Pore-water pressure measurement necessity when determining the SWCC utilizing the axis-translation technique

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1. Introduction

The Soil Water Characteristics Curve (SWCC) describes the amount of water (volumetric water content, water content or degree of saturation) retained in a soil medium at a given range of suction values (osmotic suction, matric suction (commonly used in engineering)), where numerous researches have been done on this unique function. The SWCC is widely used in various geotechnical, geo-environmental and agricultural engineering aspects. The SWCC is a key index that is commonly used in unsaturated soils hydrological relations (water and solute movement, water storage, HCF estimation and design of soil cover systems) and unsaturated soils mechanical relations (slope stability, landslides and erosion) (Fredlund et al. (1996)). This paper aims at investigating the pore-water pressure measurement necessity when determining the SWCC adopting the axis-translation technique utilizing both the Continuous Pressurization Method (CPM) (Hatakeyama, 2015; Alowaisy et al., 2017) and the Multi-Step Flow Method (MSFM).

2. Methodology and materials

The axis-translation technique (Richards, 1941) has contributed significantly to the measurement and control of suction in unsaturated soil laboratory tests. Where it refers to the practice of elevating the pore air pressure while maintaining the pore water pressure at a reference value through the pores of a saturated high Air Entry Value (AEV) medium (membrane, plate, disk), thus allowing direct control of the matric suction. Utilizing the MSFM, during the drying phase, drainage continues until the water content of the specimen reaches equilibrium under the applied air pressure. Several increments of air pressure may be applied to generate several points along the drying curve of the SWCC. While the wetting phase is carried out by reversing the water flow (into the sample) by reducing the applied air pressure. The matric suction is recorded to be equal to the applied air pressure value [$\Psi = u_a$], where the water pressure is typically assumed to be equal to the atmospheric pressure (zero). On the other hand, the newly developed CPM device is fully automatic and allows for continuous measurements of the air pressure, water pressure and drained water. A schematic diagram of the newly developed CMP cell is shown in Figure 1. During testing, the air pressure is supplied through the inlet valve attached to the top of the cell, where a regulator connected to a computer controls the rate of pressurizing. Meanwhile, a micro-tensiometer installed at the center of the sample instantly and continuously measures the developing pore water pressure in response to the changing air pressure, while the ceramic disk at the bottom retains the air pressure and allows water to drain through the drainage outlet. The water drains into a container that is continuously weighed using a balance with 0.001 g readability that is directly connected to the data acquisition system. The matric suction (Ψ) can be calculated by taking the difference between the air pressure applied to the top of the specimen and the pore water pressure measured by the micro-tensiometer [$\Psi = u_a - u_w$]. For both methods, the water content can be deduced from the drained water in relation to the initial or final water content of the tested sample.

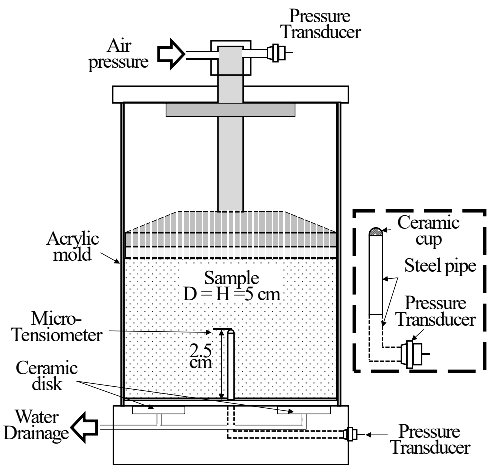

Figure 1: CPM cell (schematic).

In order to investigate the pore-water pressure measurement necessity when determining the SWCC adopting the axis-translation technique, the CPM testing setup was used adopting the MSFM where air pressure was applied incrementally then the obtained SWCCs were compared to the SWCCs determined utilizing the newly developed CPM.

Two texturally distinct sandy soils were adopted, Toyoura sand and K-4 sand. The particle size distribution curves and the adopted soils physical properties are illustrated through Figure 2 and Table. 1.

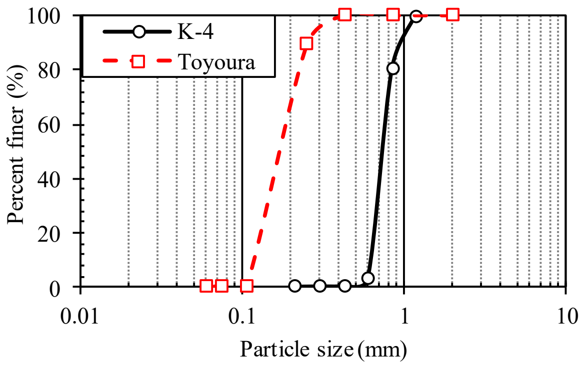

Figure 2: Particle size distribution curves.

Table 1: Soil properties.

Soil	Specific gravity	dry density (g/cm^3)	Void ratio (e)	K_s (m/s)	Uniformity coefficient (Uc)	D_{10} (mm)
K-4	2.640	1.551	0.698	2.07×10^{-3}	1.238	0.630
TOYOURA	2.646	1.560	0.693	8.25×10^{-5}	1.381	0.210

Keywords: Continuous pressurizing method, SWCC, Axis-translation technique, Pore water pressure.
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3. Results and discussion

Figure 3 and Figure 4 show the drying and wetting SWCCs for Toyoura and K-4 sands respectively. The solid line represents the SWCC determined utilizing the CPM system where the suction was calculated by taking the difference between the applied air pressure (u_a) and the instantly measured pore water pressure (u_w) at the center of the sample. While the circular scatter plots represent the SWCC determined using the conventional MSFM where the suction is assumed to be equal to the applied air pressure value at the end of the pressurizing step (when achieving equilibrium, where no more water flows out of/into the sample). In general, it can be observed that the SWCCs determined utilizing the newly developed CPM system are in well agreement with the SWCCs determined utilizing the conventional MSFM. However, it must be noted that for the SWCCs determined utilizing the newly developed CPM, the matric suction was pinned at a lower value in comparison to the SWCCs determined utilizing the conventional MSFM, where the matric suction increases by increasing the applied air pressure even after achieving the residual stage [red boxes].

Figure 5 illustrates the air pressure (u_a) and the pore water pressure (u_w) values recorded at the end of each pressurizing increment for Toyoura sand. The conventional suction determination concept [MSFM] is based on the main assumption that the pore water pressure dissipates totally once achieving the equilibrium state, where at this point the pore water pressure inside the sample is assumed to be equal to the water pressure within the water compartment beneath the high AEV medium (typically zero [atmospheric]). However, it was found that the pore water pressure did not totally dissipate at the end of each step, and is more pronounced for low Volumetric Water Content (VWC) values. Figure 6 shows the error associated with the matric suction utilizing the conventional concept [$\boldsymbol{\Psi = u_a}$]. It can be observed that neglecting the residual pore water pressure when determining the matric suction results in significant overestimation of the matric suction value, where it becomes more paramount for low degrees of saturation. The residual pore water pressure resulted in 55% and 60 % overestimation of the matric suction value for Toyoura and K-4 sands for the last pressurizing step.

The conventional MSFM concept was modified, where the suction value is determined by taking the difference between the applied air pressure and the residual pore water pressure measured at the center of the sample (equilibrium state). The modified SWCCs for both Toyoura and K-4 sands are illustrated through Figures 3 and 4 indicated by the squared plots. It can be observed that considering the pore water pressure when calculating the matric suction results in pinning the matric suction at lower values, more paramount for low VWC, leading to better agreement with the CPM obtained results. This can be attributed to the residual amount of water entrapped within the specimen even under high air pressure values. Which was confirmed by drying the samples for 24 hours at 110 (c°) where further reduction in the VWC was observed. Finally, it can be concluded that assuming that the matric suction to be equal to the applied air pressure (equilibrium state) results in significant error that cannot be neglected. Therefore, considering the residual pore water pressure when calculating the matric suction utilizing the axis-translation technique is necessary.

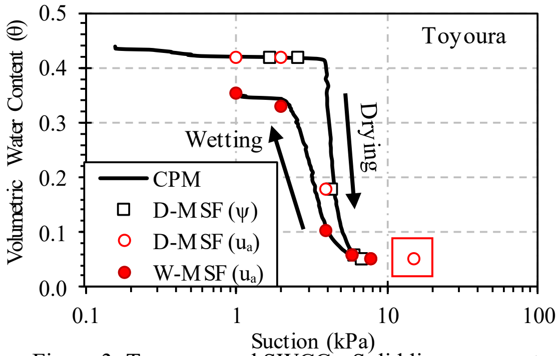

Figure 3: Toyoura sand SWCCs. Solid line represents the CPM results while the plots represent the MSFM

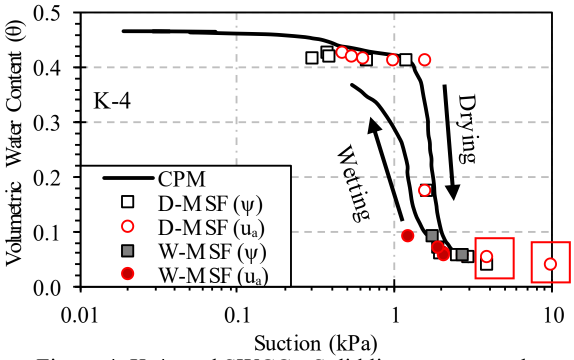

Figure 4: K-4 sand SWCCs. Solid line represents the CPM results while the plots represent the MSFM

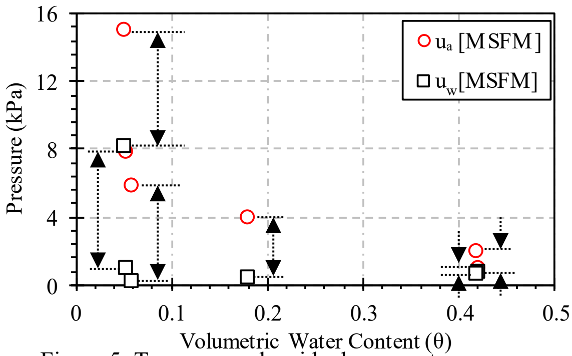

Figure 5: Toyoura sand residual pore water pressure after reaching equilibrium. [MSFM]

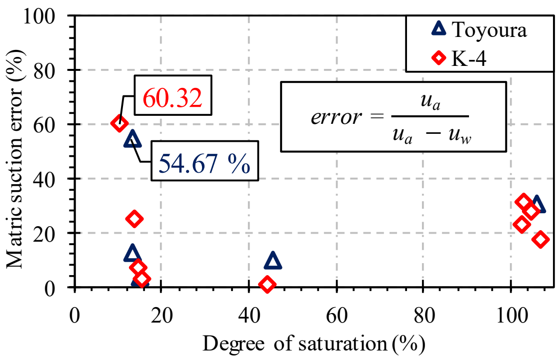

Figure 6: Error associated with the matric suction utilizing the conventional MSFM

4. Conclusions

It was found that utilizing the conventional multi-step flow, assuming that the matric suction to be equal to the applied air pressure, when determining the SWCC results in significant error. Therefore, considering the residual pore water pressure when calculating the matric suction utilizing the axis-translation technique is necessary.

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