Saturation studies of tropical residual soils – special laboratory tests

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ABSTRACT: In this study, the pairwise correlations between water content and suction of a residual soil in Rio the Janeiro state were investigated. The residual soil was characterized and includes the determination of physical indexes, unit weight, plasticity, grain size, porosity, and the characteristic curve of water retention. The study was performed with three lysimeters. Equipment such as automated tensiometers, an equi-tensiometer, TDR and an adapted system to measure the suction using a filter paper, were used, as well the automated devices. Cycles of wetting and drying in the lysimeters were simulated. The results were compared to the characteristic curve and showed good correlation. The behavior of the studied devices was good. The low presence of clay in this soil, around 7%, was important for its water retention. The equilibrium time of the soil water content and the filter paper used in the test, Whatman Nr. 42, obtained in intervals of 15 days, presented better results than the weekly intervals (seven days). The equi-tensiometer EQ2 compared to the filter paper presented efficient results for high suction values. This study also presents relevant information about residual soils under unsaturated conditions.

1 INTRODUCTION

The results were obtained after laboratory tests in a tropical unsaturated soil with the support of mini-lysimeters installed in this soil. The suction measurements were performed using an equipment designed by UFRJ in addition to other instruments. This instrument measures suctions over 100 kPa. Ridley and Burland (1993) designed a tensiometer to measure suctions over 100 kPa. The designed model worked very well and it cost little capital to build. The equipment used allows the suctions to be measured quickly. The equipment used included a ceramic stone of 1.5 bar, pressure sensors, dehydrated water and a special acrylic tube designed specifically for this instrument. The results were compared with two simple automated tensiometers and equi-tensiometers. The correlation between plant-soil-water-air is very important. The parameters associated with moisture, soil water quantity and suction are essential for geotechnics, agriculture and soil science. Thus, it is crucial for areas such as soil erosion, slope stability, soil compaction and mineral barriers in landfills. Many researchers have noted that loss of suction may be a cause for rupture of excavations and slopes. Therefore, suction is a significant part of the shear strength of unsaturated soils. In recent years, several instruments have been developed to measure soil matrix suction. The work done by Ridley and Burland (1993) is an example of this development, which showed that with a tensiometer built under special conditions, the limit of 1.0 atmosphere could be overcome. They observed that, in order to avoid cavitation near 100 kPa, it would be necessary to: minimize water volume, use de-aired water, avoid roughness on the internal surfaces of the tensiometer, use a porous stone with high air inlet pressure, use a quick response transducer with good ability to support high stresses. In addition to soil conditions, this paper discusses a variation of Ridley and Burland's (1993) system on the development of a tensiometer. A 15-bar porous ceramic stone was used in conjunction with an AshcraftR transducer (model K8) and a transparent acrylic tube, specially designed and developed for this study. The system was saturated in vacuum and then calibrated, adjusting the appropriate parameters of the constitutive model with the use of an element test program, which can simulate the test result under the same conditions as a realistic test in positive pressure range. They were installed in equal depths in the mini-lysimeter and connected to a data logger.

2 MATERIALS AND METHODS

2.1 *Materials*

2.1.1 *Automatic Tensiometer T4 (UMS)*

The T4 automatic tensiometer (UMS) was produced in Germany. It has high resolution in continuous soil suction measurements (Figure 1). Its main attribute is the ability to provide data quickly, but it measures the suction only up to 85 kPa. The specimen is made of acrylic and the transducer is located near the porous stone. The T4 automatic tensiometer (UMS) is 5 cm long and it uses a 2 cm diameter ceramic stone. The measured stress is converted into electrical signals (mV) by a conversion factor in kPa according to the calibration curve provided by the manufacturer.

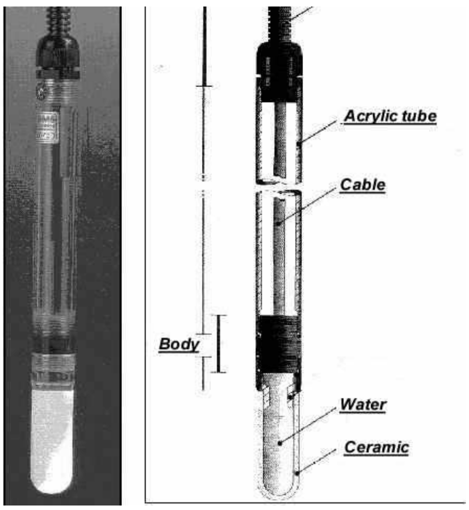

Figure 1.T4 Automatic Tensiometer(UMS).

2.1.2 *T5 Automatic Mini-Tensiometer(UMS)*

The T5 automatic mini-tensiometer (UMS) was also produced in Germany and measures suction up to approximately 150 kPa. The system includes a diaphragm, porous stone and manometer (Figure 2). Similar to the T4 tensiometer, it is also easy to be adapted for use with an automated measuring system, such as a data logger. It is made of acrylic with plastic connectors and it also provides data quickly. The T5 automatic mini-tensiometer (UMS) is 8 cm long and it uses a 5 mm diameter ceramic stone. The surface contact area with the soil is 0.5 cm^2. The sensor is located far from the porous stone. The measured stress is converted into electrical signals (mV) by a conversion factor in kPa according to the calibration curve provided by the manufacturer.

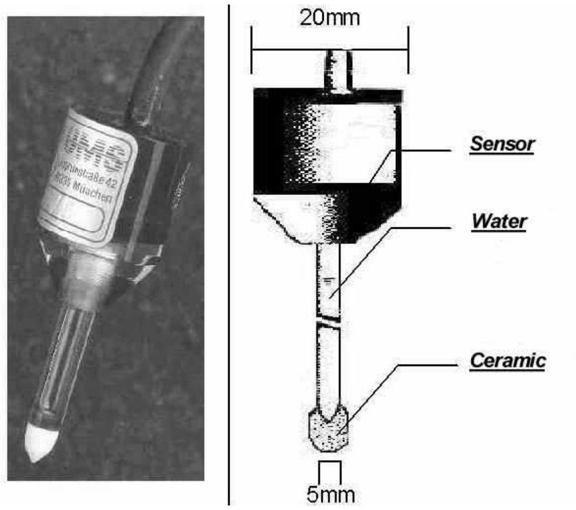

Figure 2. T5 Automatic Mini-Tensiometer (UMS)

2.1.3 *TDR (ML2 - DELTA - T)*

The TDR (ML2 - DELTA - T) was produced in England. It measures the moisture content, considering the apparent dielectric constant. Electromagnetic waves through the rods produce analogue pulses that are measured and converted to voltage (mV) proportional to the moisture content. Theta ML2 is a Time Domain Reflector (TDR). The TDR includes a wave generator that releases electromagnetic pulse to three steel bars. It is sensitive to changes in water content between the rods. The TDR releases the portion of energy from electromagnetic pulses that are reflected back from the bars to the generator. The time period between the reflection of the pulse through the soil and the final reflection back to the pulse can be measured as waves and transformed into water content in the soil. (Figure 3).

Figure 3.Time Domain Reflector (TDR) [Delta – T Devices].

2.1.4 *Equi-tensiometer*

The equi-tensiometer was produced in Germany. It is a TDR built into the specimen of a special porous material. It measures the amount of water, which is balanced with the potential of the soil matrix. The domain of this equipment is between 0 and -1000 kPa with a more precise measurement for values of stress greater than -100 kPa, in absolute value. It allows a precision level of 5% and each instrument has its calibration curve set to convert the measured mV values into kPa (Figure 4).

Figure 4.Equi-Tensiometer (EQ2) [Delta –T Devices].

2.1.5 *Tensiometer TNV (Mahler and Gonçalves)*

In order to develop the new tensiometer, the principles proposed by Ridley and Burland (1993) were applied. However, the design used an acrylic tube, especially because it allows low roughness, is inexpensive and easy to prepare (Diene & Mahler, 2007 and Mahler, 2007). The established thickness of the acrylic used was such that it could resist the high pressures during saturation of the porous stone. It was observed that the design of the acrylic specimen was easily adaptable to the saturation chamber, to the dimensions of the porous stone and to the transducer employed. This equipment consists of a single acrylic part, which on one side has the porous ceramic stone and, on the other, the transducer, which is fixed and can be easily changed (Figures 5, 6 and 7). The transducer used provided electrical signals between 6 and 18 mV / V. The system must be calibrated. A porous stone of 15 bar was used. The measurements of the porous ceramic stone chosen were 20 mm in diameter and 6.5 mm in thickness.

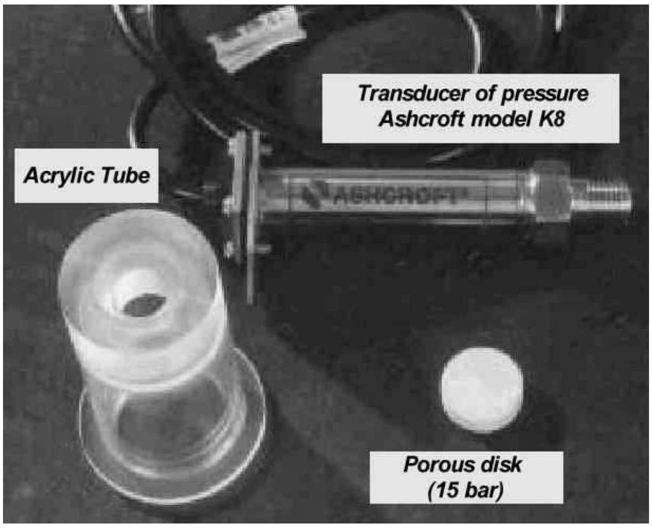

Figure 5.Components of the new instrument.

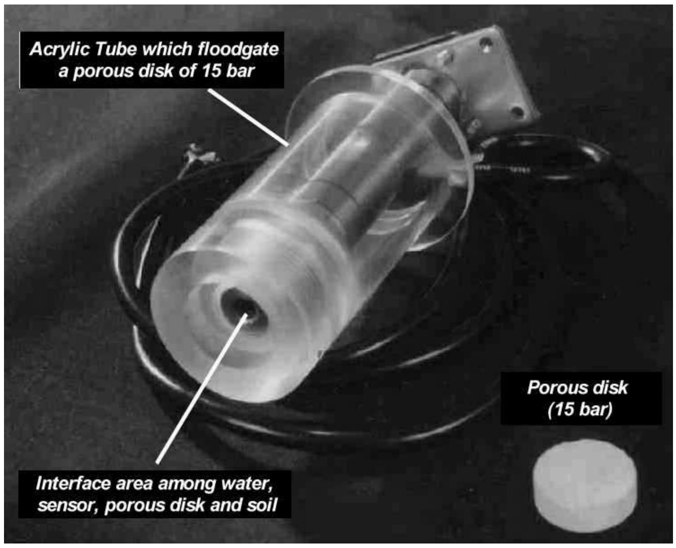

Figure 6.View of the interface area between water, sensor, porous disk and soil.

The saturation was performed with de-aired water, using the vacuum application in the system to remove possible bubbles (Mahler, Pachego and Gonçalves, 2002). Pressure cycles were applied, from positive to zero. During this procedure, maximum effort was made to avoid cavitation of the system. It was necessary to cause flow through the porous stone. The water was pressurized which created a downward flow through the stone. For a 15 bar stone, high pressures are required to ensure saturation. In this case, a special calibration chamber was developed to saturate and calibrate the system that was connected to a vacuum pump. The saturation procedure consisted of five steps, as follows:

- Placing the porous stone (already in the acrylic specimen) inside the chamber and the piezocone attached to the chamber, with an additional aspiration for 13 hours;

- Saturation of the porous stone and piezocone with distilled water aspired by the vacuum;

- Application of vacuum and water flow for two hours;

- Forming the new equipment by placing the transducer in the water instead of the piezocone;

- The chamber is filled with distilled water and the charge and discharge pressure cycles are applied in pre-set stages. These cycles were adopted to observe the initial behavior of the sensor and to calibrate it. This was achieved with the support of a volt ammeter. The responses were very fast (four seconds), so the new tensiometer also provides data quickly (Mahler, Pacheco and Gonçalves, 2002).

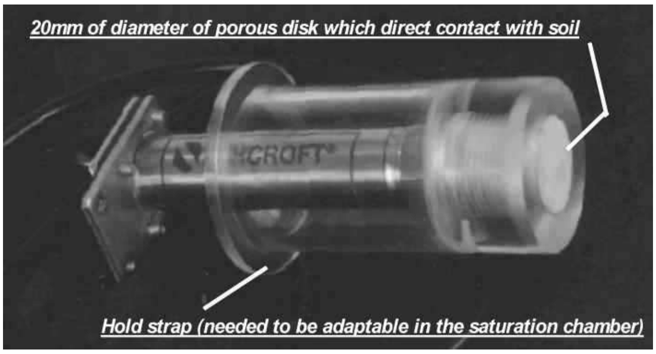

Figure 7.Tensiometer Mahler and Gonçalves

2.1.6 *Mini-lysimeters*

Lysimeters are used to study the correlation between water, soil, plants and the environment. A field lysimeter is a system that consists of a soil-filled box, usually buried, that has a drainage collector capable of monitoring weather conditions (precipitation, air temperature, air humidity, wind) in a way that can determine with precision the water balance of the study region (Saint Arnold). In addition to the control of the water in the capsule, entering and exiting the lysimeter, meteorological environmental conditions and direct measurements in situ, such as matrix suction, should be controlled. Mini lysimeters follow the same principles. A polystyrene bucket with a capacity of 120 l, 50 cm in height, 40 cm in diameter at the base and a diameter of 60 cm at the top was used. The construction created the conditions required at the bottom of the pan to ensure drainage (small stones with geosynthetic between rocks and soil) (Mahler et al, 2001). The instrument was installed in the soil, at a distanceof 10 cm from the pot and 15 cm from the edges. The initial porosity of the soil was approximately 35%. Two other mini-lysimeters used were rectangular with dimensions 1.60x0.60x0.60 m.

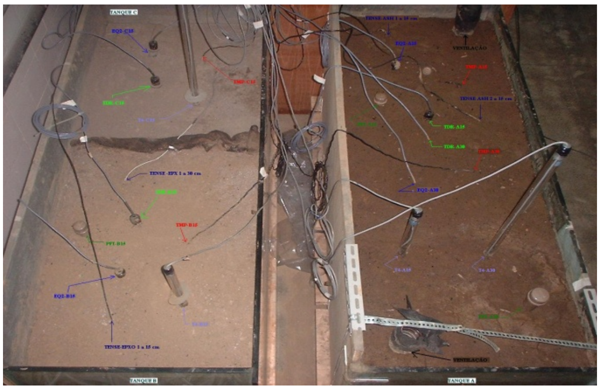

Figura 8. *Rectangular mini-lysimeters*

2.1.7 *Soil Characterisation*

The soil used was collected near Rio de Janeiro and can be characterized as silt and sand, with around 70% sand, 23% silt and only 7% clay. The description of the soil preparation and the subsequent placement in the pot can be seen in Mahler et al (2001). The moisture content was approximately 20%, very close to the field capacity.

2.2 *Methods*

The methods used included the construction of mini-lysimeters, soil filling with compaction processes, temperature and environmental conditions control, instrument placement, datalogger connection, addition of water to the lysimeters with monitoring of the instruments, drying with monitoring of the mini-lysimeters, wetting again, and other.

3 RESULTS

Figure 9 presents results of the TNV tensiometer in comparison with the measurements obtained by T4 and T5. As the T4 and T5 tensiometers showed good performance in the 0 to 85 kPa range, their results were used as reference for these suction values. The values observed with the equi-tensiometers were used as reference in the interval between -85 kPa and -400 kPa. It was verified that up to 150 kPa the tensiometer T5 presented results very close to the values observed with equi-tensiometers and new tensiometer. Figure 10 shows the results of the new tensiometer and equi-tensiometers up to -350 kPa matrix suction. As one of the equi-tensiometers was placed vertically and the other in the horizontal position, they did not have exactly the same result for the matrix suctions, with values greater than - 50 kPa. The new tensiometer, when placed vertically, had values between the two equi-tensiometers, but closer to the values presented by the equi-tensiometer in the vertical position.

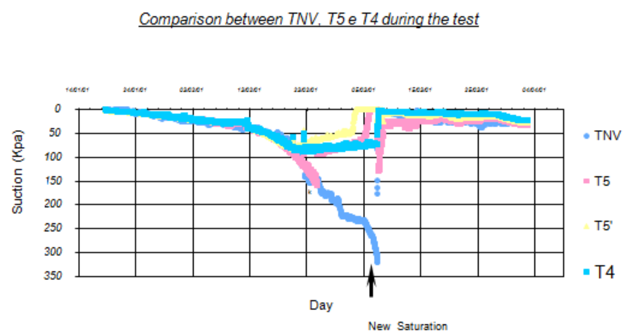

Figure 9. Results of the new tensiometer compared with the tensiometer T4 and T5.

Figure 11 shows values measured with the TNV tensiometer and the moisture content values measured with TDR. It is possible to construct characteristic curves for the soil with this results.(Mahler and Izzo, 2010).

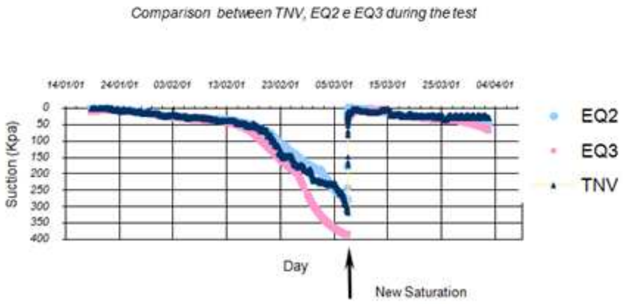

Figure 10. Results of the new tensiometer compared with the tensiometer T4 and T5.

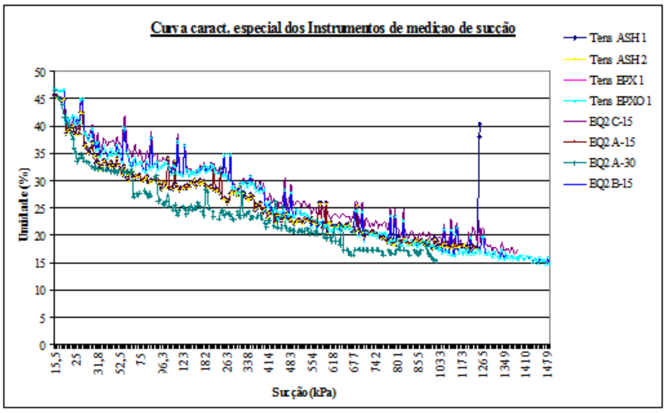

Figure 11.Correlation between the measurement of the new tensiometer and the TDR.

4 CONCLUSIONS

The results obtained were very satisfactory. The saturation process used for the ceramic stone worked very well. Furthermore, the tensiometer T5 measured values of more than 100 kPa (about 150 kPa) with enough precision.

Thus, the system proved to be a good alternative, efficient and inexpensive, for laboratory tests and for the development of instruments that measure suction and moisture.

For this tropical soil the results were positive, but it is not possible to say that other tropical soils, with different proportions of sand and clay, will have the same behavior. New studies should be done to compare other tropical soils.

5 ACKNOWLEDGEMENTS

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