A case study: conceptual rehabilitation and closure planning for the Loy Yang mine using the risk-based probabilistic approach employing the Mine Geotechnical Risk Index methodology

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Abstract

In the mining industry, risk is conventionally evaluated under absolute conditions – that is, operational scenarios or, say, a completed rehabilitated scenario. However, challenges arise when applying these methods to a mine that is in a transient state – that is, transitioning from operation to final rehabilitated conditions. Risk-based approaches, such as the Mine Geotechnical Risk Index (MGRI) developed by Narendranathan et al. (2019), may be adopted to quantify the geotechnical risks associated with lake filling, and are useful tools for assessing transient risk profiles.

AGL's Loy Yang mine, located in Victoria, Australia, is in the process of rehabilitation and closure planning and is considering a full lake option as part of their final landform.

This paper demonstrates how the MGRI approach was successfully employed to assess the batter stability implications during proposed lake filling so as to determine slope supplementation requirements under varying pit lake levels, to conceptualise transient slope supplementation measures to manage slope stability–related risks during this phase.

Keywords: rehabilitation and closure, post-closure, large open cut coal mine, risk-based stability assessment

1 Introduction

AGL's Loy Yang mine (LYM) is an open cut brown coal mine located within the Latrobe Valley, some 165 kilometres southeast of Melbourne. While LYM is currently an operational mine, AGL Loy Yang is actively in the process of planning for its rehabilitation and closure phase of the operation. At present, AGL is considering a full pit lake option as part of their final rehabilitation and closure plan.

A critical aspect of this process is understanding the potential stability implications of the mine batters under the varying pit lake levels with due consideration to the stability of the so-called transient state (i.e. transitioning from operational to final rehabilitated conditions), which includes the process of filling the pit from its empty void to its 'full-lake' outcome (i.e. lake filling to +45 mRL). Over many years, the authors have worked closely with the operators of LYM and have carried out studies and extensive modelling assessments to understand mine batter stability, groundwater characteristics and implications, associated mechanical behaviour and inherent variability of the geological units encountered at the mine. A number of these stability analyses included geotechnical analyses of batter stability under various loading (i.e. lake filling) scenarios with consideration of both the final landform and transient state stability requirements. These assessments enabled the identification of critical slope areas that would require supplementation in

the form of buttressing as an additional control during mine rehabilitation, prior to the commencement of lake filling.

This paper presents a case study that demonstrates how the MGRI approach after Narendranathan et al. (2019) was employed to assess the batter stability implications of lake filling and furthermore used to determine slope supplementation requirements under the varying and transient pit lake levels.

This paper focuses on overall and global stability considerations during the rehabilitation process, looking at instability within the constraints of the mine pit boundary. It is acknowledged that subsequent to rehabilitation, a number of secondary mechanisms may manifest, in sympathy with the final landform design, but these are not exhaustively considered in this paper.

2   Background

There are three declared mines within the Latrobe Valley (i.e. Yallourn Mine, Hazelwood Mine and LYM), as presented in Figure 1. Hazelwood Mine is currently in its closure and rehabilitation phase, while Yallourn Mine and LYM are operating and scheduled for closure in 2028 and 2048, respectively. The closure of the other Latrobe Valley mines prior to LYM provides precedence for the acceptable and 'tolerable' level of geotechnical risk during rehabilitation and provides alignment with community expectations post-closure.
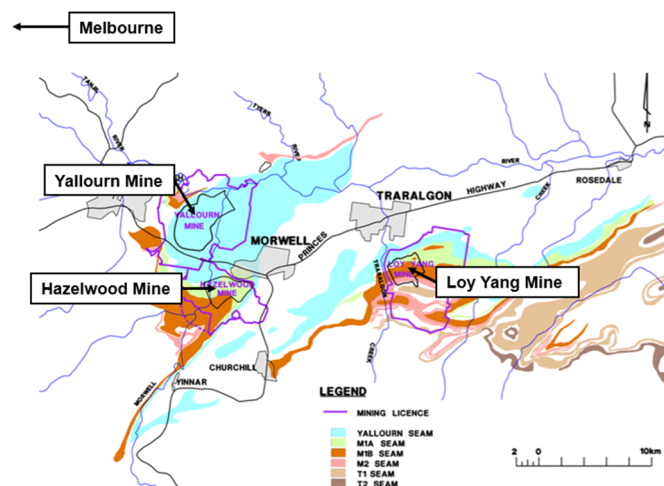

Figure 1   Plan view showing the Latrobe Valley mines

Of the three declared mines, the LYM is the most complex geologically, consisting of five primary (economically mineable) coal seams, which are separated by interseam (burden). Naturally occurring geological structures, such as joints and mining-induced plastic deformations (i.e. extensional cracks), generally create potential localised (individual batter scale) instability hazards. However, when coal structures interface with the interposing interseam strata, which are primarily constituted by variably low to high plasticity clays, a global (overall batter scale) instability risk (i.e. coal block sliding) presents. The rate of coal block movement is highly dependent upon the mine batter geometry, groundwater conditions and interseam characteristics (e.g. material strength and orientation). Given that the characteristics of the interseam material are inalterable, coal block movement at the LYM is controlled through strategic mine design and planning and is carefully monitored using surface and subsurface monitoring instrumentation.

Since the commencement of mining operations, significant effort has been invested to understand the stability implications associated with mine development and the hydrogeological setting within which operations have occurred. However, several challenges have been identified by the authors when assessing the stability conditions of the mine batters considering rehabilitation and closure scenarios, such as:

- Mechanical variability – There is significant mechanical variability in the geological materials at LYM, which is challenging to characterise using a 'singular' set of material parameters due to rapid variations over small distances.

- Final landform considerations – As part of the rehabilitation and closure planning, the potential impact and proximity to prospective public infrastructure receptors needed to be considered.

- Changes in stress regime – As the final rehabilitation concepts are considering a full pit lake option, the assessment had to consider the stability effects of a rising pit lake (i.e. as the pit lake rises, it changes the 'equilibrium' stress regime around the batter slope and at times can adversely affect batter stability).

- Serviceability considerations – Furthermore, while the stability assessments may indicate a favourable final landform option from a geotechnical perspective, the level of active care and maintenance required to maintain a safe and stable landform also needed to be considered.

Given the challenges above, probabilistic modelling methods have been introduced to better quantify stability risk. Probabilistic methods provide a useful tool to identify areas that are comparatively more sensitive to changes in stress regimes, and thus mine operators and managers are able to focus their efforts on areas attributed with higher risks and employ target stability management protocols; this approach is equally applicable during both the operational and closure phases.

As AGL LYM is considering a pit lake option as part of their final rehabilitation and closure plan, employing probabilistic methods is considered prudent, as the effects of lake filling on the slope stability performance can be assessed with an increased level of geotechnical confidence. Risk-based approaches, such as the Mine Geotechnical Risk Index (MGRI), developed by Narendranathan et al. (2019), may be adopted to quantify the geotechnical risks associated with each partial lake-fill level and is a useful tool for assessing transient risk profiles.

2.1   Introduction to the Mine Geotechnical Risk Index

Conventionally, geotechnical risk evaluation is typically conducted on a particular scenario such as operational mine conditions (i.e. current conditions) or closed and rehabilitated conditions (i.e. long-term conditions) that may need to satisfy singular acceptance criteria; this is, however, not the case during the transient stages of rehabilitation – that is, from cessation of mining to commencement and completion of rehabilitation activities. Narendranathan et al. (2019) proposed that to evaluate stability during this transitional phase, the MGRI approach can be employed to attribute 'acceptable' increases of tolerable risk thresholds based on research conducted by Bell et al. (2005) on landslides. Narendranathan et al. (2019) noted that the approach should not be extended to the post-closure phase without the benefit of dedicated risk assessments.

Narendranathan et al. (2019) defined the MGRI thus:

$$MGRI = (PC_t \times C_f \times I_f \times S_f)$$
(1)

where:

MGRI =   Mine Geotechnical Risk Index.

PC_t =   annual probability of primary instability load or scenario occurring.

C_f =   consequence factor – probability of failure (PF) × volume of failure (VF).

I_f =   impact factor.

S_f =   seasonal factor.

NB: the PF is determined by the number of occurrences where the Factor of Safety (FoS) is less than 1.0 (i.e. FoS < 1). The above approach needs to be supplemented with specific and temporal consideration for risk scenario and/or any given receptor.

Narendranathan et al. (2019) provide guidance in selecting/calculating the respective factors used in Equation 1.

2.2.1   Definition of tolerable risk increase

Narendranathan et al. (2019) defined the range of tolerable risk based on a threshold of risk variation. The percentage increase in risk (i.e. elevation of the calculated MGRI above the baseline) has been classified by the authors into four categories – very low, low, medium and high, and is based on Bell et al. (2005) – but were refined with the benefit of guidance provided by a number of authors (Ágústsson et al. 2003; Ammann 2005; Borter 1999; Geotechnical Engineering Office 1997; Jóhannesson & Ágústsson 2002; Jónasson et al. 1999; Malone 2005; The Ministry of the Environment 2000) on the topic of 'acceptable levels of risk' when considering landslide areas that are subjected to public access.

For example, if the risk level for closure is nominated as 'low' by the relevant operators and stakeholders, then an increase in risk profile beyond 13% is considered beyond acceptable tolerances, as put forward in Table 1. As outlined by Narendranathan et al. (2019), this clearly demonstrates that some form of supplementation measures is required during the closure period in order to contain risks to within a tolerable threshold for this particular slope section.

NB: it should be appreciated that Narendranathan et al. (2019) provide a baseline metric and require site-specific assessment and further consultation with relevant stakeholders to have alignment, particularly when defining site-specific (risk) threshold of variation.

Table 1   Risk increase thresholds

Risk level	Threshold of variation
Very low	≤ 0%
Low	0–13%
Medium	13–29%
High	> 29%

The case study outlined in the subsequent section demonstrates how the MGRI approach was utilised in concert with the above thresholds to:

- Quantify the geotechnical risks associated with the final landform option to aid in the overall rehabilitation and closure planning of the LYM.
- Identify key areas of the LYM that require supplementation during lake filling, prior to establishing the final rehabilitation landform.

3   Case study

3.1   Introduction

The case study presented herein demonstrates how the MGRI approach was successfully utilised by the authors to assess the stability outcomes at various stages and pit levels of mine rehabilitation for critical sections of the mine and demonstrate that a 'full' pit lake is the preferred option from a batter stability perspective. The critical and primary mechanism that can lead to a large-scale instability is referred to as the 'coal block sliding' mechanism (Figure 2). It can potentially occur across the multiple interseams where there are excessive destabilising forces (in comparison to stabilising forces) as a result of:

- Hydrostatic driving force of water contained in the predominately sub-vertical joints.
- Releasing of existing tectonic stresses by removal of coal within the mine (stress relief).
- Elevated phreatic gradient within the coal unit.
- Upthrust from underlying aquifers (floor heave).

These forces are typically counteracted by the following stabilising forces:

- The shear strength of the underlying interseam, the unit upon which the overlying coal block could 'slide'.

- Resisting forces afforded by the pit lake.

NB: measures such as aquifer depressurisation and/or suitably designed slope supplementation measures can be used to further mitigate the initiation of the block sliding mechanism.

The above forces are influenced by the geology within the specific mine batter (e.g. degree of strata dip in or out of the mine batter, thickness of interseam(s), coal seams and overburden) and on the development geometry (e.g. batter/bench configurations and overall slope angle).
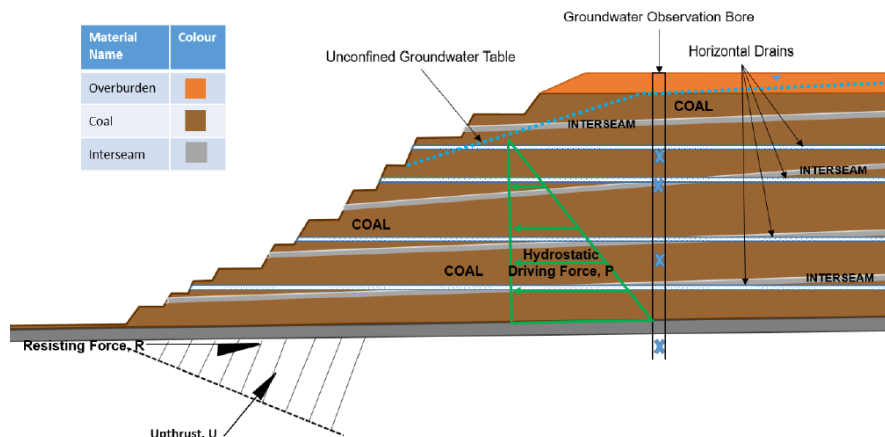

Figure 2   Schematic of block sliding instability mechanism

3.2   Investigation methodology

The following approach was employed in assessing the requirements for the batter stability supplementation for the LYM during the transient phase(s) from cessation of mining through to lake filling:

- A dedicated and extensive intrusive and analytical geotechnical investigation was employed across the mine. This investigation was utilised to supplement the already present geotechnical information base to amass a robust geotechnical database of information. The intent is to continually update this database of information throughout the mine's course of operation through to 2048.

- Upon compilation of the newly acquired data with the existing data, a probabilistic geotechnical model was developed utilising the process developed by Narendranathan (2009). This model consisted of the following features:

  ○ Material strengths and associated variability (i.e. distributions) for the key geological units, coal seam, interseams and the overburden.

  ○ Joint strength and orientation variability.

  ○ Anticipated temporal fluctuations in groundwater gradients.

- These geotechnical models were subsequently subjected to stability calculations, with the results of these calculations incorporated into the MGRI calculation process to develop a consequence-based risk map of the untreated terminal mine batters in their current form (i.e. prior to lake filling). This was the basis for the nomination of 'critical' stability sections.

- The 'critical' stability sections were then subjected to stability calculations under the various design scenarios (i.e. partial lakes during the filling process and a full lake level), and the outcomes were compared against the nominated design acceptance criteria (DAC) espoused by the authors in line

with industry published guidance – that is, CSIRO's 'Guidelines for Open Pit Slope Design' (Read & Stacey 2009).

- Areas of the mine batters that were non-conforming with the DAC and calculated to be outside the 'tolerable' MGRI thresholds, as outlined in Table 1, were subjected to further investigation to identify suitable slope supplementation measures.

- The preceding steps were repeated until the resultant risk thresholds were within the 'tolerable' range, as currently accepted by the mine operator. This signified a suitable slope supplementation outcome.

3.3   Investigation and geotechnical model development

An extensive campaign of investigation, laboratory characterisation and associated analytical interpretation of the main lithological units at the LYM (i.e. the various coal and interseam layers, and the overburden unit) has been undertaken and is anticipated to continue through the planned life of the LYM through to 2048. An example of the stratigraphy at the LYM is depicted in Figure 3.
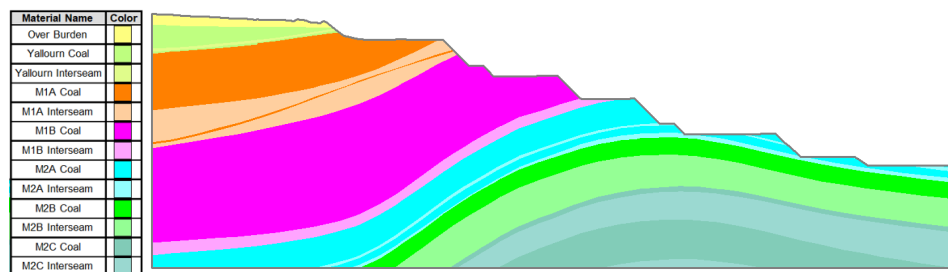

Figure 3   Cross-section depicting typical stratigraphy at LYM

The following approach was employed in the statistical characterisation of the above units along the northern batters of the Loy Yang mine to assess the variability of its properties relevant to batter stability (i.e. coal block sliding movement):

- The data from the historic borehole investigation campaign was reduced and combined with historic material strength information, which consisted of direct shear test information obtained by the State Energy Commission Victoria from circa 1970 onwards.

- A statistical interrogation was performed to assess the 'validity' of the combined dataset, whereby a dataset needs to have a certain number of minimum 'sample points' and statistical 'confidence' in relation to its variability to be considered 'valid'. This assessment was undertaken using the criteria stipulated by Harr (1984).

- This test involved the following steps and considerations:

  ○ It should be appreciated that most conventional statistical 'validity' tests have been devised for assessing the variability/tolerance of 'engineered' materials (i.e. say, the Student's *t*-test). Such tests involve 'testing' each 'sample' point against a predefined 'acceptance' value (or mean).

  ○ It also presupposes 'independence' between the individual data points as well as a Gaussian distribution. This process is difficult to apply in the context of 'naturally' occurring materials (i.e. say, the main geological units at the LYM), as they do not conform to the criteria set out in the points above.

  ○ Accordingly, Harr (1984), and others, have studied the variance of 'naturally' occurring materials and have put forward an alternative approach that looks at a collective set of data

points, and comparing the 'variance' of the set with their studied (compiled) thresholds (refer to Table 1).

- This process involves calculating a 'dispersion' metric for the dataset in question; specifically, the relative standard deviation or coefficient of variation (CoV). The CoV is defined as the ratio of the standard deviation to the mean, expressed thus:

$$c_v = \frac{\sigma}{\mu}.$$

- It shows the extent of variability in relation to the mean of the population.

With the above in mind for the context of LYM:

- Progressive strength measurements for the respective lithological units were initially sourced from a single borehole drilled as part of the contemporary investigation and then 'combined' progressively with the strength measurements from the historical campaigns, and the resulting mean value was calculated.

- The recalculated mean was utilised to compute a revised CoV, which was then compared to the criteria put forward by Harr (1984). Steps (i) and (ii) were repeated until the CoV fell 'outside' the criteria stipulated by Harr (1984). This was deemed to be the point at which the combined dataset ceased to be 'valid'.

Implementing the above approach enabled the formulation of a statistically valid distribution of material parameters for each of the pertinent geological units. These distributions were subsequently utilised to develop shear strength envelopes that replicated the behaviour of the geological units under various stress conditions, thereby enabling the effecting replication of batter stability at different lake levels. Figure 4 shows the distribution of material properties strength envelopes and for the critical coal interseam unit.
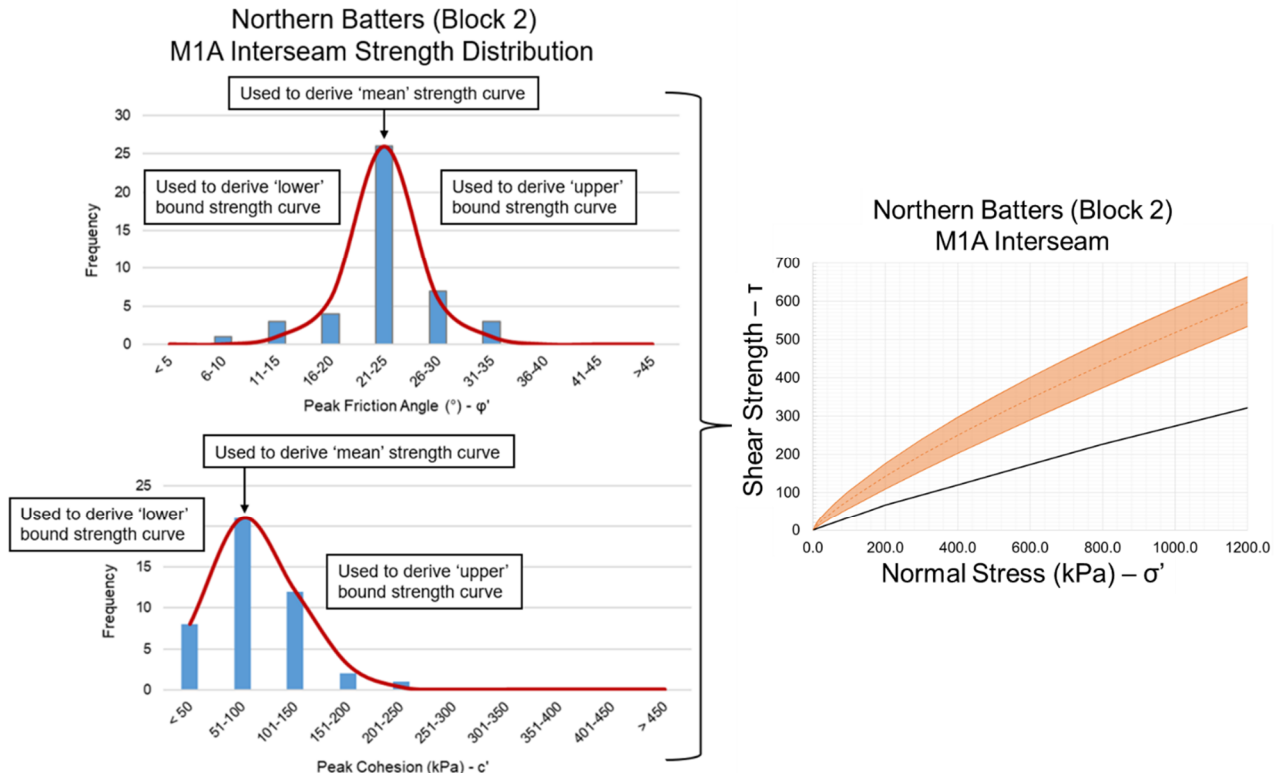

Figure 4   Example of M1A interseam strength distribution

3.4   Stability calculations

Upon developing the probabilistic geotechnical model as outlined above, limit equilibrium stability calculations were undertaken to calculate the following parameters:

- FoS: a ratio of the resisting forces against the destabilising forces. A FoS of less than 1.0 indicates that the sum of the driving forces is greater than the sum of the resisting forces. This implies that the slope is continually displacing (i.e. moving).

- PF: the PF is defined as the likelihood of the FoS falling below 1.0.

As part of the calculation process, three critical stability sections, as per Figure 5, were defined across the mine, each of which was subjected to analyses to assess the outcomes as a result of a filling mine void. Figures 6 and 7 depict the results of the FoS and PF variations for two critical stability sections, ST6 and NP17, at the various lake-fill levels, leading to the 'full lake' at the +45 mRL, respectively.
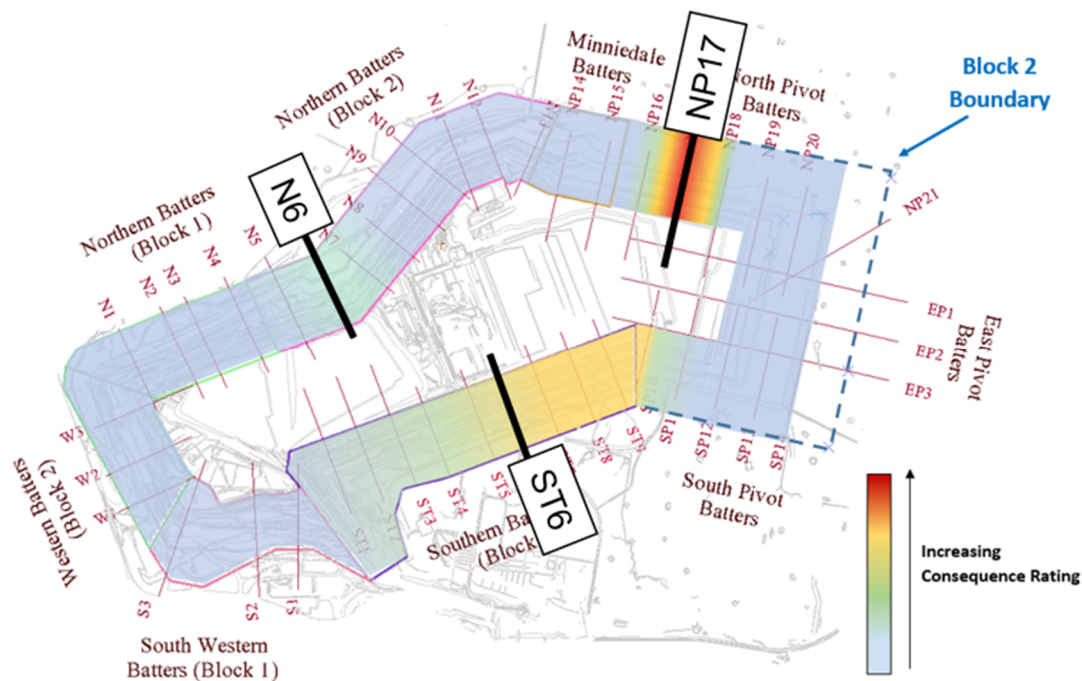

Figure 5   Potential high-risk areas during lake filling, after GHD (2022)

DAC for the LYM, considering the primary and global stability mechanism, were sourced from the CSIRO 'Guidelines for Open Pit Slope Design' (Read & Stacey 2009) and are as follows.

- Transient (i.e. during lake filling): FoS > 1.5 and PF < 5%.

- Post-closure: FoS > 2.0 and PF < 0.5%.

NB: the above criteria has been adopted as it aligns with Department of Jobs, Precincts and Regions (Victoria Mining Regulator) (2020) 'Geotechnical Guidelines for Terminal and Rehabilitated Slopes'.

From Figures 6 and 7 it can be seen that there is a comparative increase in the PF at the lower lake-fill levels. This, however, substantially reduces at RL +30 m. A similar trend is also noted when examining the distribution of the FoS for the respective stability sections, where an increase in FoS in the order of 2.0 or above is calculated at the higher lake levels.
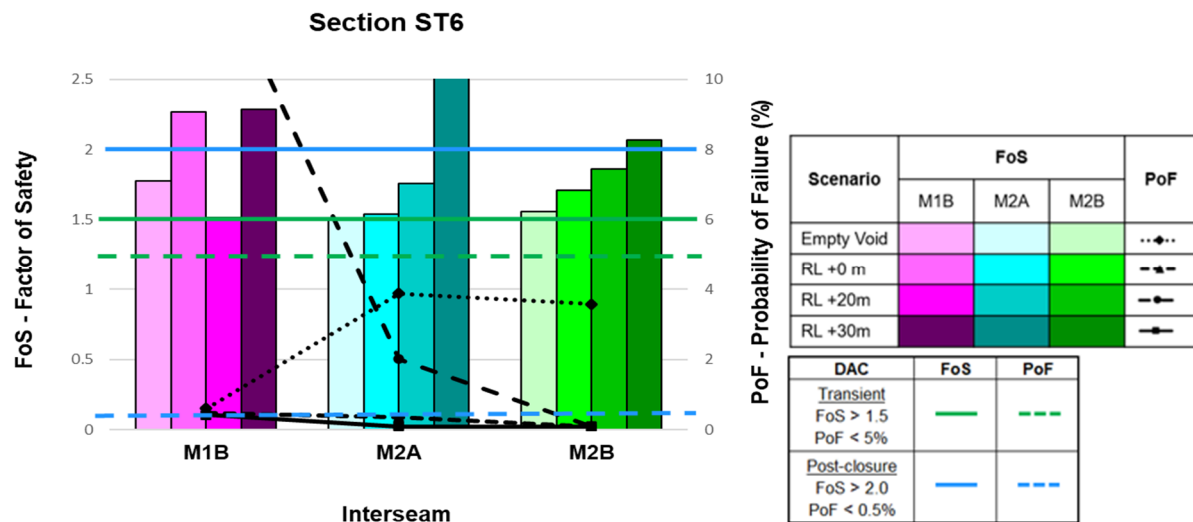
Section ST6

Figure 6   Stability analyses results – Section ST6
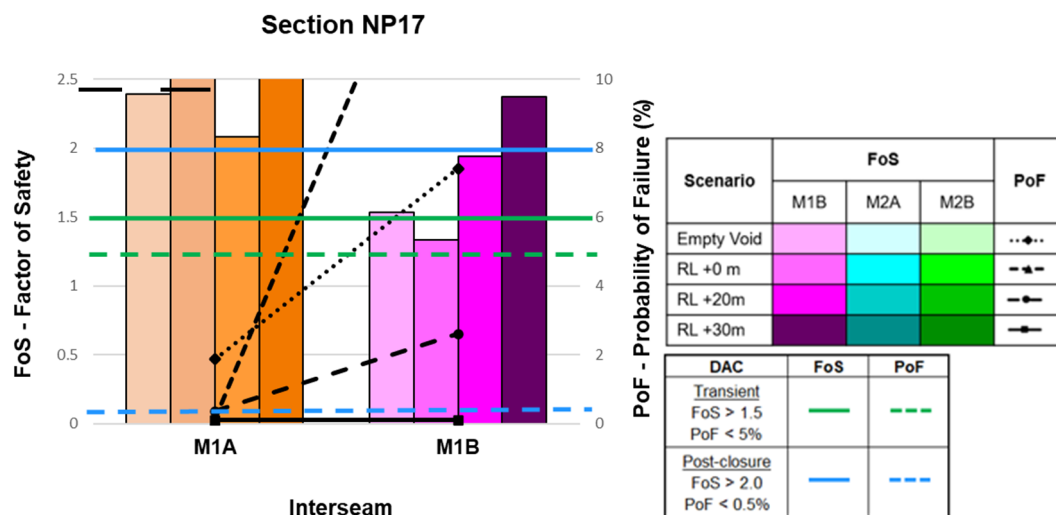
Section NP17

Figure 7   Stability analyses results – Section NP17

A critical pool level concept was originally identified by Raisbeck (1980) in relation to the Yallourn Mine. A critical pool is observed to occur between RL 0 m and RL +20 m for Section NP17, where the PF and FoS are at their highest and lowest, respectively. The point at which destabilising forces are at a maximum (e.g. groundwater pressures) and resistive forces are at a minimum (e.g. mobilised shear strength) is deemed the critical pool level. In the context of the LYM, multiple critical pool levels exist across the mine as block sliding may occur across multiple interseams, which is a unique geological feature of the LYM.

Of the lake-fill levels assessed, the stability performance of rehabilitated batters improved from the RL +30 m lake scenario, where the greatest increase in FoS and reduction in PF was calculated across all critical sections. On the contrary, there is an increase in the likelihood of instability at the lower lake levels, as reflected by the higher PF.

While there is a notable increase in the likelihood of internal instability for lower lake levels, the associated risk of the instability should be evaluated to determine if it is at a 'tolerable' level, and additional supplementation measures may need to be designed to manage these outcomes. Notwithstanding the above, the functionality and serviceability of the final landform must also be considered with due consideration to antecedent and prospective receptors around the periphery of the mine void. This has been further considered by Narendranathan et al. (2022) in the formation of a conceptual ground movement model.

3.5   Mine Geotechnical Risk Index assessment

As noted in Section 3.3, an increased likelihood of instability has been calculated during the lake filling process. In order to assess a tolerable FoS range, and to assist with the optimised design of any additional slope supplementation measures, the authors have adopted the MGRI approach to quantify risk associated with lake filling.

For the purposes of demonstrating the manner by which the MGRI calculations are undertaken, the following two-dimensional cross-section from the LYM for an RL +30 m lake, as depicted in Figure 8, has been selected.
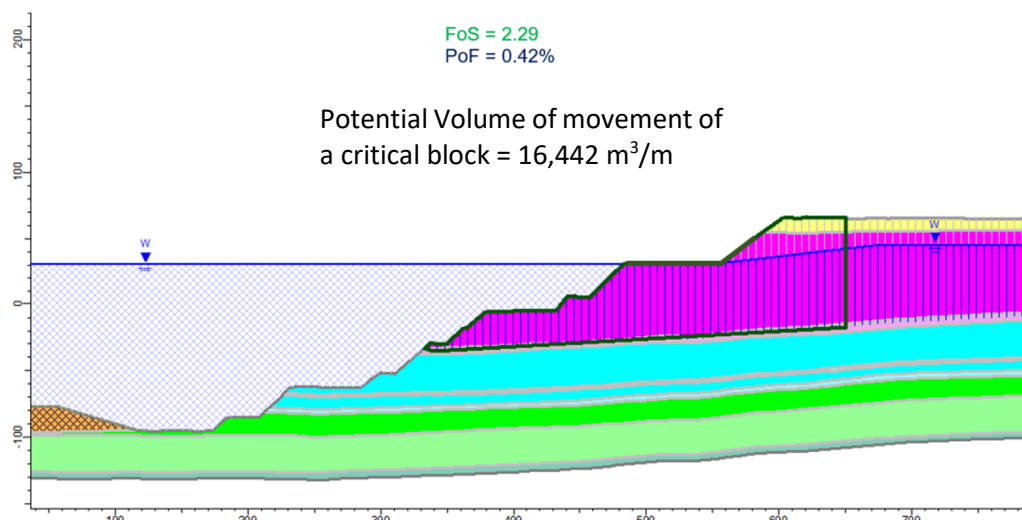

Figure 8   Stability calculations for Section ST6

Based on the calculations presented in Table 2, an MGRI of 0.86 has been calculated for this stability section. This value will serve as the metric against which comparative risk elevations will be assessed for the respective geotechnical domains within this risk. Using the process above, a geotechnical risk heat map has been developed for the LYM (Figure 5).

Table 2   Calculation of the MGRI at closure, assuming geotechnical risk management continues

Parameters	Value	Explanatory notes
PF	0.42%	Calculated PF (Figure 8)
Area (m^3/m)	16,442	Cross-sectional area of critical failure (Figure 8)
C_f	69.06	Consequence factor (PF × area)
PC_t	0.25	Based on an annualised probability of malfunctioning of the dewatering infrastructure
I_f	1.00	Assumption was that if the infrastructure arrangement became unserviceable, it could result in a 'severe' impact
S_f	0.05	Annualised probability, designs based on 1-in-20-year event
MGRI	0.86	Calculated as $PC_t \times C_f \times I_f \times S_f$

Table 3 presents the calculated MGRI value for the same geotechnical section, assuming a lake-filling stage of RL +20 m.

Table 3   Calculation of the MGRI at closure, assuming geotechnical risk management ceases

Parameters	Value	Explanatory notes
PF	13.93%	Calculated PF
Area (m^3/m)	17,352	Cross-sectional area of critical failure
C_f	2,417.13	
PC_t	0.25	Factors as Table 2
I_f	1.00	Factors as Table 2
S_f	0.05	Factors as Table 2
MGRI	30.21	
Delta	>29% increase in risk rating	

Based on the calculations summarised in Table 2 and Table 3, the outcomes indicate a partial lake fill of RL +20 m will result in a comparatively higher risk profile compared to RL +30 m. Furthermore, there is a theoretical (absolute) reduction in the overall risk profile by approximately 3500%. The overall risk for the RL +20 m partial lake is well beyond acceptable tolerances put forward by Narendranathan et al. (2019) as outlined in Table 1 of this paper. This demonstrates that leaving this slope untreated during the transient stage could result in risks in excess of a tolerable threshold.

Similar calculations were performed for other critical sections across the LYM for block sliding on the critical interseam, three of which are presented in Table 4.

Table 4   MGRI risk map of untreated batters for design closure scenarios

Geotechnical stability section	Dry void – starting pit lake (year 0)	RL 0 m	RL +20 m	RL +30 m
ST6		≤0%	>29%	2%
NP17	Base case	>29%	≤0%	≤0%
N6		12%	10%	≤0%

Based on Table 4, it can be seen that during the transient phases of lake filling of RL 0 m and RL +20 m will result in a comparatively higher risk profile compared to both the dry void and RL +30 m. The overall risk at these lake levels vastly exceeds the 'tolerable' thresholds as defined by Narendranathan et al (2019), as outlined in Table 1. As such, there are a number of sections within the LYM that require additional treatment should the final landform include a partial pit lake. The above exercise also demonstrates the impracticalities of a partial long-term lake scenario.

3.5.1   Using the MGRI approach to determine batter supplementation measures

The previous section outlined that the lake-filling process can result in an elevated increase the likelihood of instability, which requires the implementation of supplementary slope management/reinforcement measures. The measures under consideration included the installation of surcharges (i.e. bench and toe buttresses), slope flattening and additional slope drainage measures to manage the coal water gradient and joint water levels. Various iterations were considered and calculated (i.e. buttress design dimensions and drainage considerations).

Presented in Figure 9 are the results of the stability calculations incorporating slope supplementation measures (i.e. buttress), which indicate an increase in the FoS and a reduction in potential failure volume relative to the base case scenario. Table 5 presents the calculation of the MGRI for this section incorporating the slope stabilisation measures.
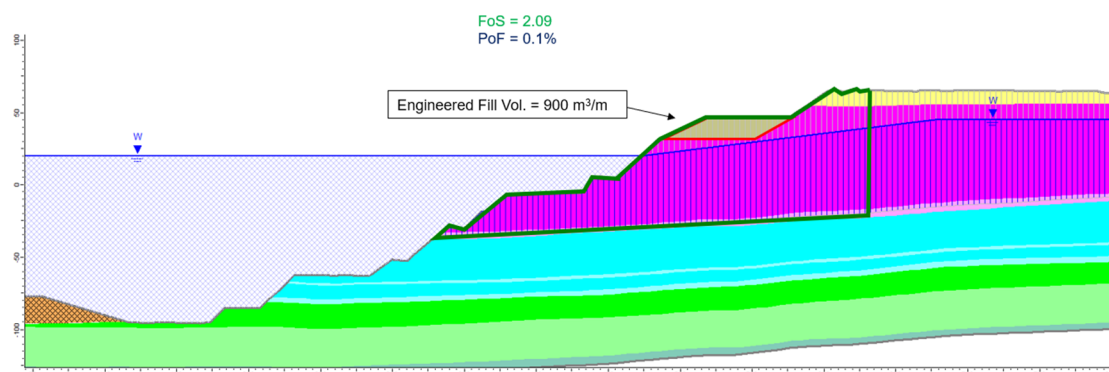

Figure 9   Derived slope stabilisation measures

Table 5   Calculation of the MGRI incorporating slope stabilisation measures

Parameters	Value	Explanatory notes
PF	0.10%	Calculated PF (Figure 9)
Area (m^3/m)	14,466	Cross-sectional area of critical failure (Figure 9)
C_f	14.47	Consequence factor (PF × area)
PC_t	0.25	Factors as Table 2
I_f	1.00	
S_f	0.05	Active groundwater management maintained post-closure
MGRI	0.18	
Delta	39% decrease	

The MGRI approach was applied for other critical stability sections across the LYM for the block sliding mechanism on the critical interseam, and the resultant values are presented in Table 6. The derived supplementary slope measures for each section are subsequently summarised in Table 7.

Table 6   Derived slope stabilisation measures

Geotechnical stability section	Dry void – starting pit lake (year 0)	RL 0 m	RL +20 m	RL +30 m
ST6		≤0%	≤0%	2%
NP17	Base case	≤0%	≤0%	≤0%
N6		≤0%	≤0%	≤0%

Table 7   MGRI risk map of treated batters

Geotechnical stability section	Lake-fill level	Volume of surcharge (m³/m)	Slope flattening[1]	Active groundwater management
ST6	RL 0 m	No supplementation required	Not required	✓
	RL +20 m	900	✓	✓
	RL +30 m	No supplementation required	Not required	✓
NP17	RL 0 m	5,474	✓	✓
	RL +20 m	–	✓	✓
	RL +30 m	No supplementation required	Not required	✓
N6	RL 0 m	1,001	✓	✓
	RL +20 m	1,001	✓	✓
	RL +30 m	No supplementation required	Not required	✓

[1]Slope flattening/reprofiling is required to facilitate for bench/toe surcharging.

By using the MGRI approach, it is demonstrated that the application of surcharges across critical areas, particularly during lake filling, can improve stability conditions and subsequently reduce the stability-related risks to a 'tolerable' threshold. Once surpassing the RL +30 m in pursuit of a full lake, stability outcomes improve notably.

3.5.2   Mine closure considerations

In addition to stability considerations, the final rehabilitation outcomes must also account for the degree of active care and maintenance required, in addition to the potential for beneficial end land use.

The adoption of an empty void, or indeed partial lakes, as the final closure scenario would require the greatest level of active care and maintenance in perpetuum, which, in the authors opinion, would be impractical and also results in an elevated risk profile into perpetuity and would preclude post mine closure beneficial land use. For a partial lake-fill scenario, the level of active care and maintenance required to maintain a safe and stable landform is considered to be similar to that of an empty/dry-void scenario, as outlined above.

4   Conclusions and stability considerations during lake filling and mine rehabilitation

The authors would like to highlight that in this particular context at the LYM, the designed supplementation measures (surcharges) are only intended to provide supplementation prior to the lake recovering to a coincident level, whereby the surcharges become progressively superfluous at this point as lake forces provide an equivalent stabilising effect (Figure 10).

This case study demonstrates how the MGRI approach was successfully employed in the development of slope supplementation measures during the transient phase of mine rehabilitation, prior to the establishment of the final mine landform. It furthermore highlights the benefits of employing a full lake-fill level for mine rehabilitation as it offers an overall lower risk profile, more potential beneficial end land use options and, as such, value added outcomes.
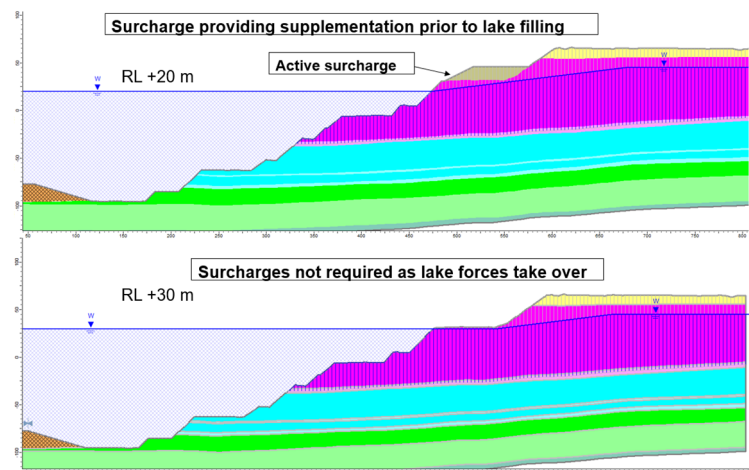
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Figure 10 Interaction of surcharge and lake forces

Acknowledgement

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