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Effect of different types of wetting fluids on the behaviour of expansive soil during wetting and drying

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Abstract

This paper presents the results of an experimental investigation into the mechanical behaviour of an expansive soil during wetting and drying cycles. The experimental tests were conducted in a modified oedometer under two different surcharge pressures (10 and 20 kPa). During the tests, the samples were inundated with different types of wetting fluids (distilled water, saline water and acidic water). The volumetric deformation, void ratio and water content of the samples were determined during cycles of wetting and drying. The results show that the swelling potential increases with an increasing number of wetting and drying cycles. The effect of the distilled water on the swelling potential is not the same as that of the saline water or the acidic water, particularly for different surcharge pressures. The variations in void ratio and water content show that, at the equilibrium condition, the wetting and drying paths converge to nearly an S-shaped curve. This curve consists of a linear portion and two curved portions, and the majority of the deformation is located between the saturation curves of 90% and 40%.
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Keywords: Expansive soil; Wetting and drying; Distilled water; Saline water; Acidic water

1. Introduction

Expansive soils are a worldwide problem as they cause extensive damage to Civil Engineering structures. The average cost of this damage to buildings, roads, airports and pipelines is about $9 billion per annum in the USA. This is more than twice the combined average annual damage due to all earthquakes, floods, tornados and hurricanes in the USA (Jones and Jones, 1987). As a result, a clear understanding of the behaviour of expansive soils is required for the effective design of structures and infrastructures on these soils.

There are many factors that govern the expansive behaviour of soils. The initial factors are the availability of moisture and the amount of clay particles in the soil. Other factors affecting the expansive behaviour include the type of soil, the condition of the soil in terms of dry density and the moisture content, the magnitude of the surcharge pressure and the amount of non-expansive material. In general, the swelling potential increases as the dry density increases and the water content decreases (Hanafy, 1991; Fredlund and Rahardjo, 1993; Marinho and Stuermer, 2000; Ferber et al., 2009). The behaviour of expansive soils under cycles of wetting and drying has been the subject of intensive investigation during recent years. A number of researchers, such as Rao and Satyadas (1987) and Chen (1988), have subjected remoulded clay samples to

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full swelling and then allowed them to dry to their initial water content. By repeating this procedure, the soil showed signs of irreversible deformation after each cycle of wetting and drying. Dif and Blumel (1991) found almost no volume change in remoulded clay after at least three or four drying and wetting cycles. Many researchers, such as Wheeler et al. (2003), Alonso et al. (2005), Nowamooz and Masrouri (2008), have studied the behaviour of expansive soils during wetting and drying cycles by controlling the suction. Tripathy et al. (2002) studied the wetting and drying behaviour in terms of the void ratio and the water content. Several investigations have shown the behaviour of expansive soils under chemical influence (Alawaji, 1999; Musso et al., 2003; Di Maio et al., 2004; Rao and Shivananda, 2005; Rao and Thyagaraj, 2007a, 2007b; Casttellanos et al., 2008; Siddiqua et al., 2011). The hydro-mechanical behaviour of compacted swelling soils at ambient temperature has been studied by a number of researchers, such as Cui et al. (2002), Lloret et al. (2003), Cekerevac and Laloui (2004), Cuisinier and Masrouri (2005), Tang et al. (2008), Wang et al. (2013). They concluded that heating has a significant effect on the mechanical behaviour of expansive soils. However, to the authors' knowledge, no research studies have ever been reported in literature on the effect of different types of wetting fluids on the behaviour of clay soil during cycles of wetting and drying. The main objective of this study, therefore, is to investigate the effect of different types of wetting fluids on the wetting and drying behaviour of clay soil. The results of this experimental study will be presented in terms of the volumetric deformation and the void ratio-water content relationship. The effect of surcharge pressure on the swelling behaviour will also be studied. It will be shown that it is possible to minimize the effects of volume changes during wetting and drying by conducting appropriate tests to characterize the potential of the swelling and shrinkage of expansive soils, taking the necessary precautions and designing a suitable foundation system.

2. Experimental work

2.1. Material

The soil used in the testing program was highly expansive clay (according to the classification by McKeen (1992)). The soil was prepared by mixing bentonite with low-plasticity kaolin. A wide range of soil mixtures was investigated to identify a mixture with the desired wetting and drying properties (a high potential for swelling and shrinkage). Finally, the soil chosen comprised a mixture of 20% bentonite and 80% kaolin. The physical and chemical properties of the soil are shown in Tables 1 and 2, respectively. According to the Unified Soil Classification System (USCS), the soil can be classified as clay with high plasticity (CH). The soil had a swelling pressure of 120 kPa and it was determined according to the ASTM D4546 (2008) standard. Drinking water, with a pH value of 7.76, a Cl^{-1} content of 1.7 meq/L and a $Ca^{+2}+Mg^{+2}$ content of 9.1 meq/L, was used to compact and prepare the samples. The optimum water content in the standard compaction test was 18% and the maximum dry unit weight was 16.0 kN/m^3.

Table 1
Physical and mechanical properties of soil.

Soil properties	Values
Specific gravity	2.75
Consistency limits	
Liquid limit (LL)	70%
Plastic limit (PL)	23%
Plastic index (PI)	47%
Shrinkage limit (SL)	13%
USCS classification	CH
Swelling pressure	120 kPa
Compaction study	
Optimum water content	18%
Maximum dry density	1.6 Mg/m^3
Grain size analysis	
Sand	27%
Silt	33%
Clay	40%

Table 2
Chemical composition of soil.

Chemical component	Amount
Na^{+} (meq/L)	73.5
K^{+} (meq/L)	0.04
Ca^{2+} (meq/L)	8.4
Mg^{2+}(meq/L)	4.9
Cl^{-} (meq/L)	35.6
CO_3^{2-} (meq/L)	0.1
SO_4^{2-} (meq/L)	50.8
HCO_3^{-} (meq/L)	31.1
pH	8.2
Electrical conductivity (μS/cm)	7610

2.2. Sample preparation

Several mixtures were prepared using kaolin and bentonite with preselected quantities of different types of wetting fluids (distilled water, saline water or acidic water). The mixtures were kept in closed plastic bags and allowed to cure for 24 h. This allowed the moisture in the soil to distribute evenly throughout the mass of soil. In order to obtain uniform and repeatable samples, a mould was designed and made from stainless steel. The mould was a split compaction mould which consisted of three sections: a top collar, a middle section and a bottom collar. The dimensions of the middle section were exactly the same as those of the ring of the oedometer. The mould was also provided with a piston that was used to compress the sample inside the mould. Silicon grease was used on the inner surface of the mould, before compaction, to reduce the friction during compaction. Samples were prepared in three layers, by static compaction of the moist soil in the mould, to a given dry unit weight of 15.7 kN/m^3 and a water content of 13.5% (4.5% less than the optimum water content

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