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Experimental study of shrinkage and swelling behaviour of a compacted expansive clay soil

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ABSTRACT

Expansive soils are considered problematic soil in geotechnical applications due to their changing behaviour, particularly during wetting and drying. Recent research has indicated that expansive soils stabilise to a stable structure and show predominantly elastic behaviour after a sufficient number of wet/dry cycles. However, experimental data were lacking specially in the dry side of optimum for compacted soils. The present paper reports further results on this issue using basaltic soil from the western region of Melbourne, Australia. The tests have been conducted on soils compacted to a known dry density on the dry side of line of optimums. The tests included wetting and drying performed under stress using a specially designed apparatus. These test results will be discussed along with the results from other researchers within the void ratio-moisture content-pressure relationship. The test results will be used to examine the behaviour of soil during wetting and drying of compacted expansive soils, especially during the first few cycles. The results will be interpreted for possibility of cracking during restrained shrinkage.

Keywords: expansive soils, swell shrink behaviour, moisture content, saturation, wet dry cycles

1 INTRODUCTION

The seasonal movements of expansive clay materials cause shrinkage of the ground surface in the summer months and drought periods and swelling during the rainy season. This well known nature of clay soils has received significant experimental investigation in field and in laboratory (Richards et al. 1983; Sharma 1998; Tripathy et al. 2002). However, in general, the studies on the cyclic swell-shrink behaviour of expansive soils for several numbers of cycles are limited.

The degree of swelling and shrinking depends on the amount of clay minerals within the soil. However, the behaviour can be assumed to be similar in any expansive soil, changing only in degree. When the soil layer is subjected to a sufficient number of wet-dry cycles, it can act predominantly in an elastic manner which is generally referred as environmental stabilization or aging. Aging of newly compacted clay soil and its effect on soils behaviour has been studied in the past by several researchers including Tripathy et al. (2002). How the aging of expansive soils will affect their swell-shrink behaviour is not yet sufficiently clear and more experimental work need to be undertaken.

The stress induced due to the change of moisture content in the soil can be analysed using a constant of proportionality (α) (Kodikara and Choi 2006 (a)), similar to thermal expansion/shrinkage in materials. However the variation of the α value due to the cyclic swell-shrink behaviour is unknown. Hence the objective of this paper is to present the laboratory experiments carried out to find the variation of α value. The behaviour of the soil is analysed when it is subjected to several wet-dry cycles. The variation of α is presented on the basis of the results obtained through laboratory experiments.

2 SOIL HYDRIC CONSTANT (α*) IN SHRINAKGE STRESS ANALYSIS

When the stresses are analysed in terms of moisture content variation, the potential strain can be obtained using constant of proportionality (α) and the change of moisture content (Δw) similar to that of heat flow analysis (i.e. $H = k\Delta T$).

(1)

It is well known that the confining stress is a function of void ratio, e and the moisture ratio, e_w, where

$e_w = wG_s$ (2)

when w is the moisture content. The stress then can be symbolised as,

(3)

By partially differentiating eq. (3),

(4)

From cyclic formula,

(5)

Substituting eq. (5) in eq. (4)

(6)

when,

(7)

and,

where K is the bulk modulus and is the hydric coefficient given by the ratio of void and moisture ratios (equation (7)). Then eq. (6) becomes,

(8)

If this relation is for only one directional stress then the K should be replaced by 3K. represents the free shrinkage, de represents the void ratio corresponding to observed or actual strain. The relation to obtain the potential free shrinkage can be written as,

(9)

Hence, from eq. (1) and (9),

—— (10)

Using the relation presented in the eq. (2) and substituting it in eq. (10) leads to the relation,

—— —— —— (11)

The relation given by eq. (11) gives the hydric coefficient to be used in eq. (1) . In terms of volumetric strains, eq. (8) can be recast as,

—— (12)

where is the observed or actual volumetric strain under partial restrained conditions. Under full restrained conditions, and full potential shrinkage strain ( ) will lead to shrinkage stress development. The hydric coefficient (α*) can be measured experimentally by following a comparatively simple tests. The following sections of this paper explain the swelling and shrinking experiments conducted to measure this coefficient.

3 EXPERIMENTAL PROCEDURE AND MATERIALS

3.1 Materials

The material was collected from the clay deposits in North Altona in Melbourne, Australia at the depths of 0.4m to 2.0m. It is light brown in colour when dry, becoming dark brown when wet. The clay is referred as Altona clay in this paper. Several basic geotechnical tests have been carried out according to Australian Standards (AS1289.2.1.1 2005; AS1289.3.1.1 2009; AS1289.3.2.1 2009; AS1289.5.1.1 2003) in order to characterise the properties. The results obtained are shown in Table 1.

Table 1: Summary of the soil classification test results

Colour	Light brown / beige
Linear shrinkage	16%
Liquid limit	70.2%
Plastic limit	21.8%
Plasticity index	48.4%
Soil group	Inorganic clays of high plasticity (CH)
Optimum moisture content	21%
compressibility parameters for loading	0.391
compressibility parameters for unloading	0.038
Specific Gravity	2.614

3.2 Sample Preparation and Set-up

The soil samples are tested in an oedometer set up manufactured at Monash University. The diameter of the samples was kept to 76mm as in the Standard test. Considering loss of energy input due to boundary friction, maintaining homogeneity throughout the sample while preparing and producing sufficient swelling and shrinking effect while testing, the sample height was selected as 12mm. Samples were prepared carefully and identically in order to maintain homogeneity and repeatability. The initial conditions of the samples were selected from the dry side of the optimum as 17±1% moisture content and 14.6±0.2kN/m^3 dry unit weight. The lack of experimental evidence for the behaviour of the dry compacted soil led to selection of the initial conditions within the dry side of the optimum.

The aim of the test was to observe the change of void ratio over time while the sample subject to different wet and dry conditions. Several types of apparatus can be used for measuring swell-shrink properties. This newly designed oedometer is simple, relatively easy to use and takes less room.

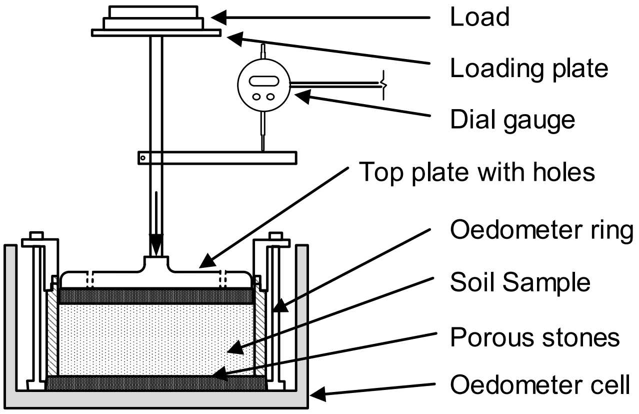

Figure 1. Schematic diagram of test set-up and placement of soil sample

The new oedometer has provisions for stress application from top so that the load is transferred to the sample at the middle point of top surface. The electronic dial gauge can be set directly to the set-up or separately aside of it. The schematic diagram of the test set up is shown in Figure 1. However, the set-up has limitations in the pressure it can handle, as it cannot apply very high pressures.

3.3 Experimental Procedure for Swell-Shrink Tests

The tests conducted comprised two main parts, wetting and drying. The samples were subjected to several wetting and drying cycles until the volume change follows a same path for both wetting and drying. This condition was considered as the stabilized condition. As the initial process wetting was selected. The tests were conducted with 5kPa constant pressure applying on the sample in a temperature controlled room. The temperature was maintained at 25°C during wetting and increased up to 40±5°C while drying using halogen lamps.

When obtaining the swelling path, moisture content was increased by adding the required amount of water through the holes in the top plate. The full potential of swell was obtained by inundating the sample in water. To trace one wetting or drying path 6 to 10 identical samples were tested. Each test produced one test result in e-e_w plot. Some additional 3 to 5 ml of water was added in addition to the calculated required quantity of water to allow for evaporation during swelling period on the basis of exploratory tests undertaken prior to the final tests.

It was decided to allow the samples to swell for three days and to shrink for 10 days while carrying out the wet dry cycles. These periods were decided after observing the shrinking and swelling behaviour with time.

While running a test vertical displacement of the sample was recorded in every 24hrs. Then at the end of the test, moisture content and unit weight were measured immediately after dismantling the sample. Even before the full shrinkage, some cracks and considerable lateral shrinkage was observed from the soil sample. Moisture content of the sample was measured by oven drying some amount of soil obtained from different locations of the sample. Sample volume (hence void ratio) was measured using water displacement technique.

4 RESULTS

Trends and variations of different parameters captured during the tests are presented in this section.

4.1 Swell-Shrink Cycles

The maximum and minimum vertical displacements observed during wetting and drying cycles for several samples were plotted as shown in Figure 2. The samples were compacted at the same initial conditions to the same vertical pressure. The tests were conducted continuously for several wet dry cycles. The first point (at first wetting) of each curve was obtained by drying the sample from the initial condition.

The results indicate that a significant change in vertical displacement can be observed during the first cycle and after that the amount of displacement does not change considerably with the wetting or drying process. The maximum average expansion of Altona north clay from the initial height is approximately 30%. The change in vertical displacement to be expected is 20% after aging. The results show a good agreement with the results of Tripathy et al. (2002).

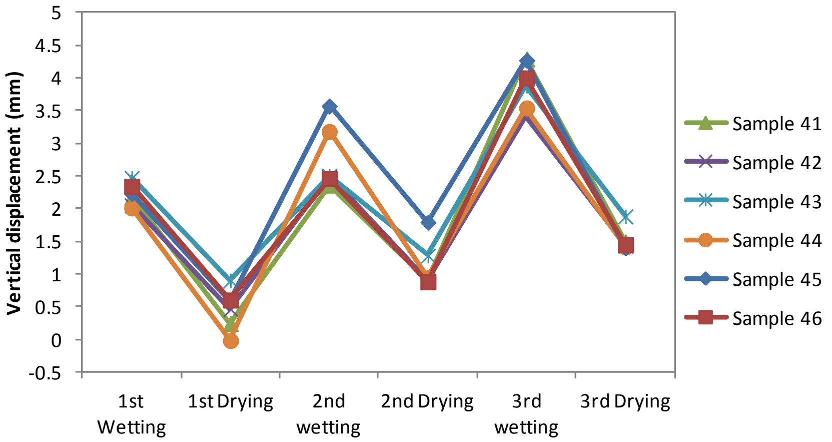

Figure 2. Vertical displacements during wet-dry cycles for several samples

4.2 Swelling and Shrinking Paths

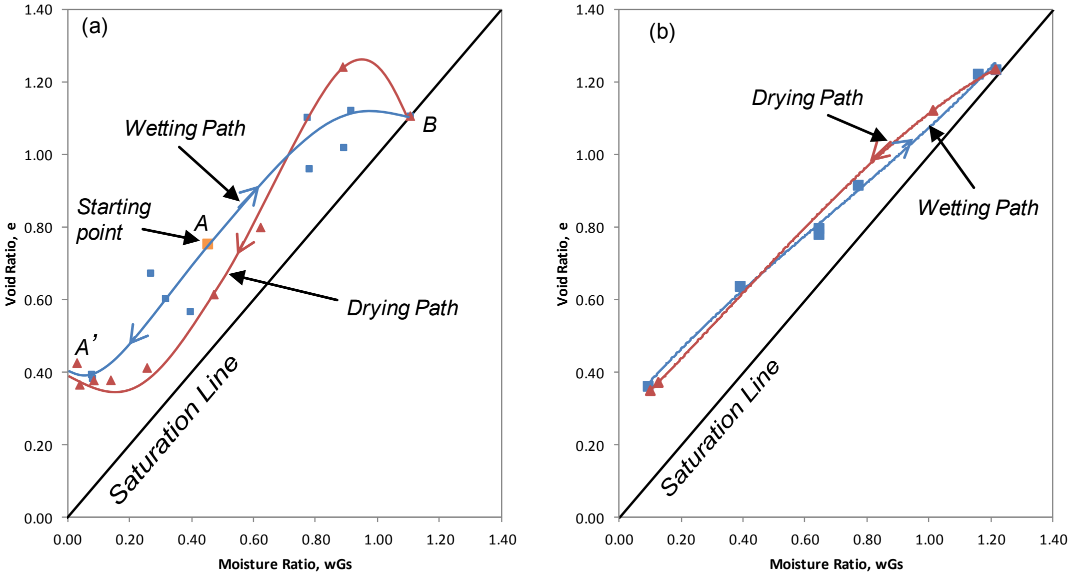

Figure 3. Swelling and shrinking paths (a) for the first cycle, (b) for the third cycle

Variation of void ratio in each cycle was examined by plotting the void ratio against the moisture ratio. Figure 3(a) and (b) shows swelling and shrinking paths obtained for the first and third cycles respectively. In each cycle wetting is followed by drying to obtain the full cycle. In Figure 3(a), the point A represents the initial point corresponding to as-compacted condition. The lower part (*A-A'*) of the curve from the initial point (*A*) was obtained by drying the sample. Then *AB* curve was obtained by allowing the sample to swell. Afterwards from *B* the sample was dried to complete the first cycle as shown in Figure 3(a). The curve at the first wetting behaves reasonably parallel to the saturation line but during the first drying cycle more wild variation can be observed. However, as the number of wet/dry cycles increase, the curve reaches a reasonably stabilized position, as shown in Figure 3(b), where drying and wetting appear to follow essentially the same path which can be considered as the stable curve (Gould et al. 2011).

4.3 Variation of hydric coefficient (α*)

The hydric coefficient was calculated from the gradients of Figure 3 and plotted in Figure 4. The first wetting and drying cycle shows an increase of α* from zero at the beginning and then drops back at higher moisture contents. However for the third cycle during both wetting and drying the α* remains almost constant at about an average value of 0.85. Since the third curve is considered to be the stabilized curve, the α* obtained from the third curve is taken as the typical variation of a stabilized soil.

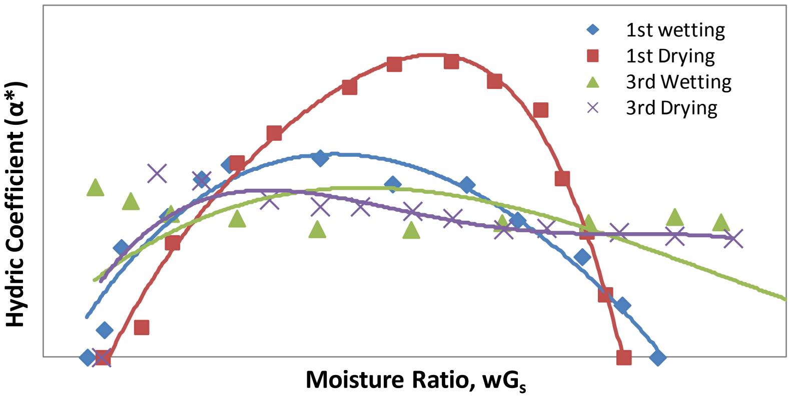

Figure 4. Variation of α with moisture ratio*

5 SUMMARY AND CONCLUSION

Modelling the swell-shrink behaviour of partly saturated soils during cycles of wetting and drying, especially those containing a significant amount of active clay minerals, seems to pose a high level of difficulty. Behaviour of soil depends on many factors, such as initial moisture content, initial dry density, net vertical stress, composition of the soil and level of wetting and drying processes.

Despite these restrictions, the expansive soil appear to reach a stable condition (within the environmental parameters they are in) after sufficient number of wet/dry cycles, and then behave elastically while wetting and drying. The path followed by a soil to reach the equilibrium curve depends on the factors such as initial void ratio (or density), initial moisture content and the stress level under which the soil undergoes wetting and drying.

The first and particularly the second of the wetting drying cycles are highly unpredictable. The soil shows a wild behaviour while relaxing after compaction depending on the initial compaction energy, history of the soil and the vertical stress on the soil.

The α* is an almost constant value for the stabilized curve (except close to saturation and shrinkage limit). The results shown in this paper are only preliminary and more wet/dry cycles needed to be undertaken to finalise the results.

6 REFERENCES

Gould, S.J.F., Kodikara, J., Rajeev, P., Zhao, X.-L., and Burn, S. 2011. A void ratio – water content – net stress model for environmentally stabilized expansive soils. *Canadian Geotechnical Journal*, **48**(6): 867-877.

Kodikara, J.K., and Choi, X. 2006 (a). A simplified analytical model for desiccation cracking of clay layers in laboratory tests. *Geotechnical Special Publication*: 2558-2569.

Richards, B.G., Peter, P., and Emerson, W.W. 1983. The effects of vegetation on the swelling and shrinking of soils in Australia (Adelaide). *Geotechnique*, **33**(2): 127-139.

Sharma, R.S. 1998. Mechanical behaviour of unsaturated highly expansive clays. *PhD Thesis*, University of Oxford.

Tripathy, S., Subba Rao, K.S., and Fredlund, D.G. 2002. Water content - Void ratio swell-shrink paths of compacted expansive soils. *Canadian Geotechnical Journal*, **39**(4): 938-959.