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FACTORS AFFECTING THE SWELLING PRESSURE MEASURED BY THE OEDEMETER METHOD

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ABSTRACT: Expansive soils are common in arid and semi-arid climate regions of the world and cause severe problems on civil engineering structures. The Swelling potential of the expansive soil mainly depends upon the properties of soil and environmental factors, and stress conditions. Swelling pressure is a key parameter used in designing structures in and on expansive soil. The swelling pressure of soil is measured in the laboratory using a representative soil samples. The size and the surface friction of the sample ring used in the swelling pressure test have effects on the measured swelling pressure and they have not properly been investigated. In this study, a series of constant volume swelling tests were conducted using an automated consolidation-swell apparatus to evaluate the effect of sample ring size, ring friction, initial dry density, and initial moisture content (IMC). Test results indicate an exponential growing trend of swelling pressure when the dry density is increased. Similarly, high swell pressures are achieved when the IMC is increased for the same dry density. A higher swelling pressure was measured when the friction of the specimen ring was reduced. The measured swelling pressure increases with increasing the height of the sampling ring and it decreases when the ring diameter is increased. Therefore, it is recommended to use a standard sample ring reducing inside wall friction using lubricants when measuring the swelling pressure in the laboratory. Further, the sample ring size, initial density and initial moisture content of soil should be given when reporting swelling pressure of soil.

Keywords: Expansive Soil, Swelling Pressure, Unsaturated Soil, Consolidation/Swell Apparatus,

1. INTRODUCTION

Expansive soils which are common in arid and semi-arid climate regions of the world contain clay minerals such as montmorillonite, smectite. These clay minerals absorb water and expand eventually and shrink when soil is dried out. A cyclic wetting and drying triggers excessive volume changes in expansive soils [1] causing significant distresses in lightweight structures such as pavements, residential slabs, driveways, sidewalks, shallow depth pipelines. The losses due to widespread damage to structures constructed on expansive soils are estimated to be in billions of dollars all over the world. In the United States alone, annual losses due to expansive soils are estimated to be approximately $1000 million [2]. Similarly, it has been estimated that the damage due to expansive soils is greater than twice as the combined damage from floods, tornadoes, hurricanes, and earthquakes [1].

Swelling pressure which is defined as the pressure required holding the soil at constant volume when water is added can simultaneously cause lifting, or heaving of structures whereas differential settlement can be caused by shrinkage [3]. Failures result when the volume changes are irregularly distributed underneath the foundation. For example, swelling pressure beneath the perimeter of the building can be caused by changes of the water content in the soil around the edge of a building while remaining the water content of the soil constant beneath the center. This resulting failure is known as end lift. The center lift is the opposite scenario where shrinkage is focused under the edges or where swelling takes place beneath the center of the structure [4]. Therefore, it is essential to estimate/measure the swelling pressure of expansive soil when designing structures to be constructed on or in expansive soils [5].

The swelling pressure is evaluated in the laboratory by a number of testing methods [6]. An oedometer testing method is extensively used to determine the swelling pressure due to its simplicity and operational ease. There are three different oedometer methods for the determination of swelling pressure [7]. They are: Swell-Consolidation Method, Different Pressure Method, and Constant Volume Method. Each of the methods is equally sensible, but provides different values of swelling pressure for the similar placement conditions of the soil [8].

As a practice, different sizes of specimens are used in testing for swelling pressure of expansive soils. According to ASTM D4546 [9], the minimum specimen diameter or inside diameter of the specimen ring used in determination of one-dimensional swell is 50 mm (2.00 in.). The minimum initial specimen height is 20 mm (0.8 in.), but it should not be less than six times the maximum particle diameter in the soil. The minimum specimen diameter-to-height ratio is 2.5.

The swell potential of an expansive soil is affected by compositional "intrinsic" factors such as clay content, clay mineralogy, pore water chemistry and gradation; placement or environmental factors such as density, water content, soil structure, temperature and stress history, and procedural factors, for example size and shape of the test specimen, its level of disturbance, methods of load and swell measurements [10].

Several research studies conducted in the past have emphasized that the development of swelling pressure in compacted expansive soils is function of initial moisture content and dry density [11]. It was accentuated that the initial compaction conditions and moisture content influence the development of swelling pressures with elapsed time during the saturation process. However, the effects of specimen size (ring size) on the laboratory measured swelling pressure have not been investigated. Similarly, the ring friction can significantly affect the swelling pressure in the laboratory.

Hence, this study investigates the effects of the diameter and the height of the sample ring, the ring wall friction, initial moisture content, and initial density of soil on the swelling pressure measured in the laboratory using an automated consolidation-swell apparatus employing constant volume method.

2. TEST MATERIAL

An expansive soil collected from Merri Creek in Victoria State of Australia was used for this study. The natural soil was soaked and washed on the 0.425 mm sieve and found that all soil particles are smaller than 0.425 mm. The hydrometer analysis, following Australian standards [12], was then conducted using a particle size analyzer and the results are shown in Fig. 1. The physical properties of the soil obtained from laboratory test procedures are presented in Table 1. The result of the compaction test conducted in accordance with Australia standards [13] is shown in Fig. 2. The mineral composition of the test material was determined using X – ray diffraction (XRD) and the results are shown in Table 2. It can be seen that Merri Creek clay contains 51% of Smectite which swells when immersed in water.

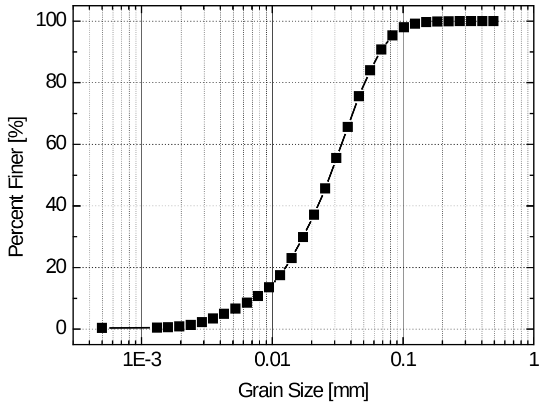

Fig. 1 The particle size distribution of the used soil

Table 1 The physical properties of the soil

Property	Value
Liquid limit, w_l [%]	73.30
Plastic limit, w_p [%]	33.00
Plasticity index, I_p [%]	40.30
Linear shrinkage [%]	13.30
Specific gravity, G_s	2.62
% passing sieve No. 40 (0.425mm)	100.00
Clay content [<0.002 mm: %]	0.90
Silt content [%]	99.10
Maximum dry density $\rho_{d(max)}$ [g/cm^3]	1.36
Optimum water content [%]	26.40
Swelling stress [kPa] for ρ_d=1.15 g/cm^3	98.10

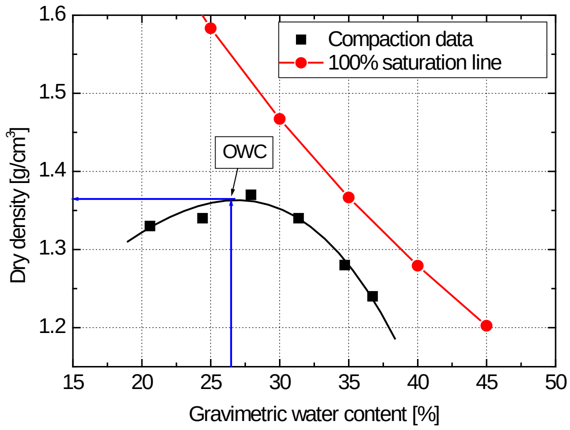

Fig. 2 The result of the compaction test

Table 2 The mineral composition of the test material

Type of Mineral	Composition (%)
Quartz	41

Albite	2
Orthoclase	3
Kaolin	3
Smectite	51
Ilmenite	1
Anatase	<1

3. TEST APPARATUS

The Fully-Automated Consolidation & Swell apparatus (LoadTrac III -Mini-LoadTrac) shown in Fig. 3 was used in this study to measure the swelling pressure of soil samples. The apparatus consists of loading frame, control panel, load cell, displacement transducer (LVDT), and consolidation cell. It utilizes a high speed, precision micro-stepper motor to apply the force or displacement controlled vertical load to the soil specimen. The load cell has the capacity to measure the force up to 11 kN and LVDT can measure up to 50 mm with 0.0025 mm resolution. The test can be controlled using the front panel or the computer connected. The base unit includes the ability to acquire and display built-in data. Further, the software that automates a test being run has capability to save data in the computer at specified time interval, displace data graphically or numerically while test is being run, sensor calibration, and editing and reporting data.

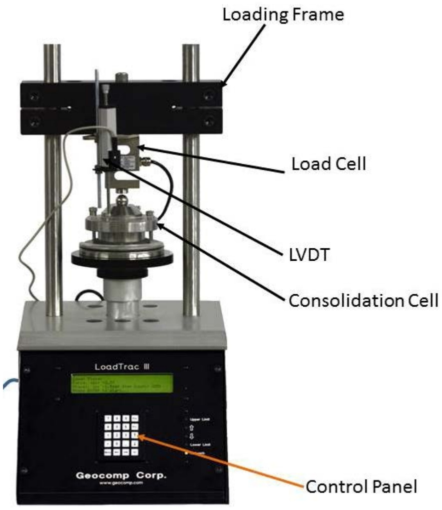

Fig.3 Fully-automated consolidation-swell apparatus

4. METHODOLOGY

4.1 Testing Program

In order to achieve the objectives of this paper, twenty two (22) constant volume swelling tests were conducted in this experimental study varying the parameters as shown in Table 3. Here, ρ and IMC respectively represent the dry density of the soil and Initial (molding) water content. The height and the diameter of the sample (or sampling ring) are denoted by D and h, respectively. Tests were conducted with grease (WG) and without grease (WOG) applied on the inner surface of the specimen ring.

Table 3 Summary of tests and testing parameters

Test No.	ρ (g/cm^3)	IMC (%)	D (mm)	h (mm)	WG or WOG
T1	1.01	10	76.0	25.5	WOG
T2	1.23	10	76.0	25.5	WOG
T3	1.36	10	76.0	25.5	WOG
T4	1.50	10	76.0	25.5	WOG
T5	1.01	20	76.0	25.5	WOG
T6	1.13	20	76.0	25.5	WOG
T7	1.23	20	76.0	25.5	WOG
T8	1.32	20	76.0	25.5	WOG
T9	1.43	20	76.0	25.5	WOG
T10	1.50	20	76.0	25.5	WOG
T11	1.68	20	76.0	25.5	WOG
T12	1.00	30	76.0	25.5	WOG
T13	1.28	30	76.0	25.5	WOG
T14	1.38	30	76.0	25.5	WOG
T15	1.52	30	76.0	25.5	WOG
T16	1.30	25	76.0	25.5	WOG
T17	1.30	25	76.0	25.5	WG
T18	1.36	25	76.0	18.5	WG
T19	1.36	25	63.0	18.5	WG
T20	1.36	25	50.0	18.5	WG
T21	1.36	25	76.0	38.0	WG
T22	1.36	25	76.0	25.5	WG

4.2 Sample Preparation Procedure

The soil was initially air dried and pulverized. It was then oven dried for 24 hours at a temperature of 105^{0}C - 110^{0}C. The soil was allowed to cool down to room the temperature after it was taken out from the oven. After measuring water content of dried soil at room temperature, a sub-sample of 1500 g was taken and mixed with water to achieve a pre-defined water content (e.g: 10%, 20%, 25%, 30%). The moist sample was left overnight in a closed contained for moisture homogenization.

The wet mass required to achieve a pre-determined dry density (e.g: 1.30 g/cm^3, 1.50 g/cm^3) in a compacted specimen of 100 mm diameter and 50 mm height was measured. The measured soil mass was poured into a stainless steel ring of 100 mm diameter and it was statically compacted (by pressing the soil using compression apparatus) to achieve the specimen height of 50 mm. The compacted soil pat was extruded from the stainless steel ring. The selected specimen ring with the desired diameter (e.g: 50 mm, 63 mm, 76 mm) and the height (18.5 mm, 25.5 mm, 38.0 mm) was then kept on the compacted soil specimen, and it was gradually pushed in to the compacted soil specimen in order to mold the sample into the specimen ring. As indicated in Table 3, grease was applied on the inner cylindrical surface of some sample rings before it was pushed into the compacted soil pat.

4.3 Testing and interpretation of test results

The soil specimen molded into the sampling ring was set in the oedometer cell which was then placed in the fully-automated consolidation and swell apparatus. The Oedometer cell was raised to be in contact with the load cell which is attached to the horizontal beam of the loading frame. The apparatus was set to control the zero load and LVDT was positioned. The apparatus was then set to perform the constant volume swell test and water was poured into the Oedometer cell and the water level was maintained just below the top surface of the soil sample.

The load cell started to record the exerted load as the soil tends to swell under constant volume conditions as the soil sample was being saturated from the bottom. Under constant volume test conditions, the zero displacement is maintained by the apparatus. The load cell readings were recorded continuously at a specified time interval. The test was stopped when the load increment was observed to be negligible.

Using the load –time plot obtained from a constant volume soil test, the swelling pressure was calculated using the Eq. (1). Where, "P_{swell}" is the swelling pressure, "F" is the maximum load observed in the test run and "D" is the diameter of the specimen ring.

$$P_{swell} = \frac{F}{\left(\frac{\pi \times D^2}{4}\right)} \quad (1)$$

5. RESULTS AND DISCUSSIONS

5.1 The Effects of Initial Dry Density and Moisture Content on Swelling Pressure

To investigate the effects of IMC and dry density on the swelling pressure, 15 constant volume swelling tests were performed as given in Table 3 (T1 – T15). The soil was mixed with water to achieve three different IMCs; 10%, 20%, and 30%. The soil with each moisture content was used to obtain 4 – 7 samples with different initial dry densities ranging from 1.00 – 1.68 g/cm^3. The diameter and the height of all specimens were 76.0 mm and 25.5 mm, respectively, and grease was not applied around the internal perimeter of the specimen ring. The results of these 15 tests are shown in Fig. 4 to demonstrate the effects of IMC and initial dry density of the swelling pressure measured in the laboratory.

Irrespective of the sample's IMC, it is observed that the swelling pressure increases as the initial dry density of soil increases. Further, no significant effects of IMC on the measured swelling pressure can be seen up to 1.25 g/cm^3 dry density of the soil. When the soil's initial dry density is increased beyond 1.25 g/cm^3, the swelling pressure increases with decreasing the IMC.

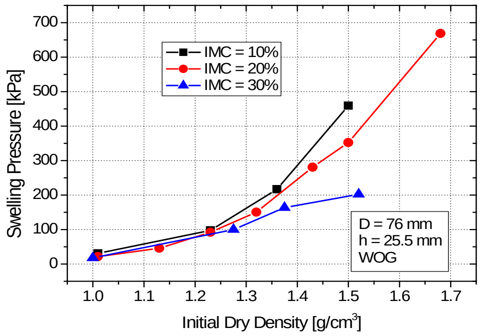

Fig.4 Variation of swelling pressure with initial dry density and IMC

When the dry density is low, more void volume is expected in the soil specimen. Hence, when soil swells, voids are filled without causing a significant pressure development within the soil which is eventually responsible for a low swell pressure. Conversely, voids are fewer when the dry density is higher therefore the volume of the soil is considerably increased when water is available, ultimately developing a high swell pressure. The similar phenomenon is occurred when cracked soils are wetted.

As shown in Fig. 4, the swell pressure increases as the IMC decreases for the same initial dry density which is greater than 1.25 g/cm^3. A low IMC is accountable for absorbing more water to supply the water demand for mineral expansion which results excessive swelling or high swelling pressure development in the volume constrained conditions. However, when the IMC is high (e.g: greater than the optimum water content), less swelling is developed as the sample is being saturated because the swelling minerals have already been expanded significantly in the initial stage. Hence, low increment of swelling pressure occurs at the end of the test run.

5.2 The Effects of Sample Ring Friction on Swelling Pressure

In order to investigate the effects of sample ring friction on the measured swelling pressure, two identical tests were conducted (T16 and T17 in Table 3). In T17, grease was applied on the inner surface of the sampling ring to reduce the wall friction but in T16, no grease was applied on the inner surface of the sampling ring. As shown in Fig. 5, a higher swelling pressure was achieved when grease was applied around the inner perimeter of the specimen ring. As the frictional stresses developed between the specimen ring and the soil sample lessen proper vertical expansion of soils, accomplishing low swelling pressures when grease is not applied. These frictional stresses cause to underestimate the swelling pressures measured in the laboratory.

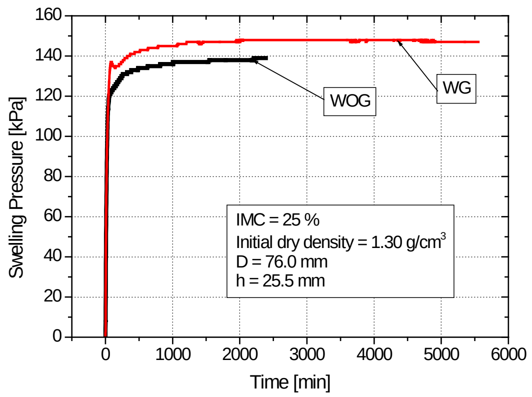

Fig.5 Swelling pressure development with and without grease on the inner surface of the sampling ring

5.3 The Effects of Sample Diameter on the Swelling Pressure

In this experimental study, the effects of the sample diameter were investigated by performing three tests (T18 – T20 in Table 3) with different ring diameters: 50 mm, 63 mm, and 76 mm. For all three tests, the height of the ring, IMC and initial dry density were 18.5 mm, 25% and 1.36 g/cm^3, respectively. Fig. 6 depicts swelling pressure development time histories for the three tests with three different sample ring diameters. According to the test results, swelling pressures are approximately 129 kPa, 197 kPa and 202 kPa for the specimens with ring diameters 76.0 mm, 63.0 mm and 50.0 mm, respectively. It is therefore clear that the measured swelling pressure decreases with the increase in the specimen diameter.

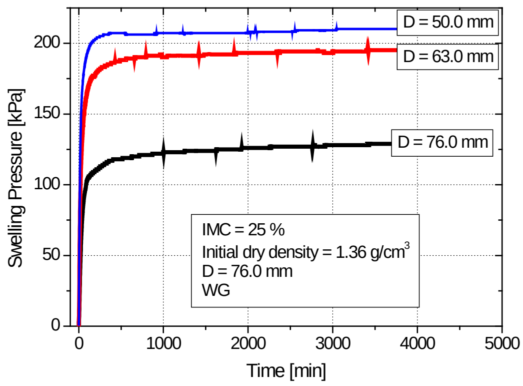

Fig.6 Swelling pressure development in soil specimens with different ring diameters

This phenomenon can be explained as the vertical swelling is reduced with the presence of significant lateral soil movement when the specimen ring diameter is increased. But, this lateral soil movement is significantly restricted by the specimen ring when its diameter is reduced. As a result, the specimen tends to expand more in vertical direction and it will develop a high swelling pressure. It is thus emphasized the laboratory measured swelling pressure depends on the diameter of the ring used.

5.4 The Effects of Sample Height of the Swelling Pressure

Figure 7 shows the development of swelling pressure with time for the specimens with different ring heights (e.g: 18.5 mm, 25.5 m, and 38.0 mm). As given in Table 3, the diameter of rings used in these three tests (T18, T21, and T22) was 76 mm and grease was applied on the inner surface of these rings. The IMC and the initial dry density for all three tests were 25% and 1.36 g/cm^3, respectively. As shown in Fig. 7, the swelling pressures of 129 kPa, 152 kPa and 200 kPa were obtained when the ring heights are 18.5 mm, 25.5 mm and 38.0 mm. The results demonstrate that the measured swelling pressure increases with the increase in the specimen height.

Increasing the specimen height while maintaining the same surface area (the same diameter) will allow more volume of soil to expand vertically. As a result, a higher swelling pressure can be achieved.

6.0 CONCLUSIONS

In this study, the influence of different factors on the laboratory measured swelling pressure using constant volume method was evaluated. The factors considered are: initial dry density, IMC, inner surface friction of specimen ring, ring diameter, and the height of the ring.

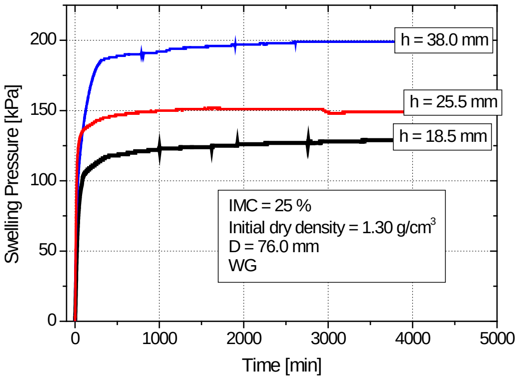

Fig.7 Swelling pressure development for specimens in rings with different heights

The following conclusions are drawn from the results:

- The swelling pressure increases with the increase in the initial dry density of the specimen.
- It is observed that the specimen with low initial moisture gives greater swelling pressure compared to that of with high initial moisture content.
- The inner surface friction of specimen ring tends to under estimate the swelling pressure of expansive soils. Therefore, it is recommended to reduce the inner surface friction of the specimen ring by applying some lubricant such as grease.
- The diameter and the height of the specimen/ring have significant effects on the measured swelling pressure in the laboratory using contact volume test method. So it is recommended to use a standard ring when measuring the swelling pressure in the laboratory. Further, the size of the specimen ring used would be reported with swelling pressure results of an expansive soil.

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