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ENGINEERING GEOLOGY CONSIDERATIONS FOR DEVELOPMENT ON BRINGELLY SHALE IN WESTERN SYDNEY

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1 1INTRODUCTION

Western Sydney is expected to undergo a substantial transformation over the coming decades, with planning for extensive residential developments and significant infrastructure projects. This rapid urban expansion requires a thorough understanding of the engineering geological behaviour of significant geological formations, in particular the Bringelly Shale. This formation is known for its high potential for shrink-swell behaviour and susceptibility to rapid degradation when exposed to wetting and drying cycles, and further exacerbated by human activities, such as excavation and earthworks, which disrupt its equilibrium state.

This paper shares project experiences to inform construction practices in the Bringelly Shale and highlights the importance of incorporating engineering geological practices. A case study demonstrates the value of developing an engineering geological model to evaluate the combined impact of removing protective sandstone caps on hills containing Bringelly Shale and the influence of subvertical joints, excavation and rainfall infiltration, in the rapid degradation of subsurface materials and impact on slope stability. Similar lithological conditions can be expected throughout Western Sydney.

Additionally, this paper outlines key considerations (e.g., identifying backfilled farm dams, understanding saturation zones, and soil creep) which should be assessed in early phase planning and design when working in Bringelly Shale, to manage and mitigate significant risks to foundation design, deep excavations, and linear infrastructure. Early identification of these risks is essential for informing planning decisions and guiding necessary investigations to support effective and safe design practices.

2 GEOLOGICAL SETTING OF BRINGELLY SHALE AND ITS ENGINEERING SIGNIFICANCE

The Bringelly Shale of Wianamatta Group is a major sedimentary formation outcrop in western Sydney, primarily confined to the Fairfield Basin, extending from the northwest near Penrith, Liverpool, Camden, Campbelltown, and part of Hawkesbury and Parramatta region (Figure 1). This unit predominantly comprises a sequence of alternating shale, claystone, siltstone, followed by decreasing order of volumetric abundance by sandstone, coal, and highly carbonaceous claystone and tuff (Herbert 1983). The Wianamatta Group was deposited during the Triassic Period and is believed to be the result of a major marine regression. The depositional environment of laminated silt of the Bringelly Shale in lagoons, marshes, levees and backswamps whereas the sandstone unit was formed in both barrier-bar and alluvial channel environments. Therefore, sandstone units are commonly juxtaposed with the shale and claystone-siltstone, but the sandstone within the Bringelly Shale generally occur sporadically and in layers of limited lateral extent (Herbert 1983). As sea levels dropped due to regional uplift associated with the breakup of Gondwana and onset of compressional forces in eastern Australia during Early to Mid-Cretaceous, the previously formed rock exposed and the surrounding weaker and more erodible siltstone and claystone beds eroded, leaving the more resistant sandstone unit. These sandstone remnants often form topography highs such as ridges or crest of hills. As such, the characteristic topography of the Bringelly Shale is generally undulating and numerous outliers of ridge tops.

The Bringelly Shale is characterised by a high proportion of a mixed layer illite-smectite, resulting in a high shrink-swell potential and susceptibility to rapid degradation when exposed to wetting and drying cycles.

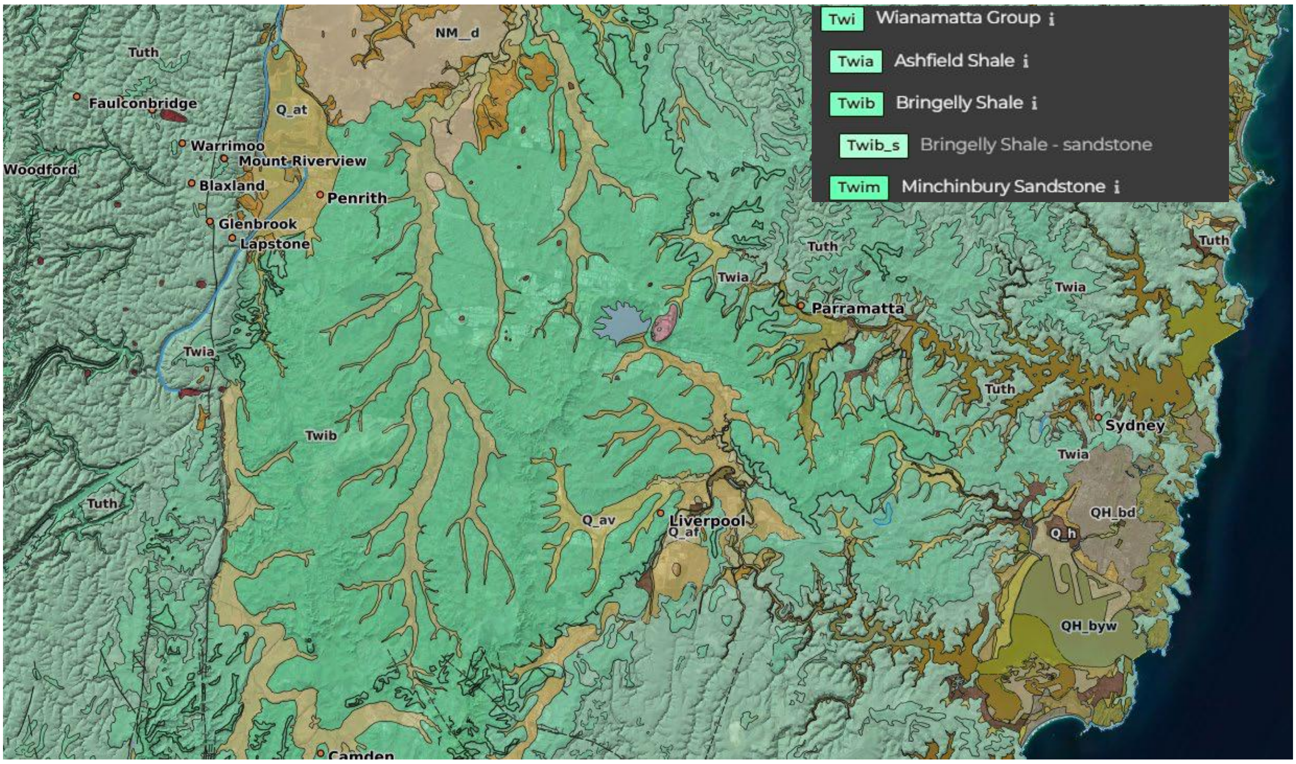

Figure 1: Geological map of Sydney and outer Sydney region (extracted from MinView https://minview.geoscience.nsw.gov.au)

3 CASE STUDY OF SLOPE STABILITY ISSUE OVERVIEW

The site of the case study, located on a hilltop underlain by the Bringelly Shale Formation in western Sydney, was developed during 2021 to 2022, which was one of the wettest years in Sydney on record. During construction work, the top 4-5m of the hill was removed to form a level platform, with retaining walls constructed at the perimeter below the platform. In addition, excavation for trenches and shafts further exposed the deep levels of the ground. To monitor the performance of the retaining wall and slope movement outside the wall, inclinometers were installed around the perimeter of the platform. These inclinometers recorded gradual and steady movement at the west and northwestern portion of the site, with displacement ranging between 10mm and 30mm within about 10 months. Major movement occurs at approximately 10-12m below the final formation level. The retaining wall did not provide adequate resistance to the excessive movements; therefore, stabilisation measures were required.

A review of the ground conditions, based on pre- and post- ground investigation information, revealed that the original ground prior to excavation comprised a thin layer of residual soils overlying predominantly weathered sandstone to a depth of 5-6m and underlain by siltstone and mudstone. After excavation, the sandstone cap was mostly removed and the interbedded siltstone, claystone and shale were exposed. The rock was generally extremely weathered to moderately weathered with very low to medium strength, extending to approximately 12m below the final formation level. The beddings were sub-horizontal with inclined to subvertical joint sets dipping from ~40° to 80°, and the presence of clay seams ranging from 0mm to 30mm. Extensive highly fractured rock zones, which were also described as shear zone in some boreholes, were identified at the northwestern portion of the site. Below this zone, moderately to slightly decomposed siltstone and sandstone overlaying fresh rock was encountered. Healed fractured rock was also observed underlying the sandstone cap, possibly associated with tectonic movement, local faulting, crush under self-weight or stress relief when overlying beds were eroded. The fractures were subsequently healed or cemented with clayey materials, silica or calcite. It is postulated that these materials were derived from surrounding materials and deposited either as water flow or through moisture ingress due to suction.

Based on the vibrating wire piezometers (VWPs) and standpipe readings, the global groundwater level was recorded at about 20m below the final ground surface level, with multiple perched water tables vary spatially at various depth, about 10 to 12m below ground and 15m below ground

4 CASE STUDY FINDINGS AND IMPLICATION

The removal of the sandstone cap exposed the interbedded siltstone and claystone, which were no longer protected from surface water infiltration. The heavy rainfall events experienced on site along with the fractured nature of the bedrock facilitated the propagation of water, resulting in moisture change in deeper rock layers. Subsequent trenching activities led to increased water infiltration into the rock layers, causing the interbedded siltstone and claystone to undergo shrink-swell cycles due to wet-dry conditions after heavy rainfall events. The presence of clay seams within this zone may induce transient perched water tables and may have exhibited shrink swell in response to the rainfall events, which could have further reduced slope stability and caused excessive movement. Also, high perched water tables were expected in the rock layers during and shortly after the rainfall events. These water tables induce additional hydrostatic water pressure behind the retaining wall and reduce effective stress within the fractured zones and decreasing factor of safety against sliding.

It is noted that areas other than the northwestern portion of the site appear to have less movement as the rate of movement reduced significantly after a few rainfall events in 2022, while the northern part of the site continued to move even in the absence of working loads on the platform. It is possible that the ground may have reached full saturation after several rainfall events following the removal of the sandstone cap and gradually reached an equilibrium state where any change in moisture content would not trigger noticeable shrink swell type behaviours. However, the northwest of the site, where continued movement was observed, may be related to extensive fractured zones and prevalent sub-vertical joints falling water infiltration. The slope instability may have been triggered by shrink swell behaviour between rock blocks or simply by jacking the blocks apart due to increased water pressure, or a combination of the two.

This case study highlights the importance of understanding geological setting and recognising the geological units have reached their equilibrium under current tectonic regime. The sandstone unit within the Bringelly Shale, typically found at the top of the topography, serves as a protective layer for the underlying siltstone and shale. The removal of this protective layer disrupts the natural equilibrium, increasing the risk of instability. Developing a comprehensive engineering geological model to assess ground conditions, lithological properties, existing geological defects and the impact of human activities for mitigating potential geotechnical risks and should be incorporated into engineering projects.

5 OTHER CONSIDERATIONS IN THE BRINGELLY SHALE

In addition to slope stability due to site formation at the crest of the hill, various engineering works such as building structures, deep excavation and installation of lineament infrastructure (e.g. pipelines) are expected to be widespread as part of the urban expansion. The following section discusses other considerations that should be incorporated into an engineering geological model for projects involving the Bringelly Shale.

5.1 IDENTIFYING FARM DAMS

Western Sydney primarily consists of agricultural lands where farm dams are commonly built and often backfilled without proper treatment. The fill material is likely site-won and derived from the Bringelly Shale, making it prone to shrink-swell behaviour. The presence of shrink-swell-prone fill materials has significant implications for foundation design. Variations in fill thickness and moisture content can result in excessive movement or differential settlement or foundation upheaval in shallow foundations. For piled foundations, swelling of backfill materials beneath the base slab can induce uplift pressures, especially when groundwater levels fluctuate, increasing tensile forces in piles.

Identifying farm dams early in the design phase is important for managing these risks. This includes a comprehensive desktop such as reviewing historical aerial imagery to locate potential former farm dams which have been decommissioned or any existing farm dams, which can guide targeted ground investigation to determine the depth, extent and properties of backfilled materials. Laboratory testing, such as free swell and degree of saturation assessments, can be conducted to evaluate swell behaviour. These findings can inform appropriate mitigation strategies such as removal and replacement with non-reactive engineered fill, lime treatment followed by compaction, or designing foundation to accommodate anticipated ground movements.

5.2 IDENTIFYING SIGNS OF SOIL CREEP

Soil creep, induced by the long-term shrink swell behaviour of expandable clays in the weathered bedrock of the Bringelly Shale, is a slow and steady downward movement. This is not unique to the Bringelly Shale derived soil, but their high shrink-swell potential may expedite the process during moisture change cycles. The shrinkage-induced cracks allow precipitation to reach deeper ground levels, reducing confinement and increasing the likelihood of downslope soil movement when swelling. This occurs when shear stress is sufficient to produce permanent deformation but not exceed the shear strength to trigger shear failures. Also, wet-dry cycles contribute to the formation of blocky clay layers through repeated expansion. This process also facilitates incremental lateral movements and the development of shear bands and slickensides within the weathered profile. Although soil creep is not an immediate safety hazard, it presents long-term impacts on buried infrastructure, particularly linear structures like pipelines. Over time, this graduate movement can exert stress on pipelines, potentially leading to deformation, joint displacement, or even service disruptions. Soil creep of the Bringelly Shale can occur on slopes as gentle as 10°.

Assessing the soil creep risk requires a desktop study, including a review of historical aerial imagery to identify visible signs of creep such as terracettes, tilted trees, or irregular surface undulations. Additionally, Digital Elevation Models (DEMs) can be used to generate slope maps, which helps identify areas where creeping behaviour is more likely to occur. These can guide targeted ground investigations to confirm subsurface conditions and evaluate potential mitigation measures including monitoring, strengthening of pipelines, or strategic routing where feasible.

5.3 SWELLING POTENTIAL IN ROCK IN EXCAVATIONS

Deep excavations in the Bringelly Shale must account for the potential swelling pressure of the rock. In its natural state, the rock at depth is typically under the groundwater table and saturated. However, dewatering is often required during deep excavation under the groundwater table. This can cause the rock to transition from a saturated state to an unsaturated state, inducing matric suction within the shale. Over time, as groundwater recharges into the excavation, the shale will reabsorb moisture, leading to swelling. This swelling pressure exerts additional lateral forces on walls that need to be considered in design.

The degree of saturation should be evaluated to assess swelling potential. To select appropriate rock samples for laboratory testing, core box photos can be reviewed to evaluate oxidation levels, which can indicate past moisture fluctuations. Rock in unoxidized zones may have remained saturated for an extended period, while heavily oxidized rock may have already undergone moisture-driven changes. This means the swelling potential can differ between these zones, free swell and swelling pressure tests should be conducted on both non-oxidized and oxidized zones samples to obtain an understanding of the swelling behaviours.

6 SUMMARY

The Bringelly Shale's high shrink-swell potential and susceptibility to rapid degradation poses challenges for construction if not managed properly. Human activities, such as excavation, exacerbate these issues. By incorporating engineering geological practices, such as desktop studies and development engineering geological models can help identify risks during the planning and design phrases. The case study highlights the importance of the sandstone cap in protecting the underlying siltstone and shale from water infiltration, preventing further degradation. Similar lithological conditions, where sandstone caps overlay weathered shale are anticipated at hilltops within the Bringelly Shale Formation. Therefore, any future development involving hilltop excavation should conduct detailed geological assessments before construction. Other considerations include identifying farm dams, assessing soil creep, and evaluating the degree of saturation to assess the swelling potential. A good understanding of these factors is essential for mitigating geotechnical risks in the region.

7 REFERENCES

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