LANDSLIDE REMEDIATION IN DIFFICULT GROUND

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ABSTRACT

A residential property on the Buderim escarpment (located on Queensland's Sunshine Coast) was slowly creeping down the hill. At the time of Core Consultants (Core) engagement on the project, some geotechnical advice had been provided to the owners by others. This advice varied between demolition (not the owner's preference) and material excavation and replacement downhill of the property (impractical). Following further geotechnical investigation by Core through boreholes, geophysical survey and test pits, a geotechnical model was developed and the mechanism of failure established.

Together with Piling & Civil Australia (PCA), a remedial solution was then designed using micropiles. Bored piles or driven piles were deemed unsuitable because of likely obstructions (large high strength basalt boulders) that would be encountered in the upper colluvial soils. The micropile technique which allows soils to be augered through and boulders penetrated by percussive techniques was ideal in these difficult ground conditions. On completion of the works the pile capping beam and residence was monitored for 18 months. No significant movement was recorded and were within the expected tolerances.

INTRODUCTION

Buderim Mountain is well known for the magnificent views it provides of the Sunshine Coast, from Noosa to Caloundra and the Glasshouse Mountains to the Hinterland. It is also well known for its slope instability issues. Throughout the authors association with Buderim (more than 20 years) several houses are known to have been demolished as a result of landslides and many others have suffered structural distress. The movements have typically been slow moving, and no injury or deaths have been known to occur. The geology/hydrogeology is complex and is a key factor, together with man-made works, that have frequently decreased the stability of the land. In addition, rainfall in the area can be high with average annual falls of approximately 1500 mm. More importantly, severe storms are known to have had intensities of more than 400 mm in 24 hours.

The residential site discussed in this paper is situated just below the Buderim escarpment on the southern side of the mountain. The original two storey timber-framed residential structure was constructed about 20 years ago and then extended in 2009. A large extension was built over a fill platform on the southern side of the original house in 2009. The extension is a two-storey development which is tied into the original garage slab and is mostly built over the fill platform. The fill platform, understood to be possibly constructed about 20 years ago, during construction of the original house, is retained by a boulder retaining wall approximately 2.5 m to 3 m in height along the southern end. A driveway from street extends along the eastern length of the house and provides access to the garage. Movement was first noticed following the significant rainfall events in 2011/2012 and geotechnical advice (from others) was sought at that time. This advice varied between demolition (not the owner's preference) and material excavation and replacement downhill of the property (impractical). Core became involved with the site in 2015.

THE GEOLOGY OF BUDERIM

Buderim Mountain is formed by a basalt cap (typically 15 m to 25 m thick) underlain by Tertiary Sediments and then the Landsborough Sandstone formation. On the flanks of the mountain, the Tertiary Sediments and Sandstone are overlain by basalt colluvium. This colluvium is generally a sandy clay material containing large boulders of high strength basalt. Typical sections are shown below in Image 1.

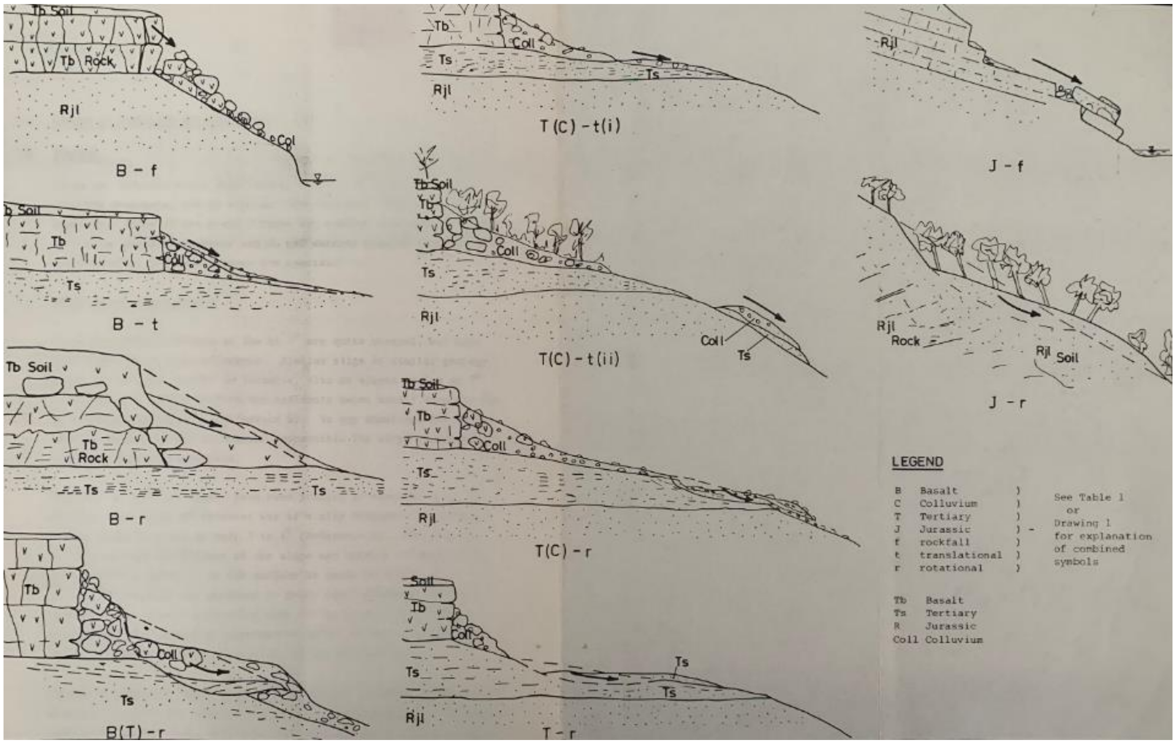


Image 1. Illustrations of geology and landslide types encountered (Courtesy of Coffey & Partners)

The basalt can be pervious or impervious and the underlying Tertiary Sediments can contain high plasticity, fissured, low strength clays. Ground movements in Buderim have been recorded on slopes as gentle as 7 degrees (ref. report by Coffey & Partners prepared for Maroochy Shire Council, '*Landslide Occurrence at Buderim Mountain',* August 1981).

SITE INVESTIGATION

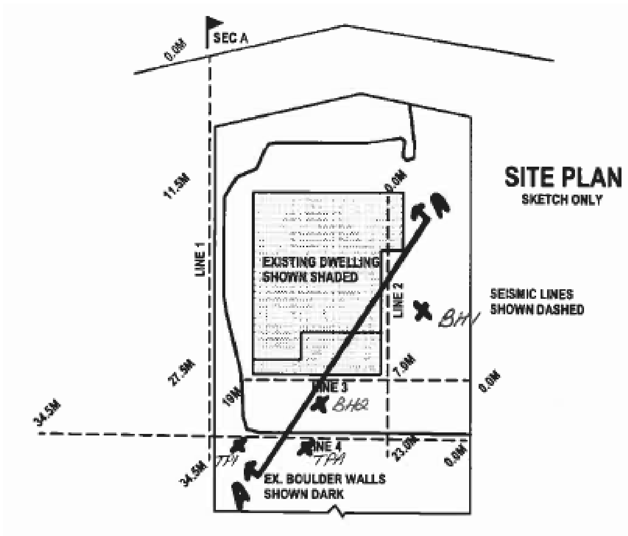
The site investigation work was carried out in several stages including a desktop study, site walkover assessment, fieldwork, laboratory testing, analysis and reporting, and development of conceptual remedial options.

Previous geotechnical fieldwork (by others) encountered fill and colluvial materials (including basalt cobbles and boulders), underlain by high plasticity pale grey clays (likely being the Tertiary Sediments). However, no previous investigations proved the thicknesses of the Tertiary Sediments, established groundwater conditions or reached the underlying sandstone formation. We also note that no material strength testing was undertaken by others.

A site walkover survey was initially conducted by an experienced geotechnical engineer. That survey included engineering geology mapping of topography, drainage, vegetation cover and geology.

Subsurface (intrusive) investigation initially comprised test pitting and borehole drilling, followed up with MASW seismic surveys. Images 2 and 3 shows the investigation layout and results of MASW survey. Using that information, together with the results from previous investigations, a geotechnical model was developed. Image 4 displays a cross-sectional profile of the subsurface conditions.

The subsurface conditions encountered in the boreholes generally included fill materials comprising silty/sandy clay mixed with basalt cobbles and boulders up to a depth of 2.5 m. Fill materials were underlain by colluvial materials (up to 2.15 m thick) generally consisting of clay soils mixed with very high strength basalt cobbles and boulders (up to approximately 600 mm in diameter). These materials were underlain by the Tertiary sediments (including fissured clays) that were up to 5.1 m thick, overlying the Landsborough Sandstone Formation.



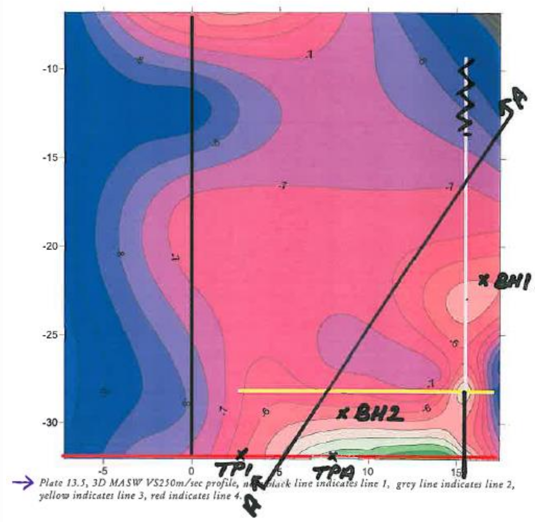


Image 2 (left) and Image 3 (right). Image 2 shows a plan of the investigation layout; Image 3 shows a 2D MASW shear wave velocity (Vs) profile

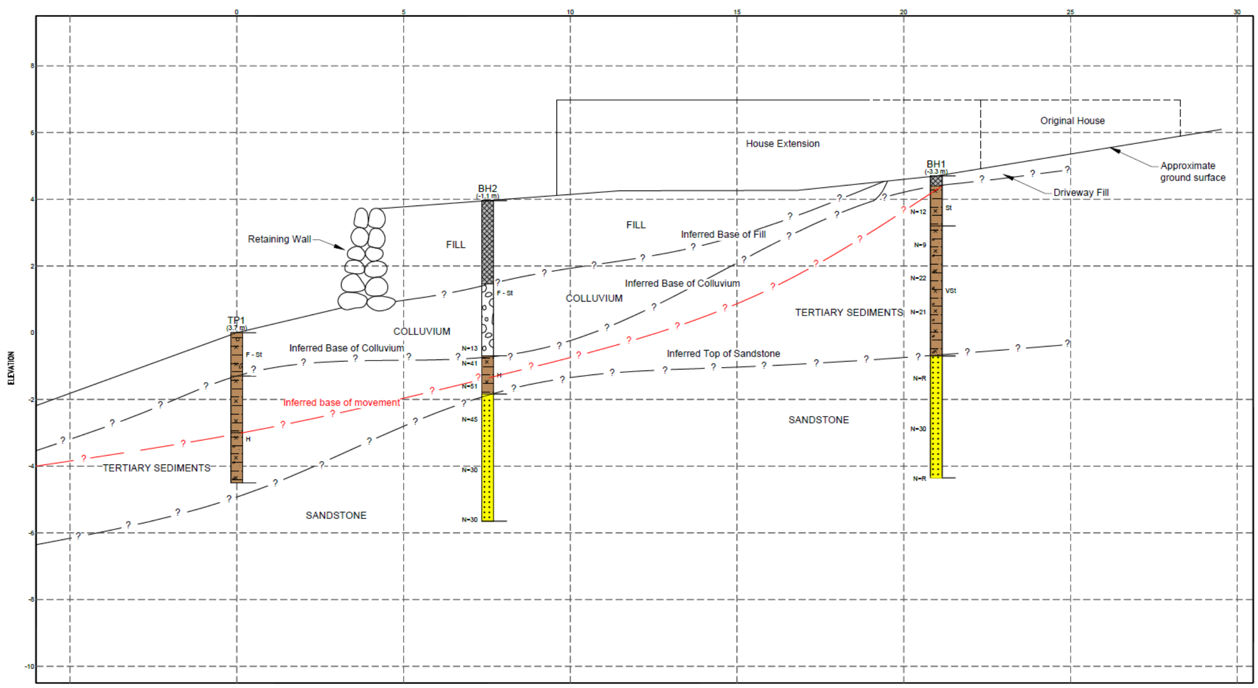


Image 4. Cross sectional profile of subsurface conditions

Deflective (flexible) standpipes were installed in the boreholes to allow ongoing monitoring of groundwater levels and movement (using different length steel rods – a 'poor mans' inclinometer). Groundwater and movement monitoring was conducted following drilling and on two subsequent occasions. Possible signs of ground movement at a depth of approximately 3 m was detected in the standpipe installed in test location TP1.

Laboratory testing comprised soil classification testing to confirm the observations made during the fieldwork, and direct shear testing to assess the strength parameters of the Tertiary Sediments.

FAILURE DESCRIPTION

As discussed in previous reports by others, there were a number of possible failure mechanisms that may have caused the distress to the residence. These included shrink swell movement or settlement of the fill platform, slope instability or a combination of all of them. The conclusions of the previous reports were that the most likely cause of the distress to the structure was landslide or soil creep. The loads exerted on the natural sloping ground profile from the fill platform and building extension have likely contributed to the movement.

One report also suggests that the cause of the damage was downhill creep movement within the fill and colluvium layer, triggered by high water pressures during and after rainfall events.

Further to the information provided in those reports, the results of our geotechnical investigation indicates that the ground movement is most likely associated with deep seated circular and/or translational movement of the fill, colluvium and underlying Tertiary Sediments. Our experience in the Buderim area suggests the Tertiary Sediments have relatively low shear strength parameters and are highly susceptible to movement, particularly when affected by groundwater.

ANALYSIS & REMEDIAL DESIGN

A geotechnical model was developed and used to carry out numerical back analysis of the ground movement. The back analysis (using the software SlopeW) aimed to identify the ground conditions at the time of failure (i.e. soil strength and groundwater conditions). Image 5 displays the SlopeW back-analysis output. This information was used for subsequent design of the remedial solution.

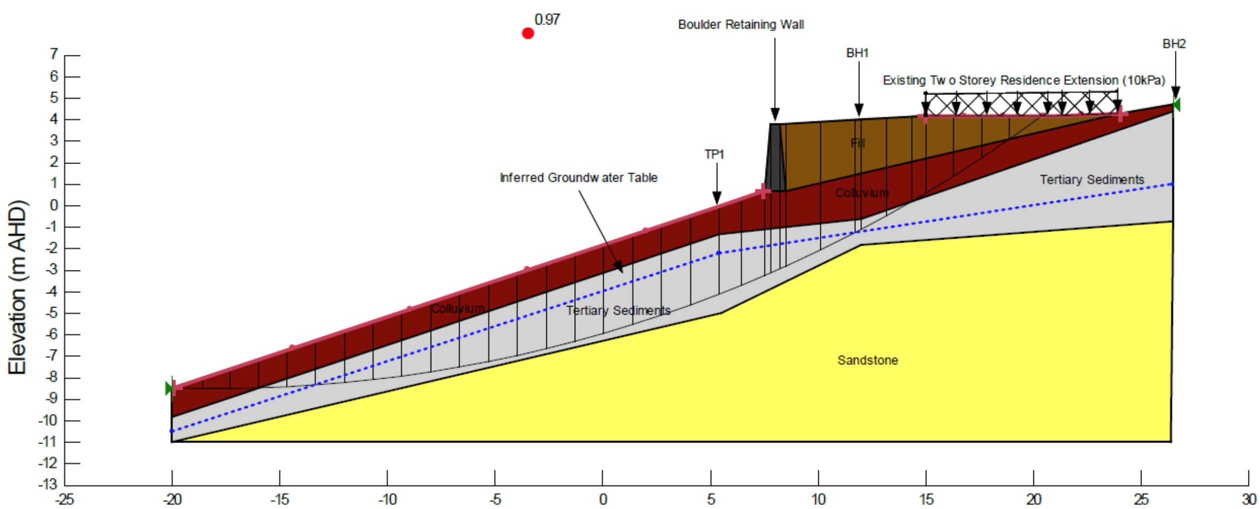


Image 5. SlopeW back-analysis output

Using the results of the geotechnical investigation and numerical analysis, conceptual remedial design options were considered for the residence and lot. These remedial options included subsurface drainage measures, an earth bund, micropiled 'A-frame' walls, and under pinning of the residence using a micropile system. Our recommendation was to adopt the micropile systems downslope of the boulder wall to arrest future ground movement. A separate micropile system was also recommended to support the residence, in particular to support the extension built over the fill platform. Images 6 and 7 below show how the micropile system was modelled using Plaxis software.

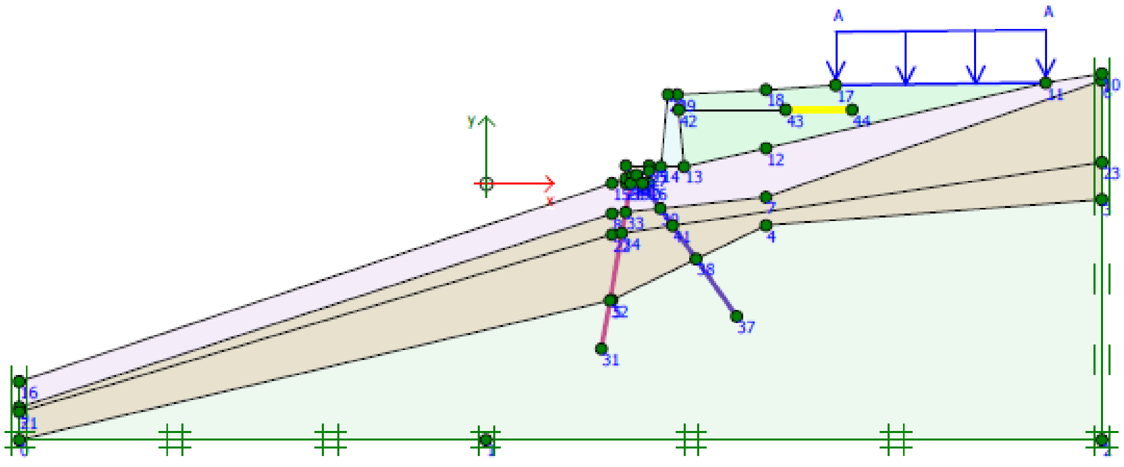


Image 6. Plaxis model inputs of micropile system

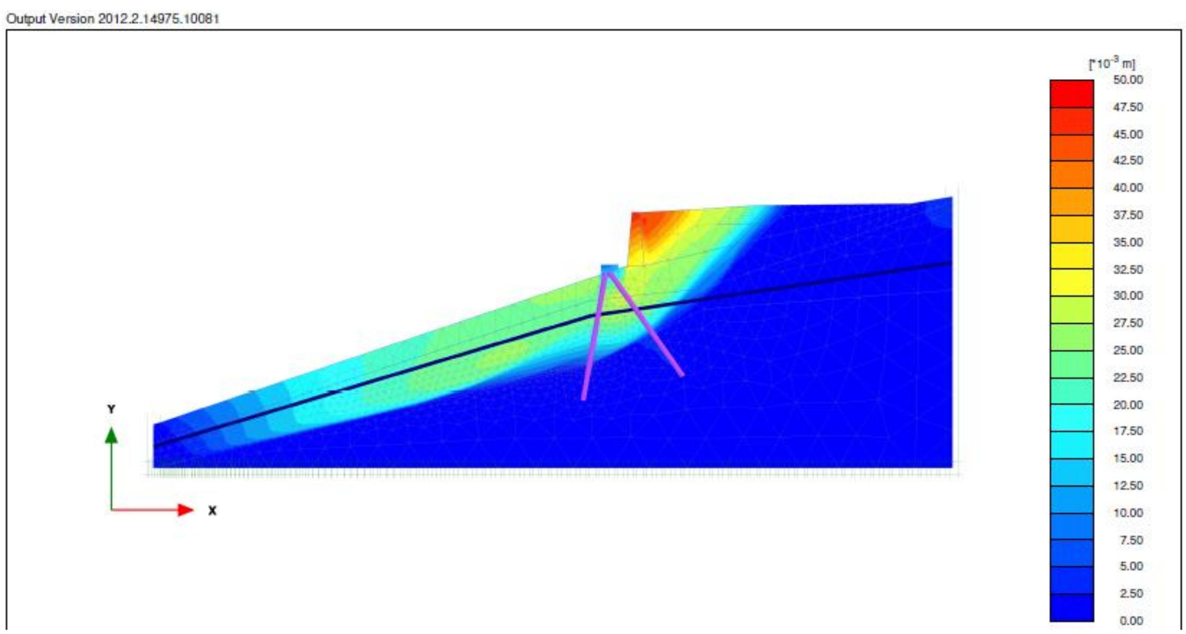


Image 7. Plaxis model outputs of micropile system showing maximum deflections

CONSTRUCTION OF THE REMEDIAL WORKS

Access to the rear of the property was via a steep track down the neighbouring allotment. This restricted the size and type of machinery that could be used to construct the micropile A-Frame structure. A fourteen-tonne excavator mounted drill rig was selected due to its ability to traverse the sloping ground and operate within the confined area below the existing boulder retaining wall.

Setout of the micropiles was done in conjunction with the supervising geotechnical engineers (Core) to ensure the A-Frame structure was perpendicular to the direction of slope movement and as close to the toe of the existing boulder wall as possible.

As the slip was active, vibration during construction was of concern to the designers in relation to the potential impact on an adjacent structure and a vibration monitoring system was installed. Results are discussed in more detail in the following section.

The micropile A-Frame structure was required to provide additional shear resistance at the slip plane which was assessed to be within three metres of the ground surface. The geology of the area provided the potential for basalt boulders to be in the colluvium matrix and as such, a tungsten carbide drill bit was selected for the micropiles.

The micropiles themselves consisted of an alternate series of vertical and raking hollow bar grout injected bars installed to a depth of 9 m. The pile heads terminated within a concrete capping beam which was constructed at ground level and along the tow of the existing boulder wall. Conduits were set within the capping beam to allow for the drainage pipes from the existing builder wall to pass through and drain downslope. The area between the capping beam and the boulder wall was backfilled with free draining material.

Survey monitoring pins were cast into the capping beam to allow for future surveys to measure the amount of movement within the structure. Additional survey points were placed at various points around the residence to also check for future movement.

A number of photographs during construction are attached.

VIBRATION MONITORING DURING CONSTRUCTION

Vibration monitoring consultants were engaged to carry out vibration monitoring at the nearest sensitive place (i.e. the adjacent house to the east) to assess the ground vibration levels generated during the installation of the micropiles.

Vibration monitoring equipment was installed at the base of that house. The purpose of the monitoring was to ensure that the buildings in the vicinity of the construction were not subjected to ground vibration levels from the piling which may cause cosmetic damage to the buildings or discomfort to the occupants.

For assessment of the potential for cosmetic damage to the neighbouring houses, the relevant criteria from German Standard DIN 4150.3 was adopted. For assessment of impact on human comfort the relevant criteria from Australian Standard AS2187.2 was used.

The results of vibration monitoring during construction indicated low vibration levels in compliance with the cosmetic damage and human comfort criteria. The consultant's report concluded the installation of the micropiles to stabilise the ground, is associated with very low ground vibrations and no building damage of discomfort to the residences could have resulted from the ground stabilisation work carried out.

A dilapidation survey of the adjacent residence was carried out by a structural engineering consultant prior to the commencement of the piling.

MONITORING SURVEY

A licensed surveyor was engaged to establish and survey monitoring points (11 in total) on and surrounding the existing residence, with an additional 7 monitoring points established on the A frame structure capping beam on completion of construction. The following monitoring program was adopted:

- Prior to the commencement of the works (for the 11 survey points)
- Immediately following Practical Completion (for the 18 survey points)
- Two further survey rounds (for the 18 survey points) were carried out on following significant rainfall events over a 24-month period.

The survey indicates that no significant movement of the original house structure or the new retaining wall (i.e. capping beam) has occurred at the monitoring points, while movement of between 6 mm to 12 mm in a south-west direction has been experienced at the survey points on the lower house structure (i.e. the extension).

The PCA design estimated movements of up to about 35 mm in the capping beam post completion, as the piles take up load from future ground movement, while the edge of the building closest to the boulder wall is anticipated to move about 20 mm.

CONCLUSIONS

A detailed investigation allowed for the development of geotechnical model and subsequent back analysis of the movement. This in turn allowed for the design of a micro-pile remedial solution.

The unique installation process associated with micro-piles in difficult ground conditions (i.e. a clay matrix containing high strength basalt boulders (colluvium)) allowed the site to be stabilised. Monitoring since construction (more than two years) has shown no movement along the capping beam or elsewhere across the site.

ACKNOWLEDGEMENTS

The authors would like to thank the property owners for allowing this paper to be published.

PHOTOGRAPHS

Photograph 1. Sacrificial cutting shoe attached to the toe of each micropile

Photograph 2. Construction of piling platform below boulder wall

Photograph 3. Micro-piling commencing at eastern end of Bay 3

Photograph 4. Grout mixing plant at crest of hill on neighbouring lot to the west

Photograph 5. Access track on neighbouring lot to the west. Piling in progress in Bay 1

Photograph 6. Micropile progress in Bays 2 and 3

Photograph 7. Underpinning in progress on eastern side of house

Photograph 8. Underpinning in progress on southern side of house

Photograph 9. Capping beam reinforcement being constructed

Photograph 10. Completed capping beam. View south-east