FIELD AND LABORATORY INVESTIGATION OF AN EXPANSIVE SOIL SITE IN MELBOURNE

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ABSTRACT

Expansive soils undergo heave and settlement due to soil moisture changes, causing differential movement to light weight structures built on them. These movements may be significant when extreme weather conditions such as prolonged droughts are encountered. Indeed, there have been major concerns regarding footing movements and cracks in houses in Victoria following the breaking of the last prolonged drought experienced in the late 90s to early 2000s.

As part of an ongoing research project at Swinburne University of Technology on damage to residential structures due to ground movements, a field site was established in a western suburb of Melbourne. *In situ* soil moisture variation and corresponding ground movements are monitored using a neutron moisture probe and magnetic extensometers respectively. In addition, various laboratory experiments including soil classification, suction, swell and shrinkage were carried out on both disturbed and undisturbed soil samples collected from the field site. Suction variations of undisturbed soil along with moisture content have been measured using miniature tensiometers and a Chilled Mirror Hygrometer to develop the Soil Water Characteristic Curve (SWCC). Atterberg limit tests and particle size distribution tests have also been carried out at different depths to classify the soil.

This paper discusses results from both the field and the laboratory investigations. In addition, it presents mechanical and hydraulic properties of the field soil that can be used in numerical analyses.

1 INTRODUCTION

Approximately twenty percent of the surface soils in Australia can be identified as expansive clay (Richards et al., 1983). In fact, most of the surface soils in Victoria are moderately to highly expansive soil (Northcote, 1962) and they are largely distributed in the west part of Melbourne (Lopes, 1999). There have been few comprehensive studies on properties of expansive soil in Melbourne; however, some researchers have focused on specific aspects of such soils and design of footing systems specially for them. In 1973, a research project at Swinburne College of Technology (now Swinburne University of Technology) was begun to investigate the behaviour of expansive soil and design of residential footings. The study includes both laboratory and site investigations of more than 20 sites in Australia. Expansive soil sites in Melbourne including Sunshine, Waverley, Horsham, Berwick, Trott Park, Modbury, Werribee and Keilor have been selected for the investigation. The expansive soil properties including Atterberg limits, linear shrinkages, swell strains and associated suction profiles in this study have been published (Cameron, 1977, Holland and Lawrance, 1980, Holland et al., 1980, Pitt, 1982, Washusen, 1977). Walsh (1978) used the data from the same study to analyse the raft slabs on expansive clay. The same soil properties have been used by Cameron and Yttrup (1992) and provided details on design of footings on expansive soil. In addition to those properties, the bearing capacities of expansive soils in Melbourne are also presented in Cameron and Yttrup (1992). Recently, researchers studying the effect of expansive soil on buried pipelines presented more comprehensive properties of soils from Altona and Fawkner in Melbourne (Rajeev et al., 2012). The properties include Atterberg limits, SWCC and other properties typically used in modelling of expansive soils. However, ground movement and suction profiles were not presented in this publication. For design purposes in accordance with AS2870 (Australian standard of Residential Slabs and Footings), site classification can be made using shrink and swell values of soil. However, for modelling ground movement due to change in climate condition, comprehensive data is required including soil properties, moisture content changes in soil and ground movement.

This paper is part of an ongoing research project which aims to provide further understanding of ground movement associated with expansive soils for the design of domestic footings systems. As part of the ongoing study, a field site was established on a vacant block of land in Braybrook, which is one of the western suburbs of Melbourne. The site was selected on the basis of Atterberg limits and linear shrinkage test results, which indicated that the site is highly reactive. Undisturbed and disturbed samples were collected from different depths to carry out laboratory tests. Shrink-swell tests were carried out on soils from different depths to classify the site according to AS2870 (2011). In addition to the shrink-swell test, particle size distribution and mineral composition tests were also carried out to understand the degree of reactivity of the site. Soil water characteristic curves (SWCC) were developed using the undisturbed soil samples collected at different depths. Moisture and ground movement measuring instruments were installed for regular site monitoring, which provided the calibration data for the numerical modelling.

This paper describes the properties of the expansive soil at the Braybrook site. The soil has been classified according to the Unified Soil Classification System (ASTM-D2487, 2011). SWCCs of the Braybrook soil in different depths along with some regular monitoring data are also presented. The monitoring data is currently being used to calibrate a detailed analytical model to estimate long term ground movement.

2 METHODOLOGY

2.1 SOIL SAMPLING AND LABORATORY TESTING

The monitoring site is a vacant block of land approximately 3000 m^2 in area. It is fairly flat with only one prominent tree. Soil samples were collected from boreholes. The clay layers in this site are deeper than usual and the boreholes were able to be drilled up to 5 m depth without encountering the Basaltic bed rock.

Steel tubes with 50 mm diameter and 0.5 m length were used to collect undisturbed soil samples. Undisturbed samples were collected at three different depths down to 3.5 m at different locations within the site. Tubes were sealed as soon as they were taken out from the ground to prevent moisture loss. Disturbed soils were collected using polythene bags in between the undisturbed sample depths. The tubes and the bags were labelled before they were taken to the lab; details included the date, the location and the depth.

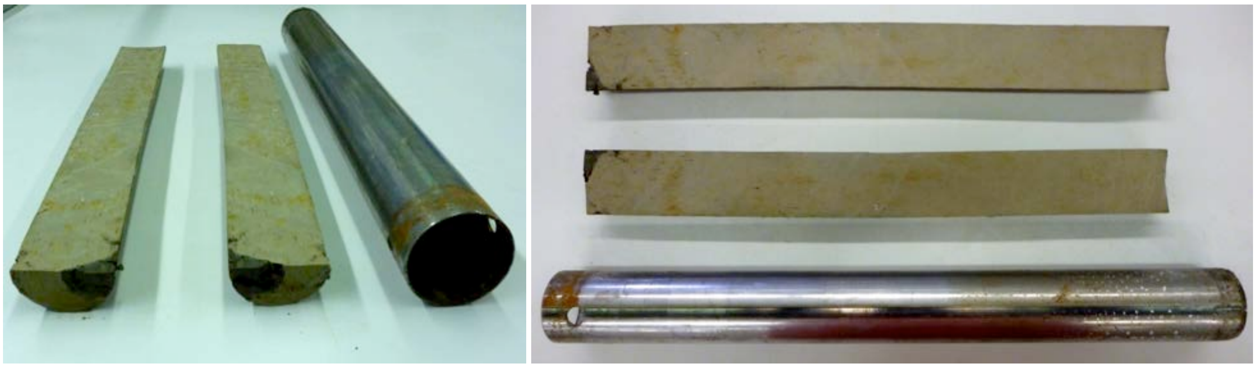

Figure 1: Cross section of an undisturbed sample extruded from a tube

Tube samples were extruded using a hydraulic extruder and used to determine shrink-swell index, suction and mineral composition measurements. Figure 1 shows the cross section of an extruded undisturbed sample at 2.5-3.0 m depth. The appearance of the soil below 2.0 m depth seems to be consistent as shown in Figure 1. Both disturbed and undisturbed samples were used to obtain the Atterberg limits, linear shrinkage and particle size distribution.

2.2 ONGOING SITE MONITORING

A primary purpose of the ongoing site monitoring is to obtain the moisture content of soil at different depths and the consequent soil movements.

Neutron probe moisture measuring was used to measure the moisture content at different depths. For this purpose, 3.0 m deep Aluminium access tubes were installed at several locations within the site. In this study, a CPN 503DR neutron probe (Ward and Wittman, 2009) was used to collect the soil moisture readings. Figure 2 shows the neutron probe control unit that sits on top of an access tube. The probe, connected through a cable into the control unit, can be lowered into the access tube and clenched at the required position. The probe emits neutrons during the measurement as a result of a reaction between Americium and Beryllium. These neutrons interact with soil particles and soil moisture that surrounds the probe. The probe consists of a detector which identifies the interacted neutrons and returns the count. The radius of the influencing sphere shown in Figure 2 can be given by Equation 1

$$R = 100/(1.4+0.1\theta) \tag{1}$$

where R is the radius in centimetres and θ is volumetric moisture content percentage. Therefore, the higher the moisture content, the lower the influenced volume of soil. More details about the CPN 503 DR probe measuring technique with the corresponding equations can be found in Ward and Wittman (2009). The calibration curve was developed for the Braybrook soil using volumetric moisture content measurements from undisturbed samples collected close to the access tube locations.

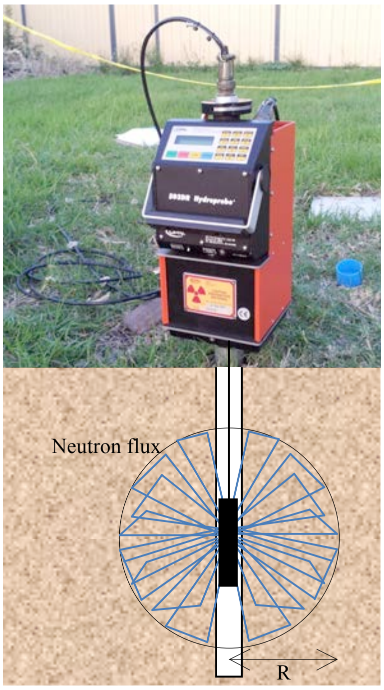

Figure 2: Moisture content measurement using Neutron probe.

Magnetic extensometers (HMA, 2013) were used to measure the soil movements at different depths. Magnetic extensometers consist of spider magnets connected through a collapsible pipe at certain intervals along a conduit pipe. The legs of the spider magnets penetrate into the surrounding soil during the installation. Therefore, when the soil is moving, magnets move up and down along the conduit with the adjacent soil. The bottom magnet is placed sufficiently deep at a stable position which can be taken as datum. In addition, a concrete paving block was placed next to the extensometer to measure the total movement between the ground surface and the datum spider magnet. A special measuring tape that comes as a part of the setup is lowered into the conduit pipe and it reads the position of each magnet along the depth with an error margin of ±2 mm.

3 RESULTS AND DISCUSSION

3.1 LABORATORY TEST RESULTS

3.1.1 Soil profile in Braybrook

The soil profile of the Braybrook site appears to be consistent and the soil colour changes gradually towards the bottom. The top soil layer contains a certain amount of grass roots. The soil between 1.0 to 1.5 m is slightly calcareous. The soils are stiffer towards the bottom. The generalized soil profile is shown in Table 1.

Table 1: Soil profile at Braybrook.

Depth (m)	Soil description
0.0-0.3	Clay (CH), Dark Brown, Soft, root fibres present
0.3-0.5	Clay (CH), Dark Brown, Stiff, root fibres present
0.5-1.0	Clay (CH), Brown, Stiff, Very slightly calcareous
1.0-1.5	Clay (CH), Brown to dark gray, Stiff, Slightly calcareous
1.5-2.0	Clay (CH), Dark gray to light gray, Very stiff, Very slightly calcareous
2.0-2.5	Clay (CH), Light gray, Very stiff, Very slightly calcareous
2.5-3.0	Clay (CH), Light gray, Very stiff
3.0-5.0	Clay (CH), Light gray, Very stiff

3.1.2 Atterberg limits and linear shrinkage

Atterberg limits tests (AS1289, 2009) were carried out at different depths to identify variation of the soil properties. Tests were conducted for three different locations and the average results are shown in Figure 3. The plastic limit varied from 20 to 25% and the liquid limit varied from 70 to 80% throughout the depth. Linear shrinkage test (AS1289, 2008) results were within 17 to 19%. According to the values of plasticity index (PI) and linear shrinkage the Braybrook soil was recognized as highly reactive (Hazelton and Murphy, 2007).

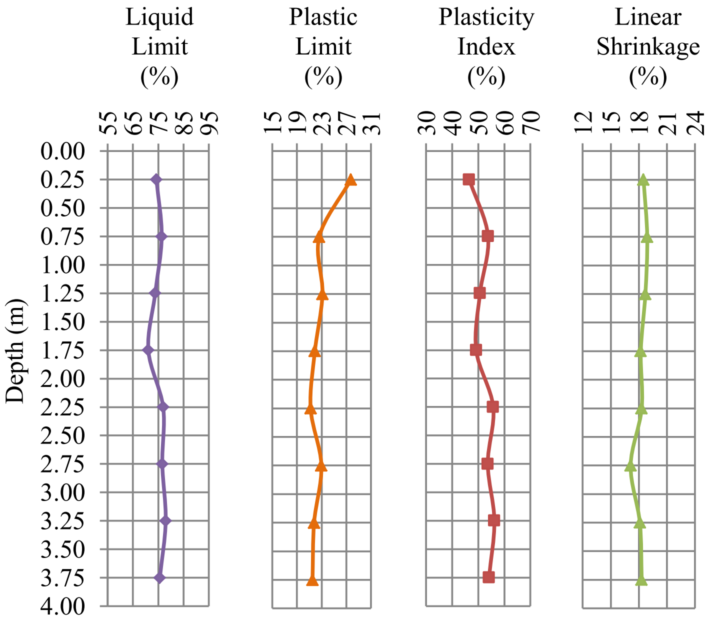

Figure 3: Atterberg limits and linear shrinkage variation with depth.

3.1.3 Particle size distribution

Fine particle percentages of the soil throughout the depth were analysed using the Hydrometer test (ASTM-D422, 2007). The specific gravity of the soils, which is a required parameter to analyse the Hydrometer test results, was obtained using a water pycnometer (ASTM-D854, 2010). Figure 4 shows the variation in particle size with depth. According to the results, the clay content of the soil below 0.5 m depth is about 45% and it is consistent up to 3.5 m. The top soil layer was contaminated with grass roots and some organic material. Specific gravity and clay content values are lower at the top layer which reflects the presence of organic material.

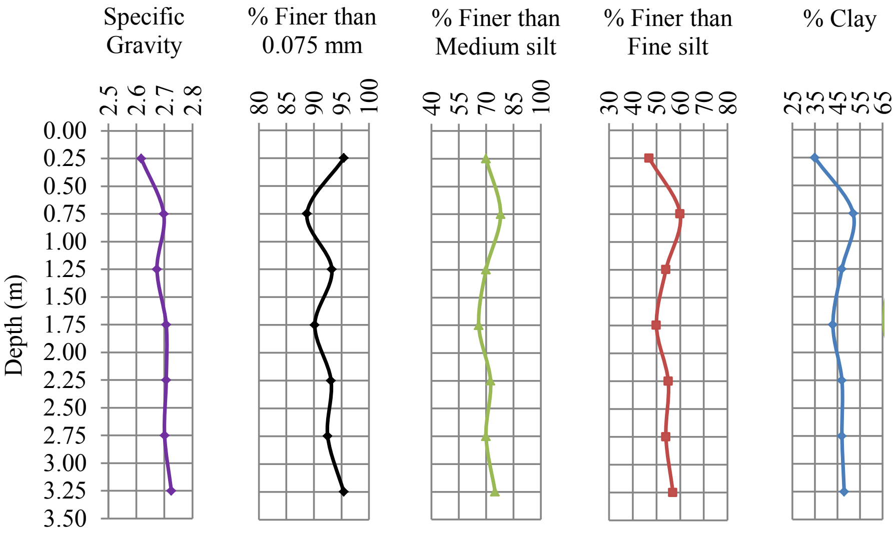

Figure 4: Specific gravity and fine particle percentages variation with depth in Braybrook Soil.

3.1.4 Shrink-swell index (I_{ss})

A one dimensional consolidometer was used to measure the swell percentage of the soil under a 25 kPa surcharge load and the core shrinkage test (Mitchell and Avalle, 1984) was performed to obtain the shrinkage percentage. The two tests were performed starting from in situ moisture condition for undisturbed samples collected at three different depths. The I_{ss} values were calculated in accordance with AS1289 (1998) and their variation with depth is shown in Table 2.

Table 2: Values of shrink-swell indexes for different depths.

Depth from surface (m)	I_{ss} (%)
0.5 – 1.0	5.69
1.5 – 2.0	5.62
2.5 – 3.0	4.88

Based on the measured I_{ss} values and the specified factors in AS2870 (2011), the characteristic surface movement (y_s) was calculated. In this calculation the design depth of suction change (H_s) was taken as 2.3 m and $0.75H_s$ crack depth was considered according to AS2870 (2011). The calculated y_s was 84 mm which led the site to be classified as E class – Extremely reactive category.

3.1.5 Mineral composition

Clay mineralogy analysis was performed using X Ray Diffraction (XRD) analysis (Burnett, 1995) to determine the fundamental mineral composition of the Braybrook soil. Results from the quantitative XRD analysis are shown in Table 3.

The mineral compositions of the soil at two different depths are almost identical, which confirms the consistency of the basic soil properties. The higher content of Montmorillonite provides evidence of the expansive properties of Braybrook soil. Similar expansive properties were reported in Tadanier and Nguyen (1984) for soils with similar clay mineralogy.

Table 3: Mineral composition of Braybrook clay

Mineral	Depth	
	0.5-1.0 m	1.0-1.5 m
Quartz (%)	53	59
Montmorillonite (%)	32.5	31
Mica/ Illite (%)	5.5	2
Kaolinite (%)	4	4
Albite (%)	2.5	2
Orthoclase (%)	2	2
Anatase (%)	<1	<1

3.1.6 Soil Water Characteristic Curve (SWCC)

2 Soil suctions and the corresponding moisture contents were measured to obtain the SWCC, which is the relationship between suction and moisture content. SWCC is an essential input to model the behaviour of unsaturated soil (Fredlund and Vu, 2003, Hung, 2002, Jones et al., 2009). Soil suctions were measured using the undisturbed samples. The measurement of the entire range of suction variation with water content, both in the field and laboratory, is not an easy task and may not be reliable (Gould et al., 2011, Tarantino et al., 2008). In this study, miniature tensiometers and a Chilled Mirror Hygrometer were used. Hyprop (UMS, 2013), which uses the tensiometers technique, can continuously measure the metric suction of soil along with moisture changes in low suction ranges. WP4C (Decagon, 2012), which is based on the Chilled Mirror dewpoint technique was used to measure the high suction values. The curves shown in Figure 5 were produced using both Hyprop and WP4C.

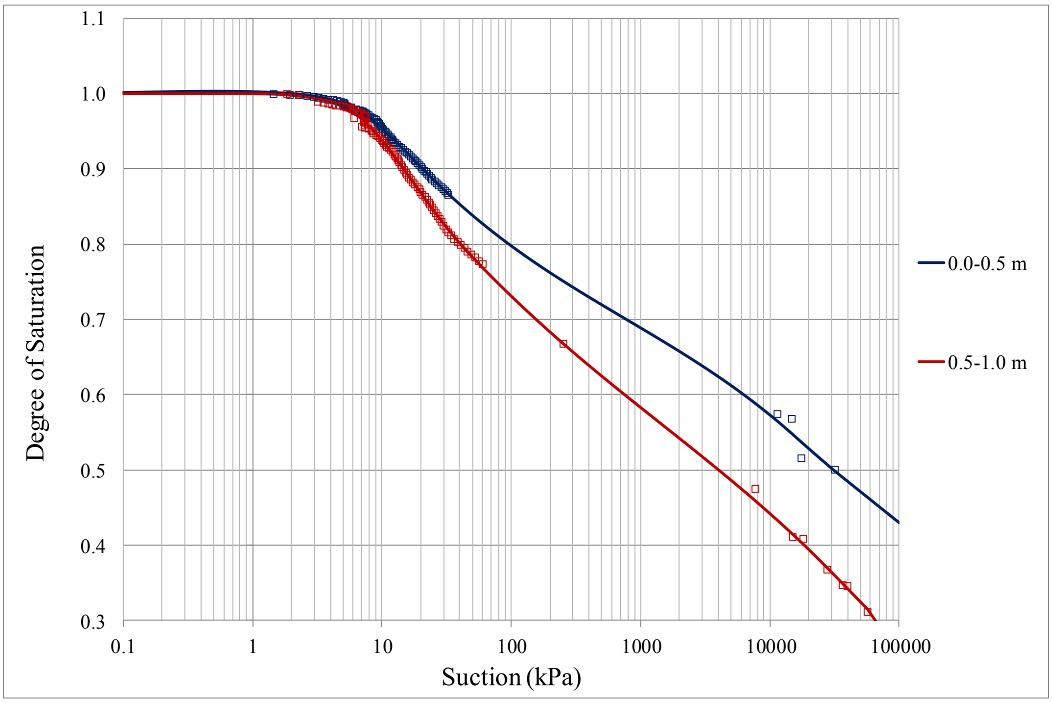

Figure 5: SWCC of Braybrook soil for two different depths.

3.2 FIELD MONITORING RESULTS

3.2.1 Moisture content change with time

Moisture content measurements were taken using the neutron probe at intervals of not less than four weeks. Figure 6 shows the volumetric moisture content variation throughout the depth over a period of 12 months. According to AS2870 (2011), H_s in Melbourne varies from 1.8 – 2.3 m, which means the soil moisture may change up to that depth within the design life of a structure. However, the soil moisture variation shown in Figure 6 indicates that within a period of 12 months, moisture varied in the first 1.25 m of depth. Since this is the early stage of ongoing monitoring, more variations are expected in the future but this also depends on the future climate condition.

Figure 7 shows the monthly rainfall data collected from the nearest weather station at Flemington Racecourse. This figure also shows the variation of gravimetric moisture content at different depths with time. The moisture content of the top soil has changed in response to the monthly rainfall. The moisture contents of the deeper layers reflect the rainfall pattern with a certain time lag which is due to the permeability of the soil. A higher variation of moisture can be observed in the top soil layers, but it is insignificant below 1.25 m depth. The moisture content variation at 1.6 m depth shown in Figure 7 provides evidence of its lower sensitivity to monthly rainfalls within the past 12 months.

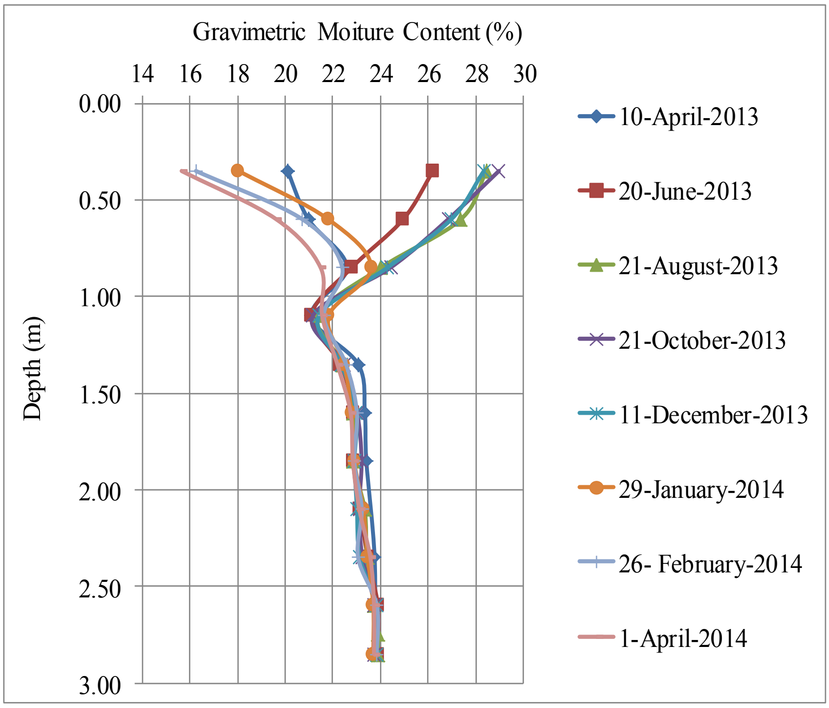

Figure 6: Volumetric moisture content variation throughout the depth.

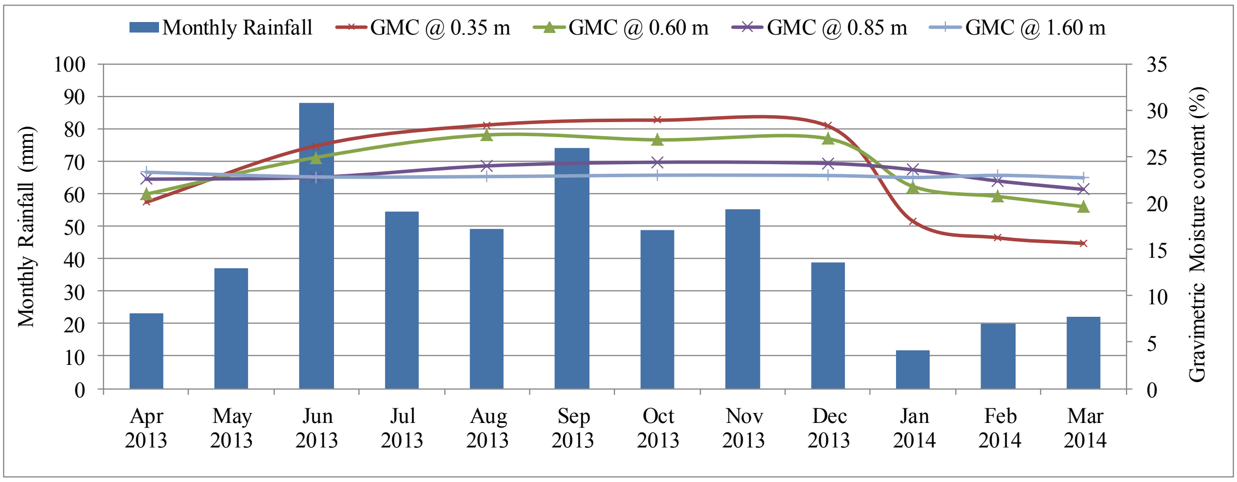

Figure 7: Monthly Rainfall in Braybrook and Gravimetric Moisture Content (GMC) variation with time.

3.2.2 Ground movement with time

Extensometer readings were collected along with the moisture measurements. Since this paper is based on an ongoing research project, the results show the behavior of the soil only for a period of 12 months, which is the early stage of the ongoing monitoring. Table 4 shows the results taken from the magnetic extensometer located next to the neutron probe access tube. The initial distances between spider magnets are shown as layer thicknesses. The measurements show that most of the movements occurred within the top two layers and the soil was relatively stable below the top two layers. This variation corresponds to the moisture variation shown in Figure 6.

Compared to the 84 mm of y_s value calculated based on I_{ss} and AS2870 (2011) specified parameters, the ground has moved by 29 mm during the period of 12 months.

Table 4: Soil layer movements measured by the extensometer

Layer number (from top to bottom)	Initial layer thickness (04/03/2013) m	Thickness change with respect to previous observation (mm)							
		25 MAR 2013	20 JUN 2013	21 AUG 2013	21 OCT 2013	11 DEC 2013	29 JAN 2014	26 FEB 2014	01 APR 2014
1	0.750	-1	14	2	0	-4	-16	-2	0
2	0.976	0	12	-4	1	4	-3	-4	-3
3	1.044	0	0	0	0	0	0	0	0
4	1.078	0	0	0	0	0	0	0	0
Total change (mm)		-1	26	-2	1	0	-19	-6	-3

4 SUMMARY AND CONCLUSIONS

This paper has presented the properties of the expansive soil in Braybrook - one of the western suburbs in Melbourne. Soil properties including Atterberg limits, linear shrinkage and particle size distribution were measured from disturbed and undisturbed soils collected from different depths. Undisturbed soils were used to measure shrink-swell index and SWCC. Soil moisture variation throughout the depth and consequent soil movements, which were obtained from a neutron probe and an extensometer, are also presented.

The derived properties show that the Braybrook site has a consistent soil profile, which is also evidenced by the mineral composition. According to the Atterberg limits and linear shrinkage values, the Braybrook soil can be identified as highly reactive. The soil can be classified as Fat clay (CH) according to the Unified soil classification (ASTM-D2487, 2011). Based on the measured parameters and the specified factors in AS2870 (2011), the characteristic surface movement was calculated as 84 mm which led the site to be classified as extremely reactive category (E).

The properties presented in this paper provide valuable data about expansive soil in western parts of Melbourne. In particular, the data can be used to identify the behaviour of expansive soil in Melbourne. SWCCs presented in this paper can be used to develop analytical models for this region.

Site monitoring and laboratory experiments are continuing. In addition, an analytical model is being developed to predict the moisture movement due to climate effects and subsequent ground movement. The analytical model will be useful to quantify the ground movement for different moisture movement scenarios within the design life of a residential structure. The knowledge of predicted ground movements will greatly assist in improving the design of residential footings on expansive soil.

5 ACKNOWLEDGEMENT

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