



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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Engineering properties of the Newer Volcanics basaltic clays

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ABSTRACT

The Newer Volcanic basaltic clays, weathered from the Newer Volcanics basalt rock, are commonly found to the north and west of Melbourne. As the Newer Volcanic basalt flow was the predominant overlay rock in the Western and Northern suburbs, the weathered basaltic soil is at a prime depth for shallow foundations of light structures. These basaltic clays can cause significant engineering problems for light structures and buried infrastructure. The shrinkage and swelling of basaltic clays due to seasonal moisture content change can damage light structures and buried infrastructure by movement in the foundation base and subsequent building movements. These movements can result in cracks and fissures within the clay as well. To date the weathering and soil formation, Atterberg limits and compaction efforts are well known for typical Victorian basaltic clay, however testing information is rarely published, and to a lesser extent mineralogy, soil strengths and swelling of the clay are not well documented. This paper discusses the reactivity of basaltic clays and examines engineering properties of the Newer Volcanics basaltic clays in Victoria based on previous testing and literature. The properties are: Atterberg limits, mineralogy, shear/tensile strength testing, drained friction angle, permeability, suctions and shrinkage testing. Data are combined from testing and from literature conducted throughout Victoria.

Keywords: Basaltic, clay, shrink, swell, reactive

1 INTRODUCTION

Basaltic clay weathered from the Newer Volcanics rock deposits can cause significant damage to foundations, buried infrastructure, road pavements, embankments and buildings if not properly managed. Foundation movement from heaving basaltic clay is a common cause of cracking in residential properties (Cameron and Walsh, 1980), movement in road pavements and road embankments (Holden and Richards, 1998), and buried pipe failures (Gallage et al., 2011). As basaltic clay normally is a highly reactive soil, care must be taken when designing structures on the basaltic clay soil found throughout Victoria.

Basaltic clays are commonly found above the Newer Volcanics rock deposits and are formed through the weathering of the Newer Volcanics rock deposits. Basaltic clays typically contain a high percentage of the smectite: montmorillonite, which is formed of diffuse double layers and has high water absorbing properties. These absorbing properties translate to high insitu water contents and high shrink/swelling capabilities. Swelling at the surface of over 40 mm is seen in basaltic clays and can reach even higher levels (Richards et al., 1983; Holden and Richards, 1998; Karunaratne, 2016). The reactivity can be classified into classes according to AS 2870 (2011), which was devised based on the work at CSIRO and Swinburne university (Walsh et al., 1981), and is currently used throughout the housing construction industry. However, there is debate as to whether this standard is in need of an update (Karunaratne, 2016).

Climate is one of the main driver for basaltic clay movement. In winter months as rain or moisture is in direct contact with the soil, the clay will swell or heave, due to the extra moisture ingress from surface. In warmer months the soil will lose moisture and

subsequently shrink. As the movement of soil is restrained the clay will crack if no protection or proactive solution is used. The depth of cracking and spacing of cracks will vary depending on the speed of moisture loss and the boundary conditions (Corte and Higashi, 1960). If repeated shrink swell cycles occur the basaltic clay may form slickensides, joints, sand contamination, fissures or surface undulations, where soil strength in the clay is reduced (Dalhaus and O'Rourke, 1992). Basaltic clays can also shrink due to desiccation by vegetation with deep roots, which alter the suction values in the clay layer (Richards et al., 1983). Desiccation by plants can lead to localised clay movements that can damage buildings. Improper drainage of the clay soil or damage to underground water pipes is another source for moisture, which can also cause differential soil swelling movements. Removal of trees or excessive watering can also lead to excess swelling in basaltic clays (Walsh et al., 1976).

General engineering properties for basaltic clay vary with the clay mineral content, moisture content and suction values. However, engineering properties in basaltic clays also vary significantly with the moisture content in the soil. If soil is allowed to heave and moisture is increased, this can reduce the engineering properties and can have significant engineering impacts.

Previous standards (AS 1289) indicate that the swelling potential is based on the suction levels and swelling strain in the soils. These suction levels vary significantly (1 pF to 7 pF), and currently there are only select monitoring of site soil suctions in basaltic clay over short periods.

This paper examines the reactivity and engineering properties of the Newer Volcanics basaltic clays in Victoria based on previous testing and literature. The properties tested and examined are: mineralogy,

friction angle, permeability, suctions and shrinkage testing. Data are combined from testing and from literature conducted throughout Victoria.

2 REACTIVITY

Basaltic clays are highly reactive when subjected to variations in climate. The following section introduces tests completed on basaltic clay reactivity in shrinking and swelling tests.

2.1 Shrink

Basaltic clays are highly reactive and shrink during desiccation due to climate and uptake of moisture from plants. Several desiccation studies were conducted on basaltic clays. Basaltic clays were found to crack when restrained with only a small change in moisture content. As the soil loses moisture, strength is increased, however cracking can generally occur frequently before the moisture in the basaltic clay reduces past the plastic limit. This means significant strength is not present. A higher number of cracks were observed when the soil was dried at a faster rate (higher temperature). The cracking pattern also depends on the depth of the soil layer and the layer restraints.

Many studies have been conducted on the shrinkage path of basaltic clays. If the soil initially starts from close to saturation the soil will follow a drying path that closely resembles the saturation path. This means that soil will stay close to saturation throughout drying (see Fityus et al., 2005; Nahlawi and Kodikara, 2006; Costa, 2010; Zou, 2015). Once the soil reaches close to the plastic limit unsaturated soil behaviour dominates and shear strengths/tensile strengths increase dramatically. Here the soil is in the best range for strength. However, as noted by many authors (Russam and Dumbleton, 1964; Holden and Richards, 1988) in this zone soil strength is high, but swelling potential is also very high. Water uptake, especially free water uptake (free swelling), is very high. Under small confining stress basaltic clays can swell to over 10% of the original height in an oedometer test or swell test.

When placing basaltic soil compacted fill the moisture content range should be similar to what the original soil moisture content is insitu (Holden and Richards, 1988; Flintoff, 1992; Wijesooriya and Kodikara, 2012). Soils will tend to move into this equilibrium moisture content. If soil is initially compacted at a low moisture content, soil will tend to gain water and swell. After numerous wetting and drying cycles the soil will tend to return to its natural state. This natural state is not a fixed moisture content, but a range of moisture contents following a shrinkage path that will depend on the current climate. Therefore, proper care must be taken to ensure basaltic clay compacted fills are operating in similar conditions as to when the compaction has taken place. This includes regular monitoring and maintenance.

2.2 Swell

The swelling test commonly conducted on basaltic clay samples collected from field is the shrink swell test (AS 1289). Moisture content (and consequently

suction) in the field varies with the seasonal variations in climate.

Moisture monitoring through neutron probes or theta probes have been conducted on basaltic clays (Kodikara et al., 2014; Karunaratne, 2016). During testing the volumetric water content varied across different sites with a range of volumetric water content change from 15% to 25% throughout the year in the top layers of the basaltic soil. After a depth of 1 to 1.5 m the soil volumetric water content change was only approximately 2 to 5%.

Swelling pressures can have a negative impact on buildings, roads and underground pipes. Differential swelling can cause extreme forces causing foundations or pipes to crack. If foundation pressure of a building is low the risk of heave is higher. Figure 1 shows a horizontal building crack in a residential home. During the recent draught in Victoria, which ended in 2009, many new development homes were built on top of basaltic clay. Once the draught ended these houses may have experienced higher levels of swelling as extra moisture was available to the soil.

Swelling pressures in basaltic clays can be as high as 200 kPa (Flintoff, 1992), and if concentrated zones of extra moisture formed, due to improper runoff, differential heaving could have caused major cracking in the new homes. In one-year Karunaratne (2016) examined swelling displacements in one of these homes. The swelling movements from the center of the house to the edges varied from 0 mm to 60 mm. This extreme differential must be avoided to avoid propagating structural cracks.

3 ENGINEERING PROPERTIES

Thickness of basaltic clay varies considerably within a site and the depth to bedrock also changes considerably (Dalhaus and O'Rouke, 1992; Weerasinge, 2016). The thickness of the basaltic layer and subsequent depth to rock can have a significant impact of surrounding infrastructure including underground pipes (Weerasinghe, 2016). The depth to rock can vary from less than a metre to 15 m.

The following section examines some important engineering properties of basaltic clay soils in Victoria. The properties are from literature and tests completed by the authors.



Figure 1. Example of a horizontal building crack caused by foundation soil swelling in a residential building

3.1 Mineralogy

Mineralogy is important when determining construction on basaltic clay sites. Theoretically basaltic clays should contain a high proportion of montmorillonite as they are weathered from Newer Volcanic basalt. Montmorillonite is part of the smectite group. The higher the content of montmorillonite, the higher the likely amount of swelling. Therefore, one must be careful when building on soils with a higher montmorillonite content. For the clays examined a high percentage of quartz was found in each case. This indicates the formation may be of part aeolian, and part fluvial (Dahlhaus and O'Rourke, 1992). Quartz sand may have been deposited in the crack formation of the basaltic clays examined. In the soils tested and examined the quartz content was 30+%. Montmorillonite was found to be over 30% in the soils tested. Table 1 shows the percentage of minerals in the clays examined from testing and literature.

Also of importance is the cation exchange capacity of the basaltic clay (Sameshima and Way, 1982). This can give an indication of the potential amount of swelling that may occur.

3.2 Physical properties

Basaltic clay soil tends to be red brown to brownish grey to light grey with increasing depth (Flintoff, 1992). The lighter grey soil tends to swell to a higher extent. Typical insitu volumetric moisture contents of basaltic clay range from 20-45%. Some typical ranges of soil properties of basaltic clays in Melbourne with data gathered from several authors (Shannon 2013; Zou, 2015; Kodikara et al., 2015; Karunarathne, 2015; Russam and Dumbleton, 1964; Aitchison and Richards, 1965; Holden, 1988) are given in Table 2. The data includes Atterberg limits, shrink swell index, clay percentages, activity, specific gravity, optimum water contents and permeability results. Thermal conductivity and volumetric heat capacity of basaltic clay soil both increase with increasing moisture content and dry density (Barry-Macaulay et al., 2011).

Compaction test results of basaltic clay show that the wet of optimum compacts close to saturation. The optimum moisture content varies depending on the percentage of fines in the soil.

3.3 Shear and tensile strength

Shannon (2013) conducted tensile (IDT tensile/shear) tests on three basaltic clays. The results of the tensile tests show clear indications that shear/tensile strength has a peak value. The peak value corresponds to about 50-80% saturation or gravimetric water contents of 13-22% and depends on the compaction level/energy. After this range the shear/tensile strength of compacted basaltic soil drops rapidly. The highest compacted tensile strengths were recorded at moisture contents of around 13-22%. At higher compaction energy (lower void ratio) the strength was highest at the lower moisture content range (13%), whereas at higher void ratio the strength was highest at the high end of moisture content (22%). This is less than the common insitu moisture contents found on site. Therefore, extreme caution should be taken in

compacting basaltic clay at this moisture content to extract the high strength.

Consolidation is generally not an issue in basaltic clays as it is heavily overconsolidated. Any weakening of the clays due to moisture increase occur at shallow depths, typically above groundwater table. This will result lower modulus and strength for the upper weakened clays. The preconsolidation pressure for undisturbed basaltic clay samples below groundwater table will be quite high.

Basaltic clays in Victoria are overconsolidated due to the seasonal variation in moisture content at least at the depths closer to the surface. This overconsolidation can give high shear strength values. However, undrained and drained properties of basaltic clay vary significantly depending on the moisture content in the soil. Typically, the drained friction angle varies in the range of 25 to 27°. However, slickensides and higher moisture areas can cause this to dramatically reduce (Flintoff, 1992).

For a remoulded basaltic clay sample with a high liquid limit (127%) consolidated to 200 kPa stress, the soil failed at a critical friction angle of 16°. If moisture is increased in basaltic clay the drained friction angle and undrained shear strength can reduce dramatically. The undrained shear strength varies and is typically less than 200 kPa (Flintoff, 1992). Undrained shear strengths (s_u) for remoulded basaltic clays, tested by the authors, normally consolidated to different pressures (120 kPa to 400 kPa) varied from 15 kPa to 84 kPa (gravimetric water content 90% to 40%).

3.4 Soil suctions

Typical suctions recorded in basaltic clay on the surface vary from 3 to 7 pF. On average the suction is approximately 4 pF, when wet 3 pF and dry 4.5 pF (Holland, 1981). This is a very broad range (to be expected) as the surface of basaltic clays can become very dry in the summer months and very wet during winter months. After a depth of around 1.5 m to 2 m the suction values remain fairly constant (Holland, 1981). Suction values from literature suggest an air entry value of around 50 kPa to 200 kPa, and then a rapid increase in suction. Deep-rooted vegetation in basaltic clays increase the total suction to an extent, however the radius of influence is smaller due to the low permeability (Richards et al., 1983). This can cause high soil movements in the direct vicinity of the root systems.

Holden and Richards (1988) found that compacted soils suction does not change much with increased soil strength. A fill height of 6 m can reduce swelling by over 5 times.

3.5 Permeability tests

Results of permeability tests and one-dimensional consolidation tests on basaltic clays were conducted for basaltic clays. Values of tests can be found in Table 2. The permeability of basaltic clays is generally low as the particle size is small. Typically 10^{-8} m/s to 10^{-10} m/s is seen from undisturbed and remoulded clay samples.

Table 1: Mineralogy for basaltic clays from literature

Mineral	Werribee clay	Merri Creek clay	Altona North clay	Tullamarine clay (Russam and Dumbleton, 1964)	Braybrook clay Karunarathne, (2015)
Smectite ^a	42	51	31	41 ^b	32.5-31 ^a
Quartz	30	41	59	59	53-59
Kaolinite	10	3	2	—	4
Orthoclase	—	3	3	—	2
Feldspars (Albite)	8	2	2	—	2.5-2
Calcite	—	—	3	—	—
Illite	10	—	—	—	5.5-2
Anatase	—	—	—	—	<1

^a Smectite includes montmorillonite. ^b Indicates 100% montmorillonite content as smectite.

Table 2: Atterberg limits, shrinkage limits and compaction results on tested basaltic clays from Victoria

Mineral	Minimum	Maximum	Notes
Liquid limit (%)	36	127	These are typical values found from literature (Aitchison and Richards, 1965; Holden and Richards, 1988; Karunarathne, 2015; Kodikara et al., 2015; Russam and Dumbleton, 1964; Shannon 2013; Zou, 2015)
Plastic limit (%)	15	42	
Plasticity index (%)	20	101	
Linear shrinkage (%)	11	26	
Shrink swell index (%)	1.6	7.1	
Percentage sand (%)	4	18	
Percentage silt (%)	10	50	
Clay (%)	35	67	These values will not add to 100% as they are minimum and maximum for a range of different soils
Activity	0.73	1.49	
Specific gravity	2.66	2.84	Activity was calculated from Plasticity index divided by percentage of clay.
Standard optimum moisture content (%)	20	38	Less percentage of sand/gravel will be closer to the lower specific gravity range (2.66).
Maximum dry density (g/cm ³)	1.3	1.6	
Modified optimum gravimetric moisture content (%)	1.6	1.8	
Modified maximum dry density (g/cm ³)	1.5	2.0	These range of values are from the modified proctor test. The testing was completed on clays with very low sand and gravel percentage.
Recompression index, C _r	0.05	0.25	
Average permeability (m/s)	10 ⁻⁸	10 ⁻¹⁰	Values were obtained from a limited amount of testing on both insitu and remoulded basaltic clay samples.
Coefficient of consolidation (m ² /s)	1.0x10 ⁻⁷	1.0x10 ⁻⁹	

4 CONCLUSION

The following paper reviews some of the knowledge of basaltic clay from Victoria. A range of basaltic clay properties from literature are presented. Basaltic clay properties vary depending on the site conditions and ground formation. Mineralogy found that of the sites examined the basaltic clay consisted of two main minerals, montmorillonite and quartz. The higher the clay content and montmorillonite content, the higher the swell in the soil. Finally, a table was given with a range of properties from Basaltic clays tested throughout Victoria.

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