Influence of the ceramic disk hydraulic conductivity on the soil water characteristics curve determination utilizing the continuous pressurization method

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1. Introduction

Recently earthquakes, typhoons and heavy rainfalls induced natural Geo-disasters occur at different locations causing serious damage to life and properties. Through heavy rain periods, the water table and river water level rise causing increase in the pore water pressure resulting in total strength and stability loss through soil embankments which finally leads to failure. The proper determination of the hydrological and water retention properties of porous mediums is necessary for understanding the unsaturated soil behavior. Among those properties, the Soil Water Characteristic Curve (SWCC) is a key index used for estimating many unsaturated soil relations such as the hydraulic conductivity function, water storage, shear strength and prediction of solute and contaminant transport. The SWCC is a function that describes the amount of water (volumetric water content, water content or degree of saturation) retained in a soil at a given range of suction values (the difference between pore air pressure and pore water pressure).
Several experimental setups and numerical methods were developed for directly and indirectly obtaining the SWCC. The hanging column, tempe cells, pressure plate, tensiometers, psychrometer, chilled mirror hygrometer, filter paper, centrifuge and humidity chamber are commonly used for experimentally obtaining the SWCC (Fredlund, Rahardjo 1993; Japanese Geotechnical Society 2000; Lu, Likos 2004). Detailed reviews illustrating the advantages and disadvantages of those methods can be found in literature. Among the developed methods, the newly developed Continues Pressurization Method (CPM) was reported to be a direct, accurate rapid SWCC determination method in comparison to the conventional methods (Alowaisy et al. 2017). The developed method adopts the axis-translation technique, where a Ceramic Disk (CD) with a known Air Entry Value (AEV) is used to retain the air pressure while allowing the water to drain out of the sample. Through this paper, the CD coefficient of hydraulic conductivity influence on the obtained SWCC and on the suction profile distribution is discussed.

2. Methodology and materials

Fig. 1 illustrates the developed CPM system experimental setup. Through testing, air pressure is supplied through the inlet valve attached to the top of the cell, where a regulator connected to a computer controls the air pressurizing rate. Meanwhile, three micro-tensiometers installed at (1, 2.5 and 4 cm from the CD surface) instantly and continuously measure the developing pore water pressure in response to the changing air pressure at different levels. The CD at the bottom retains the air pressure and allows water to drain gradually through the drainage outlet. The water drains into a container that is continuously weighed using a balance with 0.001 g resolution that is directly connected to the data acquisition system. The soil sample is contained in an acrylic cylinder with 5 cm internal radius and 8.5 cm height. The suction (ψ) can be calculated by taking the difference between the applied air pressure (u_a) at the top of the sample and the averaged pore water pressure ($u_{wavg.}$) along the soil sample. While the water content can be deduced from the drained water in relation to the initial or final water content of the tested sample.
Tests were carried out using two sets of ceramic disks with identical AEV of 100 kPa, and a saturated hydraulic conductivity (k_s) with one order difference, **Table 1**. Toyoura standard testing sandy soil was used. The particle size distribution curve and the physical properties of Toyoura sand are shown in **Fig. 2** and **Table 2**, respectively.

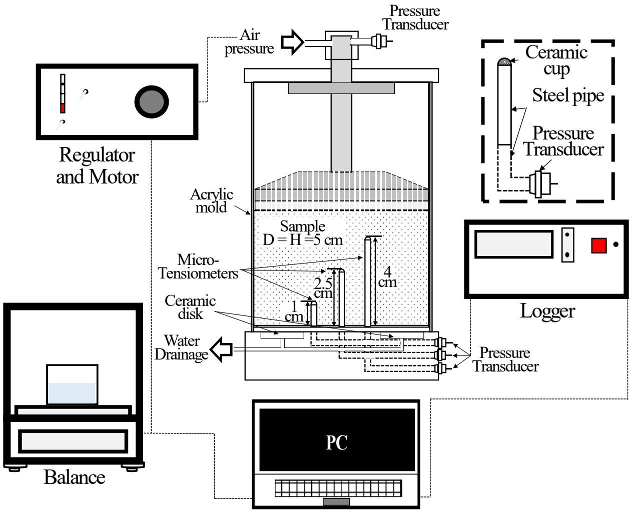

Fig. 1: Experimental setup (Schematic).

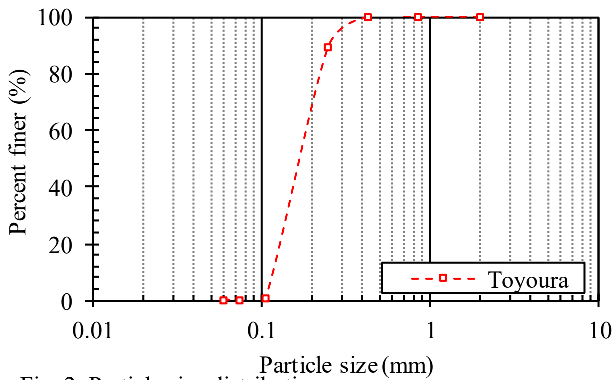

Fig. 2: Particle size distribution curve.

Table 1: Ceramic disks properties.

Ceramic Disk	AEV	k_s	Thickness
	kPa	m/s	cm
CD1	100	7.56×10^{-7}	0.4
CD2	100	8.60×10^{-6}	0.4

Table 2: Soil physical properties.

Physical Properties		Toyoura
Specific gravity		2.646
Dry density	g/cm^3	1.560
ks	m/s	1.29×10^{-4}
Void ratio (e)		0.693
D_{10}	mm	0.116

3. Results and discussion

Fig. 3 shows the SWCCs obtained for Toyoura sand utilizing the newly developed CPM system using two sets of CD with the same AEV of 100 kPa and a saturated hydraulic conductivity (k_s) with one order difference. Tests were carried out under 0.05 kPa/min. air pressurization rate where both the wetting and drying phases were obtained as illustrated in Fig. 3. It can be observed that using CDs with different saturated hydraulic conductivity results in obtaining almost identical SWCCs with the same AEV and the same residual suction value (corresponds to the residual water content). Utilizing the developed method, the calculated suction value is not affected by the coefficient of hydraulic conductivity of the CD, where the pore water pressure is measured directly and instantly within the soil sample and deducted from the applied air pressure to determine the suction value. Therefore, the pore water pressure measurement has no correlation to the CD saturated coefficient of hydraulic conductivity. Thus it can be concluded that the influence of the CD coefficient of hydraulic conductivity on the SWCC determination is minor and thus can be neglected.

It must be noted that the CD saturated coefficient of hydraulic conductivity significantly affects the SWCC obtaining time, where the saturated coefficient of hydraulic conductivity reflects the speed and ease at which the CD allows the pore water pressure to dissipate by draining water out of the sample. **Fig. 4** shows the time required to obtain a full SWCC using the two adopted CDs under both the drying and wetting phases. It can be observed that using a CD with one order higher coefficient of hydraulic conductivity results in significantly reducing the SWCC determination time, where a full SWCC under both the drying and wetting phases was obtained in less than 20% of the time required using the lower coefficient of hydraulic conductivity CD for Toyoura sand. The reduction in the required testing time is less significant for the drying phase in comparison to the wetting phase, this can be attributed to external applied head, where during the drying phase, the water was drained out by increasing the air pressure inside the testing cell. On the other hand, during the wetting phase, the water was allowed to enter the sample by capillary without external head. **Figs. 5 a and b** illustrate the suction profile distribution for Toyoura sand under the drying and wetting phases using the adopted CDs. It can be observed that the CD saturated coefficient of hydraulic conductivity significantly affects the suction profile distribution under the same degree of saturation for both the drying and the wetting phases. Under isothermal, isoelectric and isosmotic conditions it can be assumed that only the hydraulic head drives the water out of the sample. Where it can be observed that the uniformity, linearity and slope of the suction profile (which represents the hydraulic head profile) is significantly affected by the CD hydraulic properties. Finally, it can be concluded that a proper understanding of the CD hydraulic properties influence on the suction and hydraulic head profile is necessary in order to accurately evaluate porous mediums macro and micro flow properties.

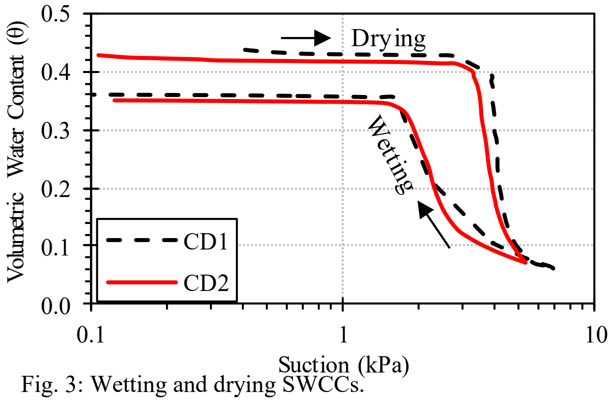

Fig. 3: Wetting and drying SWCCs.

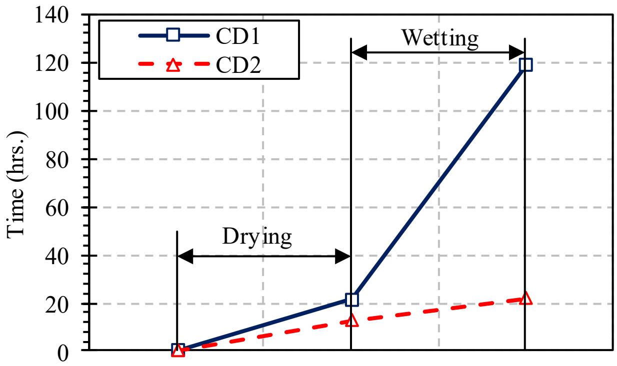

Fig. 4: SWCC obtaining time.

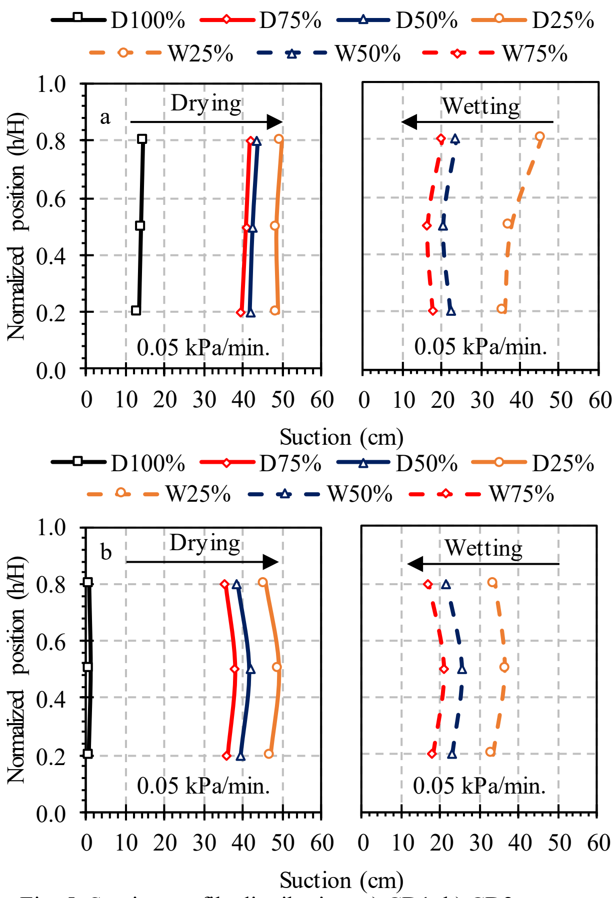

Fig. 5: Suction profile distribution. a) CD1. b) CD2.

4. Conclusions

It was confirmed that the influence of the CD saturated coefficient of hydraulic conductivity on the SWCC determination can be neglected. However, using a CD with one order higher coefficient of hydraulic conductivity significantly reduces the testing time (less than 20% of the time is required). Finally, it can be concluded a proper understanding of the CD hydraulic properties influence on the suction and hydraulic head profile is necessary for proper evaluation of porous mediums macro and micro flow properties.

References

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