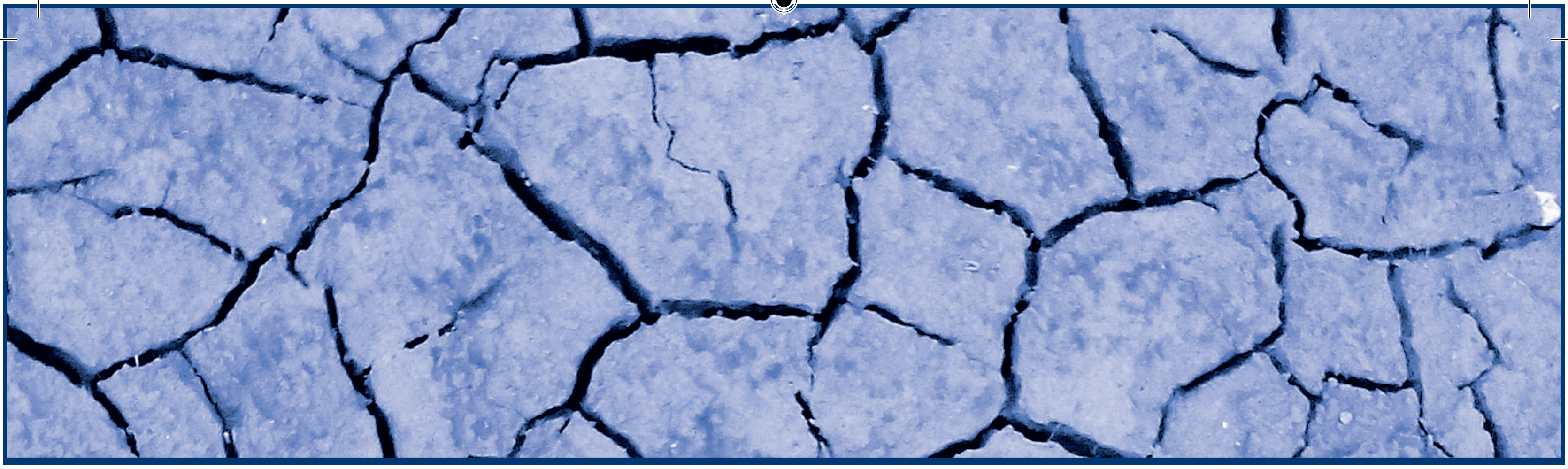
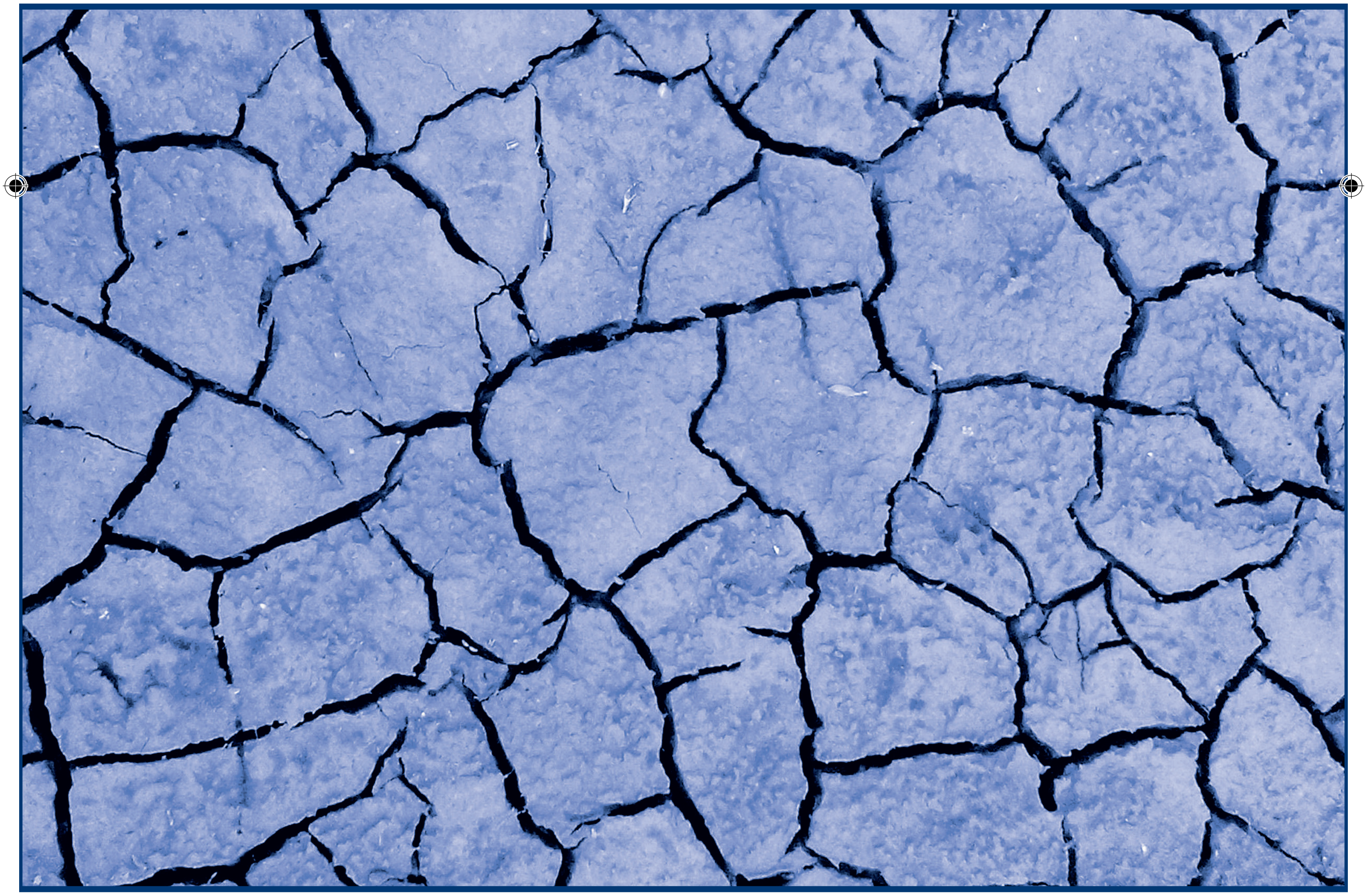


AGS VICTORIA 2017 SYMPOSIUM

Reactive clays and light structures

Wednesday, 25 October 2017, 8:15am – 7:00pm

Rydges Hotel, 186 Exhibition Street, Melbourne



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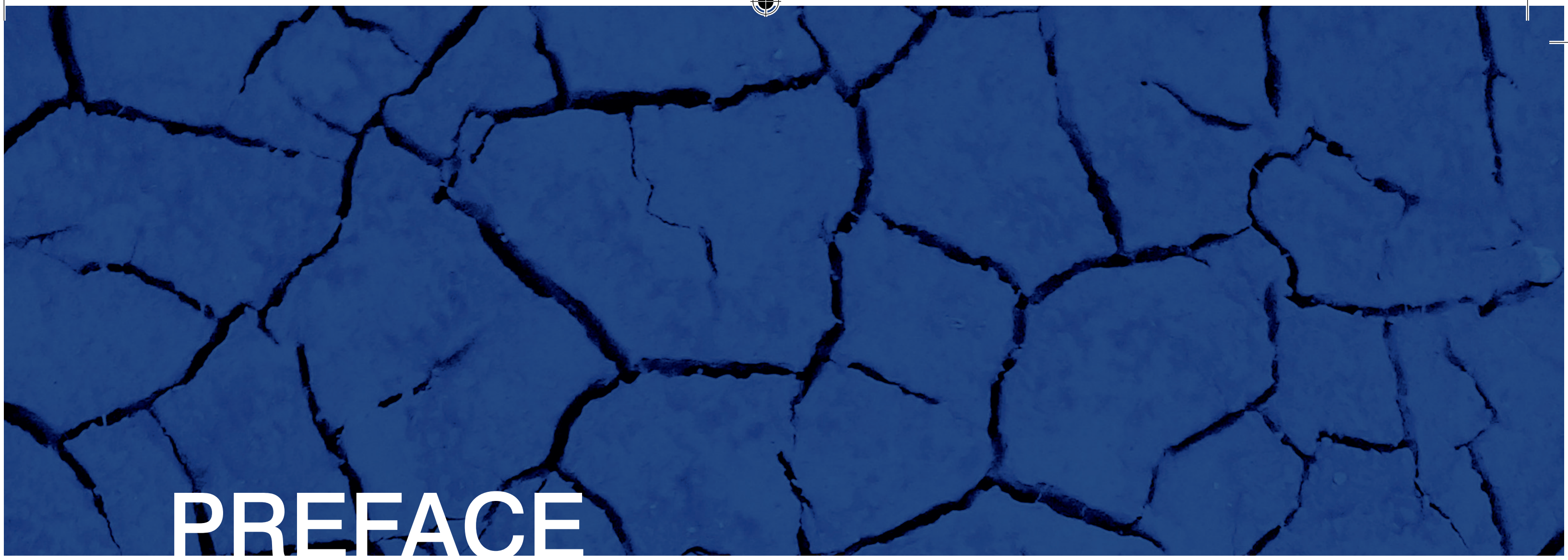

PREFACE

The Victorian chapter of the Australian Geomechanics Society invited academics and practitioners in the field of geotechnical and ground engineering to attend the 2017 Australian Geomechanics Society Victorian Symposium on 'Reactive clays and light structures' held on 25 October 2017.

The reactive soils of the Melbourne region form a large portion of its complex and variable geology. In particular, the basaltic volcanics situated to the north and west of Melbourne, which cover some 40% of the Melbourne region present numerous geotechnical challenges, particularly for lightly loaded structures. The geotechnical design and behaviour of lightly loaded structures on reactive soils is one aspect of geotechnical engineering where the public tend to have greater awareness, which is often not the case for the variety of soil and rock mechanics problems geotechnical engineers deal with. This is often borne out through their experience with their own residence, and rightly or wrongly, this contributes greatly to the public's perception of the geotechnical profession.

The 2017 Australian Geomechanics Society Victorian Symposium covered a variety of geotechnical challenges associated with reactive soils including residential slabs and footings, roads, pavements and other sensitive infrastructure that interact with reactive soils. The Symposium brought together practitioners from consulting, construction and academia to share and discuss their experiences on the topic of reactive soils and their related geotechnical applications.

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A new approach for characterising expansive clay sites

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ABSTRACT

Highly expansive soils are common throughout the world. In Australia more than 20% of the near-surface soils are considered moderately or highly expansive, many are in large cities. The Australian standard (AS2870) recommends 3 methods to 'characterise' a building site and in each case some form of regular laboratory testing is required to test the soil indices. To do so this the Standard recommends any of the following: Shrink/Swell, Loaded Core Shrinkage, or Unloaded Core Shrinkage test. The most common of these is the shrink/swell test (S/S); however in this test soil suctions are not measured and instead assume certain parameters. This paper presents a new Conditioned Core Shrinkage test (CCS) with suction measurements. This test is performed in the suction range of 3-7pF and provides the soil shrinkage index values (I_{ss}) along this range to calculate the 'characteristic surface movement' (y_s). The test can be carried out in 4 -7 days depending on the type of soil and recent climate.

Keywords: Highly expansive clays, Conditioned Core Shrinkage, Characteristic Ground Movement (y_s), Surface suction (Δu_s)

1 INTRODUCTION

This paper describes a Conditioned Core Shrinkage test designed to measure the soil shrinkage indices (I_{ps}) without lateral restraint or vertical load. This test measures suctions, shrinkage and moisture loss at each reading. The CCS test provides actual suction measurements and removes certain assumptions in the Shrink/Swell test which was first published by Colin Thorne (1984).

The CCS test has similarities to the core shrinkage test but is faster and considers the sampling climatic conditions. It achieves this as follows:

1) The sample is 38 mm ϕ (not 50mm), is easier to handle and can be collected with small drill rigs.
2) The sample is 'conditioned' by drying or wetting it to a chosen 'standardised' starting suction.
3) The suction is measured with a psychrometer and does not rely on the assumptions needed in the S/S test (AS1289.7.1, 2003).
4) The test does not rely on a contiguous and linear swell and shrink curve for all field suctions.
5) Avoiding the swell test removes the swell deformation factor of 2 caused by the brass ring.
6) The CCS test can be completed in a maximum of 4 - 7 days depending on the type of soil.

A successful soil laboratory tests should be able to:

- Compare soil properties over the relevant range.
- Determine properties for the design aims.
- Standardises the field and laboratory procedure.
- Investigate the soil parameters within the economics of the testing procedure.
- Obtain comparable results independent of different climatic conditions.

The sampling for the CCS tests shown in the Appendix 1 was carried out in the western suburbs of Melbourne (Werribee Plains) but only from Neogene age basaltic clays (Figure 1). However some typical results from other geological formations are also shown in section 4.3. Investigation of these other soil types is in progress and is hoped to be reported in late 2018.

2 RESEARCH AREA

The research area discussed in this paper has the fastest growing suburbs in Melbourne which occupy the Werribee Plains area as shown in Figure 1.

2.1 TMI in the research area

TMI has been a helpful tool to focus engineers' minds on climate effects and changes in the construction industry. However a better understanding of the as-built foundation moisture is required since the slab distortion is affected by moisture changes during construction and occupation of houses. In the past 2 decades Australia has experienced a more chaotic climate with periods of severe droughts and flooding rains very close to each other. Figure 2 indicates the severity of the recent climate effects in a test site in the suburb of Braybrook, showing the predicted ground movement using finite element models and real weather data Bureau of Meteorology (BoM) which indicates that the ground movement has increased due to recent extreme climate conditions (Karunarathne, 2016). The predicted ground movement for 1945 to 1994 indicates a y_s of 80mm and for 1994 to 2015, it appears to have increased to 95mm.

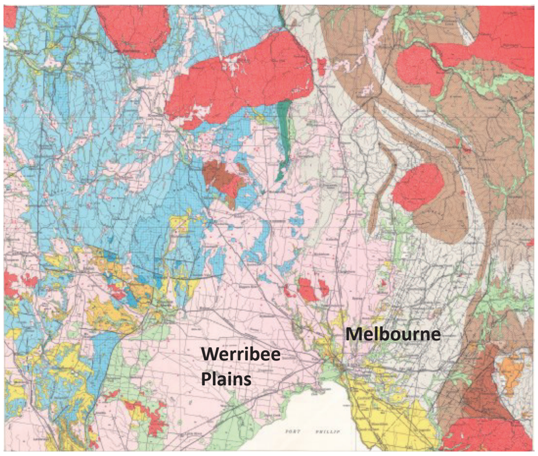

Figure 1. Werribee Plains, western suburbs of Melbourne – unscaled (Maps, 2015)

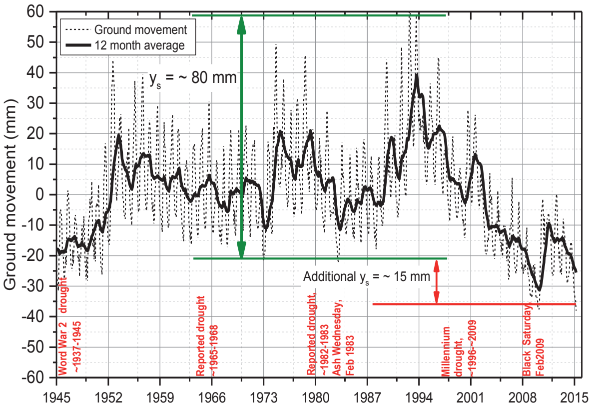

Figure 2. Predicted ground movement in Braybrook (Karunarathne, 2016)

3 FIELD AND LABORATORY TESTING

Other than a normal 'Classification' investigation in each site, undisturbed 38 mm ø tube samples are collected by slowly driving them into the desired soil layer. They are then sealed, labelled and delivered to a laboratory for 'conditioning' and testing.

All of the soil index tests in AS1289 part 7 have similar issues, i.e. the testing is carried out on samples at field moisture condition, the calculation of y_s assumes that the strain/suction relationship is linear and soil suction values are not measured. The most commonly used test to calculate soil instability in Australia is a 'composite' shrink/swell test as originally proposed by Thorne C. to the NSW Builders Licensing Board in 1984.

Other important issues in considering the measurement of soil indices are:

1) Shrink/swell test (S/S) does not consider the curvilinear relationship of suction versus shrink.
2) The higher osmotic suctions are not considered in either the Conditioned Core Shrinkage test (CCS) or the (S/S). This can affect the soil indices somewhat if very wet conditions are expected in the field.

The shrink/swell test formula in AS1289 is as follows:

$$I_{ss} = \frac{(\varepsilon_{sh} + \varepsilon_{sw}/2}{1.8} \qquad (1)$$

3.1 Conditioned core shrinkage test

The CCS test is proposed as an alternative to the soil indices tests in AS1289-1998. This test eliminates the issues that arise when testing soil indices in different field moisture conditions and avoids the variation of shrink and swell paths. All the samples were highly plastic Quaternary (Neogene) age basaltic clays sampled from the research area during 2014-2015. All samples were conditioned to suctions 3 to 3.5pF before starting the shrink test.

Samples are selected as near-identical pairs from the same tube sample and the shrink, suction and moistures are plotted as shown in Appendix 1.

The program used to draw the 'curve of best fit' is excel, polynomial order 3 or 4 for the CCS tests and polynomial order 3 for the SWCC. Figures 3 to 8 show different stages of the test.

Figure 3: Cutting samples

Figure 4. Samples being conditioned underwater

Figure 5. Initial weighing of shrink sample

Figure 6. Samples A and B being shrunk (air-dried)

Figure 7: Sample B to be trimmed for suction testing

Figure 8. Sample being placed in psychrometer

3.2 Graphical plots

Table 1 shows three S/S test results for a typical Braybrook clay tested with different initial moistures which emphasize the dependency of I_{ss} on starting moisture contents. Figure 9 shows possible variations of the slope of the strain curve in the S/S test. Clearly, standardization of the initial moisture is necessary for both the shrink and swell tests.

Although the CCS test avoids the need for a psychrometer to measure suction values it inherits some problems in doing so. It has shrink and swell components which are measured in two separate tests (shrink and swell). These curves do not join therefore by choosing only one strain path the test is better standardised. Since the swell path in the shrink/swell test is the slowest and is often the part of the test that is not well done (to save time) the authors have chosen the CCS test and 38 mm ø sampling tubes which save time and effort both in the field and laboratory.

The variation of the field moisture problems can be overcome by conditioning the sample to a standard suction value that covers the wettest 'normal' moisture conditions (e.g. 3.0-3.5pF) and testing only the shrink path.

Table 1. Shrinkage, swell strains and I_{ss} from same clay samples at different moisture (Braybrook)

Sample	Initial suction	Swell	Shrink	I_{ss}
Dry	4.5 pF	7.0%	0.7%	2.3%
Moist	3.7 pF	4.5%	3.2%	3.0%
Wet	3.0 pF	0%	7.7%	4.3%

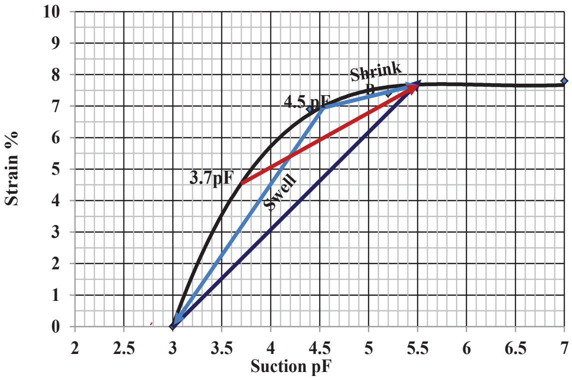

Figure 9. I_{ss} graphical plots from same clay samples at 3 different initial suctions, 3pF, 3.7pF and 4.5pF (Braybrook)

The formula for computing I_{ccs} has no approximations and the suction readings are more accurate than the estimation of the 1.8 pF suction in Equation 1.

By weighing the shrink sample at the same time as measuring the suctions, the SWC curve can also be drawn. The suction/shrink graph allows the I_{ps} to be calculated for any suction ranges. The test can be completed in 4-7 days and solves the non-linear portion of the shrink/swell relationship.

4 TYPICAL RESULTS

4.1 Calculation of CCS results

The data from both author's recent PhD research (not discussed here) suggests that the design surface suction (Δu_s) should be increased from 1.2 to 1.5pF where sites in climate Zone 3 are subject to inundation. This extra sub-classification should also be considered in the drier climates which often have floods.

Figure 10 and 11 show some typical CCS graphs for climate Zone 3 and (3a). In each case the curvilinear relationship can be simplified by lines 'A' and 'B' in Figure 10 and by 'C' and 'D' in Figure 11.

Tripathy et al., (2002) found that the swelling and shrinkage path of each specimen subjected to full swelling and full shrinkage cycles showed a sigmoidal curve and the linear portion is between 3 and 4pF. They also suggest that the swell-shrink paths can be established with a limited number of tests in the laboratory.

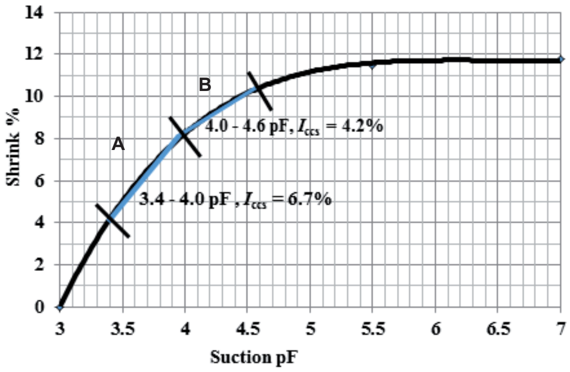

Figure 10. Typical CCS test result for Climate Zone 3

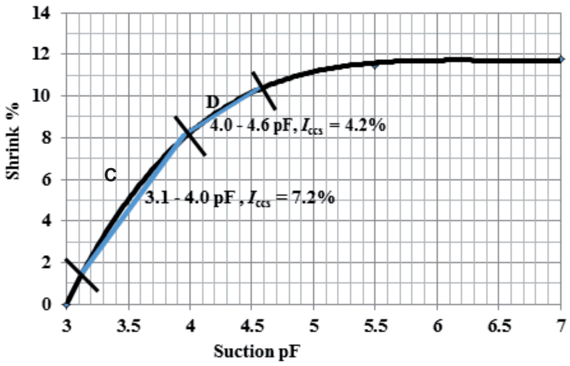

Figure11. Typical CCS result for Climate Zone 3(a)

Note : Zone 3(a) is within Zone 3 but is prone to inundation by rivers, creeks, pipe leaks or poor drainage during the design life of the houses.

Figure 12 can be used to approximate suction from moisture and vice versa. If the as-built moisture condition is measured one can ascertain if more shrink-settlement or swelling can be expected and whether the site is in 'normal' or 'abnormal' condition (as defined in AS2870). These results can also be compared with Figure 13 which is plotted using 36 CCS tests and 36 SWC curves during the study. During the research period the moisture and suction results indicate that, in general, the 90 percentile surface moistures and suction variation was 11% to 40%. (29% and 2.3pF) and the 'Normal' Δus was expected to be approximately 17%-31% (i.e.: 14% and 1.2 pF at the surface). (The 90 percentile was simply calculated by removing the upper and lower 5% of the readings).

4.2 Shapes of CCS and SWC curves

The basaltic clays in this research project are mainly Smectites which have degraded from Ca++ types to Na+ types and have therefore become highly expansive with Liquid Limits in the range of 70% to 130%. On this topic Laird (2006) stated that there are 6 separate processes which control the swelling of Smectites saturated with alkali and alkaline earth cations in aqueous systems.

Figure 14 compares the linear relationship used in the Australian S/S test with the various swelling processes described by Laird (2006). The structural changes have been placed in their approximate position on the curve to show how difficult it is to represent the process with only one straight line over a 'floating' suction range of 1.8pF.

The swelling processes of clays overlap and have different swelling rates and strain thus a sigmoidal curve best describes the whole process.

4.3 CCS in other geological settings

Recently the authors have carried out additional CCS tests in other geological environments as shown in figures 15-17 to the South East of Melbourne. These appear to indicate that the Tertiary basalt clays are less expansive than the Quaternary basalt clays, which may be due to a greater iron content. However the related pyroclastic clays in Clyde North are as expansive as the Quaternary clay to the West of Melbourne.

Clyde North has complex geological environments such as Tertiary age basaltic and pyroclastic clays, Silurian and Tertiary sediments and subsurface granites. All of these formations are common elsewhere in Melbourne and require further testing.

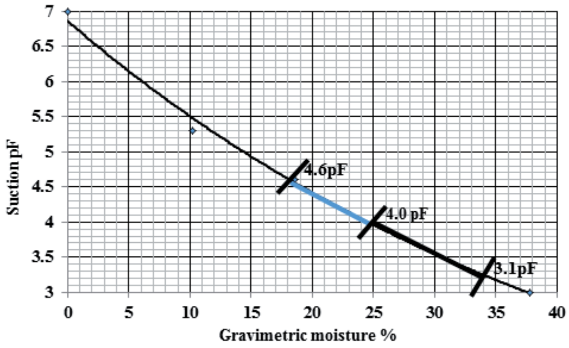

Figure 12. Typical SWCC for Climate Zone 3(a)

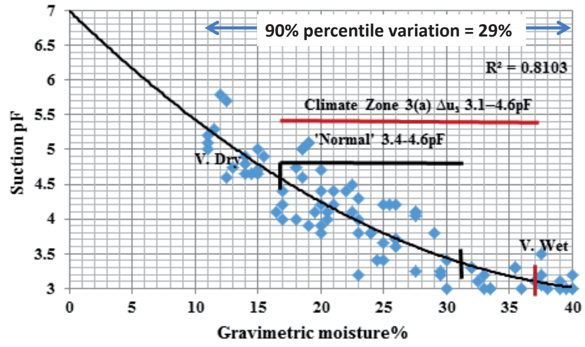

Figure 13. Grouped SWCC from CCS test results

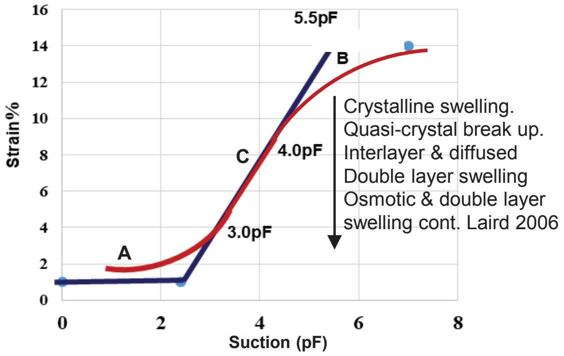

Figure 14. Swelling process and S/S representations.

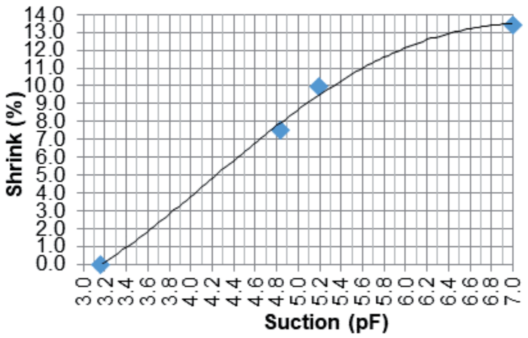

Figure 15. Tertiary pyroclastic clays in Clyde North

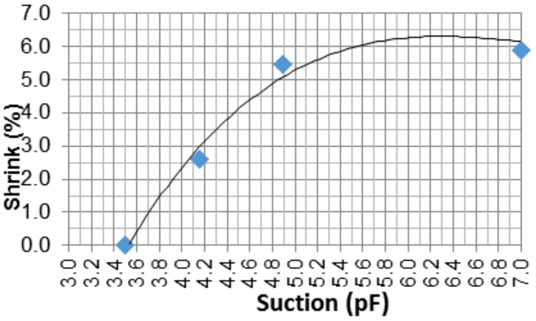

Figure 16. Tertiary basalt clay, Cranbourne West

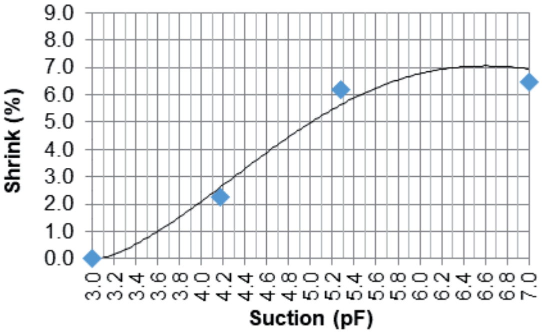

Figure 17. Silurian sediments in Clyde North

5 CONCLUSION AND RECOMMEDATIONS

The laboratory results to-date indicates that the CCS test is an improvement on other soil index tests in AS1289. The CCS tests raise a number of issues and provide some advantages, such as:

- The effect of the sigmoidal curve in determining the I_{ps}. (Fredlund et al., 2011).
- The solution of the initial moisture problem in measuring strain by ‘conditioning’ the samples.
- The use of the dew-point mirror psychrometer to draw shrink/suction graphs.
- Reducing the testing time and costs of field and testing procedures by using 38mmø samples.
- Allowing smaller drilling rigs to take samples more easily especially in dry periods.

The authors consider this research very effective in testing highly expansive basaltic clays in the western suburbs of Melbourne and should be tested with clays of similar chemistry and other geological environments elsewhere in Australia. Other important soil conditions during construction such as soil stress, diffusion and the as-built soil suction require deeper examination.

Recent research by Sun et al., (2017) have suggested that Mather’s modified TMI formula (1974) gives lower values than those based on the original Thornthwaite formula; therefore, a thorough investigation of H_s is recommended.

The authors suggest that in the research area the cations such as Ca, Mg and Fe, and carbonate and bicarbonate deposits play a part in the shrinking and swelling processes of the clay structure and should be further investigated.

ACKNOWLEDGEMENTS

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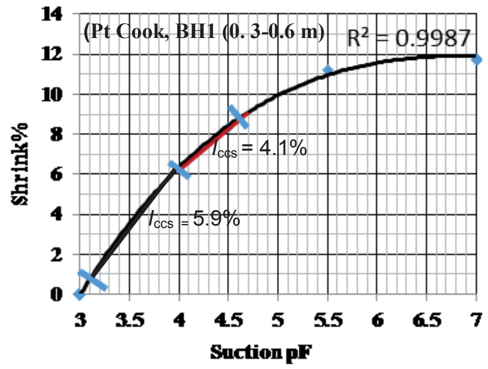
APPENDIX 1

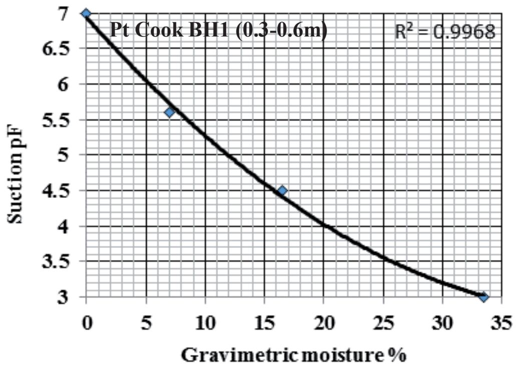
TYPICAL CCS & SWCC GRAPHICAL PLOTS.
Climate Zone 3 (a) Basaltic Clay prone-to-inundation.

POINT COOK – CCS

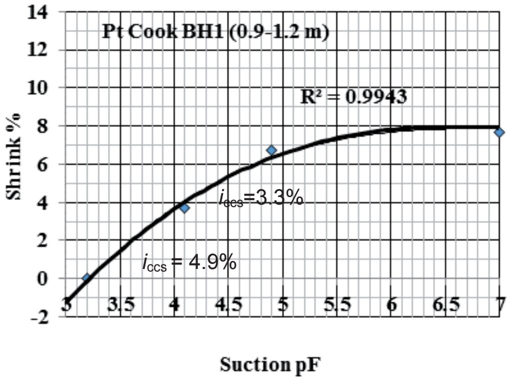
POINT COOK – SWCC



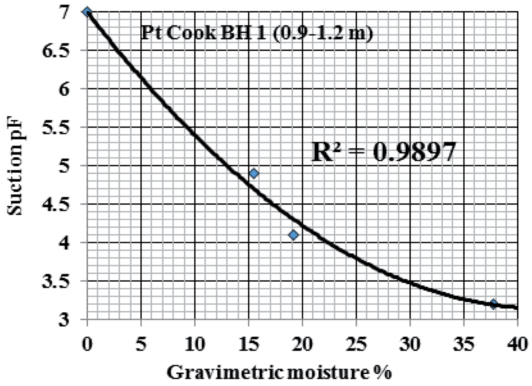
Silty Clay. Colour: Dark-brown.
Δus, 3.1–4.0 pF, I_{ccs} = 5.9%, 4.0–4.6 pF I_{ccs} = 4.1%



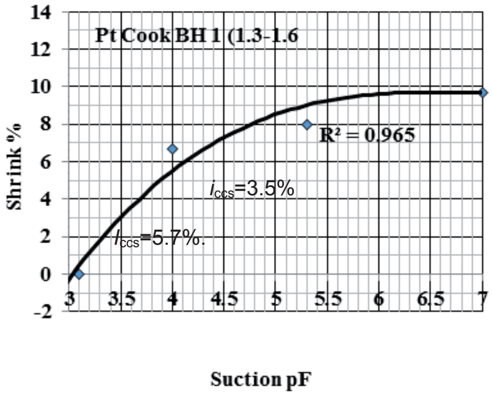
Conditioned moisture C_W = 34%.
Conditioned suction C_S = 3.0 pF.



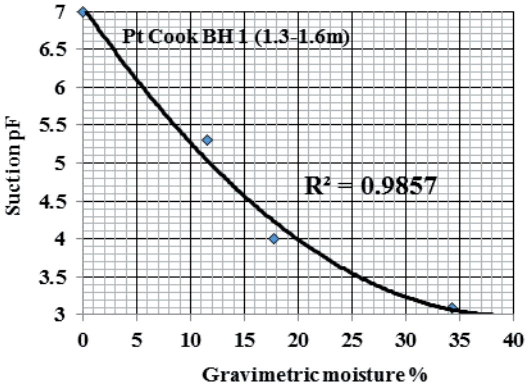
Silty Clay + calcrete. Colour : Grey/red/brown
Δus, 3.1–4.0 pF, I_{ccs}= 4.9%, 4.0–4.6 pF, I_{ccs} = 3.3%



Conditioned moisture C_W = 38%.
Conditioned suction Cs = 3.2 pF.



Silty Clay. Colour: Grey/red/brown
Δus, 3.1–4.0 pF, I_{ccs} = 5.7%, 4.0–4.6 pF, I_{ccs} =3.5%



Conditioned moisture C_W = 34%.
Conditioned suction Cs = 3.1 pF.

y_s for Point Cook BH1 = 85 mm

N B.The CCS graphs have not been drawn in the usual axis order used internationally but the values or slopes of the curves are not affected.

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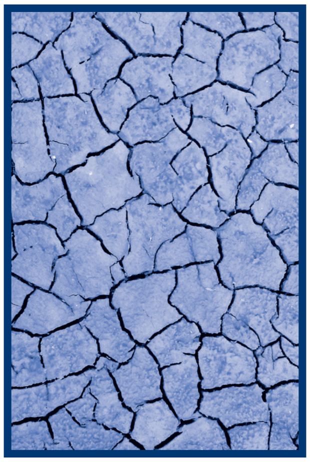

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