Geotechnical characterization of an unsaturated residual soil of granite from Pernambuco, Brazil

Caractérisation géotechnique d'un sol résiduel insaturé de granit d'un Pernambuco, Brésil

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ABSTRACT
This work presents results of the geotechnical characterization of an unsaturated residual mature soil of granite involved in a landslide which occurred in the city of Camaragibe situated in Pernambuco, Brazil. The geotechnical characterization of this material was performed including physical characterization, soil-water characteristic curve and shear strength (saturated and unsaturated condition). The soil-water characteristic curve was obtained through filter paper method, Haines Funnel and Richards pressure Chamber. The shear strength parameters were determined using direct shear tests (saturated condition) and direct shear tests with controlled suction, with suction varying from 0 - 500kPa (unsaturated condition). The results were discussed and compared with literature presenting satisfactory values.

RÉSUMÉ
Ce travail présente des résultats de la caractérisation géotechnique d'un sol résiduel insaturé de granit impliqué dans un éboulement s'est produit dans la ville de Camaragibe située dans Pernambuco, Brésil. La caractérisation géotechnique de ce matériel a été exécutée comprenant la caractérisation physique, la courbe caractéristique de la sol-eau et l'état (saturé et insaturé) de résistance au cisaillement. La courbe caractéristique de la sol-eau a été obtenue par la méthode de papier filtre, l'entonnoir de Haines et la chambre de la pression de Richards. Les paramètres de résistance au cisaillement étaient déterminés utilisant les essais directs de cisaillement (état saturé) et dirigent le cisaillement avec l'aspiration commandée, avec la variation d'aspirations de 0 - 500kPa (état insaturé). Les résultats ont été discutés et comparés à la littérature présentant des valeurs satisfaisantes.

Keywords: Unsaturated soil; soil water characteristic curve; suction, shear strength parameters.

1 INTRODUCTION

The slope where the mass movement occurred is localized in Pernambuco, in the northeastern of Brazil, in the city of Camaragibe, which belongs to the Recife Metropolitan Region. The area under study presents, as geological characteristics, an unsaturated mature residual soil of granite that is partially covered by the Barreiras Formation. The city of Camaragibe is situated in an area constituted of crystalline based rocks (Granite-Gneissic complex) covered by residual soil of granite, originated from the crystalline; by the sediments from Barreiras Formation and by pluvial deposits (Bandeira 2003). The crystalline base is formed by intrusive rocks of archaic age (1,5 a 21 billion years) belonging to Maciço Pernambuco – Alagoas (Alheiros 1998). It presents at least four phases of deformation, of which the latter, associated to the faults under deformation regime, resulted in the Formation of the Pernambuco Lineamento. The residual soil of granite is found in the entire city. The results presented were referring to the study of the characteristics of an unsaturated residual soil of granite, involved in mass movement. The landslide that occurred was classified as a multiple rotational landslide, characterized by the appearance of various steps along the slope. This study makes up part of a doctorate research that aims to give continuity to studies that are relative to understanding of mechanisms of instability of slopes, carried out by the Geotechnical Group of the DEC/UFPE which had the support of the PRONEX-CNPq/FACEPE project.

2 LABORATORY GEOTECHNICAL INVESTIGATIONS

In the doctorate research an extensive campaign of laboratory tests were carried out consisting of physical, chemical and mineralogical characterization tests, strength tests (included direct shear tests and direct shear tests with controlled suction) and edometric tests. The emphasis in this work was given for obtention of the characteristic curves by methods of filter paper, Haines Funnel and Richards pressure Chamber and direct shear test in submerged condition and with controlled suction.

2.1 Physical characterization

The mature residual soil of granite studied, presents a fine texture, with a liquid limit of 54%, plasticity limit of 32% (IP=22%), with grain size distribution of 39% of clay; 26% of silty; 23% of fine sand and 12% of medium and thick sand. The soil is classified as CL in the Unified Classification System (USCS).

Granulometric tests without the use of deflocculant also were performed, where the grain size distribution found was 5% of clay; 33% of silty; 50% of fine sand and 12% of medium and thick sand; showing a strong reduction in the fraction of clay and increased in the fine sand fraction. These results indicate that the particles of clay in this soil are found to be aggregated in their natural state. The grain size distribution with and without the use of deflocculant is presented in Figure 1.

2.2 *Soil-water characteristic curve*

2.2.1 Methodology employed

In this work, the soil water characteristic curves presented were obtained by the filter paper method, Haines Funnel and Richards pressure Chamber.

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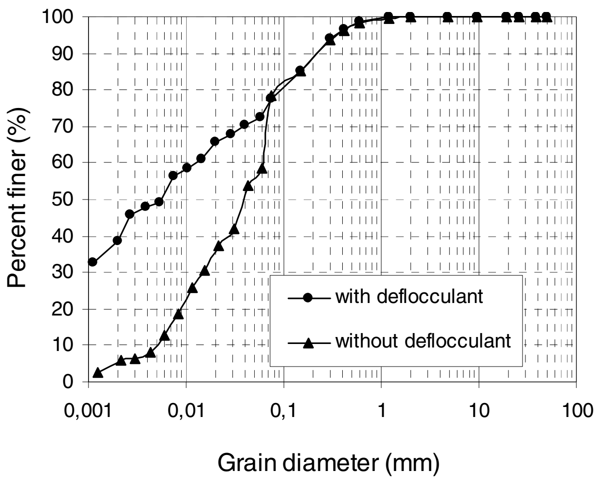


Figure 1. Granulometric test results.

The obtention of the characteristic curve through the paper filter method is based on the principle that a soil, when placed in contact with a paper filter in a hermetically sealed ambient, makes the latter absorb a certain quantity of water from the soil until the system enters into equilibrium of pressure. In this condition, the paper and the soil will have the same suction, although having different gravimetric water content. Knowing the retention curve of the paper (suction – water content relation) and its gravimetric water content, the suction of the paper is determined. In the present research, the drying and the wetting curve were obtained. The paper filter used was Whatman number 42 type 2, which allowed suction measurements of zero up to 29 MPa (Marinho 1995). For determination of the matric suction, the undisturbed samples were molded in metallic rings of 7,20cm in diameter and 3,0 cm in height. Each group (paper filter + sample) was protected by a plastic film of PVC and by a paper aluminum foil. The equilibrium time used was approximately seven days. The wetting process of the samples was carried out with the aid of a water nebulizer and waiting a minimum of two hours for placing the paper filter guaranteeing a better homogenization between the sample and water. During the drying the samples were exposed to room temperature.

For determination of the soil-water characteristic curve was also used equipment known as Richard´s pressure chamber. Figure 2 presents details of the pressure chamber equipment. This equipment can be used as much in deformed samples as in undisturbed samples, allowing the extraction of humidity from the soils by the drying process up to 1500 kPa. The Richard´s pressure chamber is made up of a chamber for supporting high pressures, its inside face being covered by a rubber diaphragm, that is sealed at its border. Two undisturbed samples were moulded in PVC rings of 5cm in diameter and 1cm in height, and taken to the Richard´s pressure chamber, where the suctions applied were 34kPa and 1549kPa. At the point of equilibrium (normally after 10 days from the beginning of the test) the applied suction was switched off, and each ring was weighed. Then the samples were taken to the heater for determination of their humidity.

The Haines funnel is an equipment that is used for determination of soil suction, only for low tension points of the characteristic curve. The samples were moulded in PVC rings of 5,2 cm in diameter and 2,5 cm in height. Then water was added up to saturation around 24 hours. After this phase the excess water was removed and pipette was adjusted, levelling the meniscus to the tension level of 0 cm marked on the support.

Suctions of 0,1 kPa; 0,3 kPa; 0,5 kPa;1,0 kPa; 1,5 kPa; 2,0 kPa; 3,0 kPa; 5,0 kPa; 7,5 kPa and 10 kPa were applied. The superior part of the funnel was covered with plastic, so as to avoid loss of humidity by evaporation. Figure 3 illustrates the equipment. The used of these equipments had the objective to obtain an adequate complete curve. Good results using these three techniques were also found by Silva & Coutinho (2007) for an unsaturated soil of the Barreiras Formation.

2.2.2 Results

The soil-water characteristic curve obtained through the paper filter, Haines funnel and Richard´s chamber method is presented in Figure 4. The format of the curve shows a "saddle" aspect, being able to be divided into three distinct stretches. The curves indicate an initial air entry suction of 1kPa, where there is the start of desaturation.

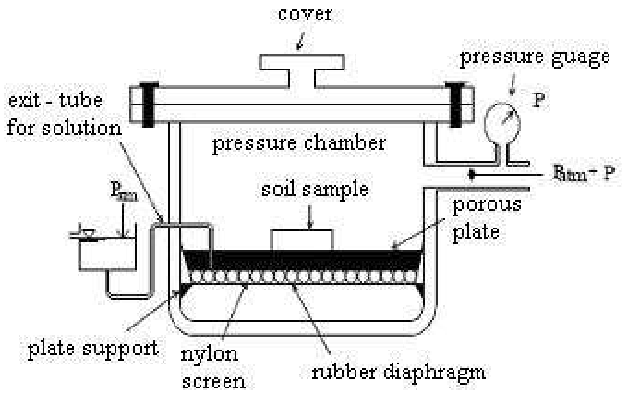


Figure 2. Richard´s Pressure Chamber (Franchi, 2000).

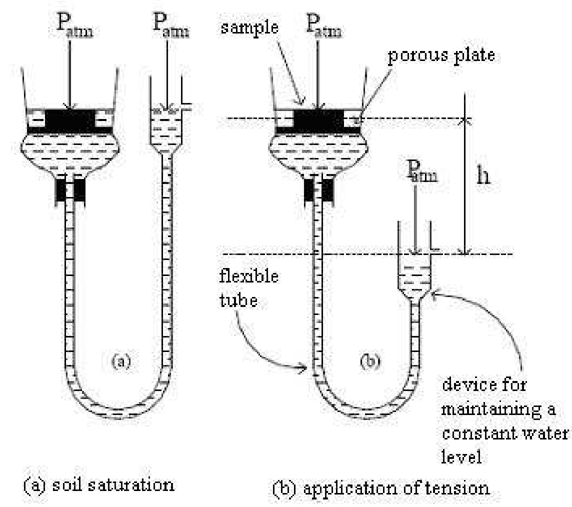


Figure 3. Illustration of Haines funnels equipment (Libardi, 1995).

After that an approximately horizontal region is observed, where the suction varies from 20 to 200kPa. In the last stretch occurs a second air entry value, where the water content starts to diminish with the increase in suction due to the removal of water from the soil micropores. The curve points, for the residual soil of granite, studied here, during the wetting process and drying process, are presented very near together, making it difficult to identify any effect of the hysteresis (Figure 4).

For Camapum de Carvalho & Leroueil (2004) this "saddle" format in soil-water characteristic curve is typical of soils that present bi-modal porous distribution (heterogenic). This distribution is due to weathering processes that are responsible for the formation of soil particle aggregation. The comparison between the granulometric test results, with and without the use of deflocculant, indicated that in the soil studied, the clay particles tended to be presented as aggregated in their natural state. A similar behaviour of soil-water characteristic curves with "saddle" format was also found in other brasilian tropical soils (see Futai et al., 2007; Lafayette, 2006; Bastos, 1999).

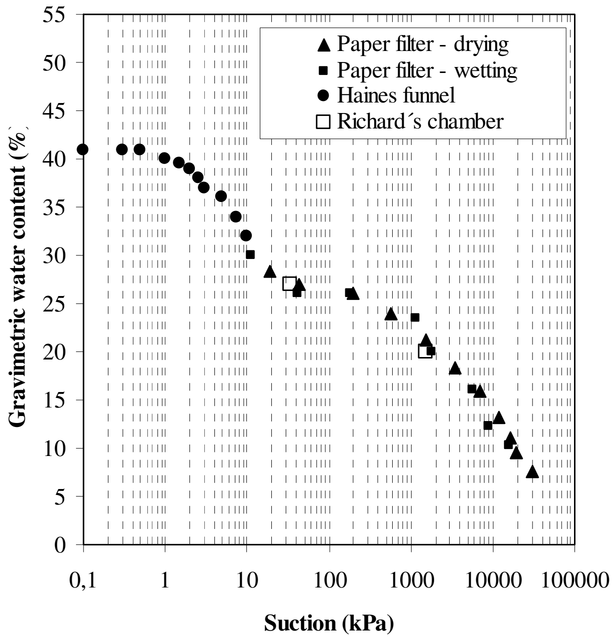


Figure 4. Soil-water characteristic curve obtained through the paper filter, Haines Funnel and Richard´s chamber methods.

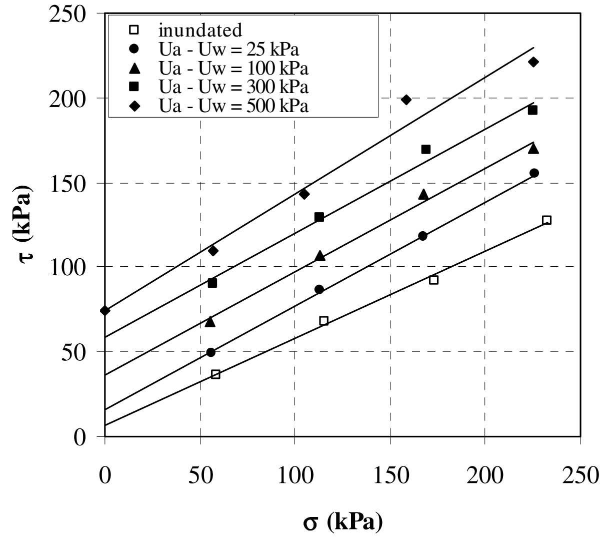
2.3 Direct shear tests with controlled suction

The equipment used consisted of a conventional press, adapted for use of a cell that allows the imposition and control of suction through the principle of translation of axes. The cell used in this research is identical to that described in Escário & Sáez (1986).

The suction is imposed to the soil by the difference between the air pressure supplied by hydrogen, applied through an air valve and the water column maintained in the reservoir fixed on top of the press. The tension is applied through a system hanging weights, identical to the conventional direct shear tests. The air pressure was applied only under the weight of charge transference plate and maintained during 10 days. The horizontal force was determined through a load ring. Samples were used, at dimensions of 50mm side and 22mm in height. The suctions adopted were 25, 100, 300 e 500kPa.

After this period (suction equilibrium) specific normal stress were applied, accompanying the deformations up to stabilization. The normal stress adopted were 50, 100, 150 e 200kPa, which were maintained for a minimum of 24 hours.

The shear strength envelopes in the plain (σ_v, τ) for the suction values of 25, 100, 300 e 500kPa are represented in Figure 5. The envelope considering suction of 0kPa, obtained through conventional direct shear tests in the submerged condition are also presented in this figure. It can be observed that the friction angles in general varied from 26,3° to 31,5°. The results indicate that the envelopes are linear, although not always parallel to each other, as have been proposed in literature (Fredlund et al. 1978; Alonso et al. 1990; Wheeler & Sivakumar 1995).



(Ua–Uw)= 0kPa	c = 9,7kpa	$\phi = 26{,}3°$	R^2= 0,996
(Ua–Uw)~ 5kPa	c = 9,8kpa	$\phi = 29{,}2°$	R^2= 0,977
(Ua–Uw)= 25kPa	c = 15,4kpa	$\phi = 31{,}6°$	R^2= 0,999
(Ua–Uw)= 100kPa	c = 36,5kpa	$\phi = 31{,}3°$	R^2= 0,991
(Ua–Uw)= 300kPa	c = 58,7kpa	$\phi = 31{,}5°$	R^2= 0,987
(Ua–Uw)= 500kPa	c = 74,7kpa	$\phi = 34{,}4°$	R^2= 0,956

Figure 5. Shear strength envelopes for different values of suction.

In the plain (s, τ) (Figure 6) a clear curvature in the shear strength envelopes is observed, which will result in the reduction of the ϕ^b parameter with the suction, according to what has been seen in various results in literature. In this plain the experimental results showed as being satisfactorily adjusted to the hyperbolic function presented by Gens (1993), presented in equation 1. Table 1 presents the parameters of hyperbolic adjustments for each vertical stress.

$$\Delta\tau_f = \tau_f - \tau_f^{\,sat} = \frac{s}{\cot g(\theta') + \frac{s}{c^*}} \qquad (1)$$

Where: s = Ua – Uw = suction matricial.

$$c^* = \frac{c_{máx}}{r}$$

, where *r* is an adjusted parameter.

Results of literature (Fredlund et al., 1995 and Vanapalli et al., 1996) show that even the air entry value the soil resistance increases linearly with the suction. From this value, the resistance increases in a non linear way until the suction corresponding to residual water content, from which the increase in the resistance becomes insignificant. The soil-water characteristic curve (Figure 4) referent to sample where resistence tests, were carried out, with suction controlled, suggested air entry value in the order of 1kPa. This low suction value in the air entry value, justified the non linearity observed in the envelope in the plan (s, τ) (Figure 6). It is verified that the resistance are still to be found elevated with the rise the suctions, suggesting that residual stage has still not been reached. In the figure 7 is also presented results of mature residual soil of granite from Cabo de Santo Agostinho by Lafayette (2006). Similar results in residual soils from Rio de Janeiro can be found in Futai et al. (2007) and Barreiras Formation from Pernambuco (Coutinho et al., 2006).

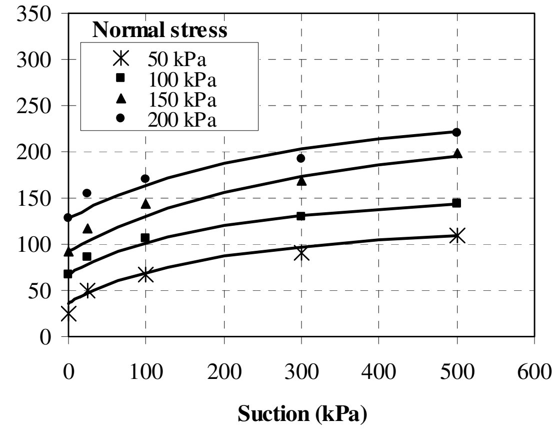


Figure 6. Shear strength envelopes in the space (s,τ) adjusted according to the hyperbolic function used by Gens (1993).

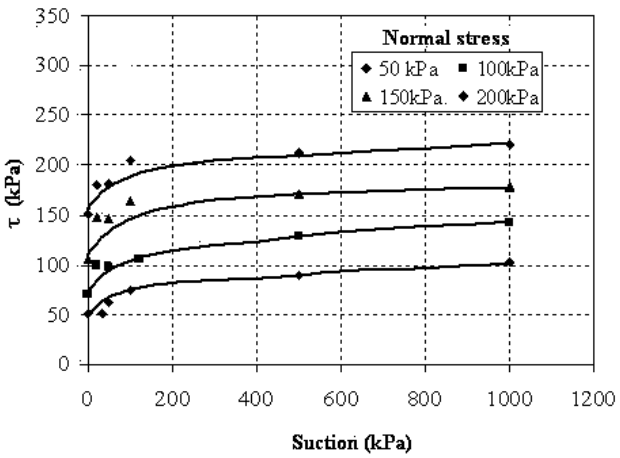


Figure 7. Shear strength envelopes in the space (s,τ) adjusted according to the hyperbolic function used by Gens (1993) – mature residual soil of granite (Lafayette, 2006).

Table 1. Parameters of adjustment of the hyperbolic function in Figure 5 for each normal stresses.

ϕ'(°)	σ_n (kPa)	τ^{sat} (kPa)	c^* (kPa)
26,3	50	36,29	103,3
	100	67,48	110,0
	150	92,22	179,0
	200	127,53	153,5

3. CONCLUSIONS

The work presented here had the objective of knowledge regarding the geomecanics characteristics of a mature residual soil of granite that was involved in a mass movement. Through the determination of the physical characterization, soil-water characteristic curve and shear strength with suction control it was possible to contribute to a better understanding of the behaviour of the unsaturated condition of this material. The good result obtained for the soil water characteristic curve show that the three methods (filter paper, Haines funnel and Richard´s chamber), were considered adequate for determination of the entire curve (including the low suction values), indicating that these techniques should be used simultaneously and more frequently in geotechnical investigations. The results obtained through the direct shear tests with controlled suction showed friction angles varying from 26,3° to 31,5°, presenting linear shear strength envelopes. Curvature was observed in the shear strength envelopes in the s, τ, plain which resulted in the reduction of the ϕ^b parameter with the suction. The experimental results showed to be satisfactorily adjusted by the hyperbolic function presented by Gens (1993).

4. REFERENCES

Alheiros, M. M. 1998. Riscos de Escorregamentos na Região Metropolitana do Recife. *Tese de Doutorado em Geologia Sedimentar,* UFBA, Salvador-BA.

Alonso, E.E; Gens, A. & Josa, A. 1990. A construtive model for partially saturated soils. *Geotechnique*, vol. 40, n°3, 405-430.

Bastos, C. A. B. 1999. Estudo geotécnico sobre a erodibilidade de solos residuais não saturados. *Tese de Doutorado*, UFRGS, 296p.

Bandeira, A. P. N 2003. Mapa de Risco de Erosão e Escorregamento das Encostas Ocupadas do Município de Camaragibe-PE. *Dissertação de Mestrado*, UFPE Engenharia Civil, Recife-PE.

Camapum de Carvalho & Leroueil, S. 2004. Curva característica de sucção transformada. *Solos e Rochas*, ABMS, 27, (3),.231-242.

Coutinho, R. C.; Souza Neto, J. B.; Santos, L. M. & Lafayette, K. P. V. 2006. Geotechnical Characterization of an unsaturated soil in the Barreiras Formation, Pernambuco-Brazil. Unsaturated Soils of on Conference.

Escário, V. e Sáez, J. 1986. The shear strength of partly saturated soils. *Geotechnique*, V.36, nº 3, p. 453-456.

Franchi, J. G. 2000. Aplicação de turfa na recuperação de solos degradados pela mineração de areia. *Dissertação de mestrado*. Escola Politécnica da Univer. de São Paulo, SP. 105 p.

Fredlund, D.G.; Vanapalli, S.; Xing, A.; e Pufahl, D.E. 1995. Predicting the Shear Strength Function for Unsaturated Soils Using the Soil-Water Characteristic Curve. *Proc. of the 1ost Internat. Confe. on Unsaturated Soils*, Paris, France, p.63-69.

Fredlund, D. G.; Morgenstern, N. R.; Widger, R. A. 1978. The shear strength of unsaturated soils. *Canadian Geotechnical Journal*, v.15, n.3, p.313-321.

Futai, M.M., Almeida, M.S.S. & Lacerda, W.A. 2007. The laboratory behaviour of a residual tropical soil. *Characterisation and Engin. Properties of Natural Soils* – Tan, Phoon, Hight & Leroueil (eds) Taylor & Francis, London, Vol. 4, pp. 2477-2505.

Gens, A. 1993. Shear strength. Unsaturated soils: Recent Developments and applications, *Civil Engineering European Courses* – Programe of Continuing Education, Barcelona.

Lafayette, K. P. V. 2006. Estudo geológico – geotécnico do processo erosivo em encostas no Parque Metropolitano Armando de Holanda Cavacalti – Cabo de Santo Aostinho / PE. *Tese de Doutorado*. UFPE. Engenharia Civil, Recife-PE.

Libardi, P. L (1995). Dinâmica da água no solo. Piracicaba, O autor.

Marinho, F. A. M. 1995. Medição de sucção com método do papel filtro. *Anais do Congr. Brasileiro de Mecânica dos solos e Engen. de Fundações*, 10, Foz do Iguaçu, ABMS, p. 515-522.

Silva, M. M. & Coutinho, R. C. 2007. Caracterização geotécnica de um solo não saturado da Formação Barreiras envolvido num movimento de massa em Camaragibe – PE. *VI Simp. Brasileiro de Solos Não Saturados*, Bahia, v.1. .391 – 398.

Vanapalli, S. K.; Fredlund, D. G.; Pufahl, D. E. 1996. The influence of soil structure and stress history on the soil – water characteristic of a compacted tell". *Geotechnique*, 49. 143-159.

Wheeler, S.J. & Sivakumar, V. 1995. An elasto-plastic critical state framework for unsaturated soil. *Geotechnique*, v.45, n°1, 35-53.