Application of micro-porous membrane technology for measurement of soil-water characteristic curve

Application de la technologie de membrane microporeuse pour la détermination de la courbe de rétention d'eau des sols

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ABSTRACT: This study focuses on the use of micro-porous membranes instead of ceramic disks for improving the time required to reach matric suction equalization. Measurements of the soil-water characteristic curve were conducted using micro-porous membranes in a new pressure plate apparatus. In the testing program, the hydraulic response of the micro-porous membrane under varying water contents corresponding to increasing or decreasing matric suction was measured. Different micro-porous membrane with different air entry values were investigated in order to compare the time required for matric suction equilibrium with that of the ceramic disk. Soil-water characteristic curves of different types of soil were measured using the axis-translation technique with both the micro-porous membrane and the ceramic disk.

RÉSUMÉ : Cette étude concerne l'utilisation des membranes microporeuses à la place des disques céramiques pour réduire le temps nécessaire pour atteindre l'équilibre en succion matricielle dans les sols. La détermination de la courbe de rétention d'eau a été faite en utilisant des membranes microporeuses dans un nouvel appareil de plaque de pression. Dans le programme d'essais, la réponse hydraulique de la membrane microporeuse sous des teneurs en eau variables correspondant à des augmentations ou diminutions de succion matricielle a été mesurée. Des membranes microporeuses différentes avec des points d'entrée d'air différents ont été étudiées afin de comparer le temps nécessaire pour atteindre l'équilibre en succion matricielle avec le temps dans le cas du disque céramique. Les courbes de rétention d'eau de différents sols ont été déterminées en appliquant la technique de la translation d'axe avec la membrane microporeuse et le disque céramique.

KEYWORDS: unsaturated soils, soil-water characteristic curve, matric suction, pressure membrane technique

1 INTRODUCTION

Unsaturated soil mechanics is becoming more widely accepted in geotechnical engineering and engineering protocols are emerging for a range of geotechnical problems. Matric suction plays an extremely important role in describing unsaturated soil property functions as well as the verification of the unsaturated soils mechanics theories (Gasmo et al. 1999). The axis-translation technique developed by Richards (1941) and the pressure plate technique suggested by Hilf (1956) have contributed significantly towards the measurement and control of matric suction in unsaturated soils laboratory tests. Bishop and Donald (1961) and Bishop and Henkel (1962) developed the triaxial apparatus for unsaturated soils, and used the pressure plate technique in order to separate the pore-air pressure and the pore-water pressure. The pressure plate technique make use of high air entry disks which allow the movement of water but resist the movement of free air. High air entry ceramic disks are generally made of sintered kaolin and have a thickness of 5 mm or 7 mm when used as part of a pressure plate apparatus. The ceramic disk is of extremely low permeability with respect to water flow (i.e., about 1×10^{-11} m/s; Fredlund and Rahardjo, 1993). Typical high air entry ceramic disk used in unsaturated soil testing equipment, such as the triaxial, direct shear and SWCC apparatuses are rated for air entry value of 1 bar, 3 bar, 5 bar and 15 bar (Padilla et al. 2006). The axis-translation technique is performed by installing (i.e., sealing) a high air entry disk into the base pedestal of a soil testing apparatus. One of the concerns related to the use of high air entry ceramic disks is the time required for equilibrium to be established in a soil specimen. Tinjum et al. (1997) observed that the equilibrium in the pressure plate was established between 5 and 8 days for clayey soils. Consequently, the testing of unsaturated soils was time consuming and therefore, costly. The long time required to reach the equilibrium is particularly of concern for the measurement the soil-water characteristic curves. This study focuses on the use of micro-porous membranes instead of ceramic disks for improving the time required to reach matric suction equalization. Measurements of the soil-water characteristic curve were conducted using micro-porous membranes in a new pressure plate apparatus. In the testing program, the hydraulic response of the micro-porous membrane under varying water contents corresponding to increasing or decreasing matric suction was measured. Different micro-porous membrane with different air entry values were investigated in order to compare the time required for matric suction equilibrium with that of the ceramic disk. Soil-water characteristic curves of different types of soil were measured using the axis-translation technique with both the micro-porous membrane and the ceramic disk.

2 TEST PROCEDURE

2.1 Soil material & micro-porous membrane

Five soil types were used in the study. The grain size distribution curves of the soils are shown in Fig. 1. The micro-porous membranes used in this study are a product manufactured by Pall. Corporation (www.pall.com/lab). Two different types of membranes (i.e., polyether sulfone and acrylic copolymer) were used in this testing program as summarized in Table 1. The air entry values of the membranes range from 40 kPa to 250 kPa depending on the pore size and manufacturing process.

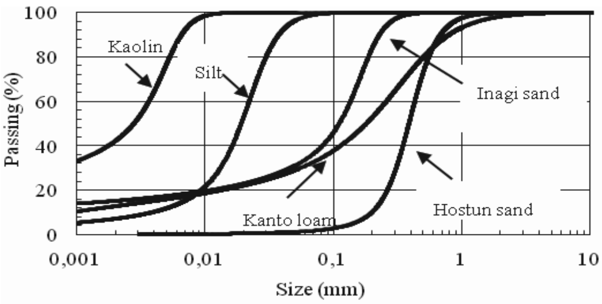

Figure 1 . Grain size distributions for five soils.

Table 1. Micro-porous membranes used in the test program.

No	Thickness (μm)	Air entry value (kPa)	Pore diameter(μm)	Material
1	140	250	0.45	Polythersulfone
2	140	100	0.8	Polyther sulfone
3	94	60	0.8	Acrylic copolymer
4	94	40	1.2	Acrylic copolymer

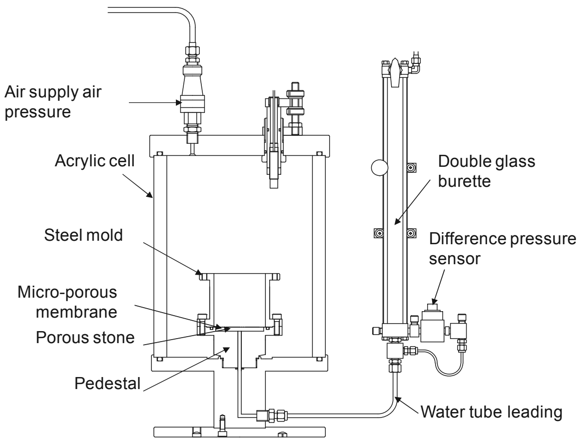

Figure 2. Illustration of the modified SWCC apparatus.

2.2 *Modified SWCC apparatus with micro-porous membrane*

The study utilized the new soil-water characteristic curve apparatus (i.e., SWCC apparatus) as shown in Fig. 2. The modified SWCC apparatus consisted mainly of a pedestal, a steel mold, a triaxial chamber and a double glass burette connected to a differential pressure transducer. Fig. 3 shows the saturated micro-porous membrane in the steel mold. The steel mold has an inside diameter of 60 mm and a height of 65 mm. The pedestal was attached to the triaxial base plate. The water compartment was connected to the base of the triaxial cell and the double glass burette. Soil water was allowed to flow into the double glass burette. A differential pressure transducer was attached to the lower portion of the double glass burette

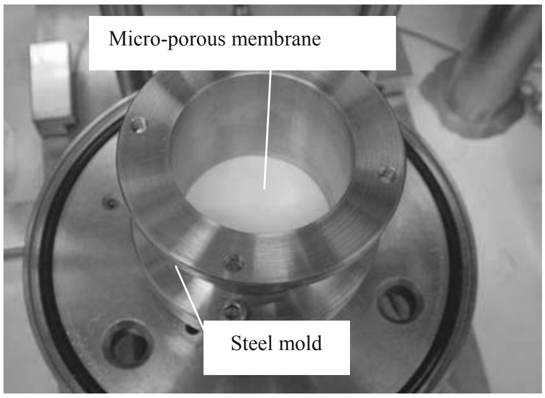

Figure 3. Assembly steel mold with developed pedestal.

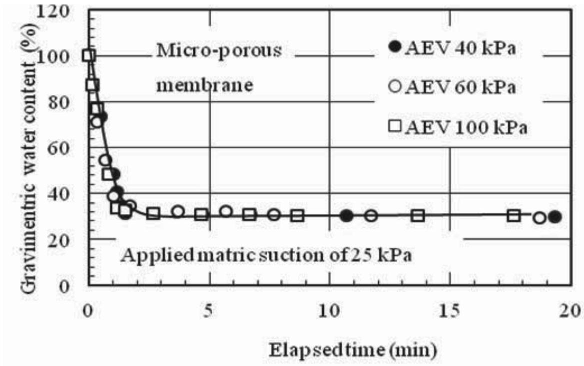

Figure 4. Changes of gravimetric water content by micro-porous membrane with AEV 40 kPa, 60 kPa and 100 kPa.

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A pressure plate apparatus with a ceramic disk was used to compare the results with those obtained from using the new micro-porous membrane apparatus. The high air entry ceramic disk was installed into the pedestal in place of the micro-porous membrane. The ceramic disk had a thickness of 7 mm and an air entry value of 200kPa or 500 kPa.

2.3 *Soil-water characteristic curve, SWCC, tests*

Soil-water characteristic curve tests were performed in the low matric suction range with a maximum matric suction of 20 kPa. Drying and wetting paths were established by progressively increasing and decreasing matric suction. The soils were prepared in a slurry condition at a high gravimetric water content. Soil water moved in response to the externally applied air pressure and accumulated in the burette with elapsed time. The gravimetric water content of the soil specimen was calculated from the changes in the amount of water in the soil. When the water level in the burette attained a steady state condition, it was assumed that equilibrium conditions have been attained with regard to the applied matric suction. As a result, the air pressure supplied to the triaxial chamber was equal to the matric suction in the soil specimen. The matric suction was progressively increased up to about 20 kPa. After the application of the applied maximum matric suction, the air pressure in the chamber was decreased following the path of decreasing matric suction.

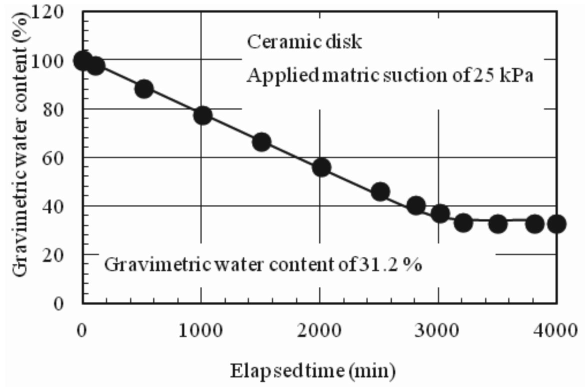

Figure 5. Changes of gravimetric water content by ceramic disk with AEV 200 kPa.

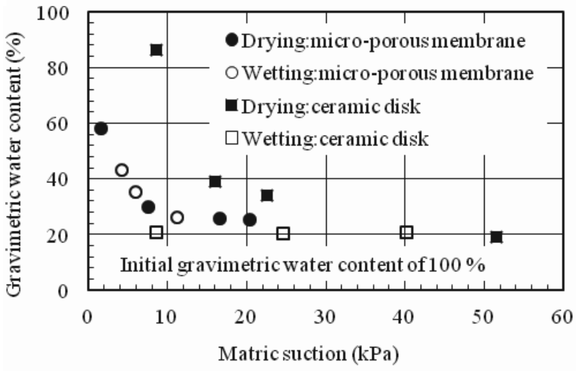

Figure 6. Soil-water characteristic curves measured for silt.

3 TEST RESULTS

3.1 Comparison of water flow characteristics

Three different micro-porous membranes (Micro-porous membrane No. 2, 3 and 4) in Table 1 were used to investigate the influence of air entry value on equilibrium time. These micro-porous membranes had different air entry values of 100 kPa, 60 kPa and 40 kPa. The silt was prepared in the steel mold, with an initial degree of saturation close to 100 %. An air pressure of 25 kPa was applied to the upper surface of the soil specimen. The soil water passed through the micro-porous membrane and drained into the burette. Figure 4 shows changes of gravimetric water content with time. Once water flow commenced, the gravimetric water content decreased rapidly. The water content reached equilibrium in about 2 minutes.

Similar tests were conducted using the saturated high air entry ceramic disks. Figure 5 shows the changes in water content with time for the ceramic disks with AEV of 200 kPa. The rate of water content decrease was slower as compared to that of the micro-porous membrane. The equilibrium time appears to occur around 3000 minutes. The test results show that considerably more time is required to achieve equilibrium when using the high air entry ceramic disks.

There are differences in the soil-water characteristic curves obtained from the micro-porous membrane and those from the ceramic disk for all soil specimens. On the drying paths, the soil-water characteristic curve obtained from the micro-porous membrane was lower than that obtained from the ceramic disk. The water content using the micro-porous membrane is less than that measured using the ceramic disk. The water content as measured using the ceramic disk was considerably larger as compared to that obtained from the micro-porous membrane. It can be observed that absorption on the wetting path would result in a significantly less water content when the ceramic disk was used. Water appeared to be able to pass through the micro-porous membrane well, increasing the water content of the soil specimen during the decrease in matric suction. The wetting soil-water characteristic curve is located close to the drying soil-water characteristic curve. The soil-water characteristic curves obtained from the micro-porous membrane showed less hysteresis as compared to those measured using the ceramic disk in the traditional testing method.

3.2 Soil-water characteristic curves for different soil materials

Soil-water characteristic curves for different soil materials as measured using both the micro-porous membrane and the ceramic disk with AEV of 500 kPa are shown in Figs. 6 to 10.

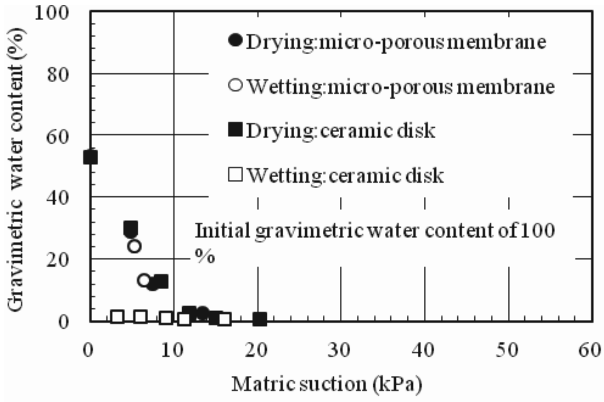

Figure 7. Soil-water characteristic curves measured for Hostun sand.

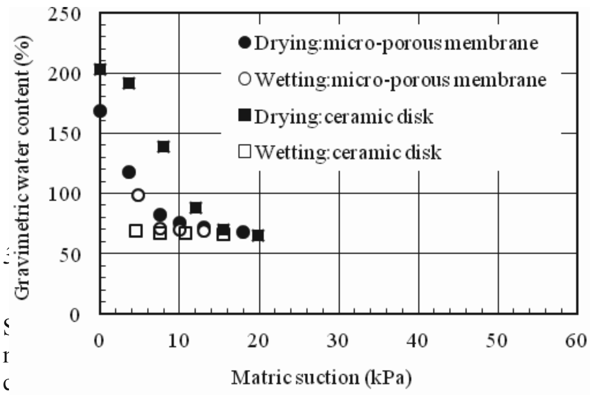

Figure 8. Soil-water characteristic curves measured for Kaolin.

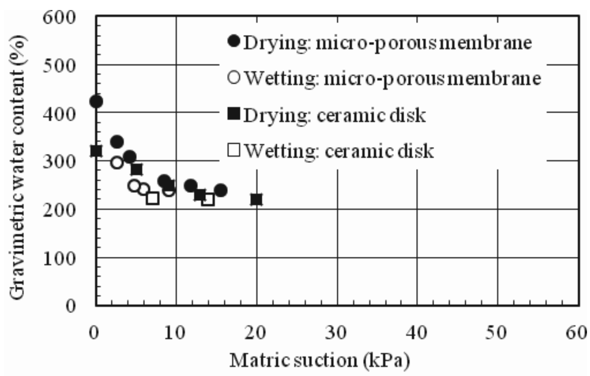

Figure 9. Soil-water characteristic curves measured for Kanto loam

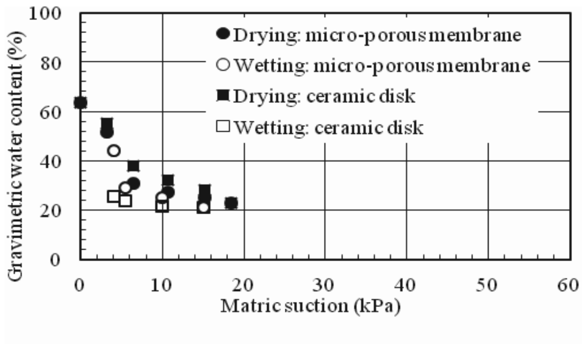

Figure 10. Soil-water characteristic curves measured for Inagi sand.

4 CONCLUSIONS

This study focused on the use of micro-porous membrane instead of ceramic disk for measuring soil-water characteristic curve and the results can be summarized as follows:

(1) Soil-water characteristic curve tests were performed in the low matric suction range. The air entry value of the micro-porous membrane was similar to that of the ceramic disk. The equilibrium time required for the SWCC measurements using the micro-porous membrane was much shorter than the equilibrium time required for the measurement using the high air entry ceramic disk. The micro-porous membrane provides more reasonable testing times for determination of SWCC for geotechnical practice.

(2) The hysteresis between the drying and wetting soil-water characteristic curves appeared to be negligible when measurements were made using the micro-porous membrane. The soil-water characteristic curve measured using the ceramic disk demonstrated larger hysteresis than the curve obtained using the micro-porous membrane.

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