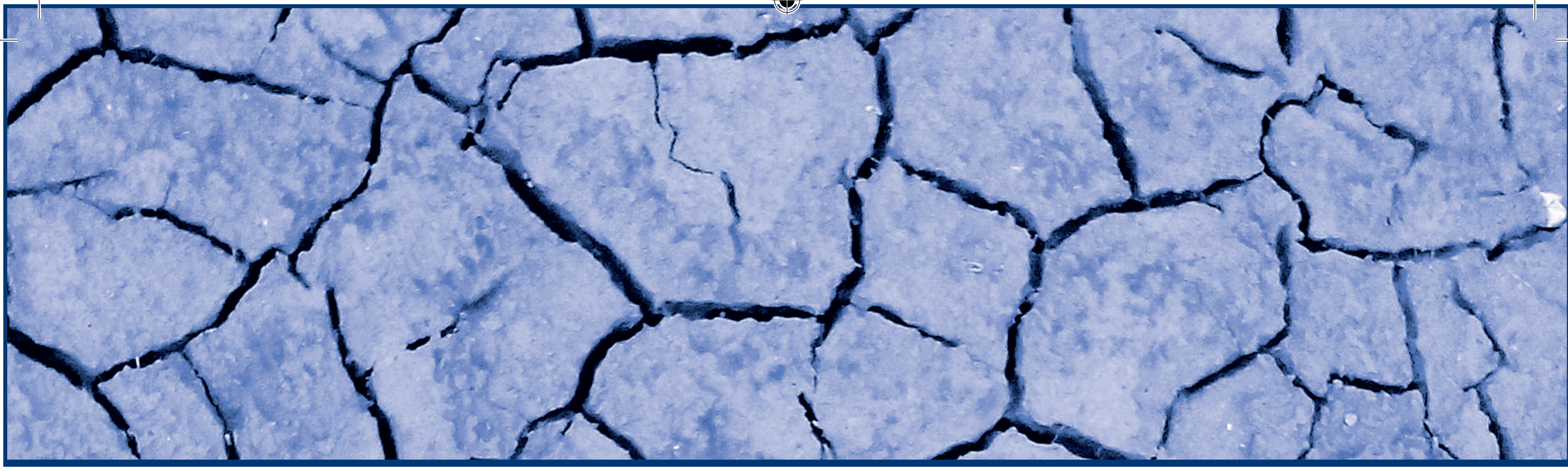
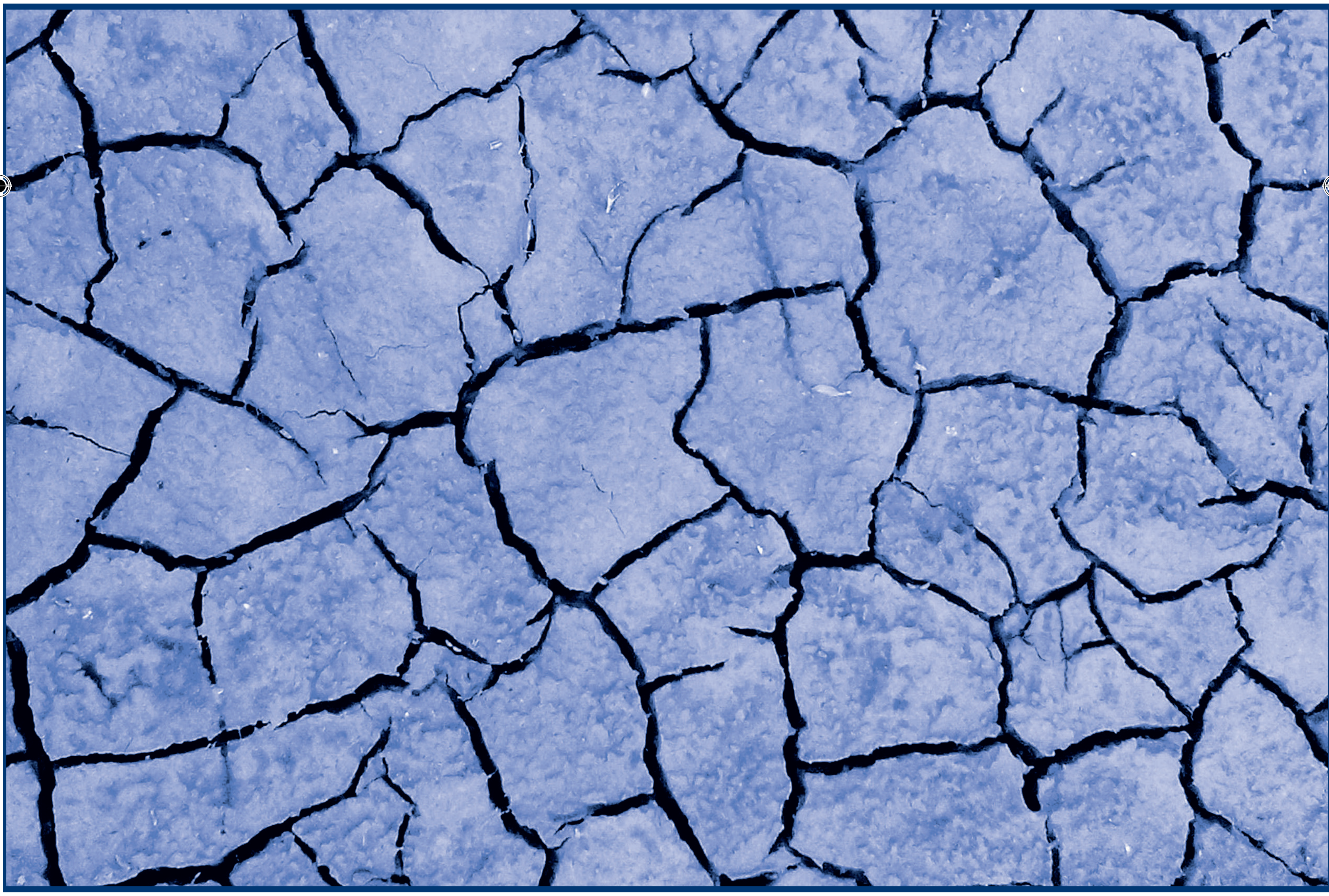


AGS VICTORIA 2017 SYMPOSIUM

Reactive clays and light structures

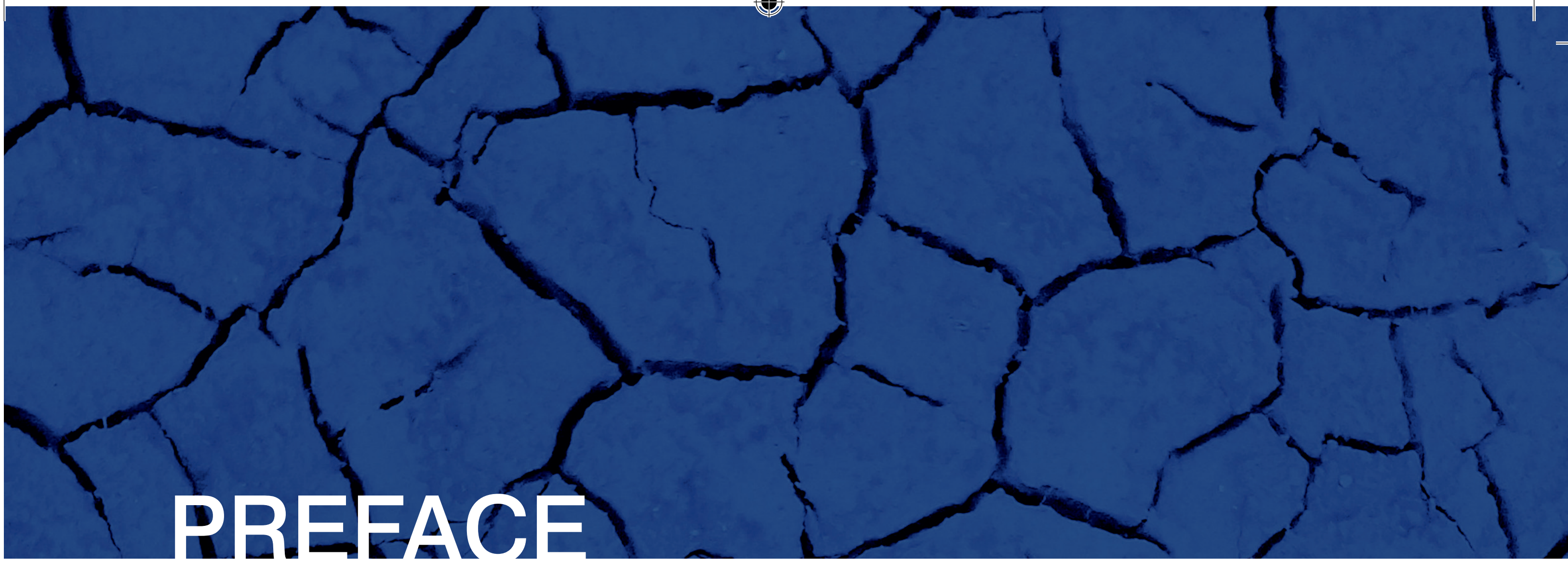
Wednesday, 25 October 2017, 8:15am – 7:00pm

Rydges Hotel, 186 Exhibition Street, Melbourne



AUSTRALIAN GEOMECHANICS SOCIETY
VICTORIA CHAPTER

CHADWICK
GEOTECHNICS



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.

ORGANISING COMMITTEE*

Daniel King (Co-chair)

Clare Bridgeman (Co-chair)

David Glover

Farshid Maghool

Vladimir Lopez Suarez

*a sub-committee of the AGS Victoria committee

SPONSORS

Platinum

Chadwicks Geotechnics

Gold

Global Synthetics Pty Ltd

Acciona Australia

Silver

Geofabrics Australasia Pty Ltd

TECHNICAL REVIEWERS

All technical papers in these proceedings, excluding the keynote addresses, were peer reviewed. The reviewers are acknowledged and listed below:

Daniel King (Technical Chair)

Greg Anderson

Clare Bridgeman

Don Cameron

Chris Coulson

Mahdi Disfani

Chris Haberfield

Jan Krestyn

Richard Kaser

Steven Lankshear

Jie Li

Ben Shannon

Justin O'Shea

Sri Srithar

Bill Tsoumbanos

Darshana Weerasinghe

Pavement design and construction in reactive clays

S. T. Srithar

Principal, Golder Associates Pty Ltd, PO Box 6079, Hawthorn West VIC 3122; PH (+61) 3 8862 3500; FAX (+61) 3 8862 3501; email: ssrithar@golder.com.au

ABSTRACT

One of the key parameters considered for pavement design in Australia is the subgrade CBR. In reactive clays the soaked CBR value is low and influenced by many factors such as moisture conditioning of the sample, variability within the sample, surcharge during soaking and duration of soaking. These clays are also prone to volume change with changing moisture condition, which is typically reflected as shape loss and cracking in overlying pavements. Measures such as provision of a low permeability capping layer, provision of minimum cover over the subgrade and moisture conditioning of the subgrade are provided to improve the long term performance of the pavements constructed on reactive clay subgrades. Preparation of reactive clay subgrades also generally encounter difficulties. This paper presents a review and discussion on the above issues. A method of assessment of the potential long term surface movements in pavements constructed in reactive clays is also presented and discussed.

Keywords: pavement, reactive clay, movement, swell, CBR

1 INTRODUCTION

The areas of northern and western metropolitan Melbourne and western Victoria are rapidly developing. The developments include upgrade of the existing road networks and construction of new roads. Considerable parts of these areas have reactive basaltic clays near the surface, which will form the subgrade of the pavements. The basaltic clays in Victoria are known to be highly reactive and undergo large shrink/swell movements when subjected to moisture changes. The basaltic clay sites are generally classified as ‘Class H’ or ‘Class E’ in accordance with Australian Standard AS 2870. The characteristic surface movements for Class H and Class E sites range from 40 mm to greater than 75 mm.

Srithar (2014a and 2014b) discussed the aspects related to engineering design and earthworks in reactive basaltic clays in Victoria. This paper focuses on pavement design and construction.

For the pavement design charts and methods adopted in Australia, the California Bearing Ratio (CBR) of the subgrade is one of the key design parameters. Even in detailed analytical pavement design methods such as that using the program CIRCLY, the subgrade resilient modulus values adopted are based on the CBR values. The resilient modulus values are typically assumed to be 10 times the CBR values.

In reactive clays, the soaked CBR value is relatively low and influenced by many factors such as moisture conditioning of the sample, variability within the sample, surcharge during soaking and duration of soaking, which are discussed in this paper. Other issues related to the long term performance of the pavements and subgrade preparation are also discussed.

2 PAVEMENT TYPES AND DESIGN

The pavement types used for roads in Australia can be broadly grouped into the following:

- Flexible pavements comprising unbound granular materials, which generally include a thin bituminous surfacing such as a sprayed seal or thin asphalt.
- Flexible pavements comprising deep strength or full depth asphalt pavement, which typically include a number of thick asphalt layers and in many instances, a cement treated crushed rock subbase layer.
- Rigid pavements comprising Concrete pavement, which includes many types of concrete pavements such as plain, jointed reinforced, and continuously reinforced.
- Semi-rigid pavements comprising interlocking block pavers over various types of bases and subbases.

The aim of this paper is not to discuss various pavement types and their design methods, but to discuss the design subgrade CBR which is one the design parameters for all pavement types.

The origins and development of pavement design charts and methods in Australia were discussed in Metcalf and Donald (1988), Jameson (1996) and Paul (1997). The pavement design charts in Australia were developed in the 1940s and based on empirical assessment of the performance of the granular pavements and correlating the thickness of the pavements to the CBR of the subgrade. It is understood that in the assessment, laboratory soaked CBR values of the subgrade were correlated with thickness of the pavements that failed and that performed satisfactorily. Soaking of the subgrade samples under a 4.5 kg (10 pounds) surcharge over 4days was used in the laboratory CBR tests.

Hence, the use of 4.5 kg surcharge load in a CBR test has a basis for assessing the subgrade stiffness and strength for granular pavement design using empirical charts. However, it may give conservative pavement design profiles for other types of pavements, designs of which are not based on an empirical assessment as the granular pavement.

Paul (1997) presented an assessment of the performance of the deep strength asphalt pavement constructed between 1971 and 1995 at 14 sites in Victoria. Predicted pavement lives based on falling weight deflectormeter testing were higher than the original design lives for all pavements. He has indicated that there could be a number of reasons for this. One of the reasons was that the in-situ CBR of the subgrade was found to be higher than the design subgrade CBR based on 4 day soaked CBR test.

This suggests that use of an appropriate surcharge load representing the actual pavement thickness rather than the nominal 4.5 kg would provide a reasonable design subgrade CBR for deep strength asphalt pavement design. This aspect is further discussed in this paper.

3 CBR TEST

The CBR test is a simple test to evaluate the stiffness and strength of soil. The test involves pushing of a plunger of standard area into a prepared soil sample at a constant rate. The force (load) required to push the plunger is recorded against penetration and the information is plotted on a standard graph. The load penetration curve is analysed and the load to cause certain penetrations (2.5 mm and 5.0 mm) are obtained and the CBR is calculated by dividing the load by a standard load.

The CBR sample preparation in the laboratory involves moisture conditioning of the sample to have a nominated moisture content and then compacting the sample in a specific mould to achieve a nominated density. If soaking is required, then the prepared sample is placed in water for a nominated time period, often with a nominal surcharge (weight) placed on top. The swelling of the sample during the soaking period is measured, if this information on swell is required.

The Australian Standard AS 1289.6.1.1 sets out the procedure for the CBR test. Some local road authorities also set out other particular requirements for the assessment of the CBR. For example, the VicRoads Code of Practice RC500.20 requires that the CBR samples are moisture conditioned to be within 95% to 105% of the Standard Optimum moisture content, compacted to be within 97% to 99% of the Standard maximum dry density and soaked under a 4.5 kg surcharge. The duration of soaking is not explicitly specified, but as it refers to AS 1289.6.1.1, the standard soaking period of 4 days indicated in AS 1289.6.1.1 is generally adopted.

Rallings (2014) presented a critical review of the CBR test. He has indicated that based on a NATA's proficiency test program involving about 50 laboratories, it was found that even on nominally homogeneous crushed rock products, over 40% of the results were outside ±30% of the average value. He argued that the CBR test has poor reproducibility and repeatability and continuing reliance on CBR hinders the development/advancement of pavement technology.

As indicated earlier, factors such as moisture conditioning of the sample, variability within the sample, surcharge during soaking and duration of soaking will have an impact on the CBR test results in reactive clays. For subgrades with low CBRs, a 1% difference in the design subgrade CBR may have a considerable impact on the pavement design and overall cost of pavement construction as the pavement extends over many kilometres. For example, the difference in the thickness of granular pavement designed for a highway traffic loading of 1×10^7 equivalent standard axles for a subgrade CBRs of 2% and 3% will be about 145 mm.

3.1 Natural variability

Variability occurs in almost all natural materials. The typical CBR values obtained on basaltic clay samples compacted to 98% Standard dry density ratio at Standard optimum moisture content and soaked for 4 days under 4.5 kg surcharge vary from 1% to 4%. The typical swell values obtained during soaking vary from 2% to 6%.

In the residual basaltic clays the natural variabilities include the presence of sands and gravels in addition to the variations in the mineralogy. Presence of small amounts of sands and gravels within the CBR sample can result in high CBR values and low swells. CBR values greater than 6% and swell values lower than 1.5% have been reported for some basaltic clay samples.

3.2 Moisture content

The CBR sample preparation in the laboratory involves moisture conditioning of the sample. Having the same moisture content throughout the sample is a very important factor in the CBR test of reactive clay sample. If the first layer placed in the CBR mould has a different moisture content compared to the entire sample, it could result in unrepresentative swell and CBR values. The Australian Standard for CBR test (AS1289.6.1.1) states that a curing time of at least four days will be required for preparation of high plasticity clay CBR test samples. This is in addition to curing times for compaction test to establish optimum moisture content etc.

A comprehensive assessment of the effect of placement moisture content and density on CBR and swell of basaltic clays in Victoria was presented in Hillard (1981). Figure 1 provides a summary of the behaviour observed in basaltic clay in the area of Melton Bypass of the Western Freeway, which is considered to be typical of basaltic clays in Victoria.

As illustrated in Figure 1, the Standard optimum moisture content of the basaltic clay tested is about 32% and the maximum dry density is about 1.37 t/m^3. If a sample compacted to a dry density ratio of 98% Standard at a moisture content wetter than the Standard optimum may give a CBR of about 2% and a swell of less than 4%. However, if the sample is compacted to the same dry density ratio at 29% moisture content (i.e. moisture ratio of about 90% of Standard optimum), it would show a CBR of about 1% and a swell of about 5.5%.

Even if the sample is compacted to a higher dry density ratio, but at a moisture content much drier than Standard optimum, it would show a lower CBR and higher swell. For example, a sample compacted to a

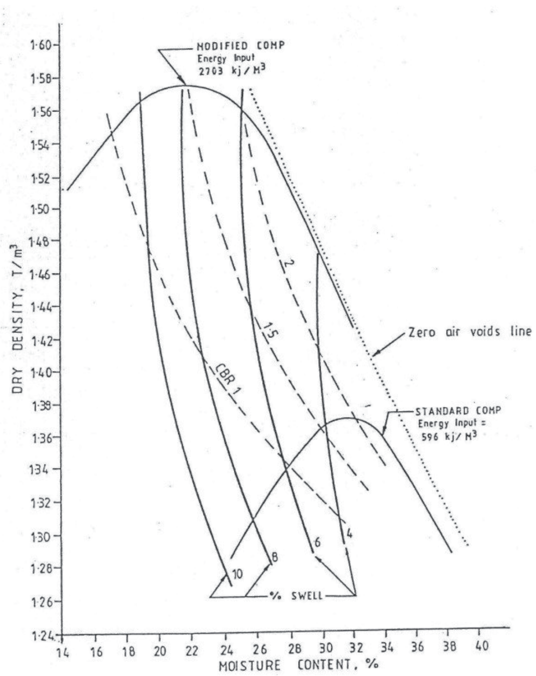


Figure 1. Effect of moisture content and density on CBR and swell (source – Hillard, 1981)

dry density ratio of about 115% Standard at a moisture content 8% drier than Standard Optimum (i.e. sample compacted with modified effort) would show a CBR of about 1% and a swell of about 8%.

3.3 Surcharge

AS1289.6.1.1 indicates that the surcharge applied during soaking of the CBR sample may need to simulate the confining effects of the overlying material layers.

For pavement layers with a total unit weight of about 20 kN/m^3, the typical surcharge loads applied during the soaking of the CBR sample and their representative pavement thickness are summarised in Table 1.

Figures 2 and 3 show the effect of the surcharge load during soaking on basaltic clays. The six test samples were compacted to a dry density ratio of about 98% Standard at moisture ratios ranging from 90% to 95% of Standard optimum. Six different symbols in the graphs represent different samples. Generally, the earthworks specification requires the materials be moisture conditioned to be within 90% to 100% of Standard optimum. The purpose of these tests was to assess the effect of surcharge load on samples compacted at a moisture content similar to that adopted in the field. The higher surcharge load during soaking resulted in lower swell and higher CBR values.

Table 1. CBR surcharge loads and representative pavement thickness

Surcharge load (kg)	Representative pavement thickness (mm)
4.5	130
9.0	250
13.5	370
18.0	490

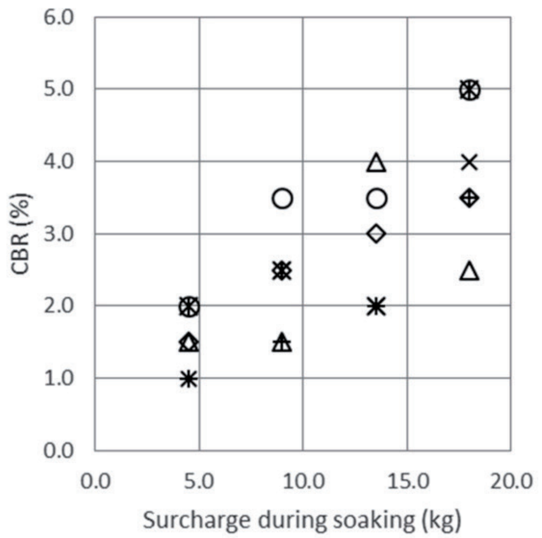


Figure 2. Effect of surcharge during soaking on CBR

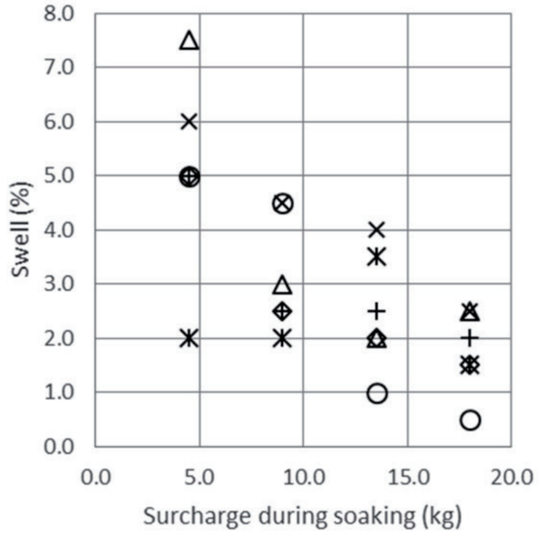


Figure 3. Effect of surcharge during soaking on swell

For pavements with thick asphalt layers and thickness greater than 500 mm, which are designed using detailed analyses such as using the program CIRCLY, the use of a design subgrade CBR obtained with 4.5 kg surcharge will provide a conservative design.

For example, based on Figure 2, for a deep strength asphalt pavement with a total thickness exceeding 500 mm thick, a design subgrade CBR of 3% is more realistic rather than 2%. For a deep strength asphalt pavement design for a traffic loading of 1×10^7 equivalent standard axles, if a design subgrade CBR of 3% rather than 2% is adopted, then the asphalt thickness can be reduced by about 20 mm.

3.4 Soaking period

In some projects, longer duration of soaking (generally 10 days) are specified for CBR testing. This is reasonable for cases, where the project area can be subjected to sustained wetter climate, poor drainage or flooding. However, if a realistic CBR is to be obtained, then realistic surcharge load representing the pavement thickness should be applied along with the longer surcharge period.

Soaking of the CBR sample for a period longer than 4 days will result in higher swell and lower CBR. During soaking of the CBR sample, the ingress of moisture will occur from the top and bottom of the sample and if the sample is soaked for a longer duration, the moisture ingress will extend deeper within the sample. It is possible that there may be a cut-off soaking period, when the upper part of the sample influencing the CBR and swell results reaches the full effect of moisture ingress and further soaking beyond this period may have negligible effects on the CBR and swell results. This cut-off soaking period may depend on the permeability of the CBR sample.

The author was involved in a highway construction project in western Victoria in basaltic clay subgrades, where more than 20 No. 4-day and 10-day soaked CBR tests with 4.5 kg surcharge were carried out on samples obtained over about 5 km section. The average CBR for the 10-day soaked tests was 1.5% and that for the 4-day soaked tests was 2%. The average swell for the 10-day soaked tests was 4% and that for the 4-day soaked tests was 3%.

4 SUBGRADE PREPARATION

The natural equilibrium moisture content of the basaltic clays in Victoria is generally close to the Standard Optimum moisture content. Considering the effect of placement moisture content on strength and swell and the natural equilibrium moisture content, for earthworks involving basaltic clay in Victoria, it is preferable that the placement moisture content to be within ±2% of the Standard optimum. A minimum dry density ratio of 98% Standard is generally specified for road subgrade materials.

Testing of earthworks to ensure that the specified compaction level is achieved is carried out using field density testing supplemented by test rolling. The performance of the prepared subgrade under test rolling will depend on the shear strength of the subgrade materials.

Undrained shear strengths obtained from laboratory vane shear and pocket penetrometer tests carried out on Standard compaction test samples and soaked CBR test samples (compacted to 98% Standard dry density ratio) of basaltic clays from three project sites in Victoria are shown in Figure 4. The results show that there is a noticeable reduction in shear strength when

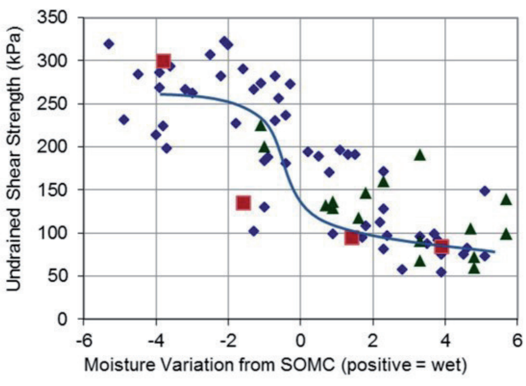


Figure 4: Variation of undrained shear strength (at 98% Std. dry density ratio) with placement moisture content

the placement moisture content is wetter than the Standard optimum moisture content.

4.1 Test rolling

In accordance with Australian Standard AS 3798, test rolling is considered to be satisfactory when no visible deformation or springing is observed when a compacted layer is subjected to one of the following vehicle/equipment movement:

- Static smooth steel wheeled roller with a mass of not less than 12 t and a load intensity under either the front or rear wheels of not less than 6 t/m width of wheel.
- Pneumatic tyred plant with a mass of not less than 20 t and a ground contact pressure under either the front or rear wheels of not less than 450 kPa per tyre. The area over which this ground contact pressure is applied should be not less than 0.035 m^2 per tyre.
- Highway truck with rear axle or axles loaded to not less than 8 t each with tyres inflated to 550 kPa.

Generally a highway truck (loaded water cart) is used for test rolling and achieving a satisfactory test roll is often difficult in basaltic clays immediately after placement, although the field density tests would indicate the specified minimum dry density ratio of 95% or 98% Standard has been achieved. The undrained shear strength of the basaltic clay placed close to Standard optimum moisture content is expected to be in the range of 100 kPa to 150 kPa and hence the ultimate bearing capacity of the compacted basaltic clay fill is expected to be in the range of 600 kPa to 900 kPa. The factor of safety for bearing failure for an applied loading of 550 kPa (i.e. required tyre pressure) will in the in the range of 1.1 to 1.6 and this is generally reflected as surface deformation or springing. Springing during test rolling is typically a reflection of the presence of a weaker layer below the surficial layer, which can occur if the underlying layer had been exposed to rainfall or moisture ingress.

The lower strength of the high plasticity clays is recognised in the Texas Department of Transport (TxDOT) guide for selection of test rolling stress level, which is presented in Figure 5. For high plasticity clays, a tyre pressure of about 275 kPa (40 psi) is recommended, which is about 50% of the minimum tyre pressure indicated in AS 3798.

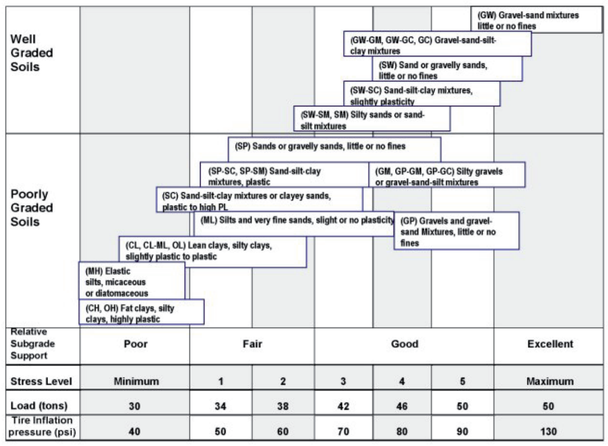


Figure 5: TxDOT Guide for selection of initial proof rolling stress level.

As the high plasticity clays placed at a moisture content close to Standard optimum would have lower strength compared to other soil types, it is important to consider the type of construction equipment to be used for test rolling in earthworks in these clays. Lighter construction equipment with low applied stress level is preferable for earthworks involving high plasticity clays.

5 PAVEMENT PERFORMANCE

The performance of the pavements constructed on reactive clay subgrades will depend on the moisture condition of the subgrade materials at the time of pavement construction and the changes in moisture during the life of the pavement. Figure 6 shows the potential moisture movements that can occur in road pavements.

The Austroads (2012) pavement design guide recommends the adaptation of some or all of the following measures to minimise volume changes in reactive clays:

- Construct the subgrade or fill materials at a time when its soil suction (ability of a soil to attract moisture) is likely to be near the long term equilibrium value.
- Compact the soil at its equilibrium moisture content.
- Provide a low permeability lower subbase or select fill capping layer above the expansive soil. The minimum thickness of the capping layer should be 150 mm. This capping layer should extend at least 500 mm past the edge of the pavement, and if provided, past the kerb and channel, to reduce edge movement.
- Provide a minimum cover of material over the expansive soil. Material used to provide this cover should have swells less than 1.5% for the top 300 mm and less than 2.5% for the remaining thickness and be placed at an appropriate moisture content to remain within this limit. The required thickness of cover increases with the traffic loading to reflect the better ride quality required on high traffic volume roads.
- Ensure that the location of pavement drains does not extend into the expansive soils.
- Restrict the planting of shrubs and trees close to the pavement.
- Provide through appropriate design of the cross section of the road, sealed shoulders and impermeable verge material. A seal width of 1 m to 1.5 m is required outside the edge of the traffic lanes to minimise subgrade moisture changes under the outer wheel path.
- Use appropriate construction techniques when placing the expansive soil.
- Incorporate lime stabilisation to reduce the plasticity and increase the volume stability of the upper layer of the expansive subgrade.

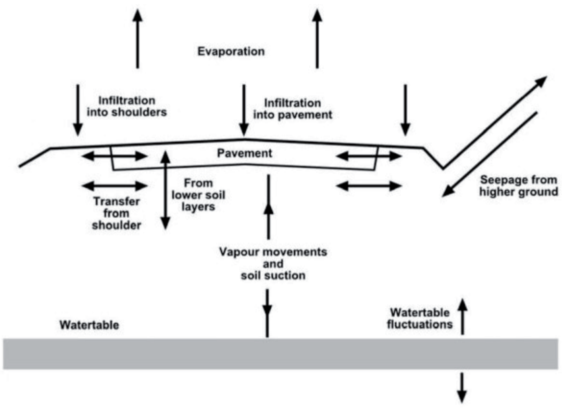


Figure 6: Potential moisture movements in road pavements (source: Austroads, 2012)

It should be also noted that the soaked CBR test provides only an indication of the potential subgrade material behaviour. The real behaviour of the subgrade materials will depend on the location of the subgrade below the finished surface (i.e. pavement thickness) and the actual moisture changes in the materials in the future. If defensive measures against moisture changes such as provisions of pavement drains, a capping layer and a sealed shoulder and verge are incorporated into a pavement design, it will greatly reduce the potential moisture changes.

5.1 Pavement surface movements

With regard to the impact of the shrink/swell movements of the subgrade on the performance of the pavement, it is the differential movements that need to be considered rather than the total movements. VicRoads specifications for road projects requires a maximum lane roughness value of about 2 (i.e. 40 mm level difference over a 20 m section) for ride quality.

A quantitative assessment of the potential long term shrink swell movements in the subgrade soil could be made using the method of assessing the characteristic surface movement for a site as outlined in Australian Standard AS 2870. For this assessment, the pavement surface will need to be assumed as the ground surface. The potential pavement surface movement will be due to the shrink/swell movement of reactive clay subgrade materials below the pavement to the maximum depth of soil suction change provided in AS 2870 for various climate zones.

For example, based on the above method, for a 700 mm thick pavement constructed on a basaltic clay subgrade with a shrink-swell index of 4, one would estimate a potential pavement surface movement of about 30 mm. The differential movement over a 20 m length could be assumed as 50% of the total movement. However, it should be noted that this method of assessment is for an open ground with free moisture ingress. The characteristic surface movement of open ground of a basaltic clay site with a shrink-swell index of 4 would be about 60 mm. The presence of a sealed pavement which sheds water to the pavement edges and provision of a capping layer are expected to result in a significantly more stable moisture regime within the subgrade materials than has been assumed in the calculations. The actual pavement surface movements could be less than half of that estimated using the method outlined in AS2870.

Midgley (1987) presented results of monitoring of surface movements of pavements constructed on basaltic clay subgrade with a lime stabilised capping layer over a period of two years between 1983 and 1985. The total thickness of the pavement was 730 mm, which included a 180 mm thick lime stabilised capping layer.

The monitored pavements include pavements constructed on subgrades compacted at a moisture content 15% drier than Standard Optimum, which showed a swell of about 8% in the CBR test. The observed pavement surface movements were mostly less than 4 mm compared to about 30 mm surface movements observed in the open ground.

6 CONCLUDING REMARKS

In reactive clays, the soaked CBR value is typically low and can be influenced by many factors such as moisture conditioning of the sample, variability within the sample, surcharge during soaking and duration of soaking. Use of standard 4.5 kg surcharge during soaking can provide conservative CBR values, in particular pavements that are not designed using empirical charts.

The requirements for equipment to be used for subgrade test rolling as documented in AS 3798 may be severe for high plasticity clays, which exhibit lower strength. Lighter equipment with lower tyre pressures can be used for test rolling of lower strength clays.

ACKNOWLEDGEMENTS

The author would like to thank Mr Doug Goad of Golder Associates Pty Ltd for his review of the paper. The views expressed in this paper are the views of the author and do not reflect the views of his organisation.

REFERENCES

Australian Standard AS 2870. “Residential slabs and footings”. Standards Australia, 2011.

Australian Standard Australian Standard AS 3798. “Guidelines on earthworks for commercial and residential developments”. Standards Australia, 2007.

Austroads (2012). “Guide to pavement technology – Part 2: Pavement structural design”.

Jameson, G.J. (1996). “Origins of Austroads design procedures for granular pavements”. ARRB Research Report APR292.

Hillard, P. (1987). “Western Freeway – Melton Bypass Section, lime stabilisation of the clay subgrade”. Road Construction Authority, Victoria, Materials Division Report No. 18X429.

Midgley, L.H (1987). “Special construction techniques to improve the performance of pavements constructed on expansive clays”. Internal technical report, Road Construction Authority, Victoria.

Metcalf, J.B. and Donald, G.S. (1988). “Road pavements in Australia”. 14th ARRB Conference, Part 1, pp 47-68.

Paul, R. (1997). “Development in the design and construction of deep strength asphalt pavement in Victoria over the past 25 years”. 10th AAPA International Flexible Pavements Conference, Paper No. 39.

Rallings, R. (2014). “CBR test – A case for change?”. Aust. Geomechanics J., Vol. 49, No. 1, pp. 41-55.

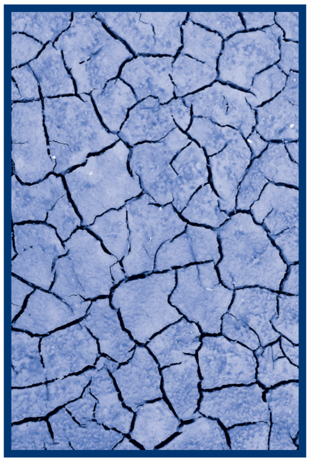
Srithar, S. T. (2014a). “Engineering design and earthworks aspects related to basaltic clays in Victoria”. Aust. Geomechanics J., Vol. 49, No. 2, pp. 1-14.

Srithar, S. T. (2014b). “Reply to discussion on paper - Engineering design and earthworks aspects related to basaltic clays in Victoria”. Aust. Geomechanics J., Vol. 49, No. 4, pp. 199-201

TxDOT. “Guide for selection of initial proof rolling stress level”. Texas Dept. of Transport, 2002 (available from http://ftp.dot.state.tx.us/pub/txdot-info/cmd/tech/103101a.pdf, sited in December 2013).

AGS VICTORIA 2017 SYMPOSIUM

Reactive clays and light structures



AUSTRALIAN GEOMECHANICS SOCIETY
VICTORIA CHAPTER