Study of Equilibrium Time in Wetting Soil-Water Characteristics Curves (SWCC) using Capillarity Column Method

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ABSTRACT

The soil-water characteristic curve (SWCC) of soil plays the key roll in unsaturated soil mechanics which is a relatively new field. To encourage the geotechnical engineers to apply unsaturated soil mechanics theories in routine practice, numerical methods, based on the SWCC and saturated soil properties, have been developed to predict unsaturated permeability function and unsaturated shear strength properties which are expensive, time consuming, and it may require specials techniques or apparatus to measure the SWCC in laboratories. However, it is important to have laboratory measured data of SWCCs to enhance and verify the proposed numerical methods. Hence, employing the capillary column method which applies the tempe cell pressure principle, namely varying the matric suction value, this study aims to obtain the water content in each matric sauction variation which is then presented in SWCC form. Saturated permeability is obtained from constant head test. Permeability function is calculated indirectlt by Fredlund and Rahardjo method (1993) using SWCC and saturated permeability.

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1. INTRODUCTION

The measurement of soil parameters for unsaturated soil conditions has always been a time-consuming and costly approach, making it difficult for geotechnical engineers to integrate general knowledge of unsaturated soil mechanics into commonly applied design and problem-solving practices. To encourage the use of unsaturated soil properties in geotechnical design, many methods have been proposed and developed over the past few decades [17],[21].

The Soil-Water Characteristic Curve (SWCC) defines the relationship between water content and matric suction in unsaturated soils [4],[5]. Soil suction and water content are key parameters that govern the geotechnical properties of unsaturated soils, including permeability, volume change, deformability, and shear strength (Barbour, 1998). SWCC plays a vital role in unsaturated soil mechanics, a relatively new field of study with wide-ranging applications, particularly in geotechnical engineering13],[14]. Several methods have been proposed to predict SWCC in order to avoid the difficulties associated with laboratory measurements. However, these measurements are time-consuming, costly, and may require specialized techniques or equipment, such as the Tempe Cell method for measuring SWCC in sandy soils [13],[14].

Currently, the cost of Tempe Cell equipment remains high, the process is time-intensive, and it requires specialized tools. Therefore, the capillary column method can be an alternative due to its simplicity and low cost. This method applies the capillary phenomenon and is designed based on the principles of the Tempe Cell, by varying the matric suction values, where the height of the soil column can be adjusted. SWCC measurement using this method has not been widely implemented, so the resulting soil-water characteristic curves may not be accurate. Thus, further research is needed to validate the accuracy of the soil-water characteristic curves obtained from instruments developed using the capillary column method [2],[15],[21].

The soil-water characteristic curve is related to the following aspects:

1. The shape of the soil-water characteristic curve represents the variation of permeability with respect to suction in unsaturated soils (permeability function).
2. The suction value at the air-entry value (AEV) condition is related to the suction value during changes in shear strength parameters under unsaturated conditions.
3. The soil-water characteristic curve is one of the components in the constitutive curve for volume change behavior in unsaturated soils (φ_b).

These three points cover the entire domain of soil mechanics analysis under both saturated and unsaturated conditions. Therefore, the soil-water characteristic curve plays a crucial role in the mechanics of unsaturated soils [14].

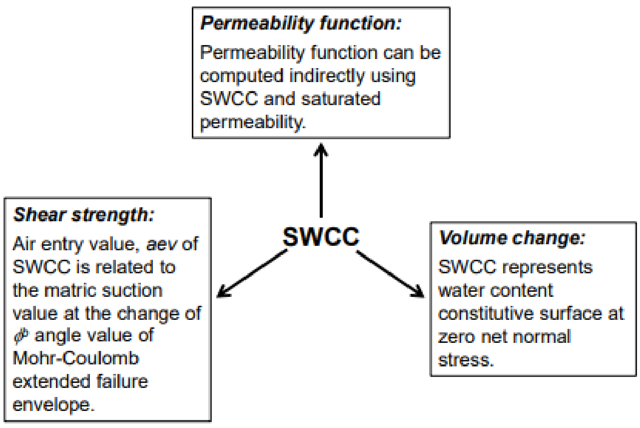


Figure 1. Relationship between Soil-Water Characteristic Curves and three domains of analysis in soil mechanics [14].

1.1 Concept of Partially Saturated Soil (Unsaturated Soil)

Rainfall that wets the ground surface infiltrates downward and is divided into a partially saturated zone and a saturated zone. The partially saturated zone is generally located above the groundwater table, with pores partially filled with water. This zone is also known as the aeration zone, extending from the ground surface down through the main root zone. Its thickness varies depending on the type of soil and vegetation. In this zone, the spaces between soil particles are partly filled with water and partly with air. This concept is illustrated in Figure 2 [4].

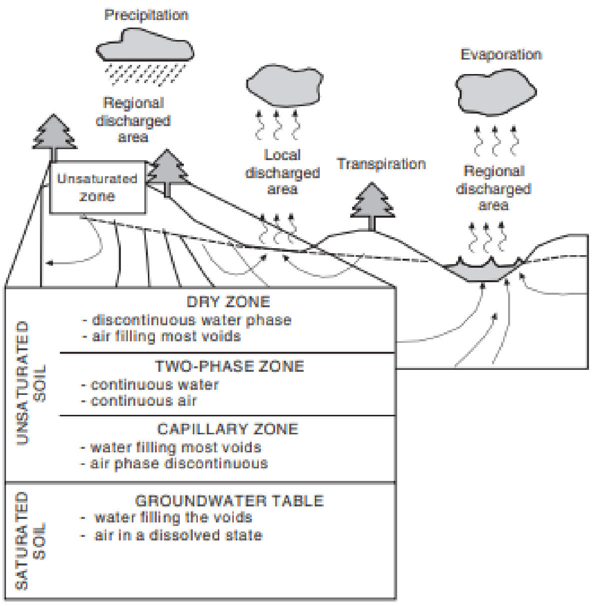
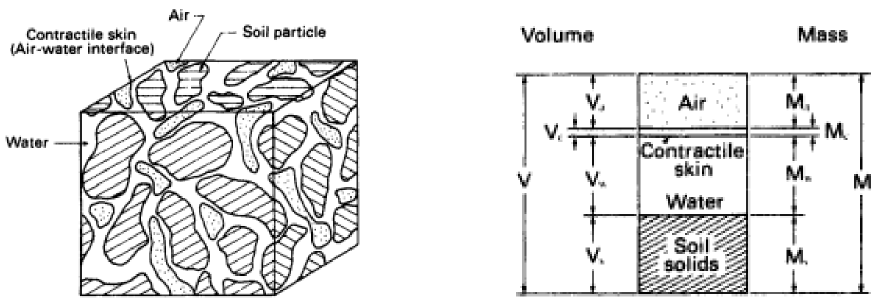


Figure 2. Division of unsaturated soil zones (vadose zone) locally and regionally

Partially saturated soil or soil is above the ground water level (m.a.t.). The soil has several phases, namely air, Unsaturated water and granular/soil phases, and there will be an interface between water and air which is known as the contractile skin. The schematic of partially saturated soil elements is as shown in Figure 3 [4].



(a) (b)

Figure 3. Unsaturated soil elements with a continuous phase of water

Contractile skin refers to the process of water surface tension in soil, which can be likened to an elastic membrane. Contractile skin is manifested as air pressure, where the difference between air pressure and water pressure is represented by the value ($u_a - u_w$) [4].

1.2 Matric Suction as a Special Physical Phenomenon in Unsaturated Soils

The negative pore water pressure (u_w) in the soil above the groundwater table can be explained by the phenomenon of high capillarity in the capillary pipe. The pore water pressure at the water surface in the capillary pipe can be expressed in the following relationship:

$$u_w = - h_c \gamma_w \quad (1)$$

where, u_w : pore water pressure , h_c : capillary rise height and γ_w : unit weight of water.

Porewater pressure can be expressed using pore air pressure (u_a) as a reference. Thus, the above relationship can be written as:

$$(u_a - u_w) = u_a - h_c\gamma_w \quad (2)$$

The parameter ($u_a - u_w$) is referred to as matric suction [4].

Pore air pressure can be expressed either as absolute pressure or gauge pressure. Technically, the use of gauge pressure is preferred in many cases, because the absolute pore air pressure is approximately 1 atm (with a gauge pressure of 0), meaning that matric suction represents the positive value of the negative pore water pressure. This approach simplifies practical engineering calculations [4],[5].

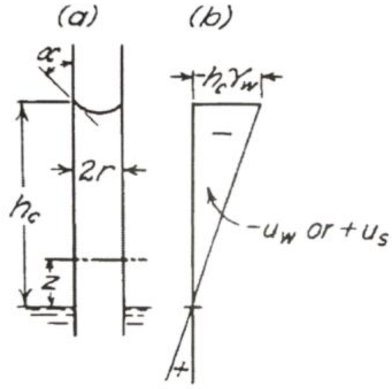


Figure 4. high capillarity

1.3 Basic Concept of the Soil-Water Characteristic Curve

The soil-water characteristic curve describes the water content in soil corresponding to variations in matric suction. The basic concept of the soil-water characteristic curve can be understood by examining the phenomenon of capillary rise in a capillary tube. The voids within the soil can be considered as a collection of capillary tubes of various sizes. When water is supplied to the base of a dry soil column, the water will rise through the dry soil until equilibrium is reached.

The soil-water characteristic curve provides an understanding of the mass (and/or volume) of water in the soil as well as the energy of the water phase. The soil-water characteristic curve can serve as a capillary model to describe the distribution of water within the pores. Laboratory measurement of the soil-water characteristic curve can take into account the effects of soil texture, gradation, and porosity. The soil-water characteristic curve can determine the properties of unsaturated soils [5].

The soil-water characteristic curve also provides important information for the analysis of seepage, shear strength, volume change, air flow, and heat flow involving unsaturated soils [4]. The shape of the soil-water characteristic curve depends on the soil's ability to undergo volume changes under different suction levels [5].

The soil-water characteristic curve will show a decrease in soil saturation. This decrease in saturation can be divided into three main zones: the boundary effect zone, the transition zone, and the residual zone [5].

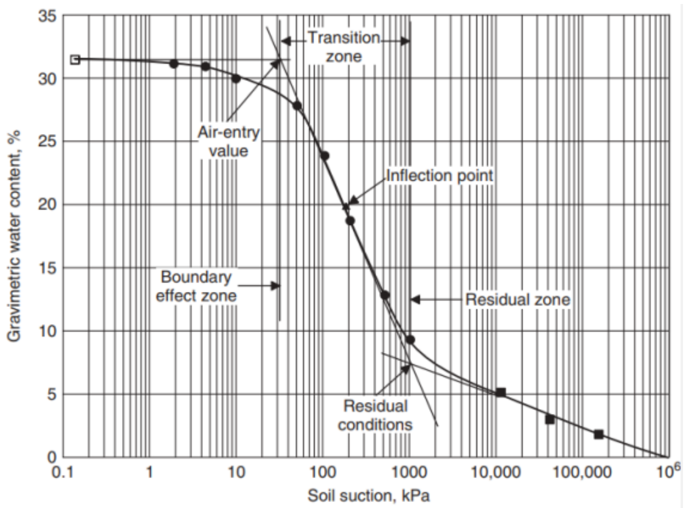


Figure 5. SWCC which shows a decrease in saturation

1.4 Column Test

The SWCC is often required for coarse-grained, non-cohesive soils, which can be obtained using a column test. The water height above the base of the column can be converted into a matric suction value by assuming hydrostatic conditions for the water within the column. A column with a height of approximately 1 meter has been shown to be effective when the soil's air entry value (*aev*) is less than about 7 kPa and the residual condition occurs around 10 kPa. Thus, column testing can be conducted in both wetting and drying modes by measuring the SWCC during each process.

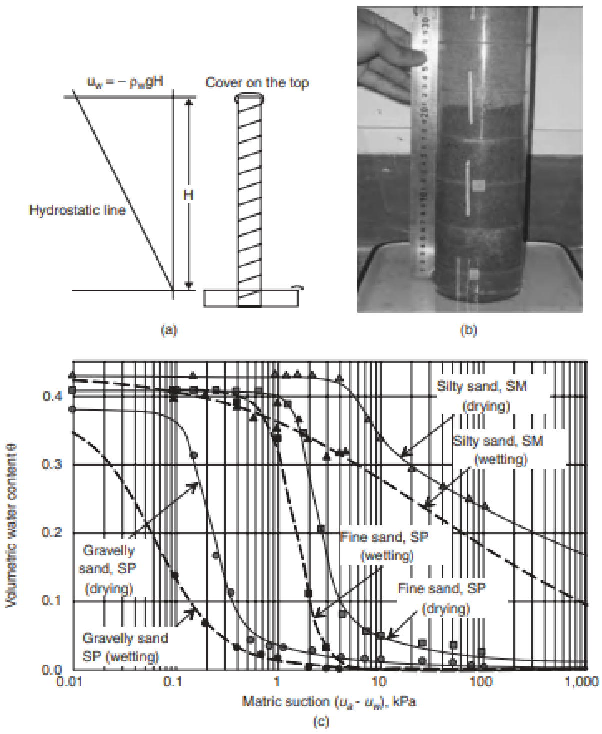


Figure 6. Column tests are carried out on coarse-grained materials to measure SWCC
(a) Equilibrated matric suction in column test, (b) column test showing capillary rise for wetting test, (c) SWCC for sand with column test [24]

Wetting SWCC is most often measured using a column test. Wetting SWCC is measured by allowing water to be drawn into the soil in a column of water that has been provided. Water content measurements can be made at various heights in the column until equilibrium has been reached. Figure II.c shows the wetting SWCC for three coarse sands tested by column test. Tempe cell testing is used to obtain drying curves [24].

2. METHODS

In this study, the capillary column method is used to obtain the Soil-Water Characteristic Curve (SWCC), which describes the relationship between water content and matric suction. The SWCC is utilized to identify and determine the properties and parameters of unsaturated soils using loose sand samples from Tasikmalaya.

2.1 Research Procedure

The research to obtain the equilibrium time curve for Galunggung sand follows a series of processes, including the preparation of sand samples, testing of the sand's index properties, and testing using the capillary column method until the equilibrium time curve is obtained.

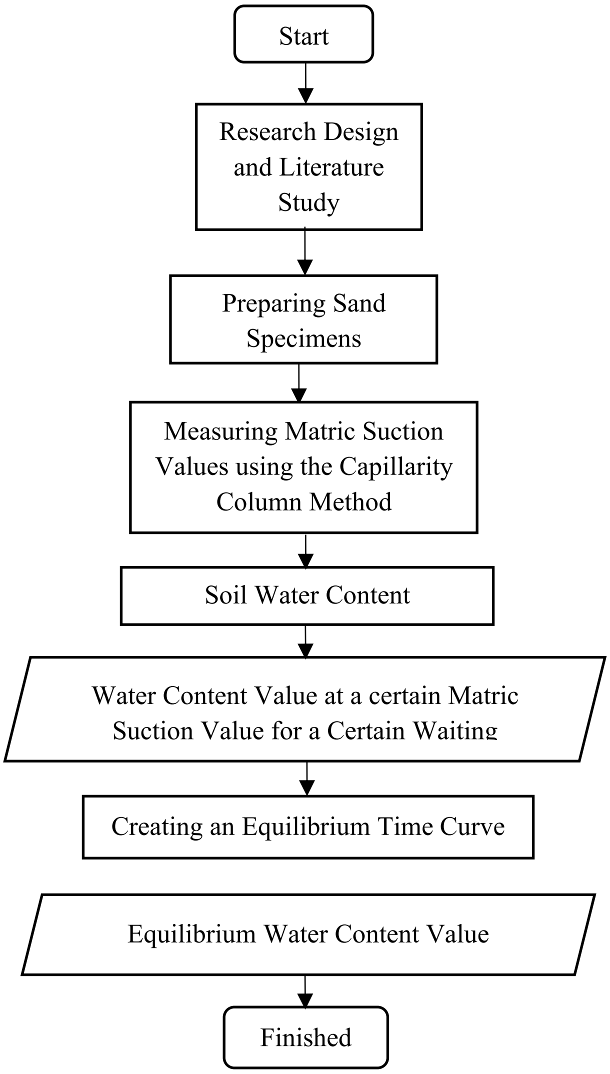


Figure 7. Research Flow Chart

2.2 Tools and materials

The object used in this research was Galunggung sand which passed through sieve number 4 and was retained on sieve number 20 and had been dried before being tested.

Figure 8. Sand samples

Figure 9. The capillarity column will be used as a test tool

2.3 measurement of matric suction value

The stages of measuring the matrix suction value using the capillarity column method are

1. Calculate the volume of the test equipment column for a height of 2 m, then record the volume.
2. Insert the sand specimen into the test equipment column until it meets the 50% Dr requirement. To obtain a density that meets the requirements, a sample preparation method is used with a tool that will be designed similar to a sieving pluviation apparatus, as in Figure 10 below.
3. Pour distilled water into the water reservoir until it is full.
4. Weigh 10 empty cups, then record the weight.
5. Wait until the specified time.
6. Insert the sand specimen from the test equipment into the cup. One cup for sand specimens taken from one segment in the test equipment column.
7. Weigh the sand specimen along with the cup, then record the weight.
8. Put the sand specimen and the cup into the oven until the weight is constant.
9. Remove the sand specimen and cup from the oven.
10. Weigh the specimen along with the cup, then record the weight.
11. Calculate the water content of sand specimens.

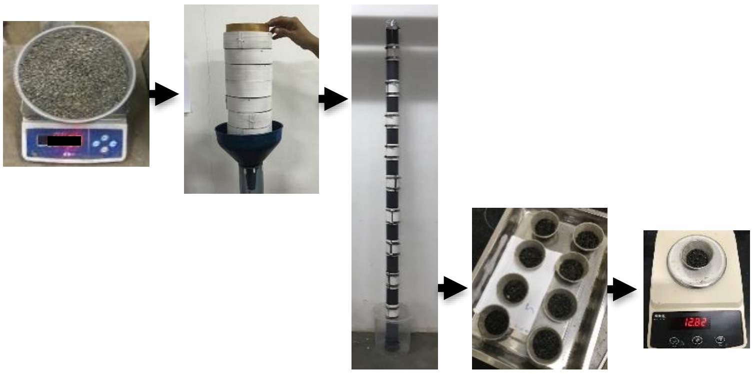


Figure 10. Column Test

3. RESULTS AND DISCUSSION

The following is data on waiting times for 3, 7, and 14 days on volumetric water content for each matric suction value from laboratory tests that have been carried out.

Table 1. Laboratory data

Matric Suction	Volumetric Water Content		
	Waiting Time (Day)		
(kPa)	3	7	14
0	0,4306	0,4623	0,4939
1,96	0,2907	0,4250	0,4333
3,92	0,2725	0,3398	0,3700
5,89	0,2477	0,2680	0,3229
7,85	0,2465	0,2816	0,2820

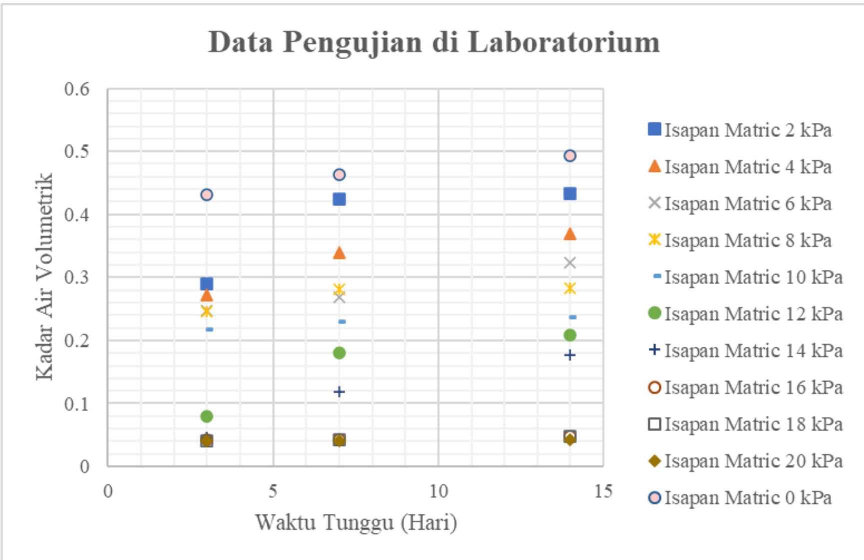


Figure 11. Laboratory Test Data

4. CONCLUSION

Tests show that the equilibrium time in the capillarity column for sand can be achieved after a period of 7 days, in the type of sand with C_u of 10,540, C_c of 1,108 and D_{60} of 1,256 which is classified as well graded. After the equilibrium time was reached, there was no significant change in the water content of the sand media. Sand with a finer particle size tends to reach equilibrium more quickly than coarser sand, because the water retention capacity of fine sand is greater and it retains moisture more easily.

A testing time that is too short can produce unrepresentative data regarding SWCC, because a stable condition has not been reached. Therefore, there needs to be more careful observation to ensure that the test is carried out in sufficient time to reach equilibrium. The equilibrium time in SWCC testing of sand with a capillarity column is a key factor to obtain accurate water retention characteristics. Proper testing and sufficient time duration will provide more accurate information about the sand's ability to store and drain water.

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