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Improved SWCC results of sensitive non-plastic soils from modified filter paper testing

Amélioration des résultats de SWCC des sols sensibles non plastiques provenant de tests de papier filtre modifiés

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ABSTRACT: The major advantage of filter paper testing for determining a soil's SWCC is a reduction in testing time. However, a comparison of water retention test for filter paper testing (ASTM D5298), Transient Retention Imbibition's Method (TRIM) and Fredlund device illustrates that the SWCC from filter paper testing yields significantly lower suction values than either the TRIM or Fredlund device. The latter two experimental methods yield comparable results. Presented herein is a critical analysis of the filter paper test for sensitive non-plastic soils. The results indicate that sealed molds used with the ASTM standard filter paper test do not allow for the specimen to achieve an adequate equilibrium state and therefore skew matric suction values. To correct this shortcoming, an energy-based sample preparation method was implemented in conjunction with a newly designed mold, consisting of a #200 wire mesh, to allow for three-dimensional vapor flow. The redesigned filter paper test was conducted over a range of densities and sensitive non-plastic soils and compared to results obtained from the Fredlund device and TRIM systems. The results of this modification significantly improved the accuracy of the filter paper test while reducing the comparative testing time.

RÉSUMÉ: Le principal avantage des tests sur papier filtre pour déterminer le SWCC d'un sol est la réduction du temps de test. Cependant, une comparaison des tests de rétention d'eau pour le test du papier filtre (ASTM D5298), la méthode TRIM (Transient Retention Imbibition's Method) Les deux dernières méthodes expérimentales produisent des résultats comparables. Présentée ici est une analyse critique du test du papier filtre, pour les sols non plastiques sensibles. Les résultats indiquent que les moules utilisés pour le test du papier filtre standard ASTM ne permettent pas à l'échantillon d'atteindre un état d'équilibre adéquat et donc faussent les valeurs d'aspiration matricielles. Pour remédier à cette lacune, une méthode de préparation d'échantillons basée sur l'énergie a été mise en œuvre en conjonction avec un nouveau moule, constitué d'un treillis métallique n ° 200, pour permettre un écoulement de vapeur en trois dimensions. Le test de papier filtre redessiné a été réalisé sur une gamme de densités et de sols sensibles non plastiques et comparé aux résultats obtenus avec les systèmes Fredlund et TRIM. Les résultats de cette modification ont considérablement amélioré la précision du test du papier filtre tout en réduisant la durée des tests comparatifs.

Keywords: SWCC, matric suction, laboratory testing, filter paper test

1 INTRODUCTION

The filter paper method used to quantify matric and total suction is an economical and relatively simple laboratory test in use since 1937. The test is conducted by placing the filter paper in direct contact with soil. The contact method comes to equilibrium by fluid flow to the filter paper for matric suctions less than 1000kPa and vapor flow for matric suctions greater than this (Leong et al. 2002). After equilibrium between the soil and filter paper is reached the filter paper water content is correlated to suction through the use of a calibration curve.

Total suction is measured by placing the filter paper above the soil sample and the filter paper and soil come to an equilibrium state by vapor flow. Equilibrium time for the contact method is in the range of 7 days according to ASTM D5298. Equilibrium times for the non-contact method are greater than 30days for matric suctions less than 100kPa (Marinho and Oliveira 2006).

Hystersis between wetting and drying of the filter paper has been noted by multiple authors including Leong et al. (2002), Bulut et al. (2001), Acikel at al. (2015), Chandler and Gutierrez (1986), and Munoz-Castelblanco et al. (2012). As a result of hysteresis it is important to choose a calibration curve based on the initial conditions of the filter paper. If the filter paper is initially wet, a drying calibration curve must be selected; likewise a wetting curve is selected if an initially dry filter paper is used (Power et al. 2008).

Filter papers distributed by different manufacturers pose different affinities for water therefore each filter paper brand has its own unique calibration curve (Houston et al. 1994). It has also been identified by Houston et al. (1994) that Whatman No. 42 filter papers provide consistent test results from batch to batch. Acikel et al. (2015) presented a wetting calibration curve for Whatman No. 42 filter papers that exhibited the same reliability.

A testing program was conducted to ascertain the soil water retention properties of a silt, silty sand, and poorly graded sand. Remolded samples were prepared for each soil type and three methods of water retention testing were conducted to ascertain the soil water characteristic curve (SWCC). The Transient Retention Imbibitions Method (TRIM), GCTS Fredlund device, and the filter paper method were used to measure the SWCC.

The TRIM device uses axis translation and the transient response of two different matric suctions at high and low pressure. An inverse model is used to calculate the SWCC fitting parameters (Wayllace and Lu 2011). The GCTS Fredlund device also uses axis translation and measures the volume of water expended after each increment of matric suction is applied, (Padilla et al. 2005).

2 LABORATORY TESTING

2.1 Sample Preparation

The reconstituted samples were prepared using an energy based method as outlined in Taylor et al. (2017). This method was employed to prepare the samples in a highly repeatable manner allowing for the direct comparison of testing results from different devices. Also, this ensured that when preparing the filter paper specimen that a comparable soil fabric was present from specimen to specimen and that a representative SWCC could be constructed.

Test samples were reconstituted using four different applied energies:, 200, 300, 600, and 1000 kJ/m^3 Due to paper limitations and brevity, a representative dataset of the larger findings is presented herein using applied energies of 200 and 600 kJ/m^3 for ML and 200 and 300 kJ/m^3 for SP. While more data is available, the results do not impact the findings presented. Specimens reconstituted at each applied energy were tested using the TRIM, Fredlund and filter paper method. While the TRIM and Fredlund devices require only one specimen to develop a single SWCC curve, eight specimens were required to develop a complete SWCC curve using the filter paper method. This is because each specimen in the filter paper test represents only one measurement of suction, either total (non-contact method) or matric (contact method).

To illustrate the repeatability of this sample preparation method a probability distribution of the dry density of each specimen per soil type and applied energy is presented in Figure 1. The normalized dry density in Figure 1 is the dry density normalized with the mean dry density.

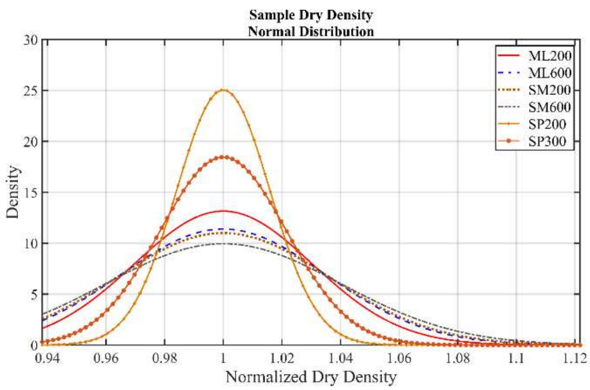

Figure 1. Probability distribution function of sample dry density.

2.2 Specimen Molds

The specimens for the Fredlund device were prepared in metal rings with an inside diameter of 5.06cm and a height of 3.17cm. The specimens for the TRIM device were prepared in an acrylic chamber that had an inside diameter of 6.15cm and specimen height was between 3.00 and 3.14cm.

Initially the filter paper specimen were constructed in a polyvinyl chloride (PVC) mold that had an inside diameter of 5.23cm and a total height of 6.00cm. When testing the poorly graded sand it was found that the specimens were not reaching equilibrium in the 14-day testing period. To speed equilibrium a novel sample mold was designed and fabricated. The mold was constructed with a coarse porous stone as a base and a flexible #200 wire mesh configured as a cylinder and attached to the base with epoxy.

The #200 screen allowed for a surface area of $120 cm^2$ compared to $21.5 cm^2$ for the PVC mold. This difference was hypothesized to allow for the equilibrium time to be achieved within the 14-day target.

The average drainage length of the #200 screen molds was equal to the radius of the specimen compared to the height of the specimen for the PVC molds. The improvement of the mold is shown in the following sections.

2.3 Filter Paper Test

For each filter paper test, eight identical specimens were prepared. Each specimen was built in two lifts, with a stack of three dry Whatman No. 42 filter papers placed between the two lifts.

After construction, the specimens were placed in a desiccator, partially submerged in water for a minimum of 14hrs. Following saturation, the specimens were removed from the desiccator and allowed to dry. At different drying intervals, each of the eight specimens were placed in an insulated chamber to come to equilibrium. After a period of fourteen days from the last specimen being placed in the insulated chamber, the water content of the filter paper and soil were collected. Reduction of the filter paper data was achieved by applying the curve suggested by Acikel et al. (2015) for a drying path.

3 TESTING RESULTS

3.1 Filter Paper Results

Results of the filter paper test comparing the PVC mold to the #200 mold resulted in a larger difference for the total suction measurements using the non-contact method compared to the contact method. Figure 2 shows the results of the tests conducted on the ML material for both the contact and non-contact method. It must be noted that

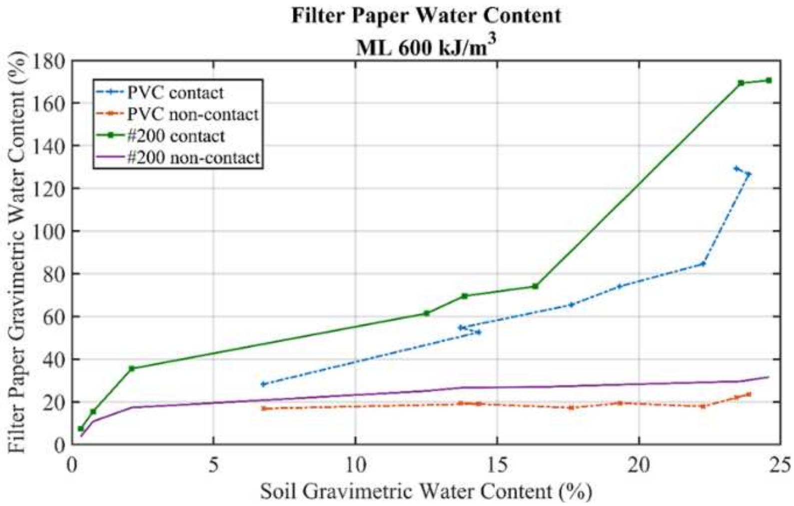

Figure 2. Filter paper water content for PVC and #200 molds, for ML material prepared at 600 kJ/m³, 14day equilibrium period.

for the non-contact method the soil and filter paper have not reached complete equilibrium. It is apparent that the #200 screen molds provide an improvement over the PVC molds with respect to equilibrium. The filter paper water contents from the contact method are consistently larger and are more consistent with the results of the TRIM and Fredlund test results, Figure 3.

The results for the non-contact filter paper tests, Figure 2, show that there is an increase in filter paper water content over the range of water contents tested. Figure 4 shows the results of a filter paper test on the poorly graded sand prepared using an applied energy of 200 kJ/m^3. These results show that there is little difference between the PVC mold versus the screen mold for the contact tests. This is contrary to the results of the tests using the silt material and is likely a result of the difference in conductivity between the two materials. The silt likely has a 5 order of magnitude decrease in hydraulic conductivity compared to the sand, i.e., the equilibrium time for the sand material is much shorter compared to

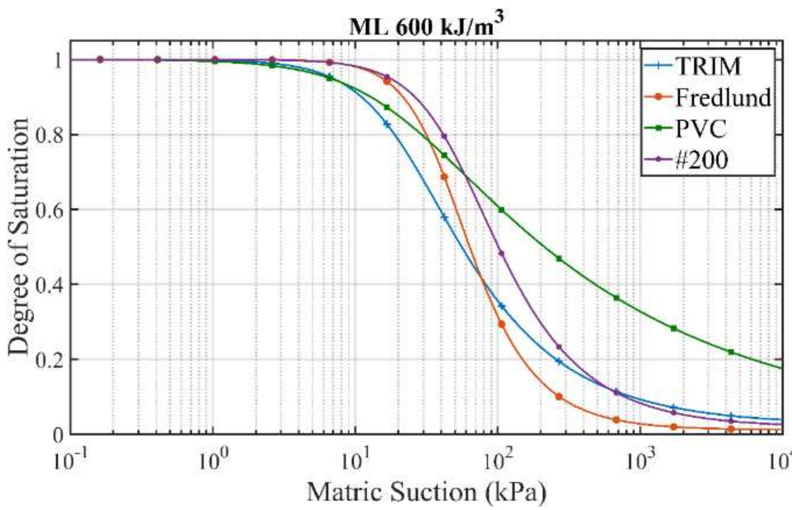

Figure 3. SWCC of the ML material prepared using an applied energy of 600 kJ/m3 for the TRIM, Fredlund and filter paper tests using PVC and #200 molds.

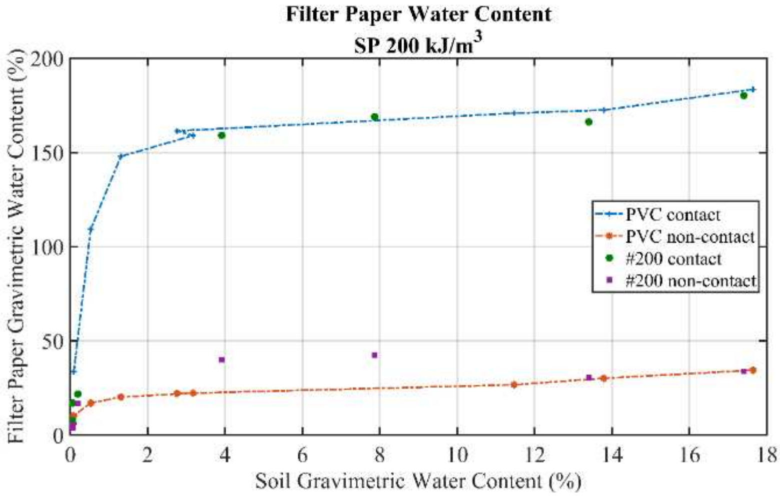

Figure 4. Filter paper water content for PVC and #200 molds, for SP material prepared using an applied energy of 200 kJ/m³, 14day equilibrium period.

the silt material when using the contact method of testing.

The results of the non-contact method of filter paper testing on the sand material show that for water contents less than 10% the #200 screen mold provides a marked improvement over the PVC mold. At water contents greater than 10% the two molds had similar results. This is likely due to the increased time that is needed to reach equilibrium at higher water contents as noted by Marinho and Oliveira (2006).

The reduction of the filter paper water contents was accomplished by using the calibration curve presented by Acikel et al. (2015) which was modified from a previous curve presented by Munoz-Castelblanco et al. (2012) for Whatman No. 42 filter papers. This curve is for tests conducted using initially wet filter papers and takes into account the hysteresis between the wetting and drying processes.

Equations 1, 2, and 3 were used to reduce the filter paper water contents to matric suction for the contact method results, based on Acikel et al. (2015).

$$\log(\psi) = 4.945 - 0.0141 * w_{fp} \quad (1)$$
$$\log(\psi) = 5.327 - 0.0779 * w_{fp} \quad (2)$$
$$\log(\psi) = 5.346 - 0.067 * w_{fp} \quad (3)$$

Where ψ is matric suction in kPa and w_{fp} is the filter paper water content in percent. Equation 1 is applicable for filter paper water contents greater than 47.39%, Equation 2 is for filter paper water contents less than 18%, and Equation 3 is for water contents between 18 and 47.39%.

Figure 3 shows the results of the reduction for the silt material prepared using an applied energy of 600 kJ/m³. From this plot it can be seen that the filter paper test slightly underpredicted the air entry value but was in general agreement with the slope of the SWCC at matric suctions greater than the air entry value. Also, the residual suction matches that measured in the TRIM and is in general agreement to that measured in the Fredlund device.

The results of the silty sand tests exhibited the same trend as that shown for the silt. The sand test results better matched the shape of the SWCC measured in the Fredlund device but had the same air entry value as the SWCC measured in the TRIM device.

4 CONCLUSIONS

The results of SWCC testing using multiple devices was discussed and results for sand and silt soils were presented. A novel sample mold that allows a quicker equilibrium time for the filter paper method was designed from a #200 mesh screen. It was found that this mesh mold provided a larger surface area which resulted in improved testing results for the contact filter paper test. Longer times are needed for the non-contact filter paper method but initial results show an improvement over PVC sample molds. It was found that the drying calibration curve performed well and the filter paper test results adequately matched those measured using other devices.

5 REFERENCES

Acikel, A.S., Singh, R.M., Bouazza, A., Gates, W.P., and Rowe, R K., 2015. Applicability and accuracy of the initially dry and initially wet contact filter paper tests for matric suction measurement of geosynthetic clay liners. *Geotechnique* 65(9): 780-87.

ASTM Standard D5298. 2016. Standard test method for measurement of soil potential (suction) using filter paper. ASTM International, West Conshohoken, PA.

Bulut, R., Lytton, R.L., and Wray, W.K. 2001. Soil suction measurements by filter paper. Expansive clay soils and vegetative influence on shallow foundations: 243-261.

Chandler, R.J. And Gutierrez, C.I. 1986. The filter-paper method of suction measurement. *Geotechnique* 36(2): 265-68.

Houston, S.L., Houston, W.N., and Wagner, A. 1994. Laboratory filter paper suction measurements. *Geotechnical Testing Journal* 17(2); 185-94.

Leong, E.C., He, L., and Rahardjo, H. 2002. Factors affecting the filter paper method for total and matric suction measurements. *Geotechnical Testing Journal* 25(3): 322-33.

Marinho, F.A. and Oliveira, O.M. 2006. The filter paper method revisited. *Geotechnical Testing Journal* 29(3): 250-58.

Munoz-Castelblanco, J.A., Pereira, J.M., Delage, P., and Cui, Y.J. 2012. The water retention properties of a natural unsaturated loess from northern France. *Geotechnique* 62(2): 95-106.

Padilla, J.M., Perera, Y.Y., Houston, W.N, and Fredlund, D.G. 2005. A new soil-water characteristic curve device. Advanced Experimental Unsaturated Soil Mechanics and International Symposium, Trento, Italy, 15-22.

Power, K.C., Vanapalli, S.K., and Garga, V.K. 2008. A revised contact filter paper method. *Geotechnical Testing Journal* 31(6): 461-69.

Taylor, O.D., Berry, W.W., Winters, K.E., Rowland, W.R., Antwine, M.D., and Cunningham, A.L. 2017. Protocol for cohesionless sample preparation for physical experimentation. *Geotechnical Testing Journal* 40(2): 284-301.

Wayllace, A. And Lu, N. 2011. A transient water release and imbibitions method for rapidly measuring wetting and drying soil water retention and hydraulic conductivity functions. *Geotechnical Testing Journal* 35(1): 103-17.