EVO010007

# Mt Rawdon Mine Progressive Rehabilitation Closure Plan (PRCP) Geotechnical Assessments – Open Pit

Report No.: Rev 1_Final
11 November 2022

# EVOLUTION MINING AUSTRALIA

MT RAWDON MINE PROGRESSIVE REHABILITATION CLOSURE PLAN (PRCP) GEOTECHNICAL ASSESSMENTS – OPEN PIT

Cartledge Mining and Geotechnics

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| | | | | | | |

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# 1 Introduction

Cartledge Mining and Geotechnics (CM&G) undertook geotechnical assessments of the Mt Rawdon Mine Operations (MRO) Open Pit, North Waste Rock Dump (NWRDP), and the MRO Tailings Storage Facility (TSF) as part of the Progressive Rehabilitation and Closure Plan (PRCP) Guideline which is a critical component of the rehabilitation policy under Queensland Government's Mine Land Rehabilitation Policy (DES, 2021).

The geotechnical assessments followed individual studies for all the infrastructures that were analysed. Geotechnical stability was assessed for post-closure and long-term stability as indicated by the landform modelling results. For the open pit, the geotechnical stability considered the effects of long-term erosion and weathering of the pit wall and the effects of significant hydrological events as outlined in the *Mount Rawdon Final Voids Study Report (SLR Ref: 620.30185-R01 Version No: v2.0 December 2020)*

According to the PRCP Guidelines, the "geotechnical report should focus on how the void will achieve post-closure slopes that will exhibit stability characteristics consistent with the planning and design of the post-closure mine void". The requirement of the Guidelines has been undertaken in this report in the analysis of the provided post-closure final void slopes.

## 1.1 Scope of work

The scope of work was split into two main categories following a meeting held between MRO Site representatives and CM&G Principal Engineer. The two main categories to be addressed in the scope were:

- Addressing the PRCP Guideline requirements and the DES feedback.
- Review and incorporate results from other relevant work being completed by other consulting parties, i.e., TSF LOM and hydraulic studies, waste dump capping design and erosion modelling.

From these two main categories, the detailed scope of work is outlined below:

1. Address the PRCP Guideline requirements and feedback from the Department of Environment & Science, which requires the following to be captured within a high-level geotechnical report:
    - *Geotechnical modelling predicting long-term stability (factor of safety etc.) of TSF and NWRD*
    - *Information about the void (pit) wall geotechnical stability and a 3D void design and consideration of the effects of long-term erosion and weathering of the pit wall and the effects of significant hydrological events (where possible/practicable/relevant)*
    - *The description of how the void will achieve post-closure slopes that will exhibit stability characteristics consistent with the planning and design of the post-closure mine void. Mechanisms for achieving acceptable geotechnical stability must be detailed in the plan. This includes any void filling, partial void filling, reshaping and void configuration through earthwork methods such as backfilling, regrading, buttressing, and benching. Where applicable, methods and techniques for achieving safe slopes must be detailed.*
2. As discussed, work completed by others that may or may not be relevant to this study includes:
    - *Mt Rawdon Post-Closure Groundwater Model - SLR*

# 2 Background

The MRO Site is located approximately 100km inland from Bundaberg in southeast Queensland, within the Burnett region. The open pit operation has existed for over twenty years and has been managed by multiple owners. Evolution Mining currently owns MRO and has been the sole operator since 2011. Mining will cease in October 2024, and processing will cease in March 2026.

The extent of the rehabilitation works for the MRO open pit currently extends to the NWRD through the placement of clay seals along the eastern berms. These seals will progressively be implemented until pit mining activities are completed, and the temporary ore stockpiles are rehandled for processing.

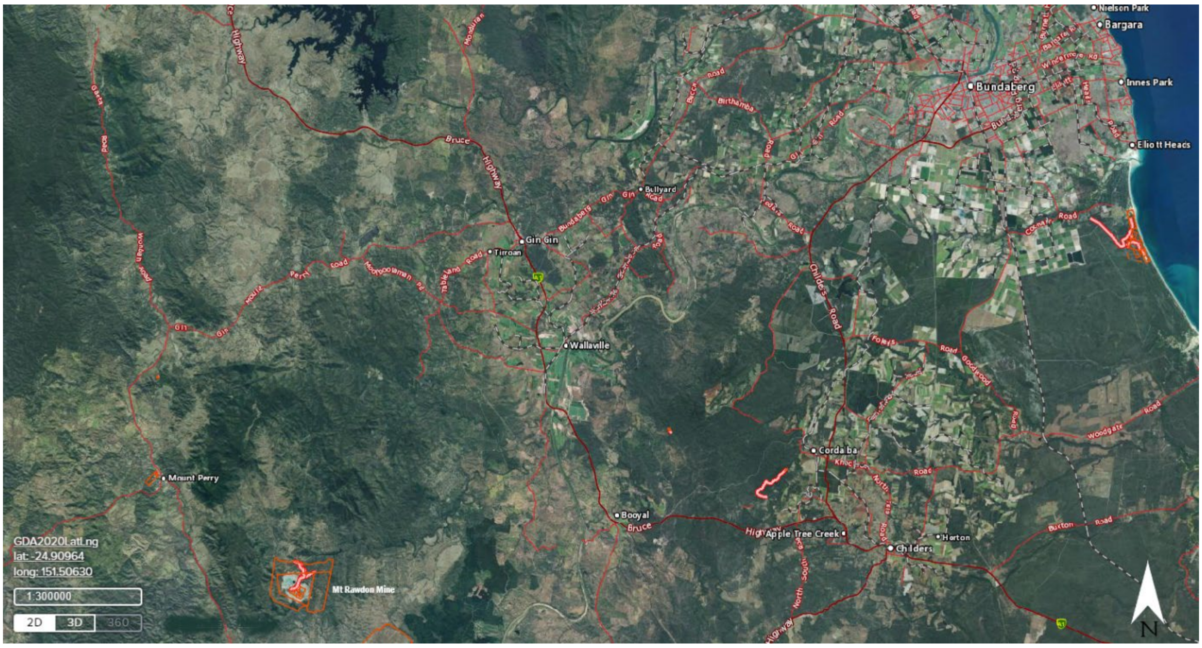



Figure 1: Mt Rawdon Operation site location

## 2.1 Information Provided

- TSF LOM design – ATC Williams consultants
- NWRD capping design – RGS consultants – refer to capping option 1B.
- Hydraulic Assessment, June 2021 – ATC Williams consultants (refer to an initial report which is being updated to reflect reshaping the TSF at closure.
- Long-term landform evolution (erosion) modelling of low slope angles for NWRD and TSF cover systems – RGS Consultants
- Topographic survey (original pre-mining surface)
- As-built surfaces and modelled closure surfaces (i.e., open pit, NWRD and TSF)
- TSF closure decommissioning and rehab plan – ATC Williams consultants, December 2017
- TSF conceptual closure and rehabilitation plan – RGC consultants, December 2017
- MRO Geochemical Report – RGS consultants, January 2021
- Open pit geotechnical review – PSM consultants, July 2021
- Assessment of long-term geochemical characteristics of Mt Rawdon tailings material-Final Report – RGS Consultants, January 2021

# 3 Document reviews

Reviewed documents in section 2.1 define different strategies and methodologies applied to analyse various aspects of the infrastructure relative to the closure requirements. Relevant information critical to the stability analysis of the infrastructure was extracted and used in the model setup for geotechnical stability assessments. MRO provided final design survey profiles at closure and post-closure, and geotechnical input parameters inferred from other studies were indicated in section 2.1.

Since the landform modelling and erosion studies were still being undertaken during the geotechnical analyses, only the final landform infrastructure was geotechnically assessed for stability. Once the landform modelling and long-term erosion analysis studies have been finalised, geotechnical investigations will be conducted on those final landforms.

# 4 Final void stability assessment

## 4.1 Geotechnical input parameters

The input parameters considered in the final void analysis are provided below. Rockmass domains defined by SRK Consulting (2017) and used in previous 3D numerical modelling of the final pit shell (Itasca, 2017,2019,2021), as shown in Figure 2, were used in the model and are provided in Table 1. The final pit lake elevation of 110mAHD (SLR,2020), which was defined by the stabilisation of the water balance model after a period of 275 years, was used in the geotechnical model, as depicted in Figure 3. Stability under these conditions was analysed as it will be the "worst-case" scenario post-closure.

The structural model used in the final void stability analysis was provided by MRO and developed by Mining One Consultants.

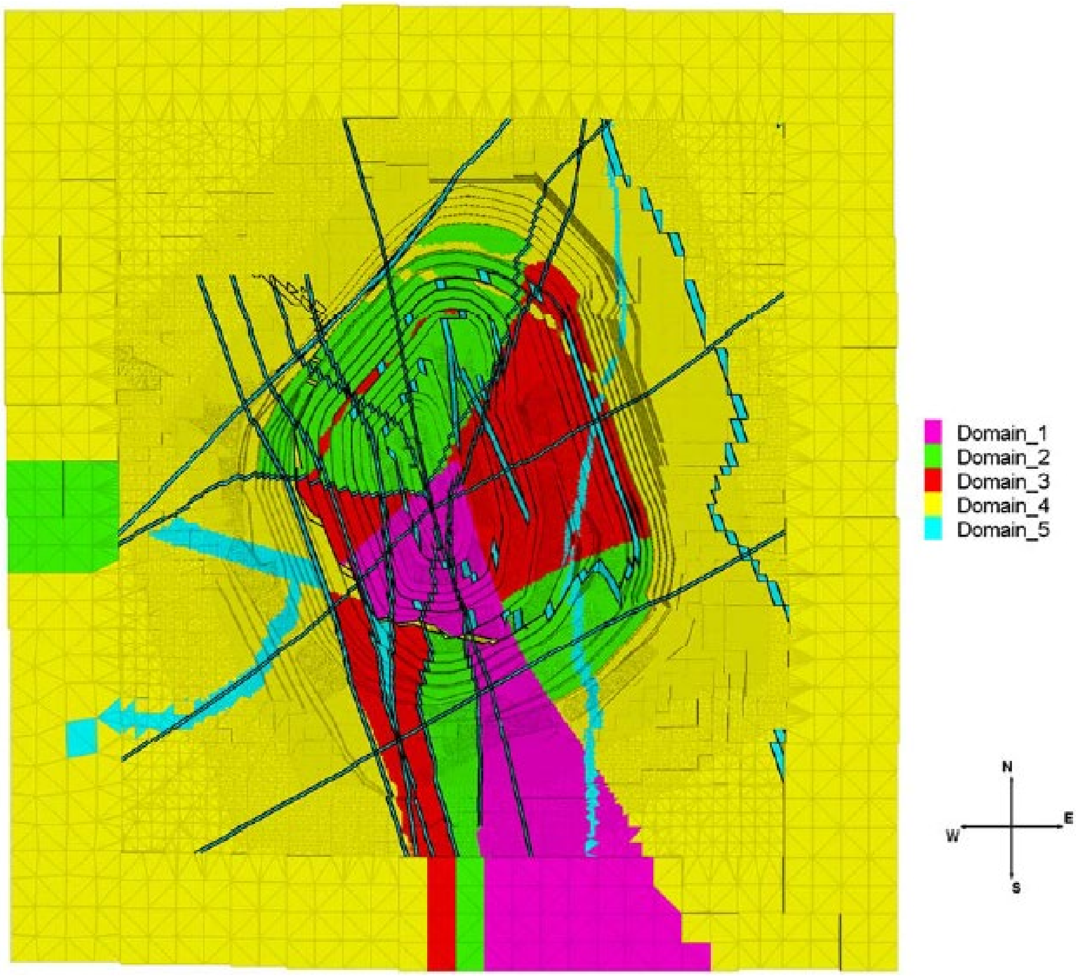



Figure 2: MRO rockmass domains

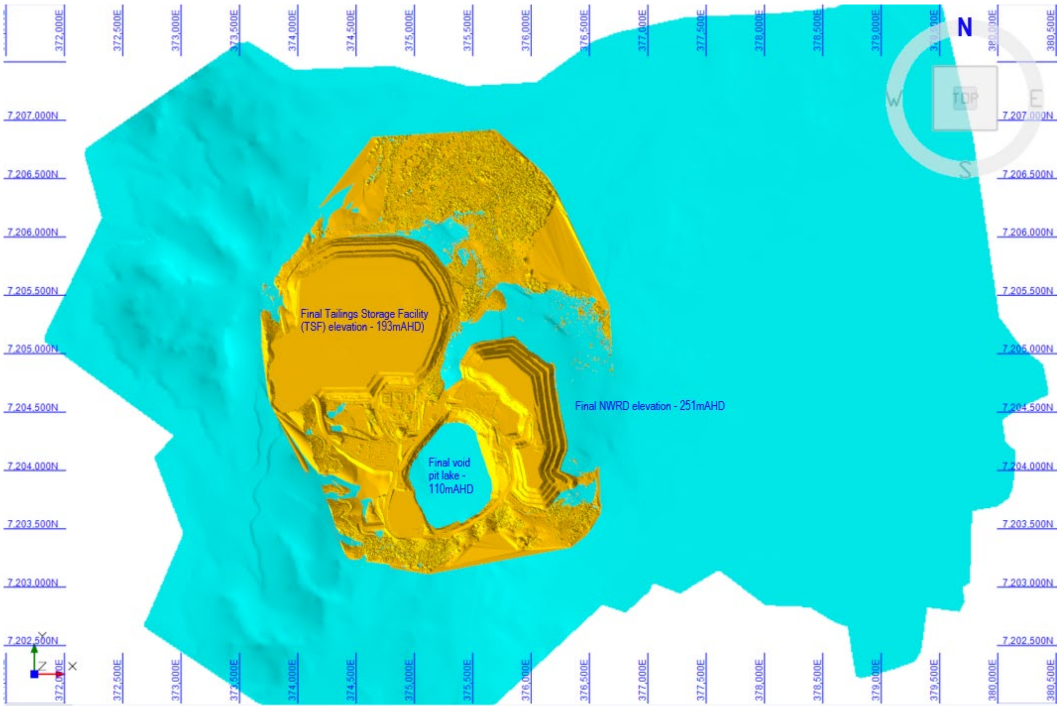



Figure 3: MRO Infrastructure showing the stabilised water balance after 275 years at elevation 110mAHD

Table 1: Rockmass material properties

| Domain | Description | ρ (t/m³) | $E_i$ (GPa) | $\sigma_{ci}$ (MPa) | GSI | $m_i$ | c (MPa) | ϕ (°) | $\sigma_{tm}$ (MPa) | ψ (°) | $E_{rm}$ (GPa) | $v_{rm}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Massive rock | 2.7 | 60 | 130 | 82 | 25 | 3822 | 57 | 937 | 10 | 21 | 0.20 |
| 2 | Very large blocky rock | 2.7 | 60 | 130 | 78 | 25 | 2741 | 57 | 640 | 10 | 18 | 0.20 |
| 3 | Blocky rock | 2.7 | 60 | 120 | 70 | 25 | 1339 | 54 | 276 | 10 | 13 | 0.22 |
| 4 | Small (to medium) blocky rock | 2.6 | 40 | 90 | 45 | 20 | 201 | 37 | 24 | 10 | 2 | 0.25 |
| 5 | Friable and very small blocky rock | 2.6 | 40 | 90 | 35 | 15 | 84 | 24 | 7 | 10 | 1 | 0.27 |

$\rho$ = Density
$E_i$ = Young's modulus for the Intact Rock
$\sigma_{ci}$ = Uniaxial Compressive Strength of Intact Rock
GSI = Geological Strength Index
$m_i$ = Hoek-Brown Material Constant for Intact Rock

$c$ = Rock Mass Cohesion
$\phi$ = Rock Mass Friction Angle
$\sigma_{tm}$ = Rock Mass Tensile Strength
$\psi$ = Rock Mass Dilation Angle
$E_{rm}$ = Young's modulus for the Rock Mass
$v_{rm}$ = Poisson's ratio for the Rock Mass

The faults and joint properties used in the model were adopted from the numerical modelling that has been conducted before, as discussed above. Each fault structure was modelled with a 5m width to represent the fault zones typical in the field. Domain 5 rockmass properties were assigned to the fault structures in the deformation analysis model using the software from Rocscience, RS3. For stability analysis, using Rocscience Slide 3 software, the parameters are in Table 2.

Table 2: Joint strength properties (SRK, 2017c)

| Domain | Description | ρ (t/m³) | Joint shear properties | | | | Comments |
|---|---|---|---|---|---|---|---|
| | | | Characteristic | | Lower bound | | |
| | | | c (MPa) | ϕ (°) | c (MPa) | ϕ (°) | |
| 1 | Massive rock | 2.7 | - | - | - | - | It is not included in the model due to a few structures. |
| 2 | Very large blocky rock | 2.7 | 10 | 36 | 25 | 25 | Lower bound – fault gouge (sand, sericite, clay) |
| 3 | Blocky rock | 2.7 | 10 | 36 | 0 | 25 | Lower bound – sericite, chlorite or thin clay |
| 4 | Small (to medium) blocky rock | 2.6 | 10 | 36 | 0 | 25 | Lower bound – sericite, chlorite or thin clay |
| 5 | Friable and very small blocky rock | 2.6 | - | - | - | - | Not included in the model due to poor rockmass |

For in-situ stress, the adopted ratio of horizontal to vertical stress was 2.2:1.5.

## 4.2 Modelling Methodology

The PRCP Guideline (DES,2021) requires that the assessment of voids for closure planning must include the following:

- Pit wall geotechnical stability considering the effects of long-term erosion and weathering of pit walls and the effects of significant hydrological events
- Proposed final slope angles of highwall of each void
- A geotechnical report focussing on how void will be achieved post-closure slopes that will exhibit stability characteristics consistent with planning and design of post-closure mine void.
- Mechanisms for achieving acceptable geotechnical stability must be detailed in the plan. This includes void filling, partial void filling, reshaping and void configuration through earthwork methods such as backfilling, regrading, buttressing, and benching. Where applicable, methods and techniques for achieving safe slopes must be detailed.

Rocscience software RS3 (Version 4.025) and Slide 3 (Version 3.020) were used to analyse the deformation and stability of the final void conditions using provided site-specific rockmass domains.

Domains were first assigned by dividing the pit geometry with all structural surfaces for Mount Rawdon provided by the client. These domains' parameters were assigned according to the domains presented by Itasca and mapped and defined by SRK (2017), as shown in Figure 2.

Two analysis methods were applied: the Spencer and Morgenstern-Price Global Limit Equilibrium (GLE). These methods were selected as they resolve both horizontal and vertical force equilibrium and moment equilibrium. Because of this, the failure surfaces calculated resolve well against weak layers. As the site is heavily faulted, failure surfaces are likely to plane against the weaker fault zones, and therefore these methods are more suitable for this analysis. Results were assessed for both to ensure a similar result and thus validate the failure surfaces.

The Slide3 model was built and run, with the associated RS3 model, to validate other failure surfaces and areas of lower Factor of Safety (FoS) to determine displacement across the pit.

## 4.3 Stability Assessment Criteria

The adopted assessment criteria for the slope stability analysis are based on the overall slope scale and the high consequence of failure, as listed in Stacey and Read, 2009. Table 3 describes the FoS and Probability of Failure (PoF) for the respective slope scale and consequence. Moreover, it is summarised below based on a static and dynamic factor of safety values. A minimum FoS of 1.5 and 1.1 has been adopted for static and dynamic analyses.

Table 3: Typical FoS and PoF acceptance criteria values (Stacey & Read, 2009)

| | | Acceptance criteria[a] | | |
|---|---|---|---|---|
| Slope scale | Consequences of failure | FoS (min) (static) | FoS (min) (dynamic) | PoF (max) P[FoS ≤ 1] |
| Bench | Low–high[b] | 1.1 | NA | 25–50% |
| Inter-ramp | Low | 1.15–1.2 | 1.0 | 25% |
| | Moderate | 1.2 | 1.0 | 20% |
| | High | 1.2–1.3 | 1.1 | 10% |
| Overall | Low | 1.2–1.3 | 1.0 | 15–20% |
| | Moderate | 1.3 | 1.05 | 10% |
| | High | 1.3–1.5 | 1.1 | 5% |

a: Needs to meet all acceptance criteria
b: Semi-quantitatively evaluated

## 4.4 Seismic Loading

A probabilistic seismic hazard analysis (PSHA) was conducted at MRO in 2020. For the final void analysis, the two design events considered were the operational basis earthquake (OBE) of peak ground acceleration of 0.09g and the site evaluation earthquake (SEE) of peak ground acceleration of 0.25g, both having a magnitude of 7.5 (ATC, 2020). For post-closure analysis, the SEE design event was applied to assess the stability of the final void under dynamic conditions.

## 4.5 Stress Regime Loading,

It is understood that no stress measurement data is available for Mt Rawdon. The following stresses from Evolution's Cracow Mine (also in Queensland) have been adopted for the analyses, as suggested by Evolution (Itasca, 2017a):

- S1 is horizontal trending SSW-NNE; S2 is horizontal trending NW-SE; S3 is steeply dipping
- S1/S3 ≈2.2
- S2/S3 ≈ 1.5

## 4.6 Phreatic Surface

A phreatic surface created from the Mt Rawdon Post-Closure Groundwater Model (SLR, 2020) was used as the groundwater table for the open pit model.

The analysis was conducted with the Hu value, the hydrogeological coefficient for the material type, in the Auto mode. According to the post-closure groundwater model, the MRO void cannot contain the runoff volume, and groundwater flows for the first 100 years. The modelling also predicted it would take 300 years to reach final void levels, where the water balance will stabilise after 275 years to a level of 110mAHD and overflow at 130mAHD (SLR,2020).

This groundwater modelling used the stabilised groundwater elevation to assess the post-closure void stability conditions.

## 4.7 Modelling Assumptions

The following design assumptions were adopted to analyse the final void for the open pit.

- Rockmass parameters were obtained from previous numerical stability assessments.
- Faults be persistent throughout the model, as per the provided structural model (MRO, 2022).
- Excavation is assumed to be saturated below the projected final groundwater surface, with constant water pressure.
- The fault structures have been assumed to have a 5m width, per the Itasca stability model.
- The final slopes analysed were based on the planned final pit shell at closure since the long-term erosion modelling was ongoing at the time of writing the geotechnical report.

## 4.8 Stability Analysis Results

### *4.8.1 Stability Analysis (Slide3)*

The factor of safety results for the static and dynamic scenarios of the Slide3 Limit Equilibrium analysis is shown below in Table 4 and in Figure, 4 to Figure 7. A suitable factor of safety was achieved for static conditions. Spencer's results for the dynamic seismic analysis were marginally below the assessment criteria, however, considering the likelihood of the event, this is considered acceptable.

Table 4: Limit Equilibrium Slide3 results under static and dynamic conditions

| Model | FoS (Spencer) | FoS (GLE/Morgenstern-Price) |
|---|---|---|
| Static Model | 2.01 | 1.99 |
| Dynamic Model (PGA: 0.25g or 1:10000) | 1.09 | 1.10 |

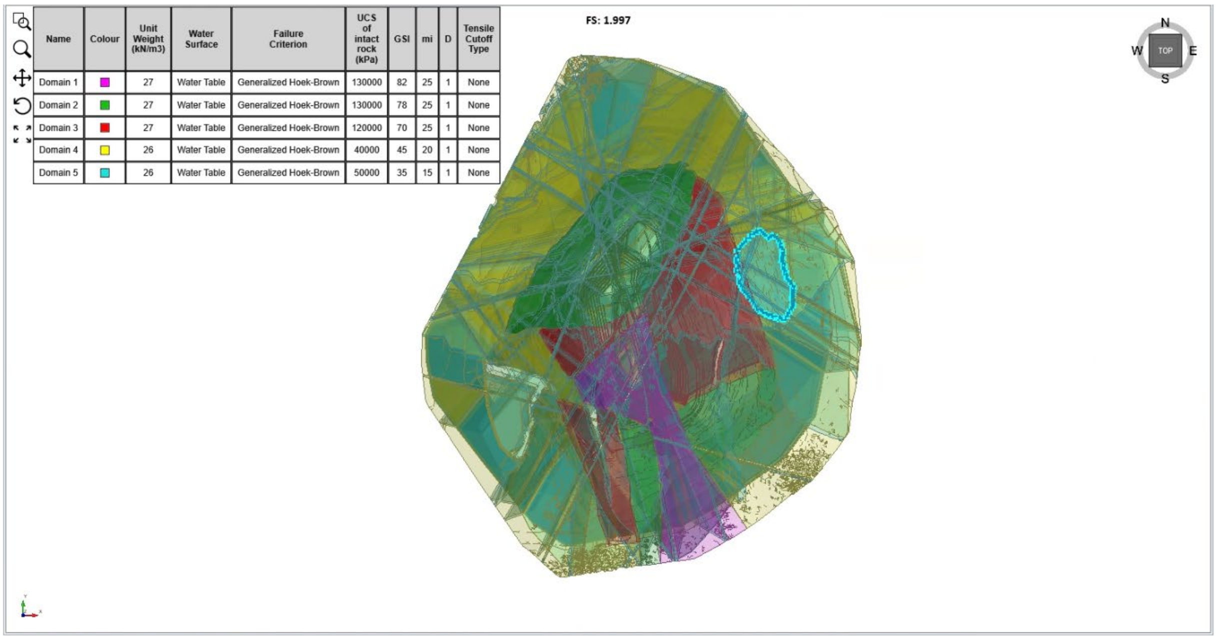



Figure 4: Limit Equilibrium Slide3 results under static conditions, showing global minimum failure surface on the east wall

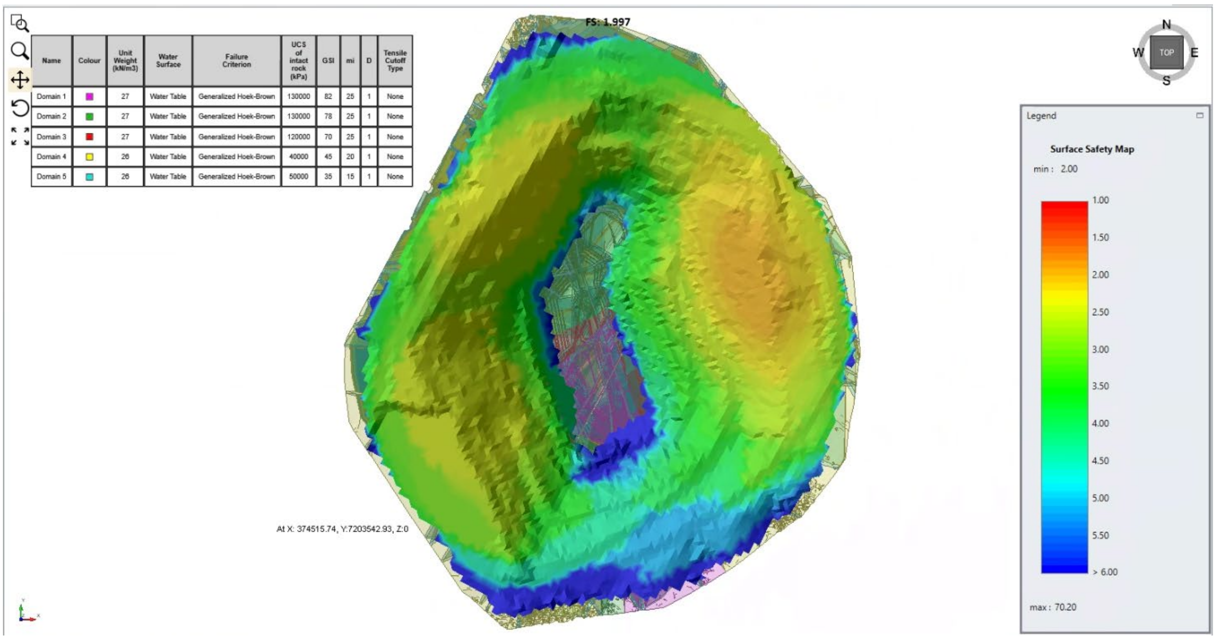



Figure 5: Limit Equilibrium Slide3 Spencer's under static conditions safety map

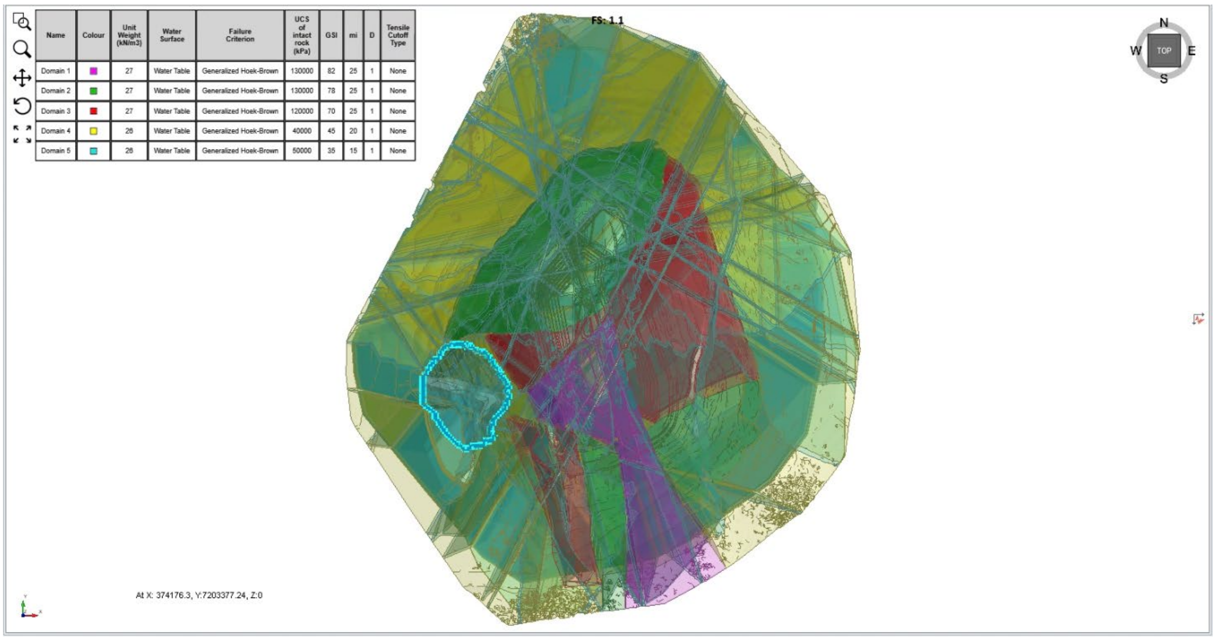



Figure 6: Limit Equilibrium Slide3 result,lts under dynamic seismic conditions, sh, owing global minimum failure surface on the west wall

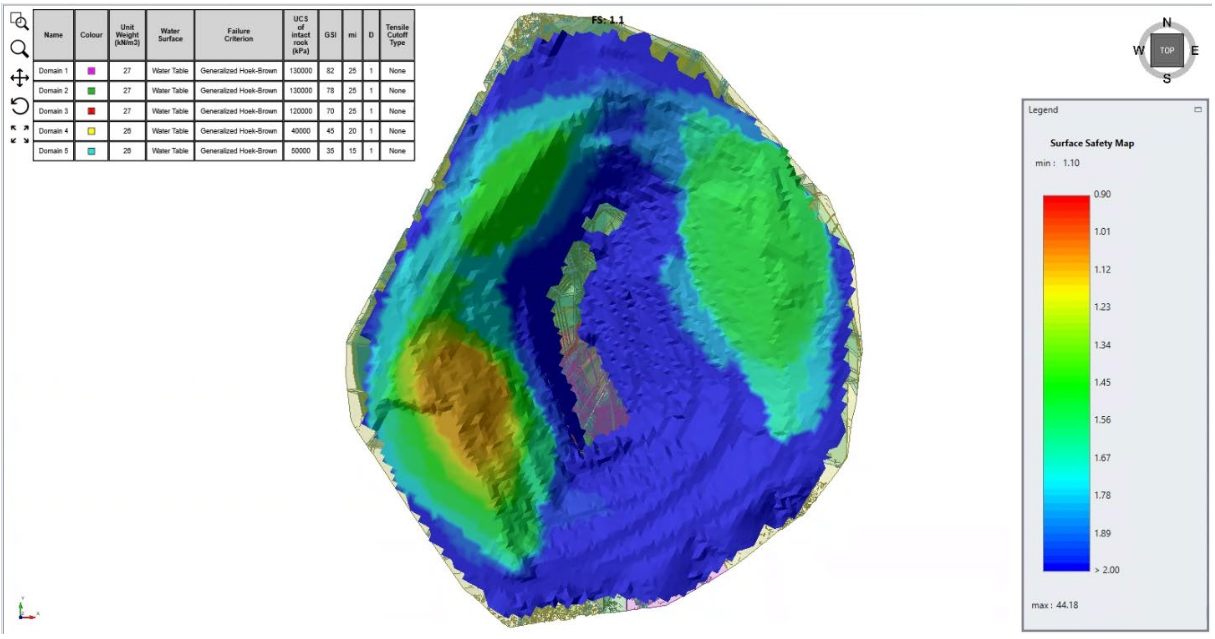
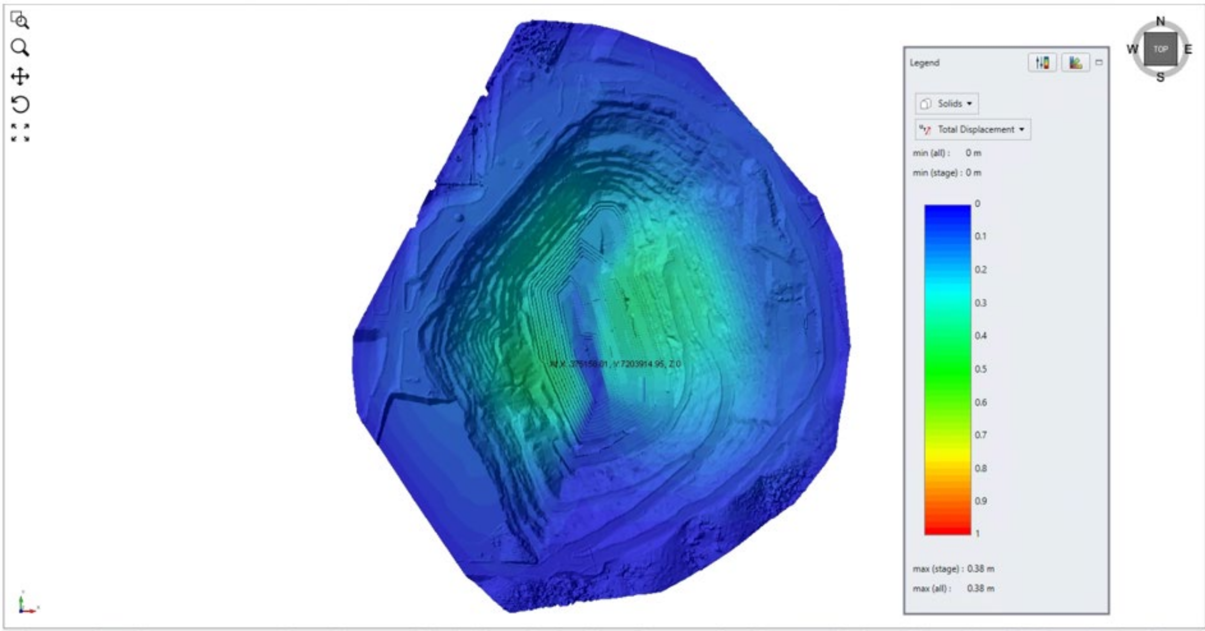



Figure 7: Limit Equilibrium Slide3 results under dynamic seismic conditions

### *4.8.2 Deformation Analysis (RS3)*

Finite element analysis using the Rocscience software RS3 was used to assess the deformation of the pit slope under closure conditions. The modelling results, as shown below in Figure 8 and Figure 9, illustrate a correlation with Limit Equilibrium (LE) analysis results, with a maximum total displacement of approximately 400 mm (an equivalent strain of 0.23%) recorded more on the west wall and east within range, under static conditions, and 530 mm (an equivalent strain of 0.32%) on the west wall under dynamic conditions, respectively. This displacement will be around areas known to have marginal stability during the operational phase of the mine and caused some instabilities during the operational phase of the Mine. However, this deformation estimate is not expected to instigate large scale failures.




| Name | Colour | Initial Element Loading | Unit Weight (MN/m3) | Failure Criterion | Material Type | Peak Cohesion (MPa) | Peak Friction Angle (°) | Peak Tensile Strength (MPa) | Unsaturated Shear Strength Angle (°) | Air Entry Value | Elastic Type | Use Unloading Condition | Poisson's Ratio | Young's Modulus (MPa) | Material Behavior Type | Porosity Type | Porosity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Joints | | Field Stress & Body Force | 0.026 | Mohr Coulomb | Elastic | 84 | 24 | 0.007 | 0 | 0 | Linear Isotropic | No | 0.27 | 1000 | Drained | Porosity | 0.3 |
| Domain 1 | | Field Stress & Body Force | 0.027 | Mohr Coulomb | Elastic | 3822 | 57 | 0.937 | 0 | 0 | Linear Isotropic | No | 0.2 | 21000 | Drained | Porosity | 0.3 |
| Domain 2 | | Field Stress & Body Force | 0.027 | Mohr Coulomb | Elastic | 2741 | 57 | 0.64 | 0 | 0 | Linear Isotropic | No | 0.2 | 18000 | Drained | Porosity | 0.3 |
| Domain 3 | | Field Stress & Body Force | 0.027 | Mohr Coulomb | Elastic | 1339 | 54 | 0.276 | 0 | 0 | Linear Isotropic | No | 0.22 | 13000 | Drained | Porosity | 0.3 |
| Domain 4 | | Field Stress & Body Force | 0.026 | Mohr Coulomb | Elastic | 201 | 37 | 0.024 | 0 | 0 | Linear Isotropic | No | 0.25 | 2000 | Drained | Porosity | 0.3 |
| Domain 5 | | Field Stress & Body Force | 0.026 | Mohr Coulomb | Elastic | 84 | 24 | 0.007 | 0 | 0 | Linear Isotropic | No | 0.27 | 1000 | Drained | Porosity | 0.3 |
| Faults structures | | Field Stress & Body Force | 0.026 | Mohr Coulomb | Elastic | 84 | 27 | 0.007 | 0 | 0 | Linear Isotropic | No | 0.27 | 1000 | Drained | Porosity | 0.3 |

Figure 8: Result showing total displacement of 380 mm at post-closure conditions s under static conditions

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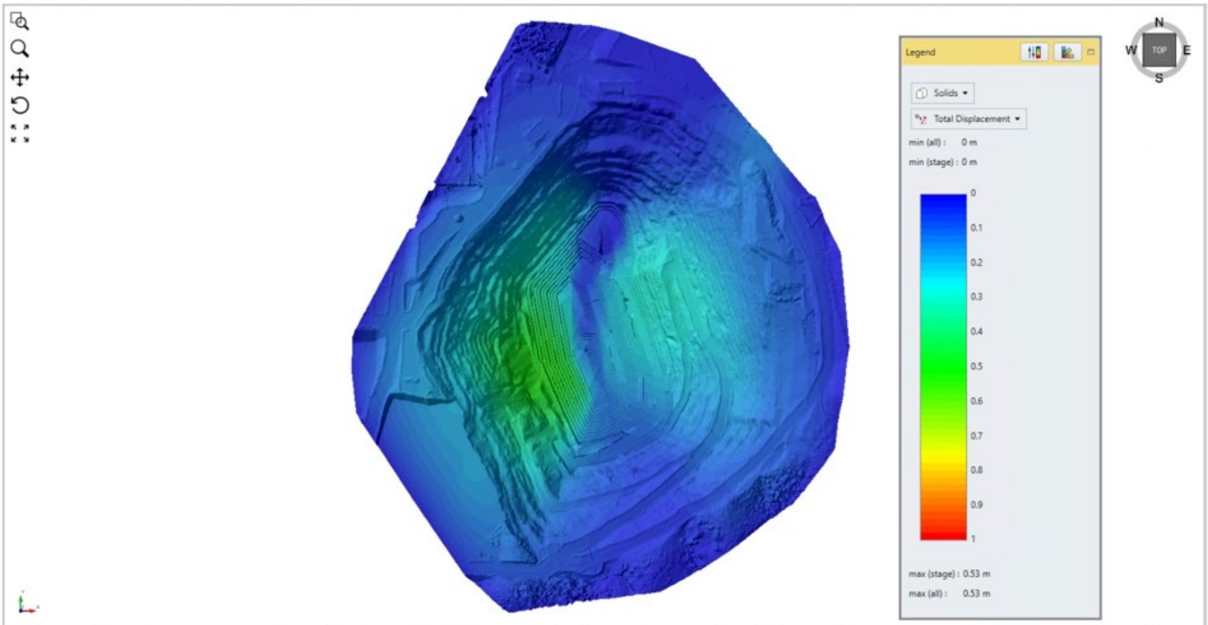


| Name | Colour | Initial Element Loading | Unit Weight (MN/m3) | Failure Criterion | Material Type | Peak Cohesion (MPa) | Peak Friction Angle (°) | Peak Tensile Strength (MPa) | Unsaturated Shear Strength Angle (°) | Air Entry Value | Elastic Type | Use Unloading Condition | Poisson's Ratio | Young's Modulus (MPa) | Material Behavior Type | Porosity Type | Porosity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Joints | | Field Stress & Body Force | 0.026 | Mohr Coulomb | Elastic | 84 | 24 | 0.007 | 0 | 0 | Linear Isotropic | No | 0.27 | 1000 | Drained | Porosity | 0.3 |
| Domain 1 | | Field Stress & Body Force | 0.027 | Mohr Coulomb | Elastic | 3822 | 57 | 0.937 | 0 | 0 | Linear Isotropic | No | 0.2 | 21000 | Drained | Porosity | 0.3 |
| Domain 2 | | Field Stress & Body Force | 0.027 | Mohr Coulomb | Elastic | 2741 | 57 | 0.64 | 0 | 0 | Linear Isotropic | No | 0.2 | 18000 | Drained | Porosity | 0.3 |
| Domain 3 | | Field Stress & Body Force | 0.027 | Mohr Coulomb | Elastic | 1339 | 54 | 0.276 | 0 | 0 | Linear Isotropic | No | 0.22 | 13000 | Drained | Porosity | 0.3 |
| Domain 4 | | Field Stress & Body Force | 0.026 | Mohr Coulomb | Elastic | 201 | 37 | 0.024 | 0 | 0 | Linear Isotropic | No | 0.25 | 2000 | Drained | Porosity | 0.3 |
| Domain 5 | | Field Stress & Body Force | 0.026 | Mohr Coulomb | Elastic | 84 | 24 | 0.007 | 0 | 0 | Linear Isotropic | No | 0.27 | 1000 | Drained | Porosity | 0.3 |
| Faults structures | | Field Stress & Body Force | 0.026 | Mohr Coulomb | Elastic | 84 | 27 | 0.007 | 0 | 0 | Linear Isotropic | No | 0.27 | 1000 | Drained | Porosity | 0.3 |

Figure 9: Result showing total displacement of 530 mm at post-closure conditions under dynamic conditions

# 5 Recommendations

The following recommendations have been made to ensure safe operations around the final pit void and maintain stability.

- Stability and deformation analyses indicate that the pit void will meet design acceptance criteria factors of safety and will be stable under analysed post-closure conditions.
- Considering that only the final pit shell was used in the stability and deformation analysis, it is recommended that long-term erosion effects be integrated into the final landform to ascertain the inherent effects on stability. However, considering the long-term effects of erosion and the expected re-profiling of the pit slopes, this report is analysed slopes to predict the pit slope's stability and deformation soon after operations cessation and closure.
- Following closure, much slope monitoring can be discontinued by ensuring that access to the pit is closed off with a physical barrier. However, a post-closure monitoring plan should be in place for intermittent void monitoring if access to the pit must be re-established following closure.
- One of the most sensitive components of this model is the hydrogeological surface used for the analysis. As stated, the surface used was predicted by previous consultants as an expected final void phreatic surface. The actual surface may vary; if groundwater levels exceed that as modelled, an additional assessment should be undertaken based on the most current information.
- The proposed rehabilitation and management strategy demonstrates that the post-closure conditions for the pit void meet stability conditions

# 6 Conclusion

A summary of the results from stability and deformation analysis was discussed in the report, and the methodology was undertaken to obtain the results. Based on the undertaken approach, it can be concluded that the geotechnical void analysis for the planned MRO post-closure pit conditions meets the post-closure slopes and will exhibit stability characteristics consistent with the planning and design of the post-closure mine void.

The mechanisms to achieve acceptable stability were detailed in the report to align with the best available leading practices. Other supporting reporting in the closure, post-closure and rehabilitation strategies were reviewed to ensure that the post-closure conditions analysed in the report aligned with the rest of the considered closure plan.

Due to the ongoing modelling of the final pit shell to include the long-term effect of erosion processes on the final shell, the final pit shell geotechnical analysed for stability does not include the effects of erosion. However, considering the rockmass conditions and modelled groundwater conditions, minimal changes in the slope profile will be anticipated and hence should not deviate much from the modelled slope configurations.

Alluding to the requirements of the PRCP guideline section 3.8, monitoring and maintenance will be critical for the pit void. Monitoring systems proposed in the closure plan should be maintained and sustained through the closure and post-closure periods to demonstrate the attainment of each proposed milestone.

# References

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