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A case study of Loy Yang Mine: geotechnical considerations when remediating heat affected coal batters

S Narendranathan *GHD Pty Ltd, Australia*

N Patel *GHD Pty Ltd, Australia*

A Symonds *AGL Loy Yang, Australia*

Abstract

Spontaneous combustion in the Latrobe Valley brown coal mines is a complex challenge that faces all mine operators in the region. If not adequately controlled, it can result in a number of issues including batter instability and loss of coal supply for the state's energy supply. From a geotechnical perspective, the authors consider that there is little guidance information available for the treatment of spontaneous combustion in brown coal and seek to share their experiences amassed at a Latrobe Valley brown coal mine. The current owner and operator of a Latrobe Valley open cut brown coal mine has recently successfully completed rehabilitation of a 'hot spot' which occurred along the southern batters of the pit. The subject area of this study, within the mine, was observed to have started combusting in early 2010 and, more actively, in 2020, when steam vents appeared along existing geological features in the coal that remained dilated from a past episode of batter movement (i.e. a batter slump) which occurred after a storm event in 2007. This paper presents a case study of the geotechnical slope stability assessments undertaken as part of the hot spot remediation. Owing to the criticality of this infrastructure carrying slope domain, which, if adversely affected, had the potential to disrupt operations at the largest coal mine in Victoria, the authors espoused a risk-based approach to the stability assessments using the Mine Geotechnical Risk Index approach, after Narendranathan & Cheng (2019).

Keywords: *rehabilitation, spontaneous combustion, brown coal, open pit, mining, slope stability, risk*

1 Introduction

Mining of brown coal in the Latrobe Valley began in the early 1920s under the management of the State Electricity Commission of Victoria (SECV). During the 1990s, the Latrobe Valley mines were privatised. For the current owners of the respective open cut mines, the development presents a number of stability-related challenges, including spontaneous combustion of the brown coal. If not adequately controlled, spontaneous combustion can result in batter instability, a potential disruption of operations and a diminishing loss of ability to control the activity.

Recently, an operator of an active brown coal mine in the Latrobe Valley Region of Victoria successfully completed rehabilitation of a 'hot spot' which occurred along the southern batters of their mine. The subject area of this study is presented in Figure 1, hereafter referred to as the area of interest (AOI). This area was observed to have started combusting in early 2010 and the activity significantly increased in early 2020, when steam vents appeared along existing geological features in the coal that remained dilated from a previous episode of batter movement (i.e. a batter slump) which occurred after a storm event in 2007.

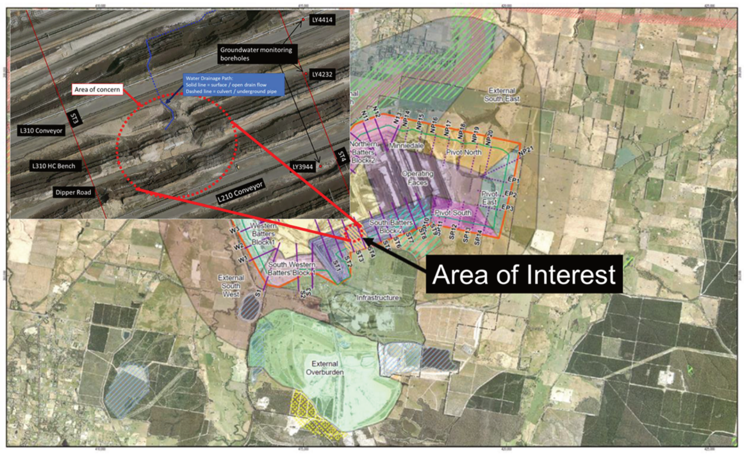

Figure 1 Area of interest at the mine

The southern batters are located in a critical area of the mine due to the presence of coal conveyors which transport excavated brown coal to the power station for subsequent energy generation.

Owing to the criticality of this infrastructure-carrying slope domain, which, if adversely affected, had the potential to disrupt operations at the mine, the authors espoused a risk-based approach to the stability assessments in determining the most suitable remedial measures using the Mine Geotechnical Risk Index (MGRI) approach, after Narendranathan & Cheng (2019).

This process involved probabilistic modelling of the remediation process, which required careful consideration of critical factors such as the staging of the excavation, the influence of in situ hydrostatic and aquifer pressures on multiple coal and associated interseams, the influence of geological defects, the batter geometry, the presence of critical infrastructure (i.e. coal conveyors), and the presence of variably 'heat affected' material (i.e. burnt coal and interseam). This paper presents a case study of the geotechnical slope stability assessments undertaken as part of the hot spot remediation for this mine.

1.1 Remediation objective

The objective for the proposed remediation design and subsequent earthworks was the following:

- Develop a design that aims to achieve safe remediation and rehabilitation.
- Ensure key mine infrastructure is protected.
- Develop a final remediated batter profile which achieves the requisite design acceptance criteria.
- Target heated zones above 50°C.

1.2 Determination of the extents of activity

In undertaking a detailed assessment of the spontaneously combusting area, data was sourced from investigative drilling, historical data of past activity, geophysical mapping, coal jointing mapping and thermistor monitoring within sub-horizontal drainholes. This assisted with delineating the AOI (i.e. lateral extents of the affected area were determined to encapsulate five main active joint sets and persistence (i.e. depth of defects) from which smouldering gases were venting).

2 Methodology

2.1 Instability mechanisms

Immediately following the elevation of the spontaneous combustion activity, hence the urgency for remedial action, the authors developed a staged excavation and rehabilitation design for the remediation of the AOI.

A probabilistic batter stability assessment was undertaken on these designs, including an analysis of the potential impacts associated with the application of targeted cooling on the batters and vent holes in a controlled manner to assist with extinguishing the hot spot. The assessment required the calculation of suitable stability thresholds to ensure that resulting elevations in coal joint water levels did not trigger instabilities.

Two potential batter instability mechanisms were identified for the AOI:

- The primary (i.e. global) instability mechanism is large-scale coal block sliding.
- The secondary mechanism was identified as small-scale wedge sliding and or toppling.

Coal block sliding can occur when the destabilising force (i.e. a build-up of hydrostatic pressure in coal joints from targeted cooling) is greater than the resisting force (i.e. in situ material strength), as depicted in Figure 2. This mechanism typically results as shear movement within the underlying interseam or near the interface of the interseam and overlying in situ coal seam. In the context of the AOI remediation, the assessment required the calculation of suitable thresholds to ensure that resulting elevations in coal joint water levels did not trigger instabilities.

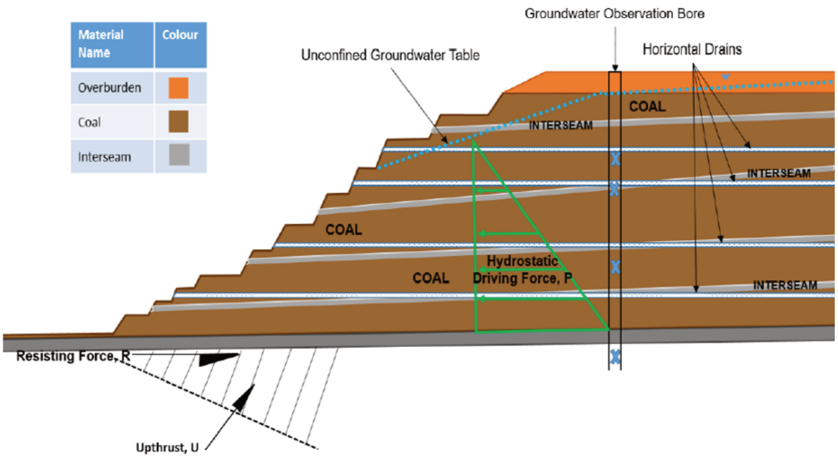

Figure 2 Schematic of driving and resisting forces acting on the batters

Structurally controlled mechanisms such as wedge sliding occurs as a result of the ubiquitous jointing within the coal unit. This mechanism results from the intersection of structural defects (e.g. joints, shears, cleavage planes) within the coal unit and with the exposed slope face.

This paper presents the results of the outcomes of the slope stability modelling undertaken on:

- The pre-excavation batter profile (i.e. 'as-surveyed' profile).
- The proposed staged excavation and the rehabilitation geometry.

Rocscience's 2D limit equilibrium (LE) modelling software, Slide2 (Rocscience 2020a), was utilised to probabilistically assess primary block sliding mechanism across the above outlined phases. Owing to the presence of multiple interseams (M1B and M2A) at the AOI, the authors assessed the potential for block sliding along both interseams (i.e. M1B and M2A) using domain specific interseam material strength parameters. Slope stability performance was measured by comparing the calculated outcomes (i.e. Factor of Safety (FoS) and Probability of Failure (PoF)) against the nominated design acceptance criteria (DAC). Rocscience's 3D LE modelling software, SWedge (2020b), was utilised to assess the potential for wedge blocks to result at the AOI from the intersection of mapped coal defects and the slope face.

2.2 Design acceptance criteria basis

The DAC adopted for this assessment was nominated in accordance with CSIRO's *Guidelines for Open Pit Slope Design* (after Read & Stacey 2009). The DAC has been stipulated as follows:

- The short-term conditions (i.e. during remediation and excavation), whereby active management protocols are to be implemented, including frequent geotechnical inspections and monitoring.
- The long-term conditions (i.e. post-rehabilitation), whereby routine inspections and monitoring is to be undertaken.

Table 1 provides a summary of the nominated DAC.

Table 1 Design acceptance criteria

Remediation phase	Design acceptance criteria	
	Mean Factor of Safety	Probability of Failure (non-annualised)
Targeted cooling (temporally restricted)	>1.2	–
Short-term conditions	>1.3	<15%
Long-term conditions	>1.6	<8%

Based on the potential for a batter instability to impact coal delivery of the mining operation, and the proximity to critical mine infrastructure such as power lines, conveyor belts, and major haul roads, a (mean) FoS of greater than 1.2 and PoF less than 15% was nominated for the short-term conditions. A (mean) FoS of greater than 1.6 and PoF of less than 8% was nominated for the post-rehabilitation phase.

In addition to assessing the base case scenario (i.e. using 'expected' material strength parameters), the authors undertook a stability check for an extreme loading case. This extreme case was analysed using degraded material strength parameters to model heat and fire affected material including an elevated groundwater gradient. This extreme case scenario was assessed against the short-term DAC.

An FoS of 1.2 was adopted for the analyses considering the application of targeted cooling on the batters. The loading (i.e. dousing with water) is temporally restricted and as such, a slightly lower FoS (i.e. FoS 1.2) was adopted.

3 Material parameters

3.1 Interseam parameters

Material parameters adopted for the assessment were obtained from the mine operator's site ground control management plan and have been derived based on laboratory test data amassed since the mine's inception. To facilitate probabilistic 2D LE modelling, statistical material parameter ranges based on trigonometric probabilistic functions were adopted for the assessment.

3.2 Degradation of material strength as a result of smouldering

Owing to the fact that the in situ materials at the AOI were being mechanically degraded due to heating, thereby resulting in a degree of strength loss, the authors relied on industry published precedents and observations at the Latrobe Valley coal mines to account for the effects of heating on the materials with regards to the stability modelling inputs. It should be noted that the effect of heat on soil material strengths has not been extensively studied for the geological units in the Latrobe Valley. Therefore, the authors have conservatively modelled the heat affected materials, i.e. heat affected coal as 'ash' (i.e. degraded strength).

Studies undertaken by Basma et al. (1994) and Abu-Zreig et al. (2001) indicated that clay soils (analogous to the interseams) which are subjected to heating resulted in a slight initial increase followed by a decrease in the shear strength of the clay material as the temperature further increased. Additionally, other mechanical properties such as particle size and plasticity were also affected by the heating. The authors inferred that the heat from the smouldering could affect the materials in the AOI in a similar manner. It is anticipated that the heat affected area is within the M2A coal and interseam and limited by the upper M1B interseam. To account for these effects, the authors assumed that the material strengths may approach residual strength parameters. A stability check of this extreme loading case was performed, the results of which are presented in the subsequent sections of this paper.

Accordingly, to conservatively replicate these potential outcomes in the stability modelling process, the authors have pessimistically applied the characteristic strength values commensurate of a lower bound skewed distribution. This approach preferentially samples material strength combinations within the lower bound extent of the shear strength distribution and conservatively under samples the mean and upper bound strength combinations. Table 2 outlines the material parameters and Figure 3 depicts the M1B and M2A interseam shear strength curves.

Table 2 Summary of material parameters

Material	Unit weight, kN/m³	Effective shear strength		Statistical interseam strength			
		Cohesion, c' (kPa)	Friction angle, ϕ' (°)	Peak cohesion, c' (kPa)	Peak friction angle, ϕ', (°)	Residual cohesion, c' (kPa)	Residual friction angle, ϕ', (°)
Overburden	19.0	50	26	–			
Clay fill (surcharge)	18.0	5	26	–			
M1B coal	11.2	150	35	–			
M1B interseam	19.0	–		60.7	28.6	20.1	28.4
M2A coal	11.2	150	35	–			
M2A interseam	19.0	–		100.9	27.8	28.7	25.9
M2A interseam (heat affected)	19.0	–		40	13	0	0

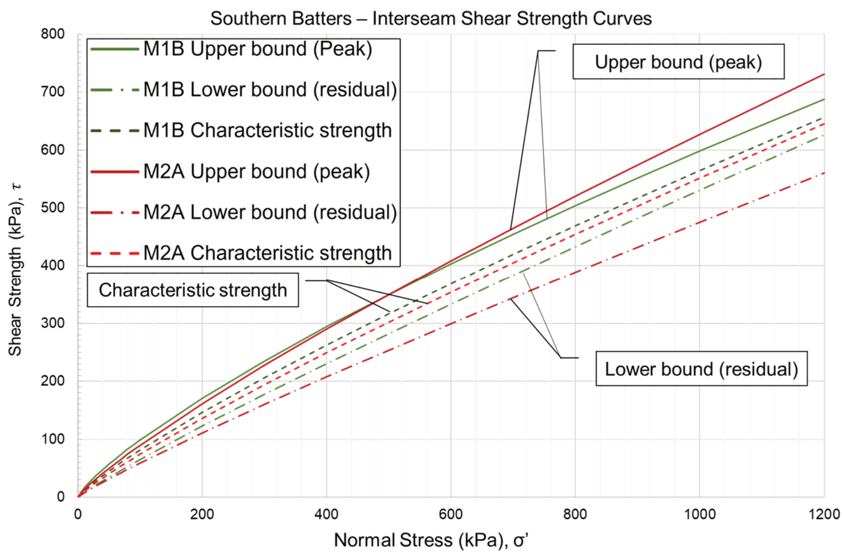

Figure 3 M1B and M2A interseam strength curves

3.3 Modelled scenarios

The authors undertook stability modelling for a number of key scenarios based on the available survey information and the provided staged excavation design. The scenarios analysed are outlined below:

- Pre-excavation profile: base case conditions (global scale instability) (Figure 4).
- Pre-excavation profile: degraded material strengths (global scale instability) (Figure 4).
- Assessment of staged excavation (i.e. using the 'heat affected' parameters) (Figure 5).
- Critical coal joint water level sensitivity analyses for:
  - Stage 1.
  - Stage 2.
  - Stage 3.
  - Stage 4.
  - Stage 5.
- Localised stability check: potential targeted cooling considerations (i.e. temporal elevations).
- Long-term stability analyses: rehabilitation design.

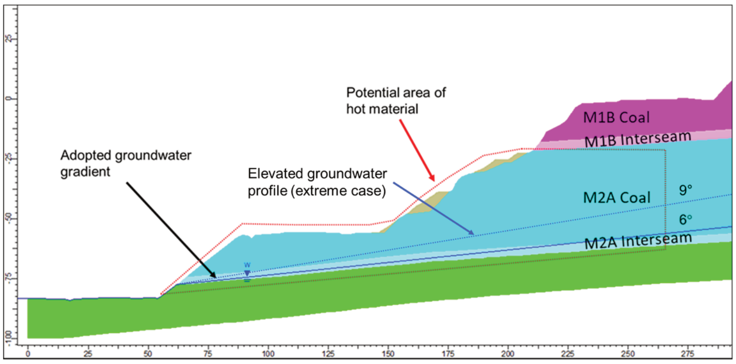

Figure 4 Schematic of batter profile: base case conditions and extreme case

The proposed staged excavation geometry is presented in Figure 5 as a series of 'cuts' from top to bottom.

The 'green' line indicates the 'as-surveyed' geometry. The 'blue' line indicates the 'maximum excavation batter profile'. A slightly 'lighter coloured blue' line indicates the horizontal 'base' of the overlying excavation stage. The remediation design, including clay backfill, is indicated by the dashed 'orange' line.

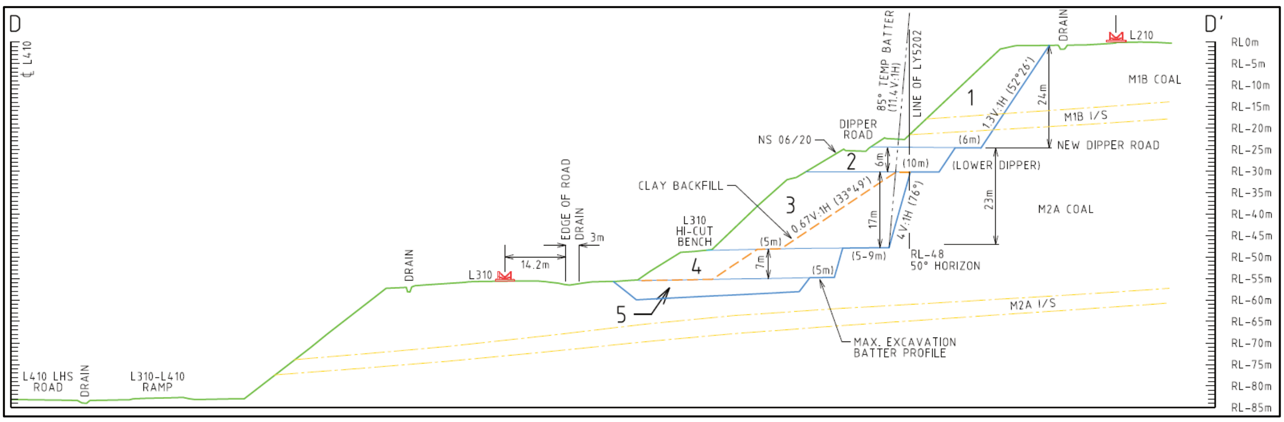

Figure 5 Schematic of staged excavation profile

4 Results of analyses for remediation design

4.1 Short-term stability analyses

4.1.1 Base case conditions: pre-excavation profile (global scale)

The results of the stability calculations for the current batter geometry (for block sliding on the M1B and M2A interseams) under expected base case conditions are presented in Table 3. The following points are noted for this scenario:

- 6° groundwater gradient (note: actual measured groundwater gradient ranges from 3–5°) was adopted.
- This scenario has been modelled as the 'base case' using the characteristic shear strengths.

Table 3 Summary of results pre-excavation profile: base case conditions

Block sliding on interseam	Factor of Safety	Probability of Failure (%)
M1B	1.91	0.2
M2A	1.64	0.4

The above results indicate that the design section meets the short-term and long-term DAC for block sliding along the M1B and M2A interseams.

4.1.2 Pre-excavation profile (global scale) incorporating degraded material strengths

The results of the global scale stability analyses, incorporating degraded material strengths, are presented in Table 4.

- A 9° groundwater gradient was adopted. This was modelled to simulate an increase in coal water levels as a result of temporarily sealing sub-horizontal drainholes to prevent oxygen ingress (i.e. as a source of fuel) into the smouldering area.
- 'Heat affected' material parameters adopted within the potential area of hot material.

Table 4 Summary of results pre-excavation profile: extreme case conditions

Block sliding on interseam	Factor of Safety	Probability of Failure (%)
M1B	1.91	0.2
M2A	1.43	17.3

The above results indicate the following:

- The short- and long-term DAC is satisfied for the degraded material strength case analyses considering block sliding along the upper M1B interseam.
- The stability calculation outcomes for block sliding along the M2A falls below the long-term DAC, however, the short-term FoS criteria is achieved, noting that the resultant PoFs are marginally higher than the nominated short-term criteria (i.e. 17.3% > 15%).

A comparison of the stability outcomes for the base case and the degraded material strength case are depicted in Figure 6.

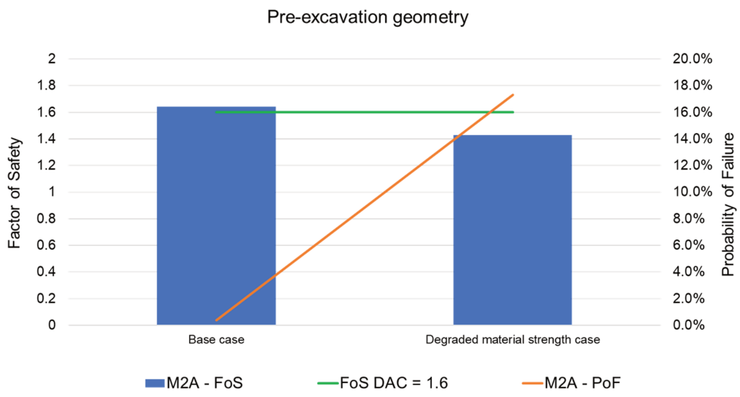

Figure 6 Summary of results: comparison of base case and degraded material strength case

The authors note that for the degraded material strength analyses and the extent of degradation/weakening of the interseam, materials was unknown. Based on the degraded material strengths adopted for the assessment, the authors developed a staged excavation design (Figure 5) with the intent to completely remove all heat affected material from the AOI, using a 'top-down' approach. Accordingly, to minimise the potential for batter instabilities, the batters were excavated to unaffected in situ materials. Delineation of heat affected materials was undertaken using intrusive investigation.

The results of the pre-excavation analyses, as presented in Figure 6, indicate an expected reduction in stability performance considering block sliding on the M2A interseam between the expected case to the degraded material strength case.

4.2 Assessment of remediation excavation

4.2.1 Assessment of staged excavation profile

The results, presented in Figure 7, were calculated for each stage of excavation using 'heat affected' material strengths, for block sliding on the M1B and M2A interseams.

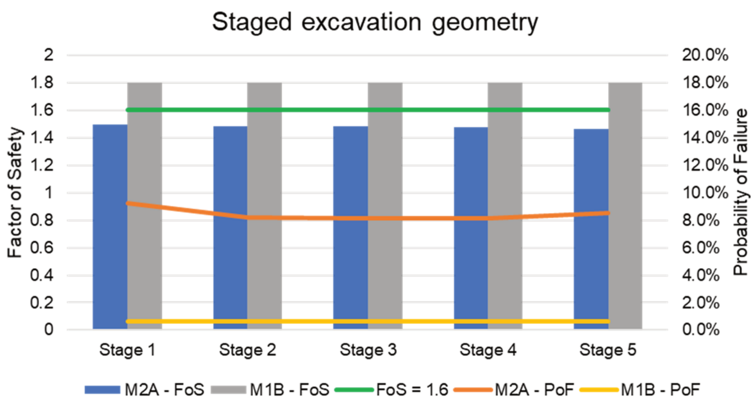

Figure 7 Summary of results: staged excavation profile

Based on stability outcomes, a slight decrease in FoS was calculated for block sliding on the M2A interseam for each progressive excavation stage (i.e. relative to the base case results). The results indicate that for block sliding on the M2A interseam, the long-term DAC criteria were not satisfied for the remediation design, however, the short-term criteria were achieved. Note, the intent was to achieve the 'long-term' criteria upon completion of the final excavation stage and placing a reinforcing buttress along the face of the slope, and this is discussed further in Section 4.3. For block sliding on the M1B interseam, both the short- and long-term DAC were achieved for the remediation geometry.

4.2.2 *Coal joint water level sensitivity during staged excavation*

As the areas of this batter were to be subjected to targeted water cooling as part of firefighting activities, coal joint water level sensitivity assessments were undertaken so as to calculate maximum tolerable hydrostatic conditions within the affected batters. However, based on the authors' experience in the Latrobe Valley, these hydrostatic pressures typically and readily dissipate as a result of localised batter movements within the area (caused by increases in hydrostatic pressure) leading to joint dilation, resulting in increased coal mass permeability and thereby reducing the hydrostatic head. However, this is a very delicate state and needs to be very carefully managed with robust monitoring protocols as will be outlined below.

The authors nominated a target FoS of 1.2. This target FoS was considered suitable due to the temporally restricted and controlled application of targeted cooling. A robust monitoring and inspection plan was put in place leading up to and during the remediation works.

Based on the above, stability calculations were performed for the elevated coal joint water level scenario for each stage of the excavation. The results presented in this section are based on a block sliding mechanism on the M2A interseam. Critical coal joint water levels were calculated to develop trigger action response plans during remediation. The critical coal joint water level was calculated by charging the modelled tension crack, until a resultant critical coal block with FoS less than 1.2 was achieved. Figure 8 presents a schematic of how this was performed for the Stage 5 excavation.

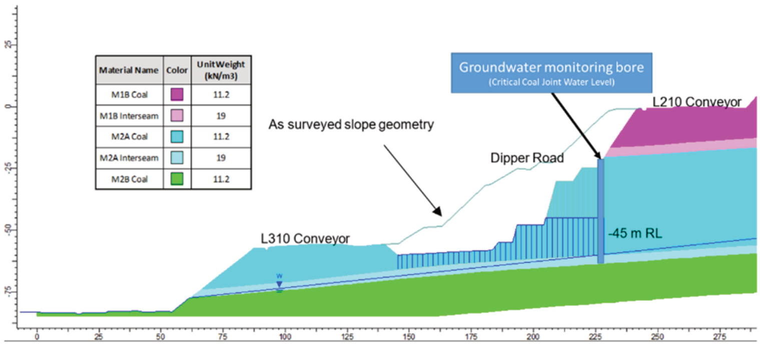

Figure 8 Schematic of coal joint water level (-45 mRL) analysis

Figure 9 presents the stability outcomes for Stage 5 excavation for the elevated coal joint water level analysis. For this analysis, it was been assumed that the preceding stage of excavation had been completed.

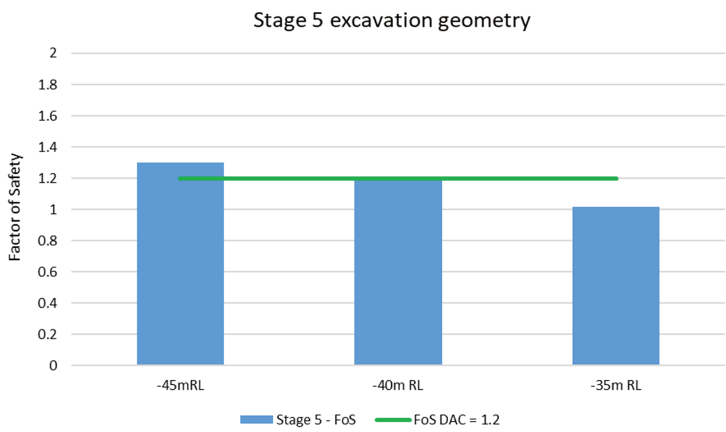

Figure 9 Summary of results, Stage 5 excavation: elevated coal joint water level

Based on the results above, coal joint water levels of -45 mRL or lower would be needed for this excavation stage to ensure an FoS of greater than 1.2 was maintained.

5 Risk-based approach to select optimal rehabilitation design

5.1 Introduction to Mine Geotechnical Risk Index approach

The authors have applied a quantitative risk and consequence measure originally put forward by Lilley (2000), which was subsequently refined by Narendranathan et al. (2009) and further in 2019, which led to the development of a metric referred to as the MGRI (Narendranathan & Cheng 2019).

Lilley (2000) states that the 'reliability' (or confidence) of a particular stability scenario outcome can be defined as (1-PoF) %. For example, say the PoF for a particular scenario is 5%, the confidence associated with that scenario is 95%, with a likelihood that 5% of the domain would have a (mean) FoS less than the acceptance criteria. However, utilising the PoF value as a comparative measure can be challenging, as the proportional implications associated with a potential failure (movement) is not captured in this value. For example, a batter with a high PoF may have a low consequence of failure. Accordingly, as outlined in Narendranathan & Cheng (2019), one way to overcome this is to include a comparative rating by multiplying the potential volume of movement by the calculated PoF.

5.2 Remediation design risk profile

Table 5 outlines the consequence rating calculated for the pre-excavation profile, considering the base case and degraded material strength case.

Table 5 Consequence ratings (after Lilley 2000 and Narendranathan & Cheng 2019)

Scenario	Probability of Failure	Volume of possible movement (m^3/m)	Consequence rating
Pre-excavation profile – base case	0.38%	28,573	110
Pre-excavation profile – degraded material strength case	1.8%	24,662	445

5.2.1 Iterative refinement of rehabilitation design

The authors assessed a number of different rehabilitation design concepts, with an aim to selecting the profile which achieved the lowest consequence rating, noting that one of the challenging constraints within the AOI was ensuring that the rehabilitation design could be readily and easily implemented in a practical manner whilst mitigating potential risk of further spontaneous combustion. This was an iterative process which involved a number of scenarios. The selected design is presented in Section 6.

6 Long-term stability analyses: rehabilitation design

6.1 Block sliding assessment of global stability along M2A interseam

The outcomes of the remediation geometry analyses indicated that in order to achieve the long-term DAC for block sliding on the M2A interseam, slope supplementation measures (i.e. surcharge backfill) would be required to augment the remediation profile to provide confinement at the base of the critical coal block. Accordingly, a technical specification was developed, which outlined the fill placement criteria and quality control processes to ensure a consistent and uniform density was achieved for the buttress, in order to achieve the long-term DAC. Figure 10 depicts the rehabilitation batter profile required to achieve the long-term DAC.

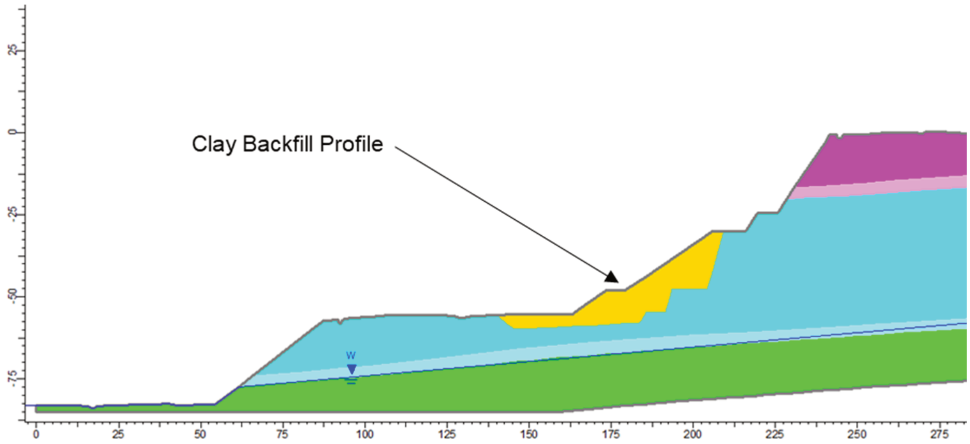

Figure 10 Schematic of rehabilitation design

The rehabilitation design geometry was assessed using both the expected case and the degraded material strength case. The results for the analyses are presented in Table 6.

Table 6 Summary of results: rehabilitation design

Block sliding on interseam	Maximum hydraulic gradient	Factor of Safety	Probability of Failure (%)
M2A (degraded material strength parameters)	5°	1.61	0.67
M2A (base case material strength parameters)	5°	1.77	0.11

The results outlined in Table 6 indicate that the assessed stability section, with due consideration to the global block sliding mechanism, improves with the proposed rehabilitation batter profile (i.e. relative to the 'base case' staged excavation results).

6.2 Consequence rating achieved

The premise of implementing the most feasible rehabilitation design was to achieve a significantly lower consequence rating than that calculated for the pre-excavation profile. The comparative reduction in risk is presented in Table 7.

Table 7 Consequence ratings (after Lilley 2000 and Narendranathan & Cheng 2019)

Scenario	Probability of failure	Volume of possible movement (m^3/m)	Consequence rating	Percentage reduction in risk
Pre-excavation profile: base case	0.38%	28,573	110	77%
Rehabilitation design: base case	0.11%	22,814	25	
Pre-excavation profile: degraded material strength case	1.8%	24,662	445	66%
Rehabilitation design: degraded material strength case	0.67	22,814	152	

From the comparison, the following points are noted:

- The rehabilitation design (with the expected material strength parameters) results in the lowest consequence rating (i.e. 25) calculated across all analysed scenarios.

- With the proposed construction of rehabilitation design, the calculated proportional reduction in risk decreases significantly as follows:
  - 77% reduction in risk for the scenario modelled using the expected material parameters.
  - 66% reduction in risk for the scenario modelled using the degraded material strengths (i.e. for heat affected material).

7 Kinematic considerations

Extensive information and data on coal joint/s was utilised to perform a kinematic potential stability analysis. The defect database contains a dataset of 6,997 defect orientations (mainly joints), the dip and dip directions of the defects, and additional discontinuity characteristics which have been recorded during various mapping campaigns at the mine.

The assessment was undertaken using the defects mapped in the AOI, and, more broadly, the defects mapped along the southern batters, to assess the likelihood and probability of structurally controlled failures manifesting in the AOI.

A stereographic projection of data from the defect database has been undertaken using Rocscience's DIPS software (Rocscience 2017). The stereonet plot (Figure 11) presents poles of 6,997 defects currently mapped, which consist of interpreted geological features. The interpreted major defect sets identified are summarised in Table 8.

Table 8 Summary of major defect sets at the mine

Defect set	Mean dip/dip direction (SECV grid)*	Description
D1	84°/084°	Sub-vertical major joint
D2	86°/265°	Sub-vertical major joint
D3	87°/236°	Sub-vertical major joint
D4	84°/057°	Sub-vertical major joint
D5	14°/331°	Bedding/joints

*Mean measured from stereonet based on the State Electricity Commission of Victoria (SECV) grid coordinate system

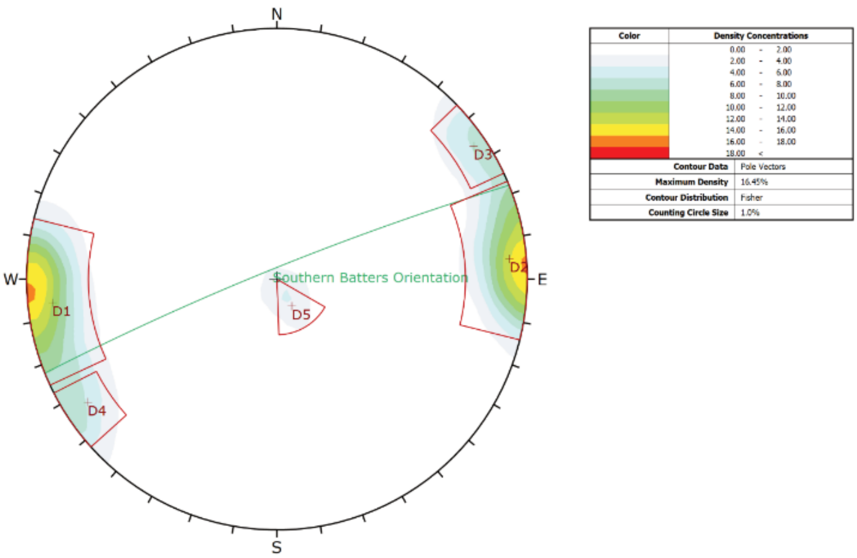

Figure 11 Mapped defects at the mine's southern batters

The (tetrahedral) wedge sliding mechanism was identified as a potential structurally controlled instability mechanism. The mechanism can eventuate as a result of the intersection of two distinct defect sets that form a tetrahedral wedge in 'space'. The formation of the wedge is contingent upon the respective geological defects being sufficiently persistent (i.e. long enough) to intersect each other. The authors consider that this may not always be the case with coal joints within the mine, which have been observed as being ubiquitous.

This instability mechanism was assessed by conservatively utilising residual coal joint strength parameters (i.e. friction angle of 35°).

The toppling mechanism (direct toppling) has also been identified as a potential kinematic instability, however, based on the authors' experience in the Latrobe Valley and ubiquitous jointing within the brown coal at this mine, this mechanism is typically of low volume and this may occur during excavation. The authors note that the contributing defects to this instability mechanism are rarely persistent enough, nor closely spaced enough, for this mechanism to manifest with any degree of criticality.

The kinematic assessment was not assessed against the MGRI as these identified structures are considered to be secondary instability mechanisms.

7.1 Potential for tetrahedral wedge sliding

The tetrahedral wedge sliding mechanism was assessed using Rocscience's SWedge (Rocscience 2020b) software package.

The results of the analyses indicate that the likelihood of tetrahedral wedge formations is approximately 13% and the maximum potential volume of instability is less than 44 m^3 (Figure 12). The authors consider that due to the limited volumes of wedges formed, it is demonstrated that potential wedge sliding was not considered to be the critical instability mechanism for the global scale.

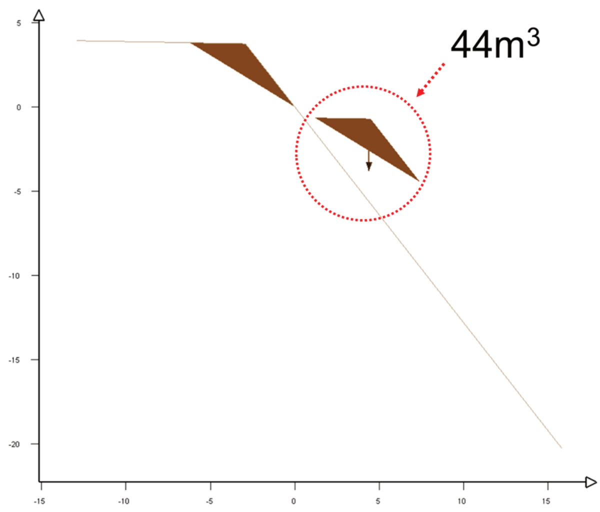

Figure 12 Calculated 3D tetrahedral wedge

8 Post-rehabilitation outcomes

Frequent and detailed geotechnical inspections and monitoring were carried out during remediation of the AOI. The following outcomes were noted:

- Prism survey data indicated low level creep movement towards the void during excavation. The rate of batter movement (towards the void) reduced once the surcharge construction commenced.
- No adverse acceleration trends of batter movement were observed during remediation.
- No coal block sliding mechanisms have manifested at the AOI since remediation commenced.

- Critical coal joint water levels were not exceeded at any stage of excavation.
- The AOI has been rehabilitated successfully (Figure 13), and no adverse movement trends have been identified since construction of the surcharge was completed in early 2021.

Figure 13 Pre- and post-remediation site conditions

9 Conclusions

This paper outlines how a risk-based modelling approach was utilised to select the optimal rehabilitation geometry for the AOI. It was important to ensure that the design would be feasible and appropriate to mitigate against unforeseen ground movements and further spontaneous combustion of the brown coal. The process undertaken by the authors demonstrated how the stability performance of the remediation and rehabilitation geometries were assessed to successfully mitigate against batter instability during excavation and post-rehabilitation. It is the authors' intent that this paper presents useful precedents in rehabilitating brown coal mine hot spots.

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