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LABORATORY BASED PARAMETRIC STUDY ON THE SWELL RESPONSES IN EXPANSIVE VERTOSOLS

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ABSTRACT: Expansive grey Vertosols are predominant in Australia, especially in Queensland. These soils induce a significant amount of swell strain on the lightweight structures founded on/in these soils when soil moisture changes due to climatic influence. According to AS2870: Residential slab and footing design code (AS2870, 2011) and available literature, active zone depth which contributes to the climate induced-soil displacement in Queensland can be up to 5m. To design lightweight structures founded within the active zone depth, it is imperative to understand swelling behavior of expansive grey Vertosols. The resultant swell strain of these expansive soils is primarily a function of initial water content or initial soil suction and overburden pressure (surcharge). However, there is an extremely limited amount of data available for unsaturated swelling characteristics of expansive soils in Queensland. In this study, a series of conventional oedometer tests were conducted to investigate the effect of the initial water content, initial soil suction and the surcharge on the swelling behavior of expansive grey Vertosol that is predominant in South-East Queensland. The swell strain of expansive grey Vertosol displayed greater sensitivity to surcharge when compared to initial water content or suction. Developed relationship between swell strain per unit change in volumetric water content and surcharge depicted statistically strong (R^2 = 0.89) agreement. The application of the knowledge gathered from this study will benefit the decision making in semi-arid regions when building lightweight structures on grey Vertosol.

Keywords: Expansive soil, Loaded Swell Test, Initial soil suction, Initial water content, Surcharge

1. INTRODUCTION

Expansive soils are naturally occurring, moisture sensitive, relatively high plastic clays that swell and shrink in significant amounts due to moisture variations in the soil. The mineralogical structure of expansive clays contains montmorillonite which attributes extreme expansiveness. This expansive behavior is usually attributed to the imbibition of water into the montmorillonites and consequently, causing detrimental impacts on the lightweight structures founded on such reactive soils [1-8]. Reactive soils are abundantly present in semi-arid countries, like Australia [9-14]. Twenty percent of the surface soils in Australia consist of the problematic expansive soils and six out of eight largest cities are significantly influenced by the adverse swell-shrink effect of the soil [15]. Vertosols in Queensland, Australia are wide-spread having greater swelling behavior of problematic soil in that region.

The swelling behavior of expansive soils was investigated by many researchers over the past 4 decades [16-25]. The common viewpoint of these investigations of expansive soils has proved that methodology adopts for swell strain-based assessment is slightly different from country to country as well as regional approaches.

Day [20] performed a series of swell tests and identified the significance of the curing time of compacted clays. Investigation of optimum and realistic curing time has always been challenging and soil specific; therefore, the author suggested conducting trial tests for a realistic aging period. The effect of the method of inundation and time dependency of swelling was recently reviewed by Nelson [26]. The importance of bottom wetting fronts in swell tests has been discussed and special consideration of the time saving from that method compared to top wetting method was emphasized.

Swell strain to change in volumetric water content (vwc) ratio, $\Delta\varepsilon/\Delta\theta$ has been identified as a crucial parameter to characterize the expansive behavior of swelling clays. Therefore, the influence of initial soil water content on the variation of $\Delta\varepsilon/\Delta\theta$ has been investigated by many researchers [27].

Although some researchers identified an insignificant relationship between the strain-vwc ratio with respect to the initial water content, these studies were carried out on a limited number of clays. To date, the problem has received scant attention in the research literature when it comes to grey Vertosol, abundant in Queensland, Australia.

The dependency of an applied surcharge or overburden pressure on volume change behavior for a unit change in volumetric water content ($\Delta\varepsilon/\Delta\theta$) has always been a critical parameter of expansive clays. Most research has been conducted to identify the relationship between the swell strain and the variation of volumetric water content [19-21], [23-24]; however, there is limited investigation of $\Delta\varepsilon/\Delta\theta$ variation over the applied surcharge for grey Vertosol.

Bridging that gap, in this study, authors made an attempt to understand the swell behavior of grey Vertosol in terms of variations in soil moisture content, initial soil moisture and overburden pressure for shallow depth. The knowledge gathered from the study is applicable to use for swell predictions of grey Vertosol that are predominantly present in South-East Queensland.

2. TEST MATERIAL AND METHODOLOGY

2.1 Test Material

In this research, the main focus is to understand the expansive behaviour of Vertosol found mostly in South-East Queensland, Australia. Soil samples were extracted from the test pits in Sherwood region (27°31'47.942"S 152°59'10.568"E) due to the pronounced reactiveness of the expansive clays in these suburbs.

Table 1. Soil classification results

Classification Test	Results
Grain size distribution	**% finer than 75μm > 77.3 %** **% Fraction of clay = 50.1 %**
Atterberg Limits	**LL = 67.0 %** **PI = 37.2 %**
Linear Shrinkage	**LS = 13.39 %**
X-ray diffraction	**Smectite Group**
Specific Gravity	**G_s = 2.67**

Table 1 summarizes the laboratory tests conducted to determine the index properties of the soil according to Australian standards [28-33]. This characterizes the type of soil as CH (inorganic clays of high plasticity) on Casagrande's plasticity chart. Further, the results represent the attributes of 'Active soil'. X-ray diffraction (XRD) analysis was conducted in order to determine the composition of the crystalline structure and identified soil components are smectite and kaolinite. According to the interpretation of the mineralogical analysis, the sample displays the attributes of smectite group minerals.

2.2 Test Methodology

A series of conventional oedometer based tests were conducted on grey Vertosol for different initial gravimetric water contents and surcharges. The selected surcharge values for this study were 1 kPa, 5 kPa, 10 kPa and 15 kPa. Samples were tested for different initial gravimetric water contents from 15% to 25% since the increased initial water contents tend to display lower vertical heaving of expansive soils [20]. In addition, the observed field moisture content of the grey Vertosol averaged at 24% and this will be within the experimental water content range since the samples are subjected to saturated conditions. The effective curing period for the test series was determined after conducting a trial for the identical samples. Oedometer based loaded swell tests were conducted for the selected curing time. Swell test series was carried out to investigate the swell behaviour of grey Vertosol under saturated and unsaturated test paths.

2.3 Selection of Sample Curing Time

Curing time of reconstituted soil samples is a significant factor in swell estimation methods [20]. According to the literature, there has been a clear reduction of the swell strain (heave) when the initial water content of the sample is increased [20]. In this study, a trial test series was conducted for 4 identical samples prepared at 15% of gravimetric water content and subjecting them to 1 kPa surcharge. Fig. 1 shows the temporal variation of the swell displacement. To avoid any unrealistic (extreme) swell strain analysis, a representative curing time of 4 days was used for the entire swell test series.

2.4 Loaded Swell Tests for Saturated Condition

The soil samples were prepared for known gravimetric moisture contents (15%, 20% and 25%) and the target density of 1.2 g/cm^3 was achieved by static compaction of the test specimens. The samples were cured for 4 days prior to the swell tests. Subsequently, a representative sample was cut into a consolidation ring, followed by the placement of filter papers and porous disks, at the top and the bottom of the sample. Thereafter, the sample was placed on the consolidation apparatus and a predetermined surcharge (1 kPa, 5 kPa, 10 kPa, 15 kPa) was applied prior to the introduction of water until the sample was inundated. Likewise, the samples were allowed to swell for 48 hours to reach the maximum swell strain under the test conditions.

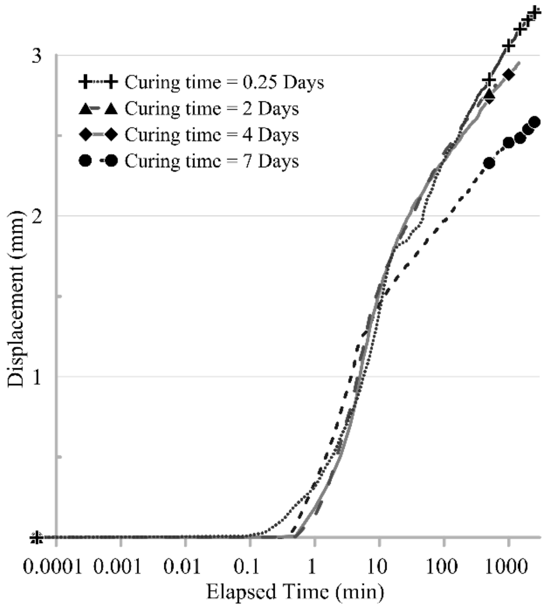

Fig.1 Temporal variation of swell strain under different curing time

After the samples had swelled, the water was removed from around the samples. After, the top porous disk was removed, the sample mass with the ring was weighed and a representative portion of the sample was oven-dried to ascertain the final moisture content.

2.5 Loaded Swell Tests for Unsaturated Condition

The unsaturated swell behaviour of grey Vertosol was investigated by controlled water ingression for five compacted soil samples (dry density = 1.2 g/cm^3) at 20% of initial gravimetric water content. The observations provide a linear relationship (R^2 = 0.99) between the volumetric water content of the sample and vertical sample strain providing evidence that the oedometer test can be used to determine the unsaturated strain-water content relationship during the swelling phase provided the initial and final vertical strain and volumetric water content conditions are known. Fig. 2 shows the linearity between water content-strain with a high correlation coefficient. Therefore, the saturated oedometer based strain variations for a given surcharge can be correlated with the unsaturated strain variations.

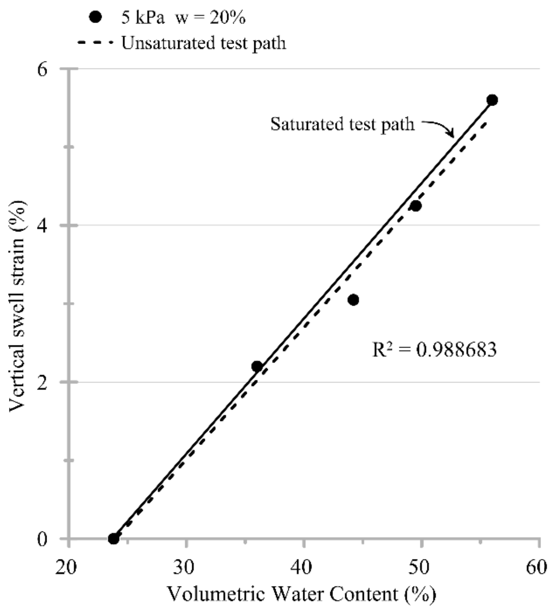

Fig.2 Unsaturated sample strain responses over vwc plot under controlled ingression

3. RESULTS AND DISCUSSION

Observed results for the saturated oedometer test series are shown in Fig. 3. This figure illustrates the variations of swell strain due to the increase of sample volumetric water content under different surcharge conditions which are representative of the shallow foundation depths. Swell behavior of grey Vertosol under different surcharge conditions showed an obvious relationship with varying water content values. The maximum swell strain induced due to change in volumetric water content was observed at 1 kPa surcharge condition and demonstrated an inversely proportional relationship with overburden pressure.

The linearity between the initial and final states of the strain-volumetric water content relationship was assumed according to the trial test conducted as per Fig. 2. Therefore, these plots can be utilized to determine the expected strain for any given water content change under a particular surcharge in unsaturated stress path.

The gradients of the graphs represented in Fig. 3 were correlated with the corresponding surcharge value to determine the statistical relationship between the swell strain – VWC ratio, ($\Delta\varepsilon/\Delta\theta$) and overburden pressure (Fig. 4). The observed relationship provided linearity with a very high Pearson's correlation coefficient (R^2 = 0.89). The standard error of the estimates amount to 0.009

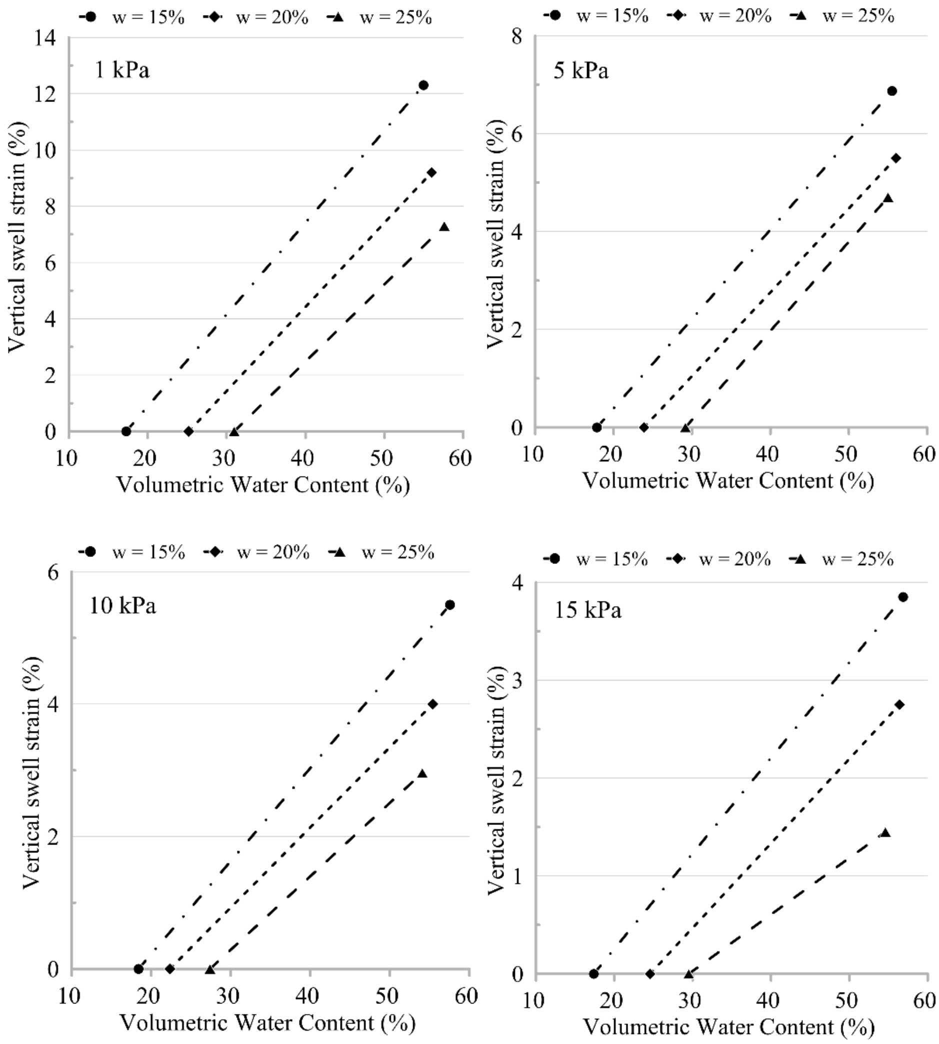

Fig. 3 Strain variation over the change in volumetric water content under surcharge conditions

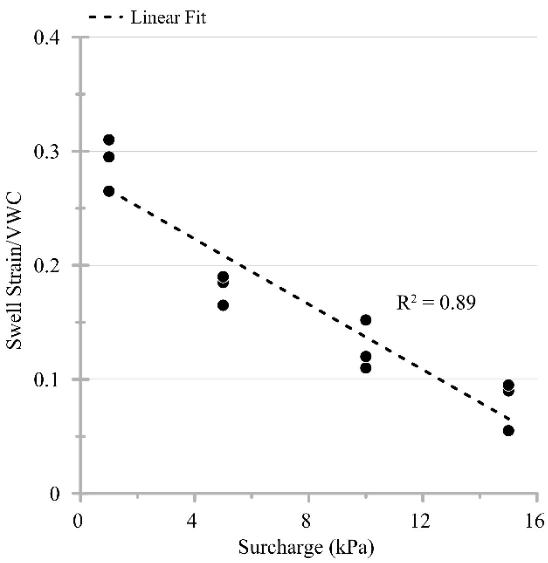

Fig. 4 Swell strain to vwc ratio over the variation in surcharge

$$\Delta\varepsilon/\Delta\theta = -0.0142 * \sigma_{ob} + 0.279 \quad (1)$$

$$((\Delta\varepsilon/\Delta\theta))/\ \Delta\sigma_{ob} = -0.0142 \quad (2)$$

Equation 1 and 2 provide statistically strong relationships between the swell strain ($\Delta\varepsilon/\Delta\theta$), change in vwc ($\Delta\theta$), and the applied surcharges (σ_{ob}) of grey Vertosol. Equation 2 represents the variation of swell strain per unit change in volumetric water content and surcharge. Therefore, swell strain per unit change in volumetric water content decrease by a factor of 0.0142 per every 1 kPa surcharge increment.

Fig. 5 displays the graphical representation of the relationship between $\Delta\varepsilon/\Delta\theta$ and corresponding initial gravimetric water content of the soil. A linear relationship was observed between the aforementioned parameters. However, the observed variation is between 0% to 0.55% when subjected to different surcharge values. Vertical strain to vwc ratio displayed gentle reduction with the increased gravimetric water content. The minimum swell strain to vwc ratio was observed at 5 kPa compared to other surcharge conditions. This could be due to the effect of the non-homogeneity of moisture in 25% vwc (initial) sample.

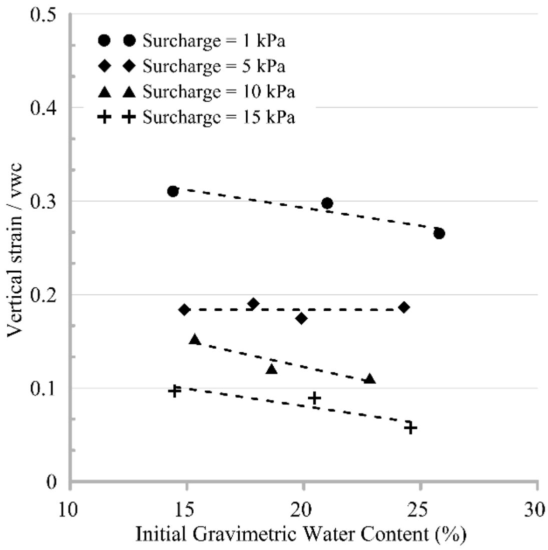

Fig. 5 Swell strain to vwc ratio over the variation in initial water content of the soil

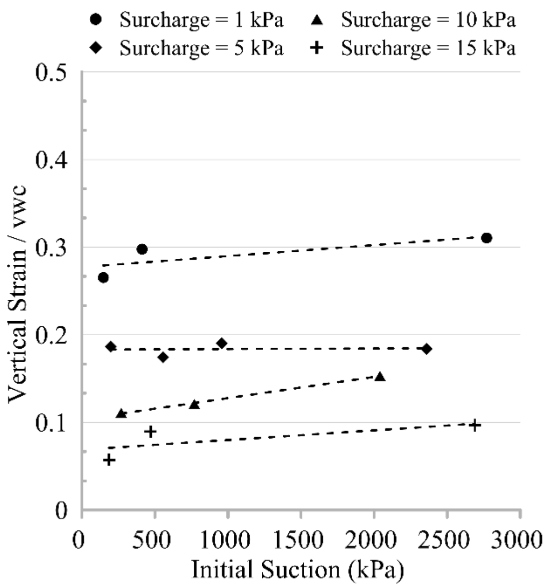

Fig. 6 Swell strain to vwc ratio over the variation in initial soil suction

Fig. 6 illustrates the variation of swell strain to volumetric water content ratio with the initial soil suction value at different surcharge conditions. Overall, linear distribution of strain per unit change in volumetric water content was displayed under all surcharge values. Insignificant variation of vertical strain per unit change in water content was observed at all initial soil suctions.

4.0 CONCLUSION

Laboratory based element scale oedometer swell test series was conducted for reconstituted to investigate the swell responses of expansive grey Vertosol soils in South-East Queensland (SEQ), Australia. The clay samples of different initial water content (or initial soil suction) were subjected to known surcharge conditions. Initial gravimetric water contents from 15% to 25% were selected based on the observed field moisture condition at the site. The loaded swell test series was conducted for the saturated stress path to record the swell strain responses for different initial water content and surcharge conditions. The linearity of the relationship between the swell strain and the corresponding change in water content was verified for the sample wetting path.

The results of the present study provide a rudimentary, yet significant understanding of the un-saturated swell behaviour of grey Vertosol in SE Queensland. Variation of initial gravimetric water content was investigated against the change in swell strain to vwc ratio ($\Delta\varepsilon/\Delta\theta$). An insignificant variation in $\Delta\varepsilon/\Delta\theta$ was observed for varied initial water contents under different surcharge conditions.

In all cases, the gradient of the variation in strain against volumetric water content ranged from 0.055 to 0.31 depending on the applied surcharge. The dependency of the applied surcharge was then investigated and the observed results provided a good statistical (R^2 = 0.89) linear relationship between $\Delta\varepsilon/\Delta\theta$ and σ_{ob} for the applied stress range of 1-15 kPa. This empirical relationship can be used to estimate the swell strain of SE Queensland grey Vertosol when the change in volumetric water content and the overburden pressure are known. Moreover, the findings showed greater sensitivity of the applied surcharge on swell strain compared to the effects of initial water content and soil suction. The application of the knowledge gathered from this study will benefit the decision making in semi-arid regions when building lightweight structures on grey Vertosols.

5.0 ACKNOWLEDGEMENT

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