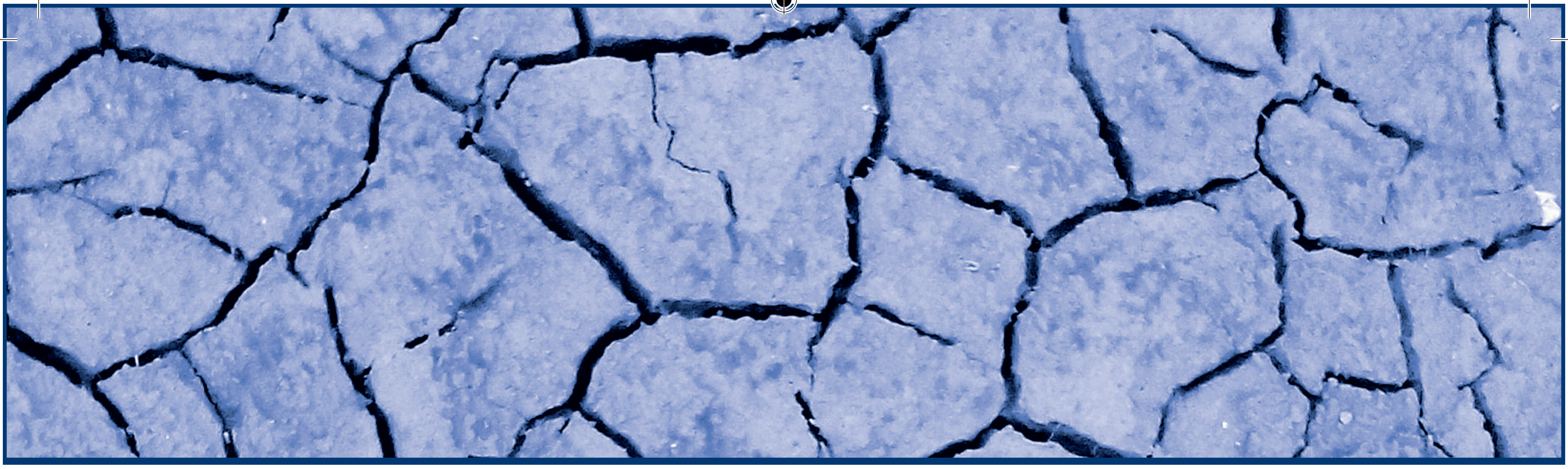
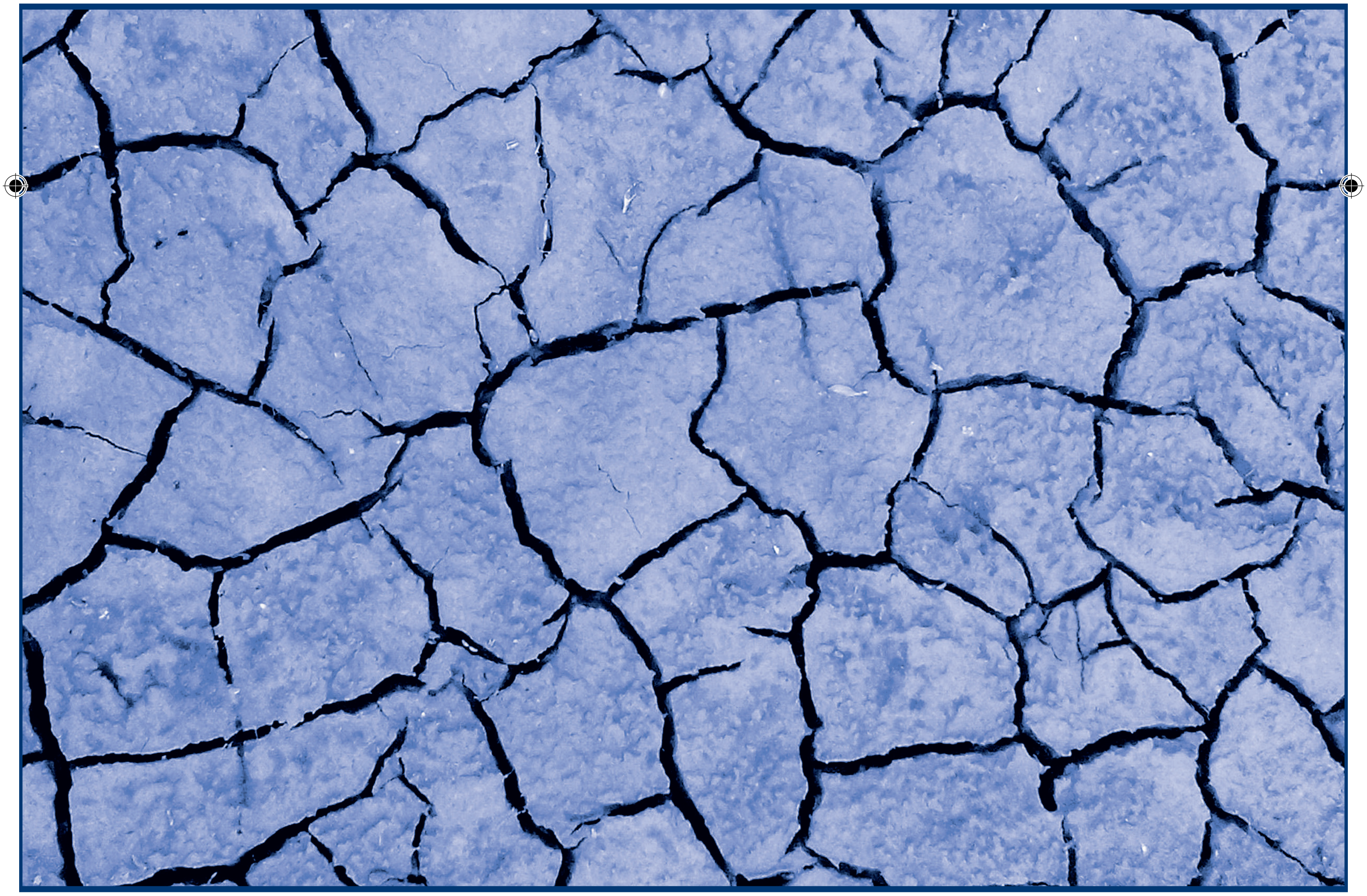


AGS VICTORIA 2017 SYMPOSIUM

Reactive clays and light structures

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

Rydges Hotel, 186 Exhibition Street, Melbourne



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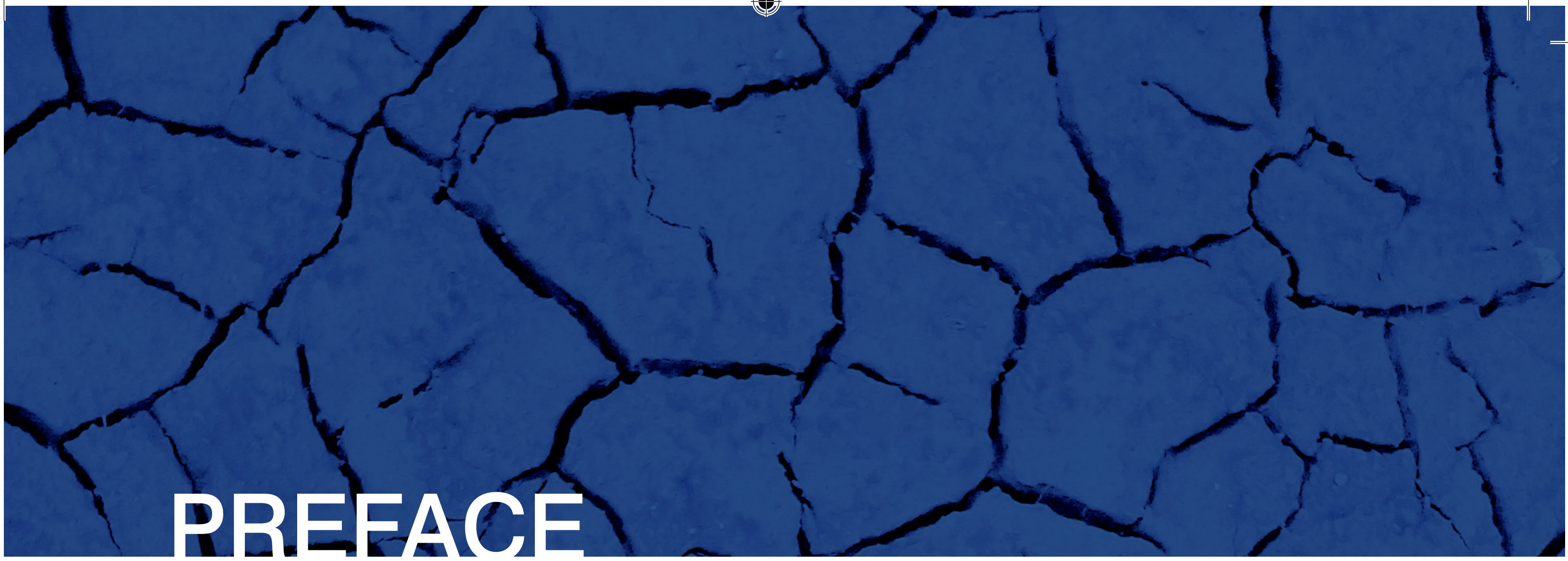

PREFACE

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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Confined and partially confined swelling pressure of basaltic clays

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ABSTRACT

This paper looks at the swell pressures developed in basaltic clay under confined and partially confined conditions, including the pressure reduction with expansion of the soil. The paper makes a comparison of the measured values with those presented in literature for similar materials and looks at the suitability of empirical equations from literature for the estimation of confined swell pressure in Melbourne's basaltic clays. The paper also considers the potential applications for the findings in design and relevant considerations with regard to design in accordance with Australian Standards.

Keywords: swell, pressure, basalt, clay, retaining, wall

1 INTRODUCTION

Project work undertaken by the authors led to the requirement for estimation of the potential swell pressure imposed on structures due to water ingress to retained or founding reactive basaltic clays.

In order to provide an upper bound estimate of swell pressure, equilibrium swell pressure (p_s) testing was undertaken on undisturbed samples of basaltic clay in the laboratory. Equilibrium swell pressure is the maximum pressure exhibited by a fully confined sample when subject to saturation.

This paper presents the results of the laboratory testing and compares them with results from similar materials in literature. Comparison is also made with estimates based on empirical equations from literature.

The paper additionally discusses the likely reduction in swelling pressure with expansion of the soil, considers the potential applications for the findings in design and discusses relevant considerations with regard to design in accordance with Australian Standards.

2 BACKGROUND AND LITERATURE REVIEW

Al-Yaqoub et al. (2016) presents results for various laboratory testing, including swell pressure testing. They created a soil with 60% Bonny silt and 40% Black Hills bentonite resulting in a test material exhibiting swelling behaviour and with a liquid limit of 126% (i.e. in the order of those values expected for high plasticity basaltic clays).

Their research indicates that the maximum swell pressure of swelling soils is inversely proportional to the initial moisture content of the material and is also proportional to the dry density of the soil.

Figure 1 shows an excerpt from their paper summarising the results of equilibrium swell pressure versus initial moisture content from constant volume oedometer testing. The results indicate a maximum measured equilibrium swell pressure of about 400 kPa from a sample with initial moisture content of 21%. Fredlund (1969) presents several equilibrium swell pressure results from constant volume consolidometer testing. The results presented are summarised in Table 1.

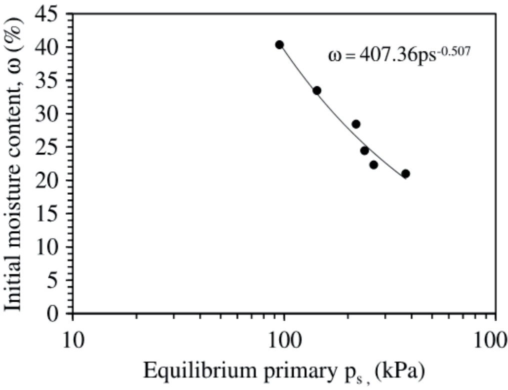

Figure 1. Swell pressure (labelled Equilibrium primary) vs. Initial moisture content (Al-Yaqoub et al. 2016)

Elbadry (2016) in a paper discussing the volumetric behaviour of swelling soils presents several equations from literature which may be used to estimate the swelling pressure of soils given various parameters. One such equation which uses readily available parameters is by Nayak and Christensen (1971) and is as follows:

$$P_s = [(3.58*10^{-2})PI^{1.12}C^2/W_i^2] + 3.79 \qquad (1)$$

Where;
P_s = *swelling pressure (PSI)*
PI = *plasticity index (%)*
C = *clay content (%)*
W_i = *initial moisture content (%)*

Table1: Equilibrium swelling pressure results (Fredlund 1969)

Liquid limit (%)	Plastic limit (%)	Initial moisture content (%)	Equilibrium swelling pressure (kPa)
82	34	27.4	443
74	32	27.9	336
73	32	30	82

3 LABORATORY ANALYSIS

Swell pressure testing was undertaken on several undisturbed samples of basaltic clay retrieved from Melbourne's north west.

3.1 Laboratory test methodology

The equilibrium swell pressure of the samples was directly measured by the constant volume one-dimensional consolidometer test outlined in Fredlund (1969). The test method involves placing a trimmed sub-sample of the undisturbed material in an oedometer cell. A nominal pressure (6.2 kPa was used in this testing) is then applied to the sample to ensure seating is achieved prior to saturation. Once the sample is seated, the cell is filled with water and the sample begins to saturate and subsequently swell. Pressure on the sample is progressively increased so that the percentage swell remains at approximately zero (i.e. the sample neither shrinks nor swells). The limiting pressure at which swell equilibrium is achieved in the saturated sample is then taken as the equilibrium swell pressure.

In order to provide results for a larger range of initial moisture contents, following the measurement of swell pressure at their in-situ moisture content the samples were allowed to air dry for between 24 to 72 hours with the test procedure then repeated on the comparatively dry samples.

In addition to the above testing, the behaviour of two samples was recorded during unloading in order to assess the reduction in swell pressure as the sample was allowed to expand. This was undertaken to assess the strain dependent swell pressure with expansion of the soil. Once the equilibrium swell pressure for each sample had been recorded, the pressure on the sample was reduced in increments and the sample was able to incrementally swell. The swell was allowed to stabilise at each unloading increment and the swell measurement recorded.

3.1.1 Equilibrium swell testing

Equilibrium swell pressure testing was undertaken on four samples of basaltic clay by the method discussed in Section 3.1. Each sample was tested at its in-situ moisture content as well as a lower moisture content following air drying. Table 2 presents a summary of the samples along with their measured equilibrium swell pressure.

As anticipated based on the results presented in literature, the equilibrium swell pressure exhibited by a sample was observed to increase with decreasing initial moisture content (i.e. the more water a sample can absorb, the higher the swell pressure).

It is noted that the literature indicates that the swell pressure of expansive soils also increases with increasing dry density. As can be seen in Table 2, the dry density of the samples was relatively consistent across the samples and so the impact of this variable on the results is likely limited.

A plot indicating equilibrium swell pressure with initial moisture content is provided as Figure 2. An exponential line of best fit has been included on the plot. The line of best fit from the Al-Yaqoub et al. (2016) data has also been included for reference.

3.1.1 Swell behaviour during unloading

Results of the recording of swell during unloading are summarised in Table 3. Figure 3 presents a plot of the strain dependent swell pressure behaviour of the samples with decreasing confining pressure.

The results indicate that as the sample is allowed to swell, the equilibrium swell pressure is reduced. The increase in swell with reduction in confinement pressure over the range tested is relatively linear, with an average swell per kPa confinement reduction in the order of 0.01%. We note that these two samples were tested from a relatively high initial moisture content generating equilibrium swell pressures of 86 and 100 kPa. If the samples had started from a lower initial moisture content, the equilibrium swell pressure

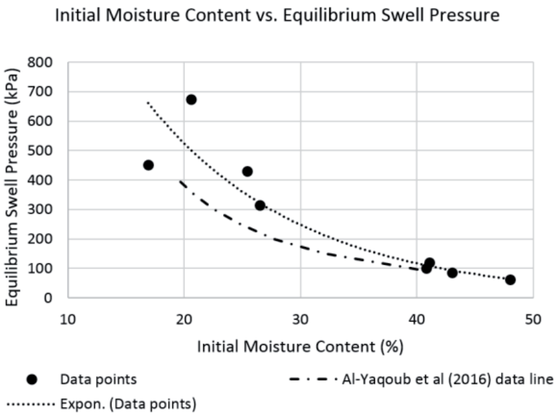

Figure 2. Equilibrium swell pressure vs. Initial moisture content results

Table 2: Summary of test samples and results

Sample	PP^1 reading (kPa)	Liquid limit (%)	Plastic limit (%)	Initial moisture content (w_i) (%)	Initial dry density (kN/m^3)	Initial void ratio, e^1	Equilibrium swell pressure from w_i (kPa)	Dried moisture content (w_d) (%)	Equilibrium swell pressure from w_d (kPa)
1	200-250	NT$^\#$	NT	48	11.7	NT	63	17	452
2	200-300	159	33	43	12.1	1.152	86	27	315
3	350-400	133	31	41	12.5	1.085	100	25	430
4	400-500	NT	NT	41	12.7	NT	119	21	673

$^\#$ NT = Not tested, ^{1} PP = pocket penetrometer, ^{2} Based on assumed soil particle density of 2.65

Table 3: Percent swell with pressure reduction

Sample	2	3
Initial moisture content (w_i) (%)	43	41
Equilibrium swell pressure (kPa)	86	100
Percent swell (%)	0	0.05[1]
Pressure at Reduction Increment 1 (kPa)	70	75
Percent swell at Reduction Increment 1 (%)	0.10	0.14
Pressure at Reduction Increment 2 (kPa)	45	50
Percent swell at Reduction Increment 2 (%)	0.31	0.34
Pressure at Reduction Increment 3 (kPa)	20	25
Percent swell at Reduction Increment 3 (%)	0.71	0.71
Average swell per kPa reduction (%/kPa)	0.0108	0.0088

[1] Minor swell of sample occurred during initial testing, however the magnitude of swell is considered unlikely to have a significant impact on the equilibrium swell pressure

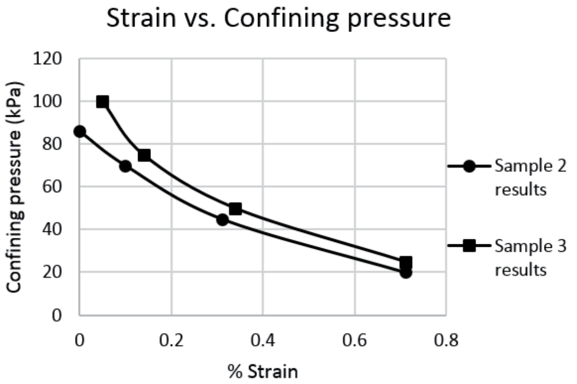

Figure 3. Strain dependent swell pressure

would be much higher and the behaviour may be significantly non-linear.

The sample with the higher initial moisture content exhibits a lower equilibrium swell pressure and therefore sits lower on the chart. However, the percentage increase in swell per unit reduction in confining pressure is very similar between the samples.

4 COMPARISON OF LABORATORY RESULTS WITH EMPIRICAL CALCULATION METHODS FROM LITERATURE

The confined swell pressure results calculated from the laboratory testing are generally consistent with the values for similar materials presented in the literature and summarised in Section 2.

The test data has been compared with predicted values derived using the equation by Nayak and Christensen (1971). Estimation of swell pressure using this method requires input of the plasticity index, initial moisture content, and clay content of the sample. Clay content of the tested samples was not measured, however based on experience, basaltic clay typically has clay content in the rangle of 50% to 70%. Figure 4 shows a comparison of the test data as compared with predictions based on the Nayak and Christensen methods for the tested plasticity index of samples 2 and 3 and for clay contents of 50%, 60% and 70%.

The plotted estimates show good agreement with the tested data, suggesting that the Nayak and Christensen method outlined may be an economical and relatively accurate method for the prediction of confined swell pressure in basaltic clays.

The line of best fit from the Al-Yaqoub et al. (2016) is shown on Figure 2 and also shows good agreement with the laboratory test results.

5 DISCUSSION OF LABORATORY TEST RESULTS

The equilibrium swell pressures presented from the constant volume one-dimensional consolidometer testing provide a likely upper bound swelling pressure for the sample at a given initial moisture content.

The in-situ moisture content of basaltic clays will vary with depth and between seasons, however a range between 20% and 30% would be considered typical for these materials around Melbourne.

The results of this testing show that for basaltic clays with in-situ moisture contents within this range, maximum swelling pressures of between 250 kPa and 700 kPa might be expected. Typical industry design standards would dictate a factor of 1.5 then be placed on these values for use in design, resulting in design swelling pressures likely in the range of 375 kPa to 1050 kPa. The results from literature for similarly reactive soils are of a similar magnitude.

Based on these values, it would generally be impractical to design retention structures or footing systems to resist the swell pressures likely to be imposed by adjacent clays should water ingress to those clays occur.

However, the results of the testing also indicate that the swell pressure of the soil reduces if the soil is allowed to expand, suggesting that for structures

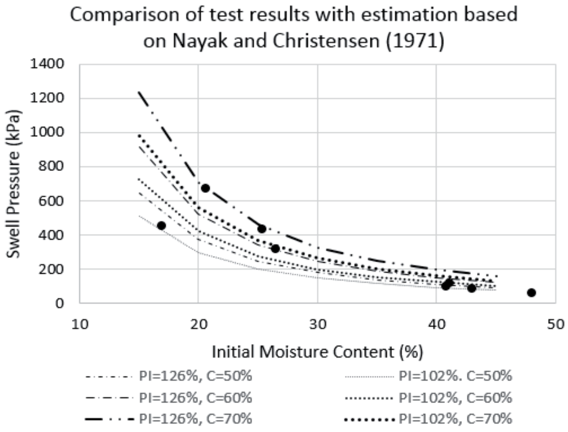

Figure 4. Comparison of laboratory test results with empirical equation from Nayak and Christensen (1971)

where some level of deflection is allowed, the resulting maximum swell pressure on the structure may be significantly reduced. This reduction would depend on the ratio of the deflection to the thickness of the swelling soil.

This suggests there is an avenue to be explored in whether movement of structures within reasonable limits might provide enough relaxation of the soil such that the swell pressure may be reduced to a reasonable level to be allowed for in design.

6 POTENTIAL DESIGN SCENARIOS

6.1 Footings / Capping beams cast on ground / Slab on ground

Materials beneath footings or structures cast against the ground are subject to very similar confining conditions as those in the laboratory testing undertaken (i.e. high lateral confinement, potential for vertical swelling with movement of the structure).

From this it follows that the results of the testing are highly applicable to estimation of potential swelling pressures under these structures.

Where there is a relatively thin layer of clay present over rock as is common in the Newer Volcanics, it is a simple equation to calculate the vertical strain in the soil for a given vertical deflection of the structure. Using this and the correlations presented in this paper, an estimated range for maximum swell pressure could be readily calculated.

6.2 Retaining walls

In the context of retained clays, it follows from the results of the testing that the swell pressure ultimately felt on the back of the wall will be related the confinement of the material which in turn depends on several factors such as:

- Overburden pressure (vertical confinement);
- Wall stiffness (lateral confinement);
- Extent of moisture ingress (volume of clay subject to swelling);
- Change in moisture content..

From the findings of this paper it may be postulated that, should the retained clays become saturated due to moisture ingress from a leaking service or similar, depending on the factors listed above the level of swell pressure felt by the wall may be significantly reduced as compared with the values derived from confined laboratory testing.

Estimation of the likely reduction in swell pressure due to reduced confinement in this context would need to consider the effects of varying lateral and vertical confinement. This presents an interesting avenue for further research.

7 CONSIDERATIONS FOR DESIGN TO AUSTRALIAN STANDARDS

Industry design standards require the consideration of the behaviour of expansive soils in design.

AS2870-2011 places significant emphasis on the consideration of swell of expansive soils in footing design. Commentary in AS2870-2011 specifically speaks about design requirements for swelling and shrinking movements and states that 'the primary cause of footing failure of domestic structures is associated with the movement of reactive clay soils'.

AS5100.3-2017, Section 3.2 Loads, requires foundations and soil supporting structures be design for loading as a result of soil movement including soil heave and reactive soils. Section 2.3.3 Soil-Supporting structures of the same standard effectively requires structural components be designed for 1.5 times the unfactored design action event. Taking the examples of ground anchor tension or pull-out through a soil nail wall facing, the resulting design pressures would range from 375kPa to 1050kPa which are impractical to reasonably design for.

AS4678-2002, Section 3.3 advises 'where soils having significant shrink/swell characteristics are encountered at a site, then consideration of the effects of the shrink/swell movements shall be taken into account in the design of the structure'. On this basis it could be considered reasonable to make an allowance for some potential swell which could occur as a result of fluctuations in moisture content in the retained or founding soil.

From a practical design perspective, the key aspect is considering if the potential saturation (and associated swell) is a case that could reasonable exist (AS 4678 Section J7.1.1). On a typical project this type of saturation may be considered unreasonable, however consideration needs to be given to the magnitude of wall and ground movement anticipated, along with the presence of potential moisture sources (e.g. pipes or drainage swales) which have the potential to (or may already be) leaking water into the retained material.

The key consideration here is the likelihood for this type of behaviour to occur. Section J7.1.1 of AS 4678 advises "the factored loads and resistance to be used in the design calculations have to be those corresponding to the most demanding combination of forces and material properties that can reasonably coexist".

8 CONCLUSION

The results of laboratory testing presented in this paper show that the equilibrium swell pressure of basaltic clays are inversely proportional to the initial moisture content of the material.

The equilibrium swelling pressure values derived for materials with initial moisture content typically in the range experienced in the field are higher than would generally be practical to design for. However, the findings also show that swell pressure is significantly reduced with expansion of the soil, leading to the conclusion that in applications where some swelling of the soil can be accommodated, maximum swelling pressures may be significantly reduced as compared with the values estimated for fully confined samples.

A comparison of the derived results with results from literature indicates that the equilibrium swell pressure of basaltic clays is generally consistent with the swell pressures of other clay materials of similar plasticity and origin.

A comparison of the results against empirical equations from literature for the estimation of equilibrium swell pressure indicates good correlation with the results for basaltic clay. This finding provides a potential method for economical estimation of equilibrium swell pressure using readily available parameters.

The findings of the paper are particularly applicable to design scenarios involving high lateral confinement and potential for vertical movement, such as soils under footings, capping beams or slabs. The results are also of interest to retaining wall problems, however the impact of variable vertical and lateral confinement would require further consideration.

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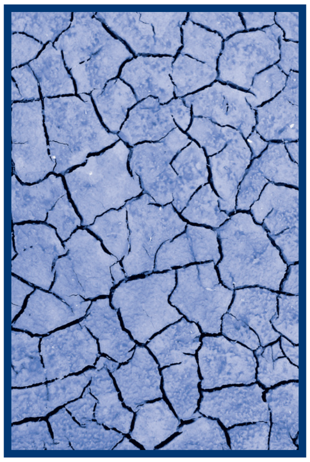

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