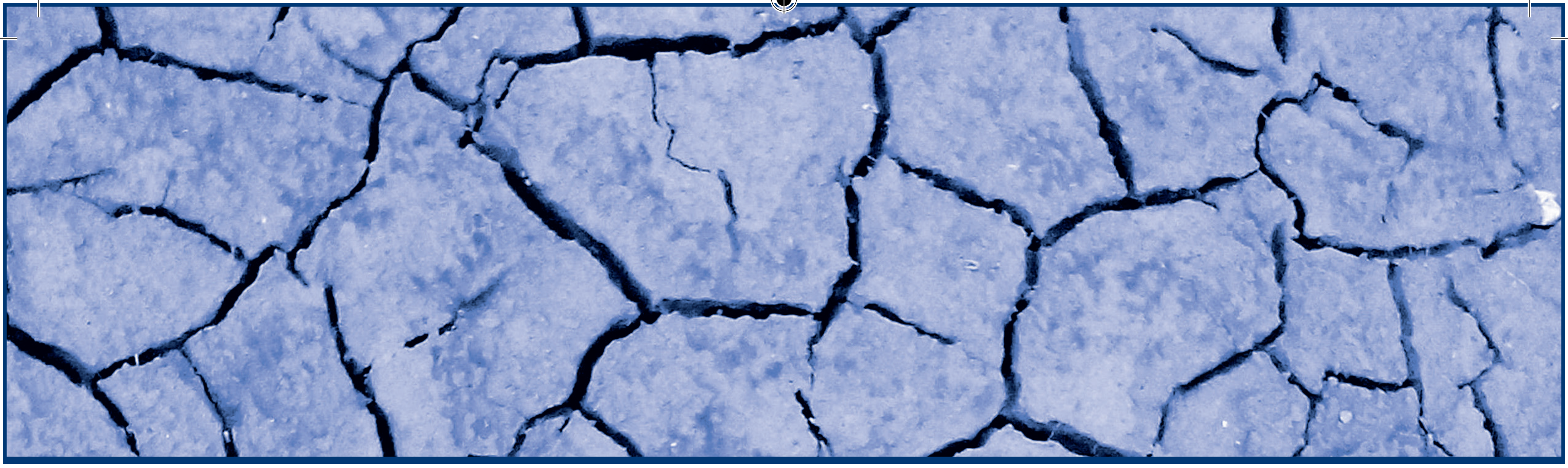
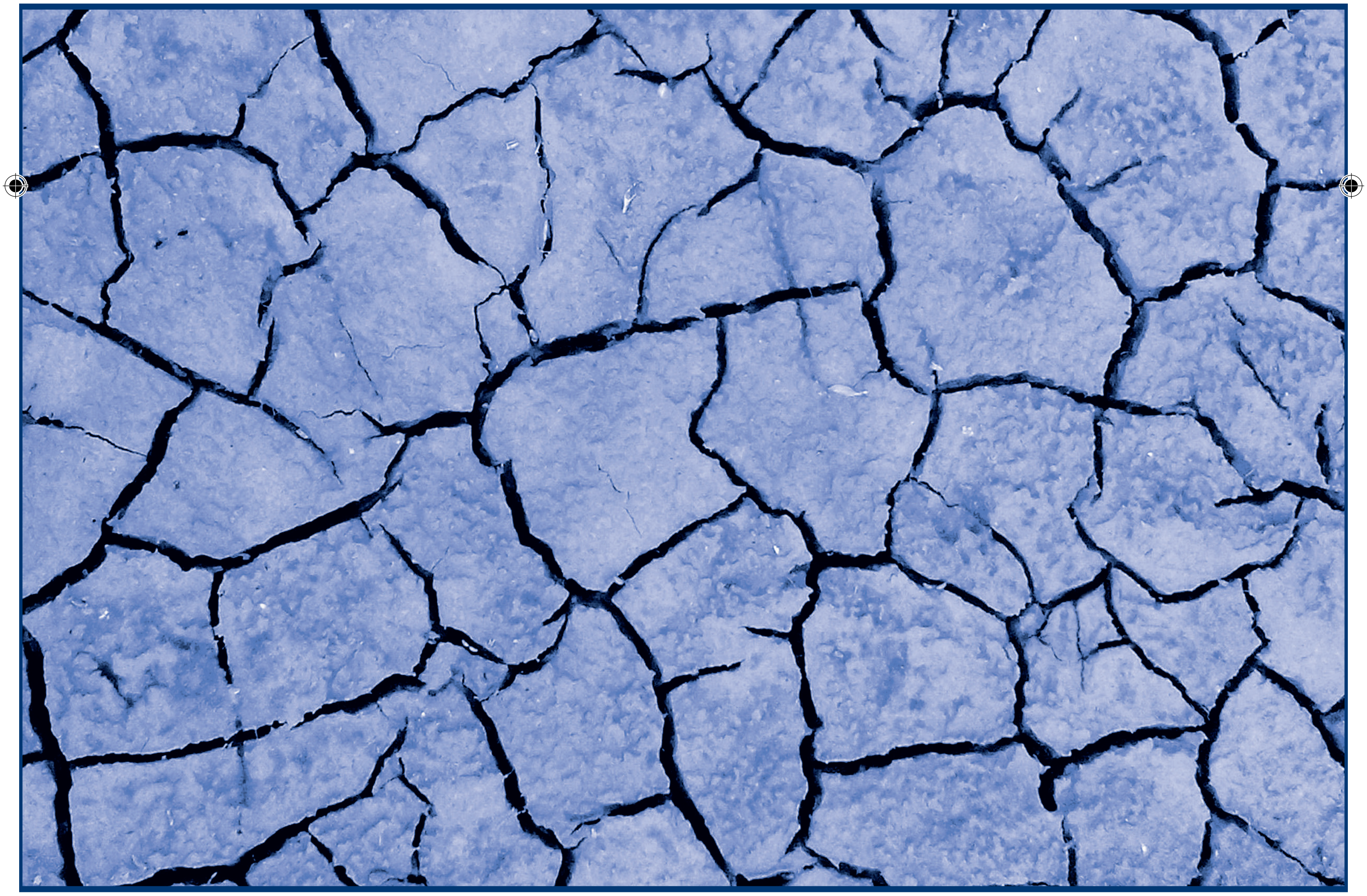


AGS VICTORIA 2017 SYMPOSIUM

Reactive clays and light structures

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

Rydges Hotel, 186 Exhibition Street, Melbourne



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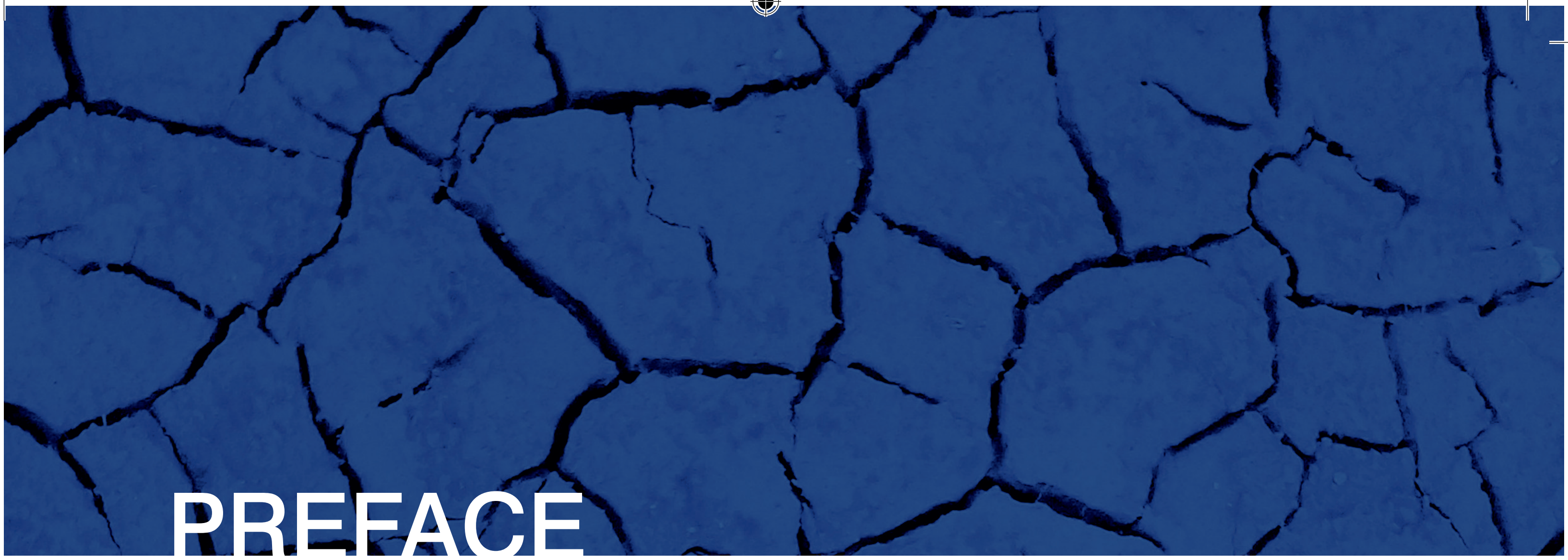

PREFACE

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

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

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

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Clare Bridgeman (Co-chair)

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Influence of trees on expansive soils in Melbourne

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ABSTRACT

In Australia, distortions of residential buildings caused by tree drying settlement have been widely reported, particularly in areas of expansive or reactive soils. The paper presents the results of two major projects dealing with trees and expansive clay soils in the Melbourne Metropolitan area. The first project is the long-term field study of the effects of trees on the performance of a building, soil moisture patterns and ground movement in basaltic clay. The second project is a case study of a residential house damaged by expansive soil movement due to tree root drying. In this field study the sap flow rate of a tree was seen to be closely correlated with solar radiation. It was also observed that the soil moisture content profile near the tree was significantly lower than that away from the tree. The findings of the second study clearly indicated that trees, growing in close proximity to a house could cause more severe damage to the buildings than the expected moisture changes due to seasonal effects and re-distribution of soil moisture arising from construction on the site.

Keywords: Tree Root Drying, Expansive soil, Residential footing, Case Study, Finite Element

1 INTRODUCTION

A great attribute of almost any modern, liveable city is the presence of trees. Trees improve the landscape, enhance the environment, reduce noise, cut energy costs, provide fauna habitat and increase property values. Trees, however, can also cause problems if they become too large for the streetscape. They obstruct light, lose branches in storms and uplift pavements. More importantly, trees can cause damage to residential buildings and light commercial structure, particularly when these are located in expansive soils (Cameron 2015; Li and Guo 2017).

Trees use soil moisture for growth. The loss of water from the leaves through the stomates produces a negative potential or suction through the tree, which creates a pulling force driving water from the soil all the way to the leaves through the tree's roots, stems, branches and twigs (Cameron 2001; Li *et al.,* 2014).

Trees near to a residential building, especially Australian native species, can extract large quantities of moisture from soils, leading to localized settlement. If the shrinkage settlements are significant, the buildings may deflect significantly and result in structural damage as shown in Figure 1.

Damage to pavements and residential buildings caused by tree root drying has been widely reported, particularly in areas of expansive soil. Holland and Richards (1982) inspected over 500 cases of foundation failures in clay soil area in Melbourne Metropolitan region and found that approximately 30% of these failures were directly attributed to tree drying settlement. Goldfinch (1995) found that the effects of tree root drying shrinkage of foundation soils caused, or contributed to, cracking in 80% of cases involving domestic dwellings and light commercial structures in Adelaide.

Current engineering guidelines given in Australian Standard AS2870 (2011) are not based on adequate field research and measurement. Consequently, attempts to design footings to resist the additional ground movement due to trees are often flawed, owing to poor understanding of the water demands of various tree species, wilting points and potential root development. More research is needed in this area. The best way to tackle the problem is to study the influence of trees in urban environments, by field monitoring of water demand of different tree species, soil moisture changes, ground movements and building responses, and case studies of buildings damaged by tree root drying. A multi-disciplinary approach and great effort are required in this area.

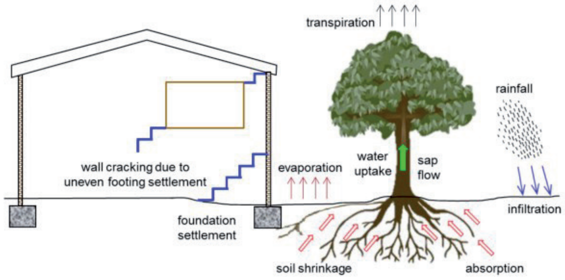


Figure 1. Interaction between atmosphere, trees, soils and buildings

This paper presents the results of two major projects dealing with trees and expansive clay soils in the Melbourne Metropolitan area. The first project is the long-term field study of the effects of trees on the performance of footings, soil moisture patterns and ground movement on a basaltic clay site. The second project is a case study of a residential house damaged by expansive soil movement due to tree root drying.

2 FIELD STUDY

2.1 Site Instrumentation

As part of a long term study of the effects of climate and trees on the behaviour of expansive unsaturated soils and performance of the residential buildings, a field site was established in early 2011 in Glenroy East, about 13 km north of Melbourne CBD. The Glenroy site was selected for this study because the geology is typical of many existing and new residential housing estates to the west and north of Melbourne; the site is underlain by basaltic clay.

A 2.05 m high red flowering gum (*E. ficifolia*) was planted at the centre of the front yard in May 2011 (Figure 2). Ficifolia was chosen for this study because it is widely used as a street tree and in home gardens. The site was instrumented to allow close monitoring of relative humidity, solar radiation, wind direction and speed, rainfall, sap flow of trees, soil moisture and suction, ground surface and sub-surface movements. A site plan showing the location of the instrumentation is shown in Figure 3.

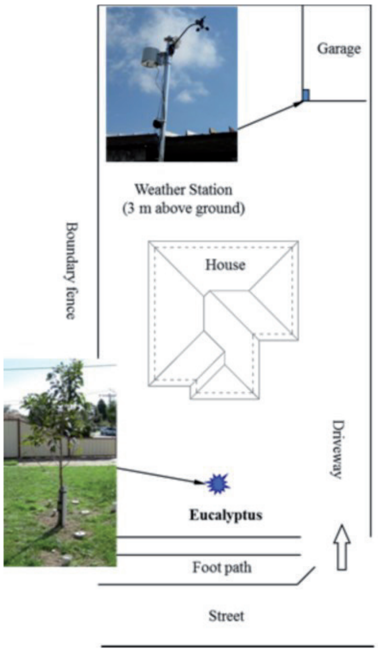


Figure 2. The general plan of the test site

A Decagon automatic weather station was installed in the backyard of the house to collect meteorological data at the site. Nine surface movement probes were installed at various distances from the eucalyptus tree on the test site so that the effect of tree root drying on ground movement could be monitored. Three sub-surface movement probes (at a depth of 0.5m, 1.0 m and 2.0 m respectively) were installed around the tree (Figure 3). A total of six neutron moisture meter (NMM) access tubes were installed at different distances from the tree to monitor the moisture patterns of the surrounding soil.

Four boreholes were drilled at the Glenroy experimental site. The soil profile across the site was relatively uniform. The average soil profile can be described as 12 cm of sandy silt topsoil underlain by high plasticity silty clay to a depth of approximately 2.5 m, then highly to extremely weathered basalt with high strength basalt encountered below 2.9 m (Figure 4). Figure 4 shows the profiles of shrink-swell indices, plastic limits and liquid limits. The site classification according to Australian Standard for Residential Slabs and Footings (AS2870, 2011) is H1 (ie. highly reactive with 40 mm < $y_s \leq 60$ mm).

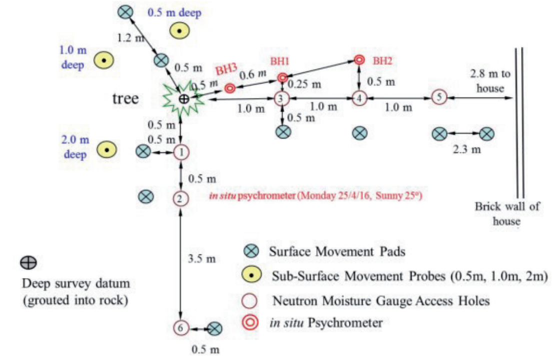


Figure 3. The instrumentation layout at the field site

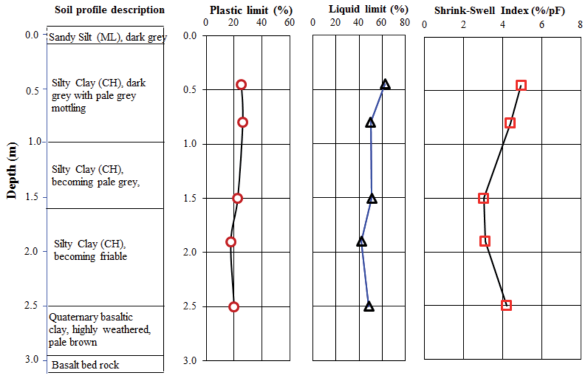


Figure 4. Typical soil profile at the Glenroy site

2.2 Sap Flow Meter

The daily transpiration of the ficifolia was monitored by using a SFM sap flow meter (Figure 5) which is a stand-alone sensor, designed for long-term, continuous, unattended logging application.

Figure 5. Sap flow meter installed on the tree

2.3 Field monitoring results

The Glenroy field site has been monitored since May of 2011. The measured solar radiation and sap flow rates of eucalyptus ficifolia during representative clear days in February 2012 are presented in Figure 6. It is interesting to observe that the sap flow rate began to rise from nearly zero after sunrise, reached a maximum around 12:00 noon, then decreased gradually to nearly zero until midnight. The diurnal courses of sap flow exhibited a bell shape curve that closely correlated with changes in solar radiation.

The measured sap flow rate from May 2011 to January 2013 is plotted in Figure 7. During the first winter (between June and early September 2011), the sap flow rate of the tree varied from 0.1 to 37 cm^3/h. Once the warm weather occurred, the sap flow rate increased to 50 – 75 cm^3/h (between October and early December). From Figure 7, it can be seen that the sap flow rate of the eucalyptus tree increased significantly in the second year.

The *in situ* soil moisture content has been regularly measured by using a CPN 503 Hydroprobe (neutron probe) at the different locations as shown in Figure 3. The complete presentation of the neutron probe soil moisture profiles for all locations is beyond the scope of this paper. Figure 8 shows the extremes of moisture content measured with the neutron probe at two different locations (NP3 and NP5).

The volumetric moisture content change profiles shown in Figure 8 represent the upper and lower envelopes of all readings taken at each depth from the beginning in May 2011 to December 2016. Intermediate values were omitted for clarity.

From Figure 8(b), it can be seen that the maximum moisture content change at NP5, 3 m away from the tree, is mainly confined to the top 2 m. Essentially there is no change below 3 m. The drying influence of the tree is apparent. As shown in Figure 8(a), the soil moisture content at NP3 (1 m away from the tree) was much lower than at NP5 (3 m away from the tree). This was due to the stand of tree extracting water all year round and depleting the soil moisture. As well, the depth of soil moisture variation at NP3 was extended below 3 m (Figure 8(a)).

Levelling surveys were used to monitor the surface and sub-surface soil movements. The results of measured soil movements show that the soil near eucalyptus experienced a larger shrinking settlement compared to soil away from the tree.

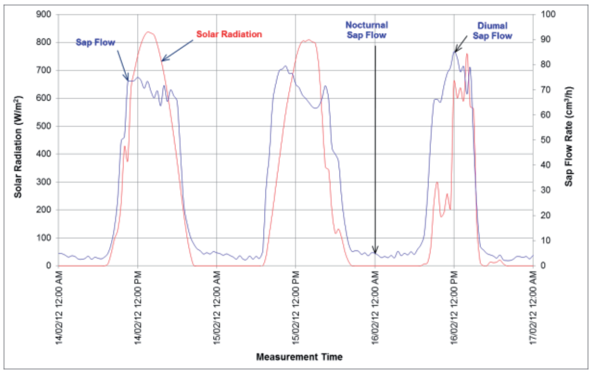


Figure 6. Diurnal variation of sap flow rate and solar radiation from14 to 17 February 2012

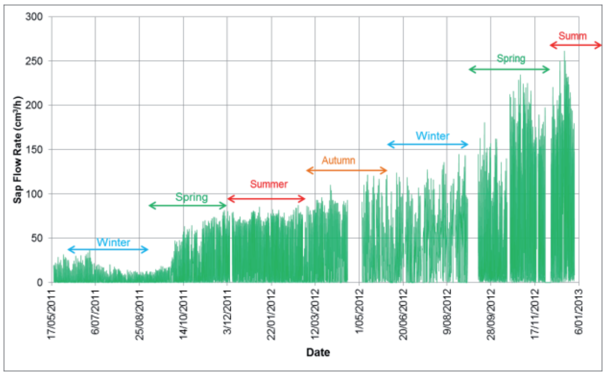
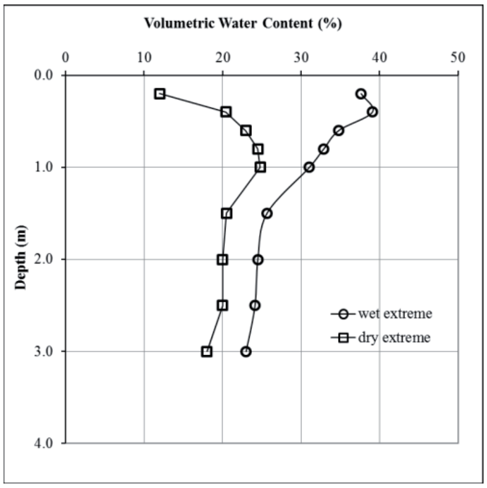
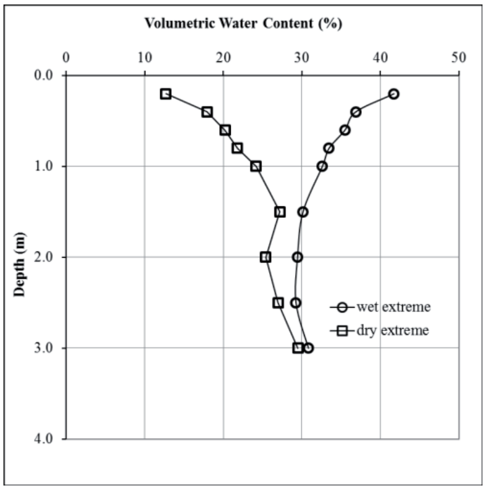


Figure 7. The measured sap flow rate (cm^3/h) from May 2011 to January 2013



(a) 1 m away from the tree



(b) 3 m away from the tree

Figure 8. Volumetric moisture content change profiles between May 2011 and December 2016

3 CASE STUDY

3.1 Description of case study

The case study described herein refers to a single storey, partially articulated masonry dwelling in a south-west suburb of Melbourne, Australia. The building is about 40 years old and is located in an area of Quaternary Newer Volcanics which is normally classified as Class H (i.e. highly reactive) according to AS2870 (2011). The footing system is a "footing slab" consisting of reinforced concrete strip footings (600 mm wide x 400 mm deep) under external walls and an infill concrete slab on ground

(100 mm thick), which is supported by the strip footings. The slab has been thickened under internal masonry walls. The site has a very slight fall of approximately 0.5% towards street and footpath (Figure 9). There is a large Eucalypt tree of approximately 15 m height, located 7 m from the north-west corner of the dwelling (Figures 9 and 10). Along the western elevation of the property, there are a few small native shrubs. The small garden at the front of living room has been apparently very well watered.

Damage to the property consisted of:

- Extensive settlement and cracking of the concrete kerb along the west boundary of the property (Figure 10);
- Severe wall cracking in bedroom 2 (Figure 11), bedroom 1, living room, bathroom, and kitchen;
- Ceiling cornice cracking in most rooms;
- Doors to front entry, bedroom 1, bathroom and kitchen were inoperable;
- Re-opening of previously repaired cracking in the garage eastern wall. The width of the new cracking was approximately 5 mm.

The extensive building distortion was the subject of investigation by various consulting engineers. The external strip footings and internal slab thickening were underpinned to rectify building cracks. The locations of underpins are illustrated in Figure 12. The underpins were approximately 1 m long and 1-2 m deep. However six months after the completion of the building reinstatement and underpinning work, the owner reported that cracking started to reappear.

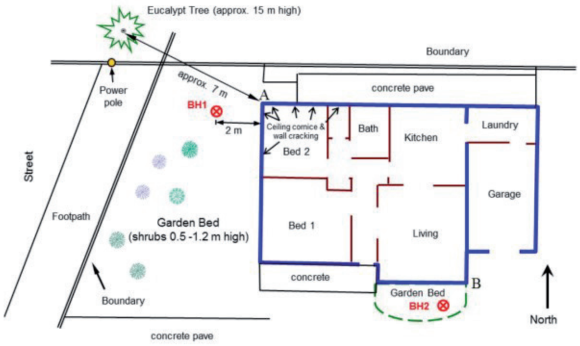


Figure 9. Site Layout showing location of tree and soil boreholes

Large settlement of the concrete curb along the west boundary of the property.

Figure 10. Large settlement the concrete curb near to a street tree

Figure 11. Cracking on the wall of bedroom

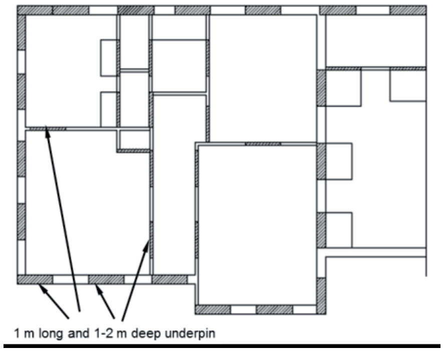


Figure 12. Locations of underpins

3.2 Field investigation

Due to site access restrictions, the drilling rig can only take soil samples from the garden bed near the street and at the front adjacent to the living room. Two boreholes were drilled to approximately 4 m deep to evaluate the soil profile and the level of reactivity of soil types within the profile. The location of boreholes is shown in Figure 9. The geotechnical profile for soil found in BH1 is presented in Figure 13. Based on the measured shrink-swell indices, the value of y_s calculated was 89 mm.

Figure 14 shows the soil suction profiles measured by using a Wescor HR-33T dew-point micro-voltmeter. The effect of tree root drying is clearly evident. The suction profile near the 15 m high eucalypt (BH1, Figure 9) indicates high suctions, or dry soil, over the full depth of sampling. The suction profile of BH2 shows that the top soil in borehole 2 was very wet. This can be attributed to water ponding due to constant garden watering. It is interesting to note that at a depth of about 3.5 m, the total soil suction values for BH1 and BH2 are almost the same and were approximately at 4.1 pF, which could be considered to be an “equilibrium” condition on this site.

Two SFM sap flow meters were installed to obtain the transpiration rate of the tree by measuring tree trunk sap flow (Figure 15). The measured data indicated that this large Eucalypt tree was transpiring 73-87 litres per day during summer.

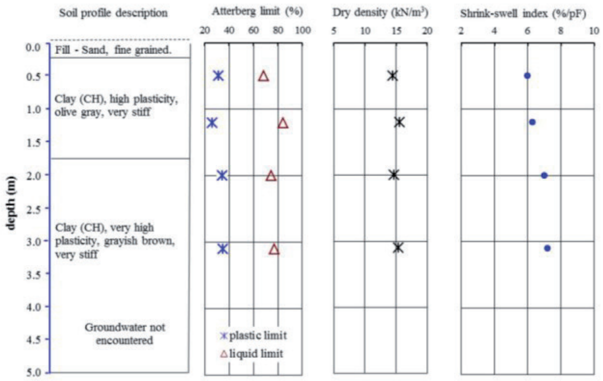


Figure 13. Geotechnical profile at BH1

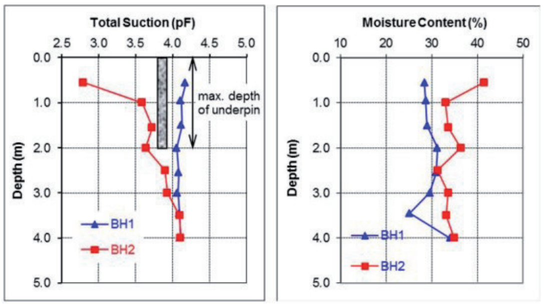


Figure 14. Soil suction and water content profiles

Figure 15. Sap flow meter installed on the street tree

3.3 Numerical Simulation

The soil moisture variation and ground movement induced by root absorption of the Eucalypt tree were simulated over a period of 90 days using the commercial finite element software, ABAQUS . The finite element model, as shown in Figure 16, consisted of 339,792 8-noded brick elements. Based on the tree height, stem diameter and canopy coverage, the horizontal distance r and the depth d of the root zone were estimated to be 3.5 m and 3 m respectively.

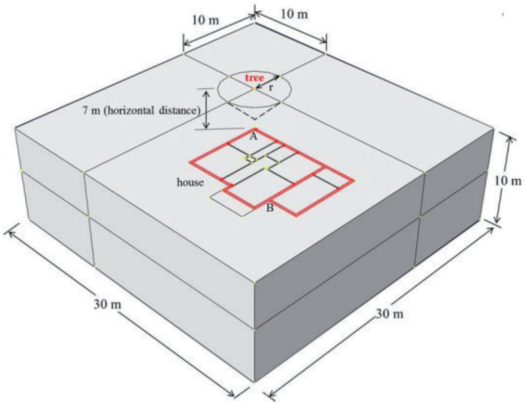


Figure 16. 3D model used for numerical analysis

The root-water uptake is described by a volumetric sink term *S(x,y,z,t)*, which is simply added to the governing equation for unsaturated soil water flow as (Li and Guo 2017):

$$\frac{\partial \theta}{\partial t} = \nabla(k\nabla\psi) - \frac{\partial k}{\partial z} - S(x,y,z,t) \qquad (1)$$

where θ is the volumetric water content; *t* is time; *k* is the unsaturated hydraulic conductivity; ψ is the soil suction; and *x, y, z* are the Cartesian coordinates.

The distribution of soil suction predicted by the numerical model is shown in Figure 17. The effect of tree root drying and garden over-watering is clearly evident in Figure 17. The contour plot of the calculated ground surface movement after 90 days (Figure 18) shows that a severe shrinkage settlement occurred at the north-west corner of the house (near to large Eucalypt tree) while heaving of foundation soil occurred near to the front garden (in the front of the living room). The maximum predicted ground settlement was about 4.2 cm, while heave was almost 4 cm. The maximum differential movement was 8 cm. The deformation pattern compared reasonably well with the observed distortion pattern of the slab. The calculated level differences between Point A (the north-west corner of bedroom 1) and Point B (the south-east corner of living room) are plotted in Figure 19.

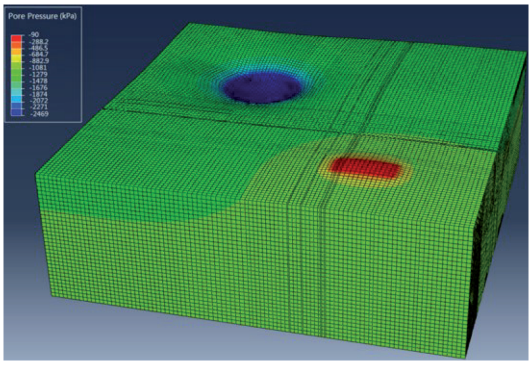


Figure 17. Contour plot of soil suction distribution after 90 days (deflection magnified by 15)

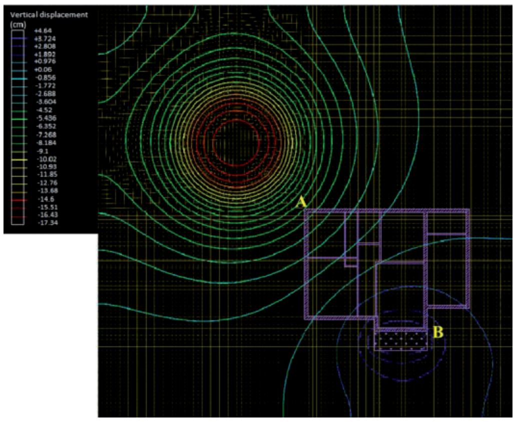


Figure 18. Contour plot of calculated ground movement after 90 days

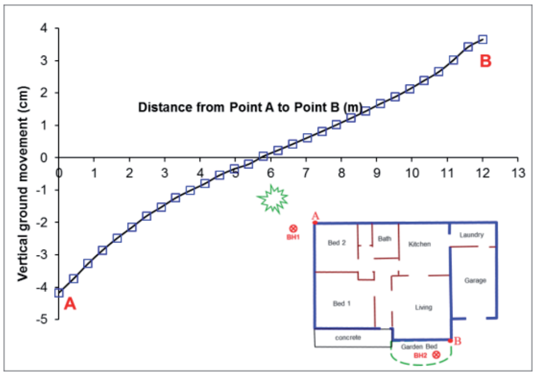


Figure 19. Calculated ground surface movement between Point A and Point B

3.4 Lessons learnt

The case study emphasized the importance of an understanding of the water demands of tree and zone of influence of tree roots. Although the underpinning and repair works appear to have generally stabilized the large distortions previously experienced by the building, the distortion and cracking due to the foundation movements are still occurring. This can be attributed to the shallow depth of underpins (less than 2 m). Past research has shown that the drying influence of tree roots can extend to depths of 3-5 m in the dry season (Cameron, 2001). As the expansive soil profile on this site is at least 4 m deep, tree drying influence below the level of the underpinning was quite plausible in this case. The soil suction profiles have clearly indicated that the depth of influence of tree roots was approximately 3.5 m, i.e. more than 1.5 m below the level of underpins.

The differential movement induced by tree root drying was exacerbated by a well-watered small garden, which caused the swelling of foundation soil and resulted in slab heave at the south-east corner of the living room. The numerical analysis indicated that the maximum vertical differential movement of the ground was 80 mm. The original footing slab system was relatively shallow and inadequate (by current standards) to cope with such a large differential movement. A much stronger footing would have been required in this case.

There is no simple method to prevent cracking and movement in residential buildings constructed on highly reactive soils in the vicinity of large trees with high moisture demand such as the large Eucalypt on this site. However, it is the writer's belief that the distortion and cracking would have been significantly reduced, if underpin depth greater than 3.5 m or a pier-and-slab type footing system had been adopted for this house.

4 CONCLUSION

Two research projects, the long-term field study of the atmosphere-tree-soil-footing interaction in a suburban environment and a case study of a residential building damaged by tree root drying, were introduced in this paper. The results of long-term field monitoring indicate that greater transpiration occurred during summer and the presence of the tree resulted in an increase in the depth of soil moisture variation. The case study has clearly shown that trees, growing in close proximity to a house could cause more severe damage to the buildings than the expected moisture changes due to seasonal influences and redistribution of soil moisture arising from construction on the site.

ACKNOWLEDGEMENTS

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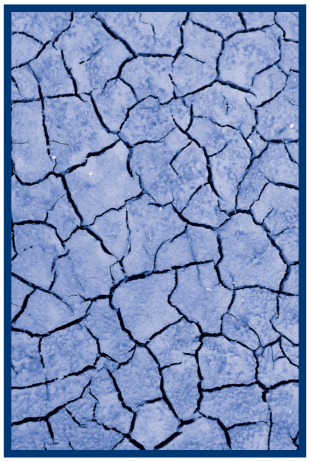

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