



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



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



AUSTRALIAN
GEOMECHANICS
SOCIETY



Foundation
& Footings Society
(VIC) Inc.



ENGINEERS
AUSTRALIA

Keynote Address

Dealing with expansive clay soils through a national standard

D. A. Cameron

Adjunct Associate Professor, RMIT University, School of Engineering, Melbourne, VIC 3000; email: donald.cameron@unisa.edu.au

ABSTRACT

Australia has had a national standard for site classification and design of footings for reactive soils for nearly 30 years. From the outset, the Standard, AS2870, has implemented a simple rational model for quantifying reactive soil foundation movement. The parameters of the model have from necessity been calibrated against empirical observations. The philosophical approach adopted in the Standard envisages that footing designers, builders and homeowners all have parts to play in managing sites on reactive soils. This paper reviews the background to the Standard and its development over time. The paper presents the site classification process, tests to quantify reactive clay reactivity, design suction changes, the Thornthwaite climate index, the impact of trees on footing design and current practice. Examples are provided of ground movement calculations for normal site classification, classification adjusted for reactive soil fills and tree-drying settlement. Research areas which are needed to improve the Standard are discussed.

Keywords: soil reactivity, soil suction, site classification, ground movement, tree-drying settlement

1 INTRODUCTION

Australia is fortunate in that it is probably the only country that has a coordinated national approach to dealing with the problem of expansive soils. The term “expansive” soil is still in common use although it does not address soil shrinkage directly, which can be just as important as soil expansion or swelling. Therefore these soils are better described as “reactive” (to change in moisture state) and that property when quantified is termed “soil reactivity”.

Approximately 20% of the surface area of the Australian continent is comprised of reactive clay soil. Reactive soils occur in most of the State capital cities, including Adelaide, Melbourne and to the west of Sydney and Brisbane. Many rural centres are also underlain by reactive soil.

1.1 Reactive clays in Australia

The most well-known reactive soil deposits in Australia near large populations are derived from basalts, such as the montmorillonite-rich residual Quaternary basaltic clays formed over sheet flows in the Western and Northern suburbs of Melbourne. In Adelaide, the fluvial Pleistocene clays (Keswick and Hindmarsh clays) have less active clay minerals, and thus can be less reactive to changes in moisture than the Melbourne basaltic clays, but it is well known that these soils cause more trouble, owing to the greater depth of soil suction changes experienced in Adelaide’s typically semi-arid climate.

Identification of reactive soils is possible by evaluating soil plasticity. However, soil reactivity to moisture change is commonly quantified by direct testing of changes in sample length with suction change, as discussed in a later section of this paper. Soil reactivity may be defined as the axial strain of the soil sample per unit logarithm of suction pressure change. That property, when representative of the axial strain of a laterally unrestrained sample is termed the

shrinkage index, I_{ps} . The term “shrinkage” index is not ideal as it is meant to include swelling behaviour as well as shrinkage.

In this paper, a simpler measure of suction will be used because of its familiarity to an Australian audience: the pF unit is equivalent to the logarithm of suction in kPa plus 1.01. So, a suction of 100 kPa is equivalent to 2 log kPa or 3.01 pF.

1.2 Climate in Australia

The climate across continental Australia is quite variable. The Thornthwaite Moisture Index or TMI has been used by agronomists, and more recently by engineers, to characterize the differences in climate across the continent; an early example of a TMI map for Australia by Aitchison (1970) is shown in Figure 1. To the author’s knowledge a more recent revision of the national map has not been published. The first inclusion of a TMI map in the Residential Slabs and Footings Standard was in the 1996 edition (Standards Australia, 1996), which included a map for the state of Victoria. The map was included to assist the site classification process for that State, which experiences substantial climate differences across the widespread suburbs of its capital city, Melbourne, and up to the North West of the State, where quite semi-arid conditions are experienced. In this edition of the Standard, TMI was linked for the first time to the potential depth of moisture change and therefore to the extent of ground movement. TMI is discussed in more detail in a later section.

1.3 Standards relating to reactive soils

For over 30 years, Australia has had a standard for the classification of reactive soil sites for residential footing design and construction purposes. The current version of the Standard is Standards Australia, Residential Slabs and Footings AS2870 – 2011.

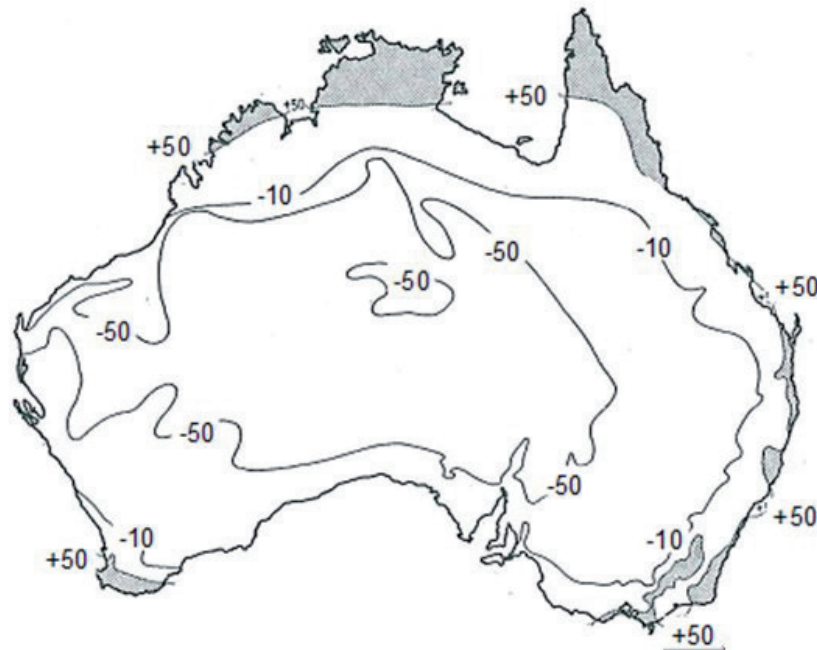


Figure 1. Thornthwaite Moisture Index distribution (Aitchison 1970)

Earlier editions were Standards Association of Australia, 1986, 1988 and 1990, and Standards Australia, 1996. The Standard will be referred to hereafter simply either as AS2870 or “the Standard”.

AS2870 arose out of the need to control different practices across States and to lessen the burden on the community of the costs of damage to lightly-loaded low-rise structures (primarily houses) on reactive clay foundations. A further impetus was the loose definition of damage then circulating in the courts, which could deem quite minor cracking as significant, all of which could deleteriously affect designers of footing systems. Costly court cases were held over quite minor damage and engineers acting as expert witnesses were criticizing and discrediting other engineers on the basis of widely different opinions about how reactive soils could be identified and managed. Differences were evident across the States and existed even down to local government level. A uniform national approach to the reactive soil problem was needed. It is generally agreed that the Standard has been beneficial in bringing consistency and rigor to the housing industry.

1.4 Standards relating to reactive soils

AS2870 (Standards Association of Australia, 1986), was the first standard to deal with reactive soils. The Standard was predominantly concerned with the design of shallow footing systems on reactive clay sites, however some guidance on piles and pier elements and systems has since been included. In 1986, the author joined committee BD25 responsible for drafting the Standard, to provide geotechnical advice, and he remains a member of BD25. Three revisions to the Standard have been made in 1988/1990, 1996 and 2011. Standards Australia requires periodic revisions of standards, and some of the changes that have been made to the Standard have arisen from conflicting opinion within the building industry about who is responsible for what. Another reason for revision has been the changing style of

housing. At the time of the first release of the Standard, houses on single allotments with yard space all around were normal, whereas smaller allotments with construction right up to boundaries is now more common. Originally, masonry and masonry veneer and clad frame forms of construction were the norm, but now there are innovations with new forms of wall construction, which may have less tolerance to differential movement. As well, the range of house sizes has expanded since 1986.

1.4.1 Overview of the Standard

AS2870 provides for the following in relation to reactive soil sites:

- Sites are classified according to ranges of surface movement potential.
- The classification can be by assessment of existing building performance or by assessment of characteristic surface movement potential, either by recognition of a known soil profile or by investigation and quantification of the soil profile and properties.
- Simplified suction change profiles are prescribed for use in the assessment of characteristic surface movement.
- The deflection tolerances of various common forms of building construction, particularly wall types, are defined.
- A 2D beam-on-mound design approach is defined along with parameters that define the mound characteristics. The design requirement is to limit the beam deflection to within the tolerance of the superstructure type.
- Importantly, the Standard also allows various forms of deemed-to-comply reinforced concrete raft slab and strip footing designs to be created, without recourse to structural design calculation, using only tables of beam sizes and reinforcement details, and rules for laying out the stiffened raft or gridded strip footing system.
- A scheme for the classification of the damage in buildings from foundation movement is provided and

the expected performance of designs complying with the standard is defined. Importantly, it is recognized that complying designs may suffer some level of damage, which will usually be cosmetic.

- A method is provided in an informative Appendix for estimating the exacerbation of reactive soil movement caused by the water demand of nearby trees and for taking that into account in the design of the footing system.
- Another informative Appendix provides guidelines for design and construction of deep footings which are additional to the Australian Standard for pile design and installation (Standards Australia, 2009).

The crux of the Standard's approach to the classification of reactive clay sites is the estimation of a design characteristic surface movement. To that end, standard test methods were drafted for determining total soil suction and for evaluating the soil response to suction change (reactivity) for the estimation of ground movements. This guidance on testing was later expanded and transferred to separate standards within the Standard for Testing of Soils, AS1289 (Standards Australia, 1998a, b and c, and 2003).

Guidelines were developed for the magnitude and depth of suction change to be used for design purposes. The design suction change profiles were simple approximations to what had been found from site investigations in populated centres, and were based on the underlying ground movement extremes that might occur as result of building a house on a Greenfield site throughout the prescribed design life of 50 years. Seasonal soil movement is only a component of this movement. Converting fields to housing allotments produces unavoidable soil moisture re-distribution below the footprint of a house. The 50-year characteristic ground movement, y_s , leads to a classification of the site as one of six possibilities ranging upwards through A, S, M, H1, H2 and E. The y_s estimate is then used to evaluate the potential unloaded differential mound movements, y_m , that are expected within the footprint of the footing system as a result of non-uniform changes in the soil moisture regime subsequent to construction.

It is assumed in AS2870 that the worst construction condition prevails, that is, a seasonally dry soil profile. Moisture re-distribution will, over subsequent wet seasons, produce edge heave, or dishing, under a raft slab and eventually, as moisture is drawn and captured below the slab, centre heave (hogging deflection) in later dry seasons.

The Standard embodied much empiricism, particularly in the calibration of parameters, as there was little theoretical development or research data available at that time to inform committee BD25. Empirical guidelines were derived from the experiences of researchers and practitioners. For example, the relationships between y_m and y_s , and the mound shape parameters, are empirical, being based largely on the cover experiments reported by Holland (1978). The design of the footing proceeds with these parameters. The design procedure has not developed significantly since the inception of the Standard. It remains as the design of an equivalent beam interacting with a reactive soil mound, in order to limit

the deflection of the beam to values that are tolerable to the superstructure.

A raft slab design is based on separately considering the major rectangular elements of the house plan, which overlap to form the whole plan. The design aim is to provide sufficient stiffness in the regular grid of beams across the slab in order to keep the deflection of the system within the tolerance of the particular form of wall and superstructure construction. In the interaction of the notional beam with the mound, the stiff beam has the effect of suppressing some of the free (unloaded) mound height, y_m , and along other parts of the beam, lift-off from the mound may occur.

Given the approximations inherent in the process, the worst case rules the design of the whole house. So, for example, if one of the overlapping rectangles requires deeper beams for centre heave, in that case all beams over the entire raft slab will be of that same depth. The design must meet three criteria; adequate footing stiffness and flexural strength, and sufficient section ductility. The latter requirement is intended to avoid rupture of the raft section and to allow some possibility of reversal of deformation. For example, if poor site management leads to excessive foundation movement, this may later be reversed by attention to the management issue (e.g. leaking drains).

The Standard in 1986 adopted a number of philosophies to counter the rising costs of court cases. Performance expectations were established for footing designs in compliance with the Standard. Accordingly, a guide to assessment of damage to walls and floors was drawn up, which was based in large part on the state of the art report on the settlement of structures by Burland and Wroth (1974). Slight damage (wall cracks < 5 mm) was deemed to be acceptable in adverse situations, although it was recognized that it should be a relatively rare occurrence for properly investigated sites and well-designed footings.

In addition, it was recognized that post-construction site management was vital and was akin to keeping a car running in good condition. The owners could choose to follow the site management recommendations to keep their house in good order, or not, and accept the possible consequences. Good site practices were recommended for post-construction management, for those owners who had footings designed according to AS2870. A pamphlet, written in simple language for homeowners on reactive soil sites, is distributed by builders and design engineers to communicate limitations of the design and the need to maintain sites on expansive clays. If homeowners chose not to accept these recommendations and limitations (and therefore put the building outside the scope of the Standard), they could ask for an upgraded footing design with greater performance expectations, albeit, at higher construction cost.

2 IDENTIFICATION OF REACTIVE SOILS

In most geotechnical engineering offices around the world, much reliance is placed on Atterberg limits for soil identification, particularly for reactive soils. Practitioners in local areas use various schemes

based on soil plasticity, an example of which is given in Table 1 (unpublished data). The shrinkage index, I_{ps} in the last column is soil reactivity as defined by AS2870, i.e. the vertical strain arising from a change of a soil's total suction by one pF, for a laterally unrestrained soil with minimal external vertical loading. In this paper, "reactivity" to moisture change will be used synonymously with shrinkage index. However, such simple soil classification schemes are often found wanting, as will be discussed in the next section.

2.1 Standard Soil Test Methods

The measurement of suction is largely reserved for investigations of damaged structures, preliminary design of highway structures and for research, rather than for routine site classification. The standard test method for total soil suction (Standards Australia, 1998a) has been written around the evaluation of dew point temperature with Wescor laboratory equipment within controlled laboratory conditions using thermocouple hygrometer chambers, although other methods may be employed. A laboratory with reasonable temperature control is required for measurement of total suctions in the approximate range of 150 to 7,000 kPa (3.3 to 4.95 pF) using the dew point measurement method, a method which is not as sensitive to temperature variations as the psychrometric approach. As with all vapour transfer methods, the accuracy of suction measurement falls away below 500 kPa (3.7 pF).

More recently, valuable experience has been gained in Australian laboratories with Decagon's WP4 and WP4C chilled mirror devices for measurement of dew point temperature and hence total suction. The WP4, or the more recent WP4C device, is claimed to be able to measure a far greater range of suction in faster time than the Wescor dew-point equipment that preceded it. It would seem that the standard test method for measuring total suction should be revised based on this experience. Although the measurement range is greater, quoting from the manual for the WP4C, "The range of 0 to (-)5 MPa has an accuracy of 0.05 MPa", which suggests that suctions less than 500 kPa (3.7 pF) cannot be reliably determined within $\pm 10\%$. The revised standard should recommend against fast mode readings which would further reduce accuracy and should also encourage regular checks of calibration.

Methods exist to measure or estimate the components of total suction. Matric suction may be determined using the filter paper absorption technique with appropriate filter papers in good contact with the soil, while solute suction can be estimated from electrical conductivity of soil water solutions (Department of Sustainable Natural Resources, year

of publication unknown). Both these methods of suction determination should be considered by Standards Australia.

The standardized tests for reactivity, namely shrink-swell, loaded shrinkage and core shrinkage (Standards Australia, 2003, 1998b and 1998c are the current versions) filled a practical need at the time and should be developed with further research. All three tests methods are designed to determine the shrinkage index for a soil. The soil samples for testing are typically obtained by thin-walled tube samplers. Of the three test methods, only the shrink-swell test permits assessment of both swelling and shrinking, and as such, it is more favoured. The other two tests concentrate on shrinkage, and so the range of moisture change and strain measured in the test may be relatively small if a sample is taken in a fairly dry condition.

The shrink-swell test was modified from a test proposed by Coffey and Partners (1984) in NSW. The test requires two "companion" samples of soil so that a core shrinkage test and a swell test may be conducted separately. The samples are assumed to have the same initial suction. In the swell test, the sample is placed in a confining ring with porous platens top and bottom of the sample, a nominal vertical pressure of 25 kPa is applied and usually distilled water is added to the soil to make it swell. The soil must be allowed to swell inside the sample ring to avoid soil dispersion and under-estimation of soil heave.

The measured swelling strain, ϵ_{sw} , is divided by 2 to correct for full lateral restraint, although a factor of 3 would apply if the behaviour was purely elastic. Fityus (1996) tested two clays from Newcastle, NSW, which were remoulded over a wide range of moisture contents. To achieve a consistent shrink-swell index for each soil, he found that the swelling strain should be divided by 1.9 and 2.2, suggesting that the value of 2 as adopted in the standard is appropriate. Puppala et al. (2014) tested unrestrained specimens undergoing swell and observed that the axial swell strain was about half the volumetric swelling strain, providing further evidence for the adoption of a factor of 2.

The core shrinkage part of the shrink-swell test is conducted on a laterally unrestrained and unloaded cylinder of soil. The soil sample is left to air-dry and is eventually oven-dried. Some care is required to avoid too rapid drying, particularly of highly reactive samples, otherwise severe cracking of the sample may occur. Changes in both the length and the sample mass are monitored with time, although the maximum shrinkage strain after oven drying, ϵ_{sho} , is all that is required for the shrink-swell index

Table 1: Example of assessment of soil

Unified Soil Classification	Plasticity	Plastic Index (%)	Shrinkage Index I_{ps} (% strain/ pF)
CL	Very low to low	0 – 10	0 - 1
CI	Low to medium	10 – 30	1 - 2
CH	High	30 – 45	2 – 3.5
CH ^a	High	45 – 60	3.5 - 5
CH ^a	Very high	> 60	> 5

^a In the Australian version of the Unified Soil Classification, CH is unfortunately the highest classification

The total strain is the sum of the maximum shrinkage strain, ε_{sho} and the corrected swelling strain, ε_{sw} . In order to obtain the swell-shrink index, the total strain is divided by an assumed suction change, which is representative of the suction change over the linear part of the strain-suction change relationship. A value of 1.8 pF has been assumed, although it has been suggested by some researchers that a value of 2.0 pF may be more appropriate and less conservative. Beal (2009) indicated from his innovative controlled suction experiments on small core samples that it could be as high as 2.2.

A great advantage of the shrink-swell test is that it does not require measurement of suction whereas the other two methods do. In the loaded shrinkage test, the initial suction is measured and then the spring-loaded specimen is conditioned over copper sulphate solution in a vacuum desiccator to obtain an end total suction (≈ 4.5 pF), which can then be confirmed by direct measurement of the sample suction. Mass equilibration can take 8 weeks or more; so the method is more suited to research.

The core shrinkage test (Standards Australia, 1998b) requires measurement of initial suction, and since the sample is air-dried, the total suction at the end of this conditioning is too high to measure by the dew point method. Instead, an estimate of the relationship between suction and moisture content is needed, which may be obtained by conditioning small sub-samples in vacuum desiccators over various salt solutions. Alternatively, an assumption may be applied concerning the hypothetical value of suction at zero moisture content by extrapolation of the linear portion of the suction - moisture content plot. The value used in Adelaide is 6.8 pF. Beal (2013) proposed that the total suction imposed by an oven operating at 107.5°C depended upon the ambient atmosphere, and so the oven dry suction could range between 6.82 and 6.98 pF. The lower limit corresponded to an ambient temperature of 30°C and a relative humidity of 60%, suggesting that the assumption of 6.8 pF may be slightly low.

Cameron (2010) showed that the correspondence between core shrink indices (determined using the assumption of an end suction of 6.8 pF) and shrink-swell indices were reasonable up to values of at least 4 %/pF. Shrink-swell index tended to be higher as the shrinkage index approached 5%/pF, possibly due in part to greater soil salinity of some of these highly

reactive soils. Higher salinity would mean greater swelling due to reduction of solute suction as distilled water flooded the swell test specimen.

2.1.1 Typical values of shrinkage index

For the majority of problem soils, I_{ps} values lie generally in between 3 and 10 %/pF. Histograms are presented in Figure 2 of distributions of shrinkage index ranges for red brown earth determined by different test methods as reported in consultant's reports and research papers (Cameron, et al., 1999). The legend indicates the number of tests in the database. The distribution of I_{ps} for the red brown earths of Adelaide is quite tight, regardless of the method of testing. Generally, the red brown earths are unlikely to possess a shrinkage index much greater than 4%/pF,

Shrink-swell indices for residual soils over the Quaternary basalts of Melbourne (Cameron and Yttrup, 1992) are presented in Figure 3. For comparison, the shrink-swell data for the more reactive gleyed clays of Adelaide (generally grey- to green-brown Pleistocene clays, refer Sheard and Bowman, 1996) are provided in the same plot. The basaltic soil is consistently recorded as having a shrinkage index in the range of 4 to 6%/pF, a little lower than that of the gleyed clays.

Researchers and practitioners have long tried to connect reactivity to Atterberg Limits as previously alluded to. Cameron (1989) found that a trend was evident between shrink-swell index and the linear shrinkage of a wide range of soils from three Australian States, however the scatter of data points made the trendline impractical to apply. Mitchell and Avalue (1984) found reasonable correlations between core shrinkage index and plastic index, provided soils were divided into soil type, such as red brown earths, black earths, etc.

A review of the database of Cameron et al. (1999) resulted in the plot of core shrinkage index against plastic index (PI) for red brown earth and gleyed clay (Figure 4). The number of data points were 56 for red brown earths and just 14 for gleyed clay. There is considerable scatter of the data, however a possible simple linear relationship for design purposes is indicated on the plot. The information from the scheme in Table 1 has been plotted on the same Figure as four solid square data points.

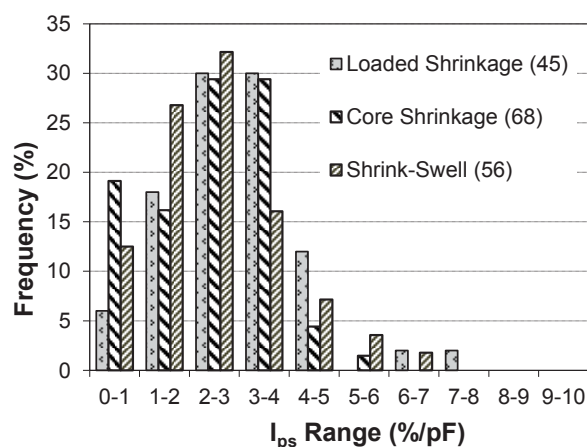


Figure 2. Shrinkage index variations of red brown earths (Cameron, et al., 1999)

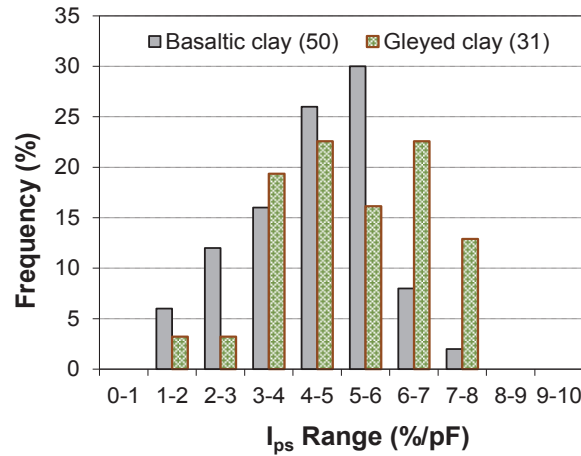


Figure 3. Shrink-swell indices, basaltic clay (Melbourne) and gleyed clay (Adelaide)

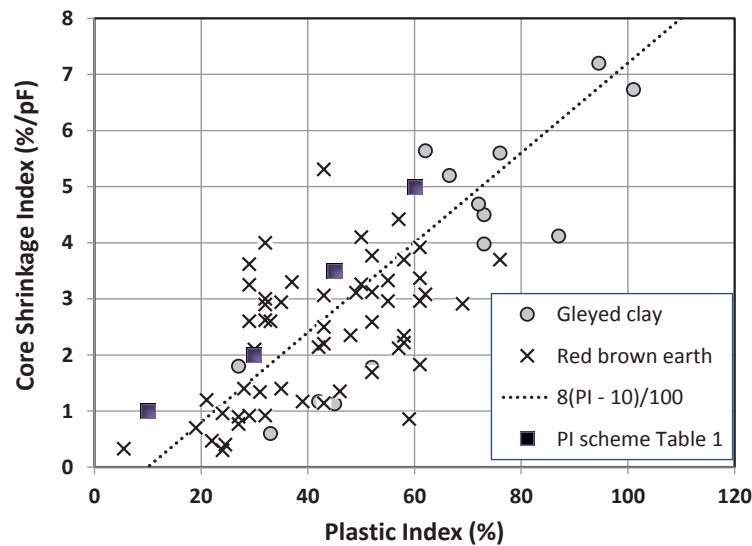


Figure 4. Core shrinkage index against plastic index (Cameron, et al., 1999)

3 GROUND MOVEMENT ASSESSMENT

The characteristic surface movement is estimated by summing the effect of suction change acting on the soil within each layer in the soil profile. However, the shrinkage index that is obtained from the standard tests represents the results for a sample that is laterally unrestrained. Account needs to be taken of the effect of lateral restraint of the soil in the ground. In the seasonally cracked zone of the soil profile, the lateral restraint may be minimal until the cracks close. Accordingly, the shrinkage index values are adjusted by the factor, α , to account for lateral restraint. The adjusted shrinkage index is then termed “the instability index” or I_{pt} :

$$I_{pt} = \alpha I_{ps}$$

In the seasonally cracked zone, $\alpha = 1$. Below the cracked zone, $\alpha = (2 - 0.2.z)$, where z = depth in metres from the soil surface. The minimum value of α is 1. The depth term, z , allows for the restraining effect that overburden pressure has on the amount of reactive soil movement.

An example of the effect of the correction factor is shown in Figure 5 for a simple design suction change

profile (or distribution) of 1.2 pF at the surface decreasing linearly with depth to zero at 2.3 m depth. The soil profile consists of just two layers. From the surface to a depth of 1.8 metres, $I_{ps} = 4$ %/pF and below this level, the soil reactivity reduces to 3 %/pF. The depth of shrinkage cracking is 1.5 m and so the correction factor takes effect from this depth onwards making I_{pt} greater than I_{ps} (refer Figure 5a). The estimated cumulative ground movement is presented in Figure 5b. A total surface movement prediction of 58.5 mm follows from the assumed suction change profile and the soil profile.

4 CLASSIFICATION OF SITES

An estimate of potential ground movement, y_s , at a site is essential to the site classification process. For this purpose, the soil profile and reactivity of soil within the profile, including the effects of lateral restraint below the cracked zone, are needed. The soil is considered to be experience a simplified suction change profile. The depth of the design suction change, H_s , has been linked to the Thornthwaite Moisture Index (TMI) (see Table 2).

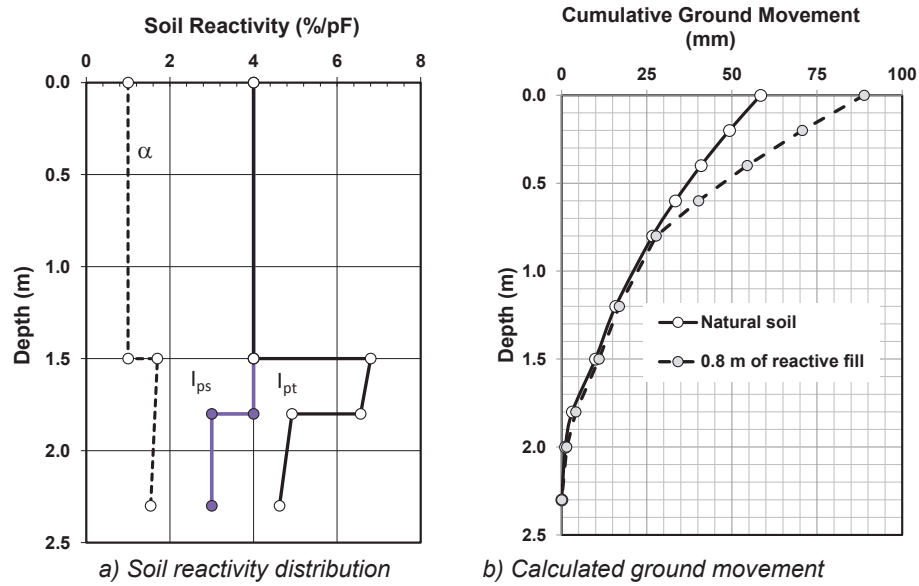


Figure 5. Example of calculation of ground movement

As previously stated, the 1996 edition of AS2870 included a TMI map for the State of Victoria, but as yet, no similar maps have been included for the other States. However, TMI maps for other States and regions can be found in the published literature, e.g. Fox 2002, for Queensland, Fityus et al. 1998 for the Hunter Valley in NSW, and Walsh et al. (1998) for Southern Western Australia. Ranges of TMI were assigned types of climate, e.g. semi-arid has a long term annual average TMI of less than -25. The depth H_s , which is tied to each climate zone, represents the depth activated by changing the environment from Greenfields to a housing subdivision and in semi-arid regions this depth can be substantially greater than the depth of seasonal movement. For example, the depth of seasonal movement in Adelaide (climate zone 4) is approximately 2 m, yet the design depth of suction change is twice that, at 4 m.

Mitchell (2008) reasoned through theoretical analysis and a case study of a building in central Australia, that H_s should not increase indefinitely as the prevailing climate becomes more severe. In arid zones the soil usually remains dry and is affected on the odd occasion by a significant rainfall event, which will be unlikely to impact at a depth greater than 2.5 m.

4.1 Thornthwaite Moisture Index

It needs to be kept in mind that TMI is a simple climatic index at best. It is the average of the annual values of TMI over a number of years; a minimum of 20 years of continuous records of temperature and

rainfall are required, and of course, more years would be more valuable.

There are a variety of methods for evaluating TMI and the different approaches can lead to different values which has generated some interesting discussion recently (e.g. Fox, 2002, Fityus and Buzzi, 2008, Leao and Osman-Schiegel, 2013, Sun, Li and Zhou, 2017). A consistent approach is needed to provide greater confidence in mapped TMIs. Complicating the issue is the downgrading of weather stations across the country to save money. So, a TMI evaluation in the middle of the 20th Century may differ from that based on the early 21st Century, since the number of weather stations has been reduced.

Fox (2002) mapped TMI for the State of Queensland based on 154 weather stations with an average operating age of 88 years. As well as the mean TMI, he reported maximum and minimum yearly TMI values; the ranges of yearly TMI provide sobering evidence of the variability of TMI. For example, over nearly 50 years of monitoring, one site had a mean TMI of -7 and the yearly TMI varied between +70 and -40. Similarly, Fityus and Buzzi (2008) reported a variation of annual TMI for the Hunter Valley in NSW of -20 to 100 for 30 to 40 years of weather records, and Li and Sun (2015) reported the yearly TMI for Melbourne varied between +12 and -33 from 1954 to 2013. So, there is an obvious need to base TMI on long-term data to find the characteristic TMI for a site.

Table 2. Relationship between TMI and H_s (AS2870, 2011)

TMI Range	Climatic Zone	Climate Description	H_s (m)
> 10	1	Alpine/ wet coastal	1.5
≥ -5 to ≤ 10	2	Wet temperate	1.8
≥ -15 to ≤ -5	3	Temperate	2.3
≥ -25 to ≤ -15	4	Dry temperate	3.0
≥ -40 to ≤ -25	5	Semi-arid	4.0
< -40	6	Arid	> 4.0

4.2 Design suction changes

In the Standard, the design changes of total suction were simplified to vary linearly with depth to the maximum depth, H_s . The suction excursion at the surface is generally taken to be 1.2 pF, which could represent total suction values of 3.3 to 4.5 pF (200 to 3,000 kPa), or perhaps 3.5 to 4.7 pF (310 to 4,900 kPa). The absolute values of suction are not defined by AS2870. Many Australian soils are saline so even when they are quite moist, they can still exert a solute suction of a few hundred kPa, while the matric suction is likely to be negligible. The total suctions of soil samples at the completion of swelling have been measured and it has been found that the final suctions ranged between 250 and 450 kPa. Electrical conductivity testing confirmed that the swollen soils had low matric suctions since the estimates of solute suction based on conductivity testing were actually higher in most cases than the measured total suctions.

It has been acknowledged that suction changes or differences in suction profiles over time across a site are rarely linear with depth and that the suction excursion near the surface can be more severe (Mitchell, 2008). However, the departures from observed suction differences in the simplified suction change profiles tend to balance out, with relatively greater effect of suction changes deeper within the soil profile and therefore greater movement; while the reverse holds for the near surface soil.

For the arid climate zone, Mitchell (2008) provided evidence that the depth of suction change should be reduced to 2.5 m, as previously discussed, and as well, that the surface suction change should be increased from 1.2 to 1.8 pF.

4.3 Other classification methods

The Standard allows that site classification can be based on assessments of the performance of existing housing in an area. The Standard requires that the buildings must be at least 10 years old for this evaluation. For the assessment to be valid, the type of footing systems supporting the buildings needs to be accounted for, together with an evaluation of the condition of the buildings. When quantifying the movement of existing structures, the observed differential movement is likely to be less than what the free mound height, y_m , would be, due to suppression of the mound by the structure.

This approach to site classification is not common, however.

4.4 Site classification levels

Site classes for reactive soils are defined based on ranges of characteristic surface movement, y_s . Deemed-to-comply footing system designs are provided with stiffness calibrated to the upper end of the range of movement for each site class, up to class H2.

The suite of deemed-to-comply designs for each class cater for the more traditional types of wall construction and their sensitivity to deflection (e.g. clad frame, articulated masonry veneer, masonry veneer and

articulated full masonry). No deemed-to-comply designs are provided for Class E; it is considered that such sites require case by case design.

The classification of Greenfield sites may be simple enough, however site works, such as cutting and filling, may introduce other factors beyond that encompassed in the original classification.

Consequently, it is of great advantage for the site classifier to work hand in hand with the designer, or else the designer may need separate geotechnical advice about the implications of site works. If reactive soil is used as compacted fill, it is considered by AS2870 that lateral restraint from compaction will not be relieved by shrinkage cracking within the first 5 years of filling. Consequently, the movement expected is greater than if cracking is assumed to exist in the soil profile. Given the time period involved, it may be argued that the clause should apply only to design for edge heave.

An example of the impact of using reactive fill is provided in Figure 5b. In this site classification example, the upper level soil (4 %/pF) has been used to fill the site to a depth of 0.8 m. The lower level soil (3 %/pF) is no longer within H_s of 2.3 m, but it is evident that this makes little difference to the cumulative movement plot. The value of y_s increases from 58.5 mm to 89 mm due mainly to the increase of I_{pt} in the top 0.8 m. Consequently, the site classification changes from H1 to E.

This clause in the Standard remains contentious as often reactive soil fill cannot be avoided, and the validity of the prescribed five-year period has not been demonstrated either theoretically or experimentally. Nonetheless, it serves to discourage the use of highly reactive soils for supporting fill, thereby promoting good engineering practice.

As with recent fill, if soil is removed by cutting through the established cracked zone, the allowance for cracking is not permitted, i.e. the cracked zone is assumed to take some time to develop.

Sites which lie outside the scope of the Standard may need special engineering consideration (including investigation) and are designated as P or Problem sites. For example, controlled filling many metres deep will settle with time and differential movements may occur especially close to the boundary of the fill. "Controlled fill" does not equate to "no settlement fill".

4.5 Common site classification practice

The foregoing discussion has focused on the engineering side of site classification, however, laboratory testing is not as common as it may seem. Since design suction profiles are prescribed by AS2870 to characterize the movement potential of the site, all that are required is knowledge of the soil profile and estimates of soil reactivity. For example, very little testing for soil reactivity has been performed in South Australia since the advent of the Standard in 1986, as it is believed that the reactivity of the commonly encountered clays can be adequately estimated simply by visual-tactile identification. The economics of the housing industry tend to preclude reactivity testing if it can be avoided. In other States,

common site classification levels for an area have been adopted.

Confirmation of the soil profile is essential to complete the soil classification. In the eastern capital cities, one borehole or pit may be the maximum required to classify an allotment. In Adelaide, y_s is determined for each site, with estimates of shrinkage indices determined by visual-tactile assessment of the soils by experienced site classifiers. In this city, gilgai formations are common (Stapledon, 1970), leading to spatially variable soil profiles within a few metres and so 3 boreholes are made on each house site. Then y_s is taken as the highest estimate made for the three soil profiles deduced from the three boreholes across the site.

The estimate of y_s is critical to the design of the footing system. Therefore, there is a need for experienced site classifiers to be used in visual-tactile evaluations of soil reactivity and for their assessments of reactivity to be checked on a regular basis. The latest version of AS2870 (Standards Australia, 2011) states: "For method (iii) above, the suitably qualified and experienced person shall check the soil property identification against laboratory testing on reactive soils at a period not longer than six months and at least once in every 50 sites personally classified." The person referred to in this clause may be an engineer or engineering geologist with "appropriate expertise and local experience".

5 GOOD CONSTRUCTION PRACTICE

AS2870 requires good construction practices to lessen the risk of concentrated sources of moisture ingress. Obviously, attention to effective site grading and drainage is essential. Services trenches can be a cause of moisture ingress into the foundation both around and under the building. On reactive sites, the Standard has requirements for backfilling service trenches with moist compacted clay rather than permeable sand. Rupture of subsurface drainage pipes is a particular problem on reactive sites because of the ground movement that the consequent leakage can cause. The Standard requires flexible lagging where pipes penetrate through footings and flexible joints in pipe work to accommodate the estimated value of y_s . Examples of various flexible joints and layouts for different site classifications are provided by Stormplastics (2017).

6 MANAGEMENT OF SITES

In the interests of economy across the community, the Standard has consistently taken the approach that avoidable moisture changes should not be routinely allowed for in the design of footings for low-rise buildings. Unavoidable moisture changes arise from the construction of housing on Greenfield sites; there is an environmental re-distribution of soil moisture as rainfall is intercepted and with slab on ground construction, evaporation is minimized. The re-distribution of moisture below sealed roads where a water table is not evident or is deep within the soil, results in a suction profile at equilibrium (or constant suction profile), which will develop and remain steady over the years (Richards and Chan 1971). A constant suction profile with depth indicates that moisture will

not flow vertically in either direction below the centre of a covered surface (road or slab). The level of the deep equilibrium suction, u_{eq} , has been linked to the Thornthwaite Moisture Index, and for semi-arid sites, the equilibrium suction may be close to a total suction of 4.19 pF (1,500 kPa). Cameron (2001) inferred values of u_{eq} from suction profiles from seven different sites across Adelaide. The values ranged between 3.95 and 4.15 pF, with an average of 4.04 pF.

Lack of adequate site drainage, overwatering of gardens, unattended water leaks and water allowed to pond near buildings for long periods, are examples of avoidable moisture changes, which can cause severe swelling movements (e.g. Li and Cameron 2002; Li, et al 2014).

Severe shrinkage settlement has been observed when trees or other substantial vegetation have been established close to structures (e.g. Pile, 1984, Silvestri, et al., 1992, Snethen, 2001). The stance taken by AS2870 in the early editions was to avoid trees within certain proximities to structures, based on tree height and numbers of trees. This restriction was a substantial limitation of the Standard. In the mid-1990s, the Footings Group in South Australia provided empirical guidelines for the extra design suction change in the soil profile due to the drying caused by tree roots; the influence of tree species was ignored owing to the paucity of published data. With the experience gained in this State through the application of the guidelines and limited case studies from Adelaide and South-East Queensland (Cameron and Beal, 2011), guidelines for additional suction changes due to trees were incorporated in AS2870 in the 2011 edition, as discussed in the following section.

7 AS2870-2011 GUIDELINES FOR TREES

Investigations of tree-related damage to houses (Cameron, 2001, Jaksa et al., 2002) indicated that the South Australian approach to design of footings for trees (Footings Group, 1996) tended to overestimate the extent of suction change at depth but underestimate the depth of soil drying from groups of trees (6 m postulated from case studies). The additional design suction change adopted in the SA method was a simplification of reality; Cameron (2001) observed that trees could not compete with high suction levels developed in near surface soils and so, to survive, would have to extend roots deeper where soil suctions were less than that capable of being imposed by the plant, i.e. at the "wilting point soil suction", or u_{wp} . The suction difference, $(u_{wp} - u_{eq})$, was determined by Cameron (2001) to range from approximately 0.25 to 0.4 pF, with the variation likely to be due to tree species and availability of soil moisture, but not numbers of trees. The numbers of trees does however influence the depth of soil drying; Cameron (2001) indicated for trees in Adelaide that a depth of 4 m should apply for a single tree and 6 m for a group of trees.

Design suction change profiles are shown in Figure 6, with Figure 6a indicating the preferred additional suction change shape for a value of H_s of 2.3 m and the drying action of either a single tree or a group of trees. For other levels of site classification, refer to

Cameron and Beal (2011). The suction change at the maximum depth of tree drying, H_t , is higher than the maximum observed value of $(U_{wp} - U_{eq})$, to provide a safety margin for designers. Figure 6b indicates the design suction change adopted in the guidelines of AS2870-2011 for this same situation. The overall shape adopted for design was altered to lessen the need for even deeper site investigations for houses to address the tree-drying issue. The maximum depth of tree drying was taken to be 4.5 m for any site and as a consequence, the suction difference at depth, H_t , was increased; essentially the area enclosed beneath the triangular design suction profile in Figure 6a should equal the corresponding area in Figure 6b.

The moderation of design suction changes based on climate, or its proxy, H_s , was based on a limited number of case studies from SE Queensland (Cameron and Beal, 2011). Much more data from case studies and research are required to justify or modify the current preliminary guidelines.

All the design suction changes presented in this section allow estimation of the maximum shrinkage settlement in the immediate vicinity of the trees, provided estimates of soil reactivity are provided to depth H_t . The maximum value can be decreased by considering the likely proximity (separation distance from building relative to tree height) of the tree/s, but almost invariably, the worst case is chosen owing to the uncertainty of mature tree heights.

In the calculation of additional shrinkage settlement attributable to the tree(s), the lateral restraint factor, α , is taken to be 1, as shrinkage cracking is likely to be deeper. The site classification example in Figure 5 has been extended to demonstrate the influence of trees (see Figure 7). The maximum tree-related settlement y_{max} , for a single tree and a group of trees are 25 and 40 mm, respectively.

For footing design purposes, the value of the mound differential movement in centre heave, y_m , increases from 41 mm to either 66 or 81 mm for a single tree or tree group.

The impact of the AS2870 guidelines depends largely on the soil profile. If reactive soils are found deeper within the soil profile, then the increase in movement over y_s will be more substantial.

8 SUMMARY

In this review of the Australian Standard for Residential Slabs and Footings and its implementation, a number of salient points have been made, including:

- Australia has had a Standard to help deal with reactive soils for over 30 years.
- Test methods exist for quantifying a soil's response to suction change (soil reactivity)
- The shrink-swell test only requires basic soil laboratory equipment and provides an estimate of reactivity over the full range of suction change relevant to footing design
- Site classification requires soil profile identification and/or estimated design ground movement
- Site classification is for normal moisture conditions – the avoidable is to be avoided
- Design suction changes are specified for the purposes of site classification
- Long term TMI is useful in defining the depth of suction change
- Long term performance of a building depends on good site investigation, competent design and detailing, good construction and maintenance of the site after construction
- Concepts of acceptable performance and associated levels of damage have been promulgated
- Design for trees was accommodated with guidelines included in AS2870-2011

9 FURTHER RESEARCH NEEDS

The reliance on empirical rules in the Standard was unavoidable and hopefully, with developments in unsaturated soil theory and innovations in design and construction, better practical guidelines and solutions will be found and incorporated into the Standard. Research effort is needed long into the future to resolve some of the issues arising from the many assumptions and empiricism within AS2870. Some of the issues that deserve investigation are:

- The 5-year rule for development of full seasonal shrinkage cracking
- A consistent study into TMI across Australia

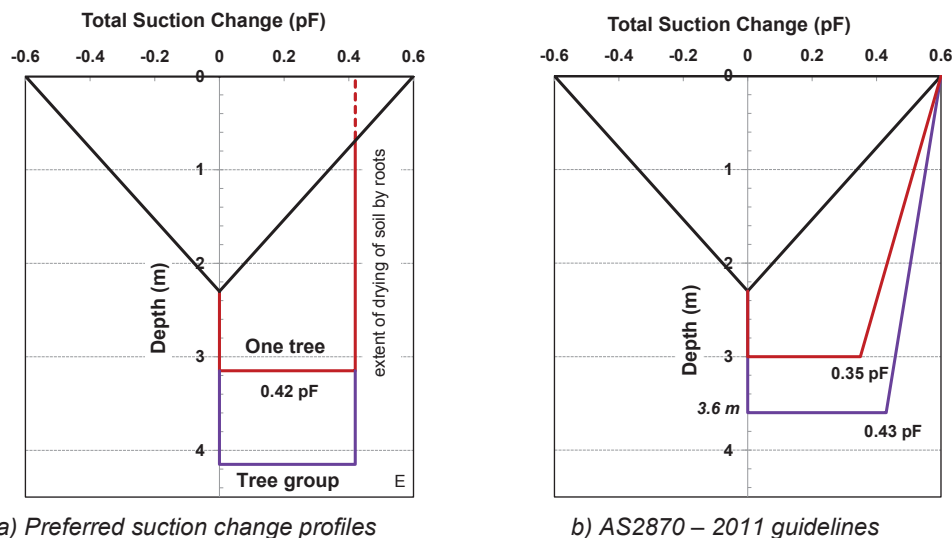


Figure 6. Suction profiles for tree drying shrinkage estimation

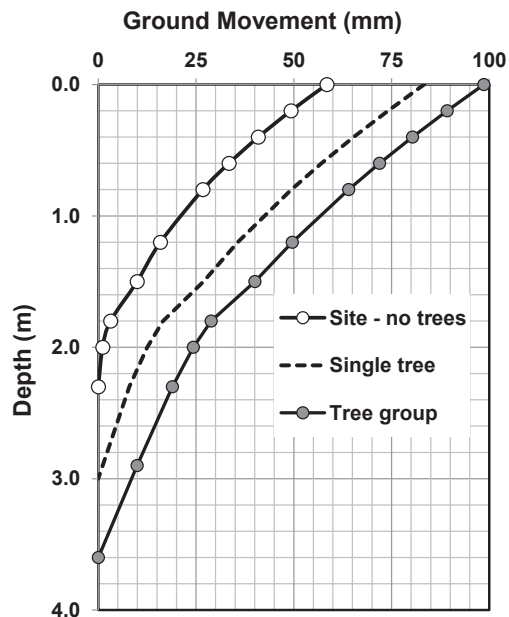


Figure 7. Ground movement estimates with trees

- The water demand of trees of different species in an urban environment
- Modelling for prediction of tree drying settlement
- Backanalysis of distressed footing systems through comprehensive numerical modelling
- Alternative methods of assessing soil reactivity
- The influence of soil suction and interface shear of typical reactive soils on the movement of piles in swelling soils

With regard to the last dot point, although there has been a program for a long time for prediction of pile movement (Poulos 1989), the parameters needed for the program to run have not been studied to any great extent. The program can provide guidance on the depth needed to minimize movement.

ACKNOWLEDGEMENTS

I wish to acknowledge my mentors with respect to expansive soils: my MEng supervisor, Dr. John Holland and Dr. Paul Walsh (both deceased) of CSIRO Division of Building Research. I would like to thank Nigel Beal for his sage advice and a number of colleagues connected with Standards Australia committee BD25, which is responsible for AS2870.

REFERENCES

- Aitchison G.D. (1970). Soil aridity during occasional drought in South-Eastern Australia. Proceedings, Symposium on Soils and Earth Structures in Arid Climates, Australian Geomechanics Society, Adelaide, 93-97.
- Beal N.S. (2009). Direct measurement of the relationships between total soil suction, free strain and moisture content. Proceedings, 4th Asia Pacific Conf. Unsaturated Soils, Newcastle, Australia, CRC Press, eds. Buzzi, Fityus, Sheng, vol. 1, 221-226.
- Beal N.S. (2013). What is the total suction of soil at oven dry? Australian Geomechanics, Australian Geomechanics Society, 48(1), 157-167.
- Burland J.B., Wroth, C.P. (1974). Settlement of buildings and associated damage: state of the art review.

- Proceedings, Conf. on Settlement of Structures, Cambridge, Pentech Press, London, 611-654.
- Cameron D.A. (1989). Tests for reactivity and prediction of ground movement. Civil Engineering Transactions, IE Aust., CE 31(3), 121-132.
- Cameron D.A., Yttrup P.J. (1992). Footings for light structures on the reactive soils of Melbourne. Seminar on Engineering Geology of the Melbourne District, eds W.A. Peck, J.L. Neilson, R.J. Olds and K.D. Seddon, Melbourne, Balkema, 345-354.
- Cameron D.A. (2001). The extent of soil desiccation near trees in a semi-arid environment. Journal of Geotechnical and Geological Engineering, Kluwer, 19(3 and 4), 357-370.
- Cameron D. A. (2010). Comparison of shrink-swell and core shrinkage tests for evaluating soil shrinkage index. Proceedings, 3rd International Conference on Problematic Soils, IAEG, Adelaide, April, 61-68.
- Cameron D.A., Walsh P.F., Richards B.G. (1991), The Australian approach to the problem of expansive soils. Proc., 9th African Regional Conference on Soil Mechanics and Foundation Engineering, 1987, Lagos, Nigeria, Balkema, 977 - 989.
- Cameron D.A., Buttignol C., Nguyen T. (1999). A database of shrinkage indices for Adelaide. Proc., 8th ANZ Conf. on Geomechanics, Australian Geomechanics Society, Hobart, Tasmania, 157-162.
- Cameron D.A., Beal N.S. (2011). Estimation of foundation movement and design of footing systems on reactive soils for the effects of trees. Australian Geomechanics Journal, 46(3), 97-113.
- Coffey and Partners Pty. Ltd., (1984), Specification for Swelling Soil Design Method, Report to the Builders Licensing Board, Report No. S7032/3-AD.
- Department of Sustainable Natural Resources (unknown). Soil survey standard test method: electrical conductivity. Test no. C1, test method type A, version no. 3, New South Wales, 3 pages.
- Fityus S.G. (1996). The effect of initial moisture content and remoulding on the shrink-swell index, I_{ss} . Proc. 7th ANZ Conference on Geomechanics, IEAust, Adelaide, 388 - 393.
- Fityus S.G., Walsh P.F., Kleeman P.W. (1998). The Influence of climate as expressed by the Thornthwaite Index on the design depth of moisture change of clay soils in the Hunter Valley. Geotechnical Engineering and Engineering Geology in the Hunter Valley, Newcastle, Australia.
- Fityus S.G., Cameron D.A., Walsh P.F. (2005). The shrink swell test. ASTM Geotechnical Testing J., 28(1), 1-10.
- Fityus S., Buzzi O. (2008). On the Thornthwaite Moisture Index to infer depths of seasonal moisture change. Australian Geomechanics, Australian Geomechanics Society, 43(4), pp. 43-54.
- Footings Group (1996). Special Provisions For The Design of Residential Slabs and Footings for South Australian conditions. IEAust, South Australian Division, 20 pages.
- Fox E. (2002). Development of a map of Thornthwaite Moisture Index isopleths for Queensland. Australian Geomechanics, Australian Geomechanics Society, 37(3), 51-59.
- Holland J.E. (1978). Residential Slab Research, Recent Findings. Report, Swinburne College of Technology, Hawthorn, Victoria, Australia.
- Jaksa M.B., Kaggwa W.S., Woodburn J.A., Sinclair R. (2002). Influence of large gum trees on the soil suction profile in expansive soils. Australian Geomechanics, Australian Geomechanics Society, 37(1), 23-33.
- Leao S., Osman-Schlegel, N.Y. (2013). TMI for urban resilience: measuring and mapping long-term climate change on soil moisture. Proc. 7th Australasian Housing Researcher's Conf., WA, Australia.
- Li J., Cameron D.A. (2002). Case study of courtyard house damaged by expansive soils. ASCE, Journal of Performance of Constructed Facilities, 16(4), 169-175.
- Li J., Cameron D.A., Ren G. (2014). Case study and back analysis of a residential building damaged by expansive soils. Computers and Geotechnics, 56(4), 89-99.

- Li, J. and Sun, X. (2015). Evaluation of changes of Thornthwaite Moisture Index in Victoria. *Australian Geomechanics Journal*, 50 (3), 39-49.
- Mitchell P.W., Avasle D.L. (1984). A technique to predict expansive soil movements. *Proc., 5th Int. Conf. on Expansive Soils*, Adelaide, South Australia, 124-130.
- Mitchell P.W. (2008). Footing design for residential type structures in arid climates. *Australian Geomechanics*, Australian Geomechanics Society, 43, 51-68.
- Pile K.C. (1984). The deformation of structures on reactive clay soils. *Proc. 5th Int. Conf. on Expansive Soils*, Adelaide, South Australia, 292-299.
- Poulos, H G (1989). Program PILES, Axial response of piles in expansive soils, Users' guide, University of Sydney.
- Puppala A.J., Manosuthikij T., Chittoori, B.C.S. (2014). Swell and shrinkage strain prediction models for expansive clays. *Engineering Geology*, 168, 1-8.
- Richards B.G., Chan C.Y. (1971). Theoretical analyses of subgrade moisture under Australian environmental conditions and their practical implications. *Australian Road Research*, 4(6), 32-49.
- Richards B.G., Peters P., Emerson W.W. (1983). The effects of vegetation on the swelling and shrinking of soils in Australia. *Geotechnique*, 33(2), 127-139.
- Sheard M.J., Bowman G.M. (1996). *Soils, Stratigraphy and Engineering Geology of Near Surface Materials of the Adelaide Plains*. Department of Mines and Energy, Report Book 94/9, vol. 1, 2 and 3, Adelaide.
- Silvestri V., Soulie' M., Lafleur J., Sarkis G. and Bekkouche N. (1992). Foundation problems in Champlain clays during droughts. II. Case histories. *Canadian Geotechnical Journal*, 29, 169-187.
- Snethen D.R. (2001). Influence of local tree species on shrink/swell behaviour of Permian clays in central Oklahoma. ASCE, *Geotech. Special Publication 115, Expansive Clay Soils and Vegetative Influence on Shallow Foundations*, eds. Vipulanandan, Addison, Hasen, 158-171.
- Standards Association of Australia (1986). *Residential Slabs and Footings - Construction*. AS2870-1986, Sydney, NSW.
- Standards Association of Australia (1988). *Residential Slabs and Footings. Part 1: Construction*. AS2870.1-1988, Sydney, NSW.
- Standards Association of Australia (1990). *Residential Slabs and Footings. Part 2: Guide to Design by Engineering Principles*. AS2870.2-1990, NSW.
- Standards Australia (1996). *Residential Slabs and Footings - Construction*. AS2870.1-1988, Sydney, NSW.
- Standards Australia (1998a). *Soil Moisture Content Tests - Determination of the total suction of a soil - Standard Method*. AS1289.2.2.1-1998, Sydney, NSW.
- Standards Australia (1998b). *Soil reactivity tests - Determination of the shrinkage index of a soil - Loaded shrinkage index*. AS1289.7.1.2-1998, Sydney, NSW.
- Standards Australia (1998c). *Soil reactivity tests - Determination of the shrinkage index of a soil - Core shrinkage index*. AS1289.7.1.3-1998, Sydney, NSW.
- Standards Australia (2003). *Determination of the shrinkage index of a soil - Shrink-swell index*. AS1289.7.1.1-2003, Sydney, NSW.
- Standards Australia (2009). *Piling - design and installation*. AS2159-2009, Sydney, NSW.
- Standards Australia (2011). *Residential Slabs and Footings*. AS2870-2011, Sydney, NSW.
- Stapledon D.H. (1970). Changes and structural defects developed in some South Australian Clays and their engineering consequences. *Proceedings, Symposium on Soils and Earth Structures in Arid Climates*, Australian Geomechanics Society, Adelaide.
- Stormplastics (2017). *Manufacturers of specialized plumbing products*. <<http://www.stormplastics.com.au/>> (11th September)
- Sun, X., Li, J. and Zhou, A. (2017). Evaluation and comparison of methods for calculating Thornthwaite Moisture Index. *Australian Geomechanics Journal*, 52(2), pp. 61-75.
- Walsh P.F., Fityus S.G., Kleeman P.W. (1998). A note on the depth of design suction change for clays in South Western Australia and South Eastern Queensland. *Australian Geomechanics*, Australian Geomechanics Society, 33(3), 37-40.

AGS VICTORIA 2017 SYMPOSIUM
Reactive clays and light structures

