

APPENDIX 13

Geotechnical Stability Review 'Borrow Pit'

Our ref: 12614909

14 August 2024

Dr. Justin Meleo
Director – Planning & Development
Australian Resource Development Group
69 Ross Street
Belmont NSW 2280

Dear Dr. Justin,

**Re: Liverpool Range Quarry
Geotechnical Assessment Satellite Extraction Area 'Borrow Pit'**

1. Introduction

GHD has been requested by Dr.

Justin Meleo from ARDG Deans Quarry (ARDG) Pty Limited (the Client) to undertake a geotechnical stability assessment for the proposed development of Liverpool Range Quarry (the Quarry), located near Cassilis, New South Wales. It is understood that the Client is preparing an Environmental Impact Statement (EIS) to accompany a State Significant Development (SSD) application to the New South Wales Department of Planning, Housing and Industry (DPHI).

As detailed in GHD (2023) *Liverpool Range Quarry – Geotechnical Assessment Review 'Main Pit'*, (GHD Ref: 12614909-19500-1, Rev 1, dated 14 August 2024), The Client has identified an opportunity to establish a hard rock quarry, exclusively dedicated to producing and supplying essential quarry products required for construction of the Liverpool Range Wind Farm (LRWF) project.. These products, including roadbase, concrete aggregates, and drainage rock, are vital for the LRWF Project internal road network, hardstand areas, wind tower footings, and associated civil works.

The Quarry resource extraction plan includes a primary hard quarry pit (designated as the "Main Pit") and a satellite extraction area, known as the 'Borrow Pit'. The 'Borrow Pit' is located to the southeast of the 'Main Pit' and covers an area of approximately 1.84 ha (Figure 1). As indicated by ARDG, highly weathered rock and clay would be extracted from the 'Borrow Pit', prior to being transported to the main processing area for blending with rock from the Main Pit. From the latter, high quality basalt resource will be extracted.

This geotechnical letter report is primarily focused on the 'Borrow Pit'. A separate geotechnical report has been prepared by GHD (2024) for the 'Main Pit'.

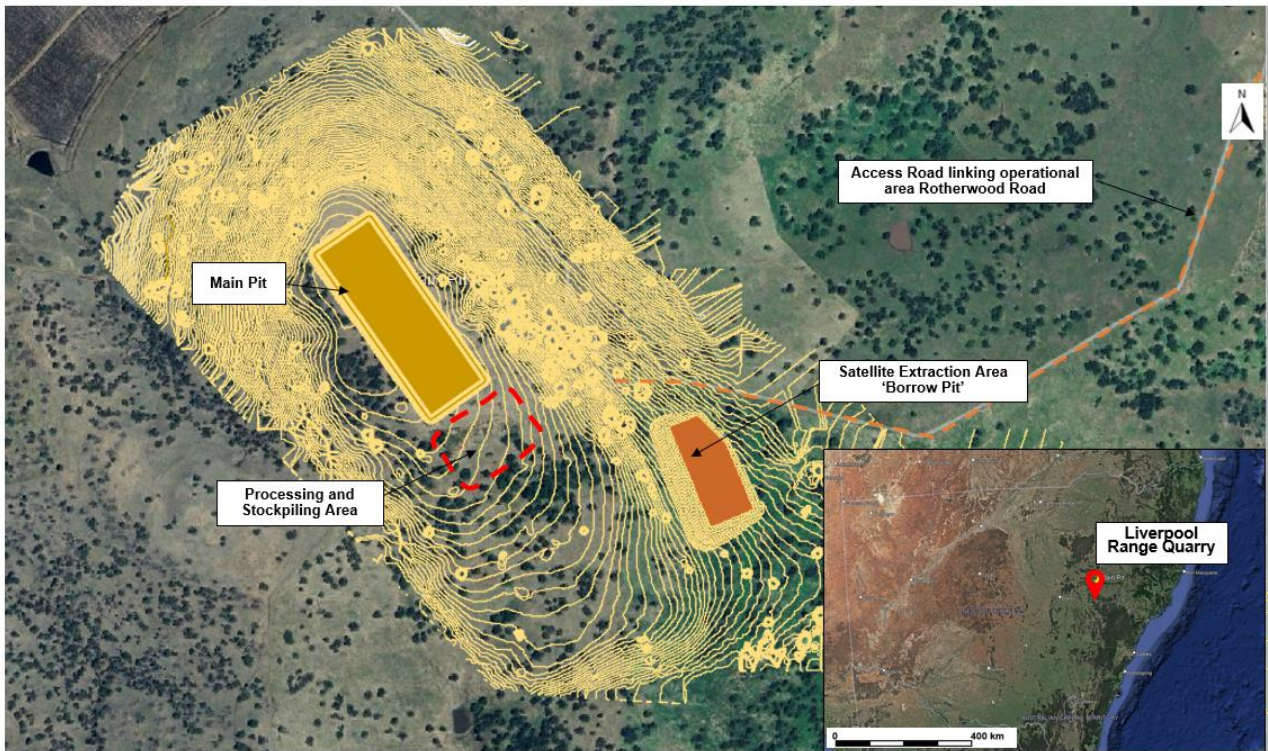


Figure 1 Plan View of the proposed Quarry depicting 'Main Pit' and Satellite extraction area

1.1 Purpose of the Letter Report

The purpose of this letter report is to:

- Assess the stability performance of excavated slopes within the satellite extraction area 'Borrow Pit' for the long term.

1.2 Limitations

This report has been prepared by GHD for the client and may only be used and relied on by The Client for the purpose agreed between GHD and The Client as set out in this report.

GHD otherwise disclaims responsibility to any person other than The Client arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect. GHD has prepared this report on the basis of information provided by The Client and Australian Resource Development Group Pty Limited and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information. Site conditions (including the presence of hazardous substances and/or site contamination) may change after the date of this Report. GHD does not accept responsibility arising from, or in connection with, any change to the site conditions. GHD is also not responsible for updating this report if the site conditions change.

1.3 Information Relied upon

GHD has relied upon the following sources of information for the current geotechnical assessment:

ARDG

- Photogrammetry (ARDG, 2023)
 - Aerial imagery of the site. File titled 'Deans Total Site_transparent_mosaic_group1.tif', received on 14 July 2023.
- Quarry Design (ARDG, 2023)
 - DQ Pit Shell Contours File titled 'DQ Pit Shell Contours MGA2020_exported.dxf', received on 14 July 2023.
 - DQ Mobile Plant. File titled 'DQ Mobile Plant MGA2020_exported.dxf', received on 14 July 2023.
 - DQ Mobile Process Configuration. File titled 'DQ Mobile Process Config MGA2020_exported.dxf', received on 14 July 2023.
- Drilling campaign (ARDG, 2023)
 - DQ collar File (22 drillholes have been completed, extending up to -35 m bgs). File titled 'DQ Collar File MGA2020_exported.dxf', received on 14 July 2023.
 - Core and Drill Chip Tray photographs. Files titled 'ARDG-DDH01_June 2023.pdf', 'ARDG-DDH03_June 2023.pdf' and 'ARDG-DDH05_June 2023.pdf' and 'Deans Quarry Chip Trays.pdf', received on 14 July 2023.
 - Geotechnical Laboratory Testing results. Folders titled 'Atterberg Testing' and 'Core Testing', received on 14 July 2023.
 - Petrographic report on four drill core samples from Dean's Quarry, file titled 'ARDG#8.petrog.doc', received on 14 July 2023.
- Quarry Project Description (ARDG, 2023), file titled 'Deans Quarry Project Description_27.07.23.docx', received on 28 July 2028.

GHD

- *GHD (2024) report titled Liverpool Range Quarry – Geotechnical Stability Review 'Main Pit', (GHD Ref: 12614909-19500-1, Rev 1, dated 14 August 2024).*

2. Quarry Setting

2.1 Inferred Stratigraphic Sequence

As explained in detail in Section 2.2.5 of GHD (2024) for the Main Pit, the stratigraphic sequence of the Quarry site typically includes the Liverpool West basalt, a subunit of the Liverpool Range Volcanic Complex. The dominant lithology in the quarry area is Basalt overlain by quaternary aged soil. A more detailed summary of the site’s geological conditions is presented in GHD (2024) ‘Main Pit’ report titled Liverpool Range Quarry – Geotechnical Stability Review ‘Main Pit’.

From the drilling campaigns conducted in the area of the proposed Quarry (refer to GHD (2024) Table 1 - Summary of Borehole Drilling Details) (Figure 2), basalt was encountered in all boreholes. The area in the vicinity of the proposed Quarry consists of two main stratigraphic units (youngest to oldest) as summarised in Table 1.

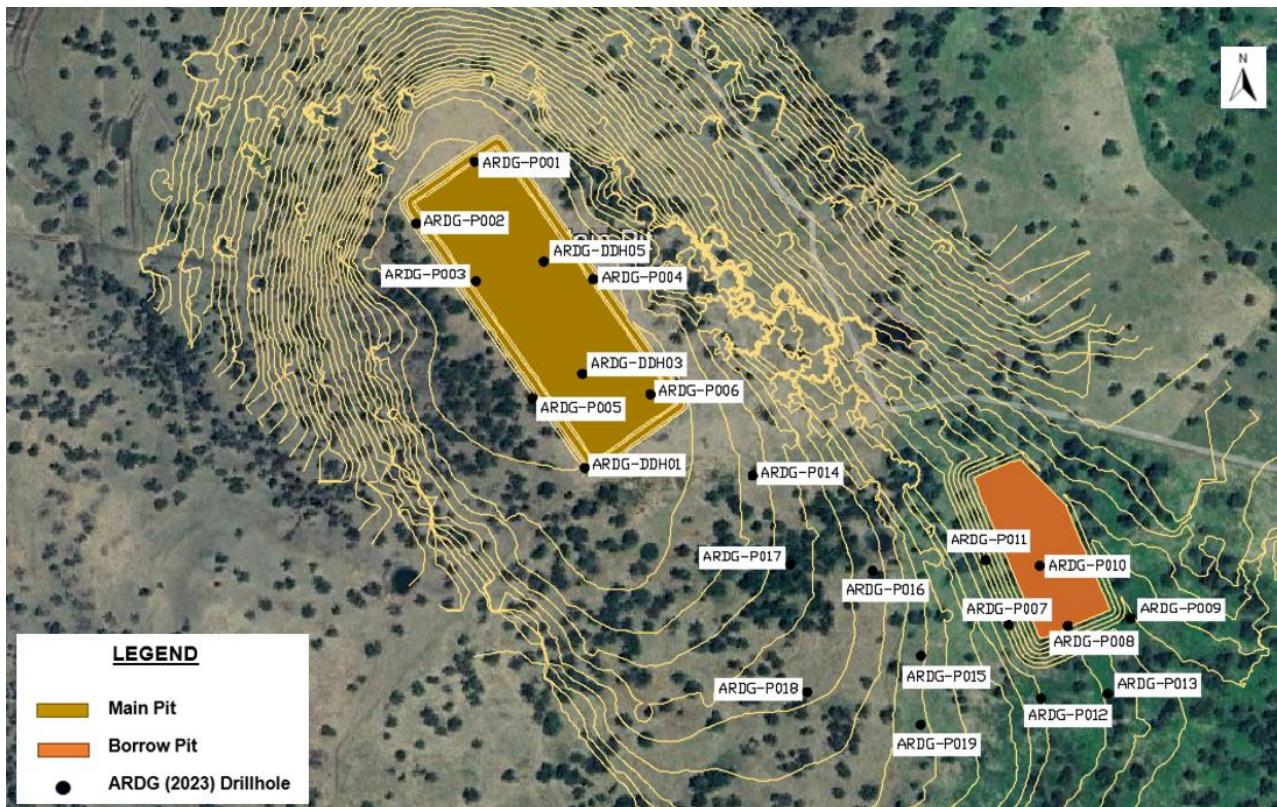


Figure 2 Location of Diamond Drill Hole Locations (ARDG, 2023)

Table 1 Stratigraphic Sequence at the Quarry Site

Geological Formation	Colour	Material Type	Lithology Code	Lithological Description
Undifferentiated	Light Yellow	Clay/Soil -	SL	Overburden / Residual Soil
Liverpool West Basalt	Yellow	Predominantly basalt and dolerite	BA	Characterised by two basalt flows separated by a thin zone of interflow oxidation. The upper flow comprises a microporphyritic olivine basalt of alkaline affinity. The lower flow comprises a more coarsely porphyritic rock best described as an alkali olivine dolerite.

Based on the interpretation of the drillholes within the footprint of the Satellite Extraction Area ‘Borrow Pit’, the upper portion of the area consists of topsoil of up to 1 m depth, followed by Highly Weathered Basalt (HW) interbedded with Clay, extending to approximately 20 m below the ground surface (at termination depth of exploration holes).

Three weathering grades were identified at the Satellite Extraction Area ‘Borrow Pit’ as follows:

- **Unit 1** – Topsoil material (Clay)
- **Unit 2** – Highly Weathered (HW) Basalt
- **Unit 3** – Interbedded Clay

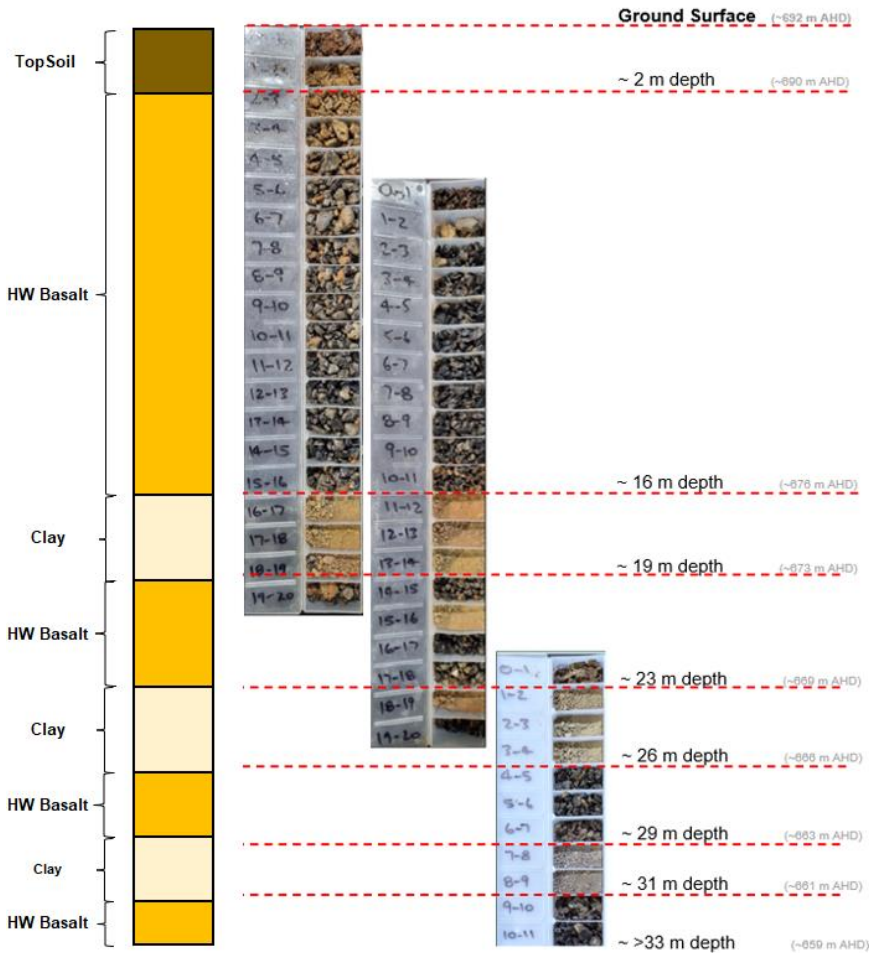


Figure 3 Schematic Depicting Typical Stratigraphic Sequence at the ‘Borrow pit’ of Liverpool Range Quarry Site

2.1.1 Laboratory Testing

Core samples obtained during the drilling campaign were specifically selected for subsequent laboratory testing to evaluate the basic physical properties of the cores. Tests undertaken on the samples, as listed in Table 2, include soil classification tests (i.e., moisture content, percentage of liquid limit, percentage of plastic limit, percentage of plasticity index).

To note, the below samples correspond specifically to two drillholes (i.e., ARDG-P007 and ARDG-P009) located within the footprint of the proposed ‘Borrow Pit’ (See Figure 2).

Table 2 Summary of Samples

Hole ID	ARDG-P007	ARDG-P009
Sample #	Sample location directional drillhole (m)	
NEWC23S-03959	1.0 - 3.0	-
NEWC23S-03960	3.0 - 5.0	-
NEWC23S-03961	5.0 - 7.0	-
NEWC23S-03962	7.0 - 9.0	-

Hole ID	ARDG-P007	ARDG-P009
NEWC23S-03963	9.0 - 11.0	-
NEWC23S-03964	11.0 - 13.0	-
NEWC23S-03965	13.0 - 15.0	-
NEWC23S-03966	-	1.0 - 3.0
NEWC23S-03967	-	3.0 - 5.0
NEWC23S-03968	-	5.0 - 7.0

2.2 Hydrogeology

As indicated in the GHD (2024) Report, based on the available groundwater data, there have been no significant fluctuations in the groundwater profile over time. The data suggest that the average groundwater level is at approximately 651 m AHD, which is approximately 25 m below the proposed floor level of the Main Pit (10 m below floor level of Borrow Pit). In addition, given the elevated nature of the site, being effectively surrounded by air, there is no significant area of recharge located at elevations above the extraction areas. Therefore, groundwater inflows into both the Main Pit and Borrow Pit are expected to be negligible.

2.3 Anticipated Pit Slope Instability Mechanisms

2.3.1 Rock Mass Instability

Rock mass stability is governed by the characteristics of both intact rock mass and structural discontinuities. Where kinematic mechanisms typically control the stability at the bench to inter-ramp scale, rock mass mechanisms control the stability at the inter-ramp and global scales. Assessment of the rock mass stability is an essential step in the design process, to check that the rock mass can sustain the proposed design over the full height of the slope. Rock mass models such as the Generalised Hoek Brown Criterion, assume that a rock mass is comprised of an isotropic clump of intact rock pieces separated by closely spaced joints for which there is no preferred failure direction. Rock mass that has a pervasive fabric e.g., bedding planes, the strength of the rock mass may be notably lower in the direction of the discontinuity system.

2.3.2 Circular/Rotational Instability

Circular/rotational instability typically occurs in highly disturbed and/or weathered material that typically does not have any remnant structure (see Figure 4).

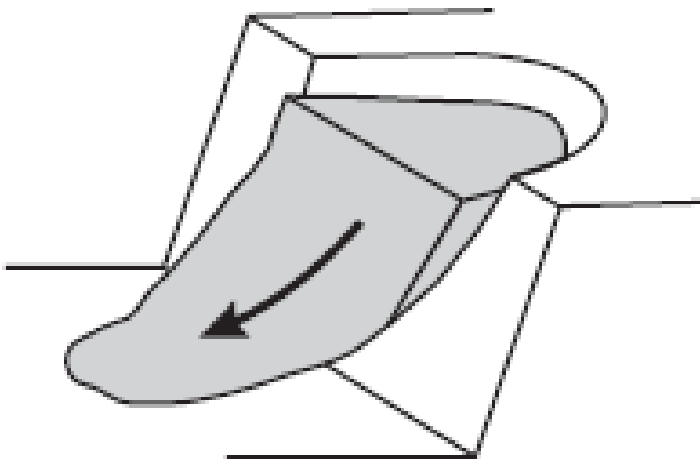


Figure 4 Schematic of a Circular Instability

Circular instability is dependent upon the shear strength characteristic of the highly weathered material and the slope angle of the cut face. Circular instability occurring as potential instability mechanism within the residual soil and soft rock units where there is no discernible structure present. Mobilisation of a circular failure is likely to be contained to bench scale instability.

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2.3.3 Structural Analyses

A fundamental component of the structural model and thus the geotechnical domain model is the orientation characteristics of critical defect structures relative to pit walls. It is important to mention that, at the time of this assessment, no information regarding defect mapping was accessible due to the absence of exposed walls or outcrops in the vicinity of the Quarry. However, given the general flat geometry of the 'Borrow Pit' slopes, structurally controlled instabilities are considered unlikely.

2.4 Interpretation of Material Strength Properties

As outlined in Section 2.1, three (3) weathering units were identified at the 'Borrow Pit' of the proposed Quarry. To adequately define the strength characteristics of each unit, a suitable strength criterion should be selected in sympathy to the rock mass characteristics (Hoek and Brown, 2019). Where there is discernible structure within a rock mass, adoption of the Mohr Coulomb criterion can result in an overestimation in the rock mass strength compared to if the Generalised Hoek Brown (GHB) criterion is adopted, particularly under low normal stresses (or confinement) (Hoek, 1994). Each strength criterion requires unique strength parameters to derive shear strength characteristic curves i.e., the relationship between normal stress and shear stress. Summarised in Table 3 is the strength criterion type along with the strength parameters required for each material type.

To note, Unit 1 (Topsoil) will not be considered in subsequent sections due to its limited thickness, as it will be excavated during the early stages as part of the landform preparation.

Table 3 Summary of Strength Criterion and Parameters by Material Type

Unit	Criterion	Required Strength Parameters
2	Generalised Hoek-Brown	Uniaxial Compressive Strength (σ_c), Geological Strength Index (GSI), Material Constant (m_i) and Disturbance Factor (D)
3	Mohr Coulomb	Cohesion (c') and Friction Angle (ϕ')

For each material type and associated strength criterion, strength parameters were obtained through available data. Each criterion and the material parameters adopted for downstream stability analyses are discussed further in the following subsections.

2.5 Material Parameters

The characteristics of the in-situ materials used to assess the stability performance have been adopted from the GHD (2024) report 'Liverpool Range Quarry – Geotechnical Stability Review -Main Pit' which were derived based on the weathering profile, lab testing and experience with similar material. The material characteristics for the in-situ lithological units are summarised in Table 4 and Table 5:

Table 4 Summary of GHB Shear Strength Parameters

Unit	Material	GSI	σ_{ci}	m_i	D
2	HW	23	5	20	0.7

Table 5 Summary of Mohr Coulomb Parameters

Unit	Description	Cohesion – c' (kPa)	Friction Angle - ϕ' (°)
3	Clay	10	28

3. Stability Analyses

3.1 Methodology

The slope stability performance at the proposed local and overall slope scales was assessed under 'expected' conditions using RocScience's Slide2 (version 9.017) Limit Equilibrium (LE) modelling software package. A Factor of Safety (FoS) was calculated and assessed against the design acceptance criteria for a typical stability section nominated for this assessment.

Slope stability analyses were undertaken for the Quarry 'Borrow Pit' site with material profiles derived from drillhole logs, as outlined in GHD (2024) for the Main Pit. Slope stability performance was measured against nominated design acceptance criteria in line with state government guidelines.

Sensitivity analyses were undertaken on slope profiles to assess the potential instability implications associated with:

- Seismic loading events
- Elevated phreatic conditions

Further discussion on each of the above sensitivities is provided in Section 3.4.

3.2 Design Acceptance Criteria

Prior to undertaking stability analyses, the design acceptance criteria (DAC) are nominated which defines the minimum requirements and limits for 'acceptable' risk and consequence levels with respect to the Factor of Safety (FoS). The DAC provides a metric for which stability performance can be assessed, and it should be noted that any slope design for open cut extraction necessitates finding a compromise between the risks associated with slope failure and the economics of mining.

The Design Acceptance Criteria for the proposed 'Borrow Pit' at the Quarry has been nominated in line with accepted industry practice as outlined in 'Table 5' of the NSW Resource Regulator's 'Guide – Health and Safety at Quarries' (2018). For the purpose of this assessment, a design FoS associated to:

- Wall Class 1 (i.e., moderately serious consequence of failure) was adopted for the stability performance analyses at the individual bench scale.

Table 6 Design Acceptance Criteria (extracted from NSW Resource Regulator, 2018)

Wall Class	Consequence of Failure	Design FoS	Design PoF	Examples
1	Moderately serious	1.2	10%	Highwalls not carrying major infrastructure
2	Serious	1.5	1%	Highwalls carrying major infrastructure (e.g., treatment plant, ROM pad, tailings structures, crushing structures)
3	Serious*	2.0	0.3%	Permanent highwalls near public infrastructure and adjoining leases

*Where a mutually acceptable agreement to allow excavation cannot be made between the quarry or mine owner and the "owner" of the adjoining structure or plot of land. Note a higher standard of geotechnical data is required for the design of wall class 3 slopes compared to wall classes 1 and 2 slopes.

3.3 Proposed Pit Design

The proposed pit geometry for the satellite extraction area 'Borrow Pit' was provided by ARDG and incorporates the following bench configurations:

- Maximum slope height of approximately 15 m (660 m AHD).
- Slope angles of 1V:2H, with no intermediate benches.

To note:

- The 'Main Pit' is located at the crest of a hill with the pit floor at approximately at 676 m AHD and the topography slopes downward from this point in all directions. The 'Borrow Pit' is located to the southeast of the pit and in the hill, with the pit floor at approximately 660 m AHD. Noting the sloping topography, the borrow pit slope is at its highest on the western side of the pit (~15 meters in height), while the pit walls on the northern, eastern, and southern sides are a maximum height of 8 meters, 5 meters, and 13 meters, respectively.
- As indicated in section 2.2, groundwater has been interpreted to occur at a level of approximately 651 m AHD.

The nominated stability section for analysis for the satellite extraction area 'Borrow Pit' corresponds to the highest slope at the western wall of the pit (Figure 5.)



Figure 5 Plan View of Proposed 'Borrow Pit' at Liverpool Range Quarry Depicting Nominated Stability Section

The construction of a stability model incorporates and combines the elements of the subsurface geology, hydrogeology, material properties and slope design geometry as defined by the geotechnical model. Example of the cross-section A-A' depicting a constructed stability model utilised in the assessment of slope stability is presented in Figure 6

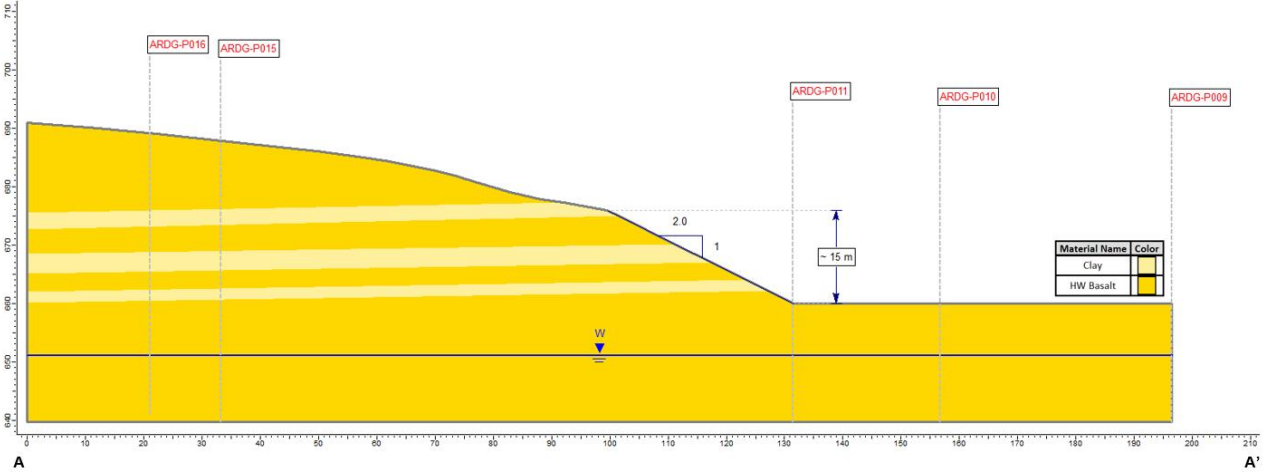


Figure 6 Geometry of Satellite Extraction Area ‘Borrow Pit’ at the Quarry

3.4 Global Slope Stability Analysis Results

Slope stability analyses has been performed under ‘expected’ conditions. The stability performance of slopes at the individual and overall slope scale were assessed and compared against the nominated Design Acceptance Criteria (DAC). The following colour coding has been adopted to denote conformance to the DAC.

- **Green** – The calculated stability performance satisfies the “Wall Class 1” DAC (FoS > 1.2, PoF < 10%).
- **Red** – The calculated stability performance does not satisfy the “Wall Class 1” criteria.

The results of the stability analysis on slopes along Section A – A’ is summarised in Table 7 and the corresponding stability model outputs are presented in Figure 7.

Table 7 Summary of Stability Analyses Results – Critical cross sections at the ‘Borrow Pit’ at the Quarry

Stability Section	DAC	Scale of Instability	Calculated FoS
Section A - A’	FoS > 1.2	Overall slope	1.96

The results of the stability analyses undertaken under ‘expected’ conditions indicate that:

- The stability performance at the overall slopes scale satisfies the nominated design acceptance criteria for the assessed critical stability section A – A’.

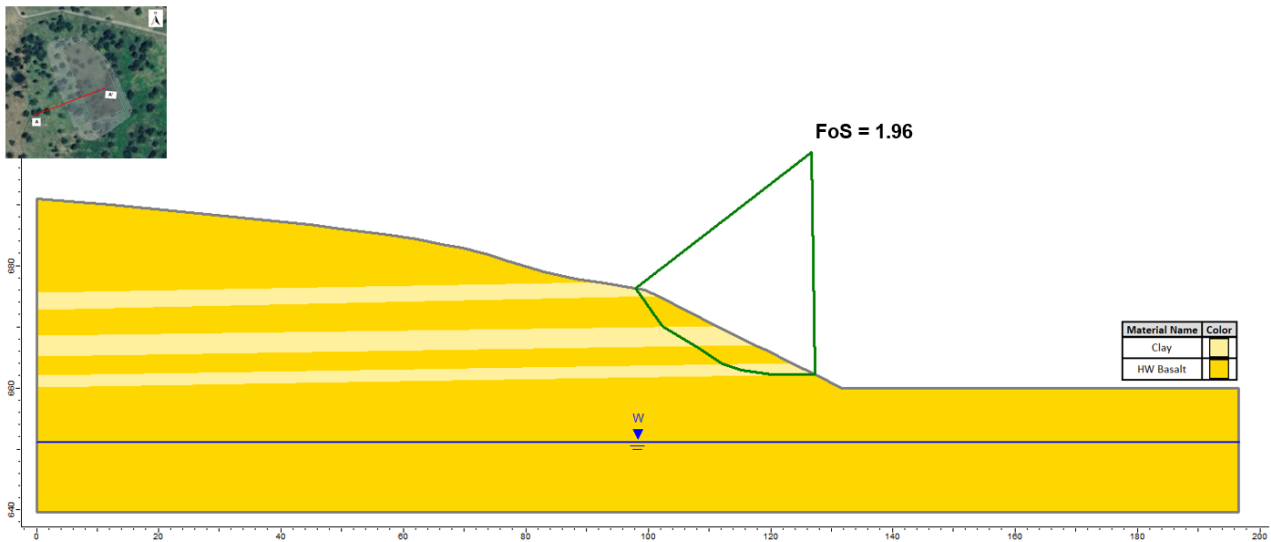


Figure 7 Base Case Scenario – Borrow Pit at the Quarry– Section A – A' - Global Stability

3.4.1 Sensitivity Analyses

Sensitivity analyses have been undertaken to assess the potential stability implications associated with seismic loading events and elevated groundwater conditions.

3.4.1.1 Seismic Loading

Sensitivity analysis has been undertaken to assess the potential stability implications associated with seismic loading events on the slope stability performance. A 1:500-year return event or 'expected' seismic loading event was considered.

A pseudo-static seismic analysis approach was adopted following the methodology outlined by Hynes-Griffin and Franklin (1984), referred to as the USACE method, which assumes:

- Earthquakes can be modelled as a static force acting on the mass of potential slide
- No dynamic pore water pressures are generated
- Materials show no significant loss of strength as a result of cyclic loading

When undertaking a pseudo-static seismic analyses, Hynes-Griffin and Franklin (1984) recommend using a seismic coefficient equal to half of the Peak Ground Acceleration (PGA). PGA values for a 1:500-year event was obtained from the National Seismic Hazard Assessment (NSHA, 2018) maps. An example of the NSHA (2018) seismic hazard atlas map is depicted in Figure 8 for a 1:500-year return event.

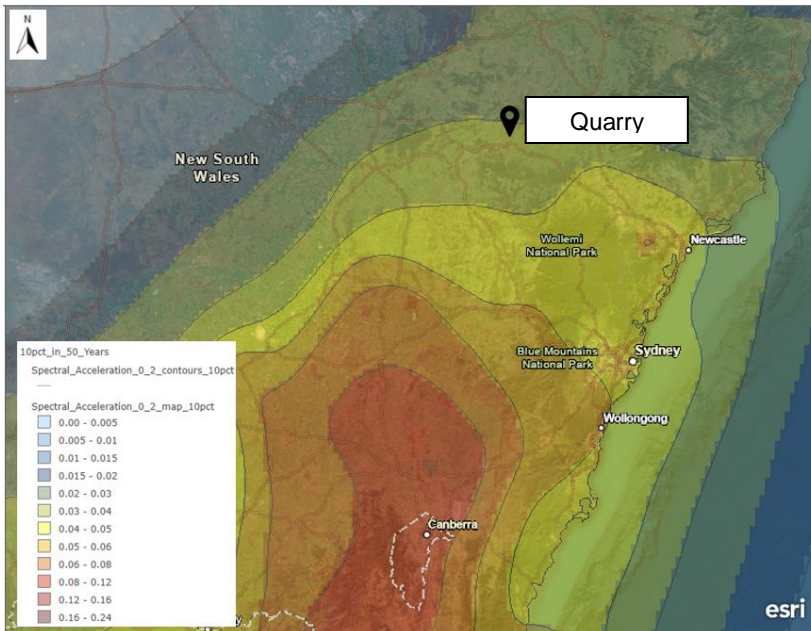


Figure 8 Seismic Hazard Atlas Map (1:500-year) proposed Quarry, after NSHA (2018)

Summarised in Table 8 are the PGA and seismic coefficient values adopted for this sensitivity analysis only.

Table 8 Summary of Seismic Input Parameters

Return Interval	Peak Ground Acceleration (g) - PGA	Seismic Coefficient - H_z
1:500	0.04	0.02

The results of the seismic sensitivity analyses are summarised in Table 9 below and the corresponding stability model outputs are presented in Figure 9.

Table 9 Summary of Sensitivity Analyses Results – Seismic Loading

Stability Section	Return Event Period	DAC	Calculated FoS
Section A – A'	1:500	FoS > 1.1	1.87

The results of the seismic loading sensitivity analysis indicate that:

- When compared to the ‘expected’ conditions, a slight decrease in the slope stability performance was calculated along Section A-A’. However, the stability performance was calculated to satisfy the design performance objectives (i.e., FoS > 1.1).

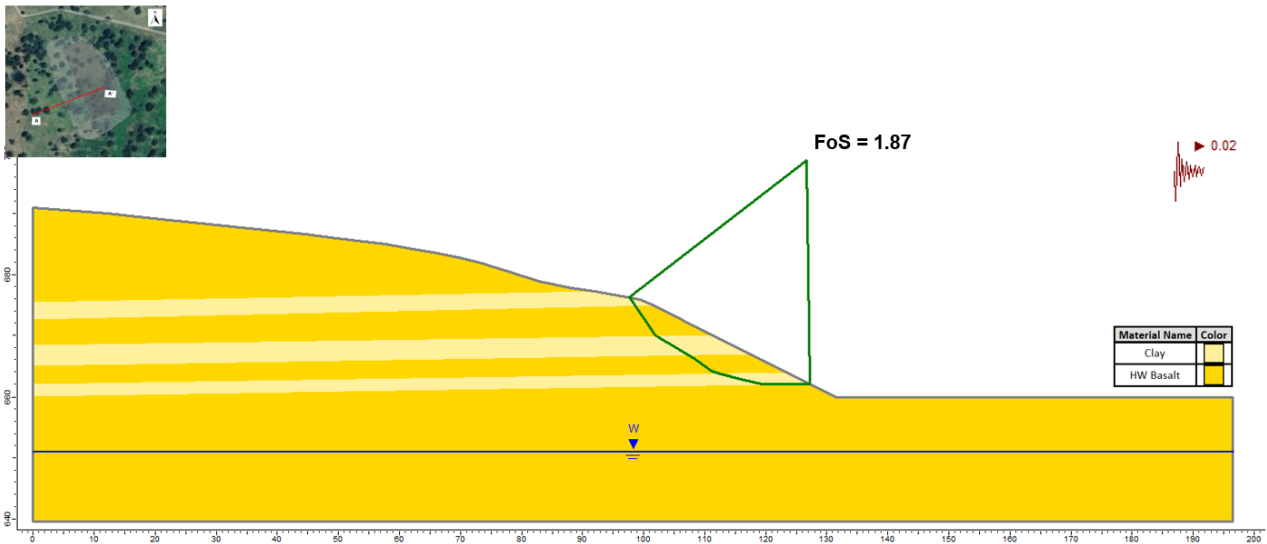


Figure 9 Sensitivity Model Output – Seismic Loading (1:500-year) – Section A – A'

3.4.2 Elevated Phreatic Conditions

Sensitivity analysis has been performed to assess the potential stability implications associated with elevated phreatic conditions, where a fully saturated 'worst case' scenario was adopted. A fully saturated scenario may reflect potential deficiencies in surface water management protocols during intense and/or prolonged rainfall events.

The results of the elevated phreatic conditions sensitivity analysis are summarised in Table 10 and the corresponding stability model outputs are presented in Figure 10.

Table 10 Summary of Sensitivity Analyses Results – Elevated Phreatic Conditions

Stability Section	Scale of Instability	Calculated FoS
Section A – A'	Overall slope	1.12

The results of the elevated phreatic condition sensitivity analysis indicates that:

- A reduction in the slope stability performance was calculated under 'worst case' fully saturated conditions compared to 'expected' conditions for the nominated critical section, however, the stability performance was calculated to be above unity (FoS > 1).
 - The results of the elevated phreatic condition sensitivity analyses highlight the importance of implementing and maintaining adequate surface water management protocols which are integrated into the final landform design.

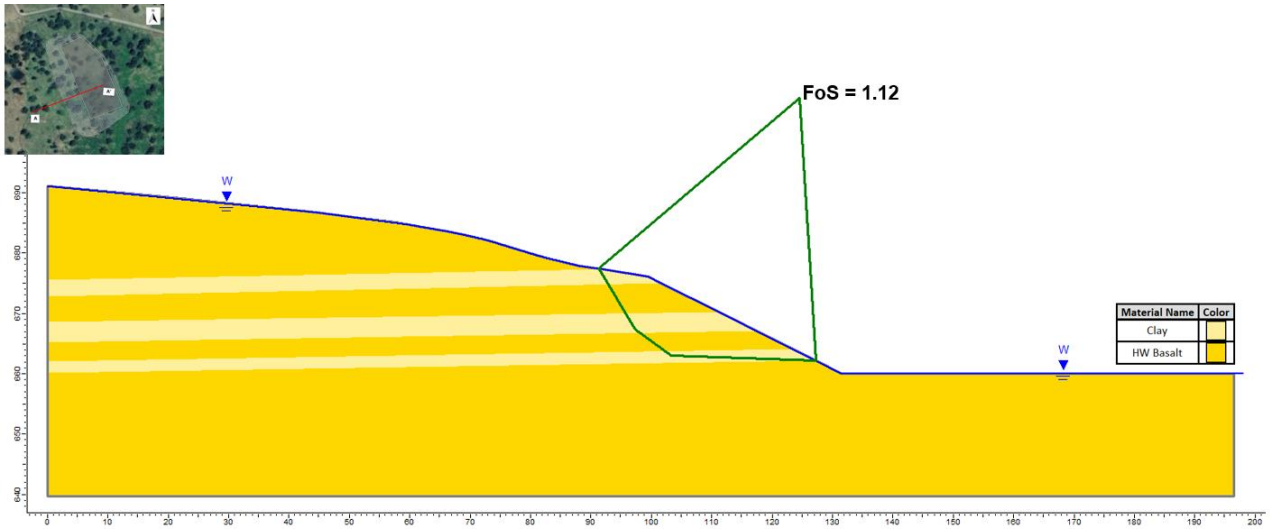


Figure 10 Sensitivity Model Output - Elevated Phreatic Conditions – Section A – A'

4. Erosion Assessment

The Revised Universal Soil Loss Equation (RUSLE) equation is a tool used to estimate the potential soil loss due to direct rainfall on an exposed slope and can provide an indication of the general erosion risk of the surface. It is also useful for quantifying the impact of various factors that contribute to erosion when designing batters, under long term conditions. In addition to the above, the area of disturbed land as a result of quarrying activities has been considered.

It is important to note that RUSLE only accounts for soil loss due to direct rainfall on the slope, not concentrated flow from any catchments flowing onto the slope.

4.1.1 Scenarios analysed

The erosion potential of the final landform slopes at the Borrow Pit of the Quarry site has considered the following scenario.

- Erosion of susceptible materials of exposed batter ‘diggable’ units (Unit 2 and 3), that corresponds to a maximum slope height of 15m to the western wall of the Borrow pit.

4.2 Nominated Erosion Potential Criteria

Two conventionally applied erodibility potential criteria have been adopted for this assessment. These design acceptance criteria, as suggested by the Commonwealth of Australia (2016) and by Morse and Rosewell (1996) and Landcom (2004) were adopted to assess the potential volume of soil loss at a site against tolerance levels. In the following subsections, each criterion is discussed in further detail.

Criterion 1

Based on the Erosion Hazard Guidelines (after Morse and Rosewell (1996) and Landcom (2004)), which are summarised in Table 11.

Table 11 Soil Loss Classes after Morse and Rosewell (1996) and Landcom (2004)

Soil loss class	Calculated soil loss (t/ha/yr)	Erosion hazard
1	0 to 150	Very Low
2	151 to 225	Low
3	226 to 350	Low-moderate
4	351 to 500	Moderate
5	501 to 750	High
6	751 to 1500	Very High
7	> 1500	Extremely High

Criterion 2

Criterion 2 is based on the tolerable soil loss tolerances which are cited in ‘Mine Rehabilitation, Leading Practice Sustainable Development Program for the Mining Industry’ (Commonwealth of Australia, 2016). This design acceptance criteria indicates that the soil loss should not exceed 4.5 tonnes per hectare per year (i.e., 4.5 t/ha/yr).

4.3 Potential Erodibility of Terminal Slopes

The RUSLE equation calculates an annual erosion rate based on the multiplication of five factors, and is expressed as:

$$A = R \cdot K \cdot LS \cdot C \cdot P$$

Where:

A = Estimated average soil loss in tonnes per acre per year

R = Rainfall erosivity factor

K = Soil erodibility factor

LS = Topographic factor that accounts for slope length and slope gradient

C = Erosion practice control

P = Ground cover factor

The above RUSLE factors are outlined in further detail in the following subsections.

4.3.1 Rainfall erosivity factor 'R'

This factor is determined by the intensity of rainfall in the area and is therefore not a design parameter. Using the aforementioned principal, empirical relationships have been established to correlate mean annual precipitation with the Rainfall Erosivity Factor (R). Yu and Roswell (1996) established a relationship to estimate the R-factor based on studies conducted in south-eastern Australia. The relationship had a very good correlation with $R^2 = 0.91$. The R-Factor and mean annual relationship is expressed as:

$$R = 0.0438 \cdot P^{1.61}$$

Where: P = Mean annual precipitation (mm)

Mean annual precipitation for the proposed Quarry site were obtained from the Bureau of Meteorology (2023) for the nearby weather station located approximately Dalkeith in Cassilis (station number 062009). The mean annual precipitation for the area is 628.7 mm, calculated using approximately 141 years of rainfall data. The calculated R-factor is equal to 1402.71.

4.3.2 Soil erodibility factor (K)

The soil erodibility factor (K) accounts for the erodibility of the soil based on its composition (e.g., clay). Nomograph equations (and visual representations) are frequently relied upon for deriving suitable K-factors, which is a simple method that makes use of basic soil properties (e.g., particle size distributions). According to the CSIRO publication after Yang et al. (2017) most of the models used to determine K-factors (e.g., Wischmeier *et al.*, 1971) have been developed for American soils and may not be representative of Australian soils. According to Yang et al. (2017) the nomograph developed by Rosewell (1993) referred to as 'K_SOILOSS' yielded comparative results to field measurements and is a preferred method for deriving a suitable K-factor for Australian soils, which contain less than 68% silt content).

The K_SOILOSS nomograph equation is expressed as:

$$K_{\text{SOILOSS}} = (2.77 \cdot M^{1.14} \cdot 10^{-7} \cdot (12 - \text{OM})) + (4.28 \cdot 10^{-3} \cdot (\text{SS} - 2)) + ((3.29 \cdot 10^{-3} \cdot (\text{PP} - 3))$$

Where:

M = Particle Size Parameter = (%Silt + %Very Fine Sand) x (100 – %Clay)

OM = Organic Matter (%)

SS = Soil Structure (ranging from; 1-very fine granular; 2-fine granular; 3-medium to coarse grained; and 4-blocky, platy or massive.

PP = Soil Permeability (ranging from; 1-rapid; 2- moderate to rapid; 3-moderate; 4-slow to moderate; 5-slow; and 6-very slow).

Available soil data required for the input into the above nomograph equation was obtained from the publicly available Soil and Landscape Grid of Australia (SGLA, 2017) database. This data access platform enables the user to query soil data based on the site location with a 95% confidence interval and provides the necessary information to estimate a K-factor. Summarised in Table 12 are the adopted overburden soil index parameters obtained from SGLA (2017) utilised to calculate the particle size parameter ‘M’.

Table 12 Summary of Soil Properties (after SGLA, 2017)

%Sand (0.05-0.1 mm)	%Silt (0.002-0.05 mm)	%Clay (< 0.002 mm)	M – Particle size Parameter
0	30	70	900

Summarised in Table 13 are the parameters obtained from SGLA (2017) used to calculate the K-Factor for the Quarry – ‘Borrow Pit’ site.

Table 13 Summary of K-Factor Parameters after Rosewell (1933)

M	% Organic matter (OM)	Soil structure (SS)	Permeability (PP)	K-factor (Rosewell, 1993)
900	0.5	2 Fine Granular	5 Slow	0.014

Based on the above, a K-factor of 0.014 has been adopted for this assessment.

4.3.3 Topographic Factor (LS)

The topographic factor (LS) accounts for a slopes height (L) and gradient (S) and is used to represent the effect of topography on erosion rates. The equations for calculating the LS in RUSLE are:

$$LS = L \cdot S$$

$$L = \left(\frac{\lambda}{22.13} \right)^m$$

$$m = \frac{\beta}{(1 + \beta)}$$

$$\beta = \frac{\sin(\theta)}{[3 \cdot \sin(\theta)^{0.8} + 0.56]}$$

$$S = 16.8 \cdot \sin(\theta) - 0.5; \quad \theta \geq 9\%$$

Where:

λ = Slope length (m)

m = Variable length-slope component

β = Variable slope gradient component

θ = Slope angle

The calculated topographic factors for the excavated slopes and overburden emplacement areas are summarised in Table 14.

Table 14 Summary of Topographic Factor Parameters

Geometry	Slope angle (°) - θ	Maximum slope height (m) - L	Topographic factor - LS
Maximum excavated slope 'Borrow Pit'	~26.6	15	8.51

It should be noted that for this assessment, the rock slope is considered to be a continuous slope and does not consider the potential slope flattening associated with intermediated benches.

4.3.4 Erosion control factor (C)

The erosion control factor (C) is used to measure the effect of vegetation and management practices on erosion rates. This includes the effects of vegetation, soil cover, soil biomass and soil disturbing activities. Typical cover factors are presented in Table 15.

Table 15 Summary of Typical C-factors

Treatment	Time after application (months)	Assumed grass coverage (%)	C-factor after Landcom (2004)	C-factor after Sprague, (1999)
Untreated	Undefined	0	1.0	1.0
Topsoiled and vegetated	0	0	1.0	0.7
	1 – 3	15	0.55	0.1
	3 – 6	30	0.32	
	6 - 12	45	0.18	0.05
	12 – 18	60	0.1	0.01
	18 – 24	75	0.05	0.01
	> 24	80	0.03	0.01

It is anticipated that rehabilitation of excavated batters and the rock slope will include the application of topsoil and perennial grasses. Accordingly, a temporal overlay to soil erosion has been added, which reflects a reduction in the erosion potential commensurate with increased grass coverage. It should be noted that the correlated C-factors presents a conservative approach to reducing soil erosion over time, (i.e., C-factor reductions may be quicker than those tabulated). It is also assumed that the ongoing and active maintenance is employed until grass covers reach the desired level and have become 'fully' established (i.e., can maintain grass coverage without active maintenance).

4.3.5 Ground Cover Factor (P)

The erosion control practice factor (P) measures the effect of practices that reduce flow velocity and tendency for water to flow directly downhill (e.g., track-walking or punching straw into the ground). Table 16 presents a summary of typical erosion control practices and the respective P-factor.

Table 16 Ground Cover Factor Scenarios

Surface condition	Erosion control practice factor, P
Compacted and Smooth	1.3
Track-walked along contour	1.2
Track-walked up and down the slope	0.9
Punched Straw	0.9
Sacrificial Layer (Loose to 0.3 m in depth)	0.8

Typical ‘C’ and ‘P’ factors presented in Table 15 and Table 16 have been adopted from various sources, including Meyer and Ports (1976), Israelson *et al.* (1980), Goldman *et al.* (1980), URS Greiner Woodward Clyde (1999), the North American Green website (2020) and Sprague (1999).

4.4 Results and discussion

The results of the erodibility potential analyses are based on the assumptions outlined above for the respective input factors. The results are summarised in Table 17 and presented graphically in Figure 11.

Table 17 Summary of Erosion Potential Analyses Results

Geometry	At approximately 30 Months	
	Soil Loss Rate (t/ha/yr.)	Erosion Hazard
Rehabilitated slope (treated)	2.37	Very Low
Untreated 26.6 °slope	118.5	Very Low

The results of the analyses indicate that:

- The erosion potential of the excavated batters is considered ‘Very Low’ (0– <150 t/ha/yr- Criterion 1) and satisfies the Commonwealth (2016) guidelines (Criterion 2) after ~30 months of perennial grass coverage.
- The susceptibility to erosion within these units is largely controlled by the topographic factor and ability to apply cover. Erosion in these areas is expected to be ongoing which is likely to result in some minor sloughing of the excavated face. It is anticipated that in the long-term, erosion of these faces would not pose a significant geotechnical risk.

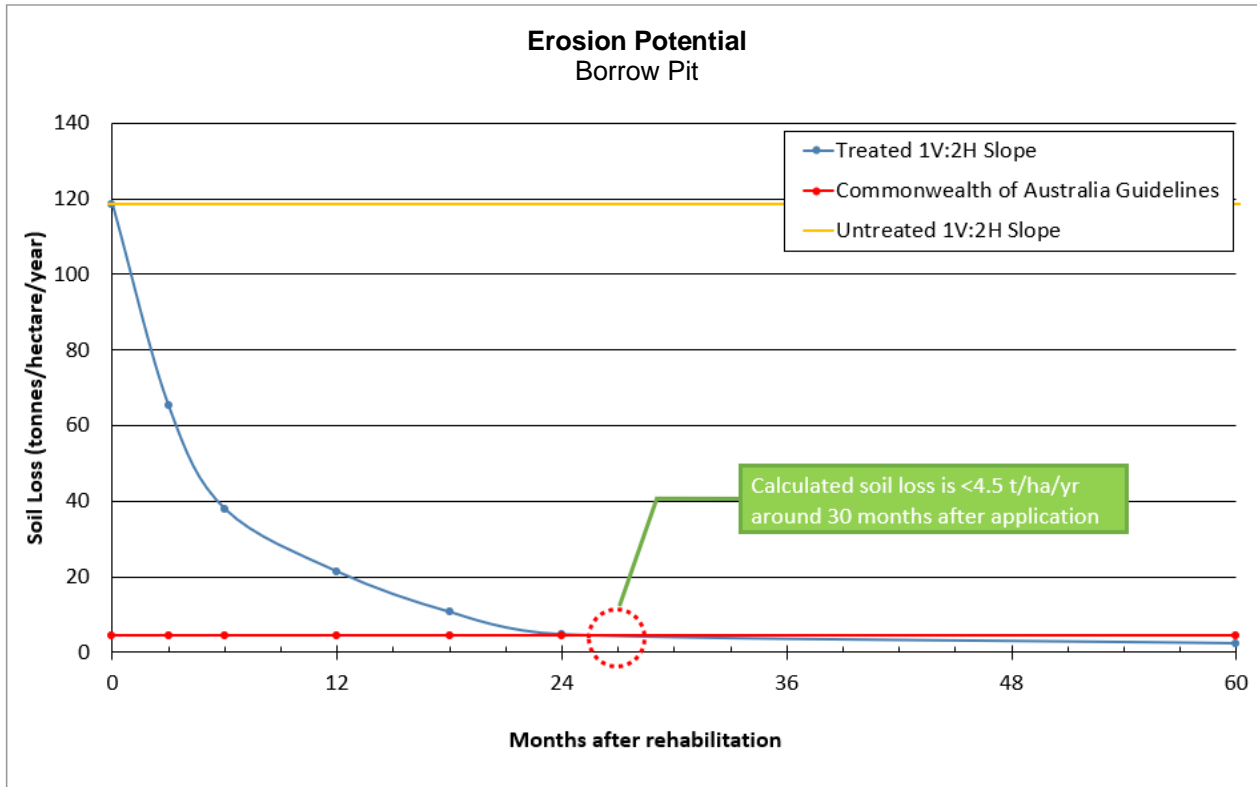


Figure 11 Calculated Rate of Soil Loss –highest excavated slope at Borrow Pit of the Quarry

5. Conclusions

The results of the stability analyses indicate that:

5.1 Slope Stability Analyses

Overall Slope Stability

- Under 'expected' conditions, the proposed slope design geometry (i.e., slope of up to 15 m height with slope angle of 1V:2H and no intermediate benches) achieve the nominated Design Acceptance Criteria for 'Wall Class 1' slopes.

Seismic Loading

- Under a 1:500 year seismic loading event, the stability performance was calculated to satisfy the design performance objectives.

Elevated Phreatic Conditions

- A reduction in the slope stability performance was calculated under 'worst case' fully saturated conditions compared to 'expected' conditions.
 - At the overall slope scale the stability performance was calculated to be above unity (FoS > 1) for all stability sections.
 - The results of the elevated phreatic condition sensitivity analyses highlight the importance of implementing and maintaining adequate surface and groundwater management protocols which are intergrated into the final landform design.

5.2 Potential Erodibility of Terminal Slopes

- The erosion potential of the highest slope of the 'Borrow Pit' (i.e., west wall) is considered 'Very Low' (< 150 t/ha/yr) and satisfies the Commonwealth (2016) guidelines after ~30 months of perennial grass coverage.
- The susceptibility to erosion within these units is largely controlled by the topographic factor and ability to apply cover. Erosion in these areas is expected to be ongoing which is likely to result in some minor sloughing of the excavated face. It is anticipated that in the long-term, erosion of these faces would not pose a significant geotechnical risk.

6. Recommendations

As part of subsequent stages of design, the following broad scope elements are recommended:

- When quarrying commences, regular site inspections should be undertaken to observe for signs of adverse geotechnical conditions. Furthermore, where site conditions are observed to deviate from those outlined in this report, additional intrusive investigation and / or defect mapping (defect type and orientation, alteration and potential fracture or fault zones) should be undertaken.
 - This may include core sampling of key stratigraphic units, and laboratory testing to confirm the geomechanical properties and strength parameters of the material.
- Where deemed required (i.e., notable deviation in site conditions compared to those outlined in this report) a full suite of stability analyses with the benefit of additional data obtained from the intrusive investigation and hydrological studies should be undertaken.

7. References

GHD

- GHD (2024) report titled *Liverpool Range Quarry – Geotechnical Stability Review ‘Main Pit’*, (GHD Ref: 12614909-19500-1, dated 14 August 2024).

Legislation and Guidance Documents

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Commonwealth of Australia (2016), *‘Mine Rehabilitation, Leading Practice Sustainable Development Program for the Mining Industry*, Commonwealth of Australia 2016

NSW Resources Regulator. Guide – Health and Safety at Quarries. November 2018.

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Online Databases

Commonwealth of Australia (2020). Climate Data Online, Bureau of Meteorology, URL: <http://www.bom.gov.au/climate/data/index.shtml>, accessed in August 2023

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Relevant Site Documentation/Studies

Information provided by the Client Included:

- Photogrammetry (ARDG, 2023)
 - Aerial imagery of the site
- Quarry Design (ARDG, 2023)
 - DQ Pit Shell Contours
 - DQ Mobile Plant
 - DQ Mobile Process Configuration
- Drilling campaign (ARDG, 2023)
 - DQ collar File (22 drillholes have been completed, extending up to -35 m bgs)
 - Core and Drill Chip Tray photographs.
 - Geotechnical Laboratory Testing results
 - Petrographic report on four drill core samples from Dean’s Quarry.
- Quarry Project Description (ARDG, 2023)

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We trust this meets your current requirements. Should you have any queries regarding this assessment, please contact the undersigned.

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