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Laboratory investigation of the effect of cyclic wetting and drying on the behaviour of an expansive soil

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Abstract

The behaviour of an expansive soil was studied through a number of experiments involving cycles of wetting and drying. Laboratory tests were conducted on compacted samples of an expansive soil (a mixture of bentonite and kaolin, CH) in a modified oedometer under different constant surcharge pressures. The void ratio and water content of samples were determined at different stages. The results show that the swelling–shrinkage was reversible after the soil reached the equilibrium condition where the deformations were the same and the wetting and drying paths (in the water content–void ratio space) converged to an S-shaped curve. The hysteresis phenomenon was studied through the variation of the void ratio with suction, and the results showed that it diminished gradually with the increase in cycles of wetting and drying. The effect of fabric on the behaviour of soil samples was studied during cycles of wetting and drying. The results show that the samples with lower initial water content (on the dry side of optimum) have more swelling potential than samples with a higher initial water content (on the wet side of optimum).
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Keywords: Expansive soil; Wetting and drying; Void ratio; Water content; Deformation; Fabric; Hysteresis

1. Introduction

From an engineering point of view, an important characteristic of some clay soils is their susceptibility to volume change due to wetting or drying which can occur independent of loading. Expansive soils swell and shrink periodically when subjected to seasonal water content changes. The variation in water content due to the periods of precipitation and evaporation affects the volume change response of the active clay beneath a structure. These volume changes can give rise to ground movements which may result in damage to the buildings. As a result, they are a constant source of concern in the design and construction of foundations.

It is generally accepted that the water content, void ratio and type of clay minerals in the soil are the main factors affecting the volume change potential of the soil (Jones and Jones, 1987, El-Sohby and Rabba, 1981, Fredlund and Rahardjo, 1993; Hanafy, 1991; Ho et al.,1992; Mitchell and Van Genuchten, 1992; Komine and Ogata, 1996; Marinho and Stuermer, 2000, Bell, 2000 and Ferber et al., 2009). When the water content of expansive clay changes due to drying or wetting, it leads to changes in the volume and void ratio of the soil. When a sample of dry expansive clay is wetted, the increase in water content will cause an increase in the volume of voids (i.e. swelling).

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The three phases of swelling are the primary phase, the secondary phase and the no swelling phase (Day, 1999). The primary phase occurs at a very fast rate and the cracks developed during drying are closed. The secondary phase includes closure of the micro-cracks and the reduction of entrapped air. During the third phase, no further volume change or change in void ratio occurs. Similarly the drying curve of a soil has three phases as a result of progressive drying (Haines, 1923) namely structural shrinkage, normal shrinkage and residual shrinkage. The extent of each process depends on the soil structure and, importantly, the number of inter-particle bonds causing resistance (Bell, 2000; Popescu, 1979). While the change of soil volume in structural and residual phases of shrinkage is less than the change in the volume of water, they are the same in the normal phase of shrinkage. Haines (1923) stated that at the shrinkage limit (or at the start of residual stage) the decrease in the volume of soil is less than the volume of water lost as the particles come in contact. It was also noted that when all the particles are close together, no further shrinkage occurs even while water is still being lost.

Hanafy (1991) suggested that these two curves (wetting and drying) can be combined and integrated into one S shaped curve at the equilibrium condition. It is possible to characterize the volume change in the terms of the changes in the void ratio in relation to changes in water content. Tripathy et al. (2002) and Estabragh et al. (2013) determined a characteristic S shaped curve for two expansive soils. They used this curve to explain the potential of volume change in terms of void ratio and water content resulting from wetting and drying cycles. Many researchers, including Wheeler et al. (2003), Alonso et al. (2005) and Nowamooz and Masrouri (2008), have studied the cyclic wetting and drying behaviour of the expansive clayey soils by a suction control method. Wheeler et al. (2003) showed that irreversible compression occurs during drying stages of wetting–drying cycles. They studied the influence of a wetting–drying cycle on subsequent behaviour during isotropic loading. Based on the results they proposed a model for the coupling of hydraulic hystersis and mechanical behaviour. Alonso et al. (2005) reported that samples experience progressive shrinkage during successive cycles of wetting and drying until finally a reversible elastic response occurs. This progressive shrinkage process leads to an increase in the overconsolidation ratio (OCR). Nowamooz and Masrouri (2008) found that wetting and drying cycles significantly influence the preconsolidation pressure, virgin compression index and elastic compression index. Wang et al. (2013) studied the effect of voids on the hyro-mechanical behaviour of compacted bentonite–sand mixture through different suction controlled tests. They found that the amount of water absorbed in the soil depends only on suction at high suctions, whereas it depends on both suction and void ratio of bentonite at low suctions.

The effect of fabric on the behaviour of unsaturated soils is of great significance, particularly for compacted soils (Alonso et al., 1987). The term 'fabric' refers to the geometrical arrangement of particles within a soil. The fabric of compacted soils is generally explained in terms of a number of variables, namely the compaction water content with regard to the optimum, the energy of compaction (or attained density) and the compaction method. Gens (1996) explained some aspects of the compaction procedure, such as the compaction water content and the compactive effort, which have a significant influence on the subsequent mechanical behaviour of compacted fine-grained soils. The influence of the compaction procedure on the subsequent mechanical behaviour is commonly attributed to the different forms of soil fabric produced when the compaction procedure is varied (Seed and Chan 1959; Barden and Sides 1970). Lambe (1958) proposed a conceptual model for the fabric of clays. Significant information about the fabric of soil was made available with the advent of scanning electron microscopy (SEM) and mercury techniques. SEM and porosimetry studies are now widely used to describe the fabric of different types of soil (Diamond, 1970; Collins and McGown, 1974). Researchers such as Delage and Lefebvre (1984) and Lapierre et al. (1990) reported the data for compacted fine-grained soil and stated that on the dry side of optimum moisture content, compacted fine grained soils tend to develop a bimodal distribution of pore size. In contrast, on the wet side of optimum, soils tend to have a fabric with a unimodel distribution of pore size. This information can be used to explain the mechanical and physical behaviour of soil. Although many researchers have studied the behaviour of expansive soils, the study of the wetting and drying paths in the form of variations of the water content and void ratio during cycles of wetting and drying is mainly limited to the work of Tripathy et al. (2002) and Estabragh et al. (2013). Other researchers, including Sharma (1998), Wheeler et al. (2003), Sivakumar et al. (2006) and Jotisankasa et al. (2009), have studied the variations of specific volume $(1+e)$ with suction. Their tests were conducted on unsaturated samples in a modified triaxial cell. They found that during drying (increasing suction) and wetting (decreasing suction) the values of specific volume for a given suction are not the same for wetting and drying because of the hysteresis phenomenon. The void ratio and water content of an expansive soil are changed during wetting and drying. Since suction is dependent on the water content, the variations of void ratio during wetting and drying can be a function of suction. A review of the literature indicates that there has been considerable amount of research on the deformation behaviour of expansive soils during wetting and drying but the investigation into the variations of void ratio, with water content and suction has been limited. The main objective of this study is to investigate the variation of void ratio with water content and suction under different surcharge pressures for an expansive soil. The results of this research study will be presented in terms of axial deformation, dry unit weight, and void ratio–water content and void ratio–suction relationships. The effect of fabric on the swelling potential of soil will also be studied during wetting and drying cycles.

2. Experimental work

2.1. Material

The soil used in this study was made by mixing kaolin and bentonite. A wide range of soil mixes were investigated to identify a mix with desired drying and wetting properties (a high potential for swelling and shrinkage). Consideration was

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