The Drying Behavior of a Disturbed Soft Clay

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2011 Pan-Am CGS Geotechnical Conference

ABSTRACT
To make some improvement in Santos Harbor (SP), Brazil, it is mandatory, for environmental reasons, to use contaminated underwater soft clays as a backfill material. The soft clay, which is treated with a polymer to induce its flocculation, is placed into geotextile bags (geotubes). In one such geotube, which is exposed to climatic conditions for 8 months, geotechnical tests were performed to characterize the soft clay and obtain its undrained shear strength and drying features. Data associated with the soil water retention curve of the material were obtained and helped to interpret the behavior of the clay during drying (including the induced fissures). The results of the development of the suction and the increase in the undrained shear strength of the material, as determined by a mini-vane, are also presented. In addition, evaporation experiments simulating the bare clay, the clay within the bag and the clay covered with sand demonstrate the effect of the cover on the drying behavior of the clay.

RÉSUMÉ
Pour la mise en œuvre de certaines zones dans le Santos Harbor (SP), Brésil, il est obligatoire, pour questions environnementales, à utiliser argiles molles contaminés comme matériau de remblai. L'argile molle, traités avec un polymère pour provoquer sa floculation, est placé dans des sacs en géotextile (Geotube). Dans l'une de ces Geotube, exposés à condition climatique pendant 8 mois, essais géotechniques ont été réalisées pour caractériser l'argile molle et obtenir sa resistance au cisaillement et leur caractéristiques de séchage. La courbe de rétention en eau a été obtenu et a contribué à l'interprétation du comportement de l'argile au cours du processus de séchage. Résultats de l'évolution de la succion et l'augmentation de la résistance au cisaillement du sol sont également présentées. En plus des expériences d'évaporation illustre l'effet de la couverture sur le comportement au séchage de l'argile.

1 INTRODUCTION

Drying materials is extremely common in the chemical, pharmaceutical, agriculture and paper industries, among others. In geotechnical engineering, this process is usually unwanted, particularly when dealing with plastic materials. Crack formation can result in increased compressibility and air and water permeability and reduced shear strength.

This work concerns a soft clay that was deliberately placed within a geotextile bag to allow its rapid drainage, which increased its shear strength and reduced its compressibility. The material was placed in the geotextile bag above water level and exposed to the climatic conditions at the coast of São Paulo State, Brazil. For eight months, the bag and the material were allowed to drain via gravity and evaporation. The soil that was placed in this manner was probably subjected to ripening, as described by Kim et al. (1993), but this will not be investigated here. An interesting review of clay structure due to dry and wet cycles is also presented by Kodikara et al. (1999).

The cross-section of the bag before opening was elliptical, with a maximum height of approximately 1.8 m. Figure 1 illustrates the condition of the material after the bag was opened and after the position of the "undisturbed" block was measured. The maximum size of the cracks was on the order of 6 cm, and the cracks reached a depth of approximately 0.7 m.

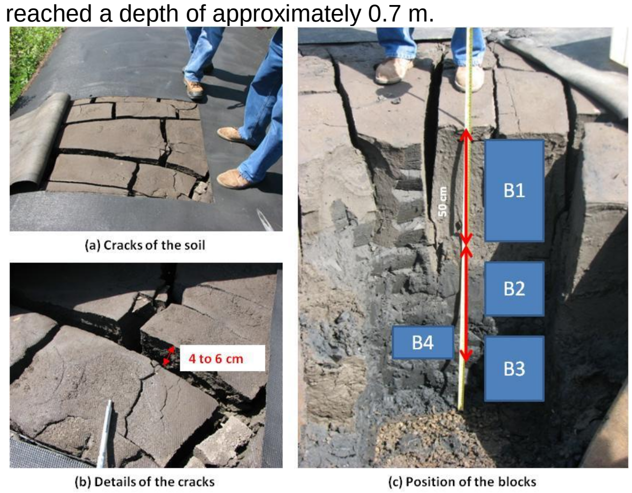

Figure 1 – Views of the material inside the geotextile bag, showing cracks and the position of the samples tested.

2 SOIL SHRINKAGE

When a compressible saturated soil is allowed to lose water via evaporation, its volume is reduced by the same amount as the water lost. This process is exactly the same phenomenon that occurs during isotropic consolidation due to mechanical compression.

Figure 2 presents the relationship between the volume per 100 g of dry soil vs. the water content. During the drying of a compressible soil with a high water content (e.g., at the liquid limit), the volume will be reduced following the line for a 100% degree of saturation. During drying, the suction is increased, and the grains start to approach one another. A point is reached at which the reduction in volume is not equal to the volume of water lost. This point is called the air entry point. At this point, the soil starts to desaturate.

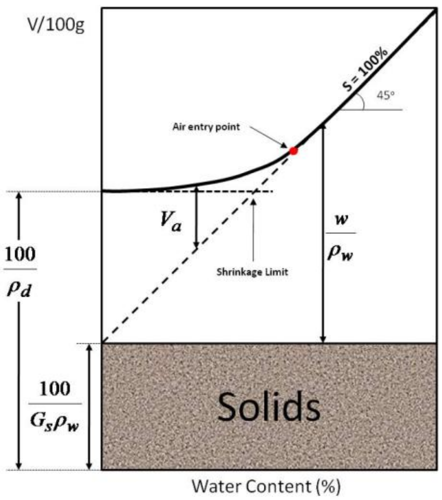

Figure 2 – Idealized drying behavior of 100g mass of dry soil (Marinho, 1994).

Before the soil reaches the desaturation point, the void ratio reduction is due to an increase in the effective stress because the soil remains saturated. Afterward, the increase in suction and the reduction in the void ratio are not controlled by Terzaghi's effective stress principle.

The soil within the geotextile bag is subjected to various degrees of drying, depending on its position. The position is related to both the top surface and lateral sides of the bag.

3 SOIL CHARACTERISTICS

The soil is a mangrove clay that was sedimented along the channel of the port of Santos in the last few centuries. The environmental characteristics of the clay required that the material be placed inside geobags. During the placement of the soil inside the bag, the material was mixed with a polymer that was used to flocculate the clay. Grain size distribution tests were performed on three samples. The tests were performed with or without a defloculant (as prescribed by most standards). Figure 3 presents the grain size distribution of the soil, which shows a large difference between the curves when the defloculant was used.

Table 1 presents the liquid and plastic limits of the material and its organic content. Based on the results of the characterization tests, the clay was classified as an organic clay with a high plasticity.

Table 1 – Characteristics of the soil after its placement in the geotube.

Sample	w_l (%)	w_p (%)	Organic content (%)
B1	128.6	53.6	11.10
B2	142.2	68.7	9.96
B3	125.3	59.2	10.60

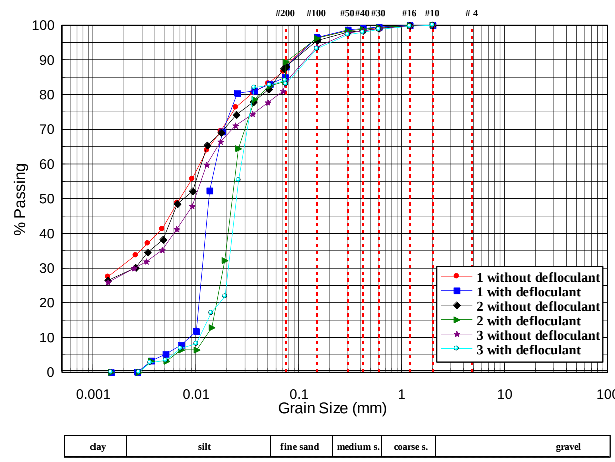

Figure 3 – The grain size distribution of the clay tested.

Figure 4 presents the suction, void ratio, water content and degree of saturation of the specimens subjected to the mini-vane test, which were taken from sample B2. The results of the vane test are shown in Session 6. Each specimen was subjected to suction that was induced by a suction plate (up to 30 kPa) and a pressure plate (up to 500 kPa). The end of the curve was incompletely characterized, and the shrinkage limit could not be definitively identified using this test.

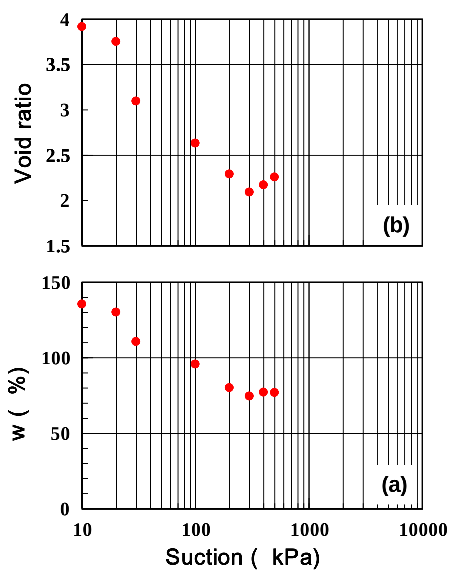

Figure 4 – The soil water retention of some specimens from sample B2.

4 DRYING BEHAVIOR

4.1 “Undisturbed” soil

The clay tested was considered to be disturbed because its placement inside the bag required the complete loss of its structure. The “undisturbed” condition refers to the material placed within the geotextile bag, which differed from the original condition of the clay in the seabed. To evaluate the drying behavior of the soil within the bag, three specimens from samples B1, B2 and B3 were trimmed and allowed to air-dry. During drying, the volumes of specimens were obtained using vernier calipers. The results indicated that the soil remained saturated down to a water content of 60%, which can be observed in Figure 5a. The volume of the material did not stop decreasing until it was completely dry. As shown in Figure 5b, the reduction in the water content was associated with the time. Air-drying was performed in a laboratory, where the relative humidity was approximately 60% (average).

Given that the water content at which the volume started to decrease its rate of reduction was about 60%, it is possible to state that the specimens shown in Figure 4 were all saturated and had not reached the shrinkage limit.

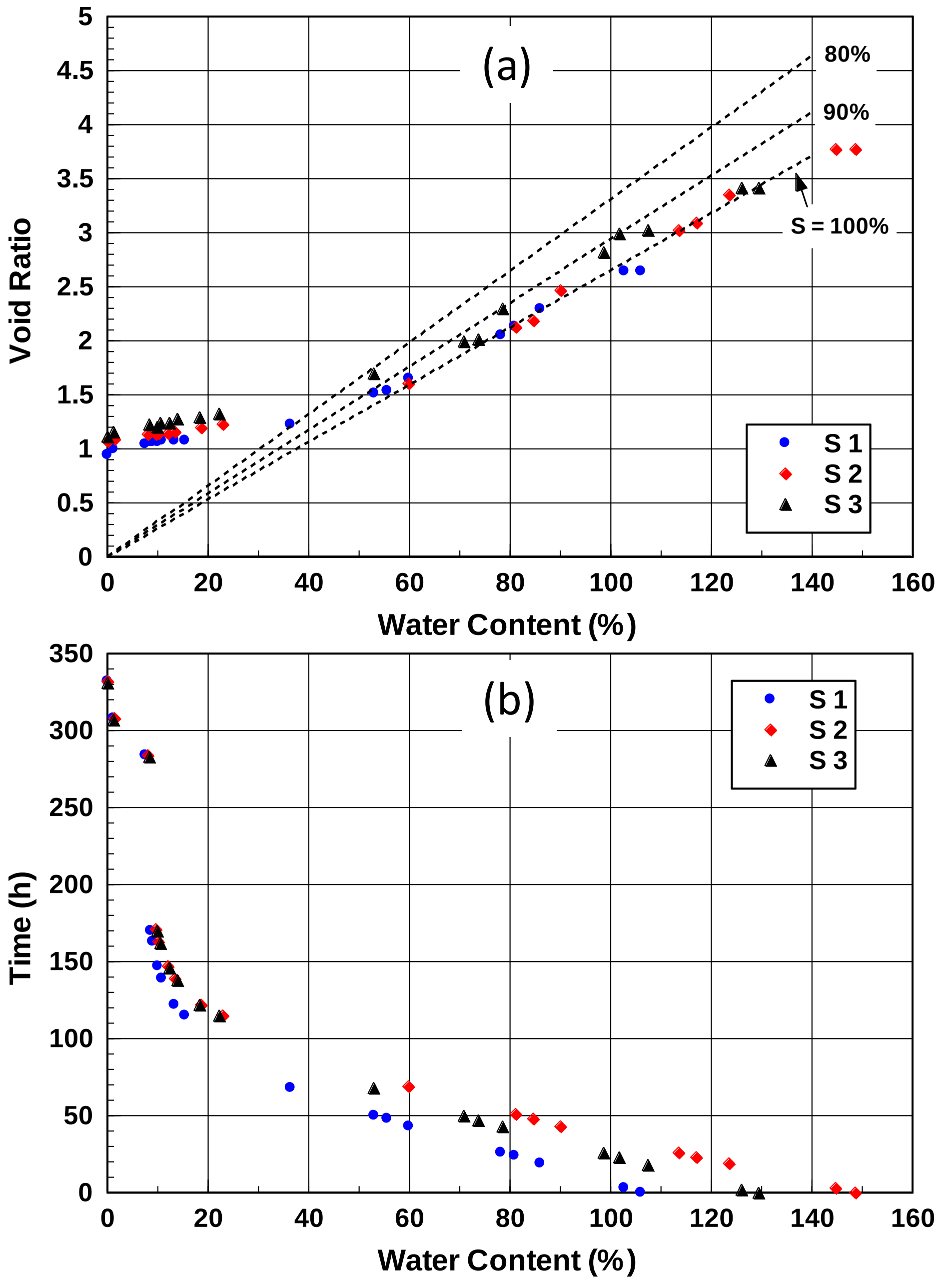

Figure 5 – The drying behavior of the “undisturbed” material.

Figure 6 presents the results of the oedometer tests performed on the specimens from sample B2 and the data for the specimens used for the vane test that are presented later in this paper. The results of the oedometer test are shown in terms of the vertical stress and octahedral stresses. K_o was assumed to be 0.6. The points associated with the suction are not from the same specimen, and the volume measurements were inaccurate. However, the trend indicates that the soil followed the consolidation curves, as expected.

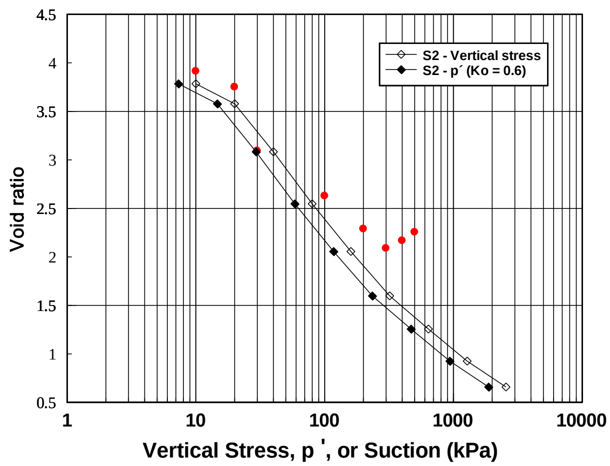

Figure 6 – The oedometer test and the state of the vane test specimens.

4.2 Remolded soil

The remolded soil is the material taken from the geotextile bag and mixed with distilled water. In the field, the geotextile bag was exposed to atmospheric conditions, and the soil within the bag may have dried and created an excessive system of cracks, as mentioned above, that would have induced macro-compressibility. To investigate the drying behavior of the material with no cover (or protection), with a geotextile net and with sand, reconstituted soil was used.

The soil was thoroughly mixed with a water content of 180%. The material was placed into three plastic containers (closed at the base) that allowed free evaporation at the top. Two of the containers were covered. In one container, the same geotextile as the bag was used, and in the other, uniform medium sand was used to cover the soil. The third container was open to the atmosphere, with no cover. Figure 7a presents a photo of the three containers and the change in water content during drying with time. In Figure 7b, the temperature and relative humidity during the test are indicated. The relative humidity oscillated between 40 and 80%, and the temperature varied from 5°C to 30°C. It can be observed from the results that the bare soil dried more quickly than the other soils. The soil covered with the geotextile net exhibited a significant reduction in its rate of evaporation. In all of the cases, the minimum water content reached was approximately 10%.

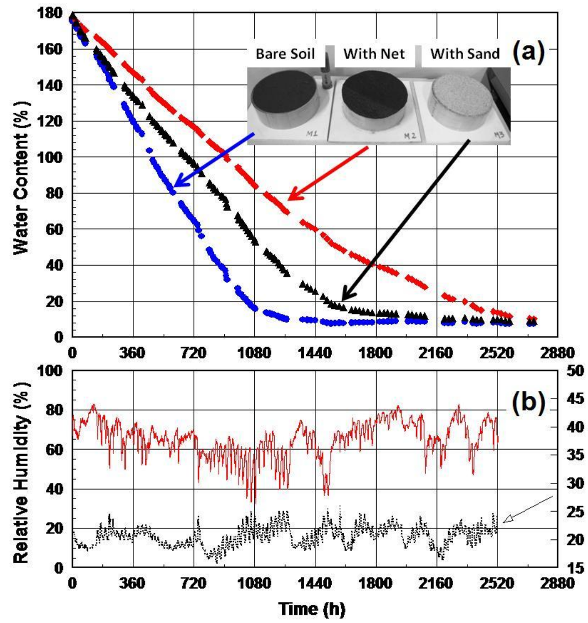

Figure 7 – The drying behaviors of three cover conditions.

5 THE UNDRAINED TEST IN THE “UNDISTURBED” SOIL

The undrained shear strength was obtained using a mini-vane. Testing was performed directly on the “undisturbed” block samples, without trimming the specimens. The data associated with each sample are shown in Table 2. The samples were obtained from the positions shown in Figure 1.

Table 2 – The field conditions of the samples.

Sample	w (%)	G	e	γ_d (kN/m^3)
B1	99.3	2.65	2.720	0.712
B2	141.2	2.69	3.972	0.541
B3	130.3	2.75	3.717	0.583

The results obtained suggest that the sample that was closed to the atmospheric boundary had a higher undrained shear strength (S_u). The tests were performed at the top and at the base of each block sample. Figure 8 shows that the results obtained from the top of sample B1 produced an S_u of approximately 36 kPa and that the other samples produced an S_u that varied from 11 kPa to 23 kPa. All of the tests gave identical residual strength results, which varied from 0.5 kPa to 3 kPa. Each point shown in Figure 8 was determined by testing a different specimen (S).

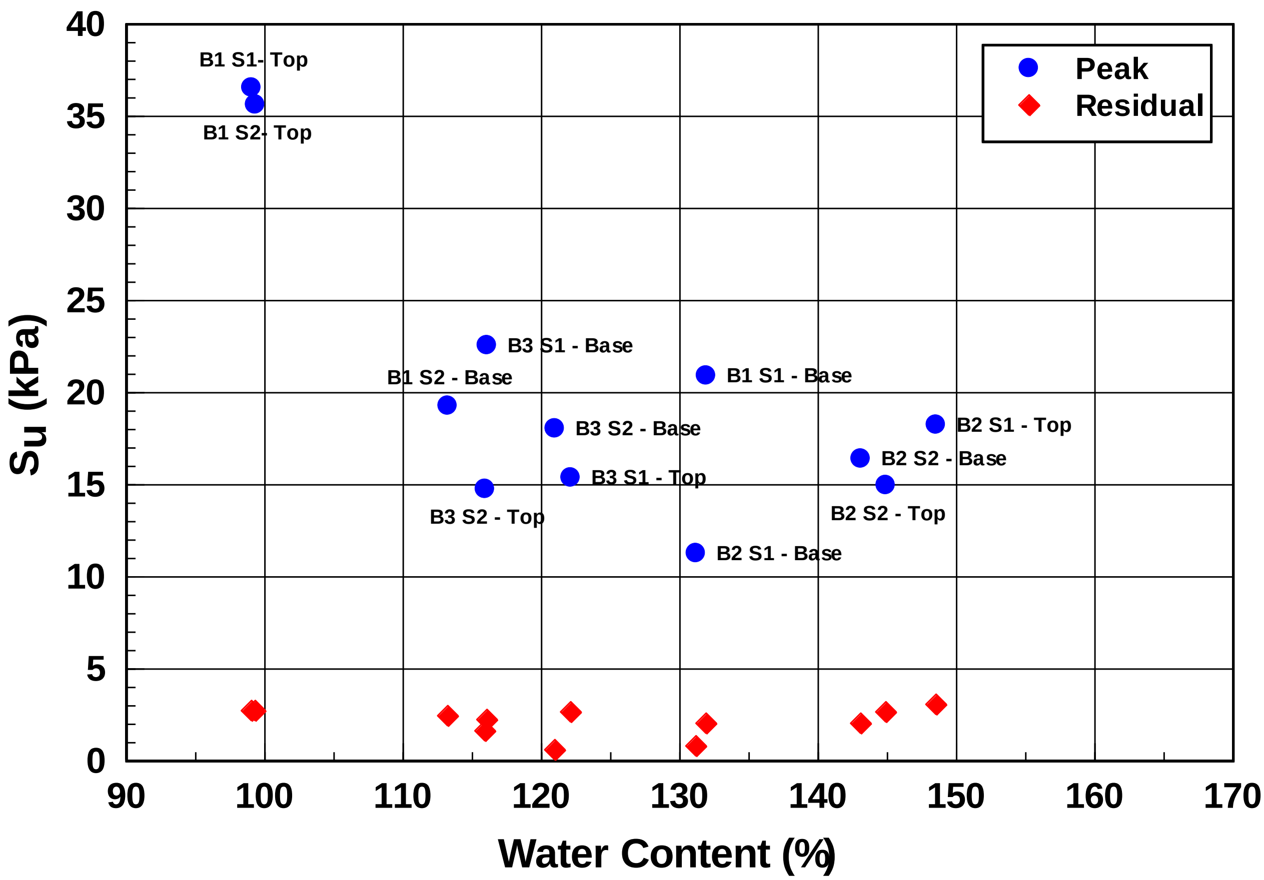

Figure 8 – Undrained shear strength vs. water content for the “undisturbed” specimens.

6 UNDRAINED SHEAR AND SUCTION

The increase in the soil’s shear strength is due to the reduction in the void ratio. Drying induces a reduction in water content that, in turn, generates a suction, which is responsible for the reduction in the void ratio. Undrained shear tests were performed on specimens trimmed from the top of sample B2 using the mini-vane.

The results of the undrained shear test are presented in Figure 9 as a function of the suction. The suction was induced using a suction plate and a pressure plate. The results show an increase in the S_u with an increase in the suction (a decrease in the water content) up to a certain level of suction. The undrained shear strength increased up to 108 kPa, which was associated with a suction of 200 kPa, and then it started to decrease. This reduction in the shear strength is probably associated with the failure mode of the mini-vane test and not an actual reduction in the S_u.

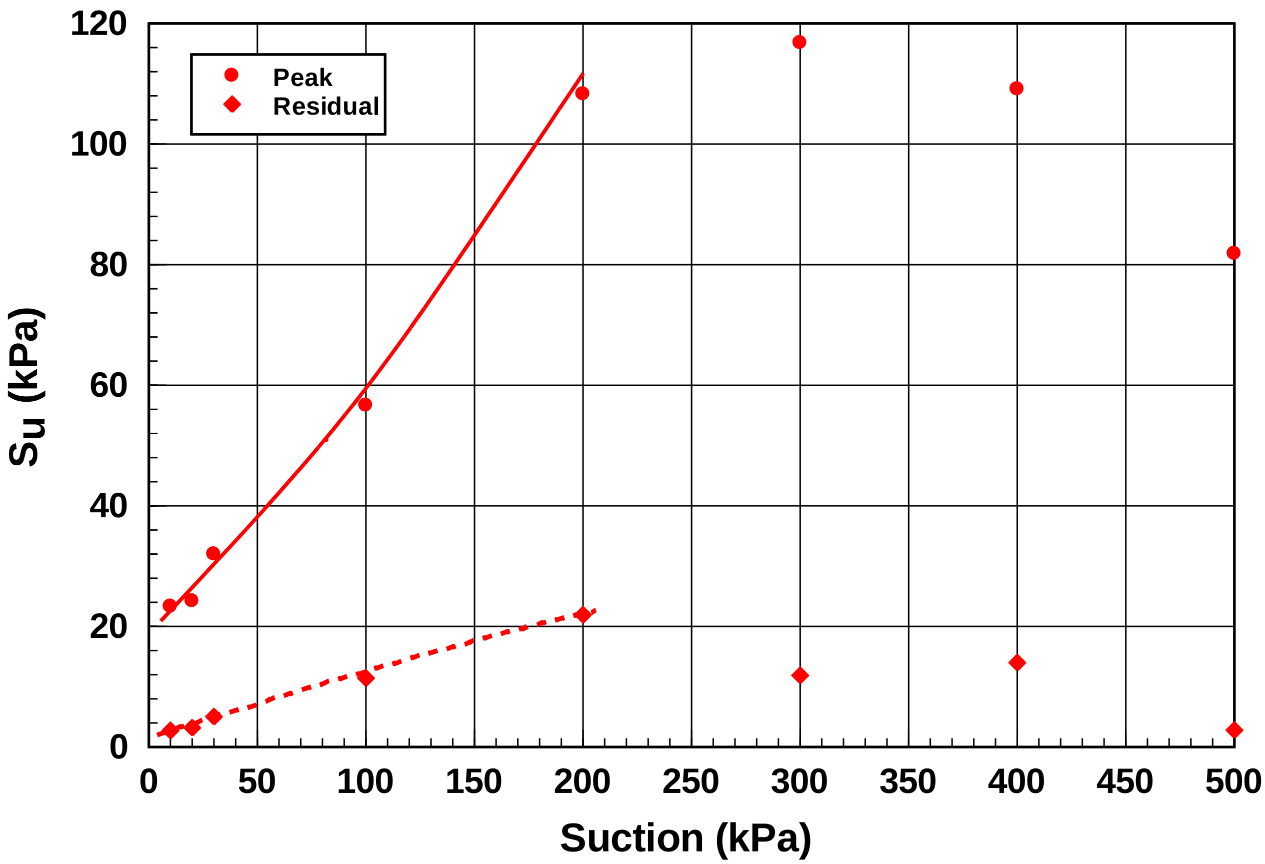

Figure 9 – Undrained shear strength vs. suction.

7 CONCLUSIONS

The soil responded to drying by reducing its volume and increasing its undrained shear strength.

The drying induced in the upper part of the geotube was reflected in the maximum value of the undrained strength (S_u) obtained using the mini-vane. The dry part of the soil had an S_u of approximately 36 kPa. In the remaining portions, the S_u ranged from 11 kPa to 23 kPa. The residual strength was significantly reduced (between 0.5 and 3 kPa).

The air-entry suction of the material was approximately 200 kPa. Although the shrinkage limit was approximately 60%, the actual volume of the material did not stop changing until the soil was completely dry.

The vane-test apparatus was able to record an increase in the undrained shear strength up to a suction of approximately 200 kPa.

The presence of the geotextile reduced the evaporation compared to the situation in which the soil was directly exposed to the atmosphere or when sand was used to cover the soil. The use of sand on top of the geotextile was not investigated. However, this may decrease evaporation even more. It should be noted that evaporation may help increase the shear strength and reduce the compressibility. Evaporation can be monitored to avoid the creation of macro-cracks.

ACKNOWLEDGEMENTS

The authors would like to thank the Polytechnic School of São Paulo University and Eng. Leo César Q. C. Melo for his support.

REFERENCES

Kim, D. J.; Feyena, H. Vereeckenb, D. Boelsc, D. And Bronswijkc, J. J. B. (1993) Quantification of physical ripening in an unripe marine clay soil. Geoderma Volume 58, Issues 1-2, pp. 67-77.

Kodikara, J., Barbour, S. L., Fredlund, D. G. (1999). Changes in clay structure and behaviour due to wetting and drying. Proceedings of the 8th Autralian-New Zealand Conference on Geomechanics, 179-186.

Marinho, F. A. M. (1994). Shrinkage behaviour of some plastic soils. PhD Thesis. Imperial College. 216p.