A simple device to measure soil water retention curve

Lin Li i) and Xiong Zhang ii)

i) Professor, School of Civil Engineering, Nanjing Forestry University, 159 Longpan Rd, Nanjing 210037, China
ii) Professor, Civil, Architectural and Environmental Engineering, Missouri University of Science and Technology, 135 Butler-Carlton Hall, 1401 N Pine St., Rolla, MO 65409-0030, US.

ABSTRACT

The soil water retention curve is very critical in the assessment of unsaturated soil behavior. In the past, with the help of the axis translation technique, the pressure plate method was usually used to measure the soil water retention curve. However, this test was very time-consuming and required using specimens with the same loading history which was difficult to achieve. In this study, a simple device is proposed to measure the water retention curve of poorly graded sand with silt through a discrete evaporation test in which the soil suction and water content are measured using a high-capacity tensiometer and a digital balance, respectively. Measurement of representative soil suction was achieved through sealing the specimen to allow the water redistribution in the soil after a certain time of free evaporation. Results from this evaporation test indicate that the time required for the soil water retention curve can be significantly reduced from weeks to 1-2 days when compared with the conventional pressure plate method.

Keywords: soil water retention curve, discrete evaporation test, and high-capacity tensiometer

1 INTRODUCTION

The soil water retention curve is the relationship between the soil water content and water potential. The soil water retention curve is extensively used to characterize the relationship between soil suction and moisture content. Several methods, as presented in D6836 (ASTM 2008), which include the hanging column test, pressure extractor, chilled mirror hygrometer, and centrifuge test, can be used to measure the water retention curve of cohesive soils. Among these methods, the pressure extractor was the most extensively used (e.g. Richards 1941; and Péron et al. 2007; Sun et al. 2010). However, due to the low permeability of unsaturated soils, several weeks are typically required for the water retention curve determination of a single soil using this pressure extractor method. With the development in soil suction measurement, high-capacity tensiometers has also been developed and reported to be used for direct unsaturated soil suction measurement. In Lourenço et al. (2011), the soil water retention curve was measured through a drying test. During testing, the soil specimen was exposed in the atmosphere to allow a continuous dry process. A high-capacity tensiometer and a balance were used to record the variation of soil suction and moisture content. However, a problem associated with this method is the soil suction was not uniformed distributed in the entire soil sample. Since the soil suction was measured at the bottom of the sample, the representativeness of the measured soil suction was questionable due to the suction non-uniformity during drying.

In this paper, a new device is proposed to measure the soil water retention curve through a discrete evaporation test. The soil suction variation during drying is measured using a newly developed high-capacity tensiometer. Meanwhile, the soil water content is measured through the variation of soil mass during testing using a balance. A discrete evaporation test was also conducted to measure the soil water retention curve of poorly graded sand with silt.

2 A DISCRETE EVAPORATION TESTING DEVICE

2.1 Soil suction measurement

In the past, several methods (e.g. tensiometer, high-capacity tensiometer, psychrometer, filter paper, and thermal conductivity sensors) have been developed for field and laboratory suction measurements on unsaturated soils. Due to the simplicity and availability, the conventional tensiometer is extensively used to measure the suction of unsaturated soils. However, the measurement range of the conventional tensiometer is limited to 100 kPa due to water cavitation (Fredlund and Rahardjo 1993). As a result, the conventional
tensiometer cannot be applied on unsaturated soils with suction greater than 100 kPa. Ridley and Burland (1993) developed the first high-capacity tensiometer which allowed direct suction measurement on an unsaturated soil greater than 100 kPa. Since then, many high-capacity tensiometers (Guan and Fredlund 1997; Meilani et al. 2002; Tarantino and Mongiovi 2002; Take and Bolton 2003; Lourenco et al. 2006; and Li and Zhang 2014) have been developed and successfully used in both laboratory and field experiments as summarized in Toll et al. (2013). With the recent development of high-capacity tensiometers, direct and reliable suction measurements during a drying test became possible.

In this study, a high-capacity tensiometer developed based on a miniature pressure transducer was used to measure the soil suction during drying. Detailed tensiometer fabrication and evaluation can be found in Li and Zhang (2014, 2015a, 2015b). Figure 1a shows a picture of the used high-capacity tensiometer.

Before any soil suction measurement, the tensiometer was required to be saturated and calibrated. The high-capacity tensiometer was saturated in a cell as shown in Figure 1b, which was filled with de-aired water. A water pressure of 600 kPa was repeatedly applied to saturate the high-capacity tensiometer. After that, the tensiometer was calibrated in a positive pressure range. Negative pressure range calibration was based on extrapolation, which was also used by Lourenco et al. (2008). The tensiometer after calibration was then exposed in air. A quick decrease of negative pressure to a value less than -100 kPa indicated a saturated tensiometer. The accuracy of the calibration was examined by the water pressure immediately after cavitation, which should be approximately -100 kPa. The response time of the developed tensiometer was determined to be less than 2 seconds as presented in Li and Zhang (2015a). The maximum attainable suction of the used tensiometer was evaluated to be approximately 1100 kPa through a free evaporation test as recommended by Guan and Fredlund (1997). This high-capacity tensiometer was successfully used for suction measurement on unsaturated soils during triaxial and unconfined compression tests as presented in Li and Zhang (2015a) and Li and Zhang (2015b), respectively.

### 2.2 Testing system setup

With the high-capacity tensiometer, a new device was developed to measure the water retention curve of poorly graded sand with silt through a discrete drying test. The setup for the shrinkage test system was very simple as schematically shown in Figure 2. A two-part pedestal was designed to accommodate the high-capacity tensiometer during testing. The tensiometer rested on the lower part of the pedestal. The upper part, which surface was designed to be flush with the tensiometer tip, was used to hold the soil sample during drying. To ensure a good contact between the soil and the tensiometer tip, an O-ring was placed underneath the tensiometer to allow a slight movement of the tensiometer tip as needed during testing. During testing, the entire system rested on a balance to record the soil weight variation which would be used to back-calculate the soil water content. To perform a discrete drying test, the plastic cover which was used to seal the soil specimen as shown in Figure 2, was removed at different times to allow water evaporation.
3 EVAPORATION TEST

3.1 Specimen preparation

A sieve analysis test was performed on the used soil according to ASTM D412. Figure 3 presents the gradation curve of the soil (classified as poorly-graded sand with silt, SP- SM according to ASTM D2488). The soil was oven-dried and then mixed with water as shown in Figure 4a. After this, the soil was compacted in a consolidation ring with a filter paper inside at the bottom. Subsequently, the ring with soil inside was placed in an oedometer cell (25.4 mm in height and 63.5 mm in diameter). Then, the cell was filled with distilled water as shown in Figure 4b to saturate the soil. The soil water retention curve measurement was performed after this soil saturation process.

The device, as schematically shown in Figure 2, was placed on a digital balance to monitor the soil water content variation during drying. To ensure a good contact, the tensiometer surface was smeared with a thin layer of saturated Kaolin paste as shown in Figure 5a as recommended by Colmenares and Ridley (2002), Thu et al. (2006), and Le et al. (2011). The tensiometer tip was in direct contact with the bottom surface of the soil sample. Figure 5b shows a picture of the used soil water retention curve measurement device with a soil sample. In this measurement, during continuous drying, the soil suction may not be uniformly distributed. To extract representative soil suction results, after exposing in the air for a certain time, the soil sample was covered with a plastic cap as shown in Figure 5c to allow the water redistribution in the soil. When the soil suction stabilized, the weight and suction of the soil were recorded. The test was stopped once the tensiometer cavitated. Then, the soil was oven-dried to determine the soil moisture content. Figure 6 shows the soil surface during the drying process from the saturated to completely dry condition.
3.2 Experimental results

After the soil water retention curve test, the soil suction and weight during drying process were recorded. The soil suction variation during testing is presented in Figure 7. When the soil was exposed in the atmosphere, the soil suction rapidly increased due to water evaporation. When covered with the plastic cap, the soil suction gradually decreased, equalized, and then slightly increased as shown in Figure 7. This slight increase of soil suction after being sealed for a long time was because of the water evaporation could not be completely stopped by sealing the sample with the plastic cap. However, the evaporation was at a very low rate. Under this situation, the measured soil suction was more representative than that measured during continuous drying. The tensiometer cavitated at suction of 545.3 kPa and the tensiometer reading suddenly decreased to approximately 100 kPa due to water cavitation. The total time required for the soil water retention curve determination was reduced to within two days as shown in Figure 7.

Fig. 7. High-capacity tensiometer responses with time

With the final moisture content at cavitation (i.e. 3.57%), the soil moisture contents during testing were back-calculated as presented in Figure 8. At the very beginning of the test, the soil was saturated and the measured soil suction was very close to 0 kPa which was reasonable. Due to water evaporation, the soil weight continuously decreased which lead to decreases of soil moisture content and increases of suction as shown in Figure 8. For the tested soil, at the beginning of the drying process, the soil suction slightly increased with decreasing water content when soil suction was lower than 50 kPa. However, with soil suction greater than 50 kPa, a slight decrease in soil water resulted in a much higher increase in soil suction when compared with the soil behavior near saturation.

Fig. 8. Measured soil water retention curve

4 CONCLUSIONS

This paper proposes a new device to measure the soil water retention curve through a discrete drying test on a single soil specimen. During testing, a high-capacity tensiometer and a digital balance are utilized to measure soil suction and water content variations, respectively, during the drying process. Through the test on the poorly graded sand with silt, the new device proved to be able to significantly reduce the time required for soil water retention curve measurement from weeks to 1-2 days when compared with the conventional pressure plate method. In addition, the use of a single specimen successfully eliminated the influence of loading history on the accuracy of the soil water retention curve measurement.

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