



**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.

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David Glover

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# The interplay of site reactivity, design practice and construction procurement in structural failures on expansive clay sites

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## ABSTRACT

The expansion of housing into the Western suburbs of Melbourne has involved, effectively, mass-production of conventional, masonry veneer dwellings on highly reactive sites. The design favoured by constructors for reasons of cost and speed is the "waffle pod" system, typically 385mm deep on highly reactive sites, with the performance of such footings generally predicated on adequate control of soil moisture in the foundations close to the footprint of the building, both during construction and in the permanent condition.

Damage to masonry facades and excessive floor slab deformations, evidently due to serviceability failure of footing systems, have led to recent publicity and litigation. Whilst the underlying geotechnical characteristics may be causative of soil heave, the unique characteristics of waffle pod footing systems and the associated landscaping and drainage provisions stipulated by the designers, along with the method of procurement of the house itself point to the contribution of systemic and contractual factors in footing failures.

A further aspect is the interplay of differing deformation criteria between AS2870 ("the Standard") and the structural design standards such as AS1684, whereby, again, dissociated procurement and design of building components (footings and roof trusses in this instance) can lead to incompatibilities in structural behaviour and consequent damage to cladding and finishes. This paper examines the interplay of geotechnical, structural, construction detailing and contractual aspects that can lead down the path to poor footing performance, dispute, and litigation. The question is raised as to whether, given these relatively gross uncertainties relating to the input parameters for codified standard designs and design methods, the degree of refinement and accuracy implicit in the Standard is warranted, and whether more robust standardised designs are justified.

## 1 INTRODUCTION

The characteristics and technical challenges of highly reactive sites are well defined in the literature, and have been addressed (with periodic and ongoing development) in the Australian Standard AS2870 since 1986. This standard incorporates relatively generous performance standards (refer AS2870 – 2011: Table C1) with a presumption of footing design and construction occurring as part of an integrated engineering system that includes footings, superstructure and drainage, designed as a compatible and interacting assembly.

In the case of drainage, the requirement for control of runoff is further supported in consumer literature prepared by The CSIRO (Lewer, 2003) and the Victorian Building Authority (*Housing Engineering, Design and Research Association*, August 2015) - in terms of the implicit obligations of the owner of a site in taking landscaping and drainage measures sufficient to control soil moisture - such that the standard designs or procedures in AS2870 will perform.

With building superstructure (specifically roof trusses) it is the case that *maximum* deflections under specified loads are described in the respective standards - for example Table 4.1 in AS2870-2011 or Appendix B of AS1720.1-2010). However, the requirement for timber roof systems to accommodate deformations imposed by the sub-structure is not explicit in the Standard, even though the forces in timber roof trusses consequent of footing movement may be very significant (Ytrup and Drew, 2012).

In the respective cases, that is, (i) footing and drainage design, and (ii) footing and superstructure design, the components are often either being supplied under entirely separate contracts, or are designed and supplied as substantive elements to the structural design prepared by the consulting engineer. In the case of drainage design, the landscaping and external drainage works are often to be completed by the owner, effectively acting as an owner-builder. In the case of roof trusses, these are typically supplied as a design and construct element under the main building contract.

A consequence of this fragmentation in design and procurement of structural components of residential buildings is that elements critical to the performance of footings (viz. external drainage and paving) are significantly delayed in procurement, or in fact never constructed. Furthermore, in respect of the supply of roof structure for houses, deformation compatibility between superstructure (roof trusses) and footings is not realised. In both cases significant building distress can be consequent of these omissions and inconsistencies.

## 2 FOOTINGS AND DRAINAGE DESIGN

### 2.1 The design of footing systems with associated drainage provisions for dwellings

The fundamental reliance of standard footing systems on site drainage and maintenance is outlined in clause C1.3 of the commentary to AS2870 2011 (BD-025, 2011):

*“To avoid extreme moisture conditions, it is essential that owners become aware of their responsibility to care for and adequately maintain a reactive clay site. Guidance to the owner is given in Clauses 1.3.2 and 1.3.3, and a CSIRO Building Technology File 18...entitled: “Foundation maintenance and footing performance: a Homeowner’s Guide”...It is suggested that a copy be given to the new homeowner by the builder. The problem of subsequent owners is not simple, and it is suggested that the owner should pass on the information sheet. In reactive soil areas it is expected that the building surveyor will be interested in ensuring that the Information Sheet is disseminated. Site maintenance after occupation becomes part of an owner’s accepted responsibilities.”*

Earlier this same clause notes:

*“If the homeowner’s maintenance role is to be diminished, or higher expectations of performance are demanded, then the footing system should be designed according to engineering principles...if extreme moisture conditions occur (which may have been avoided had a reasonable level of site maintenance been achieved), then significant damage will be more likely and probably more severe. To attempt to design for such conditions on every clay site would add significantly to the cost of housing in Australia.”*

The first consideration in respect of the foregoing design philosophy, is its reliance on subjective assessment of the acceptability of a given frequency and magnitude of damage to the walls and floors of dwellings. AS2870 is reasonably explicit on this subject in clause 1.3.1 (as well as in Appendix B of the standard):

*“Buildings...(designed to AS2870 and with a drainage and maintenance regime as outlined in the foregoing)... are expected to experience usually no damage, a low incidence of damage Category 1 and an occasional incidence of damage Category 2.”*  
*“For most situations Category 0 or 1 should be the limit; however, under adverse conditions, category 2 should be expected...”*

The relevant damage criteria are noted in Appendix C of AS2870, and it should be noted that in this context cracks up to 5mm wide (Category 2) are considered “slight” in Table C1 of the Standard. To be clear, the designs and approaches of AS2870 are predicated on assumptions of: (i) what level of damage is acceptable to the consumer in a new dwelling, and (ii) that the external landscaping and works will be constructed and maintained to a minimum standard assumed in the design standard.

It is the contention of the author that that in the context of new dwellings built for an increasingly diverse population of consumers, these underlying assumptions are open to question. The acceptability of 2mm to 5mm wide cracks in the wall of a house less than one-year old, with consideration of contemporary consumer expectations, would have to be queried. Yet this is what is referenced in the Standard, and this level of damage is not infrequently observed in virtually new dwellings in the Western suburbs of Melbourne, particularly in the case of “waffle pod” rafts built on highly or extremely reactive



Figure 1. Example of a “slight” (category 2) crack to AS2870 (noting that plasterboard is rarely articulated).

sites. (The susceptibility of “waffle pod” footings to damage is a multifactorial issue relating to its relatively shallow founding depth, construction practices, vulnerability to drainage issues, and stiffness characteristics. Refer section 2.3 following).

The CSIRO document (Lewer, 2003) referred to in the Standard AS2870 is a 12-page normative document incorporating considerable discourse on causative factors of damage due to footing movement, as well as containing construction advice on exterior landscaping. Another CSIRO publication (Lewer, A builder’s guide to preventing damage to dwellings, 2003) notes:

*“It should be understood that ground drainage is a complex subject, often requiring the expertise of an engineer who is suitably competent in hydrology and geotechnics. For anything other than straightforward problems, even drainers or builders experienced in installing ground drainage should engage a consultant to assist in the design.”*

Given this, to be confronted with the CSIRO BTF 18 document provided by the building surveyor upon hand-over of a new house, might understandably provoke consternation on the part of the new building owner.

The reality is that external, landscaping works are generally excluded from the main contract, and the exterior of a dwelling when handed over to a new home owner is something like that shown in Table 1 below. In this typical situation, the external perimeter of the house is raw earth, without any appropriate landscaping provisions (often specified in the engineer’s footing drawings) namely; (i) surface fall away from the dwelling footings, (ii) impervious paving to the perimeter of the house, (iii) spoon drains and/or other methods of diverting and collecting stormwater, and (iv) other provisions for sealing the building perimeter against water infiltration into the foundation.

## 2.2 Control of water on the site

Compounding the foregoing is the increasing prevalence of relatively very small sites in tract housing development, whereby it is not possible to simply divert water from the dwelling, as the building

may be in close proximity to the boundaries or adjacent buildings. The result being that water is often diverted a short distance from the edge of the building and ponds, soaking the sub-grade and sometimes exacerbating the ground heave issues.

As noted in the foregoing, design engineers may provide generalised details of perimeter paving designed to divert water away from the edge of the house, but often this documentation provision is ineffective because:

- (i) the paving and surface drainage is considered to be part of the "landscaping package" by the builder. Although this element is key to the functionality of the structurally designed footings, it is not built, or is delayed indefinitely in construction, due to the lack of appreciation of the issues, or insufficient financial resources of the owner
- (ii) there is insufficient fall provided to the perimeter concrete slabs (if present) - the water ponds and infiltrates into the building's foundations,
- (iii) there is no effective seal between the walls and the paving and so the water infiltrates into the sub-grade, and in the case of a waffle slab, under the building via a packing sand layer and,
- (iv) the water is not collected and discharged to the stormwater system. Accordingly, water ponds in relative proximity the building's walls, and causes soil heave with damage to the building or adjacent property.
- (v) Garden beds and planting are indicated in landscape designs without reference to AS2870 or the design engineer's recommendations.
- (vi) The common practice of using sand as a construction platform to receive the damp-proof plastic ("poly" sheeting) can be counter-productive as it provides a highly porous path for the infiltration of water into the foundations.

Further to that outlined in the foregoing, water must carefully controlled during construction as ponding in the excavation and saturation of the sub-grade can cause a "pre-heave" situation. Subsequent drying out of the foundation soil will cause very significant soil shrinkage and consequent "centre heave" on highly reactive sites.

It would appear clear therefore, that improvement in the procurement of the exterior works (with drainage provision) attendant to successful footing performance recommends itself to improve the performance of footing systems in Melbourne's Western suburbs. Nonetheless considerable uncertainties remain regarding the efficacy of controlling soil moisture for general housing sites into the indefinite future, and relying upon third party technical literature to adequately inform the consumer on the subjects of site maintenance and drainage design.

### 2.3 Waffle pod slabs

Waffle slabs present substantive issues to conventional "stiffened raft" designs in AS2870 as they are shallower and maintain a constant soffit/excavation surface to the foundation material. For example, for a "Class H1" site, a waffle slab will

typically be 385mm deep and of constant depth (refer Figure 1, whereas a stiffened raft correspondingly would have downturn beams 600mm deep from a slab 120mm thick that form a barrier to the ingress of water to the foundation material.

Furthermore, on sloping sites the waffle system is typically kept at a constant level, in consequence the external ground surface may come in close proximity to the soffit of the footing system; sometimes even with the slab soffit exposed at the edge. The use in Victoria of permeable sand under waffle slabs in combination with the shallow footing depth means that water can percolate under the building with relative ease and cause soil expansion due to osmotic and solute suction action associated with clay soils.

In the experience of the author, the standard AS2870 waffle design for a class H2 site (a relatively common category in Western Melbourne), does not always provide sufficient structural depth to provide the performance level implied in AS2870. Given the degree of uncertainty of the potential for control of soil moisture on housing sites over an indefinite future, it is in the view of the author advisable for design engineers to increase the standard 385mm waffle design(s) to a 460mm *minimum* structural depth for articulated masonry veneer dwellings on class H2 (and probably H1) sites. It may be observed however, that for so long as minimum provisions counter to this exist in the Standard, commercial pressures would make this an unlikely outcome in the main.

This increase in structural depth would also provide the benefits of deeper founding depth to; (i) provide a more reliable founding on natural soil, (ii) mitigate the infiltration of surface runoff under the waffle footing system, and (iii) lessen the occurrence of the waffle slab soffit "daylighting" on sloping sites with the attendant potential infiltration of run-off, under-scour and occupation of any voids by vermin.

As noted in the foregoing, there are two key aspects needed in combination for footing design on highly reactive sites: (i) controlling soil moisture change, and (ii) provision of sufficient footing stiffness to accommodate the reactive soil – structure interaction. The reality is that for one reason or another, soil moisture control measures may be (or may become) ineffective, and the building footings will need to rely on reserves of structural strength and sufficient stiffness to prevent undue damage to the superstructure. In respect of this (with consideration of current consumer expectations), and particularly in the environment of Melbourne's Western suburbs, it is in the view of the author advisable to have higher minimum, structural standards for waffle footings in particular, than the minimum levels often adopted from AS2870 - 2011.

It is implicit therefore, that in the absence of a higher level of footing design, the only recourse to prevent significant cracking and damage is rigorous control of soil moisture. This clearly implies that the drainage and landscaping provisions, upon which soil moisture control depends, must be more reliably provided – as noted in section 2.1 of this paper.

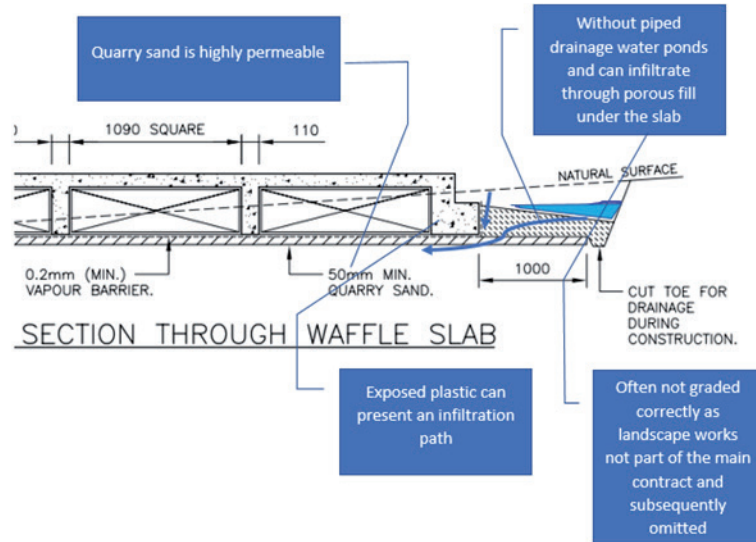


Figure 2. Typical “waffle pod” perimeter detail.



Unsealed building perimeter with no collection and sub-surface discharge of stormwater. Permeable “tan-bark” landscaping.



Unsealed building perimeter with reverse slope towards footings. No stormwater collection or diversion. (Note soil cracking indicating highly reactive clays present.)

Figure 3. Photographs of completed house construction in the Western suburbs of Melbourne.

### 3 THE INTERACTION OF FOOTINGS AND DOMESTIC TIMBER ROOF TRUSSES

Nail-plated timber roof trusses have been used in residential construction since the 1950’s, generally designed as “simply supported” structural elements, independent of internal walls for vertical support.

In recent years the residential timber truss industry has exploited internal walls to support roof trusses, but generally without consideration of support movements. Footing systems designed to AS2870 “Residential slabs and footings construction” have permissible vertical movement limits of footing beam span divided by 400, with a maximum of 30 mm for articulated masonry veneer.

These support movements are often realized and should not be disregarded in the structural design of the roof structure as the limited ductility of timber structures, especially struts in compression does not allow ready redistribution of structural actions. Consideration of structural actions induced by support movement and deformation compatibility is vital in

situations of limited ductility – such as nail plated timber trusses (refer Figure 5).

It is now relatively common for truss fabricators, who are also the structural designers for the trusses, to take advantage of internal walls for support of the roof trusses. The design of such trusses usually proceeds

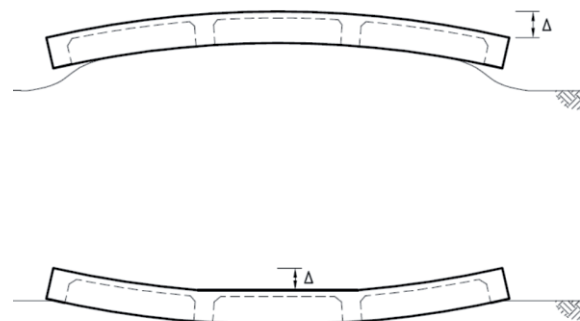


Figure 4. Footing movement: centre heave (above) and edge heave cases respectively.

upon the assumption that the trusses supports do not move. This is often an inaccurate assumption, most especially for buildings constructed in areas with reactive or expansive clay foundations.

The actual structural actions in trusses, with realistic support movements included in the design, may be an order of magnitude different from the solution with no support movements. Structural elements originally designed as ties to carry tension forces, may become subject to compression.

Timber roof trusses are relatively stiff elements with typical deflection in the order of 1 in 1000 of their span. The footing systems which support a residential building is based on design deflection limits of about 1 in 400 of the “span” or width of the footing system. When the roof trusses are coupled to the footing system by the internal wall frames an interactive and complex structural system is often the consequence.

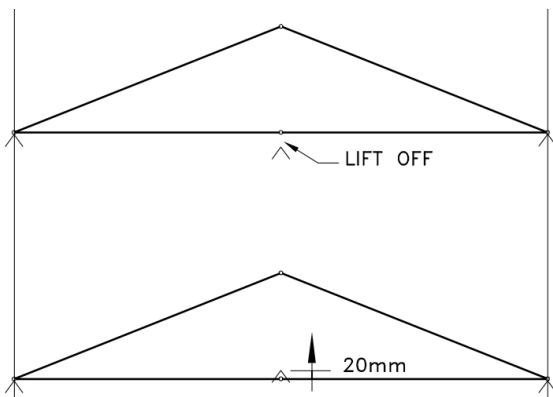


Figure 5. Consequence of footing movement on rigid trusses employing internal walls for support: edge heave (above) and centre heave (below) cases

Current practice in the sub-contractor “design and construct” provision of statically indeterminate timber trusses to residential and other projects typically does not consider structural actions induced by foundation movement effects. AS1170 in its various parts does not specifically emphasise this issue, and the deformation compatibility issues between the various design standards (AS2870, AS1170, AS1720) are not in general considered by industry.

A basic analysis (Yttrup and Drew, 2012) of indeterminate timber truss structures subjected to even relatively small foundation movements demonstrates that structural actions may be generated that are not insignificant relative to individual element ultimate capacities, with load reversals occurring in some circumstances. More commonly, fracturing of the nail plated joints occurs where connections are subject to unintended tension (refer Figure 6), or the entire internal wall that is attached to the truss may lift off the concrete slab (refer Figure 7).

Accordingly, the design of such trusses should be carried out with reference to such imposed movements and careful consideration given to the range of support movement effects that might occur during the life of the structure.



Figure 6. Fractured truss chord at a tie-down to internal wall.



Figure 7. Internal stud wall attached to roof trusses, entirely lifting off floor slab due to edge heave.

From the point of view of the base building designer, the trend of design and construct delivery of timber roof trusses with nominal imposed load analysis needs to be carefully considered, and likely additional design criteria prominently outlined in the design documents of the engineer of record. As noted in previous contributions by the author (Yttrup and Drew) more specific consideration of these issues is considered appropriate for revised editions of the respective Australian design Standards.

#### 4 CONCLUSION

The successful design of a building structure recommends an integrated, systems approach to its engineering elements. In the case of the engineering aspects in house design for reactive sites considered in this paper, the engineered components include the concrete (raft) footing design, the site drainage / siteworks (*viz. civil engineering*), and the structural timber roof trusses.

Compatibility of these engineering elements is needed, but the approaches generally adopted in the building contracts for houses often mean that effective perimeter paving and drainage to dwellings is not provided, and timber roof trusses are not designed with due consideration of foundation movement.

Footing performance to the relevant Australia design standard is dependent on effective site drainage and appropriate landscaping works. To achieve this,

complete, engineered pavement and drainage design are recommended to accompany footing designs, and to be built with the house structure.

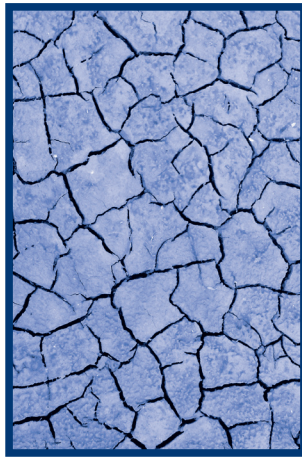
If an appropriate drainage and soil moisture control regime (such as provided by a complete, engineered drainage system) cannot necessarily be relied upon into the foreseeable future, then in the context of contemporary consumer expectations, there are, in the opinion of the author, grounds for providing more structurally robust footing designs for highly reactive sites in the Standard.

It may also be concluded that the residential footing design standard could benefit from more defined consideration of the deformation compatibility of the roof structure for houses, if these timber truss designs are to continue to adopt internal walls for support. Given that this design approach for roof trusses is to continue, the case for design standards to adopt less flexible and stronger, standardised footing systems is further supported.

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