Experimental Study on Influence of Dry Density on Soil-water Characteristic Curve of Hefei Expansive Soil

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Abstract. The soil-water characteristic curve is an important curve in the study of unsaturated soil mechanics. It plays an important role in improving theoretical analysis and numerical calculation in geotechnical engineering to find out the effect of initial dry density on SWCC. Based on the filter paper test, four soil-water characteristic curves of Hefei remolded expansive soil samples under different initial dry densities were determined. The influence of initial dry density on SWCC was systematically analyzed. The results show that: (1) In the w-s curve, the suction will increase with the decrease of moisture content, and SWCC will move to the upper right with the decrease of dry density. (2) In the s-w curve, the influence of the dry density on SWCC decreases as the suction becomes larger. When the moisture content is less than 10%, the difference in dry density no longer affects the SWCC. (3) Part of the SWCC with moisture content below 10% can be measured only once, which has important guiding significance for improving the efficiency of SWCC test. (4) In the Sr-s curve, the suction will increases with the decrease of the saturation, and the increase of the dry density of the sample causes the move of SWCC to the upper right.

1. Introduction

The soil-water characteristic curve (hereinafter referred to as SWCC) is a curve showing the relationship between the matric suction (hereinafter referred to as suction) and the moisture content of unsaturated soil. It is important for predicting and analyzing the hydraulic properties, permeability coefficient, shear strength of unsaturated soil. SWCC is an important relationship curve in the study of unsaturated soil mechanics. The study of SWCC, especially its relationship with initial dry density, has been one of the research hotspots.

Many scholars have studied this aspect: Zhou Baochun [1] measured the suction of Jingmen expansive soil samples with six different compactness by filter paper method. Analyzed the influence of compaction degree on suction. Stange CF [2] considered that the porosity of the soil affected the soil-water characteristic curve. Salager S [3] measured porosity, suction and moisture content of the clayey silt under five different initial states. Zhang Xuedong [4] based on the capillary model and the statistical
assumptions proposed by Childs (1950) [5], analyzed the variation of the soil-water characteristic curve when the void ratio changed. It can be seen that the initial dry density has a great influence on SWCC. Therefore, it is important to understand the variation of SWCC under its influence, which is important for improving theoretical analysis and numerical calculation in geotechnical engineering.

At present, the filter paper method is more and more widely used due to its low price, simple operation and high precision [6-7]. In this paper, the soil-water characteristic curves of remolded expansive soil with different initial dry densities were determined by this method. The effect of initial dry density on SWCC was systematically analyzed.

2. The Filter Paper Method

2.1. Test Materials and Instruments

The soil for the test was taken from Hefei, and the soil sample was grayish yellow. The physical and mechanical properties are shown in Table 1.

| Liquid limit W_L/\% | Plastic limit W_P/\% | Plasticity index I_P/\% | free swelling ratio/\% | particle density G_s |
|---------------------|---------------------|--------------------------|------------------------|----------------------|
| 72                  | 30                  | 42                       | 44                     | 2.68                 |

Whatman No. 42 filter paper (diameter 55 mm) was used for the test to measure suction, and the No. 201 filter paper (cut to diameter 61 mm) was used as the protective filter paper for test accuracy. The expression of rate curve equation of Whatman No. 42 filter paper is:

\[ \lg \psi = 2.909 - 0.0229w \quad (w \geq 47) \]  
\[ \lg \psi = 4.945 - 0.0673w \quad (w < 47) \]

Where, \( \psi \) (kPa) is the matrix suction. \( w \) (%) is the moisture content of filter paper.

The main equipment used in the test includes: (1) closed container and plastic partition (Lock Lock box was used as closed container). (2) Electronic balance with accuracy of 0.0001g. (3) Oven, control temperature is \( 110^\circ C \pm 1^\circ C \). (4) Weighing box. (5) Tweezers, scissors, etc. The schematic diagram of the test equipment is shown in Figure 1:

![Figure 1. Suction test diagram](image-url)
2.2. Test Scheme and Steps

2.2.1. Test Scheme. Preparing several ring-shaped soil samples, its dry density is 1.55, 1.60, 1.65 and 1.70 g/cm³, and also have moisture content which is 3%, 5.5%, 8%, 10.5%, 13%, 15.5%, 18% and 20.5%. Measuring the suction of these prepared soil samples.

2.2.2. Test Steps. ① Filter paper preparation: Each group of samples used two Whatman filter papers to measure the suction and four double-circle filter papers to protect it. Before the test, the filter paper was baked at 110°C for 24 h.
② Suction measurement: four samples per group, placing one Whatman filter paper between two double-circle filter papers, in order to avoid the filter paper being contaminated by soil samples. The three sheets of filter paper are placed between two soil samples, and two soil samples are pinched so that the filter paper is in close contact with the sample for moisture migration, achieving a higher measurement accuracy (Figure 2).
③ Suction balance: put the closed container into the incubator, the temperature is 20°C, and the time of suction balance is 14d.
④ Determine the quality of the filter paper: After the end of the suction balance, determine the mass of the weighing box and the total mass of the filter paper and weighing box. Place the weighing box with filter paper in an oven for drying. The weighing box containing the filter paper is taken out of the oven to determine the total mass of the drying. Remove the filter paper quickly and determine the mass of the weighing box. This process was repeated for all Whatman filter papers.
⑤ Determine the actual moisture content of the sample: put the soil sample into a weighing box, and then dry the weighing box at 110°C for 72 h. This process was repeated for all soil samples.

![Figure 2. The filter paper method](image-url)

3. Characteristic Analysis of Soil-Water Characteristic Curve

Figure 3 shows the relationship between moisture content and suction at different dry density. It can be seen that the dry density of the soil will have a certain impact on soil-water characteristic curve.
Figure 3. The soil-water characteristic curve of Hefei expansive soil (w-s curve)

As can be seen from Figure 3, when the soil-water characteristic curve is expressed by the relationship between the moisture content and suction, the suction will increase with the decrease of moisture content, and SWCC will move to the upper right with the decrease of dry density. When the suction is the same, the higher dry density, the smaller moisture content. When the moisture content is the same, the smaller dry density, the higher moisture content.

For soil samples with different dry densities, the moisture content varies greatly with the lower suction. As the suction becomes larger, the effect of dry density on the soil-water characteristic curve is gradually reduced. Until the suction exceeds 5000 kPa, there is basically no effect. The similar test results were obtained from the suction tests of Romero and Vaunat [8] and Sun Dean [9-10].

Therefore, part of the SWCC with moisture content below 10% can be measured only once, which has important guiding significance for improving the efficiency of SWCC test.

Figure 4. The soil-water characteristic curve of Hefei expansive soil (Sr-s curve)

Figure 4 shows the relationship between saturation and suction at different dry density.

As can be seen from Figure 4, when the soil-water characteristic curve is expressed by the relationship between saturation and suction, the suction will increase with the decrease of the saturation, and the increase of the dry density of the sample causes the move of SWCC to the upper right. When the suction is the same, the higher dry density, the lager saturation. When the saturation is the same, the higher dry density, the lager suction. This is consistent with the experimental conclusion that obtained by Sun [11].
4. Conclusion
In this paper, four soil-water characteristic curves of Hefei remolded expansive soil samples under different initial dry densities were determined by filter paper method. The influence of initial dry density on SWCC was systematically analyzed. The main conclusions are as follows:

(1) In the $\omega$-$s$ curve, the suction will increase with the decrease of moisture content, and SWCC will move to the upper right with the decrease of dry density. (2) In the $w$-$s$ curve, the influence of the dry density on SWCC decreases as the suction becomes larger. When the moisture content is less than 10%, the difference in dry density no longer affects the SWCC. (3) Part of the SWCC with moisture content below 10% can be measured only once, which has important guiding significance for improving the efficiency of SWCC test. (4) In the $Sr$-$s$ curve, the suction will increases with the decrease of the saturation, and the increase of the dry density of the sample causes the move of SWCC to the upper right.

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