



**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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# Two case studies of movement and damage in relatively new domestic dwellings

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## ABSTRACT

This paper presents cases of damage in two dwellings in Victoria that occurred because of soil movement. The paper explains the mechanisms of movement that lead to the damage, based on site specific geotechnical investigations.

In the first case study, significant localised heave occurred beneath the front section of a residence supported on a slab founded on a highly reactive, compacted clay fill. The other sections of the slab exhibited little movement. No site drainage issues were observed around the front of the building, where the heave has occurred. The front section of the slab was constructed over an access roadway for heavy earth moving machinery that was required during development of the estate where the house was built. The effect of the heavy machinery traffic on the performance on the fill, and therefore, on the slab is examined and discussed in this paper.

The second case study relates to significant localised heave beneath the front of another residence supported on a slab founded on highly reactive clay soil. The other sections of the slab exhibited little movement. The subject site sloped from front to back, requiring site levelling works. As a result of these works, the front section where the heave has occurred, is located within a site cut constructed just prior to the construction of the slab, whilst the rear section of the slab is suspended on deep piers over the filled area. The effect of the site cut, undertaken just prior to slab construction, on the performance of the slab is examined and discussed in this paper.

## 1 INTRODUCTION

The purpose of this paper is to explore the likely reasons why, in both cases, such significant, localised and differential heave occurred beneath the slabs. Both of these dwellings, are founded on highly reactive clay soil. The geology of the site in Case Study 1 is Quaternary Basalts. This site is located in climate category 3 as provided in AS 2870 2011 and was originally classified as Class P due to fill. The geology of the site in Case Study 2, is Tertiary Limestone Deposits. This site is located in an area of climate category 2 and was originally classified as Class H. Both buildings are supported on waffle type slabs and exhibited evidence of heave and associated distress, within one to two years after construction. In both cases the heave has occurred differentially, with the front sections of both buildings experiencing the most heave. The other sections of both buildings appear to be performing within normal seasonal expectations.

No significant issues with site drainage or plumbing services were observed around the sections of the slabs that had heaved. Both sites has some site drainage and plumbing issues around other unrelated areas of the sites. Based on the consistent floor levels and the lack of distress in these areas, it is considered that these issues have not contributed significantly to the movement and distress experienced by the affected sections of the subject buildings. The amount of differential heave in both buildings was observed to be considerably greater than would normally be expected, given the relatively minor nature of the plumbing and drainage issues, in each case. The construction time frame is also likely to have influenced the heave to some degree, however, it is unlikely to be the main reason for the heave, because only the front sections of both buildings have been affected.

## 2 CASE STUDY 1

### 2.1 Type of Structure

The building that is the subject of this study is a double storey dwelling which was constructed around 2 years ago. The house is brick veneer and has been constructed on an engineer designed waffle slab. The slab was designed to be founded on the fill placed as part of the estate development works. Although the reactivity of this fill was not tested, during our site specific geotechnical investigation it was clearly evident that the filling was of Quaternary Basaltic origin.

### 2.2 Background

The current owners have occupied the subject building since completion and report that movement and distress became apparent around the front of the house, soon after construction.

The plumbing services around and beneath the subject building have been investigated, with only minor faults being reported. None of these faults were in the area where the most significant heave is apparent. The faults have been rectified.

Based on satellite imagery from Nearmaps, this section of the estate was completed around two years before the slab was constructed. The imagery clearly shows that the section of this site directly beneath the front of the slab was used as the main access roadway for the heavy earth moving machinery required for estate construction. The time frame satellite imagery from Nearmaps indicates that heavy equipment continued to pass over the front of the building area up until about 12 months prior to construction.

**2.3 Site Conditions**

**2.3.1 Site Drainage**

Site drainage around the affected front section of the house is fair with the perimeter ground surface consisting of paving and established gardens, which slope away from the house adequately. The site drainage on the east side of the house is poor, as the ground surface consists of poorly graded crushed rock. No significant heave is apparent on the east side of the building.

**2.3.2 Soil Moistures**

Soil moisture content tests were undertaken on samples of the highly reactive, clay fill material. One sample was collected beneath the slab edge beams that exhibited the most heave and another sample was collected as a control from the rear of the site. As can be seen from Table 1, there was no significant variation in the moisture levels between the 2 samples. In most cases, heave due to significant soil moisture differential is reflected in the soil moisture content tests. This suggests that the heave is unlikely to be the result of a locally elevated soil moisture condition, as is typically the case.

**2.4 Movement and Distress**

As can be seen from Figure 1, which shows the floor levels, significant heave has developed beneath the front section of this building. The contours are closely spaced at the front of the house indicating movement. The floor level contours across the rest of the house are meandering and spaced well apart, indicating that the remaining sections of the slab are performing within normal seasonal expectations.

The distress in this building manifested in the form of internal, diagonal plaster tears, distortion of internal door frames perpendicular to external walls, separation of cornices and ceilings and horizontal brick work cracking.

**2.5 Discussion**

In this case, there was insufficient geotechnical evidence to support the conclusion the heave is the result of significantly elevated soil moisture levels commonly caused by plumbing leaks or site drainage issues. The soil moisture content tests revealed that the soil in the area where the heave occurred had a similar moisture condition to the soil at the control location. Based on many hundreds of similar investigations, this result is considered to be atypical. In vast majority of the heave cases investigated by the author, the moisture content at the location of the heave is significantly elevated compared to the control location.

From past experience, there have been many cases where heave has been caused by over compaction of highly reactive clay subgrades, usually placed dry of optimum moisture content. In these cases, because

*Table 1. Soil moistures – Case study 1*

Depth	Borehole 1	Borehole 2
500 mm	28.1%	24.5%

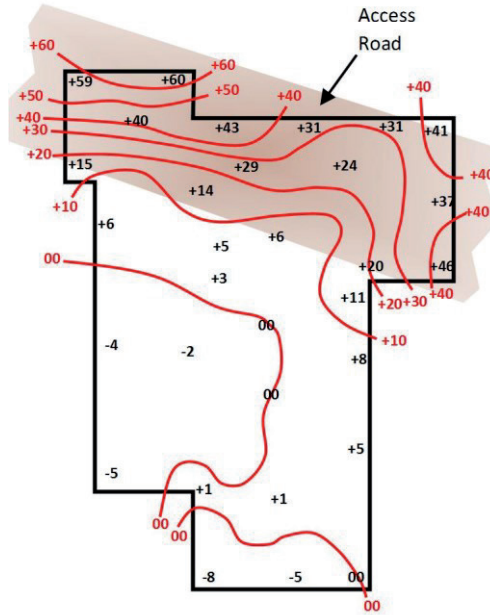


Figure 1. Floor Levels, Case Study 1

the entire slab is supported on filling with a similar degree of compaction, the heave tends to occur more uniformly beneath the slab. However, in a number of recent cases, including this case, significant, differential heave has developed in slabs founded on compacted, highly reactive, clay filling.

Machinery traffic over the access roads beneath the front of the slab (refer to Figure 2) is likely to have over compacted the highly reactive clay filling in this area, making it more susceptible to heave, or swelling upon re-wetting, than the reactive clay filling beneath the other sections of the slab. This susceptibility is explained in more detail below. It is possible that the soil re-wetting may have been compounded by the establishment and maintenance of gardens around the newly constructed domestic dwelling.



Figure 2. Image from Nearmaps, showing the location of the access road with respect to the subject building.

In addition to the above, it is likely that the heave has been compounded by the effective removal of the cracked zone from the reactive soil profile. This aspect is shown in Figure 3 below.

In reactive clay soil profiles, seasonal drying causes desiccation cracks in the soil. In the Quaternary Basalts west and north of Melbourne, these cracks can be over 100 mm wide and tend to close up in the seasonally wetter periods as a result of the reactive clays swelling with re-wetting.

Filling placed over the natural soil leads to material falling into the cracks. Compaction of the filling tends to force material into the cracks. Over consolidation of the filling as a result of continued heavy machinery traffic, is likely to increase the density of the “back fill” in the cracks, which effectively eliminates the cracked zone of the soil profile within the Hs depth. The filling of the cracks reduces the capacity of the cracks to absorb soil swelling, upon re-wetting of the underlying reactive clay, resulting in greater upward surface movement. This process could be considered to be a ‘man made gilgai’.



Figure 3. Photograph of the “Cracked Zone” (courtesy Paul Saunders). This image is not of the subject site it is for illustration only.

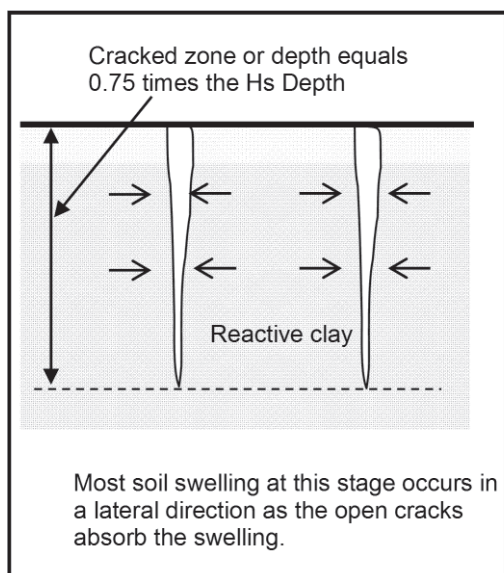


Figure 4. The “Cracked Zone” Diagram.

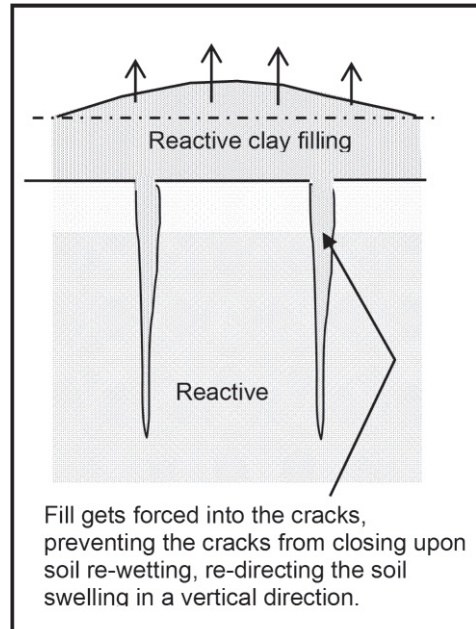


Figure 5. The filled, “Cracked Zone” Diagram.

In each the recently investigated cases, where significant differential heave has occurred in the absence of soil moisture variations, a common factor has become apparent. It is evident that the section of the slabs that have experienced the most significant heave, have been located directly over access road ways used by heavy earth moving machinery during estate development, prior to the construction of the slabs.

### 3 CASE STUDY 2

#### 3.1 Type of Structure

The building that is the subject of this second study is a single storey dwelling which was constructed around 7 years ago. The house is brick veneer and has been constructed on an engineer designed waffle slab.

#### 3.2 Background

At the time of the investigation, the subject building was occupied by long term tenants. The tenants reported that the movement and distress around the front of the building became apparent within the first one to two years of construction, and although some distress is still evident in this area, it appears to have stabilised over time.

The front of the building is located at the base a cut, and initially the ground surface adjacent to the dwelling sloped inwards. These issues were addressed by grading the ground surface away and by the installation of additional drainage. The grated surface drain and driveway at the front of the building have recently experienced distortion due to the heave and it is also partially blocked with leaf debris.

The plumbing services around and beneath the subject building have been investigated. Some breaks were discovered in the storm water pipes, however, these faults were located away and downslope from the area where the most significant heave is apparent. The faults have been rectified.

### 3.3 Site Conditions

The site slopes relatively steeply from back to front and required significant site levelling works to facilitate the construction of the slab. These works included a cut at the front and fill at the back (refer to Figures 7 and 8 below). It is apparent that the fill material is site derived from the cut area. Dynamic Cone Penetrometer testing indicated that while the fill may have been tracked rolled it was not placed under controlled conditions. The site levelling was undertaken just prior to the construction of the slab. The front section of the slab is located in the cut and has been designed and constructed to be founded directly on the highly reactive clay exposed in the cut area. The rear of the slab extends into the filled area and has been designed and constructed to be fully suspended and supported on piers founded well into the underlying natural clay soil below the filling.



Figure 6. Case Study 2 subject site, just prior to construction.

#### 3.3.1 Site Drainage

The site drainage around the front of the slab is relatively poor as a result of this section of the slab being founded within a significant site cut, below road level. The site drainage issues in this area were compounded by some the driveway and grated drains becoming misaligned due to the significant movement of the slab in this area. The site drainage around the remaining sections of the slab appears to be fair, with the ground surface sloping away.

#### 3.3.2 Soil Moistures

Soil moisture analyses were undertaken on samples of the highly reactive, clay material. However, it was not possible to collect a sample from beneath the slab edge beams that exhibited the most heave. A sample was collected from the closest location which was to the side of the house and another sample was collected as a control. As can be seen from Table 2, there was a significant variation in the moisture levels between the 2 samples.

It is important to note, that borehole 1 was located in the vicinity of the reported plumbing leaks which would explain the elevated soil moisture levels at this location. In addition, it should be noted that although the sample of soil from borehole 2 was taken from the

same depth into the natural sandy clay as borehole 1, there was more material overlying the natural sandy clay at the location of borehole 2, which is also likely to explain the lower moisture content of the sandy clay soil at this location.

It is interesting to note that the section of the slab located in the vicinity of borehole 1 which is where the plumbing leaks were reported and measured soil moisture levels were elevated, is not the section of the slab where the heave is most apparent. The most significant heave has occurred beneath the section of the slab that is located in the deepest section of the site cut.

Table 2. Soil moistures – Case study 2

Depth	Borehole 1	Borehole 2
500 mm	37.6%	22.2%

### 3.4 Movement and Distress

As can be seen from Figure 9, which shows the floor levels, significant heave has developed beneath the front section of this building. The contours are closely spaced across the mid to front section of the building, which is located within the site cut. The floor level contours across the rear of the house are spaced much further apart, indicating that the remaining sections of the slab are performing within normal seasonal expectations. While the floor levels at the rear of slab are slightly lower than the central sections, this degree of difference is not considering to be outside of the normally expected construction tolerances. The lack of any distress in this area suggests that this difference is likely to be due to initial construction differences.

The distress in this building manifested in the form of internal, diagonal plaster tears and distortion of internal door frames perpendicular to external walls.

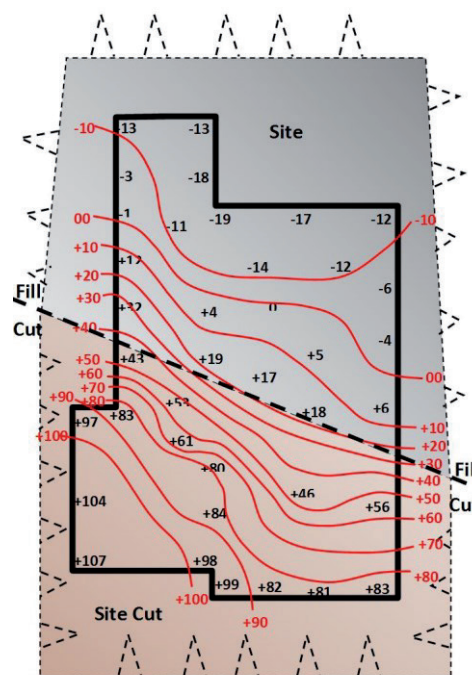


Figure 7 - Floor Levels, Case Study 2.

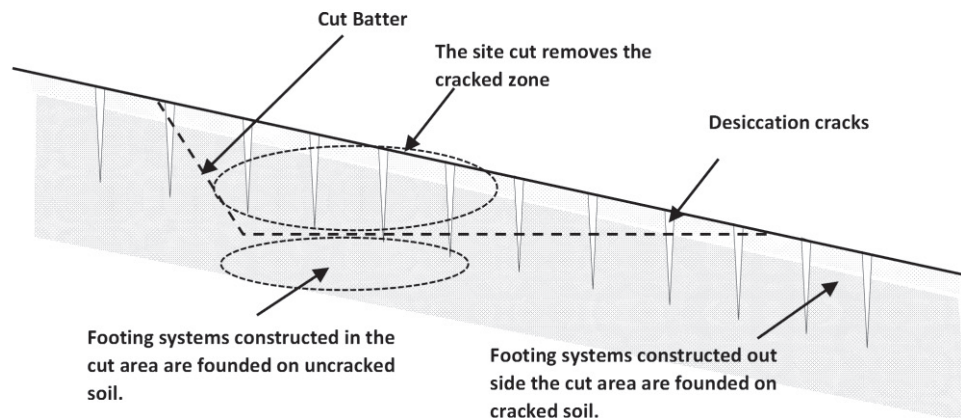


Figure 8 – Removal of Cracked Zone of soil profile due to site cutting

### 3.5 Discussion

In this case, there was also a lack of the normal empirical evidence that would be expected to justify a conclusion that localised heave was the main cause of the movement and distress in this building. Although one of the soil samples was found to be relatively wet, this elevated soil moisture condition was not in an area where the heave was most apparent. A local plumbing leak had been reported in this area, but this leak was down slope from the building. The front of this building is located in a deep site cut, and as a result there are some site drainage issues in this area.

In a number of cases, including this case, significant, differential heave has developed beneath sections of slabs located within site cuts on reactive clay sites. What is common in each of these cases, is that the site cuts were undertaken just prior to construction of the slabs.

Prior to site cutting, the underlying reactive clay soil is relatively protected from excessive moisture variations by the overlying soils. Once this overburden is removed, it exposes the underlying soils for the first time. This exposure leads to significant, short term moisture variations in the underlying, highly reactive clay, which in turn, can lead to soil and footing system movements.

The type of soil movement is dependent on the seasonal conditions at the time the site levelling works are undertaken. If undertaken in seasonally wet conditions, the cut exposes relatively moist clay, which is then, particularly susceptible to future drying, whilst cuts undertaken in the seasonally drier months, expose relatively dry clay which is then, particularly susceptible to wetting.

In this case, it is apparent that the site cut was undertaken in 2010 towards the end of an extended period of drought. As a result of this, it is highly likely that the clay in the cut area would have been relatively dry, making it particularly susceptible to wetting once it was exposed in the cut. This significant potential for soil moisture change is consistent with the timing and location of the heave that has occurred in this building.

In addition to the above, the site cut at this property removed virtually all of the cracked zone from the soil

profile within the site cut. The section of the slab in the cut area was therefore constructed on uncracked clay, which has reduced capacity to absorb soil swelling, upon re-wetting. Similar to Case Study 1, the effective removal of the cracked zone of the soil profile beneath affected sections of the slab is likely to have significantly increased the potential for heave to occur in these areas.

## 4 CONCLUSION

The two properties that are the subject of this paper, experienced relatively unique site conditions, that lead to, significant, localised, differential heave. Detailed geotechnical investigations revealed that the typical causes of heave on highly reactive clay sites (i.e. plumbing insufficiencies and/or poor site drainage) were not particularly pronounced around the affected sections of the buildings.

In both cases, the significant, localised, differential heave was attributed to the effective removal of the cracked zone of the soil profile, beneath the affected sections of the slabs. When the cracks in a dry, reactive clay soil profile are effectively removed, either by filling, or by site cutting, the capacity of the soil profile to absorb swelling movements upon re-wetting is reduced. When cracks are present, the initial soil swelling is mostly absorbed as the open cracks close with soil swelling. In the absence of cracks, the soil swelling is redirected vertically, where it can cause significant heave beneath footing systems founded on such profiles.

In Case Study 1, the cracked zone was effectively removed by the installation of over consolidated, highly reactive clay filling, which is likely to have completely filled the desiccation cracks in the underlying soil as a result of continual heavy machinery traffic over the estate construction roadway beneath the affected section of the slab.

In Case Study 2, the cracked zone was removed by a significant site cut, undertaken just prior to construction, beneath the affected section of the slab.

The purpose of this paper, is to raise awareness, of atypical geotechnical factors which can have a significant impact on the performance of lightly loaded structures, on reactive clay soil profiles. The factors

raised in this paper are readily identifiable, by detailed geotechnical investigations.

These investigations should obviously include a site specific geotechnical investigation, undertaken by an experienced geotechnical practitioner. Laboratory based soil testing is not typically undertaken for geotechnical investigations related to dwellings. Even if it had been undertaken in each of these cases, it is unlikely to have identified these atypical factors. It is important to understand that in addition to onsite soil logging, geotechnical investigations should also include a review of the readily available, up to date, satellite imagery which reveals the conditions around the site, in the important period before testing and construction.

With respect to sites that are subject to significant site levelling works, the sites should be re-investigated by a suitably experienced geotechnical practitioner, after the site levelling works have been completed. The purpose of this re-investigation, is to determine if the original site classification and/or footing recommendations contained in the original geotechnical report remain appropriate, or if they need to be re-considered.

By raising awareness to the two atypical factors highlighted in each of these case studies, it is hoped that these specific factors will be more readily considered, by the engineer responsible for carrying out the footing design on such sites.

Given that the design engineer is made aware of these factors, and is provided with the relevant geotechnical advice relating to the presence of these factors, an appropriate footing design should be able to be prepared, by suitably qualified and experienced engineer using the methodology outlined in Section 4.0 of AS 2870 2011.

In conclusion, it is considered that the performance of lightly loaded structures on highly reactive clay sites is likely to be enhanced, if the factors highlighted in these two case studies were to be identified in geotechnical investigations and reports and also addressed in the engineer's footing design.

## ACKNOWLEDGEMENTS

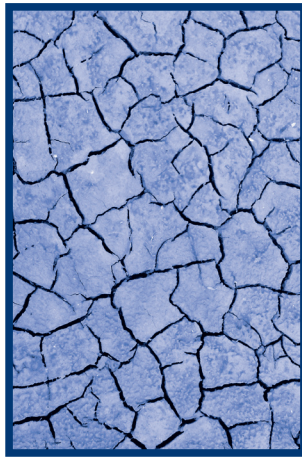
I would like to acknowledge the Australian Geomechanics Society for provided the opportunity to submit this paper. I also acknowledge, the support of my two clients, who gave their permission to use their information for this paper. Although they wish to remain anonymous, both clients have expressed an enthusiastic interest in learning about the factors that affect footing performance, which is an refreshing approach in a competitive domestic building market.

Finally I would like to acknowledge the Foundation and Footings Society (Vic) Inc and the Association of Civil and Structural Engineers of Victoria, for the continued professional development opportunities that they provide.

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