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Effect of shrinkage on air-entry value of soils

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Abstract

The soil–water characteristic curve (SWCC) is an important property of unsaturated soils. One key parameter of the SWCC is the air-entry value. For a soil that does not shrink as soil suction increases, the air-entry value is the same regardless of whether the gravimetric water content-based SWCC (SWCC-w), the volumetric water content-based SWCC (SWCC-θ) or the degree of saturation-based SWCC (SWCC-S) is used. However, for a soil that shrinks as soil suction increases, the air-entry value depends on the SWCC. The air-entry value determined from the SWCC-w is shown to underestimate the air-entry value for a soil that shows shrinkage as soil suction increases. For such cases, the SWCC-S should be used to determine the air-entry value. The SWCC-S can be constructed using the SWCC-w and the shrinkage curve. The shrinkage curve provides the void ratio and the water content for calculating the degree of saturation which can then be used to transform the SWCC-w to the SWCC-S. The shrinkage curve can be easily constructed from the final volume measurement of a drying soil specimen, as shown in this paper. The sensitivity analyses performed on 40 soils showed that the minimum void ratio of the shrinkage curve (a_{sh}) has a very significant effect, while the curvature of the shrinkage curve (c_{sh}) has a negligible effect on the SWCC-S, and therefore, on the determination of the AEV. A procedure is proposed for determining the air-entry value of soils exhibiting shrinkage upon drying.

Keywords: Shrinkage; Soil–water characteristic curve; Air-entry value; Water content; Degree of saturation; Unsaturated soil

1. Introduction

In the application of unsaturated soil mechanics, the engineering properties of unsaturated soils are required. However, the test duration for unsaturated soils is several times longer than that for equivalent saturated soil tests. To alleviate the problem of the long unsaturated soil test duration in geotechnical engineering practice, the soil–water characteristic curve (SWCC) has been heavily utilized to determine the unsaturated soil properties indirectly. The SWCC is the relationship between the soil–water content (by mass or volume) and the soil–water matric potential (Leong and Rahardjo, 1997). One key parameter of the SWCC is the air-entry value (AEV) which demarcates the change from boundary effect zone to transition effect zone, as shown in Fig. 1. The AEV is defined as the matric suction where air starts to enter the largest pores in the soil (Fredlund and Xing, 1994). The AEV appears in many equations used to estimate unsaturated soil properties, such as the shear strength (e.g., Bao et al., 1998; Goh et al., 2010; Khalili and Khabbaz, 1998; Lee et al., 2005; Rassam and Cook, 2002; Rassam and Williams, 1999; Tekinsoy et al., 2004; Xu, 2004) and the permeability function (e.g., Hunt, 2004; Mbonimpa et al., 2006; Philip, 1986; Rijtema, 1965; Watabe and Leroueil, 2006).

In Fig. 1, the ordinate axis labelled “water content” can be either gravimetric water content w, volumetric water content θ or degree of saturation S. Fredlund et al. (2001) suggested that the same information in the SWCC is conveyed regardless of the term used to describe the water content provided that the

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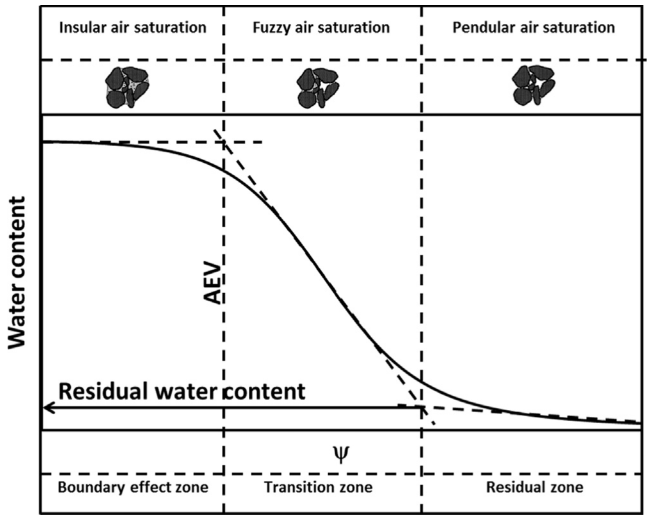

Fig. 1. Soil–water characteristic curve and parameters adopted from Kohgo (2003).

structure of the soil is incompressible. If the soil shrinks, as a result of an increase in soil suction, the AEV should be obtained from the SWCC where the ordinate axis is the degree of saturation, i.e., the SWCC-*S*. In agriculture-related disciplines, the volumetric water content is commonly used to plot the SWCC. The volumetric water content is defined as the volume of water in the soil referenced to the instantaneous total volume of the soil. However, it is quite common to use the initial total volume of the soil to determine the volumetric water content (Fredlund et al., 2011). If this is the case, both SWCCs, where the ordinate axis is the gravimetric water content (SWCC-*w*) and where the ordinate axis is the volumetric water content (SWCC-θ), show similar information. The use of the SWCC-θ is ambiguous as it may be plotted with the volume of water in the soil referenced to the initial total volume or the instantaneous total volume of the soil. In geotechnical engineering, the gravimetric water content is commonly used to describe the amount of water in the soil, and it should be used to plot the soil–water characteristic curve when continuous volume measurements have not been made (Fredlund et al., 2001).

Some soils undergo volume change as their water content changes. The relationship between the gravimetric water content (w) and the void ratio (e) is known as the shrinkage curve. Fredlund et al. (2011) has shown that the SWCC-*S* can be constructed using the shrinkage curve and the SWCC-*w*. Ignoring the shrinkage curve and using only the SWCC-*w* to determine the AEV will underestimate the AEV of the soil. There are at least two important parameters in describing the shrinkage curve (Fredlund et al., 2002). The first is the minimum void ratio (e_{min}) and the second is the curvature of the shrinkage curve. In practice, it is usually very difficult to accurately measure the volume of a soil during the SWCC test (Peron et al., 2007; Liu et al., 2012). Some reasons are due to the non-homogenous shrinkage and cracks that may occur during the drying process, as shown in Fig. 2. Fredlund et al. (2002) proposed to estimate the minimum void ratio by using

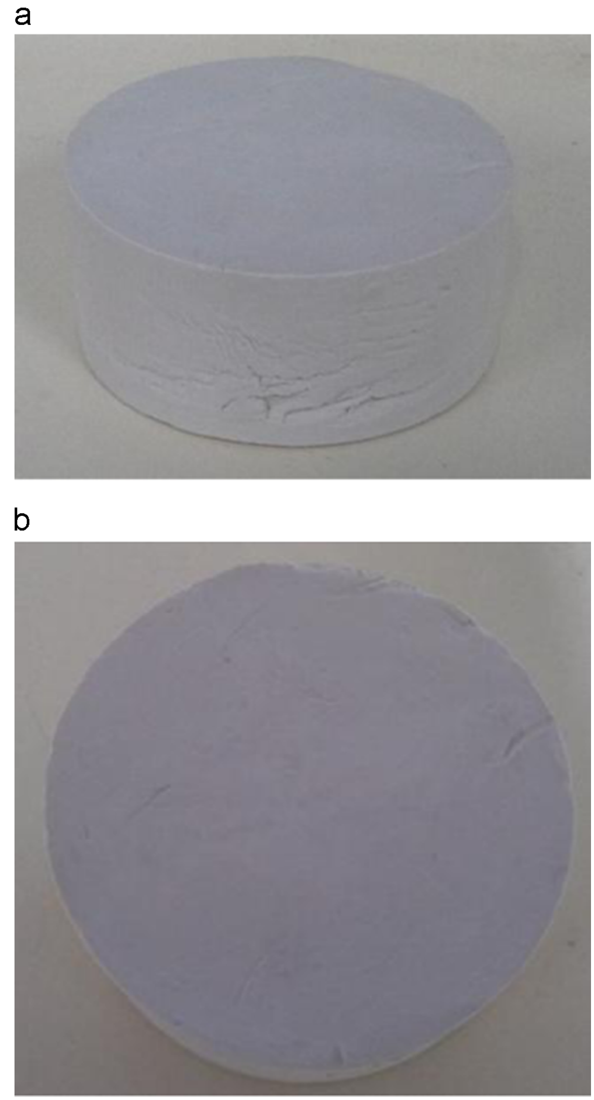

Fig. 2. Cracks and non-uniform deformation in a kaolin specimen that cause uncertainty in volume measurement. (a) Crack appears at the side of the soil specimen and causes inaccuracy in the volume measurement and (b) Non-uniform deformation at the perimeter of the specimen causes a lot of difficulty in measuring the volume.

the shrinkage limit. However, the accuracy and the sensitivity of the minimum void ratio and the curvature of the shrinkage curve on the AEV are not clearly understood. The objective of this paper is to investigate the effect of shrinkage on the determination of the AEV. Forty soils from the literature and the SoilVision (2003) database were used to analyse the effect of the shrinkage curve parameters (minimum void ratio and curvature of the shrinkage curve) on the AEV of soils. Shrinkage tests on kaolin specimens were then conducted to illustrate the effect of the shrinkage curve on the AEV.

2. Shrinkage curve

In order to construct the SWCC-*S*, the shrinkage curve is needed. When a soil is saturated, the reduction in void ratio due to the decrease in water content is linearly related (line 1 in Fig. 3). This type of shrinkage is called normal shrinkage.