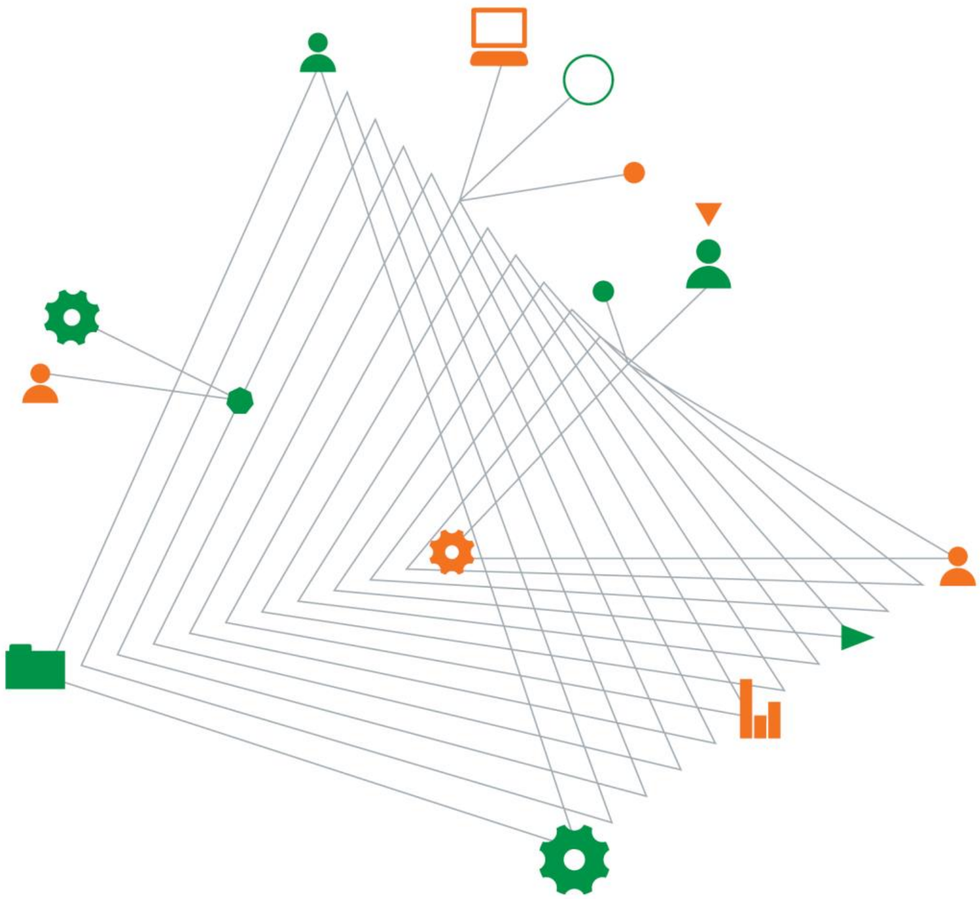
Roads and Maritime Services

Geotechnical Assessment of the Hornsby Quarry Void

Geotechnical Assessment Report

16 November 2016



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Geotechnical Assessment of the Hornsby Quarry Void

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For and on behalf of Coffey

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1. Introduction

The report presents the results of a geotechnical assessment carried out by Coffey Geotechnics Pty Ltd (Coffey) for the Roads and Maritime Services (RMS) at Hornsby Quarry, NSW. The work was commissioned by Mr Matthew Zielinski of RMS and carried out in general accordance with our proposal (Ref: GEOTLCOV25707AA-AA, dated 18 July 2016) under the RMS professional services contract (Ref: no. 16.0000302622.1452).

RMS has been given approval from Hornsby Shire Council to partially backfill the Hornsby Quarry void with spoil generated by the NorthConnex Public infrastructure Project. Up to 800,000 cubic metres of excavated rock and spoil will be deposited in the quarry throughout the course of the project. RMS requires an independent assessment of geotechnical risks associated with the infilling works, during both establishment and operational phases of the project. Periodic geotechnical monitoring throughout the backfilling operations is also required.

A significant amount of work has already been carried out by others in relation to geotechnical risks associated with quarry instability over the past few decades. It was not the intention of this study to re-visit all previous geotechnical assessments in detail, but rather conduct a broad review of the stability issues and failure mechanisms in order to assess whether or not the hazards and risks associated with the backfilling works have been adequately addressed and reported.

As requested by RMS, this report has been divided into two sections. The main body of this report deals with the review of potential global failure mechanisms within the quarry void and associated risks. Local failure mechanisms (i.e. rockfalls) are discussed in Appendix A.

This report presents our review of previous studies at the site, together with the results of stability assessments and risk assessments.

2. Scope of work

More specifically, the scope of this study includes the following:

- Review the Lend Lease Bouygues Joint Venture (LLBJV) proposed construction methods / logistical plans, and provide a summary of geotechnical risks and risk mitigation measures.
- Assess slope stability with respect to potential global failure mechanisms within the quarry void and grounds immediately surrounding the void.
- Complete a desktop study of available published information and existing previous studies for the site, and highlight any data gaps warranting additional assessment (if required).
- Predict potential changes in void stability during the void backfilling, including consideration of the potential stability effects of changed groundwater conditions.
- Recommend measures to be implemented to reduce the likelihood of quarry wall instability prior to, and during spoil placement works within and adjacent to the void.
- Carry out periodic monitoring and review of the implementation of these measures (this work will be carried out during the operation phase of the project).

- Undertake a risk management exercise (in accordance with AGS 2007 guidelines[1]) including risk analysis, evaluation and treatment and addressing the following concerns:
    1. Hazard Identification (what might happen?)
    2. How likely is it to occur (frequency or likelihood)
    3. What damage or injury might occur (consequences)
    4. Level of risk
    5. Slope design acceptance criteria
    6. Stabilisation treatment and risk mitigation recommendations

3. Information provided by RMS

The following information has been provided by RMS, to support this study:

- Northconnex- Hornsby quarry, Geotechnical Assessment and Recommendations for Access and Filling Works, Report number: PSM2820-004R, PSM Consult Pty Ltd, 23 February 2016.
- Former CSR Quarry Hornsby & Associated Lands, Report number: PSM1059.TR1, PSM Consult Pty Ltd, dated 6th February 2007.
- Drawing No. PSM1059-18 Rev 3, “Risk of Instability Associated with the Quarry Slopes”, Note: this drawing appears to be a marked up drawing from the abovementioned 2007 report.
- Hornsby Quarry Redevelopment – Geotechnical Study and Stability Assessment – Draft Report, PSM Consult Pty Ltd, Report number: PSM2542-004R DRAFT, 31st March 2015
- Hornsby Quarry Redevelopment Study – Slope Design and Hazard Mitigation Assessment – Draft Report, PSM Consult Pty Ltd, Report number: PSM2542-008R DRAFT, 2nd April 2015
- Northconnex – Hornsby Quarry Detail Site Installation- Construction Methods Drawing ALL-LLB-01-0100-MD-DG-0209 Sheets 1 to 10 issue 01E
- Northconnex – Hornsby Quarry Proposed Site Stabilisation Plan- Construction Methods Drawing ALL-LLB-01-0100-MD-DG-0206 Sheets 1 to 2 issue 01E
- Northconnex – (PDF of presentation?) “Hornsby Quarry Project, Conveyor Prelim. Option for Stockpile and Pit Area – April 2016”. 13 pages.

We were also supplied with the following survey file in .dwg format:

- REP-REP-LLB-0094-160804 LG142849 HQ004 Hornsby Quarry 151015

[1] AGS (2007c) “Practice Note Guidelines for Landslide Risk Management”, Australian Geomechanics Society, Australian Geomechanics Vol 42 No1 March.

The file contained raw point cloud data (i.e. no labels, contours or interpretation). We do not know when the survey was performed or the methods used, although it is likely that the data was acquired using 3D laser scanning.

The 2007 PSM report was prepared for Hornsby Shire Council (Council) and presented the findings of a study of geotechnical and hydrological constraints to development of the Hornsby Quarry. The 2015 PSM report (also carried out for Council) focused on future works and controls that would be required to allow public access into the quarry void. The subsequent PSM reports provided to Coffey were prepared for the LLBJV. These reports provide LLBJV with advice for managing geotechnical risk related to quarry instability during backfilling works.

4. Proposed backfilling works

We are advised that the quarry will not be completely backfilled, but rather to approximately RL. 50 m, which will leave the upper few batter slopes exposed for heritage and scientific reasons. Following this, we understand Council intend to further develop the area for use as open space.

Based on review of the LLBJV construction drawings, a summary of the void filling operation methodology is provided below:

- Installation of a primary retracting conveyor belt system at the crest of the eastern wall of the quarry void. The site installation is shown on Plate 1.
- Trucks will bring in tunnel spoil material to be stockpiled in the Old Mans Valley area above the eastern wall. A ‘truck unloader’ will distribute the fill onto the conveyor.
- The telestacker conveyor will extend out over the eastern wall and deposit fill at the floor of the quarry.
- A tunnel reclaimer will be constructed at the floor of the quarry to reclaim the fill placed by the telestacker conveyor.
- Prior to the construction of the reclaimer, dozers and excavators will prepare “a sound platform” using new spoil material mixed with existing pit floor wet material for the initial layers of the backfill. A sacrificial steel truss system will then be constructed for the tunnel reclaimer system.
- A series of tracked telestackers will then be used to distribute fill from the reclaimer around the quarry void (see Plate 2)
- The placement of fill will comply with the recommendations provided in PSM report Ref: PSM2820-004R, dated 23 February 2016.
- The PSM report recommends that an exclusion zone be established that comprises all areas in the quarry floor within 10 m of the batters. This exclusion zone will result in the formation of a perimeter ditch as shown in Plate 3.
- The PSM report also designates a ‘person access zone’ where people not in vehicles are allowed to occupy. This zone comprises anywhere in the quarry floor with a set-back distance greater than 25 m from the base of the quarry face.

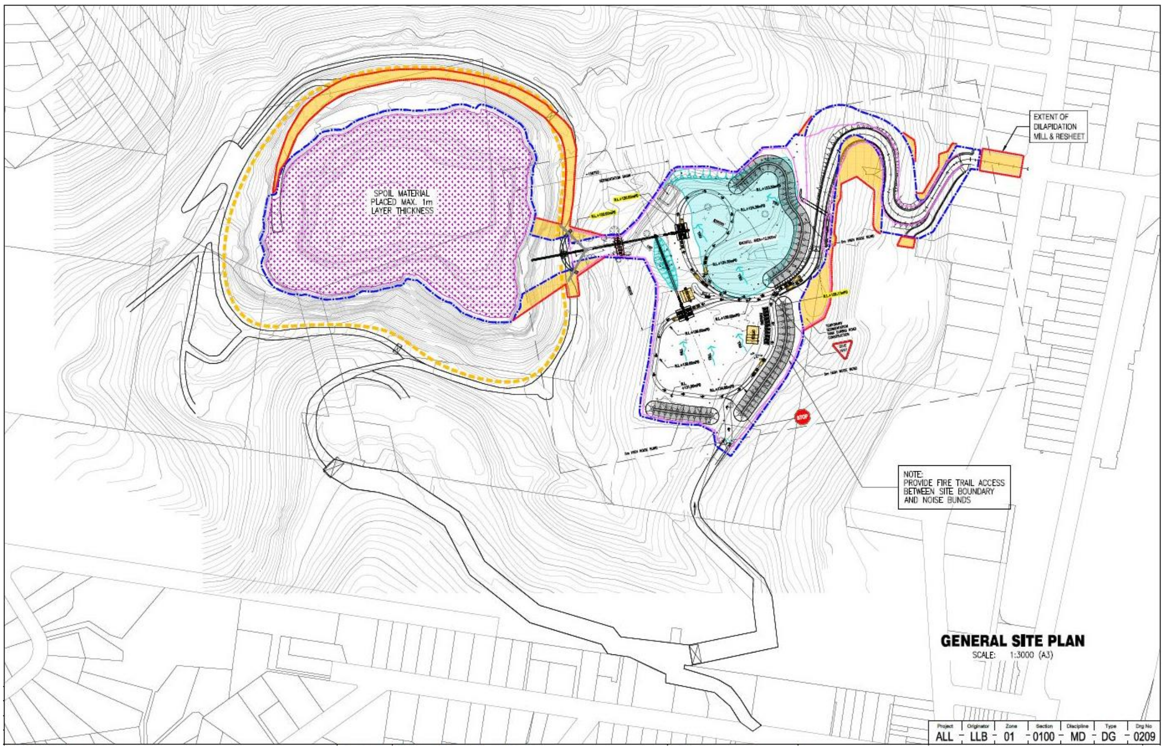


Plate 1. LLBJV proposed site installation.

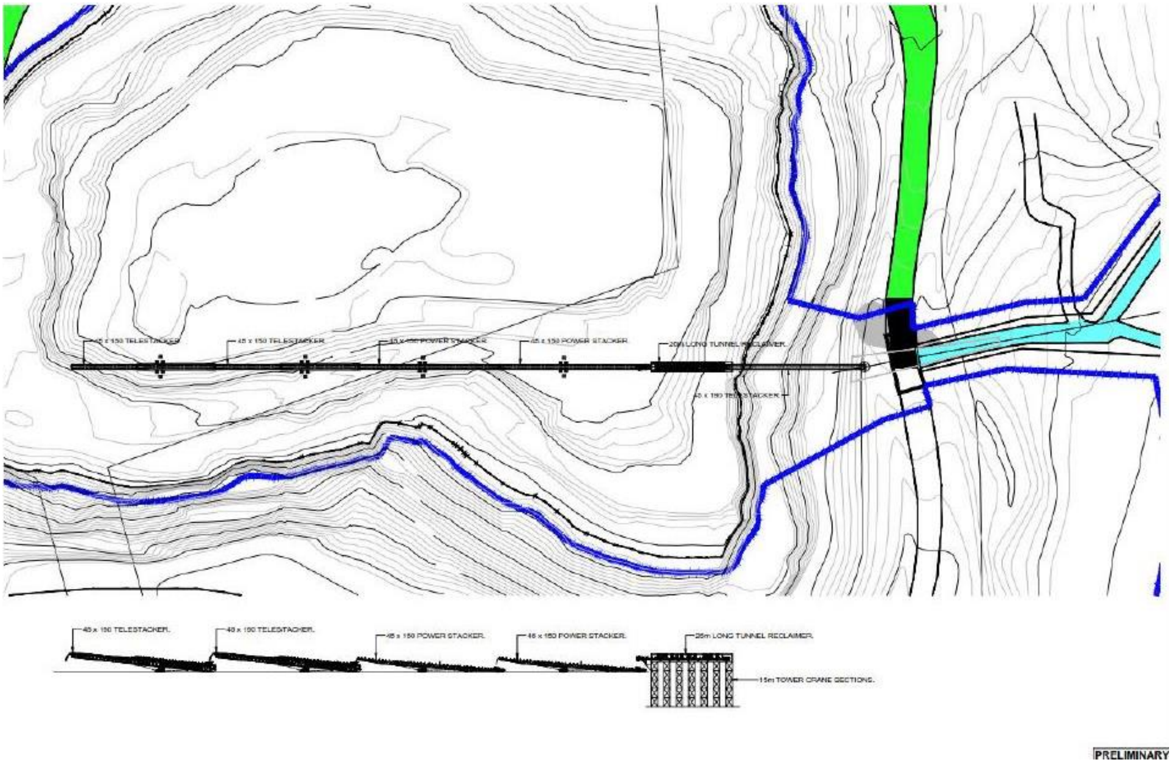


Plate 2. LLBJV proposed equipment layout.

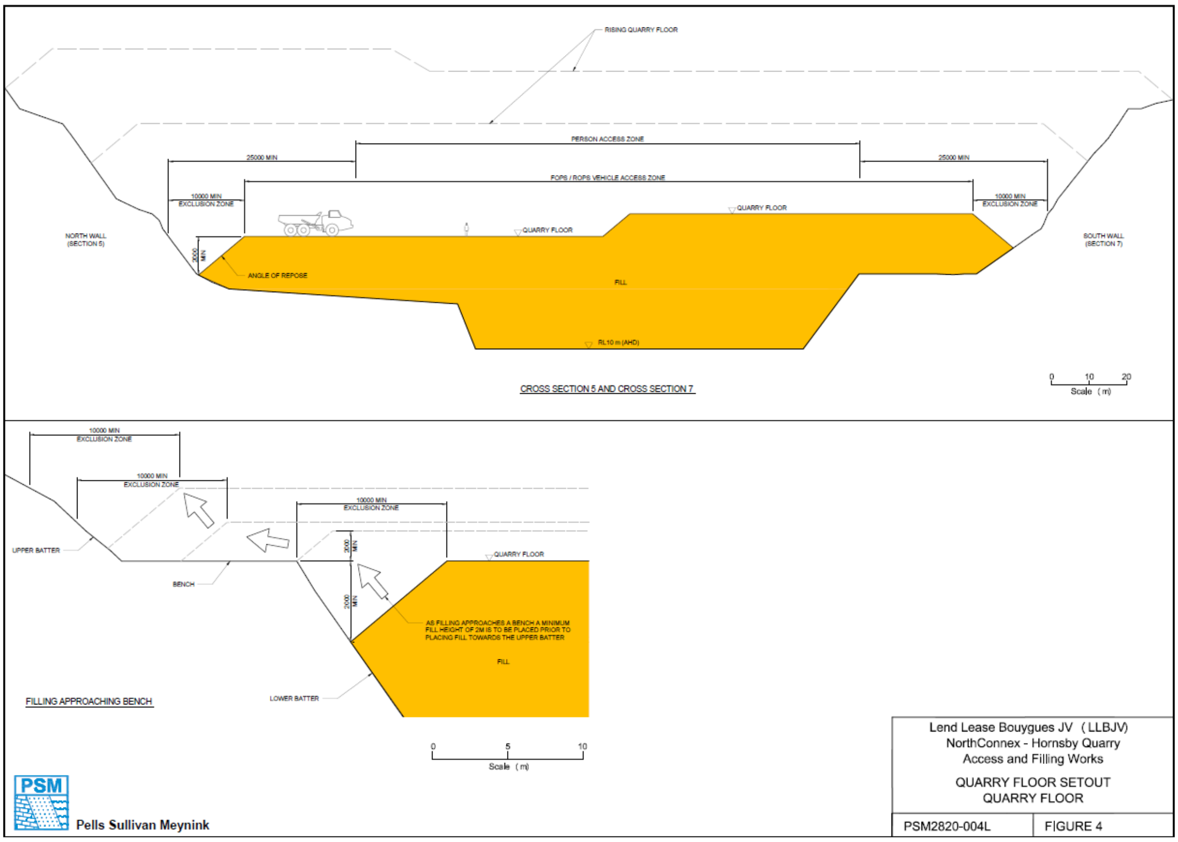


Plate 3. PSM proposed quarry floor set-out.

5. Fieldwork

The site was visited by two engineering geologists from Coffey on 4 and 11 August 2016. The visit comprised a site walkover along the quarry access road and the upper access road near the crown of the quarry. Access was limited to the length of quarry access road above approximately RL 46 m, access below RL 46m (i.e. to the floor of the quarry void) was not permitted for safety reasons. The visit included a walkover along the access road around the southern perimeter of the pit, although due to vegetation cover, quarry observations were limited.

The purpose of the above site visit(s) was to observe site conditions and geotechnical features reported during previous studies at the site, and characterise obvious slope hazards.

An Unmanned Aerial Vehicle (UAV) was deployed to obtain information in parts of the quarry which were inaccessible at the time of our assessment. The UAV was supplied and operated by a specialist subcontractor on 22 August 2016. Live video footage from the UAV was observed by Coffey during the operation.

Photogrammetry data collected by UAV survey was used to produce slope profiles for subsequent rockfall modelling. Video footage and photographs acquired during the assessment has been provided to RMS. A 360° panorama of the quarry can be viewed at the hyperlink below.

[360° panorama of the Hornsby Quarry Void]

6. Observations

The following sections summarise pertinent observations made during our site visit, and review of UAV footage. A contoured site plan is presented in Figure 1.

6.1. North wall

Photomosaics of the north wall and upper north wall are presented in Figures 2 and 3. The north wall comprises six steeply inclined batters, varying in height up to about 20 m.

The uppermost batter is more gently inclined at between about 30° and 40° and is covered with dense grasses, shrubs and scattered trees. A previous slope failure is apparent in the central area of this batter with the scarp area apparently having been supported by an anchored pile wall with shotcrete infill panels. Rock exposed in the sides of the scarp has been treated with pattern rock bolts.

An open concrete drainage channel (Plate 4) extends for the majority of the length of the north wall between the toe of the uppermost bench and the upper access road. Based on the reports provided, we understand that this channel was formed to divert Old Mans Creek. An earth mound about 1.5 m high separates the channel from the upper access road. Several rocks were observed in the channel. A corroded metal grate is located at the west end of the drain. The grate appears to be partially blocked by leaf litter and slopewash.

Plate 4. View of drainage channel and partially blocked grate above north wall.

The batters adjacent to the access road were observed to comprise volcanic breccia with isolated areas or beds of ‘muddy breccia’. The muddy breccia was often observed to be highly fragmented and prone to fretting and degradation. Several boulders were observed along the toe of the slope adjacent to the quarry access road (Plate 5). Boulders were typically between 0.3 m and 0.8 m across and located between about 3 m to 6 m from the toe of the batter. There is currently a ‘clear fall zone’ up to about 7 m wide between the toe of the batter and the access road. Scarps associated with previous wedge failures with estimated volumes up to 30 m^3 wedge were observed along the crest of the batter between the upper and lower access roads.

Rock exposed in the batters below the access road is typically blocky with obvious blast damage exhibited by open joints and fractures. Large quantities of rock debris have accumulated on the majority of benches, particularly on the lower benches that were inundated when quarry water levels were higher (Plate 6). Based on the previous reports provided, we understand many of these rockfalls and bench scale failures were likely induced by softening and dewatering effects associated with the variable water levels.

Plate 5. View of fretting of 'muddy breccia'.

Plate 6. View of rock debris on lowermost bench of north wall.

6.2. East wall

Photomosaics of the east wall are presented in Figure 4. The east wall comprises five steeply inclined batters up to 30 m in height. The east wall was not accessible at the time of our site visit, therefore observations are based solely on footage captured by the UAV survey.

Distinct basinal layering can be observed in three uppermost benches of the east wall. The layering in the lowermost batter slopes become sub-horizontal towards the centre of the fold. The width of the benches generally increases with increasing quarry depth. Large quantities of rock debris has accumulated on most benches with block sizes up to about 1 m across (Plate 7). Trees and shrubs have become established on many of the benches.

Plate 7. Rock debris accumulations on bench.

An extremely to highly weathered breccia horizon was observed in the top 3m to 5m of the uppermost batter (Plate 8). Erosion and slumping of this material is evident in the batter.

Plate 8. Extremely to highly weathered breccia horizon on uppermost batter of the east wall.

A possible previous slope failure can be observed in a wedge-shaped area in the northeast corner of the second top batter. Rock exposed on this batter slope has been treated with pattern rock bolts. A large quantity of rock debris has accumulated on the bench below (Plate 9).

Volcanic breccia exposed in the remaining benches shows obvious blast damage with closely-spaced open joints and fractures (Plate 10). Erosion of muddy breccia horizons has led to undercutting of more competent blocky volcanic breccia, particularly in the northeast and southwest of the quarry adjacent to the proposed conveyor location (Plate 11).

Plate 9. View of rock debris below possible failure on northeast corner of the east wall.

Plate 10. Drill holes with adjacent blast damage / open fractures and fretting of muddy breccia horizons at the northeastern corner of the quarry.

Plate 11. Blast damage and fretting / erosion of breccia horizons at the south-eastern corner of the quarry adjacent to proposed conveyor location. Note: scree material on bench below.

6.3. South wall

The south wall was also inaccessible at the time of the site visit, therefore observations are based solely on footage captured by the UAV survey. Photomosaics of the south wall are presented in Figure 5.

Extremely to highly weathered breccia was observed in the upper approximately 10 m of the south wall. This material is eroding and several apparently recent small slides in soil-strength material were observed at the crest of the wall (Plate 12 and Plate 13). This material contains intact blocks of rock (corestones) up to about 0.5 m across.

Plate 12. View of recent slide in extremely weathered rock at crest of south wall.

Plate 13. View of recent slide in material mounded at crest of south wall.
Note: intact blocks of rock (corestones) exposed in batters.

Plate 14. View of possible failure surface in muddy breccia on eastern south wall.

The eastern south wall is steeply inclined and appears to be defined by a previous sliding failure along a geological structure (Plate 14). Blocks of more competent breccia (up to about 0.4 m diameter) can be observed in the muddy breccia. Jointed volcanic breccia was observed in isolated areas of the eastern south wall and at the boundary between the eastern and western south walls.

Previous slide(s) appears to have largely removed the benches in the eastern part of the wall. Sliding in this area was discussed in the 2007 PSM report with large scale failures apparently occurring during mining. The slide plane appears to terminate at a bench towards the base of the quarry above the access road ‘switchback’. Scarps associated with previous sliding failures were observed in the batter above the road.

An apparently recent rockfall was observed approximately mid-height in the central area of the wall (Plate 15). The rockfall comprises several cubic metres of debris and appears to have been triggered by root jacking associated with a tree goring out of the rock face above. Much of this debris is located on a narrow bench, however it is clear that the bench did not contain all of the rockfall.

Plate 15. View of rockfall, possibly triggered by root jacking from trees.
Note: tree roots on joint plane above rock debris.

Rock exposed in the batters adjacent to and below the access road is typically very blocky with obvious blast damage, closely spaced open joints and fractures (Plate 16 and Plate 17). Large quantities of rock debris have accumulated on the lower benches and near the toe of batters in areas that were previously inundated by quarry water. Water staining of the batters is evident in these areas.

Plate 16. View of highly fractured, water stained batter below access road on south wall.

Plate 17. View of rockfall debris adjacent to access road on south wall.

The western area of the south wall comprises four steeply inclined batters up to 28 m in height. The access road is located on the bench above the lowermost batter. The width of the benches generally increases with increasing quarry depth.

The western south wall is predominately comprised of blocky volcanic breccia with isolated zones of muddy breccia. Layering is steeply inclined and at an oblique angle to the wall. Well developed, near-vertical and near-horizontal, closely spaced joints are common, as are a high number of seemly randomly orientated joints. These features are conducive to wedge and block fall hazards and there as evidenced by numerous past failure scarps (Plate 18). Large quantities of rock debris have accumulated on the benches and the toe of the batter slope adjacent to the access road.

Plate 18. View of previous wedge failure and closely spaced joints on western area of south wall.

6.4. West wall

Photomosaics of the west wall are presented in Figure 6. The west wall comprises 3 to 4 steeply inclined batters, varying in height up to about 20 m. The quarry access road traverses the wall, grading down from north to south. Access to the west wall was restricted to the access road above about RL 46m for safety reasons.

A weathered breccia horizon was observed at the top of the uppermost batter. Below this horizon, the batter is comprised of blocky volcanic breccia and muddy breccia. Scarps associated with previous sliding failures within the weathered and muddy breccia were observed along the crest of the uppermost batter. Rock debris have accumulated on the bench below.

The batter slope adjacent to the access road was observed to mostly comprise blocky volcanic breccia with beds of muddy breccia. In places the rock is highly fractured with obvious open joints and fractures (Plate 19). There is currently a ‘clear fall zone’ between the toe of the batter and the access road. The width of this zone increases with decreasing elevation from about 2.5 m to 10 m. Large amounts of rock debris have accumulated in this zone, particularly at the south end of the west wall. Chain-link wire mesh has been draped over sections of this batter slope adjacent to the access road in an apparent attempt to control rockfalls. The mesh does not appear to comprise purpose designed rockfall mesh. Undercut areas of muddy breccia adjacent to the mesh appear have been treated with rock bolts (Plate 20).

Plate 19. View of loose rock, open joints and mesh along the west wall.

Plate 20. View of overhanging rock (muddy breccia) with rock bolts.

Rock exposed in the batters below the access road is typically blocky volcanic breccia with obvious blast damage, closely-spaced joints and fractures. A highly fragmented zone of muddy breccia was observed in the two lowermost benches (Plate 21). Large quantities of rock debris have accumulated on the lower benches and near the toe of batters in areas that were previously inundated by quarry water.

Plate 21. View of fractured rock and fragmented muddy breccia lowermost batter of the west wall.

7. Review of previous geotechnical reports

The geotechnical work previously completed at the Hornsby Quarry site as outlined in historical reports and reference material provided by RMS to Coffey is collated and summarised below. These reports include:

1. PSM, 2007. Hornsby Quarry. PSM report ref PSM1059.TR1 and associated appendices, dated April 2007.

2. PSM, 2015. Hornsby Quarry Redevelopment – Geotechnical Study and Stability Assessment. PSM report ref PSM2542-004R, dated March 2015.

3. PSM, 2016. NORTHCONNEX – Hornsby Quarry Geotechnical Assessment and Recommendation for access and filling works. PSM report ref PSM2620-004R, dated February 2016.

7.1. Summary of previous reports

7.1.1. Reference 1 – PSM 2007 Geotechnical report

This report provides an interpretation of the formation of the breccia diatreme geological environment in which the Hornsby Quarry is formed, including geology, geotechnical and hydrogeological models. A number of land use options are evaluated for the quarry area.

The geological model was compiled using previously published geological papers, borehole data available from the original quarry operation, evaluation of aerial stereo photos over the development of the quarry, and additional test pits in the southern area of the quarry extents. The report states that the quarry is formed primarily within volcanic breccia with moderately thick beds of a low to medium strength muddy breccia. Major structures outlined include the contacts between the muddy breccia and volcanic breccia units, sheared zones, joint swarms and bedding within the breccia. The weathering profile of the region shows extremely weathered rock masses to approximately RL 95 m, moderately to highly weathered between RL 80 to 95 m with slightly weathered to fresh rock masses to the extent of the slope depth.

The geotechnical model was developed by zoning the quarry into 4 structural domains, primarily formed by slope aspect. Extensive kinematic assessments within each of these structural domains outlined 12 subdomains, in which there are 7 with kinematically feasible instability mechanisms driven by structural patterns and 5 with circular instabilities likely through weathering and the presence of weak rock masses.

Material strength parameters were provided as shown in Table 1 below (as provided in Table B1 of Appendix B in PSM report), with site specific parameters benchmarked against a PSM database of similar muddy breccia material.

Table 1. Material strength parameters.

	Fill	Breccia			Sandstone			Muddy Breccia	Defects	
		RES/EW	HW/MW	SW/FR	RES/EW	HW/MW	SW/FR		Seams in SW/FR Breccia	Shears in Muddy Breccia
Unit Weight (kN/m^3)	20	19.5	23.5	23.5	19.5	24	24	22	-	-
Design Shear Strength c' (kPa)	10	20	75	300	50	400	1000	35	0	0
Design Friction Angle ϕ (°)	30	25	40	45	30	45	45	40	35	28

Six sections were modelled to assess the stability of the quarry slopes with respect to stability scenarios highlighted during previous kinematic assessments during geotechnical domain zoning. Three of these sections, and the additional modelling information provided in Appendix E of the report were assessed as part of this literature review. The modelling rationale for each of these critical sections used is provided below:

PSM Section 5: This north wall section is characterised by slightly weathered breccia with bands of muddy breccia inferred from the geology model and pitwall mapping data. Instabilities form through the weaker muddy breccia units and extend to the slope face along seams within the slightly weathered breccia at approximately 25° dipping into the void.

PSM Section 11: This south wall section is characterised by slightly weathered breccia with discreet seams of approximately 5 m width behind the pit slope. Instabilities are controlled by the strength of the seams within the breccia and extend along bedding at approximately 25° from horizontal dipping into the void.

PSM Section 12: This south wall section is characterised by slightly weathered breccia with bedding dipping 30-50° towards the void with a bedding shear strength of 0 kPa cohesion and 35° friction utilised. The instability mechanism is controlled by rock mass strength in the upper weathered rock masses, and bedding shear strength within the slightly weathered breccia.

The above modelling rationale may be considered conservative on the basis that the models appear to have been assessed considering current slope geometry which returned Factors of Safety (FoS) of less than 1. However, much of the slope geometry remains intact, which would suggest that the previously calculated FoS may not be representative of actual conditions.

7.1.2. Reference 2 – PSM 2015 Redevelopment geotechnical study

This report provides an updated geotechnical model, based on the inclusion of additional subsurface data from two cored boreholes completed as part of the assessment. Updates to material strength parameters are provided as given in Table 2 below (as per Table 7.5 of PSM2542-004R report).

Table 2. Material strength parameters.

	Fill	Breccia		Sandstone		Muddy Breccia	Defects	
		Contact	Inner Zone	Weathered	Bedded		Seams in SW/FR Breccia	Shears in Muddy Breccia
Unit Weight (kN/m^3)	20	24	26	21	24	26	-	-
Design Shear Strength c' (kPa)	10	180	355	62	320	100	-	-
Design Friction Angle ϕ (°)	30	47	60	15	57	28	32	28

The kinematic analysis undertaken in the initial 2007 report was repeated using updated mapping and logging data. The failure mechanisms highlighted by this analysis includes sliding along muddy breccia units, with rock mass toe breakout for both North and South walls. Sliding along shears in clastic breccia behind the south wall was also highlighted. The muddy breccia units have been updated to more localised structures, reducing the level of conservatism built into the models, particularly for sections 11 and 12.

Limit equilibrium modelling undertaken as part of this report was simplified from the 2007 modelling, with isotropic strength parameters only applied. Structurally controlled instability mechanisms have only been considered using a cumulative frequency analysis. This approach results in significantly higher factors of safety reported over the same design sections when compared to the 2007 analysis and is considered under conservative.

8. Stability analyses

Stability analyses have been undertaken using the limit equilibrium software Slide 7.0. Models have been constructed of critical sections as selected from the existing PSM studies. The selected sections are north wall section 5 and south wall sections 11 and 12. The modelled section locations are shown on Figure 1.

The models have been constructed using the provided 'REP-REP-LLB-0094-160804 LG142849 HQ004 Hornsby Quarry 151015' survey file. The topography surveys, including contours and the recent UAV survey were assessed for variations over time, with only minor disparities noted. For the purposes of overall scale slope stability, these variations are insignificant, and hence the survey that covers the greatest extent was used for model preparation.

The geological model behind the quarry slope(s) and rock mass strength parameters were applied in accordance with the most recent (2015) PSM study. Defect shear strengths have been applied using anisotropic strength models as per the 2007 PSM study.

The following scenarios have been assessed for each section:

- Current topography and standing water level at RL 17 m;
- Current topography post dewatering, with the water table in the void at RL 10 m;
- Infilling stages at RL 20 m, RL 30 m, RL 40 m and final RL 50 m. The groundwater has assumed to rise with infilling. This assumption is likely to introduce a small amount of conservatism to the model as the water table rise is anticipated to occur more slowly than infill activities.

It is noted that the approach of incorporating consistent structural anisotropies within the volcanic breccia rock mass for these analyses, as per the 2007 PSM geotechnical model, resulted in very low factors of safety that are not consistent with field observations for Sections 11 and 12. To account for this, a back analysis was applied on the critical structure shear strength within each section until a marginally stable instability with factor of safety of >1 was reached. This represents the lower bound only of the shear strength of the defects as the 'true' factor of safety is unknown, only that the slope has not experienced major instability. For this assessment, 'inter-ramp' scale instabilities are considered, i.e. large instabilities that affect multiple benches over a height greater than about 20 m (i.e. 'global failures').

Observations of the slope face and evaluation of previous reports indicate that the defects (bedding, shears and joints) will likely form part of the instability mechanism, but may not exhibit full persistence throughout the thickness of the breccia unit. As such, an isotropic, rock mass only model has been included as the upper bound factor of safety for both Section 11 and 12.

Section 11 returns a factor of safety of 1.71 when assessed using isotropic rock mass strength. A shear strength of 50kPa and 37° is required to model a marginally stable inter-ramp slope in current conditions. This is the bedding strength used in the anisotropic stability analysis for this project. The anisotropic stability analysis represents the lower bound factor of safety for this section only and is included solely to indicate the maximum change in stability anticipated by back filling works.

Section 12 returns a factor of safety of 3.08 when assessed using isotropic rock mass strength. A shear strength of 35kPa and 37° is required to model a marginally stable inter-ramp slope in current conditions. This is the bedding strength used in the anisotropic stability analysis for this project. The anisotropic stability analysis represents the lower bound factor of safety for this section only and is included solely to indicate the maximum change in stability anticipated by back filling works.

The results of these analyses are provided in Table 3 and a full suite of figures are provided in Appendix B.

Table 3. Stability analysis results.

	Strength Model	Current FOS	Dewatered		Fill to RL 20m		Fill to RL 30m		Fill to RL 40m		Fill to RL 50m	
			FOS	Δ%	FOS	Δ%	FOS	Δ%	FOS	Δ%	FOS	Δ%
Section 5	Anisotropic	1.21	1.21	0%	1.14	-6%	1.24	+2%	1.41	+17%	1.50	+24%
Section 11	Isotropic	1.71	NA		NA		1.71	0%	1.72	+1%	1.71	0%
	Anisotropic	1.05	NA		NA		1.05	0%	1.05	0%	1.15	+9%
Section 12	Isotropic	3.08	3.11	+1%	3.03	-2%	3.23	+5%	3.26	+6%	3.31	+7%
	Anisotropic	1.08	1.08	0%	1.06	0%	1.09	0%	1.06	0%	1.06	0%

These results show that the effect of dewatering from RL 17 m to RL 10 m will result in a negligible change to global stability. Back filling of the quarry void will result in a minimal increase in global stability on the south wall of the void and a small increase in stability for the north wall.

The global stability of the quarry slopes is anticipated to be controlled by a step-path failure mechanism, which is not captured in either of the geotechnical models proposed in previous detailed geotechnical studies. The step-path failure mode is characterised by failure along both the bedding and joint structures and through the intact rock mass between these structures. The failure path follows weaker structure planes where present, with ‘steps’ through the intact rock mass between structures.

It is important to note that the lower bound anisotropic models, with instabilities controlled by defect strength, have been produced with the input that at a minimum, the current slope is stable. These factors of safety have been calculated using back analysed strength parameters and are therefore likely to be somewhat conservative. Slope performance over a significant period of time has been good, with no significant instabilities noted. It is reasonable to conclude that the stability of the slopes are likely to continue perform well.

9. Hazards

The risk mitigation measures outlined in PSM report ref: PSM2820-004R, dated 23 February 2016 have been formulated around the following hazards:

1. Major slides (e.g. multi-bench or bench scale rock mass failures)
2. Minor failures (e.g. shallow rock mass slides, erosional rilling)
3. Structurally controlled failures (e.g. planar slides, wedge failures, toppling etc.)
4. Rockfalls.

Based on our review of the reports provided, this hazard assessment seems reasonable. In addition, evidence of these hazards is supported and discussed in our site observations above based on our site visit and review of UAV footage.

‘Global’ failures would take the form of the ‘major slide’ hazard listed above. Such slides could comprise multi-bench slides (i.e. more than one bench) along rock defects or through the rock mass as well as smaller bench scale failures. Multi-bench slides would result in large quantities of rock debris accumulating in the floor of the quarry. Bench scale failures are likely to be more localised and could be similar in nature to some of the previous failures presented in the plates in Section 6 above. These failures are likely to result in rock debris accumulating on the benches below with some rock debris rocks possibly bouncing down the quarry faces to the quarry floor.

The 2007 PSM report mentioned that at least one major slope failure occurred on the south wall of the quarry during mining. This failure was located in the south eastern part of the quarry and is clearly apparent on the photomosaic in Figure 5. A close up view of the slide surface is also shown in Plate 14 above. The PSM report surmised that "a moderately large section of the wall failed by sliding of a mass of slightly weathered and fresh breccia rock". Sliding was thought to have occurred on a steeply dipping unit of weaker, muddy breccia rock, possibly with a small toe failure through the breccia rock. The failure resulted in the loss of a number of benches.

Local rockfall hazards will be discussed in Appendix A.

10. Risk assessment

10.1. Background

Where geotechnical slope hazards have the potential to cause harm to individuals it is normal practice to adopt a risk management approach rather than to describe features using absolute terms such as whether a rock face is stable or unstable. By using this framework a range of options can be considered to reduce or manage the risk at a site, depending on the level of risk the owner of the site wishes to tolerate or accept. Such an approach usually involves risks to be estimated based on the product of the likelihood and consequences of an event such as a rockfall impacting a person.

When dealing with natural or man-made slopes it is normal practice to assess risks using methods consistent with the principles of the Australian Geomechanics Society's Practice Note Guidelines for Landslide Risk Management (AGS 2007[2]). The AGS (2007) guidelines provide a national framework for Landslide Risk Management and are widely used. AGS (2007) makes it clear that where risk to life is considered, the risks involved should be quantified. This assessment has been carried out using methods consistent with the guidelines outlined above. AGS risk terminology used in this report is summarised in Appendix C.

The purpose of the risk assessment is to estimate the annual risk of 'loss of life' to an individual working in the quarry. The individual is taken to be the 'person most at risk', who typically has the greatest exposure to the risks (i.e. greatest spatial temporal probability). The risk of 'loss of life' to an individual is calculated from:

$$\mathbf{R}_{(LoL)} = \mathbf{P}_{(H)} \times \mathbf{P}_{(S:H)} \times \mathbf{P}_{(T:S)} \times \mathbf{V}_{(D:T)}$$

Where

$\mathbf{R}_{(LoL)}$ is the risk (annual probability of death of an individual).

$\mathbf{P}_{(H)}$ is the annual probability of the hazard occurring (event).

$\mathbf{P}_{(S:H)}$ is the probability of spatial impact of the event impacting an individual taking into account the travel distance and travel direction given the event. For example, if a rockfall occurs at a site

[2] AGS (2007c), "Practice Note Guidelines for Landslide Risk Management", Australian Geomechanics Society, Australian Geomechanics Vol 42 No1 March.

when an individual is present, the individual may be located at another part of the site and therefore will not be affected.

$P_{(T:S)}$ is the temporal spatial probability (e.g. of the building or location being occupied by the individual) given the spatial impact and allowing for the possibility of evacuation given there is warning of the event occurrence.

$V_{(D:T)}$ is the vulnerability of the individual (probability of loss of life of the individual given the impact).

As requested, we have estimated the risk associated with working in the quarry for the following two scenarios:

- **Construction Phase** – includes work such as construction of the reclaimer and telestackers, upgrading access roads, scaling batters adjacent to access tracks and installing barriers.

- **Operation Phase** - includes work such as operation and maintenance of the reclaimer and telestackers, vehicle movements along access road.

Further discussion on the nature of the individual work activities associated with each of these phases is provided below. It is important to note that we have assumed all the PSM recommended risk mitigation measures will be in place during the Operation Phase.

The risk assessment presented below deals with global failure mechanisms (i.e. major slide hazards). The risk assessment for local rockfall hazards is presented in Appendix A.

10.2. Temporal considerations $P_{(T:S)}$

The risk assessment process necessarily requires a number of judgements to be made, particularly in relation to individual's exposure to risks and the frequency of hazard events. The exposure of individuals working in the quarry has been largely based on information provided by RMS. Where such information was not available, such as the duration of certain construction activities, we have used estimates. It should be noted that the exposure of an individual to hazards will have a significant effect on the level of risk. Our risk assessment has been based on each of the predicted work activities in the quarry during the construction and operational phases of the project. These activities and associated estimated durations used in the assessment are summarised in Table 4 and Table 5 below.

We have assumed that monitoring proposed by LLBJV / PSM will be in place during both the construction and operation phases of the project. We have also assumed that the monitoring discussed in this report below will be implemented. The monitoring works, which comprise survey, inspections and quarry closure in response to rainfall threshold exceedances further reduce an individual's exposure to risks because warning signs of impending failures are likely to be observed and recognised and work in the quarry would stop. We have therefore assumed that in about 90% of cases, early warning signs of impending failure would be recognised and work in the quarry would stop (i.e. about a 10% chance of not evacuating the quarry).

Table 4. Construction phase activities and estimated durations.

Activity number	Activity description	Person at risk	Estimated duration
1A	Upgrade of the existing access road, installation of safety bunds/barriers and scaling works to remove loose rock from batters along access road	Person working in open directing installation of concrete barriers or soil mounds on the access road along the north and west walls	2 weeks
1B		Person in excavator (fitted with FOPS / ROPS) working on the access road / scaling loose rocks along the north and west walls	2 weeks
1C		Person in FOPS / ROPS vehicle working on the access road near the batter along the south wall	3 weeks
2A	Travel along access road	Person in light vehicle driving on the access road near the batter along the north and west walls	We have assumed that a person will make 6 trips (3 return trips) on average each day
2B		Person in FOPS / ROPS vehicle driving on the access road near the batter along the south wall	
3	Preparation of a 'sound platform' by personnel in earthmoving equipment / construction of the conveyor footing in the pit	Person in earth moving equipment (FOPS / ROPS) working on the quarry floor	3 weeks
4	Construction of the reclaimer*	Person working on quarry floor in vicinity of reclaimer location	3 weeks
5A	Installation of telestackers*	Person working on quarry floor in vicinity of telestacker location	4 weeks
5B		Person in FOPS / ROPS vehicle working on the quarry floor in vicinity of telestacker location	

*Note: For these activities we are advised that vehicle and people movements will comply with the access zone restrictions outlined in the PSM report Ref: PSM2820-004R, dated 23 February 2016.

Table 5. Operational phase activities and estimated durations.

Activity number	Activity description	Person at risk	Estimated duration
6A	Travel along access road with risk mitigation controls in place	Person in light vehicle driving on the access road near the batter along the north and west walls	We have assumed that a person will make 6 trips (3 return trips) on average each day
6B		Person in FOPS / ROPS vehicle driving on the access road near the batter along the south wall	
7	Repositioning and maintenance of the telestackers	Person working on quarry floor in Person Access Zone	We have assumed that this activity will take 1hr on average each day
8	Personnel working within pit on daily basis	Person working on quarry floor in Person Access Zone	We have assumed that a person will spend up to 4 hrs in the pit on average each day

10.3. Likelihood estimation $P_{(H)}$

For the purposes of the risk assessment, we have simplified the hazards described above into two broad categories; major slides and rockfalls. 'Major slides' represent vary large multi-bench and/or bench scale rock mass failures (i.e. 'global failures'), whereas 'rockfalls' represent hazards associated with individual falling rocks, as well as rockfalls that may originate from the 'Minor failures' and 'Structurally controlled failures' mentioned above.

The likelihood (annual probability of failure) for major slides has been estimated based on the results of a study of historical failures published by Lambe (1985)[3] and updated by Silva et al (2008)[4]. This paper provides a semi-empirical relationship between factor of safety and annual probability of failure. Based on this method we envisage that the quarry could be classified as a 'Category II' type project, considering that it has generally been designed, built and operated using standard engineering practices. In addition, a substantial amount of geotechnical investigation, testing and analyses has been carried out at the quarry by PSM over the last 10 years.

In order to estimate the annual probability of failure for global failure mechanisms (i.e. major slide hazards), we have adopted a FoS of 1.2 based on the stability analyses presented above. This corresponds to an annual probability of failure in the order of 10^{-2} (i.e. about 1 in 100).

Local rockfall hazard likelihoods will be further discussed in Appendix A.

[3] Lambe, T. W. (1985). Amuay landslides. In: Proc., 11th Int. Conf. on Soil Mechanics and Foundation Engineering, Golden Jubilee Volume, San Francisco, Balkema, Boston, 137–158.

[4] F. Silva, T. W. Lambe and W. A. Marr (2008). Probability and Risk of Slope Failure. Journal of Geotechnical and Geoenvironmental Engineering, 134(12), pp:9.

10.4. Vulnerability $V_{(D:T)}$ (i.e. consequences)

The quantitative risk management approach outlined in AGS (2007) uses vulnerability ($V_{(D:T)}$) of the elements at risk to the landslide to estimate consequences. Fell et al (2005[5]) defines vulnerability as the degree of loss within the area affected by the hazard. In regards to the risk assessment process, vulnerability is the probability of loss of life to an individual given the landslide event (e.g. impact by rock fall, burial by debris etc.) The following factors can influence the likelihood of deaths and injuries (vulnerability) of persons who are impacted by a landslide:

- Volume of slide.
- Type of slide, mechanism of slide initiation and velocity of sliding
- Depth of slide
- Whether the landslide debris buries the person(s)
- Whether the person(s) are in the open or enclosed in a vehicle or building
- Whether the vehicle or building collapses when impacted by debris

AGS (2007) publishes a range of vulnerability values for different scenarios that are based on published case studies. The values we have adopted for our analysis are based on these ranges and are presented in Table 6.

Table 6. Adopted vulnerability values.

Scenario	Rockfall	Major Slide
Person in open space	0.5	1
Person in light vehicle	0.2	1
Person in FOPS / ROPS vehicle	0.01	1

The values presented in the table above highlight the inherent vulnerability of persons in the event of complete or substantial burial by debris, such as would be the case should a major slide occur. In contrast, should an individual rockfall impact a conventional light vehicle, the chance of survival is relatively high. People in the open are obviously the most vulnerable and it should be noted that even small rockfalls can cause death.

The RMS brief also asks for discussion on 'what damage might occur'. We interpret this to mean possible damage to property in the quarry such as the telestackers, access tracks and vehicles, in response to hazards. Should they occur, major slides would obviously cause catastrophic damage to any property in the quarry. The damage to property caused by individual rockfalls is likely to be more localised. For example, a direct rockfall impact to a telestacker could foreseeably cause significant damage and render it unserviceable.

10.5. Summary of risk estimation

Risks at the site have been estimated using spreadsheets developed to address each of the predicted work activities in the quarry discussed above. The risks for each individual work activity are presented

[5] Fell R; Ho KS; Lacasse S; Leroi E, 2005, 'A framework for landslide risk management', in International Conference on Landslide Risk Management, International Conference on Landslide Risk Management, Vancouver BC Canada, presented at International Conference on Landslide Risk Management, Vancouver BC Canada, 31 May - 03 June 2005

in Appendix D. The combined estimated risks for all work activities are presented in Table 8 below. The risk assessment for local rockfall hazards is presented in Appendix A.

Table 7. Summary of risk estimation for major slide hazards (i.e. global failures).

Filling phase	Estimated Loss of Life Risk for the person most at risk (per annum)
Construction	4.0×10^{-5}
Operation	2.8×10^{-6}

There are currently no legislated risk acceptance criteria for loss of life due to landslides in Australia and it is the responsibility of the property owner or managing authority to set the Tolerable Risk Criteria for loss of life. AGS (2007) provide the following recommendations in relation to tolerable risk criteria for loss of life:

Table 8. AGS 2007 suggested tolerable loss of life individual risk.

Situation	Suggested Tolerable Loss of Life Risk for the person most at risk
Existing Slope / Existing Development	10^{-4} / annum
New Constructed Slope / New Development / Existing Landslide	10^{-5} / annum

It should be pointed out that "acceptable" risk levels are usually considered to be an order of magnitude smaller than the assessed "tolerable" risks. AGS provide the following commentary of acceptable and tolerable risks:

- *"Tolerable Risks are risks within a range that society can live with so as to secure certain benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if practicable."*
- *"Acceptable Risks are risks which everyone affected is prepared to accept. Action to further reduce such risk is usually not required unless reasonably practicable measures are available at low cost in terms of money, time and effort."*
- *"AGS suggests that for most development in existing urban area criteria based on Tolerable Risks levels are applicable because of the trade-off between the risks, the benefits of development and the cost of risk mitigation."*

While there are no internationally accepted risk criteria for landsliding, AGS (2007b[6]) provides an interesting summary of individual life loss risk criteria in use in a number of engineering related disciplines both in Australia and internationally.

[6] AGS (2007b), "Commentary on Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning", Australian Geomechanics Society, Australian Geomechanics Vol 42 No1 March.

Table 9. Examples of individual life loss risk criteria used in other organisations.

Organization	Industry	Description	Risk/annum	Reference
Health and Safety Executive, United Kingdom	Land use planning around industries	Broadly acceptable risk. Tolerable limit	10^{-6}/annum, public and workers 10^{-4}/annum public(1) 10^{-3}/annum workers	HSE (2001)
Netherlands Ministry of Housing	Land use planning for industries	Tolerable limit(2)	10^{-5}/annum, existing installation 10^{-6}/annum, proposed installation	Netherlands Ministry of housing (1989), Ale (2001), Vrijling *et al.* (1998)
Department of Urban Affairs and Planning, NSW, Australia	Land use planning for hazardous industries	"acceptable" (tolerable) limits (2)	$5x10^{-7}$/annum hospitals, schools, childcare facilities, old age housing 10^{-6}/annum residential, hotels, motels $5x10^{-6}$/annum commercial developments 10^{-5}/annum sporting complexes	
Australian National Committee on Large Dams	Dams	Tolerable limit	10^{-4}/annum existing dam, public most at risk subject to ALARP 10^{-5}/annum new dam or major augmentation, public most at risk, subject to ALARP.	ANCOLD (2003)
Australian Geomechanics Society guidelines for landslide risk management	Landslides (from engineered and natural slopes)	Suggested tolerable limit	10^{-4}/annum public most at risk, existing slope 10^{-5}/annum, public most at risk, new slope	AGS (2000)
Hong Kong Special Administrative Region Government	Landslides from natural slopes	Tolerable limit	10^{-4}/annum public most at risk, existing slope. 10^{-5}/annum public most at risk, new slope	Ho et al. (2000), ERM (1998), Reeves *et al.* (1999)
Iceland ministry for the environment hazard zoning	Avalanches and landslides	"acceptable" (tolerable) limit	$3x10^{-5}$/annum residential, schools, daycare centres, hospitals, community centres. 10^{-4}/annum commercial buildings $5x10^{-5}$ recreational homes(3)	Iceland Ministry for the environment (2000), Arnalds *et al.* (2002)
Roads and Traffic Authority, NSW Australia	Highway landslide risk	Implied tolerable risk	10^{-3}/annum(4)	Stewart *et al.* (2002), RTA (2001)

11. Monitoring

11.1. Visual monitoring

To assist with the management of risks at the site, RMS has engaged Coffey to undertake periodic monitoring of the quarry during infilling works. This is also to include a review of the risk management measures implanted by LLBJV. The monitoring will involve observations by experienced geotechnical personnel during periodic site visits. This will involve site walkovers to observe site conditions from safe vantage points as well as UAV inspections. Live video footage obtained via the UAV will be viewed on site and will also be reviewed on return to our office. The monitoring will be aimed at investigating the presence of the following features that could be indicative of instability:

- Tension cracks behind the crests of batters and on access tracks;
- Deformation / changes to the condition of batters (i.e. opening of fractures, obvious bulging);
- Recent rockfalls on benches and access tracks;
- Blockages / obstructions in the concrete lined drainage channel on the north wall
- Water and/or seepage discharging from batters

Based on our recent discussions we propose the following visual monitoring regime:

- Site walkovers on a 3 monthly basis;
- Additional site walkovers be made in the event that the PSM / LLBJV rainfall thresholds are reached or exceeded;
- UAV inspection on a 6 monthly basis or more frequent should the site walkovers indicate any cause for concern;

Following each site visit we would provide a brief memo summarising our observations and recommendations for any further risk management measures. We will also provide video footage obtained by the UAV.

11.2. Survey monitoring

We understand from the reports provided that survey will be undertaken “as required” or “as directed by PSM” to monitor global instability. No further details have been provided. Based on the information provided, the existing council survey monuments are typically set back a short distance from the crest of the quarry walls. It would be useful to install additional survey monuments set back further from the crest (outside the potential failure zone) to provide a ‘stable baseline’ for review of the existing survey monuments. These should be located about 30m to 50m back from each of the existing survey monuments.

Reflective survey targets could also be installed directly on the south wall of the quarry. These should be located at approximately 30m centres and positioned near the crest of each batter / bench face. Given the irregular nature of the south wall and the presence of trees, the targets would need to be positioned such that surveyors be able to take ‘line of sight’ measurements. Care should be taken to ensure there is a good coverage of targets in areas of the quarry walls subject to the stability analyses above (i.e. within the modelled failure zones).

We recommend survey monitoring initially be undertaken on a monthly basis for the first 6 months of the project. The data should then be reviewed with a view to reducing the monitoring frequency to a 3 monthly period if no adverse movements have been observed.

There is currently limited slope monitoring in place to allow trigger monitoring levels to be adopted using actual site ground movement records. Accordingly, it is recommended that an initial alert trigger value of 5mm (total ground movement) is set for all surface monitoring points. It is recommended that baseline readings be taken 1 month prior to commencement of construction activities, and again immediately prior to construction. Following each periodic review thereafter, the trigger values for each instrument/reflector should be reassessed and, where appropriate, adjusted based on the observations made during the previous period.

Where exceedances are noted, appropriate notifications must be made to all relevant parties (including Coffey). A preliminary Trigger Action Response Plan (TARP) is presented in Table 10 below. As discussed above, this plan will need to be reviewed following initial data collection and further observations of slope performance.

Table 10. Preliminary Trigger Action Response Plan.

DRAFT INITIAL PLAN ONLY – Must be revised as background data is collected				
Trigger Action Response Plan (TARP): Hornsby Quarry Slope Monitoring				
Monitoring system and objective: Monitoring prisms at approximately 30m spacing, initially surveyed on monthly basis, monitoring displacement and deformation; and regular visual inspection monitoring, including following rainfall events.				
Status and Response Level	**Condition: Green**	**Condition: Orange**	**Condition: Red**	**Notes**
Instrumentation	Alarm thresholds			
Monitoring Prisms	<5mm total ground movement between monthly survey for all monitoring points.	>5mm total ground movement from prior monthly survey for any monitoring point.	>10mm total ground movement from prior monthly survey for any monitoring point.	These thresholds are to be revised following initial data collection for relevance to current slope performance. Distinction between orange and red conditions would be made following evaluation of initial survey data.
Visual Monitoring	All observations confirm no obvious visual indication of instability or other geotechnical or safety concern.	Any observation of an indication of instability or other geotechnical or safety concern.	Any observation of an indication of instability or other geotechnical or safety concern.	
Required Response				
Monitoring Engineer	Following check of survey data, record advice that slope monitoring is clear of signs of instability	Notify all relevant parties (including Coffey).	Notify all relevant parties (including Coffey). Review requirements for additional monitoring.	
Site Supervisor	Maintain awareness of and familiarisation with monitoring systems including objectives and monitoring frequency and locations of equipment.	Notify all personnel working within the quarry area. Personnel to be evacuated from within quarry void until alarm trigger evaluated.	Notify all personnel working within the quarry area. Personnel to be evacuated from within quarry void until alarm trigger evaluated.	

12. Closing comments

This report has presented a review of previous stability assessments and modelling carried out for the Hornsby Quarry. We have carried out a limited amount of analysis and modelling in order to undertake this review and provided comments where appropriate. This assessment returned a range of FoS values, depending on the analysis model being considered. It should be noted that, like most quarries and open pit mines both within Australia and internationally, the Hornsby Quarry was likely to have been designed and operated with a low factor of safety. It is common for quarries of this nature to adopt factors of safety of around 1.1 to 1.15, and thus we note that the Hornsby Quarry is unlikely to pose a risk any greater than what is commonly accepted. Furthermore, the Hornsby Quarry was decommissioned some 20 years ago and, based on recent visual observations, the quarry slopes remain largely intact and in a relatively stable condition. The mitigation measures currently proposed, including toe exclusion zones, survey monitoring, wet weather warnings and access restrictions further serve to reduce risks to personnel.

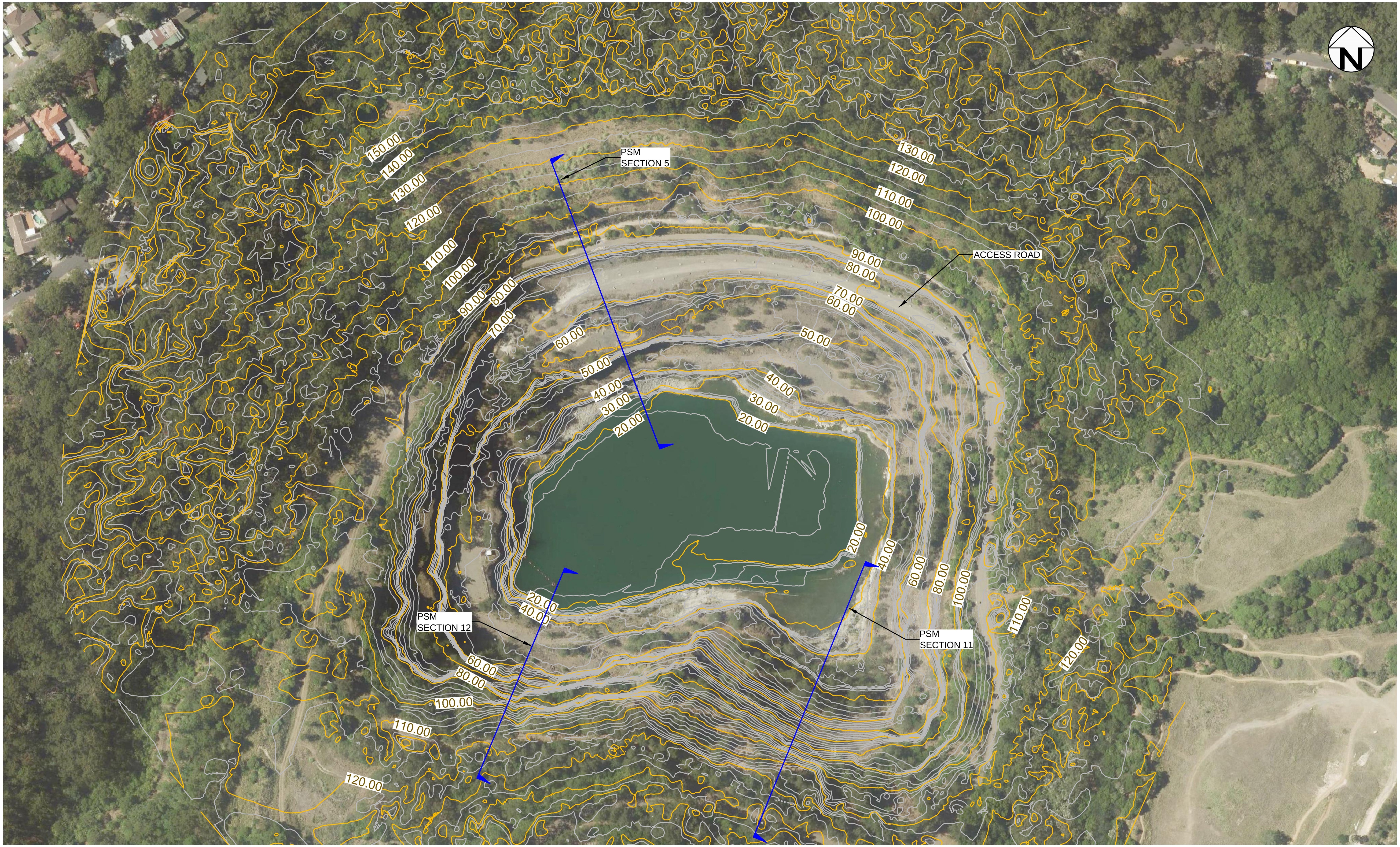
This report also presented our own observations of geotechnical site features and assessment of rock fall hazards observable at the time of the fieldwork. These features will change and may deteriorate over time, which could change existing hazards or create new ones.

The risk assessment presented in this report estimated risks associated with global failure mechanisms (i.e. major slide hazards). It should be noted the exposure of an individual to hazards will have a significant effect on the level of risk and we have necessarily been required to estimate the duration of some of the work activities. RMS has advised that for this project they will adopt the AGS (2007) suggested tolerable risk criteria for loss of life for existing slopes (10^{-4} per annum). The level of risk estimated for both the construction and operation phase works is lower than the suggested AGS (2007) criteria for loss of life for existing slopes. The risks would therefore be considered ‘tolerable’ based on this criteria.

The risk assessment for local rockfall hazards is presented separately in Appendix A. Tables F1 and F2 in Appendix F summarise the total risk at the site, estimated by summing the local failure mechanism risks with the global failure risks. These risks are lower than the suggested AGS (2007) criteria for loss of life for existing slopes. The risks would therefore be considered ‘tolerable’ based on RMS’ criteria.

The attached document entitled “Important information about your Coffey report” forms an integral part of this report and presents additional information about it uses and limitations.

Figures



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coffey
A TETRA TECH COMPANY

client:	ROADS AND MARITIME SERVICES
project:	GEOTECHNICAL ASSESSMENT OF THE HORNSBY QUARRY VOID HORNSBY, NSW
title:	SECTION LOCATION PLAN
project no:	GEOTLCOV25707AA
figure no:	FIGURE 1
rev:	A

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client: ROADS AND MARITIME SERVICES

project: GEOTECHNICAL ASSESSMENT OF THE HORNSBY QUARRY VOID
HORNSBY, NSW

title: NORTH WALL PHOTOMOSAIC

project no: GEOTLCOV25707AA | figure no: FIGURE 2 | rev: A

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HORNSBY, NSW

title: UPPER NORTH WALL PHOTOMOSAIC

project no: GEOTLCOV25707AA | figure no: FIGURE 3 | rev: A

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project: GEOTECHNICAL ASSESSMENT OF THE HORNSBY QUARRY VOID HORNSBY, NSW

title: EAST WALL PHOTOMOSAIC

project no: GEOTLCOV25707AA | figure no: FIGURE 4 | rev: A

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original size	A3

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client: ROADS AND MARITIME SERVICES

project: GEOTECHNICAL ASSESSMENT OF THE HORNSBY QUARRY VOID
HORNSBY, NSW

title: SOUTH WALL PHOTOMOSAIC

project no: GEOTLCOV25707AA | figure no: FIGURE 5 | rev: A

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client: ROADS AND MARITIME SERVICES

project: GEOTECHNICAL ASSESSMENT OF THE HORNSBY QUARRY VOID
HORNSBY, NSW

title: WEST WALL PHOTOMOSAIC

project no: GEOTLCOV25707AA | figure no: FIGURE 6 | rev: A

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Appendix A – Assessment of Local Failure Mechanisms (i.e. rockfalls)

Appendix A

Assessment of Local Failure Mechanisms (i.e. rockfalls)

1. Introduction

This appendix presents our assessment of local failure mechanisms (i.e. rockfall hazards) in the Hornsby Quarry void and the risks associated with the infilling works, during both establishment and operational phases of the project. The main body of this report deals with the review of potential global failure mechanisms within the quarry void and associated risks. This appendix should be read in conjunction with the report.

This appendix presents our review of previous studies at the site, together with the results of rockfall modelling and risk assessments.

2. Scope of work

More specifically, the scope of this study includes the following:

- Review the Lend Lease Bouygues Joint Venture (LLBJV) proposed construction methods / logistical plans, and provide a summary of geotechnical risks and risk mitigation measures.
- Review previous reports for the Quarry prepared by PSM, provide comment on the adequacy of the recommendations presented therein with regard to quarry backfilling operations, and provide counter recommendations if deemed necessary.
- Assess slope stability with respect to potential local failure mechanisms within the quarry void and grounds immediately surrounding the void.
- Complete a desktop study of available published information and existing previous studies for the site, and highlight any data gaps warranting additional assessment (if required).
- Predict potential changes in void stability during the void backfilling, including consideration of the potential stability effects of changed groundwater conditions.
- Recommend measures to be implemented to reduce the likelihood of quarry wall instability prior to, and during spoil placement works within and adjacent to the void.
- Carry out periodic monitoring and review of the implementation of these measures (this work will be carried out during the operation phase of the project).
- Undertake a risk management exercise (in accordance with AGS 2007 guidelines[1]) including risk analysis, evaluation and treatment and addressing the following concerns:
    1. Hazard Identification (what might happen?)

[1] AGS (2007c) "Practice Note Guidelines for Landslide Risk Management", Australian Geomechanics Society, Australian Geomechanics Vol 42 No1 March.

2. How likely is it to occur (frequency or likelihood)
3. What damage or injury might occur (consequences)
4. Level of risk
5. Slope design acceptance criteria
6. Stabilisation treatment and risk mitigation recommendations

3. Rockfall modelling

3.1. Background

Rockfall modelling has been carried out at selected profiles across the site to assess the trajectories of falling rocks and help assess the validity of recommendations provided by PSM to manage risks during the backfilling works. The modelling was carried out using the commercially available software RocFall™ V5 produced by Rocscience Inc. Rigid body rockfall analyses were used for the assessment. This is a newer version of the software than was used for the previous studies at the site and uses new algorithms which take into account the geometric shape of the falling rocks based on rigid body dynamics. The software producers claim that the introduction of rock shapes to rockfall simulations allows a more realistic interpretation of rockfall events. Despite this we recommend that the results be viewed with caution and used as a guide to rockfall behaviour. It is inherently difficult to model the effect of small scale irregularities on slopes using RocFall[2].

Rockfall parameters used in the modelling (e.g. coefficients of normal and tangential restitution) were similar to those used by PSM and were also guided by software recommended values and our experience with similar sites. We used a tabular shaped rock in the modelling to mimic the 'blocky' nature of the rockfall debris observed on site. Rockfall analysis information and parameters are presented in Appendix G.

Rockfall modelling was carried out at one cross section at each of the north, east and west quarry walls and two cross sections for the south wall. Slope profiles used for the modelling were extracted from a combination of UAV borne photogrammetry and survey data.

For modelling purposes, we have typically initiated rockfalls from near the crest of each batter face, which is a conservative approach. The analysis modelled 1,000 boulder initiations at each initiation location and assumed falling rocks had no initial velocity, to simulate rocks falling out of a rock face (i.e. starting from rest). It is important to note that RocFall does not consider the mass of rocks when modelling rockfall behaviour (i.e. mass has no bearing on modelled rockfall trajectory).

The following sections summarise the results for each of the modelled profiles. At each profile we have modelled existing conditions as well as the effect of the proposed perimeter ditch during filling operations. It should be noted that the rock catching effectiveness of the perimeter ditch may vary with changing fill heights and we have not modelled every scenario.

[2] Hunter AJ, Nicholson T, Burgess PJ, and Brizga V (2011) Rock Fall Risk and Remediation on the Lake George Escarpment. Australian Geomechanics, 46(1):1-12.

3.2. North wall

The rockfall modelling results for this profile are presented in Figure A1. The results indicate that rockfalls will be contained on the benches in the upper portions of the quarry. In addition, the majority of rockfalls originating from the uppermost batter face are contained in the concrete drainage channel. These results are consistent with our observations of rockfalls on site.

The concrete barriers and / or earth mounds that have been proposed to control rockfalls along the access road will have limited effectiveness if located close to the toe of the batter due to high bounce heights. As can be seen in Figure A1, such barriers would need to be located several metres out from the toe of the batter to effectively prevent rocks reaching the road. The modelled run-out distances of rocks on the access road are in general agreement with the locations of rocks observed during our site visit.

The results indicate that the benches in the lower portion of the quarry are not sufficiently wide to contain all rockfalls. This is not surprising given how narrow the benches are and is consistent with our site observations.

Based on the current geometry of the site, rockfalls could be expected to have a ‘run out’ of several metres across the floor of the quarry. The modelling indicates that the proposed perimeter ditch will contain all rockfalls at this location.

3.3. East wall

The rockfall modelling results for the east wall section profile are presented in Figure A2. The profile used for the rockfall modelling was at the approximate location of the tunnel reclaimer.

Modelled rockfall trajectories indicate that all benches on the east wall, with the exception of the uppermost bench, are not sufficiently wide to contain rockfalls. Modelled rockfall trajectories demonstrated ‘run-out’ distances of up to 19 m across the floor of the quarry.

The modelling indicates that the proposed perimeter ditch is likely to contain rockfalls at this location.

3.4. South wall

Rockfall modelling was carried out at two cross sections for the south wall. The rockfall modelling results for the eastern south wall profile are presented in Figure A3 and the western south wall profile are presented in Figure A4.

Based on the current slope geometry, the rockfall modelling results indicate that rockfalls will have a ‘run-out’ of up to 54 m across the quarry floor at the eastern south wall.

The rockfall modelling results for the western south wall indicate that the benches are not sufficiently wide to contain the majority of rockfalls. Prior to the establishment of the perimeter ditch, rockfalls could be expected to have a ‘run out’ of up to about 52m at the western south wall. However, the modelling indicates that less than 2% of rockfalls reach the proposed ‘person access zone’, set back 25m from the quarry walls.

During the operation phase, rockfall modelling results for the eastern and western south wall indicate that more than 99% of total rockfalls are likely to be contained by the proposed perimeter ditch. The modelling indicates that less than 1% of rockfalls reach the proposed ‘person access zone’.

The concrete barriers and / or earth mounds that have been proposed to control rockfalls along the access road along the south wall are expected to have very limited effectiveness due to slope geometry and high bounce heights.

3.5. West wall

The rockfall modelling results for this profile are presented in Figure A5. The results indicate that rockfalls are likely to be contained on the benches in the upper portions of the quarry, however, will ‘run out’ onto the existing access road. The existing concrete barriers appear to be effective at retaining some of the rockfalls along the west wall.

The effectiveness of the proposed concrete barriers and / or earth mounds in controlling rockfalls will depend on their proximity to the adjacent batter due to the bounce heights of rocks. As can be seen in Figure A5, such barriers would need to be located several metres out from the toe of the batter to effectively prevent rocks reaching the road.

Rockfalls originating from the lower benches could be expected to have a ‘run out’ of up to about 9 m across the floor of the quarry.

The modelling indicates that the proposed perimeter ditch is likely to contain all rockfalls at this location.

4. Hazards

The risk mitigation measures outlined in PSM report ref: PSM2820-004R, dated 23 February 2016 have been formulated around the following hazards:

1. Major slides (e.g. multi-bench or bench scale rock mass failures)
2. Minor failures (e.g. shallow rock mass slides, erosional rilling)
3. Structurally controlled failures (e.g. planar slides, wedge failures, toppling etc.)
4. Rockfalls.

Based on our review of the reports provided, this hazard assessment seems reasonable. In addition, evidence of these hazards is supported and discussed in our site observations above based on our site visit and review of UAV footage.

The UAV footage may have improved the understanding regarding the triggering mechanisms for some of these hazards. For example, a source of rockfalls was observed along the crest of the south wall where rocks (corestones) were observed to be exposed in steep batters in weathered rock and residual soil. Apparently recent slides in soil materials were observed in this area, some of which may have occurred in a fill berm at the crest of the quarry. Such slides, as well as erosion of rock will lead to rockfalls.

The root jacking effect of tree roots was also observed on the south wall and appears to have triggered a rockfall with a volume of several cubic metres. Trees are quite common on the quarry batters, particularly the south, east and west walls. The source areas of rockfalls triggered by root jacking may show little, or no distress prior to failure and can occur at any time (i.e. rockfalls are not necessarily triggered by rainfall).

5. Risk assessment

5.1. Background

Where geotechnical slope hazards have the potential to cause harm to individuals it is normal practice to adopt a risk management approach rather than to describe features using absolute terms such as whether a rock face is stable or unstable. By using this framework a range of options can be considered to reduce or manage the risk at a site, depending on the level of risk the owner of the site wishes to tolerate or accept. Such an approach usually involves risks to be estimated based on the product of the likelihood and consequences of an event such as a rockfall impacting a person.

When dealing with natural or man-made slopes it is normal practice to assess risks using methods consistent with the principles of the Australian Geomechanics Society's Practice Note Guidelines for Landslide Risk Management (AGS 2007[3]). The AGS (2007) guidelines provide a national framework for Landslide Risk Management and are widely used. AGS (2007) makes it clear that where risk to life is considered, the risks involved should be quantified. This assessment has been carried out using methods consistent with the guidelines outlined above. AGS risk terminology used in this report is summarised in Appendix C.

The purpose of the risk assessment is to estimate the annual risk of 'loss of life' to an individual working in the quarry. The individual is taken to be the 'person most at risk', who typically has the greatest exposure to the risks (i.e. greatest spatial temporal probability). The risk of 'loss of life' to an individual is calculated from:

$$\mathbf{R}_{(LoL)} = \mathbf{P}_{(H)} \times \mathbf{P}_{(S:H)} \times \mathbf{P}_{(T:S)} \times \mathbf{V}_{(D:T)}$$

Where

$\mathbf{R}_{(LoL)}$ is the risk (annual probability of death of an individual).

$\mathbf{P}_{(H)}$ is the annual probability of the hazard occurring (event).

$\mathbf{P}_{(S:H)}$ is the probability of spatial impact of the event impacting an individual taking into account the travel distance and travel direction given the event. For example, if a rockfall occurs at a site when an individual is present, the individual may be located at another part of the site and therefore will not be affected.

$\mathbf{P}_{(T:S)}$ is the temporal spatial probability (e.g. of the building or location being occupied by the individual) given the spatial impact and allowing for the possibility of evacuation given there is warning of the event occurrence.

$\mathbf{V}_{(D:T)}$ is the vulnerability of the individual (probability of loss of life of the individual given the impact).

As requested, we have estimated the risk associated with working in the quarry for the following two scenarios:

- **Construction Phase** – includes work such as construction of the reclaimer and telestackers, upgrading access roads, scaling batters adjacent to access tracks and installing barriers.

[3] AGS (2007c), "Practice Note Guidelines for Landslide Risk Management", Australian Geomechanics Society, Australian Geomechanics Vol 42 No1 March.

- **Operation Phase** - includes work such as operation and maintenance of the reclaimer and telestackers, vehicle movements along access road.

Further discussion on the nature of the individual work activities associated with each of these phases is provided below. It is important to note that we have assumed all the PSM recommended risk mitigation measures will be in place during the Operation Phase.

The risk assessment presented below deals with local rockfall hazards. The risk assessment for global failure mechanisms (i.e. major slide hazards) is presented in the main body of this report.

5.2. Temporal considerations $P_{(T:S)}$

The risk assessment process necessarily requires a number of judgements to be made, particularly in relation to individual's exposure to risks and the frequency of hazard events. The exposure of individuals working in the quarry has been largely based on information provided by RMS. Where such information was not available, such as the duration of certain construction activities, we have used estimates. It should be noted that the exposure of an individual to hazards will have a significant effect on the level of risk. Our risk assessment has been based on each of the predicted work activities in the quarry during the construction and operational phases of the project. These activities and associated estimated durations used in the assessment are summarised in Table 1 and Table 2 below.

Table 1. Construction phase activities and estimated durations.

Activity number	Activity description	Person at risk	Estimated duration
1A	Upgrade of the existing access road, installation of safety bunds/barriers and scaling works to remove loose rock from batters along access road	Person working in open directing installation of concrete barriers or soil mounds on the access road along the north and west walls	2 weeks
1B		Person in excavator (fitted with FOPS / ROPS) working on the access road / scaling loose rocks along the north and west walls	2 weeks
1C		Person in FOPS / ROPS vehicle working on the access road near the batter along the south wall	3 weeks
2A	Travel along access road	Person in light vehicle driving on the access road near the batter along the north and west walls	We have assumed that a person will make 6 trips (3 return trips) on average each day
2B		Person in FOPS / ROPS vehicle driving on the access road near the batter along the south wall	
3	Preparation of a 'sound platform' by personnel in earthmoving equipment / construction of the conveyor footing in the pit	Person in earth moving equipment (FOPS / ROPS) working on the quarry floor	3 weeks
4	Construction of the reclaimer*	Person working on quarry floor in vicinity of reclaimer location	3 weeks
5A	Installation of telestackers*	Person working on quarry floor in vicinity of telestacker location	4 weeks
5B		Person in FOPS / ROPS vehicle working on the quarry floor in vicinity of telestacker location	

*Note: For these activities we are advised that vehicle and people movements will comply with the access zone restrictions outlined in the PSM report Ref: PSM2820-004R, dated 23 February 2016.

Table 2. Operational phase activities and estimated durations.

Activity number	Activity description	Person at risk	Estimated duration
6A	Travel along access road with risk mitigation controls in place	Person in light vehicle driving on the access road near the batter along the north and west walls	We have assumed that a person will make 6 trips (3 return trips) on average each day
6B		Person in FOPS / ROPS vehicle driving on the access road near the batter along the south wall	
7	Repositioning and maintenance of the telestackers	Person working on quarry floor in Person Access Zone	We have assumed that this activity will take 1hr on average each day
8	Personnel working within pit on daily basis	Person working on quarry floor in Person Access Zone	We have assumed that a person will spend up to 4 hrs in the pit on average each day

5.3. Likelihood estimation $P_{(H)}$

For the purposes of the risk assessment, we have simplified the hazards described above into two broad categories; major slides and rockfalls. 'Major slides' represent vary large multi-bench and/or bench scale rock mass failures (i.e. 'global failures'), whereas 'rockfalls' represent hazards associated with individual falling rocks, as well as rockfalls that may originate from the 'Minor failures' and 'Structurally controlled failures' mentioned above.

Apart from the qualitative descriptions provided in previous reports, the record of rockfall frequency is scarce. Consequently the rockfall likelihoods (frequency) has necessarily been based on judgements. These judgements are guided by observed rockfalls at the site and observations of the batters. A summary of these assumptions used in the risk assessment are provided in Table 3 below.

Table 3. Adopted rockfall frequencies.

Location*	Likelihood / annual frequency (during construction phase)	Likelihood / annual frequency (with proposed risk mitigation measures in place during operation phase)
Rockfalls reaching access track on north and west wall	About 3	About 0.5
Rockfalls reaching access track on south wall	About 6, possibly more	About 6, possibly more (no change)
Rockfalls reaching vicinity of reclaimer location*	About 0.04	About 0.04 (no change)
Rockfalls reaching 'Person Access Zone' near south wall*	About 0.1	About 0.06

*Note: We are advised that vehicle and people movements will comply with the access zone restrictions outlined in the PSM report Ref: PSM2820-004R, dated 23 February 2016.

5.4. Vulnerability $V_{(D:T)}$ (i.e. consequences)

The quantitative risk management approach outlined in AGS (2007) uses vulnerability ($V_{(D:T)}$) of the elements at risk to the landslide to estimate consequences. Fell et al (2005[4]) defines vulnerability as the degree of loss within the area affected by the hazard. In regards to the risk assessment process, vulnerability is the probability of loss of life to an individual given the landslide event (e.g. impact by rock fall, burial by debris etc.) The following factors can influence the likelihood of deaths and injuries (vulnerability) of persons who are impacted by a landslide:

- Volume of slide.
- Type of slide, mechanism of slide initiation and velocity of sliding
- Depth of slide
- Whether the landslide debris buries the person(s)
- Whether the person(s) are in the open or enclosed in a vehicle or building
- Whether the vehicle or building collapses when impacted by debris

AGS (2007) publishes a range of vulnerability values for different scenarios that are based on published case studies. The values we have adopted for our analysis are based on these ranges and are presented in Table 4.

Table 4. Adopted vulnerability values.

Scenario	Rockfall	Major Slide
Person in open space	0.5	1
Person in light vehicle	0.2	1
Person in FOPS / ROPS vehicle	0.01	1

The values presented in the table above highlight the inherent vulnerability of persons in the event of complete or substantial burial by debris, such as would be the case should a major slide occur. In contrast, should an individual rockfall impact a conventional light vehicle, the chance of survival is relatively high. People in the open are obviously the most vulnerable and it should be noted that even small rockfalls can cause death.

We are not aware of any published vulnerability data for individuals in vehicles and plant fitted with Falling-Object Protective Structures (FOPS). We understand the FOPS system is to be designed for 100kg rocks falling unimpeded for 20m. In view of this considerable impact capacity, the chance of survival is high and we have therefore adopted a very low vulnerability value.

The RMS brief also asks for discussion on 'what damage might occur'. We interpret this to mean possible damage to property in the quarry such as the telestackers, access tracks and vehicles, in response to hazards. Should they occur, major slides would obviously cause catastrophic damage to any property in the quarry. The damage to property caused by individual rockfalls is likely to be more localised. For example, a direct rockfall impact to a telestacker could foreseeably cause significant damage and render it unserviceable.

[4] Fell R; Ho KS; Lacasse S; Leroi E, 2005, 'A framework for landslide risk management', in International Conference on Landslide Risk Management, International Conference on Landslide Risk Management, Vancouver BC Canada, presented at International Conference on Landslide Risk Management, Vancouver BC Canada, 31 May - 03 June 2005

Damage to light vehicles will vary greatly depending on the size of the rockfall and the fall height. However, it should be pointed out that even relatively small rocks can penetrate vehicle windscreens / windows and cause considerable harm to individuals. For example, the damage caused to the vehicle shown in Plate 1 below was caused by a rock with dimensions of about 0.40m x 0.30m x 0.12m falling from a height of approximately 10m. The rock penetrated the windscreen of the car, breaking the steering wheel and landing on the lap of the driver. The two passengers were injured and received hospital treatment.

Plate 1. Example of damage caused to vehicle from small rockfall.
(Image source: Sydney Morning Herald, 11 February 2015).

5.5. Summary of risk estimation

Risks at the site have been estimated using spreadsheets developed to address each of the predicted work activities in the quarry discussed above. The risks for each individual work activity are presented in Appendix D and Appendix E. The combined estimated risks for all work activities are presented in Table 5 below.

Table 5. Summary of risk estimation.

Filling phase	Estimated Loss of Life Risk for the person most at risk (per annum)
Construction	5.3×10^{-5}
Operation	8.1×10^{-6}

There are currently no legislated risk acceptance criteria for loss of life due to landslides in Australia and it is the responsibility of the property owner or managing authority to set the Tolerable Risk Criteria for loss of life. AGS (2007) provide the following recommendations in relation to tolerable risk criteria for loss of life:

Table 6. AGS 2007 suggested tolerable loss of life individual risk.

Situation	Suggested Tolerable Loss of Life Risk for the person most at risk
Existing Slope / Existing Development	10^{-4} / annum
New Constructed Slope / New Development / Existing Landslide	10^{-5} / annum

It should be pointed out that “acceptable” risk levels are usually considered to be an order of magnitude smaller than the assessed “tolerable” risks. AGS provide the following commentary of acceptable and tolerable risks:

- *“Tolerable Risks are risks within a range that society can live with so as to secure certain benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if practicable.”*
- *“Acceptable Risks are risks which everyone affected is prepared to accept. Action to further reduce such risk is usually not required unless reasonably practicable measures are available at low cost in terms of money, time and effort.”*
- *“AGS suggests that for most development in existing urban area criteria based on Tolerable Risks levels are applicable because of the trade-off between the risks, the benefits of development and the cost of risk mitigation.”*

While there are no internationally accepted risk criteria for landsliding, AGS (2007b[5]) provides an interesting summary of individual life loss risk criteria in use in a number of engineering related disciplines both in Australia and internationally.

[5] AGS (2007b), “Commentary on Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning”, Australian Geomechanics Society, Australian Geomechanics Vol 42 No1 March.

Table 7. Examples of individual life loss risk criteria used in other organisations.

Organization	Industry	Description	Risk/annum	Reference
Health and Safety Executive, United Kingdom	Land use planning around industries	Broadly acceptable risk. Tolerable limit	10^{-6}/annum, public and workers 10^{-4}/annum public(1) 10^{-3}/annum workers	HSE (2001)
Netherlands Ministry of Housing	Land use planning for industries	Tolerable limit(2)	10^{-5}/annum, existing installation 10^{-6}/annum, proposed installation	Netherlands Ministry of housing (1989), Ale (2001), Vrijling *et al.* (1998)
Department of Urban Affairs and Planning, NSW, Australia	Land use planning for hazardous industries	"acceptable" (tolerable) limits (2)	5×10^{-7}/annum hospitals, schools, childcare facilities, old age housing 10^{-6}/annum residential, hotels, motels 5×10^{-6}/annum commercial developments 10^{-5}/annum sporting complexes	
Australian National Committee on Large Dams	Dams	Tolerable limit	10^{-4}/annum existing dam, public most at risk subject to ALARP 10^{-5}/annum new dam or major augmentation, public most at risk, subject to ALARP.	ANCOLD (2003)
Australian Geomechanics Society guidelines for landslide risk management	Landslides (from engineered and natural slopes)	Suggested tolerable limit	10^{-4}/annum public most at risk, existing slope 10^{-5}/annum, public most at risk, new slope	AGS (2000)
Hong Kong Special Administrative Region Government	Landslides from natural slopes	Tolerable limit	10^{-4}/annum public most at risk, existing slope. 10^{-5}/annum public most at risk, new slope	Ho et al. (2000), ERM (1998), Reeves *et al.* (1999)
Iceland ministry for the environment hazard zoning	Avalanches and landslides	"acceptable" (tolerable) limit	3×10^{-5}/annum residential, schools, daycare centres, hospitals, community centres. 10^{-4}/annum commercial buildings 5×10^{-5} recreational homes(3)	Iceland Ministry for the environment (2000), Arnalds *et al.* (2002)
Roads and Traffic Authority, NSW Australia	Highway landslide risk	Implied tolerable risk	10^{-3}/annum(4)	Stewart *et al.* (2002), RTA (2001)

6. Comments on PSM proposed risk mitigation measures

6.1. Summary

We are advised that LLBJV will adopt the risk mitigation measures outlined in PSM report ref: PSM2820-004R, dated 23 February 2016. As discussed above, our risk assessment carried out for the construction phase of the project assumes that all these measures will be implemented. The risk mitigation measures are aimed at managing the risks associated with the PSM assessed hazards summarised previously in this report. The proposed risk mitigation measures can be broadly summarised below:

- Preparatory works along the access road.
- Implementation of vehicular and pedestrian exclusion zones by constructing physical safety barriers / bunds.
- Implementation of an exclusion zone between batter and fill operation area including a perimeter ditch. This forms part of the filling operation methodology
- All vehicles and plant travelling daily on the access road into the quarry to be fitted with Roll-over Protective Structures (ROPS) and Falling-Object Protective Structures (FOPS).

- Inspections and maintenance regimes.
- Restrictions on personnel exiting vehicles.

For descriptive purposes, the PSM report divides the access road into seven areas. These are shown the figure reproduced in Plate 2 below.

It should be pointed out that the word “safe” has been used a number of times in the recommendations of the 2016 PSM report, for example the recommendations in Section 4.1 are titled “Safe access into the quarry”. When dealing with geotechnical and landslide risks it is normal practice to adopt a risk management approach rather than to describe features using absolute terms such as this. Rather, the PSM and LLBJV proposed risk mitigation measures are aimed at reducing, not eliminating the risks associated with quarry instability.

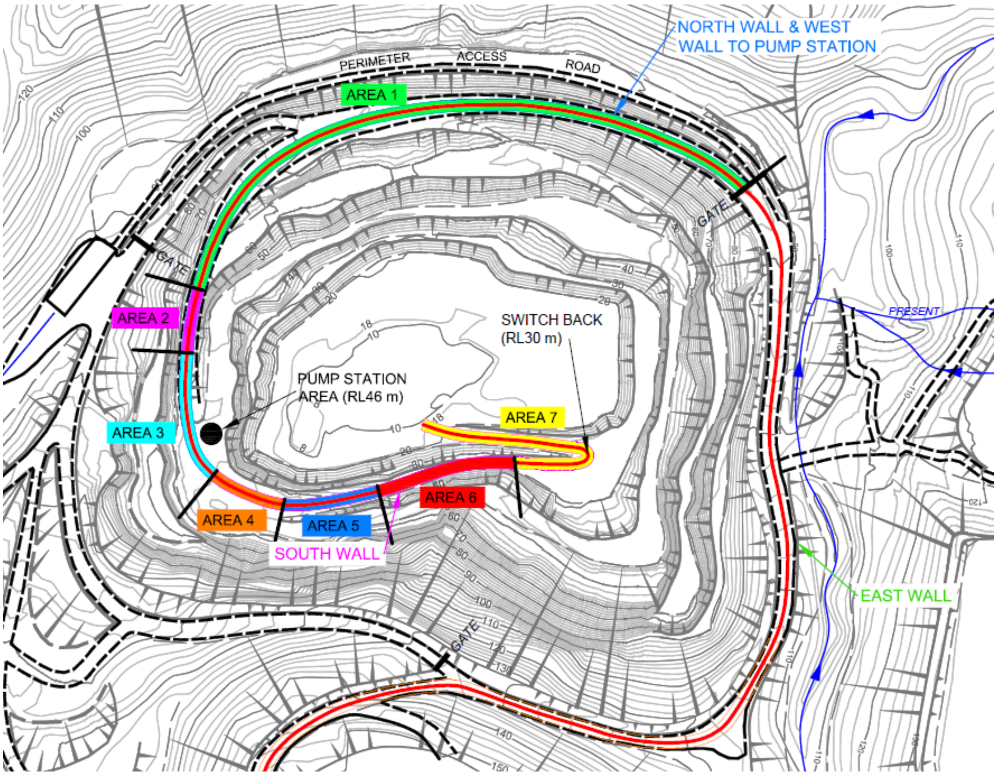

Plate 2. PSM proposed treatment areas for the access road.

6.2. Access road preparatory works

Rock scaling has been proposed for the rock batters to remove loose rock along the access road. The scaling will be carried out by a minimum 30t excavator to the limit of its reach. This is a reasonable means of reducing rock fall incidences however the effectiveness is obviously limited to the reach of the excavator. It should be recognised that there is a possibility that the scaling works could destabilise rock masses at the limit of the excavators reach, leaving rocks with a high likelihood of instability unable to be removed. We suggest that a contingency be developed to manage this risk. This could include using a long reach excavator, scaling by personnel in a boom lift (cherry picker) or rock removal using rope access methods or personnel in a crane box.

6.3. Vehicular and pedestrian exclusion zones

The proposed use of safety bunds or precast concrete barriers (PCB) / jersey barriers are a reasonable means to reduce the incidence of rockfalls reaching access tracks. However, the effectiveness of barriers will depend on the distance they are able to be set back from the batter. For example, along the north wall access track, which located on a wide bench, the barriers are likely to be effective at stopping the majority of rock falls originating from the adjacent batter. However we recommend that the barriers are located as far as practicable from the batter to reduce the likelihood of rocks bouncing over them.

As demonstrated by the rockfall modelling in Figures A3 and A4, the barriers will be significantly less effective in reducing rockfalls reaching the access track along the south wall. The majority of rockfalls originating from the batters in the upper portion of the quarry are likely to bounce well clear of the barriers and onto the track or quarry floor. This is not surprising given the height of the south wall and slope geometry. The barriers may be effective at stopping a proportion of rock falls from the batter immediately adjacent to the track, however they should not be relied upon to provide protection from rock falls originating from higher batters on the south wall.

It should also be recognised that the energy absorbing capacity of a PCB is between about 20kJ and 30kJ[6]. Based on our site observations and rockfall modelling it is unlikely that rockfalls of this magnitude will occur at the barrier locations along the north wall. However, rockfall energies will be considerably larger along the south wall and could exceed these capacities.

6.4. Access road restrictions

All vehicles travelling to the base of the pit will be required to have both ROPS and FOPS, with the FOPS designed for 100kg rocks falling unimpeded from 20 m. We are in agreement with this recommendation.

Vehicles not fitted with ROPS / FOPS will only be permitted to travel in Areas 1 to 3 but under special circumstances may be allowed to travel with Areas 4 to 7 (i.e. to the base of the pit). People in the open (i.e. not in a vehicle) are allowed on the access road in Areas 1 to 3, but not in Areas 4 to 7. We are in general agreement with this proposal, however LLBJV will need to accept that there is a higher risk associated with allowing vehicles not fitted with ROPS / FOPS to travel in Areas 4 to 7.

6.5. Exclusion zones during filling

As mentioned above, an exclusion zone will be established that comprises all areas in the quarry floor within 10 m of the batters. This exclusion zone will result in the formation of a perimeter ditch. Based on the rock fall modelling we have carried out, this appears to be a reasonable recommendation. The modelling indicates the perimeter ditch is likely to catch rock falls from the east, west and north walls. However, there is a possibility that a small number of rock falls originating from the south wall will not be caught by the perimeter ditch.

It should also be noted that we have only modelled one fill level scenario, whereby the fill is at a low level in the pit. The effectiveness of the perimeter ditch may vary as the fill height increases due to changes to the slope geometry. This is particularly apparent along the south wall which has either no or narrow benches and larger predicted rock bounce heights. We are not aware whether or not PSM /

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[6] Patnaik, A., Musa, A., Marchetty, S., & Liang, R. 2015. Full-Scale Testing and Performance Evaluation of Rockfall Concrete Barriers, Journal of the Transportation Research Board, Transportation Research Record 2522.

LLBJV modelled the effect of the changing fill height on the rock catching effectiveness of the perimeter ditch. We recommend that this issue be clarified.

Only ROPS / FOPS vehicles are allowed to work in the floor of the quarry, provided they are outside the exclusion zones. We are in general agreement with this recommendation.

The ‘person access zone’ comprises anywhere in the quarry floor further than 25 m from the base of the quarry face. People in the open will be allowed to work in this zone. With exception of the south wall, the modelling indicates that rockfalls will not reach this zone. However, as discussed above, the modelling indicates that there is possibility of a small proportion of rockfalls originating from the south wall that could reach this zone. Less than 2% or rockfalls originating from the south wall were modelled to reach the ‘person access zone’ prior to the establishment of the perimeter ditch. During the operation phase when the perimeter ditch is present, the modelling indicates that less than 1% of rockfalls reach the proposed ‘person access zone’. LLBJV should be aware of this and decide if this risk is acceptable.

6.6. Inspections and maintenance regimes

Access restrictions will also be imposed in response to wet weather. PSM proposed that a real time weather station be installed on site, however we are not aware whether or not this has occurred.

During rain only ROPS / FOPS vehicles are permitted to travel along the access road and no people are to traverse the access road in the open. These are reasonable recommendations.

Following a rainfall event, exceeding predetermined rainfall triggers, no access to the quarry is permitted until the quarry is inspected. The rainfall triggers are as follows:

- 20 mm in one hour;
- 50 mm from 9am to 9am
- 3 day total of 100 mm.

We are not aware of the justification behind these thresholds, however they cover both short duration, high intensity rainfall events and longer duration events. On this basis they appear to be reasonable.

The following inspection regimes have been proposed to *“maintain safe access to and working conditions within the quarry”:*

- Daily;
- Monthly and after rainfall event;
- 6 monthly.

The inspections are to be undertaken by a LLBJV representative. The purpose of the inspections are to observe features such as *“loose rocks on batters, new rock boulders on the access road, free flowing water from the batter faces and road cracks*”. These observations will be useful to calibrate the frequency of rock falls at the site and may also help monitor the condition of the access road. The inspections may also help observe the presence of loose rocks on batters adjacent to the access road or nearby vantage points. However, observations from ground level are unlikely to be an effective means of assessing the condition of batters and rock fall hazards at higher locations in the quarry. For example, rock falls on the south wall could originate from locations almost 100 m above the quarry floor. Observations of these source areas will be limited by distance as well as line of sight restrictions caused by slope geometry and vegetation. LLBJV should be aware of these limitations. Other inspection methods that could overcome these limitations could include UAV / Drone inspections or rope access methods (subject to risk assessment).

We understand from the reports provided that survey will be undertaken “as required” or “as directed by PSM”. No further details have been provided.

Maintenance, comprising scaling of rock batters immediately adjacent to the access road will be carried out by a minimum 20t excavator to the limit of its reach. This will be carried out at no less than 6 monthly intervals. This is a reasonable recommendation however the limitations regarding the reach discussed above will still apply. In addition, it is not clear why a 20t excavator was recommended when a 30t excavator is required for the initial scaling.

7. Closing comments

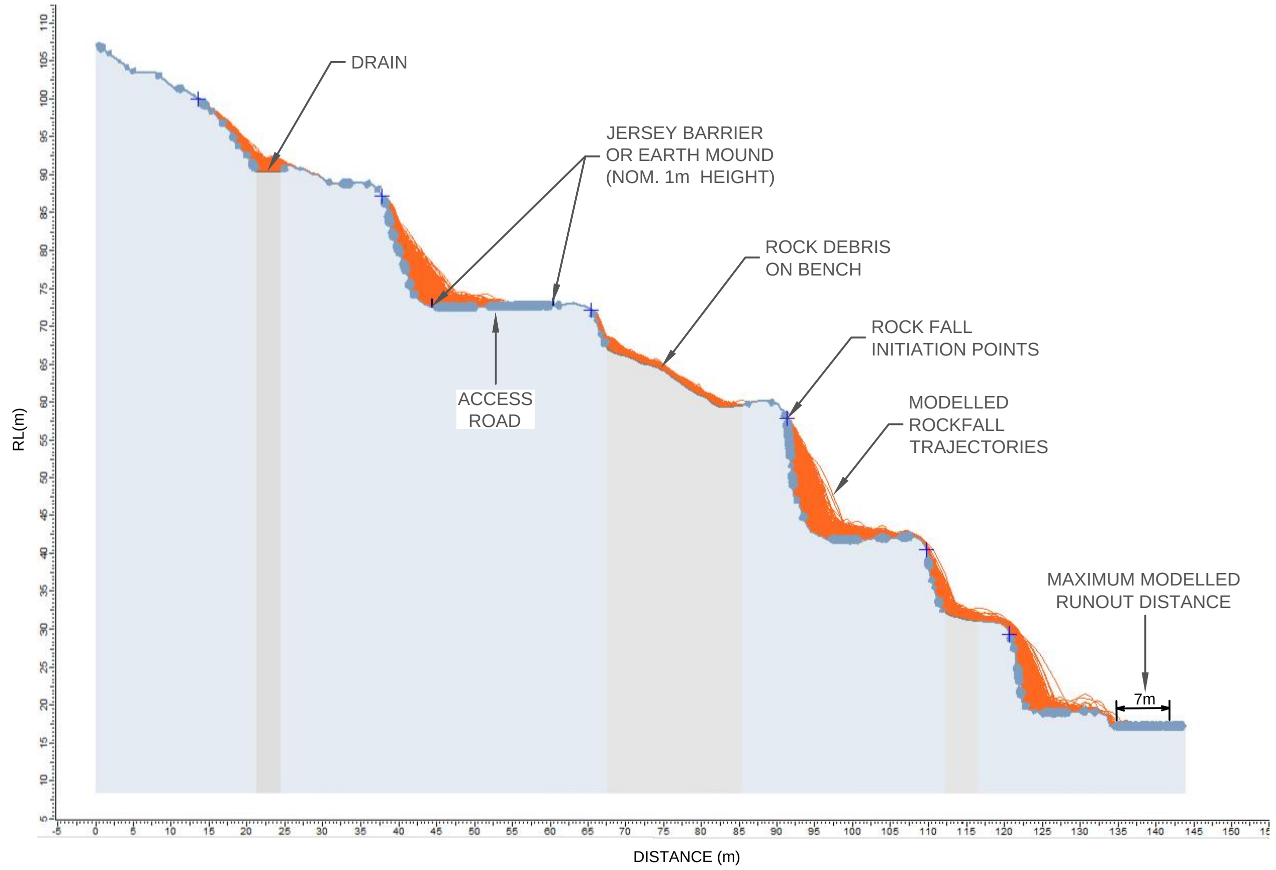
This report has presented a review of previous stability assessments and modelling carried out for the Hornsby Quarry. We have carried out a limited amount of analysis and modelling in order to undertake this review and provided comments where appropriate.

This report also presented our own observations of geotechnical site features and assessment of rock fall hazards observable at the time of the fieldwork. These features will change and may deteriorate over time, which could change existing hazards or create new ones.

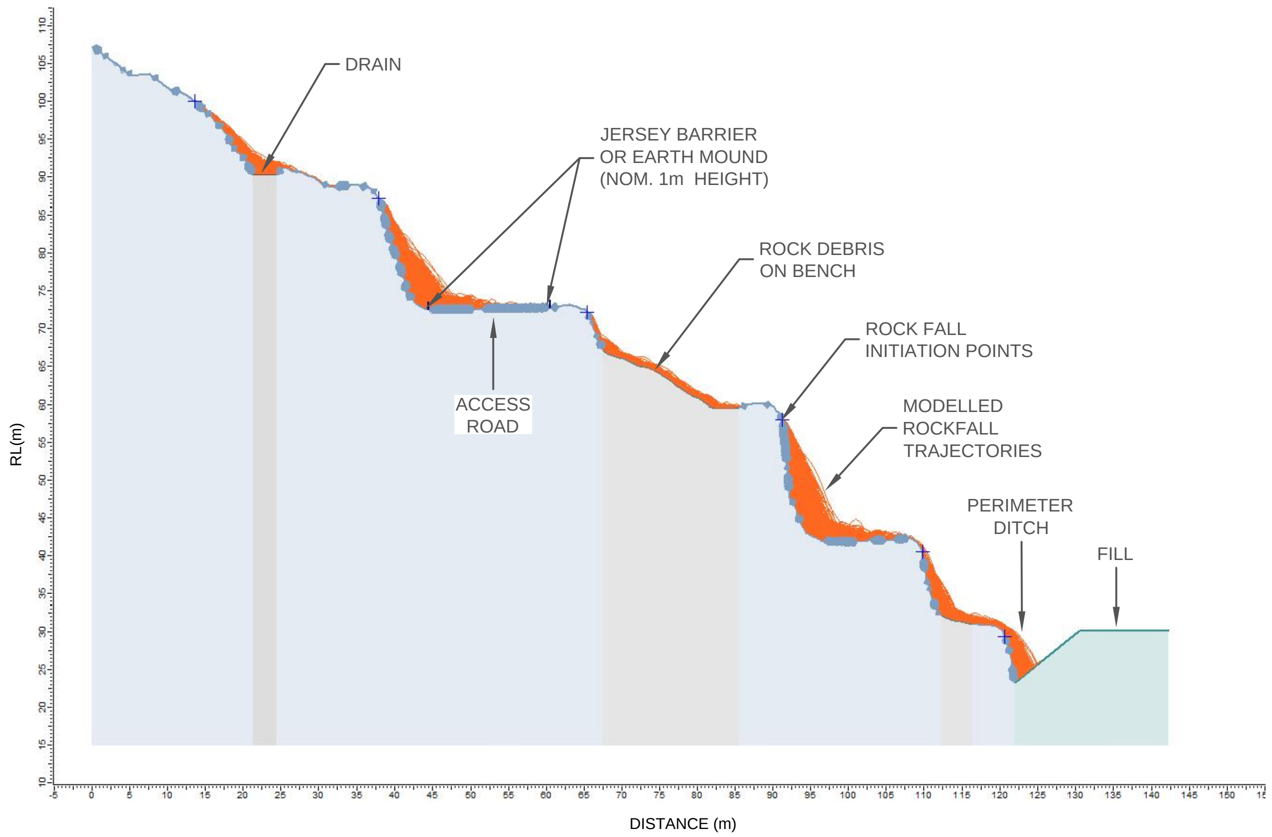
The risk assessment presented in this appendix estimated risks associated with local failure mechanisms (i.e. rockfalls). It should be noted the exposure of an individual to hazards will have a significant effect on the level of risk and we have necessarily been required to estimate the duration of some of the work activities. RMS has advised that for this project they will adopt the AGS (2007) suggested tolerable risk criteria for loss of life for existing slopes (10^{-4} per annum). The level of risk estimated for both the construction and operation phase works is lower than the suggested AGS (2007) criteria for loss of life for existing slopes. The risks would therefore be considered ‘tolerable’ based on this criteria.

The risk assessment for global failure mechanisms (i.e. major slide hazards) is presented separately in the body of the main report. Tables F1 and F2 in Appendix F summarise the total risk at the site, estimated by summing the local failure mechanism risks with the global failure risks. These risks are lower than the suggested AGS (2007) criteria for loss of life for existing slopes. The risks would therefore be considered ‘tolerable’ based on RMS’ criteria.

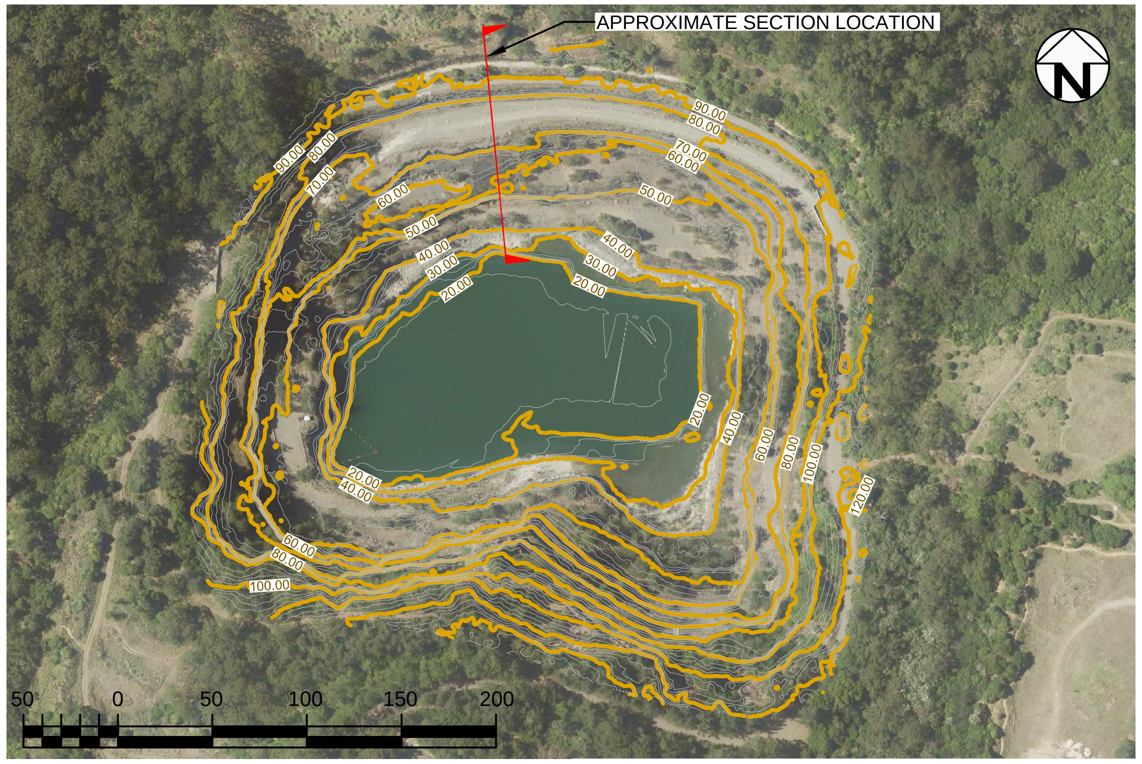
Figures – Appendix A



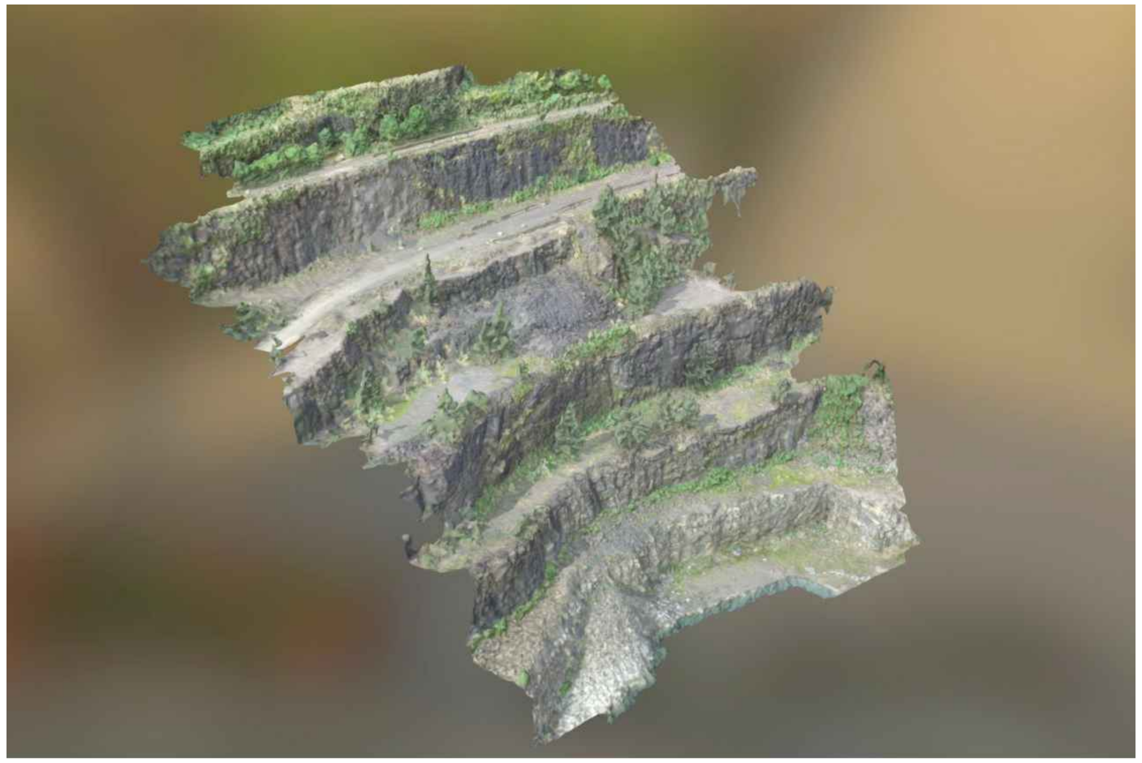
NORTH WALL SECTION



NORTH WALL SECTION SHOWING PERIMETER DITCH



HORNSBY QUARRY VOID WITH APPROXIMATE SECTION LOCATION



NORTH WALL 3D PHOTOGRAMMETRY MODEL (AT SECTION LOCATION)

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approved	AJH
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scale	AS SHOWN
original size	A3

coffey
A TETRA TECH COMPANY

client: ROADS AND MARITIME SERVICES

project: GEOTECHNICAL ASSESSMENT OF THE HORNSBY QUARRY VOID
HORNSBY, NSW

title: ROCKFALL MODELLING RESULTS FOR NORTH WALL SECTION

project no: GEOTLCOV25707AA | figure no: FIGURE A1 | rev: A

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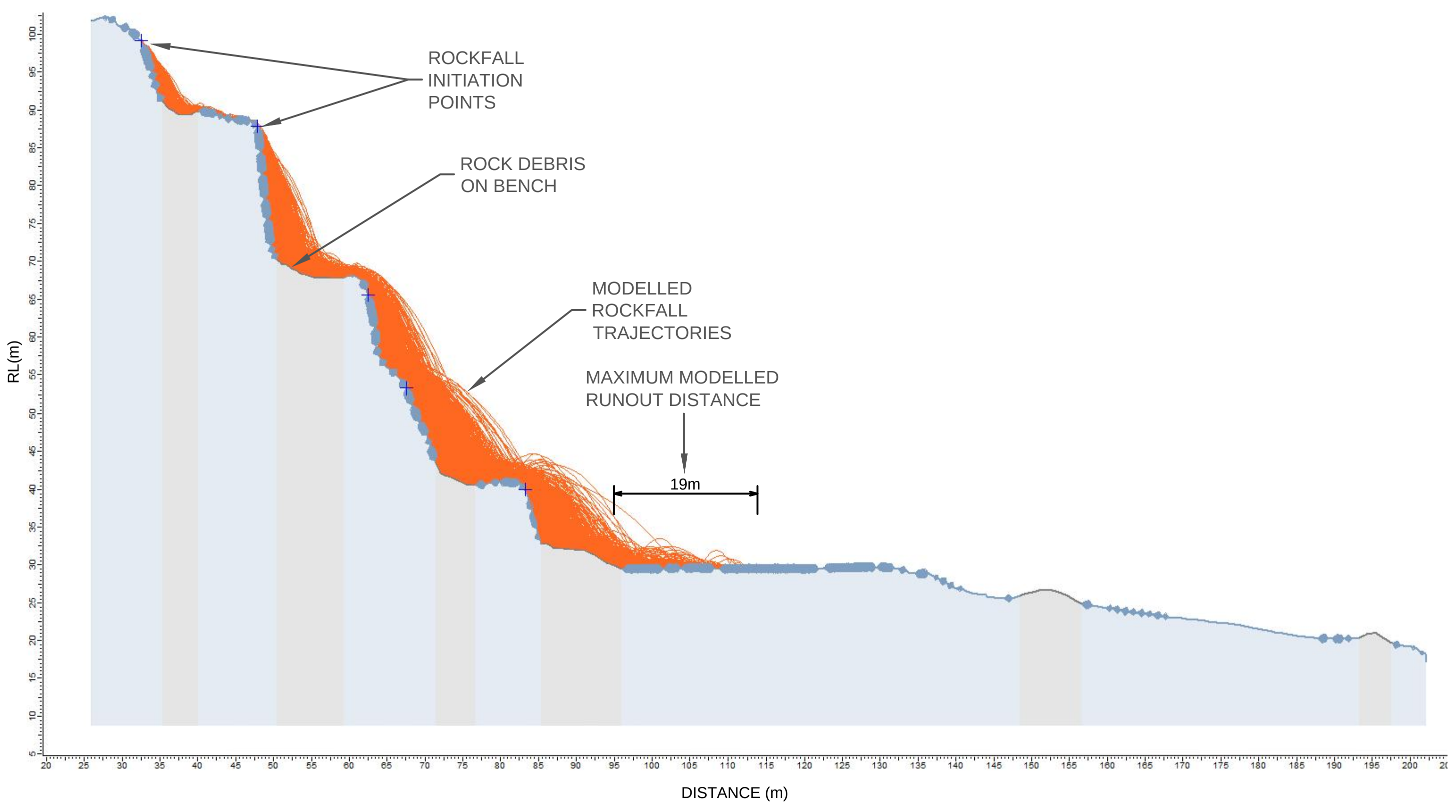
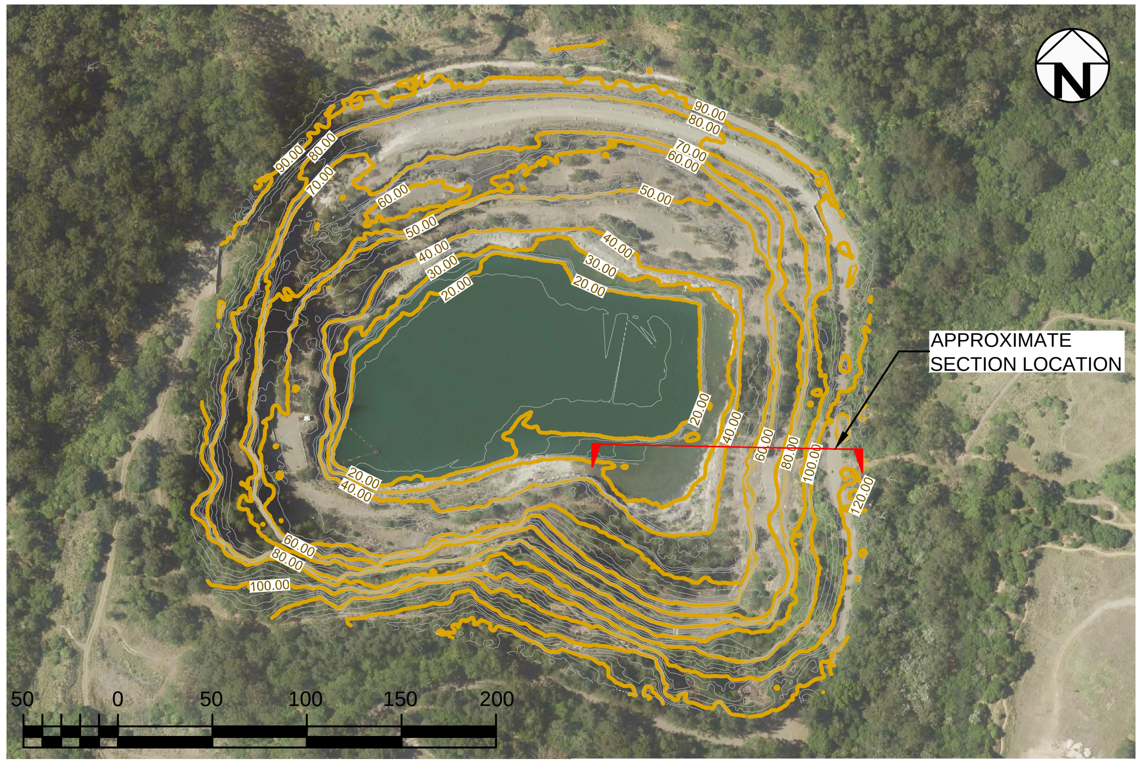


EAST WALL SECTION



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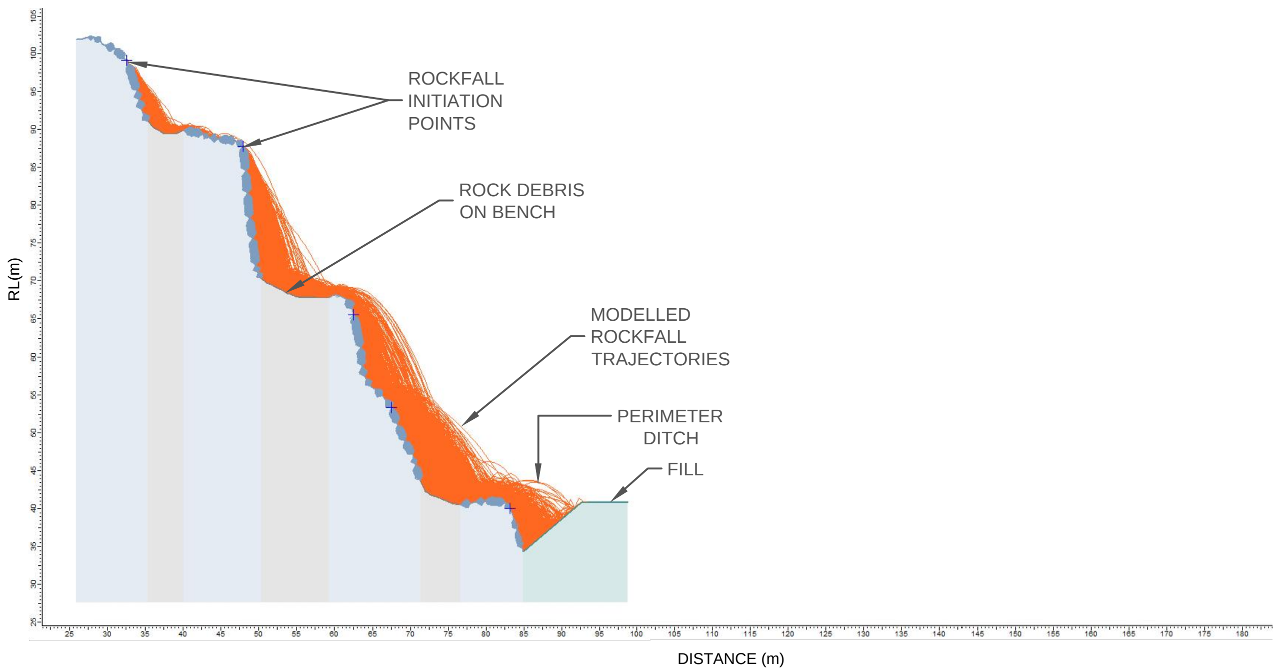

EAST WALL SECTION WITH PERIMETER DITCH

EAST WALL 3D PHOTOGRAMMETRY MODEL (AT SECTION LOCATION)

revision

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HORNSBY, NSW

title: ROCKFALL MODELLING RESULTS FOR EAST WALL SECTION

project no: GEOTLCOV25707AA | figure no: FIGURE A2 | rev: A

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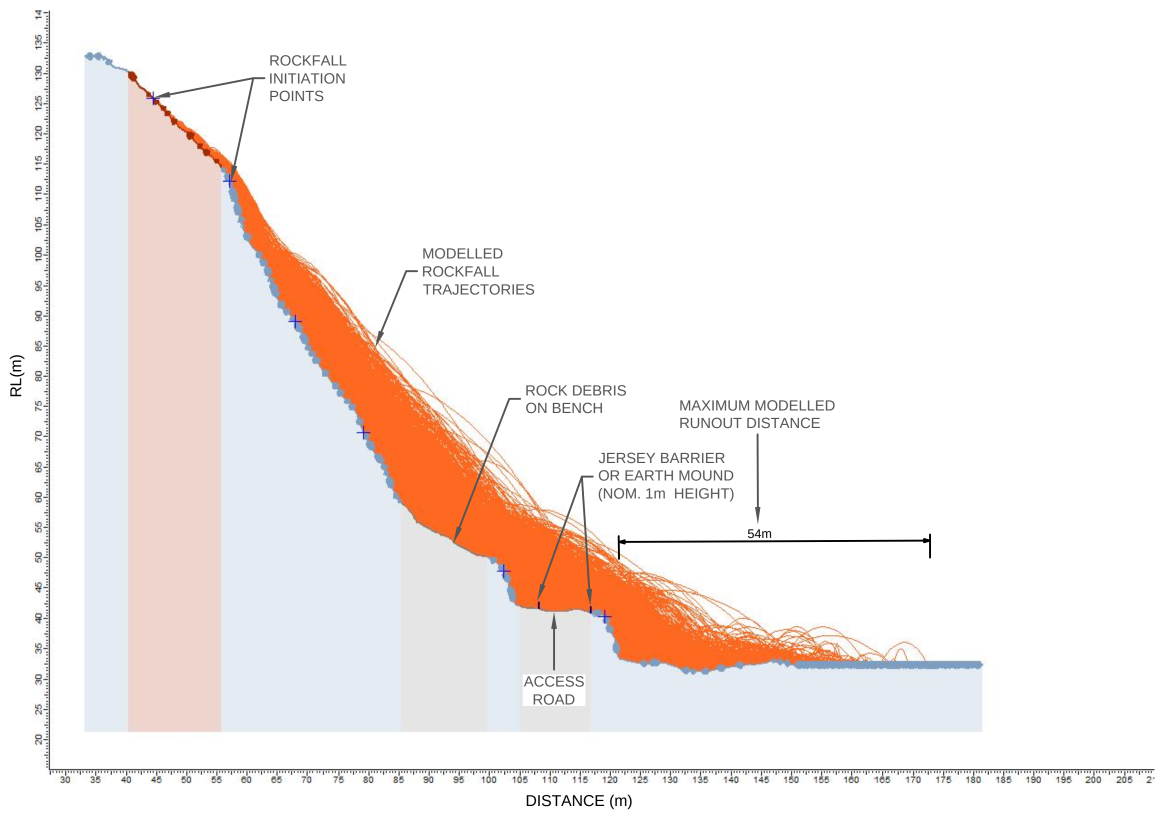
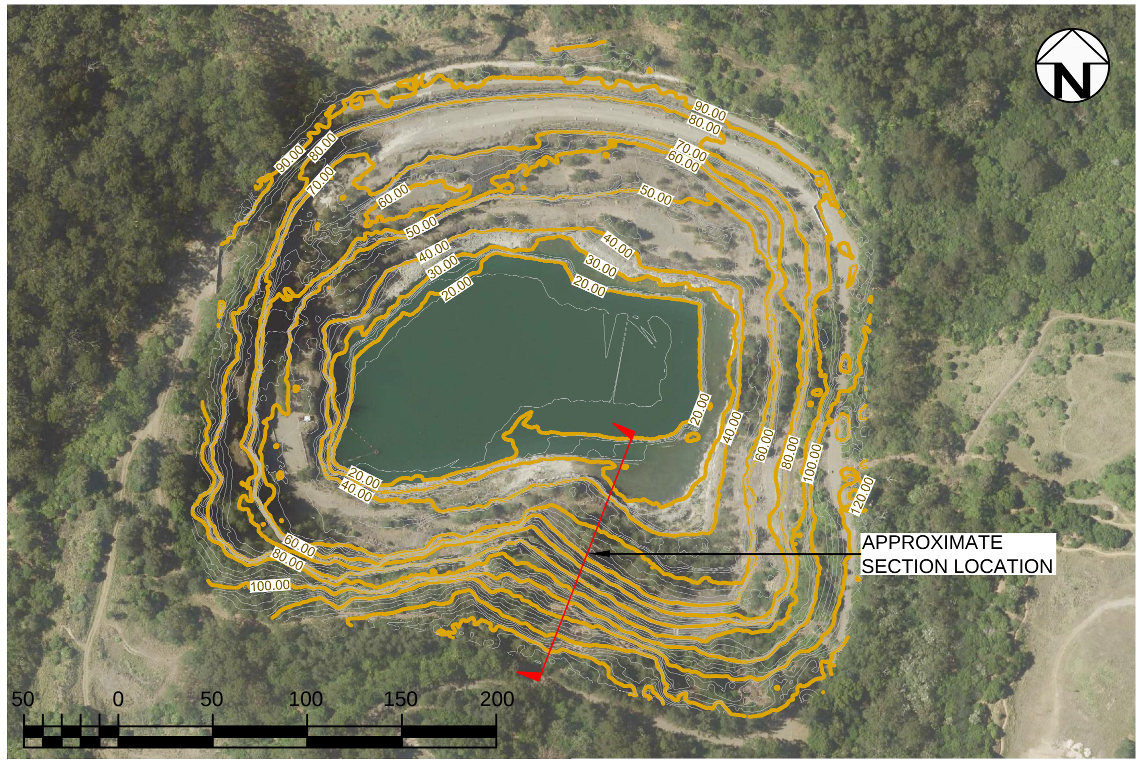


EASTERN SOUTH WALL SECTION



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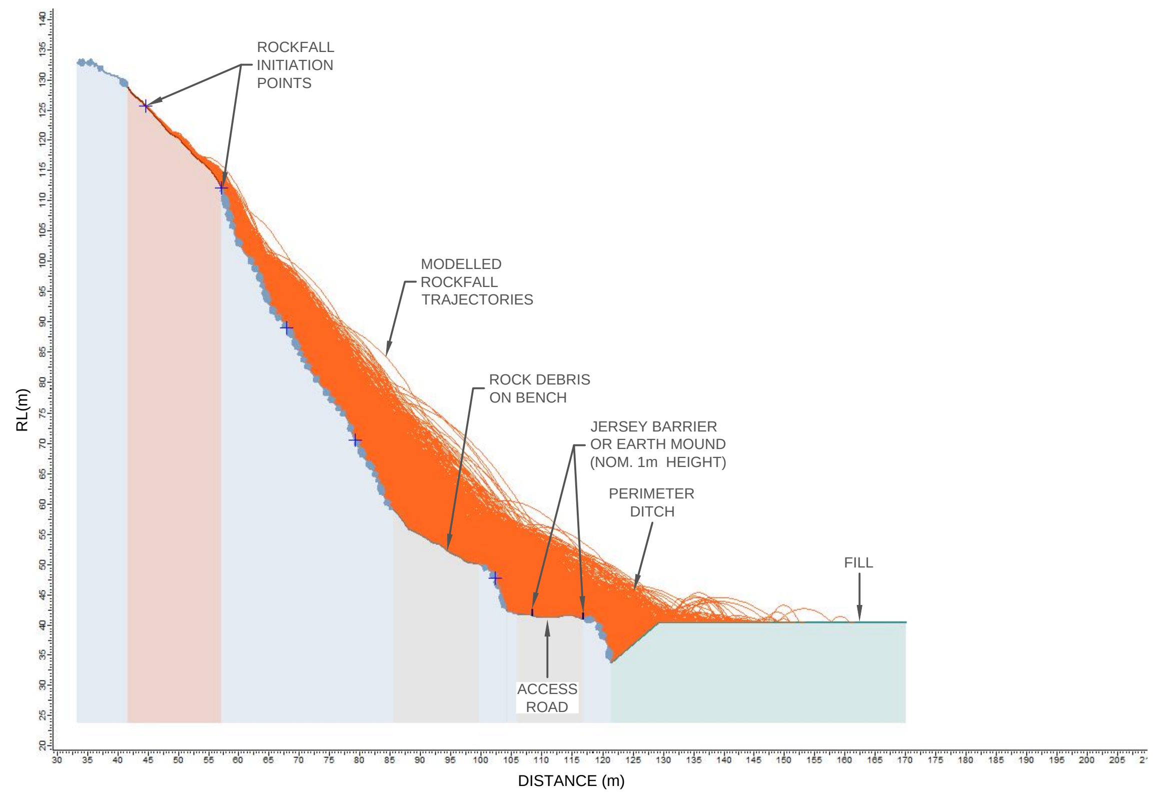

EASTERN SOUTH WALL SECTION WITH PERIMETER DITCH

EASTERN SOUTH WALL 3D PHOTOGRAMMETRY MODEL (AT SECTION LOCATION)

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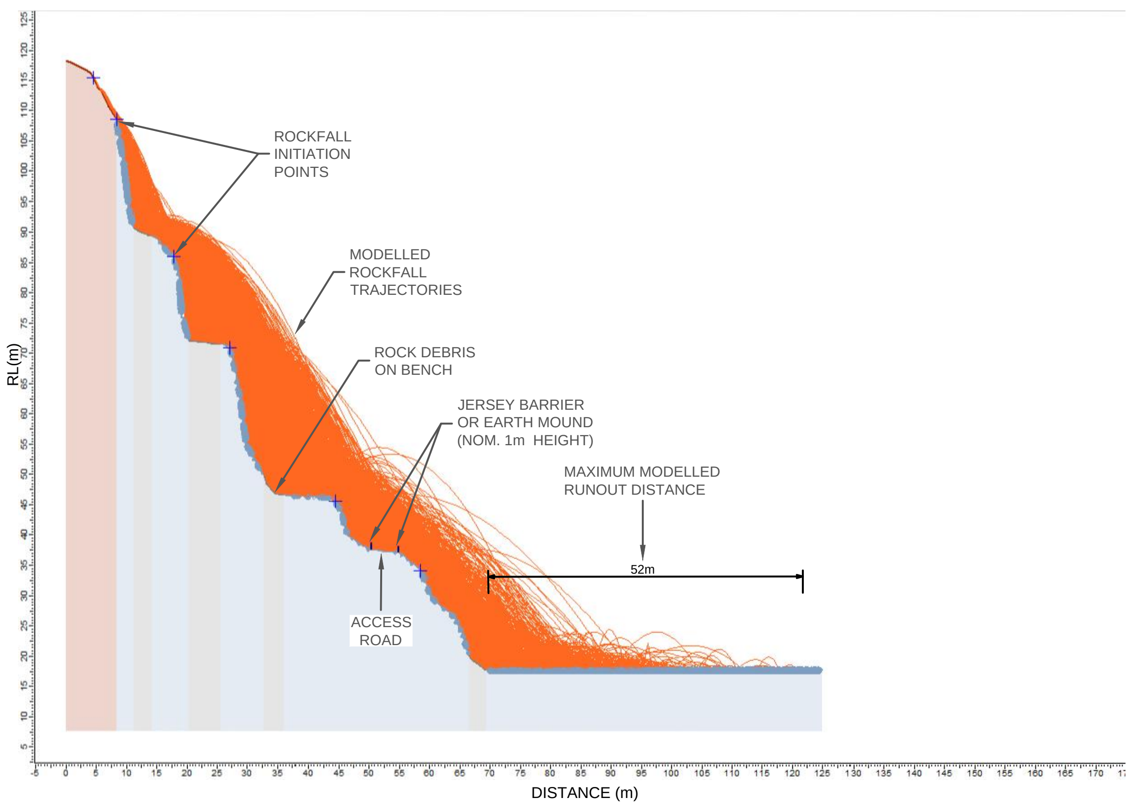
HORNSBY, NSW

title: ROCKFALL MODELLING RESULTS FOR
EASTERN SOUTH WALL SECTION

project no: GEOTLCOV25707AA | figure no: FIGURE A3 | rev: A



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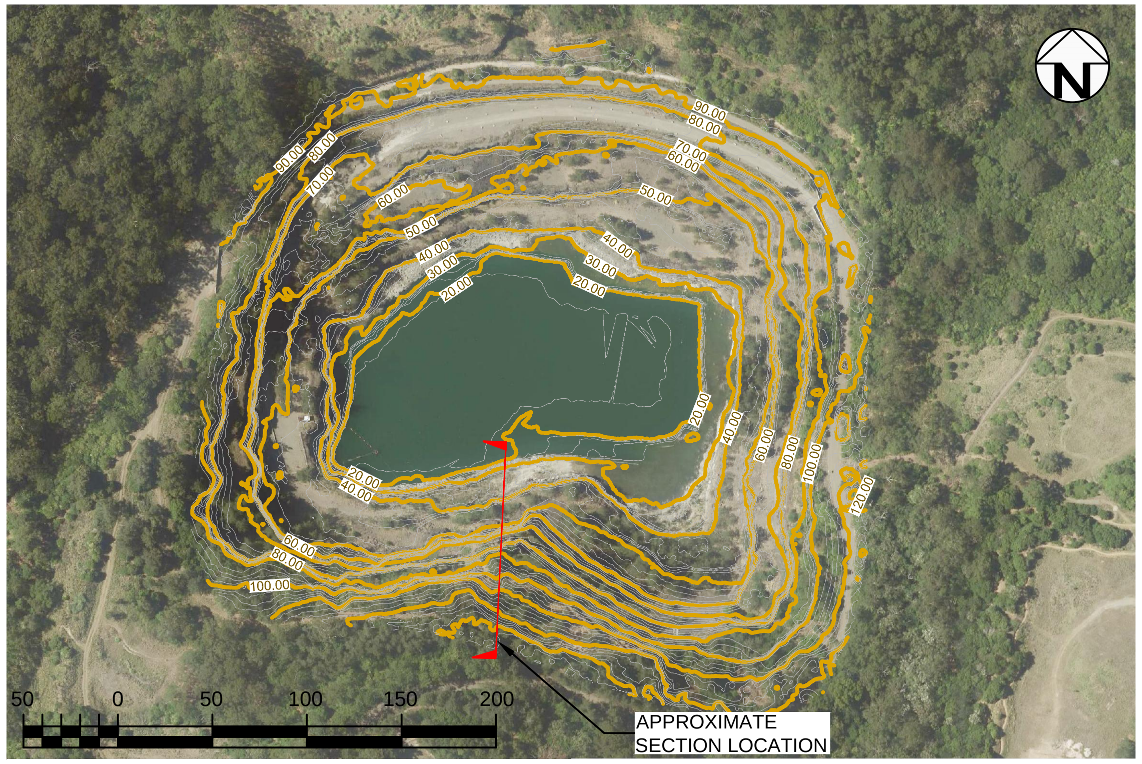

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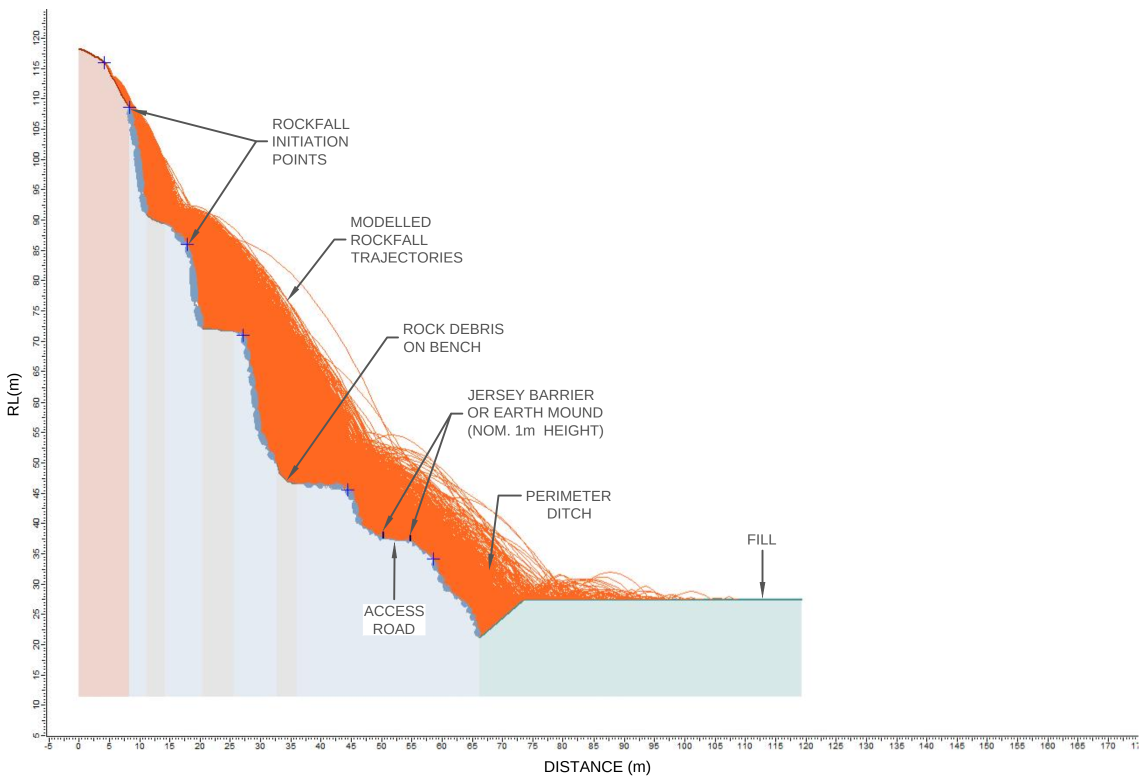

WESTERN SOUTH WALL SECTION WITH PERIMETER DITCH

WESTERN SOUTH WALL 3D PHOTOGRAMMETRY MODEL (AT SECTION LOCATION)

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original size	A3

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HORNSBY, NSW

title: ROCKFALL MODELLING RESULTS FOR
WESTERN SOUTH WALL SECTION

project no: GEOTLCOV25707AA | figure no: FIGURE A4 | rev: A

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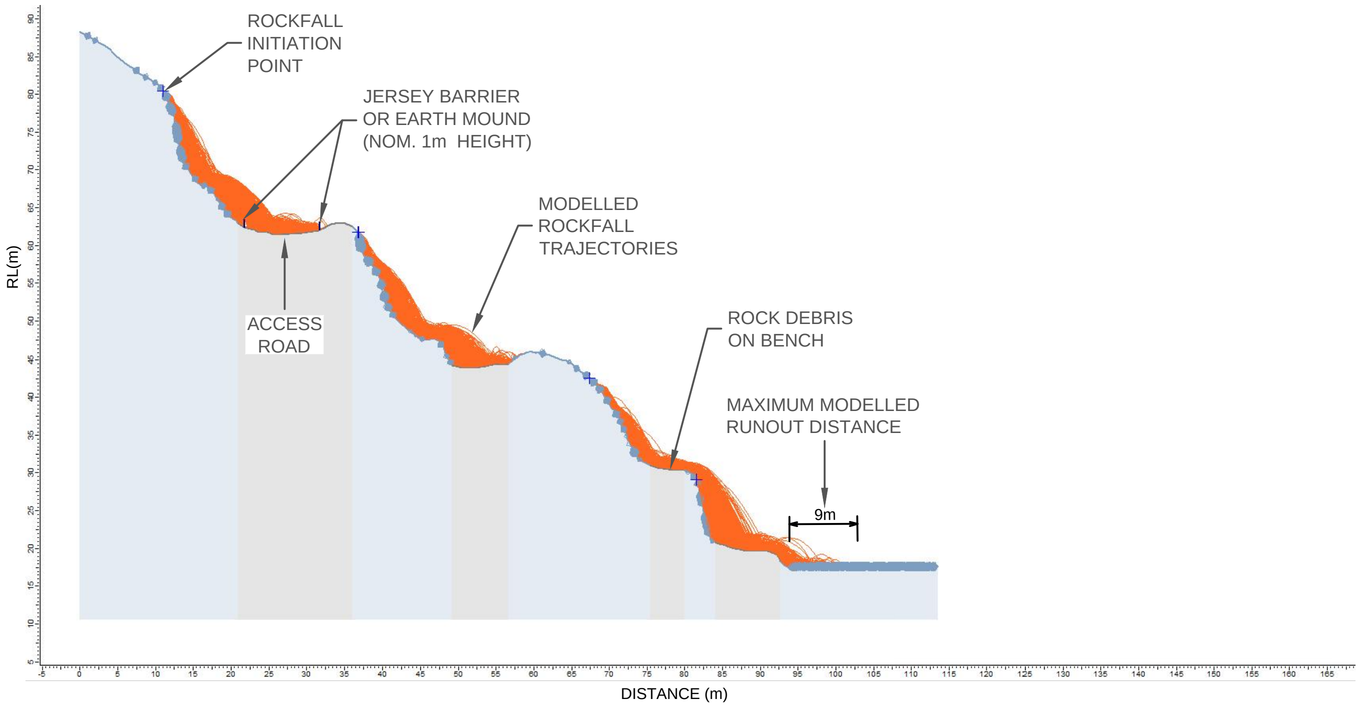

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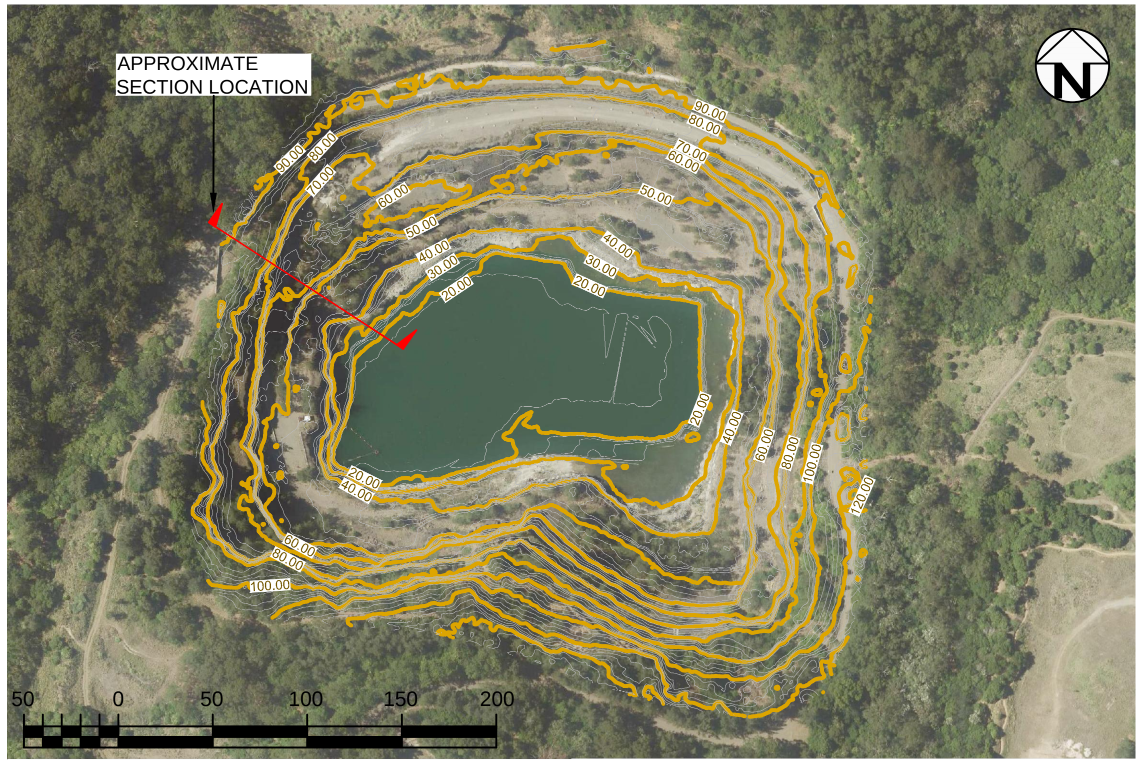

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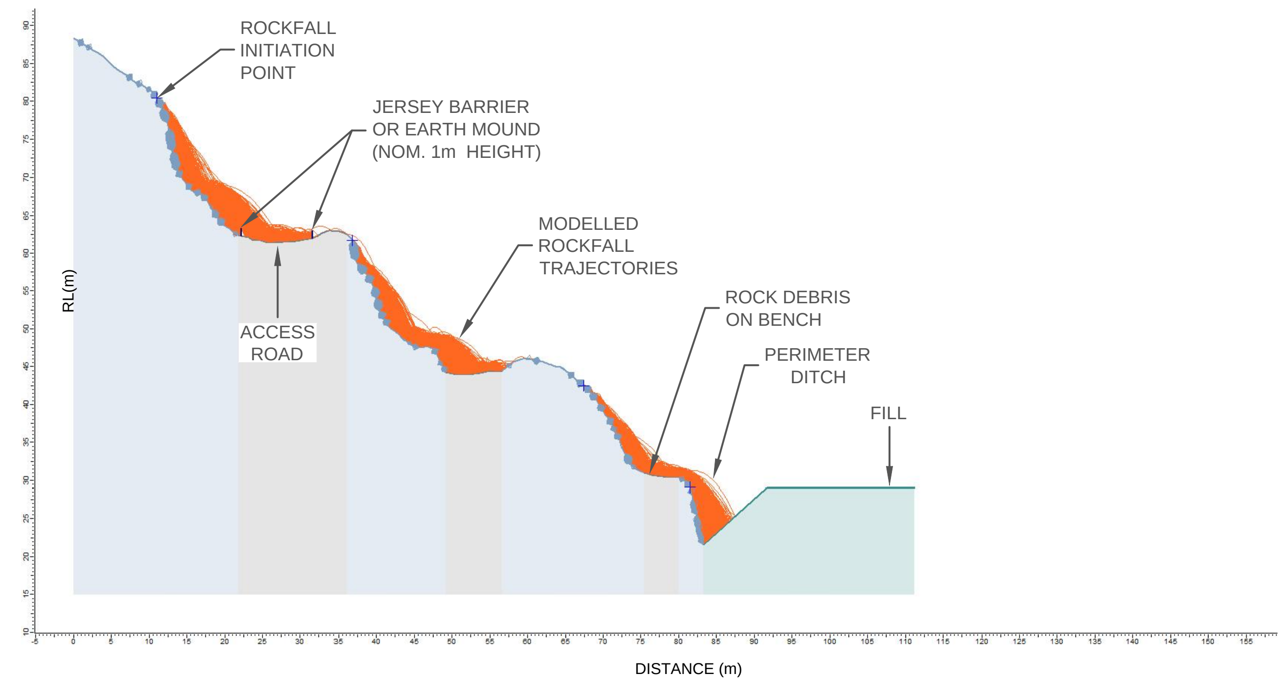

WEST WALL SECTION WITH PERIMETER DITCH

WEST WALL 3D PHOTOGRAMMETRY MODEL (AT SECTION LOCATION)

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date	12 / 10 / 16
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original size	A3

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client: ROADS AND MARITIME SERVICES

project: GEOTECHNICAL ASSESSMENT OF THE HORNSBY QUARRY VOID
HORNSBY, NSW

title: ROCKFALL MODELLING RESULTS FOR
WEST WALL SECTION

project no: GEOTLCOV25707AA | figure no: FIGURE A5 | rev: A

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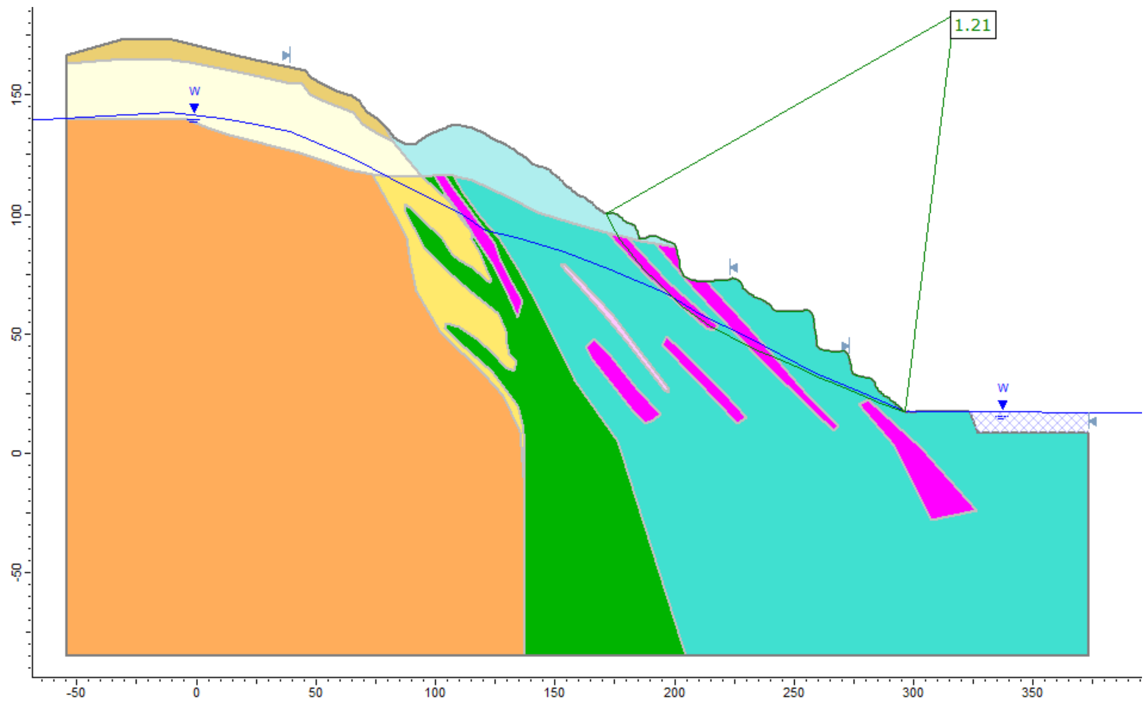
Appendix B – Stability Analysis Results

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	UCS (kPa)	m	s	a	Water Surface	Hu Type	Hu	MS A1 (deg)	MS A2 (deg)	MS B1 (deg)	MS B2 (deg)	MS Angle (ccw to 1) (deg)
Muddy Breccia		26	Mohr-Coulomb	100	28					Water Surface	Custom	1					
Weathered Sandstone		24	Mohr-Coulomb	400	45					Water Surface	Custom	1					
Sandstone		24	Generalized Hoek-Brown			40000	1.8878	0.00303634	0.502841	Water Surface	Custom	1					
Weathered Dolerite		21	Mohr-Coulomb	110	29					Water Surface	Custom	1					
Dumped Fill		20	Mohr-Coulomb	10	30					Water Surface	Custom	1					
Residual Sandstone		19.5	Mohr-Coulomb	50	30					Water Surface	Custom	1					
Volcanic Breccia		26	Snowden Modified Anisotropic Linear							Water Surface	Custom	1	2	2	45	45	-25
Shear planes in VB		26	Mohr-Coulomb	0	32					Water Surface	Custom	1					
Flow Banded Dolerite		20	Generalized Hoek-Brown			30000	0.970825	0.000616591	0.506143	Water Surface	Custom	1					
Altered Sandstone		24	Generalized Hoek-Brown			250000	0.880418	0.00082391	0.50535	Water Surface	Custom	1					



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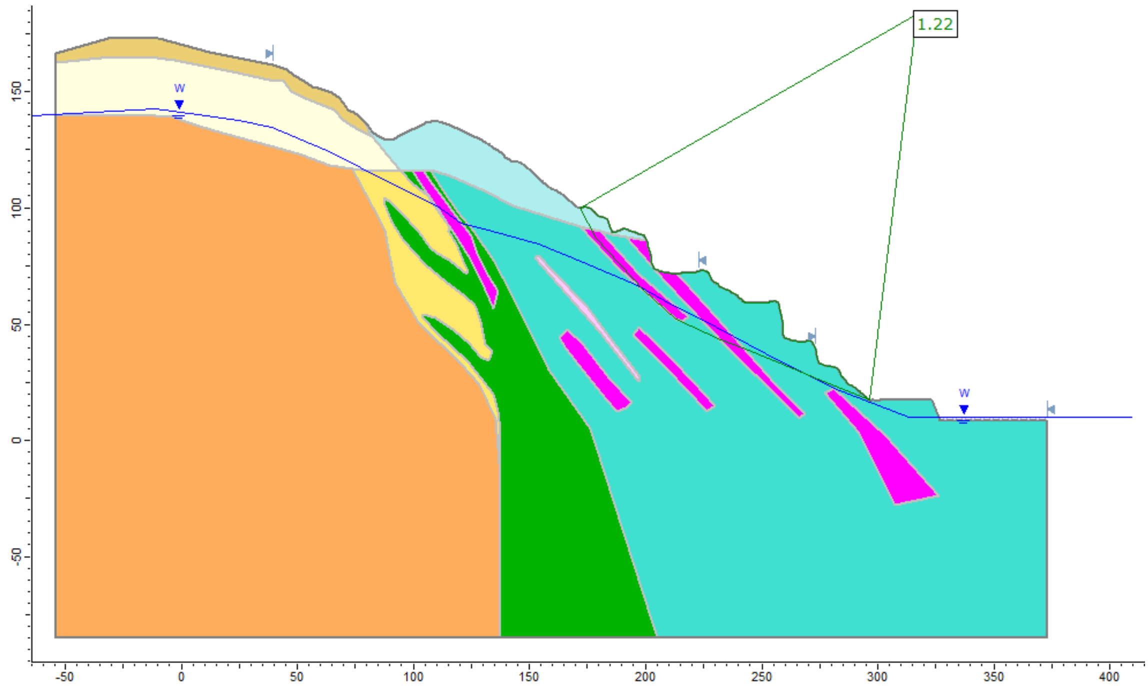
date	23/09/2016			HORNSBY QUARRY
original	A4		Title:	Section 5 – Current
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	UCS (kPa)	m	s	a	Water Surface	Hu Type	Hu	MS A1 (deg)	MS A2 (deg)	MS B1 (deg)	MS B2 (deg)	MS Angle (ccw to 1) (deg)
Muddy Breccia		26	Mohr-Coulomb	100	28					Water Surface	Custom	1					
Weathered Sandstone		24	Mohr-Coulomb	400	45					Water Surface	Custom	1					
Sandstone		24	Generalized Hoek-Brown			40000	1.8878	0.00303634	0.502841	Water Surface	Custom	1					
Weathered Dolerite		21	Mohr-Coulomb	110	29					Water Surface	Custom	1					
Dumped Fill		20	Mohr-Coulomb	10	30					Water Surface	Custom	1					
Residual Sandstone		19.5	Mohr-Coulomb	50	30					Water Surface	Custom	1					
Volcanic Breccia		26	Snowden Modified Anisotropic Linear							Water Surface	Custom	1	2	2	45	45	-25
Shear planes in VB		26	Mohr-Coulomb	0	32					Water Surface	Custom	1					
Flow Banded Dolerite		20	Generalized Hoek-Brown			30000	0.970825	0.000616591	0.506143	Water Surface	Custom	1					
Altered Sandstone		24	Generalized Hoek-Brown			250000	0.880418	0.00082391	0.50535	Water Surface	Custom	1					



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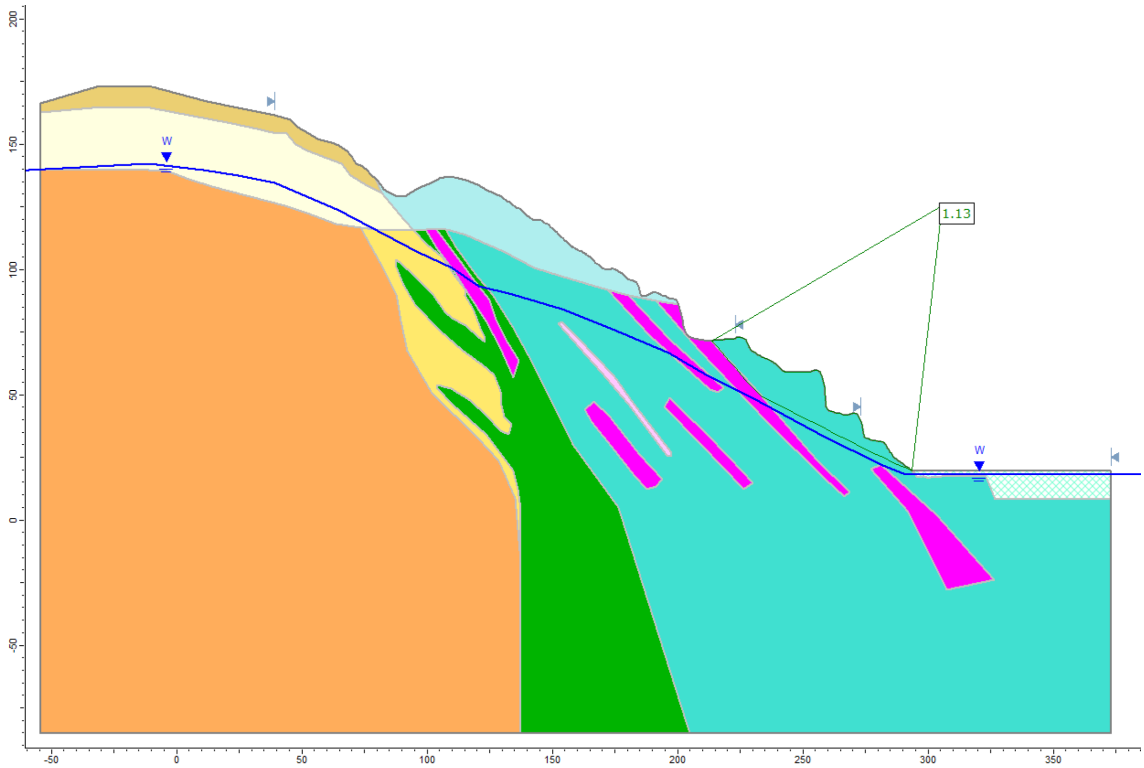
original	A4		Title:	Section 5 – Dewatered
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	UCS (kPa)	m	s	a	Water Surface	Hu Type	Hu	MS A1 (deg)	MS A2 (deg)	MS B1 (deg)	MS B2 (deg)	MS Angle (ccw to 1) (deg)
Muddy Breccia		26	Mohr-Coulomb	100	28					Water Surface	Custom	1					
Weathered Sandstone		24	Mohr-Coulomb	400	45					Water Surface	Custom	1					
Sandstone		24	Generalized Hoek-Brown			40000	1.8878	0.00303634	0.502841	Water Surface	Custom	1					
Weathered Dolerite		21	Mohr-Coulomb	110	29					Water Surface	Custom	1					
Dumped Fill		20	Mohr-Coulomb	10	30					Water Surface	Custom	1					
Residual Sandstone		19.5	Mohr-Coulomb	50	30					Water Surface	Custom	1					
Volcanic Breccia		26	Snowden Modified Anisotropic Linear							Water Surface	Custom	1	2	2	45	45	-25
Shear planes in VB		26	Mohr-Coulomb	0	32					Water Surface	Custom	1					
Flow Banded Dolerite		20	Generalized Hoek-Brown			30000	0.970825	0.000616591	0.506143	Water Surface	Custom	1					
Altered Sandstone		24	Generalized Hoek-Brown			250000	0.880418	0.00082391	0.50535	Water Surface	Custom	1					



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date	12/09/2016			HORNSBY QUARRY
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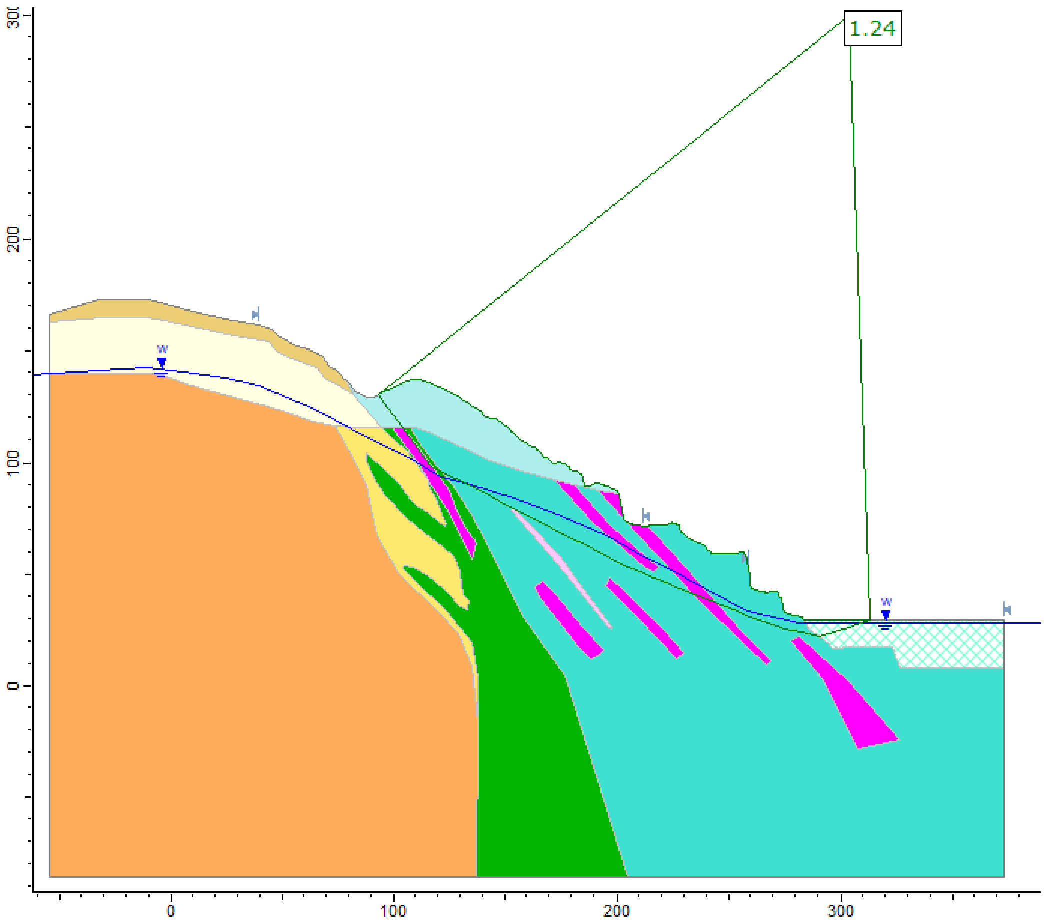
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	UCS (kPa)	m	s	a	Water Surface	Hu Type	Hu	MS A1 (deg)	MS A2 (deg)	MS B1 (deg)	MS B2 (deg)	MS Angle (ccw to 1) (deg)
Muddy Breccia		26	Mohr-Coulomb	100	28					Water Surface	Custom	1					
Weathered Sandstone		24	Mohr-Coulomb	400	45					Water Surface	Custom	1					
Sandstone		24	Generalized Hoek-Brown			40000	1.8878	0.00303634	0.502841	Water Surface	Custom	1					
Weathered Dolerite		21	Mohr-Coulomb	110	29					Water Surface	Custom	1					
Dumped Fill		20	Mohr-Coulomb	10	30					Water Surface	Custom	1					
Residual Sandstone		19.5	Mohr-Coulomb	50	30					Water Surface	Custom	1					
Volcanic Breccia		26	Snowden Modified Anisotropic Linear							Water Surface	Custom	1	2	2	45	45	-25
Shear planes in VB		26	Mohr-Coulomb	0	32					Water Surface	Custom	1					
Flow Banded Dolerite		20	Generalized Hoek-Brown			30000	0.970825	0.000616591	0.506143	Water Surface	Custom	1					
Altered Sandstone		24	Generalized Hoek-Brown			250000	0.880418	0.00082391	0.50535	Water Surface	Custom	1					



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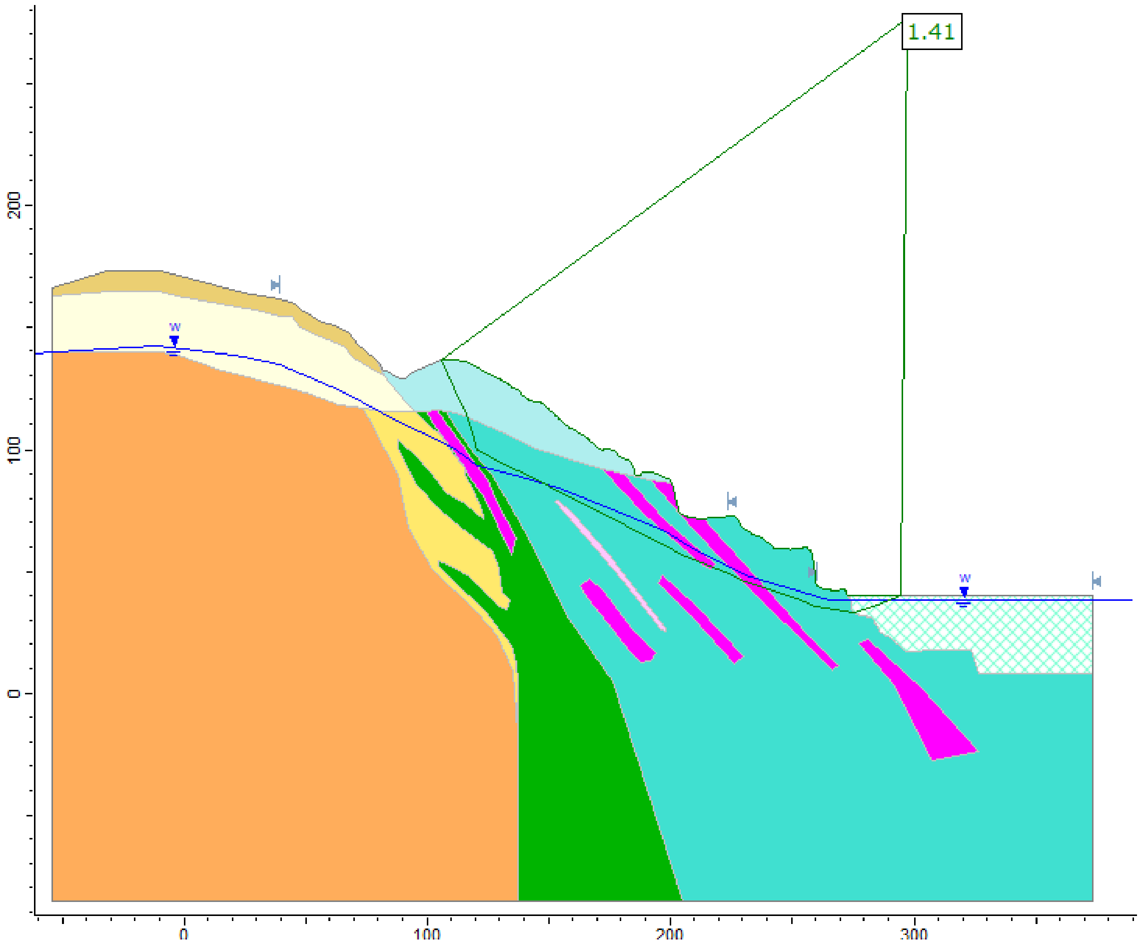
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	UCS (kPa)	m	s	a	Water Surface	Hu Type	Hu	MS A1 (deg)	MS A2 (deg)	MS B1 (deg)	MS B2 (deg)	MS Angle (ccw to 1) (deg)
Muddy Breccia		26	Mohr-Coulomb	100	28					Water Surface	Custom	1					
Weathered Sandstone		24	Mohr-Coulomb	400	45					Water Surface	Custom	1					
Sandstone		24	Generalized Hoek-Brown			40000	1.8878	0.00303634	0.502841	Water Surface	Custom	1					
Weathered Dolerite		21	Mohr-Coulomb	110	29					Water Surface	Custom	1					
Dumped Fill		20	Mohr-Coulomb	10	30					Water Surface	Custom	1					
Residual Sandstone		19.5	Mohr-Coulomb	50	30					Water Surface	Custom	1					
Volcanic Breccia		26	Snowden Modified Anisotropic Linear							Water Surface	Custom	1	2	2	45	45	-25
Shear planes in VB		26	Mohr-Coulomb	0	32					Water Surface	Custom	1					
Flow Banded Dolerite		20	Generalized Hoek-Brown			30000	0.970825	0.000616591	0.506143	Water Surface	Custom	1					
Altered Sandstone		24	Generalized Hoek-Brown			250000	0.880418	0.00082391	0.50535	Water Surface	Custom	1					



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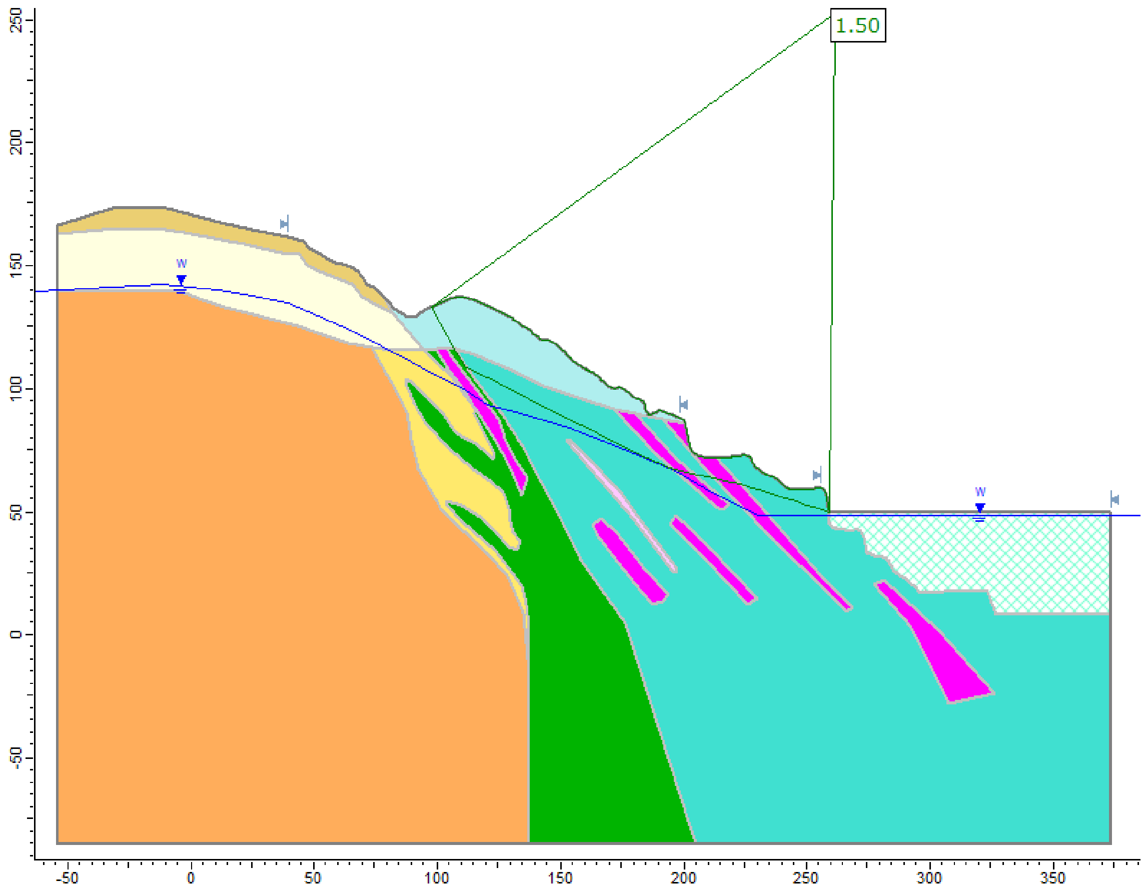
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	UCS (kPa)	m	s	a	Water Surface	Hu Type	Hu	MS A1 (deg)	MS A2 (deg)	MS B1 (deg)	MS B2 (deg)	MS Angle (ccw to 1) (deg)
Muddy Breccia		26	Mohr-Coulomb	100	28					Water Surface	Custom	1					
Weathered Sandstone		24	Mohr-Coulomb	400	45					Water Surface	Custom	1					
Sandstone		24	Generalized Hoek-Brown			40000	1.8878	0.00303634	0.502841	Water Surface	Custom	1					
Weathered Dolerite		21	Mohr-Coulomb	110	29					Water Surface	Custom	1					
Dumped Fill		20	Mohr-Coulomb	10	30					Water Surface	Custom	1					
Residual Sandstone		19.5	Mohr-Coulomb	50	30					Water Surface	Custom	1					
Volcanic Breccia		26	Snowden Modified Anisotropic Linear							Water Surface	Custom	1	2	2	45	45	-25
Shear planes in VB		26	Mohr-Coulomb	0	32					Water Surface	Custom	1					
Flow Banded Dolerite		20	Generalized Hoek-Brown			30000	0.970825	0.000616591	0.506143	Water Surface	Custom	1					
Altered Sandstone		24	Generalized Hoek-Brown			250000	0.880418	0.00082391	0.50535	Water Surface	Custom	1					



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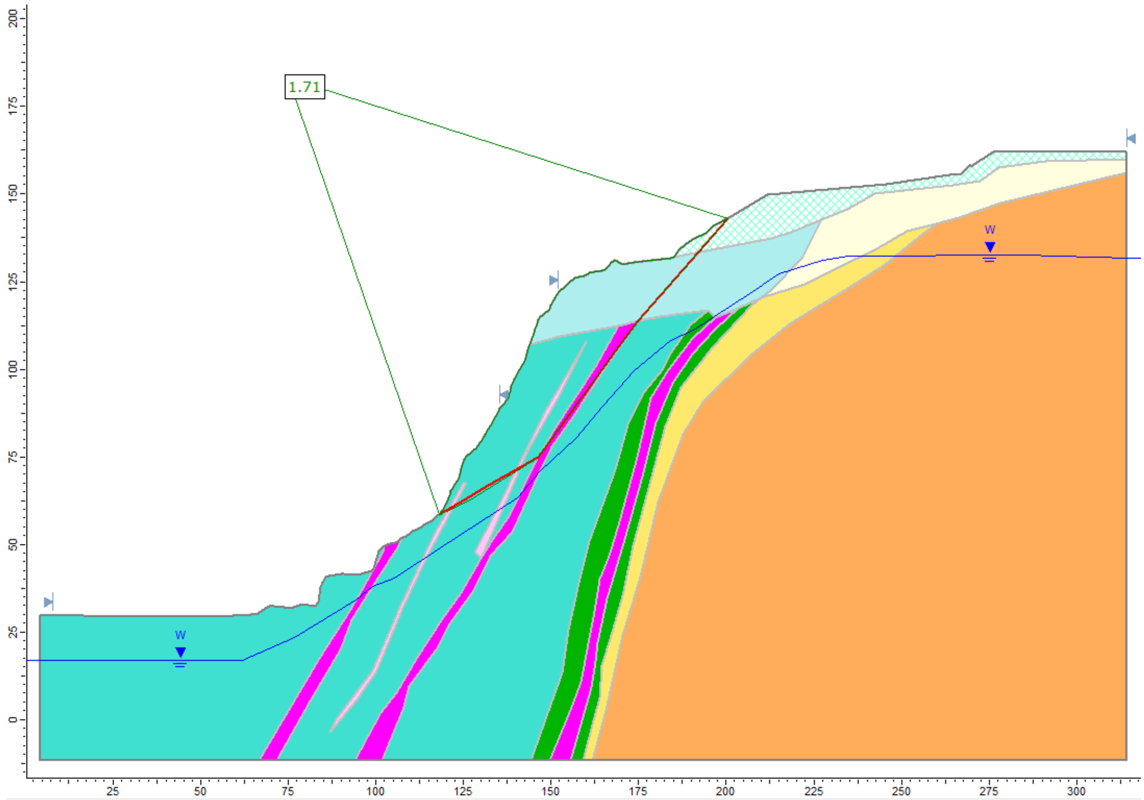
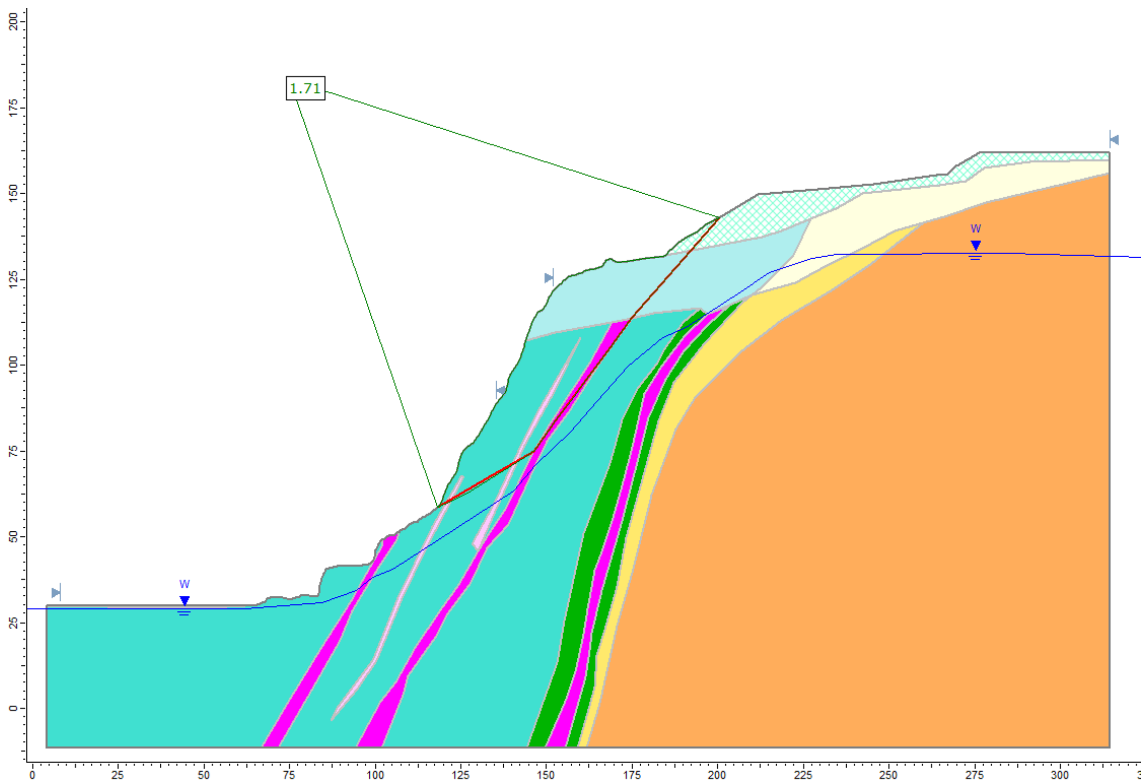
Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	UCS (kPa)	m	s	a	Water Surface	Hu Type	Hu
Muddy Breccia		26	Mohr-Coulomb	0	28					Water Surface	Custom	1
Weathered Sandstone		24	Mohr-Coulomb	400	45					Water Surface	Custom	1
Sandstone		24	Generalized Hoek-Brown			40000	1.8878	0.00303634	0.502841	Water Surface	Custom	1
Weathered Dolerite		21	Mohr-Coulomb	110	29					Water Surface	Custom	1
Dumped Fill		20	Mohr-Coulomb	10	30					Water Surface	Custom	1
Volcanic Breccia		26	Generalized Hoek-Brown			70000	1.34994	0.00147111	0.504048	Water Surface	Custom	1
Shear planes in VB		26	Mohr-Coulomb	0	32					Water Surface	Custom	1
Flow Banded Dolerite		20	Generalized Hoek-Brown			30000	0.970825	0.000616591	0.506143	Water Surface	Custom	1
Altered Sandstone		24	Generalized Hoek-Brown			250000	0.880418	0.00082391	0.50535	Water Surface	Custom	1



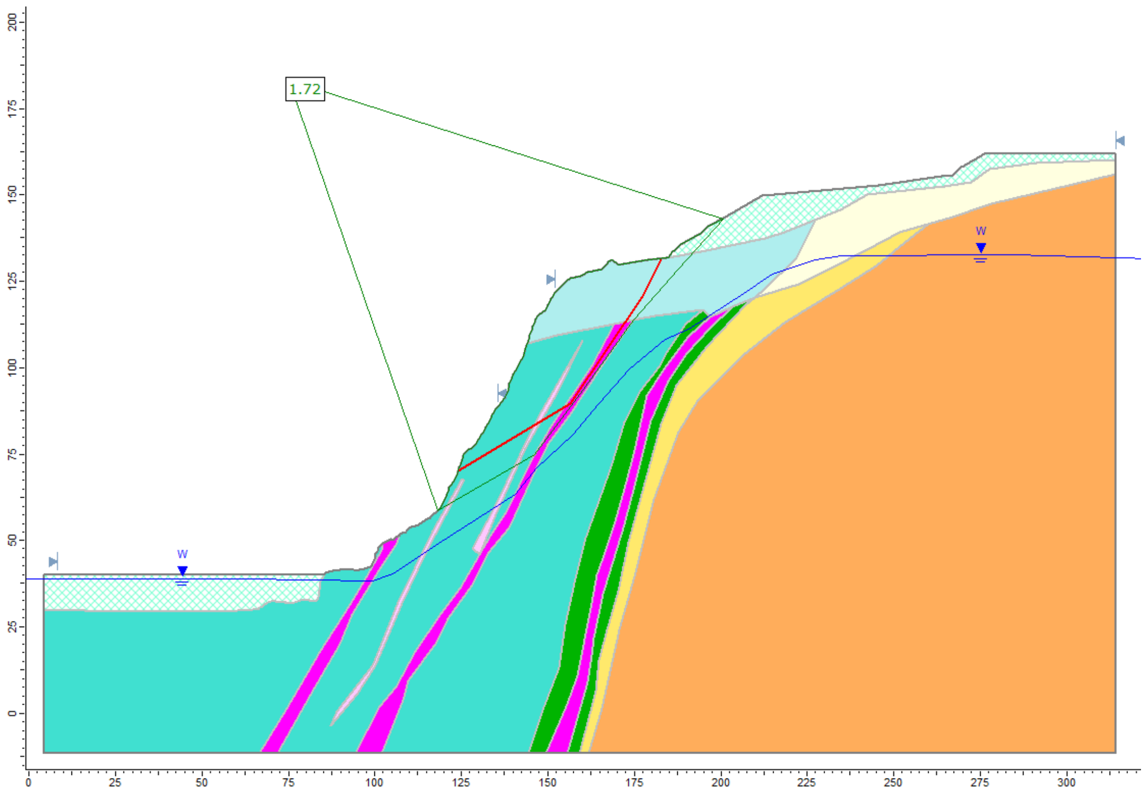
drawn	JN	coffey A TETRA TECH COMPANY	Client:	Roads and Maritime
approved	PP		Project:	GEOTECHNICAL
date	23/09/2016			HORNSBY QUARRY
original	A4		Title:	Section 11 – Current - Isotropic Only
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	UCS (kPa)	m	s	a	Water Surface	Hu Type	Hu
Muddy Breccia		26	Mohr-Coulomb	0	28					Water Surface	Custom	1
Weathered Sandstone		24	Mohr-Coulomb	400	45					Water Surface	Custom	1
Sandstone		24	Generalized Hoek-Brown			40000	1.8878	0.00303634	0.502841	Water Surface	Custom	1
Weathered Dolerite		21	Mohr-Coulomb	110	29					Water Surface	Custom	1
Dumped Fill		20	Mohr-Coulomb	10	30					Water Surface	Custom	1
Volcanic Breccia		26	Generalized Hoek-Brown			70000	1.34994	0.00147111	0.504048	Water Surface	Custom	1
Shear planes in VB		26	Mohr-Coulomb	0	32					Water Surface	Custom	1
Flow Banded Dolerite		20	Generalized Hoek-Brown			30000	0.970825	0.000616591	0.506143	Water Surface	Custom	1
Altered Sandstone		24	Generalized Hoek-Brown			250000	0.880418	0.00082391	0.50535	Water Surface	Custom	1



drawn	JN	coffey A TETRA TECH COMPANY	Client:	Roads and Maritime
approved	PP		Project:	GEOTECHNICAL
date	23/09/2016			HORNSBY QUARRY
original	A4		Title:	Section 11 – Fill to 30mRL - Isotropic Only
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	UCS (kPa)	m	s	a	Water Surface	Hu Type	Hu
Muddy Breccia		26	Mohr-Coulomb	0	28					Water Surface	Custom	1
Weathered Sandstone		24	Mohr-Coulomb	400	45					Water Surface	Custom	1
Sandstone		24	Generalized Hoek-Brown			40000	1.8878	0.00303634	0.502841	Water Surface	Custom	1
Weathered Dolerite		21	Mohr-Coulomb	110	29					Water Surface	Custom	1
Dumped Fill		20	Mohr-Coulomb	10	30					Water Surface	Custom	1
Volcanic Breccia		26	Generalized Hoek-Brown			70000	1.34994	0.00147111	0.504048	Water Surface	Custom	1
Shear planes in VB		26	Mohr-Coulomb	0	32					Water Surface	Custom	1
Flow Banded Dolerite		20	Generalized Hoek-Brown			30000	0.970825	0.000616591	0.506143	Water Surface	Custom	1
Altered Sandstone		24	Generalized Hoek-Brown			250000	0.880418	0.00082391	0.50535	Water Surface	Custom	1



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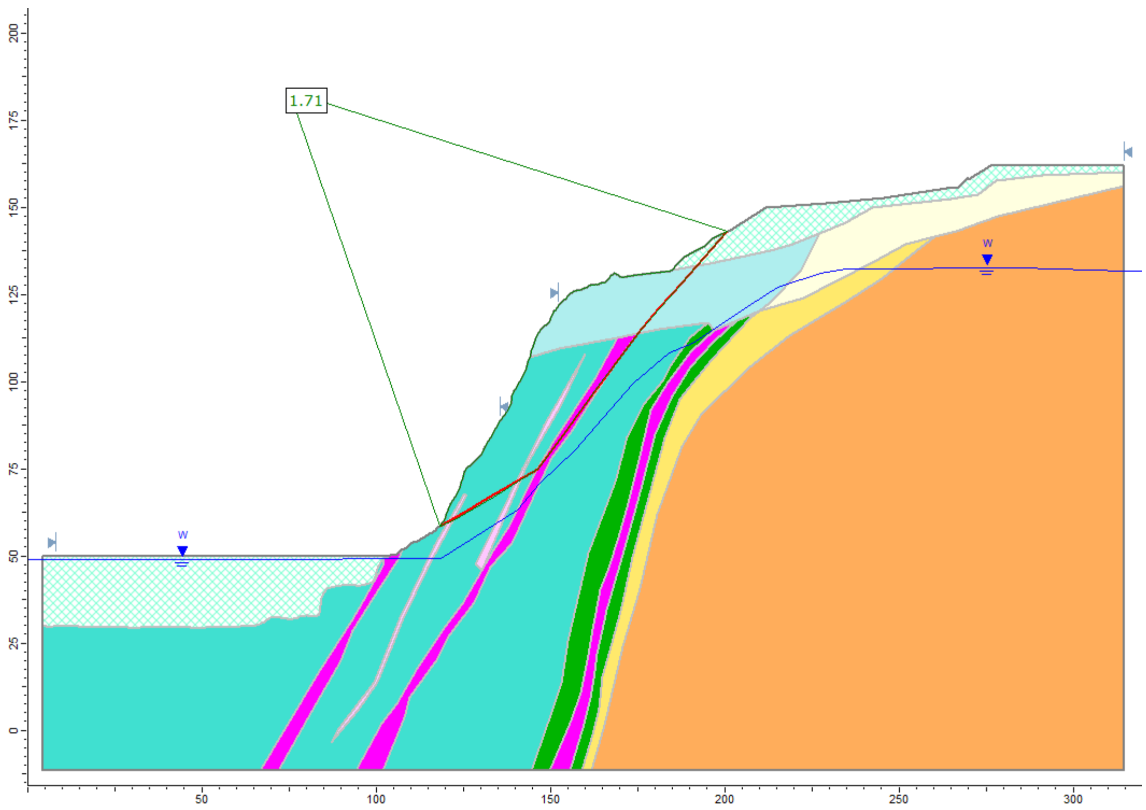
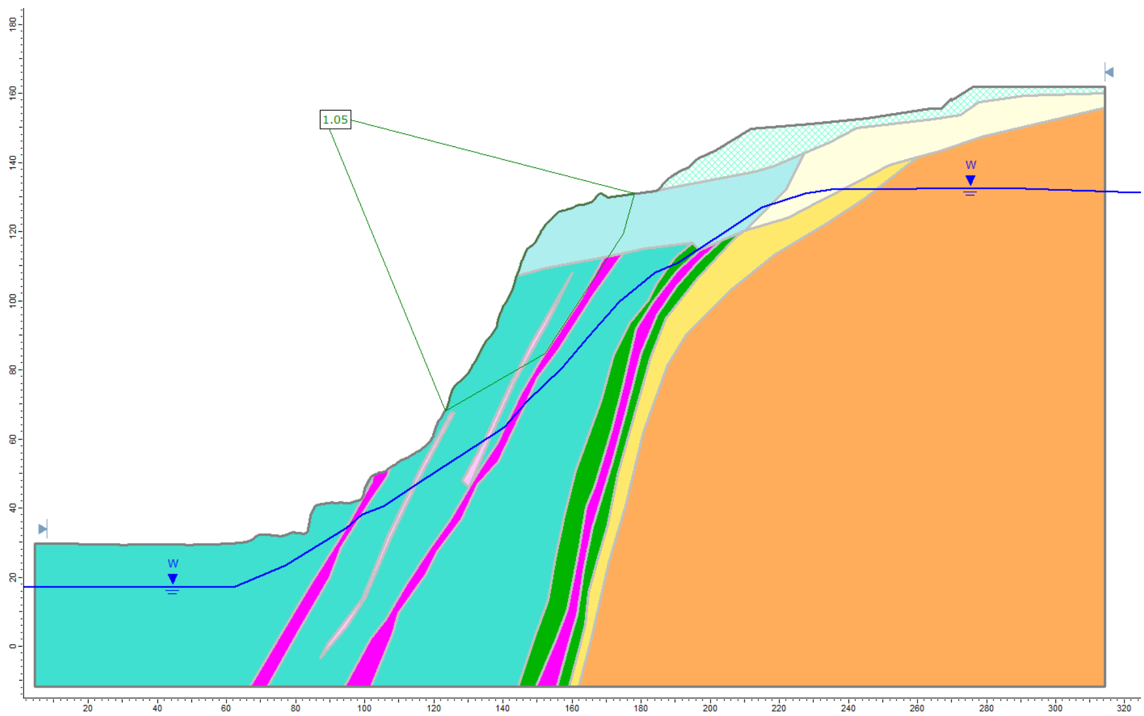
approved	PP		Project:	GEOTECHNICAL
date	23/09/2016			HORNSBY QUARRY
original	A4	coffey A TETRA TECH COMPANY	Title:	Section 11 – Fill to 40mRL - Isotropic Only
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	UCS (kPa)	m	s	a	Water Surface	Hu Type	Hu
Muddy Breccia		26	Mohr-Coulomb	0	28					Water Surface	Custom	1
Weathered Sandstone		24	Mohr-Coulomb	400	45					Water Surface	Custom	1
Sandstone		24	Generalized Hoek-Brown			40000	1.8878	0.00303634	0.502841	Water Surface	Custom	1
Weathered Dolerite		21	Mohr-Coulomb	110	29					Water Surface	Custom	1
Dumped Fill		20	Mohr-Coulomb	10	30					Water Surface	Custom	1
Volcanic Breccia		26	Generalized Hoek-Brown			70000	1.34994	0.00147111	0.504048	Water Surface	Custom	1
Shear planes in VB		26	Mohr-Coulomb	0	32					Water Surface	Custom	1
Flow Banded Dolerite		20	Generalized Hoek-Brown			30000	0.970825	0.000616591	0.506143	Water Surface	Custom	1
Altered Sandstone		24	Generalized Hoek-Brown			250000	0.880418	0.00082391	0.50535	Water Surface	Custom	1



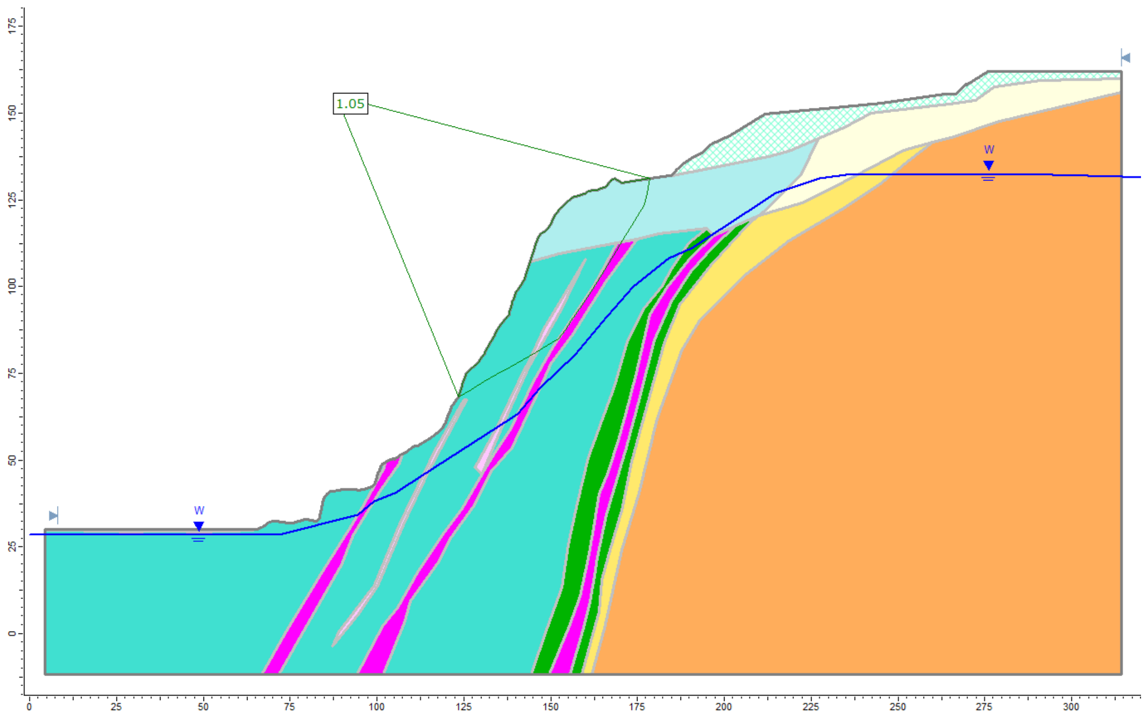
drawn	JN		Client:	Roads and Maritime
approved	PP		Project:	GEOTECHNICAL
date	23/09/2016	coffey A TETRA TECH COMPANY		HORNSBY QUARRY
original	A4		Title:	Section 11 – Fill to 50mRL - Isotropic Only
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Cohesion 2 (kPa)	Phi 2 (deg)	UCS (kPa)	m	s	a	Anisotropic Linear A (deg)	Anisotropic Linear B (deg)	Water Surface	Hu Type	Hu
Muddy Breccia		26	Mohr-Coulomb	100	28									Water Surface	Custom	1
Weathered Sandstone		24	Mohr-Coulomb	400	45									Water Surface	Custom	1
Sandstone		24	Generalized Hoek-Brown					40000	1.8878	0.00303634	0.502841			Water Surface	Custom	1
Weathered Dolerite		21	Mohr-Coulomb	110	29									Water Surface	Custom	1
Dumped Fill		20	Mohr-Coulomb	10	30									Water Surface	Custom	1
Volcanic Breccia		26	Anisotropic Linear	50	37	355	60					5	30	Water Surface	Custom	1
Shear planes in VB		26	Mohr-Coulomb	0	32									Water Surface	Custom	1
Flow Banded Dolerite		20	Generalized Hoek-Brown					30000	0.970825	0.000616591	0.506143			Water Surface	Custom	1
Altered Sandstone		24	Generalized Hoek-Brown					250000	0.880418	0.00082391	0.50535			Water Surface	Custom	1



drawn	JN	coffey A TETRA TECH COMPANY	Client:	Roads and Maritime
approved	PP		Project:	GEOTECHNICAL
date	23/09/2016			HORNSBY QUARRY
original size	A4		Title:	Section 11 – Current with upgraded bedding strength
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Cohesion 2 (kPa)	Phi 2 (deg)	UCS (kPa)	m	s	a	Anisotropic Linear A (deg)	Anisotropic Linear B (deg)	Water Surface	Hu Type	Hu
Muddy Breccia		26	Mohr-Coulomb	100	28									Water Surface	Custom	1
Weathered Sandstone		24	Mohr-Coulomb	400	45									Water Surface	Custom	1
Sandstone		24	Generalized Hoek-Brown					40000	1.8878	0.00303634	0.502841			Water Surface	Custom	1
Weathered Dolerite		21	Mohr-Coulomb	110	29									Water Surface	Custom	1
Dumped Fill		20	Mohr-Coulomb	10	30									Water Surface	Custom	1
Volcanic Breccia		26	Anisotropic Linear	50	37	355	60					5	30	Water Surface	Custom	1
Shear planes in VB		26	Mohr-Coulomb	0	32									Water Surface	Custom	1
Flow Banded Dolerite		20	Generalized Hoek-Brown					30000	0.970825	0.000616591	0.506143			Water Surface	Custom	1
Altered Sandstone		24	Generalized Hoek-Brown					250000	0.880418	0.00082391	0.50535			Water Surface	Custom	1



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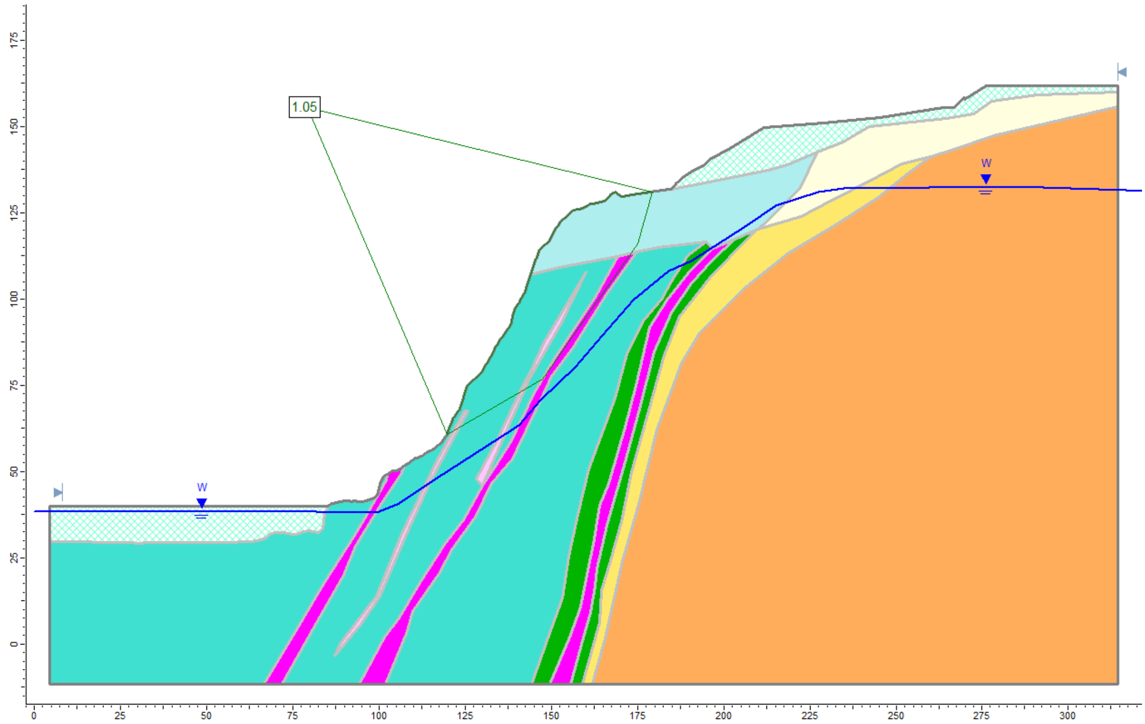
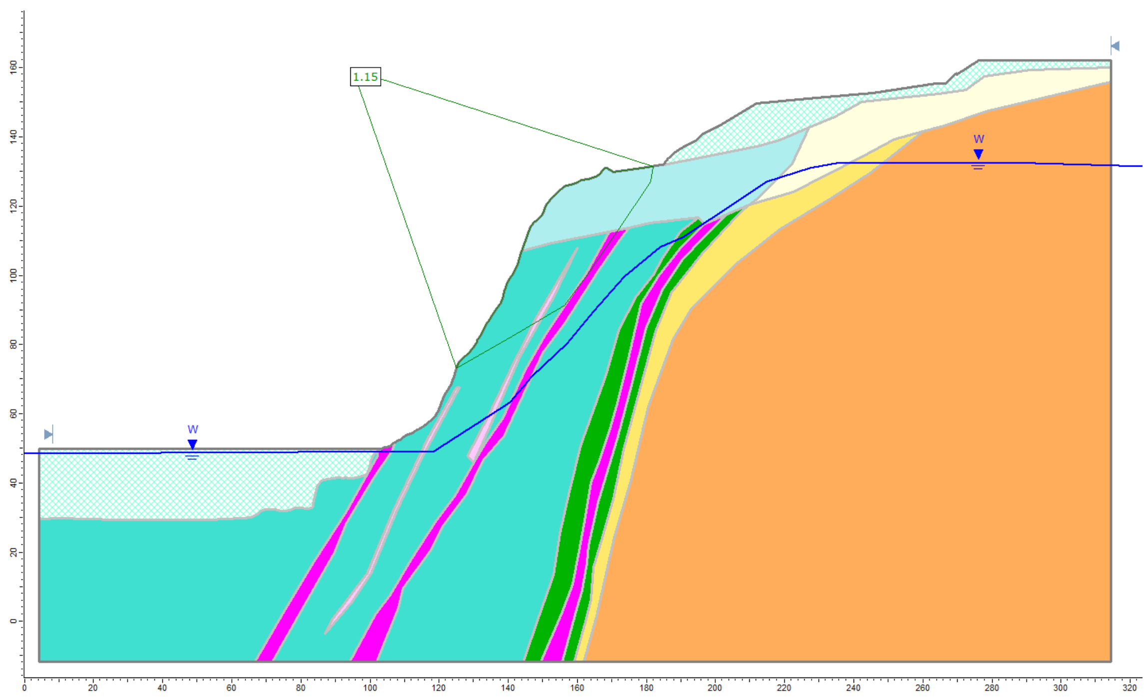
approved	PP		Project:	**GEOTECHNICAL**
date	23/09/2016			**HORNSBY QUARRY**
original size	A4		Title:	**Section 11 – Fill to 30mRL - Anisotropic**
			Project	**GEOTLCOV25707AA**

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Cohesion 2 (kPa)	Phi 2 (deg)	UCS (kPa)	m	s	a	Anisotropic Linear A (deg)	Anisotropic Linear B (deg)	Water Surface	Hu Type	Hu
Muddy Breccia		26	Mohr-Coulomb	100	28									Water Surface	Custom	1
Weathered Sandstone		24	Mohr-Coulomb	400	45									Water Surface	Custom	1
Sandstone		24	Generalized Hoek-Brown					40000	1.8878	0.00303634	0.502841			Water Surface	Custom	1
Weathered Dolerite		21	Mohr-Coulomb	110	29									Water Surface	Custom	1
Dumped Fill		20	Mohr-Coulomb	10	30									Water Surface	Custom	1
Volcanic Breccia		26	Anisotropic Linear	50	37	355	60					5	30	Water Surface	Custom	1
Shear planes in VB		26	Mohr-Coulomb	0	32									Water Surface	Custom	1
Flow Banded Dolerite		20	Generalized Hoek-Brown					30000	0.970825	0.000616591	0.506143			Water Surface	Custom	1
Altered Sandstone		24	Generalized Hoek-Brown					250000	0.880418	0.00082391	0.50535			Water Surface	Custom	1



drawn	JN		Client:	Roads and Maritime
approved	PP		Project:	GEOTECHNICAL
date	23/09/2016			HORNSBY QUARRY
original size	A4		Title:	Section 11 – Fill to 40mRL - Anisotropic
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Cohesion 2 (kPa)	Phi 2 (deg)	UCS (kPa)	m	s	a	Anisotropic Linear A (deg)	Anisotropic Linear B (deg)	Water Surface	Hu Type	Hu
Muddy Breccia		26	Mohr-Coulomb	100	28									Water Surface	Custom	1
Weathered Sandstone		24	Mohr-Coulomb	400	45									Water Surface	Custom	1
Sandstone		24	Generalized Hoek-Brown					40000	1.8878	0.00303634	0.502841			Water Surface	Custom	1
Weathered Dolerite		21	Mohr-Coulomb	110	29									Water Surface	Custom	1
Dumped Fill		20	Mohr-Coulomb	10	30									Water Surface	Custom	1
Volcanic Breccia		26	Anisotropic Linear	50	37	355	60					5	30	Water Surface	Custom	1
Shear planes in VB		26	Mohr-Coulomb	0	32									Water Surface	Custom	1
Flow Banded Dolerite		20	Generalized Hoek-Brown					30000	0.970825	0.000616591	0.506143			Water Surface	Custom	1
Altered Sandstone		24	Generalized Hoek-Brown					250000	0.880418	0.00082391	0.50535			Water Surface	Custom	1



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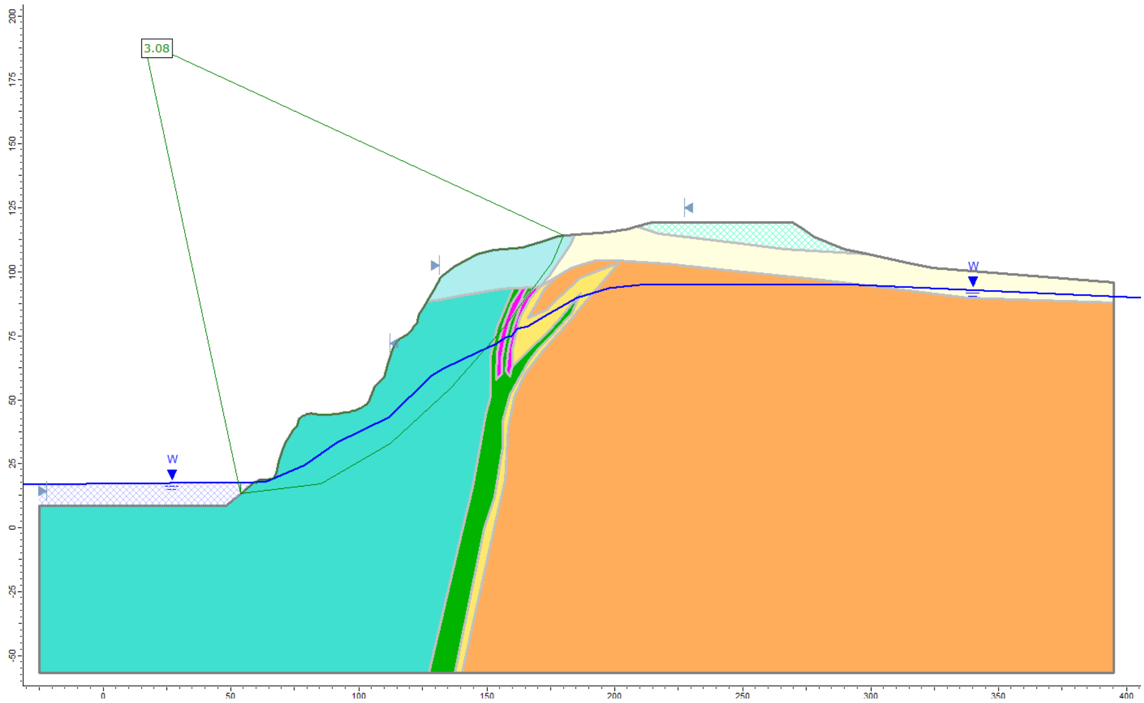
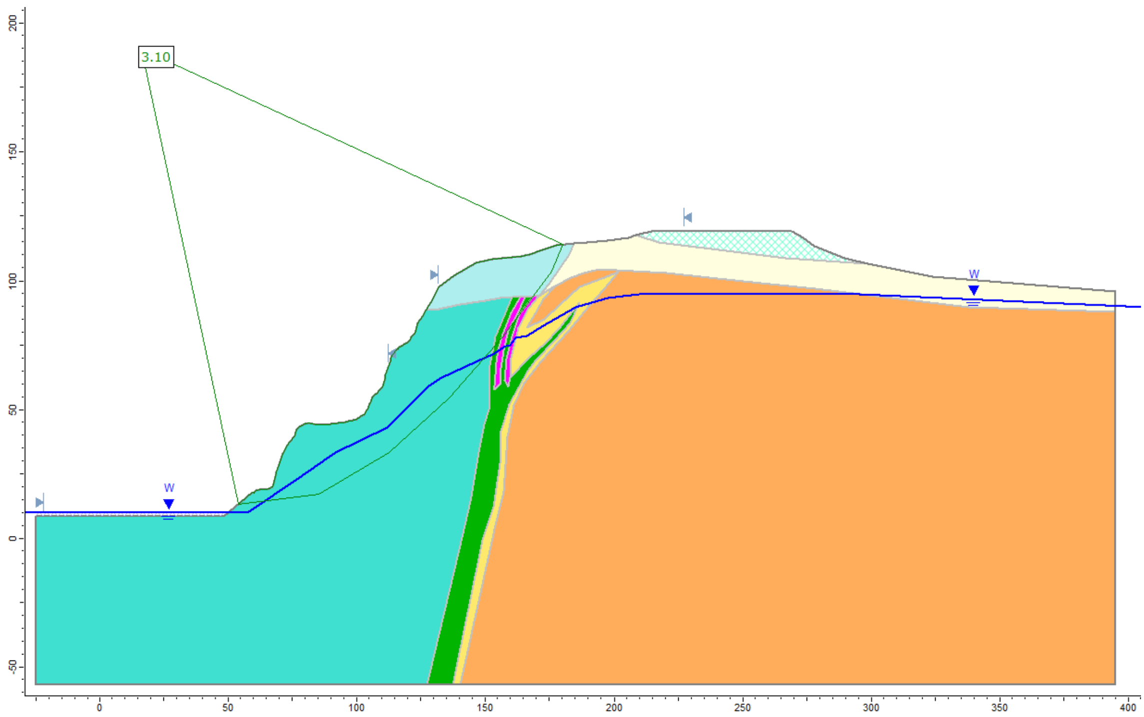
approved	PP		Project:	GEOTECHNICAL
date	23/09/2016			HORNSBY QUARRY
original size	A4		Title:	Section 11 – Fill to 50mRL - Anisotropic
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	UCS (kPa)	m	s	a	Water Surface	Hu Type	Hu
Muddy Breccia		26	Mohr-Coulomb	0	28					Water Surface	Custom	1
Weathered Sandstone		24	Mohr-Coulomb	400	45					Water Surface	Custom	1
Sandstone		24	Generalized Hoek-Brown			40000	1.8878	0.00303634	0.502841	Water Surface	Custom	1
Weathered Dolerite		21	Mohr-Coulomb	110	29					Water Surface	Custom	1
Dumped Fill		20	Mohr-Coulomb	10	30					Water Surface	Custom	1
Volcanic Breccia		26	Generalized Hoek-Brown			70000	1.34994	0.00147111	0.504048	Water Surface	Custom	1
Flow Banded Dolerite		20	Generalized Hoek-Brown			30000	0.970825	0.000616591	0.506143	Water Surface	Custom	1
Altered Sandstone		24	Generalized Hoek-Brown			250000	0.880418	0.00082391	0.50535	Water Surface	Custom	1



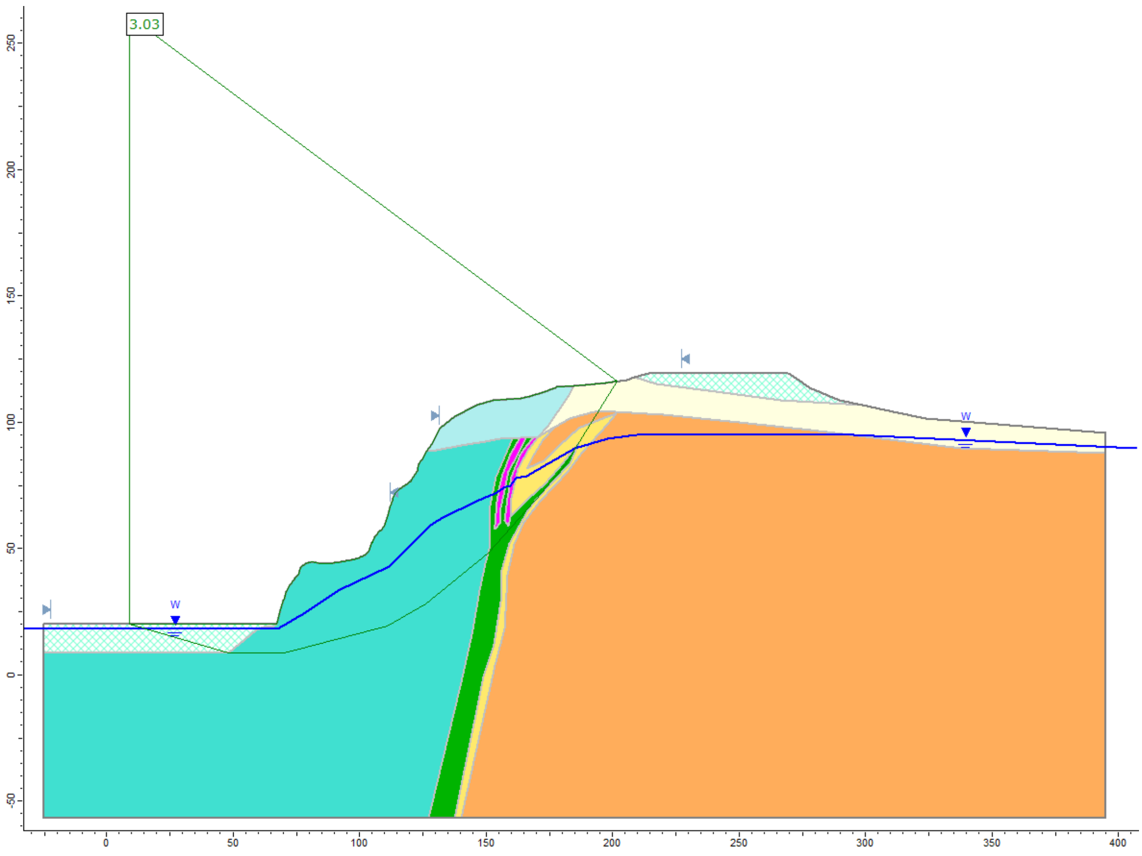
drawn	JN	coffey A TETRA TECH COMPANY	Client:	Roads and Maritime
approved	PP		Project:	GEOTECHNICAL
date	23/09/2016			HORNSBY QUARRY
original	A4		Title:	Section 12 – Current - Isotropic Only
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	UCS (kPa)	m	s	a	Water Surface	Hu Type	Hu
Muddy Breccia		26	Mohr-Coulomb	0	28					Water Surface	Custom	1
Weathered Sandstone		24	Mohr-Coulomb	400	45					Water Surface	Custom	1
Sandstone		24	Generalized Hoek-Brown			40000	1.8878	0.00303634	0.502841	Water Surface	Custom	1
Weathered Dolerite		21	Mohr-Coulomb	110	29					Water Surface	Custom	1
Dumped Fill		20	Mohr-Coulomb	10	30					Water Surface	Custom	1
Volcanic Breccia		26	Generalized Hoek-Brown			70000	1.34994	0.00147111	0.504048	Water Surface	Custom	1
Flow Banded Dolerite		20	Generalized Hoek-Brown			30000	0.970825	0.000616591	0.506143	Water Surface	Custom	1
Altered Sandstone		24	Generalized Hoek-Brown			250000	0.880418	0.00082391	0.50535	Water Surface	Custom	1



drawn	JN	coffey A TETRA TECH COMPANY	Client:	Roads and Maritime
approved	PP		Project:	GEOTECHNICAL
date	23/09/2016			HORNSBY QUARRY
original	A4		Title:	Section 12 – Dewatered - Isotropic Only
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	UCS (kPa)	m	s	a	Water Surface	Hu Type	Hu
Muddy Breccia		26	Mohr-Coulomb	0	28					Water Surface	Custom	1
Weathered Sandstone		24	Mohr-Coulomb	400	45					Water Surface	Custom	1
Sandstone		24	Generalized Hoek-Brown			40000	1.8878	0.00303634	0.502841	Water Surface	Custom	1
Weathered Dolerite		21	Mohr-Coulomb	110	29					Water Surface	Custom	1
Dumped Fill		20	Mohr-Coulomb	10	30					Water Surface	Custom	1
Volcanic Breccia		26	Generalized Hoek-Brown			70000	1.34994	0.00147111	0.504048	Water Surface	Custom	1
Flow Banded Dolerite		20	Generalized Hoek-Brown			30000	0.970825	0.000616591	0.506143	Water Surface	Custom	1
Altered Sandstone		24	Generalized Hoek-Brown			250000	0.880418	0.00082391	0.50535	Water Surface	Custom	1



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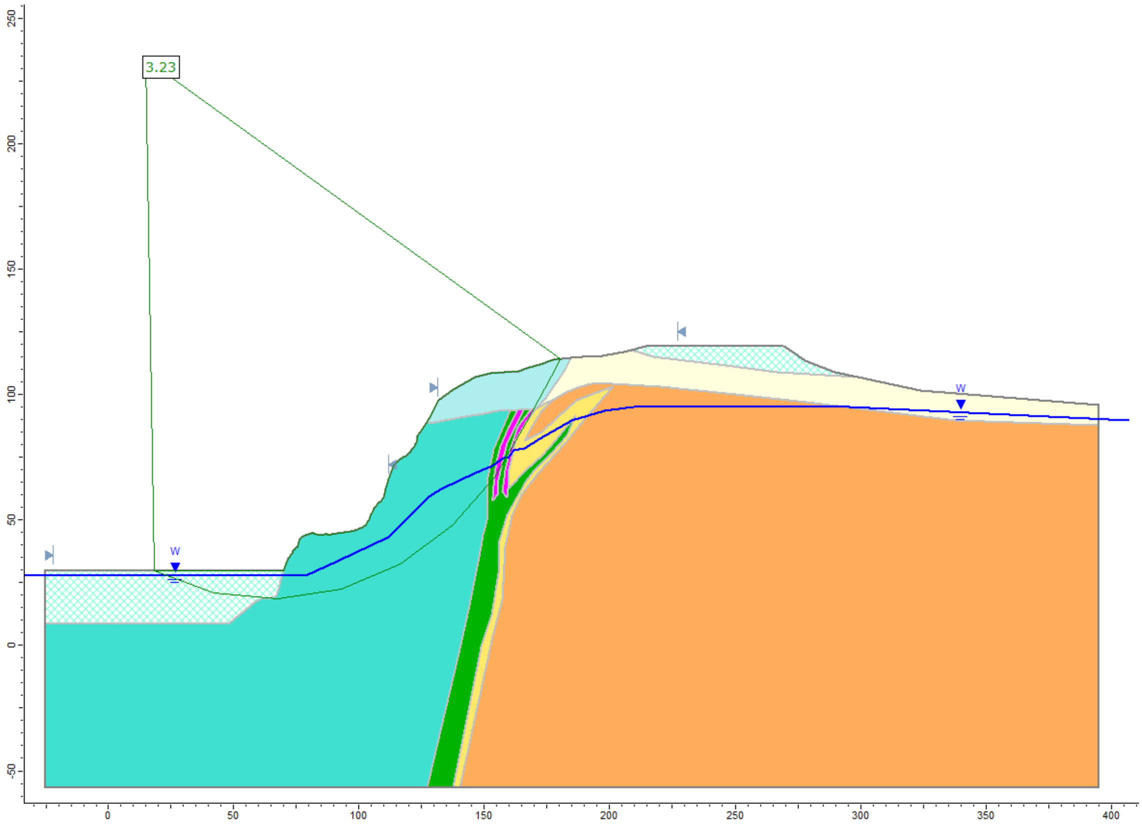
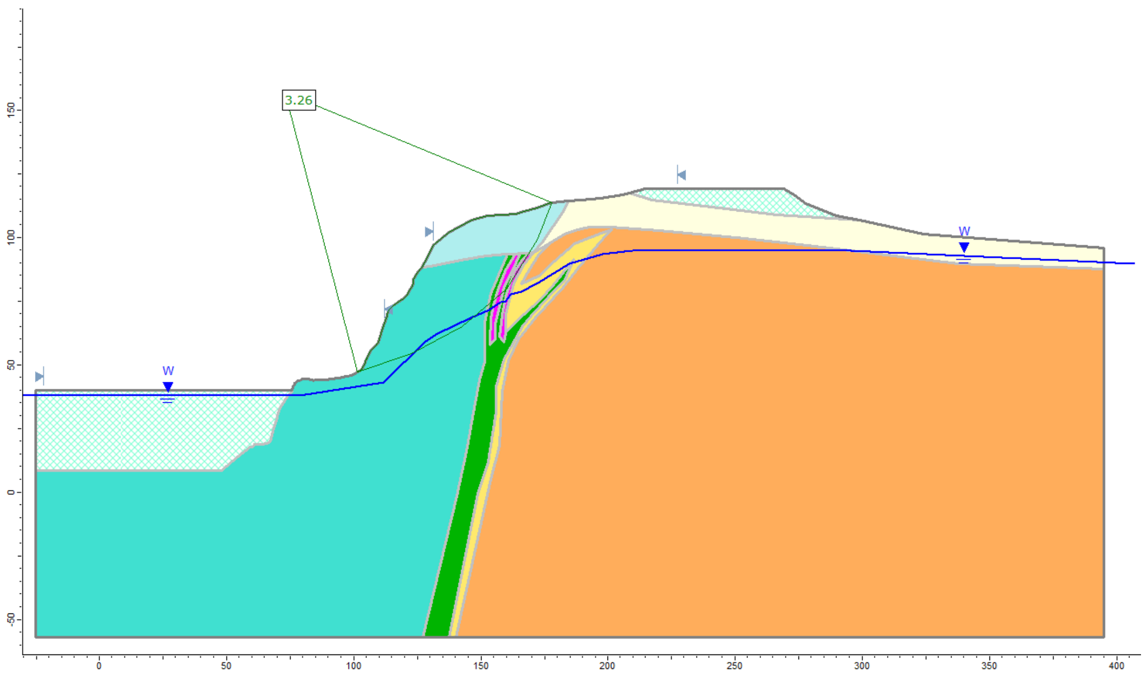
approved	PP		Project:	GEOTECHNICAL
date	23/09/2016			HORNSBY QUARRY
original	A4		Title:	Section 12 – Fill to 20mRL - Isotropic Only
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	UCS (kPa)	m	s	a	Water Surface	Hu Type	Hu
Muddy Breccia		26	Mohr-Coulomb	0	28					Water Surface	Custom	1
Weathered Sandstone		24	Mohr-Coulomb	400	45					Water Surface	Custom	1
Sandstone		24	Generalized Hoek-Brown			40000	1.8878	0.00303634	0.502841	Water Surface	Custom	1
Weathered Dolerite		21	Mohr-Coulomb	110	29					Water Surface	Custom	1
Dumped Fill		20	Mohr-Coulomb	10	30					Water Surface	Custom	1
Volcanic Breccia		26	Generalized Hoek-Brown			70000	1.34994	0.00147111	0.504048	Water Surface	Custom	1
Flow Banded Dolerite		20	Generalized Hoek-Brown			30000	0.970825	0.000616591	0.506143	Water Surface	Custom	1
Altered Sandstone		24	Generalized Hoek-Brown			250000	0.880418	0.00082391	0.50535	Water Surface	Custom	1



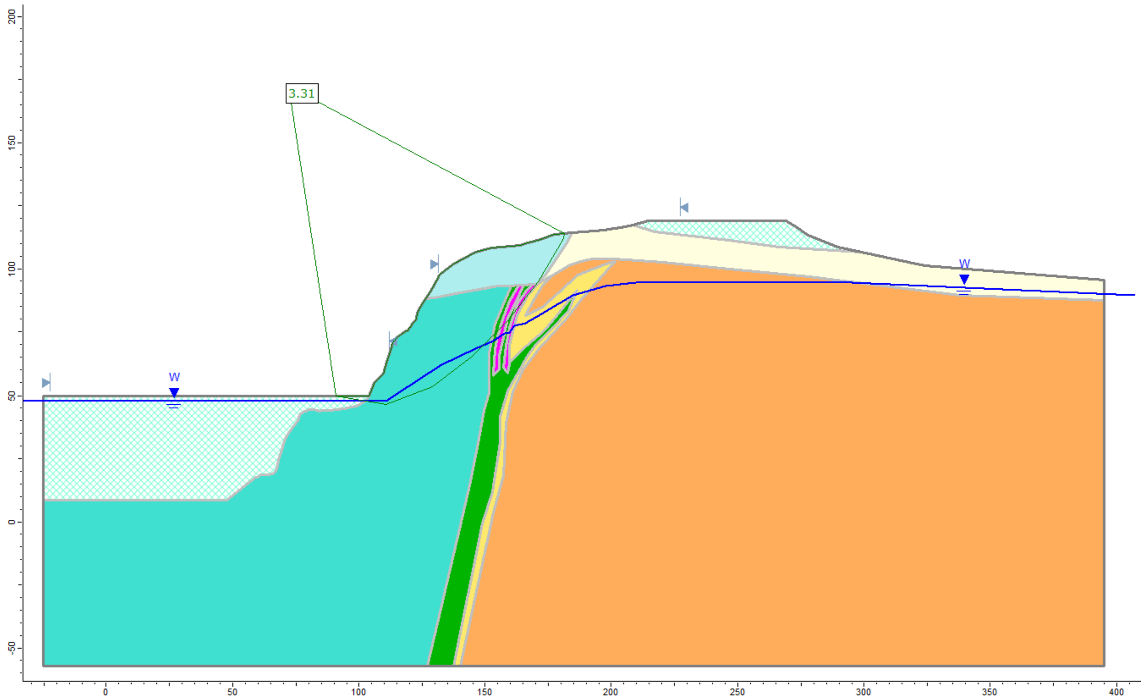
drawn	JN	coffey A TETRA TECH COMPANY	Client:	Roads and Maritime
approved	PP		Project:	GEOTECHNICAL
date	23/09/2016			HORNSBY QUARRY
original	A4		Title:	Section 12 – Fill to 30mRL - Isotropic Only
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	UCS (kPa)	m	s	a	Water Surface	Hu Type	Hu
Muddy Breccia		26	Mohr-Coulomb	0	28					Water Surface	Custom	1
Weathered Sandstone		24	Mohr-Coulomb	400	45					Water Surface	Custom	1
Sandstone		24	Generalized Hoek-Brown			40000	1.8878	0.00303634	0.502841	Water Surface	Custom	1
Weathered Dolerite		21	Mohr-Coulomb	110	29					Water Surface	Custom	1
Dumped Fill		20	Mohr-Coulomb	10	30					Water Surface	Custom	1
Volcanic Breccia		26	Generalized Hoek-Brown			70000	1.34994	0.00147111	0.504048	Water Surface	Custom	1
Flow Banded Dolerite		20	Generalized Hoek-Brown			30000	0.970825	0.000616591	0.506143	Water Surface	Custom	1
Altered Sandstone		24	Generalized Hoek-Brown			250000	0.880418	0.00082391	0.50535	Water Surface	Custom	1



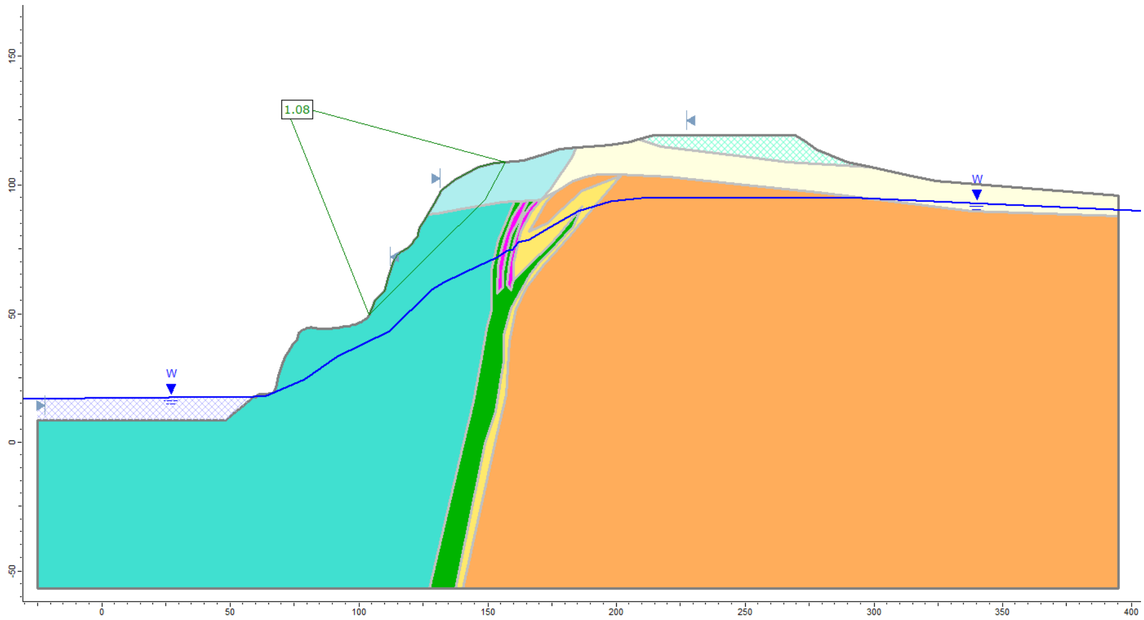
drawn	JN	coffey A TETRA TECH COMPANY	Client:	Roads and Maritime
approved	PP		Project:	GEOTECHNICAL
date	23/09/2016			HORNSBY QUARRY
original	A4		Title:	Section 12 – Fill to 40mRL - Isotropic Only
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	UCS (kPa)	m	s	a	Water Surface	Hu Type	Hu
Muddy Breccia		26	Mohr-Coulomb	0	28					Water Surface	Custom	1
Weathered Sandstone		24	Mohr-Coulomb	400	45					Water Surface	Custom	1
Sandstone		24	Generalized Hoek-Brown			40000	1.8878	0.00303634	0.502841	Water Surface	Custom	1
Weathered Dolerite		21	Mohr-Coulomb	110	29					Water Surface	Custom	1
Dumped Fill		20	Mohr-Coulomb	10	30					Water Surface	Custom	1
Volcanic Breccia		26	Generalized Hoek-Brown			70000	1.34994	0.00147111	0.504048	Water Surface	Custom	1
Flow Banded Dolerite		20	Generalized Hoek-Brown			30000	0.970825	0.000616591	0.506143	Water Surface	Custom	1
Altered Sandstone		24	Generalized Hoek-Brown			250000	0.880418	0.00082391	0.50535	Water Surface	Custom	1



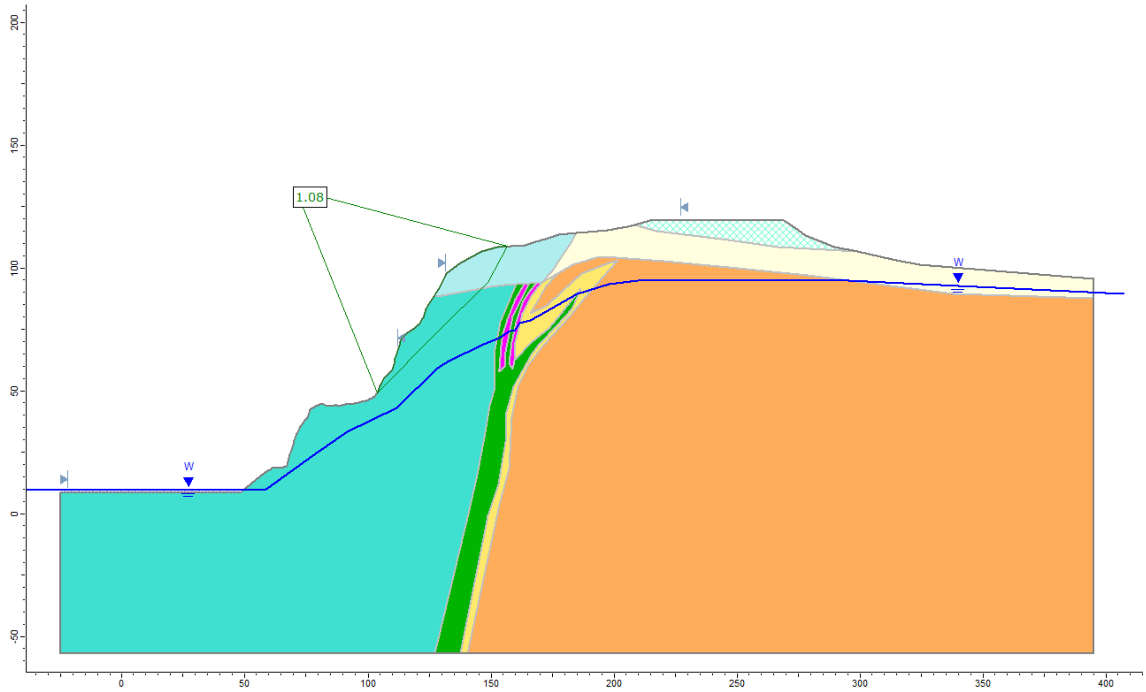
drawn	JN		Client:	Roads and Maritime
approved	PP		Project:	GEOTECHNICAL
date	23/09/2016			HORNSBY QUARRY
original	A4		Title:	Section 12 – Fill to 50mRL - Isotropic Only
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Cohesion 2 (kPa)	Phi 2 (deg)	UCS (kPa)	m	s	a	Anisotropic Linear A (deg)	Anisotropic Linear B (deg)	Water Surface	Hu Type	Hu
Muddy Breccia		26	Mohr-Coulomb	100	28									Water Surface	Custom	1
Weathered Sandstone		24	Mohr-Coulomb	400	45									Water Surface	Custom	1
Sandstone		24	Generalized Hoek-Brown					40000	1.8878	0.00303634	0.502841			Water Surface	Custom	1
Weathered Dolerite		21	Mohr-Coulomb	110	29									Water Surface	Custom	1
Dumped Fill		20	Mohr-Coulomb	10	30									Water Surface	Custom	1
Volcanic Breccia		26	Anisotropic Linear	35	37	355	60					5	30	Water Surface	Custom	1
Flow Banded Dolerite		20	Generalized Hoek-Brown					30000	0.970825	0.000616591	0.506143			Water Surface	Custom	1
Altered Sandstone		24	Generalized Hoek-Brown					250000	0.880418	0.00082391	0.50535			Water Surface	Custom	1



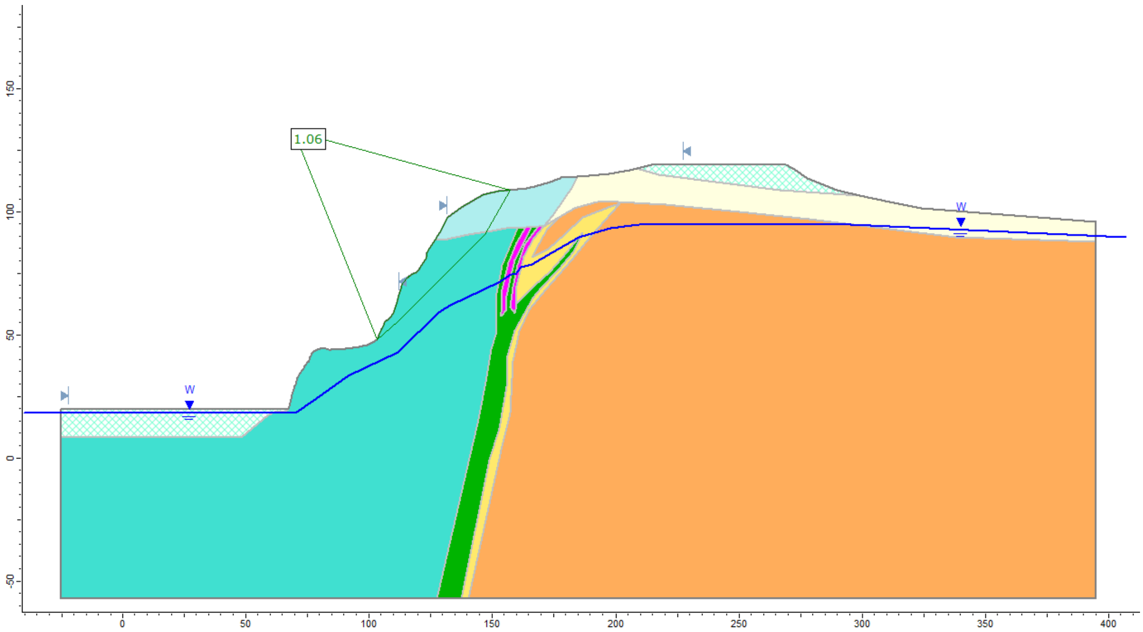
drawn	JN		Client:	Roads and Maritime
approved	PP		Project:	GEOTECHNICAL
date	23/09/2016			HORNSBY QUARRY
original	A4	coffey A TETRA TECH COMPANY	Title:	Section 12 – Current with upgraded defect strength
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Cohesion 2 (kPa)	Phi 2 (deg)	UCS (kPa)	m	s	a	Anisotropic Linear A (deg)	Anisotropic Linear B (deg)	Water Surface	Hu Type	Hu
Muddy Breccia		26	Mohr-Coulomb	100	28									Water Surface	Custom	1
Weathered Sandstone		24	Mohr-Coulomb	400	45									Water Surface	Custom	1
Sandstone		24	Generalized Hoek-Brown					40000	1.8878	0.00303634	0.502841			Water Surface	Custom	1
Weathered Dolerite		21	Mohr-Coulomb	110	29									Water Surface	Custom	1
Dumped Fill		20	Mohr-Coulomb	10	30									Water Surface	Custom	1
Volcanic Breccia		26	Anisotropic Linear	35	37	355	60					5	30	Water Surface	Custom	1
Flow Banded Dolerite		20	Generalized Hoek-Brown					30000	0.970825	0.000616591	0.506143			Water Surface	Custom	1
Altered Sandstone		24	Generalized Hoek-Brown					250000	0.880418	0.00082391	0.50535			Water Surface	Custom	1



drawn	JN	coffey A TETRA TECH COMPANY	Client:	Roads and Maritime
approved	PP		Project:	GEOTECHNICAL
date	23/09/2016			HORNSBY QUARRY
original	A4		Title:	Section 12 – Dewatered - Anisotropic
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Cohesion 2 (kPa)	Phi 2 (deg)	UCS (kPa)	m	s	a	Anisotropic Linear A (deg)	Anisotropic Linear B (deg)	Water Surface	Hu Type	Hu
Muddy Breccia		26	Mohr-Coulomb	100	28									Water Surface	Custom	1
Weathered Sandstone		24	Mohr-Coulomb	400	45									Water Surface	Custom	1
Sandstone		24	Generalized Hoek-Brown					40000	1.8878	0.00303634	0.502841			Water Surface	Custom	1
Weathered Dolerite		21	Mohr-Coulomb	110	29									Water Surface	Custom	1
Dumped Fill		20	Mohr-Coulomb	10	30									Water Surface	Custom	1
Volcanic Breccia		26	Anisotropic Linear	35	37	355	60					5	30	Water Surface	Custom	1
Flow Banded Dolerite		20	Generalized Hoek-Brown					30000	0.970825	0.000616591	0.506143			Water Surface	Custom	1
Altered Sandstone		24	Generalized Hoek-Brown					250000	0.880418	0.00082391	0.50535			Water Surface	Custom	1



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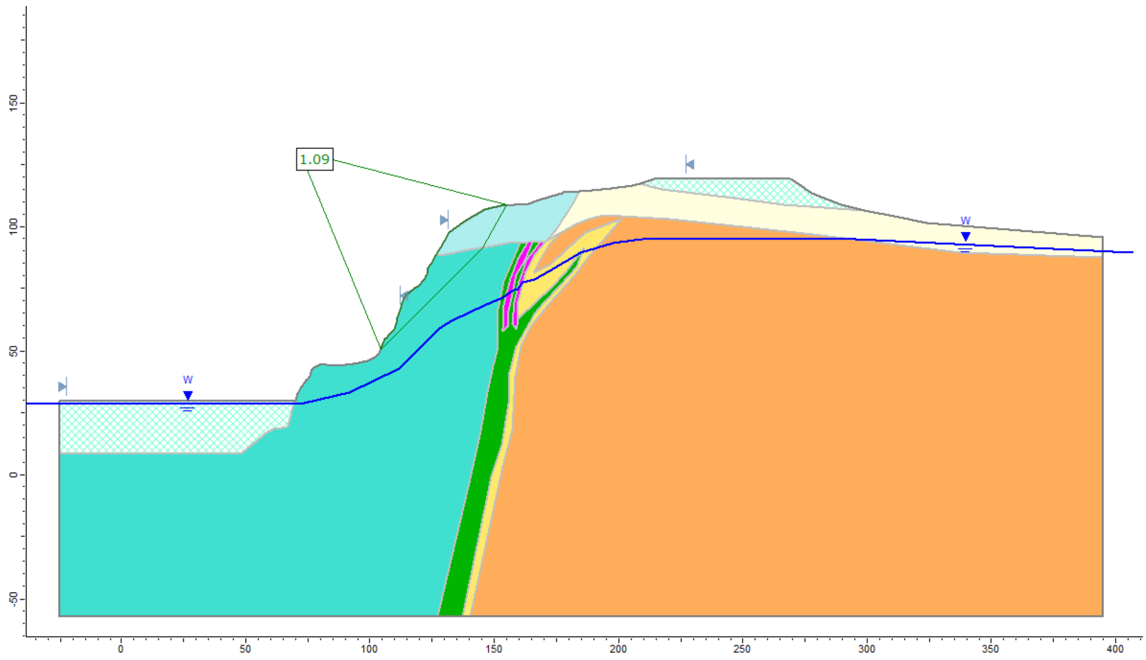
date	23/09/2016			HORNSBY QUARRY
original	A4		Title:	Section 12 – Fill to 20mRL - Anisotropic
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Cohesion 2 (kPa)	Phi 2 (deg)	UCS (kPa)	m	s	a	Anisotropic Linear A (deg)	Anisotropic Linear B (deg)	Water Surface	Hu Type	Hu
Muddy Breccia		26	Mohr-Coulomb	100	28									Water Surface	Custom	1
Weathered Sandstone		24	Mohr-Coulomb	400	45									Water Surface	Custom	1
Sandstone		24	Generalized Hoek-Brown					40000	1.8878	0.00303634	0.502841			Water Surface	Custom	1
Weathered Dolerite		21	Mohr-Coulomb	110	29									Water Surface	Custom	1
Dumped Fill		20	Mohr-Coulomb	10	30									Water Surface	Custom	1
Volcanic Breccia		26	Anisotropic Linear	35	37	355	60					5	30	Water Surface	Custom	1
Flow Banded Dolerite		20	Generalized Hoek-Brown					30000	0.970825	0.000616591	0.506143			Water Surface	Custom	1
Altered Sandstone		24	Generalized Hoek-Brown					250000	0.880418	0.00082391	0.50535			Water Surface	Custom	1



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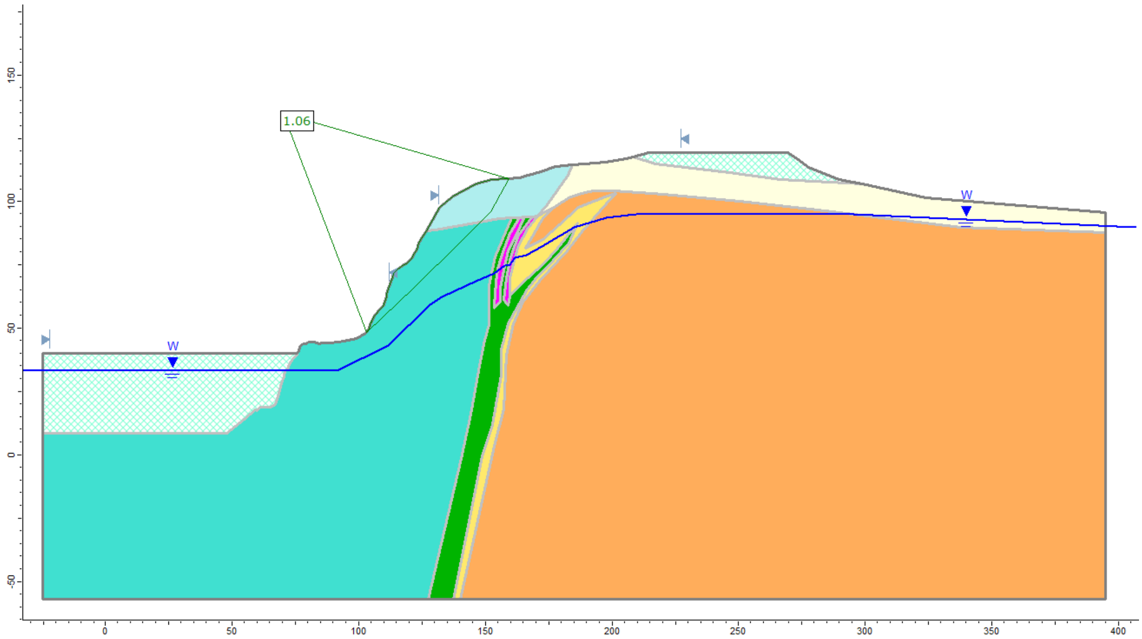
approved	PP		Project:	GEOTECHNICAL
date	23/09/2016			HORNSBY QUARRY
original	A4		Title:	Section 12 – Fill to 30mRL - Anisotropic
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Cohesion 2 (kPa)	Phi 2 (deg)	UCS (kPa)	m	s	a	Anisotropic Linear A (deg)	Anisotropic Linear B (deg)	Water Surface	Hu Type	Hu
Muddy Breccia		26	Mohr-Coulomb	100	28									Water Surface	Custom	1
Weathered Sandstone		24	Mohr-Coulomb	400	45									Water Surface	Custom	1
Sandstone		24	Generalized Hoek-Brown					40000	1.8878	0.00303634	0.502841			Water Surface	Custom	1
Weathered Dolerite		21	Mohr-Coulomb	110	29									Water Surface	Custom	1
Dumped Fill		20	Mohr-Coulomb	10	30									Water Surface	Custom	1
Volcanic Breccia		26	Anisotropic Linear	35	37	355	60					5	30	Water Surface	Custom	1
Flow Banded Dolerite		20	Generalized Hoek-Brown					30000	0.970825	0.000616591	0.506143			Water Surface	Custom	1
Altered Sandstone		24	Generalized Hoek-Brown					250000	0.880418	0.00082391	0.50535			Water Surface	Custom	1



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approved	PP		Project:	GEOTECHNICAL
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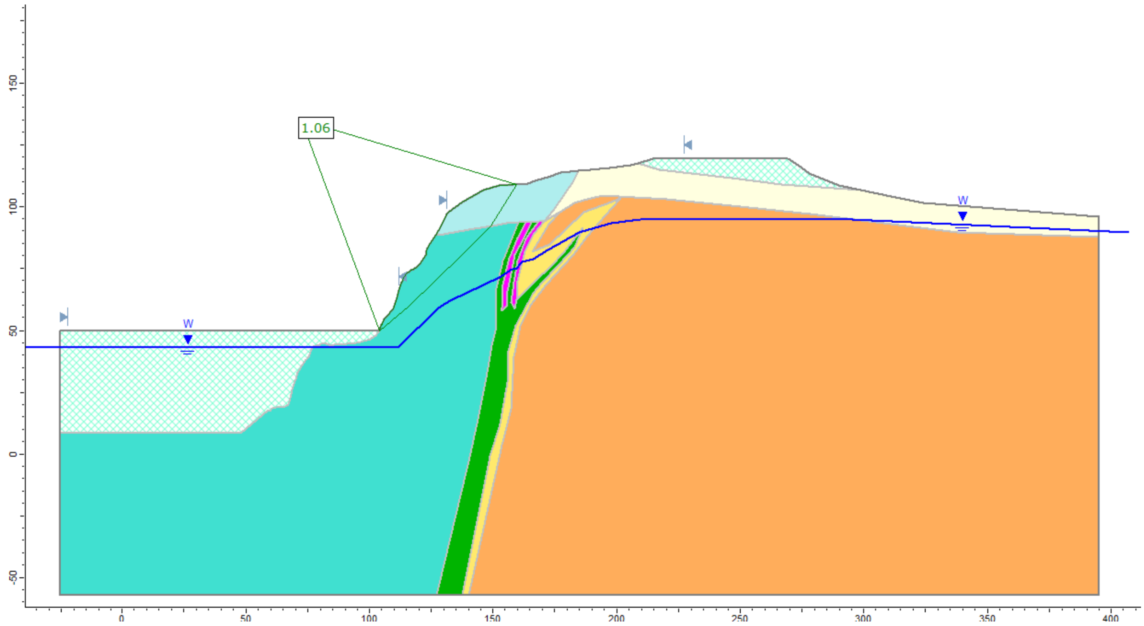
original	A4		Title:	Section 12 – Fill to 40mRL - Anisotropic
			Project	GEOTLCOV25707AA

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Cohesion 2 (kPa)	Phi 2 (deg)	UCS (kPa)	m	s	a	Anisotropic Linear A (deg)	Anisotropic Linear B (deg)	Water Surface	Hu Type	Hu
Muddy Breccia		26	Mohr-Coulomb	100	28									Water Surface	Custom	1
Weathered Sandstone		24	Mohr-Coulomb	400	45									Water Surface	Custom	1
Sandstone		24	Generalized Hoek-Brown					40000	1.8878	0.00303634	0.502841			Water Surface	Custom	1
Weathered Dolerite		21	Mohr-Coulomb	110	29									Water Surface	Custom	1
Dumped Fill		20	Mohr-Coulomb	10	30									Water Surface	Custom	1
Volcanic Breccia		26	Anisotropic Linear	35	37	355	60					5	30	Water Surface	Custom	1
Flow Banded Dolerite		20	Generalized Hoek-Brown					30000	0.970825	0.000616591	0.506143			Water Surface	Custom	1
Altered Sandstone		24	Generalized Hoek-Brown					250000	0.880418	0.00082391	0.50535			Water Surface	Custom	1



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			Project	GEOTLCOV25707AA

Appendix C – Landslide Risk Terminology

Landslide Risk Terminology

The following terms are as defined by Appendix A of AGS 2007:

Acceptable Risk – A risk for which, for the purposes of life or work, we are prepared to accept as it is with no regard to its management. Society does not generally consider expenditure in further reducing such risks justifiable.

Annual Exceedance Probability (AEP) – The estimated probability that an event of specified magnitude will be exceeded in any year.

Consequence –The outcomes or potential outcomes arising from the occurrence of a landslide expressed qualitatively or quantitatively, in terms of loss, disadvantage or gain, damage, injury or loss of life.

Elements at Risk– The population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by landslides.

Frequency – A measure of likelihood expressed as the number of occurrences of an event in a given time. See also Likelihood and Probability.

Hazard– A condition with the potential for causing an undesirable consequence (the landslide). The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the likelihood of their occurrence within a given period of time.

Individual Risk to Life– The risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide; or who follows a particular pattern of life that might subject him or her to the consequences of the landslide.

Landslide Activity – The stage of development of a landslide; pre failure when the slope is strained throughout but is essentially intact; failure characterised by the formation of a continuous surface of rupture; post failure which includes movement from just after failure to when it essentially stops; and reactivation when the slope slides along one or several pre-existing surfaces of rupture. Reactivation may be occasional (eg seasonal) or continuous (in which case the slide is “active”).

Landslide Intensity – A set of spatially distributed parameters related to the destructive power of a landslide. The parameters may be described quantitatively or qualitatively and may include maximum movement velocity, total displacement, differential displacement, depth of the moving mass, peak discharge per unit width, kinetic energy per unit area.

Landslide Risk - The AGS Australian GeoGuide LR7 (AGS, 2007e) should be referred to for an explanation of Landslide Risk.

Landslide Susceptibility – The classification, and volume (or area) of landslides which exist or potentially may occur in an area or may travel or retrogress onto it. Susceptibility may also include a description of the velocity and intensity of the existing or potential landsliding.

Likelihood – Used as a qualitative description of probability or frequency.

Probability – A measure of the degree of certainty. This measure has a value between zero (impossibility) and 1.0(certainty). It is an estimate of the likelihood of the magnitude of the uncertain quantity, or the likelihood of the occurrence of the uncertain future event.

There are two main interpretations:

(i) Statistical – frequency or fraction – The outcome of a repetitive experiment of some kind like flipping coins. It includes also the idea of population variability. Such a number is called an “objective” or relative frequentist probability because it exists in the real world and is in principle measurable by doing the experiment.

(ii) Subjective probability (degree of belief) – Quantified measure of belief, judgment, or confidence in the likelihood of an outcome, obtained by considering all available information honestly, fairly, and with a minimum of bias. Subjective probability is affected by the state of understanding of a process, judgment regarding an evaluation, or the quality and quantity of information. It may change over time as the state of knowledge changes.

Qualitative Risk Analysis– An analysis which uses word form, descriptive or numeric rating scales to describe the magnitude of potential consequences and the likelihood that those consequences will occur.

Quantitative Risk Analysis – An analysis based on numerical values of the probability, vulnerability and consequences and resulting in a numerical value of the risk.

Risk–A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability x consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.

Risk Analysis – The use of available information to estimate the risk to individual, population, property, or the environment, from hazards. Risk analyses generally contain the following steps: Scope definition, hazard identification and risk estimation.

Risk Assessment – The process of risk analysis and risk evaluation.

Risk Control or **Risk Treatment** – The process of decision making for managing risk and the implementation or enforcement of risk mitigation measures and the re-evaluation of its effectiveness from time to time, using the results of risk assessment as one input.

Risk Estimation– The process used to produce a measure of the level of health, property or environmental risks being analysed. Risk estimation contains the following steps: frequency analysis, consequence analysis and their integration.

Risk Evaluation – The stage at which values and judgments enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental and economic consequences, in order to identify a range of alternatives for managing the risks.

Risk Management – The complete process of risk assessment and risk control (or risk treatment).

Societal Risk – The risk of multiple fatalities or injuries in society as a whole: one where society would have to carry the burden of a landslide causing a number of deaths, injuries, financial, environmental and other losses.

Susceptibility– see Landslide Susceptibility

Temporal Spatial Probability – The probability that the element at risk is in the area affected by the landsliding, at the time of the landslide.

Tolerable Risk – A risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.

Vulnerability – The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the landslide.

Appendix D – Risk to Life Calculations (Global Failures)

Table D1: Risk Assessment - Construction Phase (Global Failures)

Activity Number	Hazard	Activity Description	Person at Risk	Annual Probability - $P_{(H)}$	Probability of Spatial Impact - $P_{(S:H)}$	Temporal Spatial Probability - $P_{(T:S)}$	Vulnerability - $V_{(D:T)}$	Annual Probability of loss of life (death) of an individual - $R_{(LoL)}$
1A	Major Slide	Upgrade of the existing access road, installation of safety bunds/barriers and initial scaling works to remove loose rock along access road	Person working in open directing installation of concrete barriers or soil mounds on the access road along the north and west walls	0.010	0.333	1.14E-03	1.000	3.8E-06
1B	Major Slide		Person in excavator (fitted with FOPS / ROPS) working on the access road / scaling loose rocks along the north and west walls	0.010	0.333	1.14E-03	1.000	3.8E-06
1C	Major Slide		Person in FOPS / ROPS vehicle working on the access road near the batter along the south wall	0.010	0.333	1.71E-03	1.000	5.7E-06
2A	Major Slide	Travel along access road	Person in light vehicle driving on the access road near the batter along the north and west walls	0.010	0.333	7.15E-05	1.000	2.4E-07
2B	Major Slide		Person in FOPS / ROPS vehicle driving on the access road near the batter along the south wall	0.010	0.333	3.70E-05	1.000	1.2E-07
3	Major Slide	Preparation of a 'sound platform' by personnel in earthmoving equipment / construction of the conveyor footing in the pit	Person in earth moving equipment (FOPS / ROPS) working on the quarry floor	0.010	0.333	1.71E-03	1.000	5.7E-06
4	Major Slide	Construction of the reclaimer	Person working on quarry floor in vicinity of reclaimer location	0.010	0.333	1.71E-03	1.000	5.7E-06
5A	Major Slide	Installation of telestackers	Person working on quarry floor near the south wall in vicinity of telestacker location	0.010	0.333	2.28E-03	1.000	7.6E-06
5B	Major Slide		Person in FOPS / ROPS vehicle working on the quarry floor in vicinity of telestacker location	0.010	0.333	2.28E-03	1.000	7.6E-06
							Estimated Risk of "Loss of Life" for an Individual	**4.0E-05**

Table D2: Risk to Life Calculations - Operation Phase (Global Failures)

Activity Number	Hazard	Activity Description	Person at Risk	Annual Probability - $P_{(H)}$	Probability of Spatial Impact - $P_{(S:H)}$	Temporal Spatial Probability - $P_{(T:S)}$	Vulnerability - $V_{(D:T)}$	Annual Probability of loss of life (death) of an individual - $R_{(LoL)}$
6A	Major Slide	Travel along access road	Person in light vehicle driving on the access road near the batter along the north and west walls	0.010	0.333	5.44E-04	1.000	1.8E-06
6B	Major Slide		Person in FOPS / ROPS vehicle driving on the access road near the batter along the south wall	0.010	0.333	2.81E-04	1.000	9.4E-07
8	Major Slide	Personnel working within pit on daily basis	Person working on quarry floor in Person Access Zone	0.010	0.0001	1.67E-02	1.000	1.7E-08
							Estimated Risk of "Loss of Life" for an Individual	**2.8E-06**

Appendix E – Risk to Life Calculations (Local Failures / Rockfalls)

Table E1: Risk Assessment - Construction Phase (Local Failures - i.e. rockfalls)

Activity Number	Hazard	Activity Description	Person at Risk	Annual Probability - $P_{(H)}$	Probability of Spatial Impact - $P_{(S:H)}$	Temporal Spatial Probability - $P_{(T:S)}$	Vulnerability - $V_{(D:T)}$	Occurrences per year	Annual Probability of loss of life (death) of an individual - $R_{(LoL)}$
1A	Rockfall	Upgrade of the existing access road, installation of safety bunds/barriers and initial scaling works to remove loose rock along access road	Person working in open directing installation of concrete barriers or soil mounds on the access road along the north and west walls	1.000	0.001	0.011	0.500	3.000	2.0E-05
1B	Rockfall		Person in excavator (fitted with FOPS / ROPS) working on the access road / scaling loose rocks along the north and west walls	1.000	0.009	0.011	0.010	3.000	3.1E-06
1C	Rockfall		Person in FOPS / ROPS vehicle working on the access road near the batter along the south wall	1.000	0.018	0.017	0.010	6.000	1.8E-05
2A	Rockfall	Travel along access road	Person in light vehicle driving on the access road near the batter along the north and west walls	1.000	0.009	0.001	0.200	3.000	3.9E-06
2B	Rockfall		Person in FOPS / ROPS vehicle driving on the access road near the batter along the south wall	1.000	0.018	0.0004	0.010	6.000	3.9E-07
3	Rockfall	Preparation of a ‘sound platform’ by personnel in earthmoving equipment / construction of the conveyor footing in the pit	Person in earth moving equipment (FOPS / ROPS) working on the quarry floor	1.000	0.0001	0.017	0.010	6.000	1.1E-07
4	Rockfalls from east and south walls	Construction of the reclaimer	Person working on quarry floor in vicinity of reclaimer location	0.040	0.013	0.017	0.500	-	4.3E-06
5A	Rockfall	Installation of telestackers	Person working on quarry floor near the south wall in vicinity of telestacker location	0.100	0.002	0.023	0.500	-	2.5E-06
5B	Rockfall		Person in FOPS / ROPS vehicle working on the quarry floor in vicinity of telestacker location	0.100	0.018	0.023	0.010	-	4.1E-07
								Estimated Risk of "Loss of Life" for an Individual	**5.3E-05**

Table E2: Risk to Life Calculations - Operation Phase (Local Failures - i.e. Rockfalls)

Activity Number	Hazard	Activity Description	Person at Risk	Annual Probability - $P_{(H)}$	Probability of Spatial Impact - $P_{(S:H)}$	Temporal Spatial Probability - $P_{(T:S)}$	Vulnerability - $V_{(D:T)}$	Occurrences per year	Annual Probability of loss of life (death) of an individual - $R_{(LoL)}$
6A	Rockfall	Travel along access road	Person in light vehicle driving on the access road near the batter along the north and west walls	0.500	0.009	0.005	0.200	-	5.0E-06
6B	Rockfall		Person in FOPS / ROPS vehicle driving on the access road near the batter along the south wall	1.000	0.018	0.003	0.010	6.000	3.0E-06
7	Rockfall	Repositioning and maintenance of telestackers	Person working on quarry floor in Person Access Zone	0.060	0.0001	0.042	0.500	-	1.3E-07
								Estimated Risk of "Loss of Life" for an Individual	**8.1E-06**

Appendix F – Total Risk to Life Calculations

Table F1: Total Estimated Risk of "Loss of Life" for an Individual - Construction Phase

Construction Phase	Annual Probability of loss of life (death) of an individual - $R_{(LoL)}$
Global Failures	4.0E-05
Local Failures (i.e. rockfalls)	5.3E-05
Total Estimated Risk of "Loss of Life" for an Individual	**9.3E-05**

Table F2: Total Estimated Risk of "Loss of Life" for an Individual - Operation Phase

Operation Phase	Annual Probability of loss of life (death) of an individual - $R_{(LoL)}$
Global Failures	2.8E-06
Local Failures (i.e. rockfalls)	8.1E-06
Total Estimated Risk of "Loss of Life" for an Individual	**1.1E-05**

Appendix G – Rockfall Modelling Parameters

RocFall Analysis Information

Project Settings

General Settings:

Engine	Rigid Body
Units	Metric (m, kg, kJ)
Rock Throw Mode	Number of rocks controlled by seeder

Engine Conditions:

Maximum time per rock	5s
Maximum steps per rock	10000
Normal velocity cutoff	0.1m/s
Stopped velocity cutoff	0.1m/s
Maximum timestep	0.01s

Random Number Generation:

Sampling Method	Monte-Carlo
Random Seed	Pseudo-random seed: 12345234

Material Properties

Bedrock

"Bedrock" Properties					
	Mean	**Distribution**	**Std.Dev.**	**Rel. Min**	**Rel. Max**
Normal Restitution	0.35	Normal	0.04	0.12	0.12
Tangential Restitution	0.85	Normal	0.04	0.12	0.12
Dynamic Friction	0.5	Normal	0.04	0.12	0.12
Rolling Resistance	0.4	Normal	0.02	0.06	0.06
Slope Roughness Spacing	1	Normal	0.2	0.6	0.6
Slope Roughness Amplitude	0	Normal	0.2	0.6	0.6

Rock Debris

"Rock Debris" Properties					
	Mean	**Distribution**	**Std.Dev.**	**Rel. Min**	**Rel. Max**
Normal Restitution	0.32	Normal	0.04	0.12	0.12
Tangential Restitution	0.8	Normal	0.04	0.12	0.12
Dynamic Friction	0.5	Normal	0.04	0.12	0.12
Rolling Resistance	0.55	Normal	0.04	0.12	0.12

Concrete

"Concrete" Properties					
	Mean	**Distribution**	**Std.Dev.**	**Rel. Min**	**Rel. Max**
Normal Restitution	0.48	Normal	0.04	0.12	0.12
Tangential Restitution	0.53	Normal	0.03	0.09	0.09
Dynamic Friction	0.5	Normal	0.04	0.12	0.12
Rolling Resistance	0.4	Normal	0.01	0.03	0.03

Fill

"Fill" Properties					
	Mean	**Distribution**	**Std.Dev.**	**Rel. Min**	**Rel. Max**
Normal Restitution	0.32	None			
Tangential Restitution	0.8	None			
Dynamic Friction	0.5	None			
Rolling Resistance	0.6	None			

Seeder Properties

Rocks to Throw	
Number of Rocks	1000 Overall
Rock Types	Rock

Initial Conditions					
	Mean	**Distribution**	**Std.Dev.**	**Rel. Min**	**Rel. Max**
Horizontal Velocity (m/s)	0	None			
Vertical Velocity (m/s)	0	None			
Rotational Velocity (°/s)	0	None			
Initial Rotation (°/s)	0	Uniform		0	360

Rock Types

Rock

Properties	
Name	Rock
Colour	
Shapes	Super Ellipse^6 (2:3)

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Mass (kg)	10.1	None			
Density (kg/m^3)	2700	None			

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