laboratoire. Dans le domaine des sciences du sol, la résistivité du sol a déjà été employée pour la détermination de la capacité du sol pour stocker de l'eau. Pour le géotechnicien, la suction du sol ne pas encore un des paramètres pour tirer d'avantage. Dans ce travail, les auteurs présent une étude sur la corrélation entre des mesures de suction et de la résistivité pour des sols compactés. Il est montré comment la valeur de résistivité est affectée pou la densité, le dégrée de saturation et la teneur en eau. La forme de cette relation est clairement non-linéaire.

Keywords : Soil suction, resistivity, dry density, degree of saturation, water content, soil water characteristic curve.

1 INTRODUCTION

The resistivity is defined as a measure of how well a soil passes electric current. The higher the resistivity, the less electric current passes through the soil mass. Abu-Hassanein, et al (1996) published a paper on electrical resistivity of compacted clays in which they showed how the soil resistivity varied with water content and the influence of the compaction effort on the same parameter. Their results demonstrated that the more compaction energy the less resistivity of the soil, this means that the resistivity decreases as the dry unit weight increases for a certain value of water content.

When studying unsaturated soil mechanics, it is clear that one of the disadvantages is the lack of proper equipment to measure large values of suction. One of the main problems when developing equipment is to avoid the cavitation problem. As a matter of fact, some of the equipments to measure soil suction in field are the tensiometers, filter paper, thermal conductivity sensors, etc. On the other hand, to measure soil suction in laboratory there are other procedures such as the axis translation technique, filter paper as well, control of suction with salt solutions, and so on. All these techniques are very time consuming, therefore this is an area that need to be explored in order to find suitable procedures to measure soil suction in less time.

This paper presents a series of measurements of resistivity conducted on three types of soil. They are a CH, ML and MH. Plots of soil suction versus resistivity are discussed at the end.

The tested soils were selected such that they could be located in different areas of the plasticity chart in order to see if different soils show different curves of resistivity versus soil suction.

The soils are classified as ML, MH and CH soils in the USCS. Their location on the plasticity chart are shown in Figure 1 and their properties are summarized in Table 1.

Table 1. Index properties of the test soil

USCS class	Atterberg limits			Compaction characteristics (Proctor Standard)		Pass 200 sieve (%)	Gs
	LL (%)	PL (%)	PI (%)	w_{opt} (%)	γ_{dmax} (kN/m^3)		
ML	46.5	36.0	10.5	36.5	12.32	92.4	2.66
MH	54.0	34.0	20.0	38.5	12.34	94.4	2.64
CH	72.0	26.0	46.0	34.0	12.55	92.9	2.59

2 SOIL WATER CHARACTERISTIC CURVE

The soil water characteristic curve is one of the most important relationships in the area of unsaturated soils. It shows the soil's capacity to retain water at a certain value of suction (Fredlund and Rahardjo, 1993). This curve can be determined by means of direct or indirect measurements in field or laboratory. The time that takes to determine it will depend on the desired number of points on the curve, which can go from one to many.

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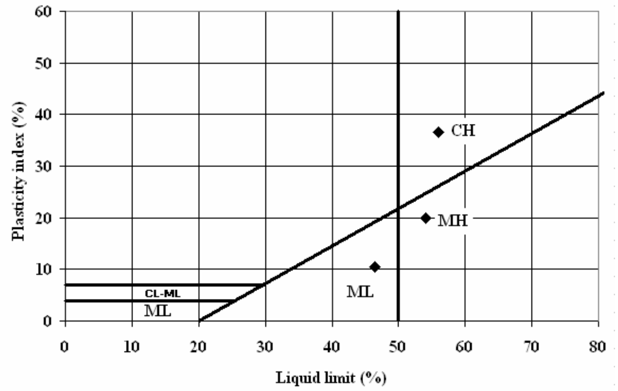

Figure 1. Location of the test soils on plasticity chart.

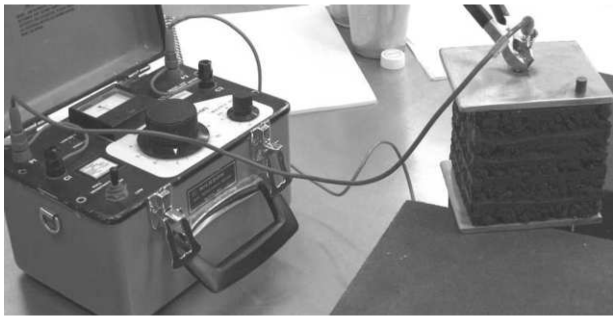

Figure 3. Soil resistor meter together with a compacted sample placed on the stainless steel plates.

Many researchers have proposed models to predict this relationship based upon index properties. Zapata (1999) published a model to predict the soil water characteristic curve of fine-grained soils or sandy soils based upon one parameter. This parameter is the so called "wPI" (which is the percent passing the sieve 200 multiplied by the plasticity index) for the case of plastic soils. For granular soils, the parameter to be used is the D_{60} obtained from the gradation curve.

In this research work, Zapata's model was utilized to predict the soil water characteristics curves of the three test soils. The wPI of the soils correspond to 9.7, 18.9, and 32 for the ML, MH and CH soils, respectively.

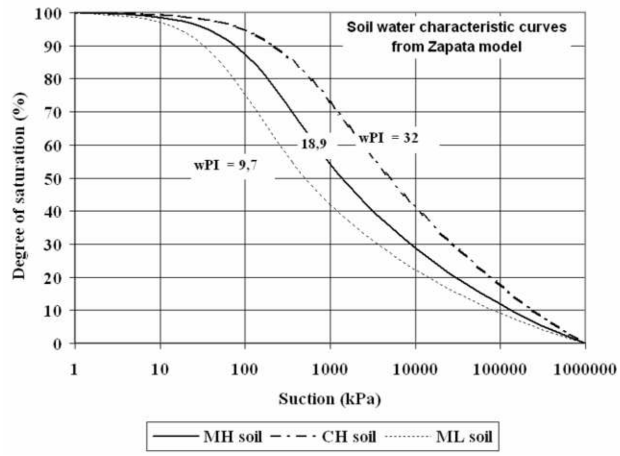

Figure 2. Soil water characteristic curves predicted from Zapata's model.

The soil water characteristics curves shown in Figure 2 will serve in a later section to determine the soil suction provided the degree of saturation of the sample is known.

3 APPARATUS AND TEST PROCEDURE

The test procedure followed in this investigation was to compact the specimen at the desired water content in a squared mold of 10 cm side and 10 cm height. The amount of material required to achieve the dry density was compacted in five layers.

Once the specimen was compacted, one stainless steel plate was place on the bottom and top surfaces (these plates serve as conductive plates). A one-dimensional electrical field is induced through the specimen via the two stainless steel plates pressed against the ends of the specimen and then the reading of resistance can be taken from the resistor meter (Figure 3).

The soil resistivity equipment comes with a lucita box in which soil is placed to measure the resistance, however, during this research it was planned to compact at different dry densities and water content, thus, this box was not appropriate when samples had to be reconstituted at a high dry density. An alternative procedure to measure resistivity was devised as described in previous paragraphs.

The equipment provides values of resistance in Ohm. To transform these values to resistivity the next equation was required:

$$\rho = R_e (A/L) \tag{1}$$

Where:

ρ = Electrical resistivity (Ohm-m)
R_e = Electrical resistance (Ohm)
A = Cross section of the specimen
L = Length of the specimen or distance between stainless steel plates

4 SPECIMEN PREPARATION AND LOCATION ON THE COMPATION SPACE

After the soil was sampled, it was thoroughly mixed and split to obtain representative samples. Then, it was stored in plastic bags for water content to homogenize.

The determination of the initial water content followed the procedure. Based on this value, it was calculated the amount of water to be added to reach the desired value. Afterwards, the water was sprayed on the surface of the soil, mixed thoroughly and then stored for 24 hours. Finally, the sample was compacted in a split mold in five layers. The dimensions of the mold are 10 cm length and 10 cm wide (squared mold).

Figures 4, 5 and 6 illustrate the location of all compacted samples for each soil. As can be seen, the range of dry unit weight and water content that was tested is wide.

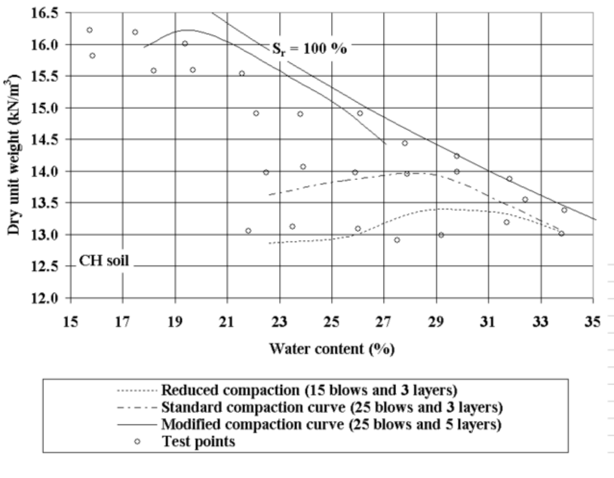

Figure 4. Compaction space for CH soil. Location of the test points.

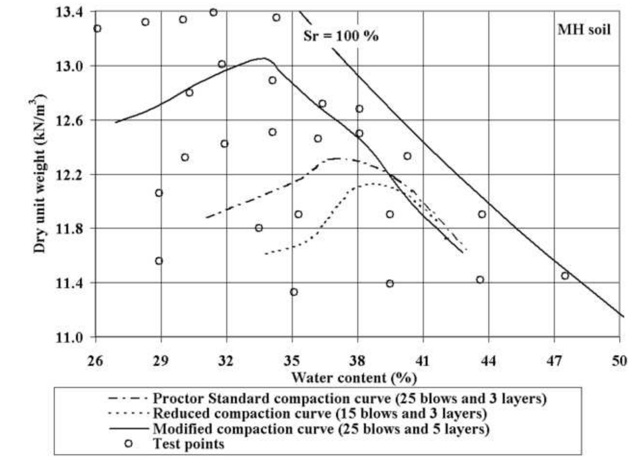

Figure 5. Compaction space for MH soil. Location of the test points.

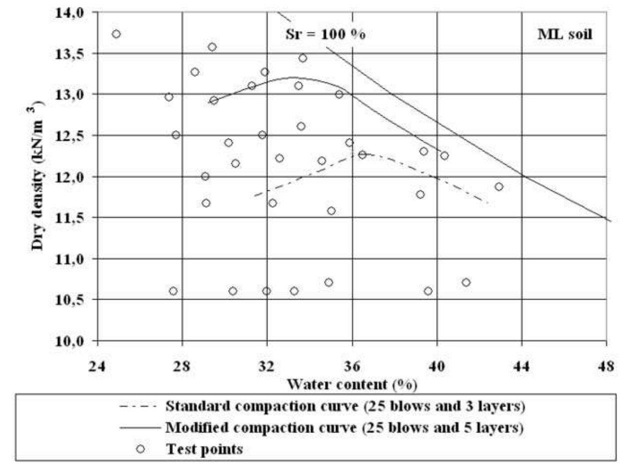

Figure 6. Compaction space for ML soil. Location of the test points.

5 SOIL RESISTIVITY RESULTS

Soil resistivity values were plotted versus volumetric water content (Figures 7 to 9). The results obtained for the CH soil show that there is a non-linear relationship between these two parameters. Therefore, as degree of saturation or volumetric water are related to suction, then, the degree of saturation of each sample will be used later to determine suction from the soil water characteristic curve shown in Figure 2.

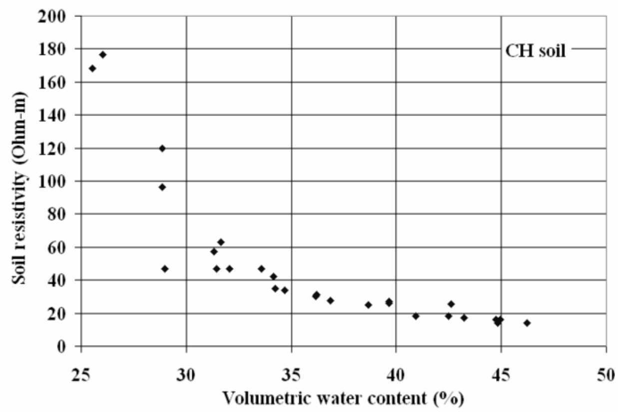

Figure 7. Relationship between volumetric water content a soil resistivity.

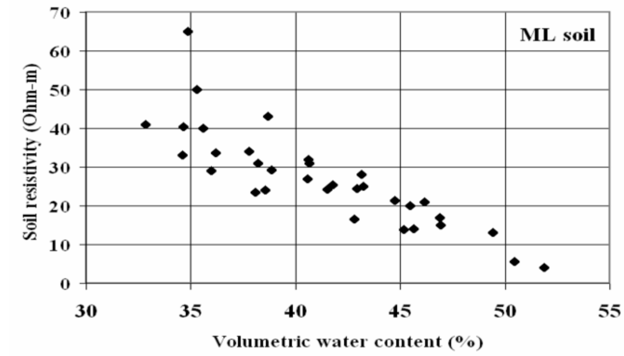

Figure 8. Volumetric water content versus soil resistivity for the ML soil.

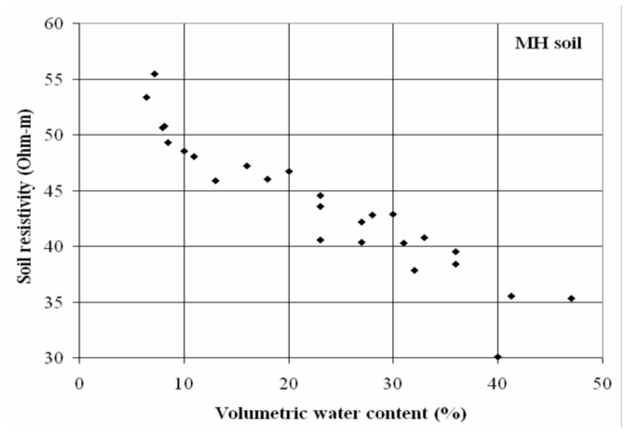

Figure 9. Volumetric water content versus soil resistivity for the MH soil.

Note that the relationship for the ML and MH soil is almost linear contrary to the response obtained for the CH soil.

6 SUCTION AND SOIL RESISTIVITY

After obtaining the results from Figures, 7, 8 and 9, it comes to mind the idea that it is likely to exists another relationship between suction and soil resistivity. The authors of this paper made use of Zapata's model to determine the suction value of each sample. It was assumed that the soil water characteristic curve was the same for one soil regardless of the compaction characteristics. The test points were plotted along the soil water characteristic to obtain the soil suction (Figure 10).

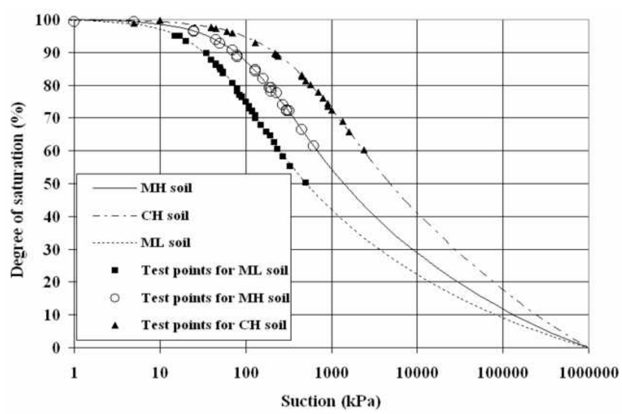

Figure 10. Test points of each soil along the soil water characteristic curves.

Now, the relationship between suction and soil resistivity can be plotted as illustrated in Figures 11, 12 and 13.

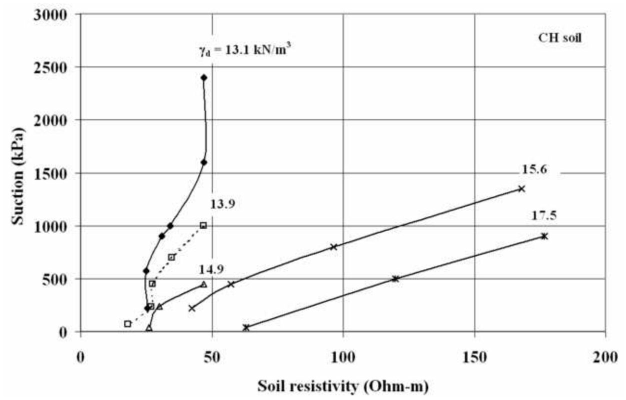

Figure 11. Soil suction versus resistivity for the CH soil

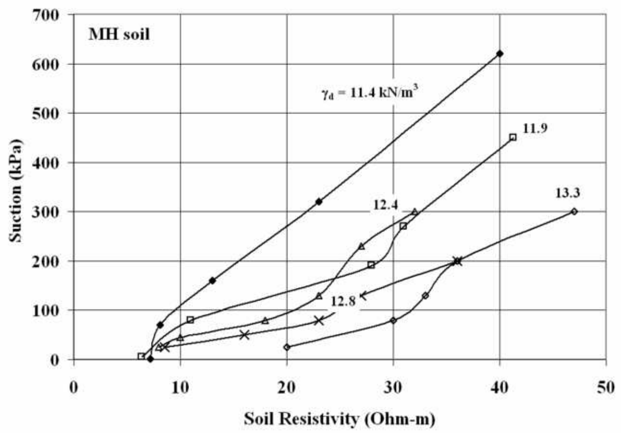

Figure 12. Soil suction versus resistivity for the MH soil

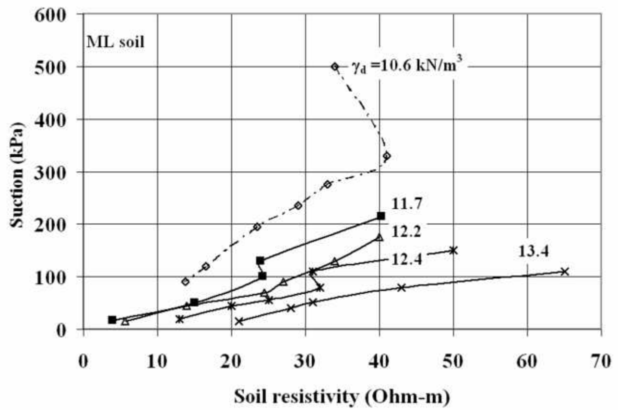

Figure 13. Soil suction versus resistivity for the ML soil

If we analyze the data of Figure 12 it is noticeable that as the resistivity increases the suction also increases for a constant dry density. The three soils analyzed show the same trend, however, for the CH soil, the curve corresponding to the lowest density differs from a linear trend.

Now, if resistivity keeps a constant value and dry density is increased, soil suction tends to decrease, as shown in any of the three figures (11, 12 or 13). Therefore, there is not a unique relationship between suction and resistivity and most of the data exhibit dependence on the dry density, meaning that this parameter is very sensitive to many factors like water content, dry density, temperature, salt content, etc.

7 CONCLUSIONS

The results presented in this paper show that the resistivity of the soil is very sensitive to many factors. Herein it was presented the effect of water content and dry density. Published data demonstrate the effect of other factors.

The findings of this research show that as the resistivity increases the suction also increases for a constant dry density. This trend is followed for the analyzed soils.

Therefore, it is needed more research to reach a final conclusion on the relationship between soil suction and resistivity.

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