Determination of the Subsidence Mechanism for Subcritical Miniwall Panels, Airly Coal Mine

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Summary

Airly Mine is a miniwall operation mining the Lithgow Seam in the Western Coalfield, NSW. Airly Mine currently mines beneath the Mt Airly mesa, where the Lithgow Seam outcrops near the base of the mesa. Each miniwall panel is subcritical in its geometry with 60m wide panels and depth of cover ranging 200-270m. The surface subsidence produced vertical displacements significantly greater than the empirical predictions, up to 713mm, prompting the numerical modelling approach discussed in this paper. The numerical rock failure modelling assessment illustrated the mechanism for the magnitude of subsidence experienced at Airly Mine.

The subsidence was found to be caused by the fracturing of strata for 30-35m above the pillars (between the caved zones). The fractured strata is less stiff and, as such, compresses greater under the vertical abutment load. The chain pillar width, weak strata and reduction in confinement caused by the caved zones and pillar width were key factors contributing to the fracturing of the strata above the pillars, causing relatively high levels of surface subsidence.

The modelling also provided an engineering solution to control the fracturing above the pillars resulting in a significant reduction in surface subsidence.

1. Introduction

Airly Mine is predominately a miniwall operation that mines the Lithgow Seam in the Western Coalfield of NSW. Airly Mine currently mines beneath the Mt Airly mesa. The location of Airly Mine is presented in Figure 1.

The miniwall geometry results in 61m wide panel void widths and 30m chain pillars. Each miniwall panel has a subcritical geometry with the depth of cover primarily ranging 200-270m. The miniwall operation produced surface vertical subsidence up to 713mm for the extraction of 11 adjacent miniwall panels. The observed subsidence was significantly greater than the empirical predictions, prompting a numerical modelling approach to understand the subsidence mechanism at Airly Mine.

The results of the numerical rock failure modelling assessment that illustrates the mechanism for the magnitude of subsidence experienced at Airly Mine is presented in this paper. The modelling outcomes were validated with the site subsidence survey data.

Figure 1 Location of Airly Coal Mine.

The Airly Mine plan showing the miniwall locations, adjacent pillar extraction panels and depth of cover contours is presented in Figure 2.

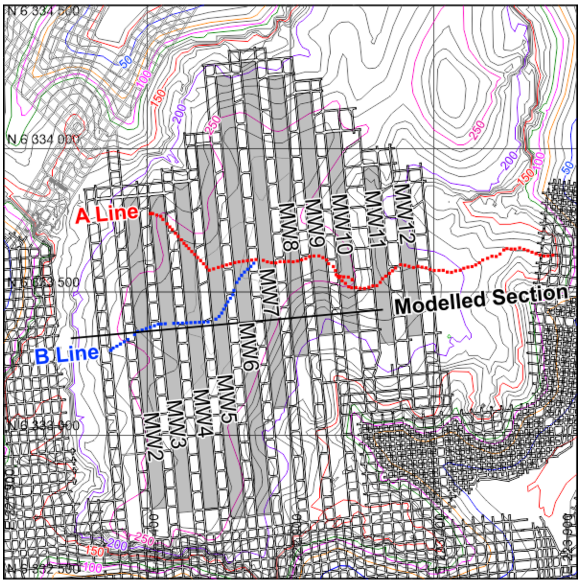

Figure 2 Mt Airly mining area of Airly Coal Mine, MW2-12.

2. Site Description

The current mining area (MW2-MW12) is located under Mt Airly. Mt Airly is a mesa, whereby the surrounding strata has been eroded away. The Lithgow Seam is the mined seam at Airly Mine and outcrops near the base of the Mt Airly escarpments.

The Lithgow Seam is stratigraphically at the base of the Permian Illawarra Coal Measures, which overlies the marine sediments of the Shoalhaven Group. At Airly Mine, the Illawarra Coal Measures are approximately 110m thick. The Triassic Caley Formation and the Burra-Moko Sandstone overly the Illawarra Coal Measures.

The Burra-Moko Sandstone is a massive sandstone that forms the upper unit of Mt Airly. Figure 3 shows a photograph of the massive sandstone cliffs of the Burra-Moko Sandstone on the Mt Airly mesa. Figure 4 shows a schematic of the geology that forms the Mt Airly mesa.

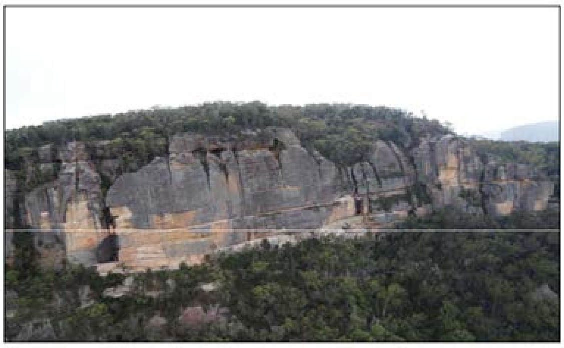

Figure 3 Sandstone cliffs of Mt Airly (Source: MSEC, 2015).

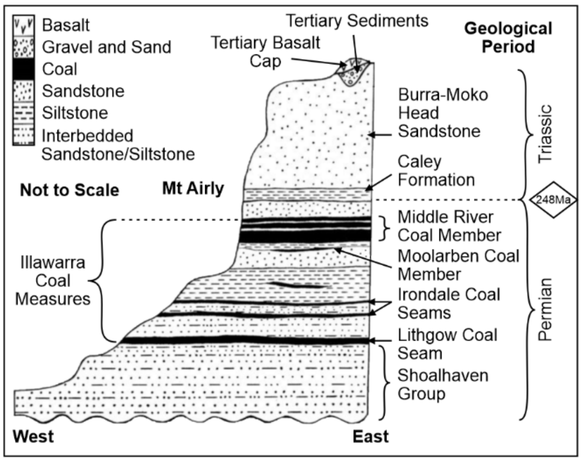

Figure 4 Schematic of Mt Airly Lithology (Source: MSEC, 2015).

3. Subsidence Survey Data

Subsidence survey lines A and B were used to create a section line perpendicular to the miniwall panels (subsidence lines shown on Figure 1). The compiled subsidence data relative to the tailgate edge of MW2 is presented in Figure 5.

The subsidence survey data shows an increase in subsidence magnitude with each additional miniwall panel extracted. After extraction of 6 panels (MW7), the surface subsidence exceeded 600mm. By the extraction of MW12, the subsidence has reached maximum subsidence at 713mm.

4. Methodology

A numerical modelling approach was used to investigate the mechanism for the high levels of observed surface subsidence for the subcritical panel geometry at relatively shallow depths. The numerical model simulated the miniwall extraction and caving process.

Panel width cross section models were created to model the rock failure and resulting subsidence from extraction of MW2-MW7. The rock failure model was based on Mohr-Coulomb failure criteria using FLAC 2D by Itasca.

Site-specific stratigraphy, lithology and geotechnical properties were used to model the panel extraction, rock failure and caving, to provide the resulting surface subsidence.

The rock failure model used in this assessment is not discussed in this paper. Validated case studies of the model approach at numerous mine sites can be found in a number of papers (Gale, 1998; Gale *et al.*, 2004; Gale, 2005; Heritage *et al.*, 2015), in addition to subsidence outputs validation (Gale & Sheppard, 2011, Heritage, 2017).

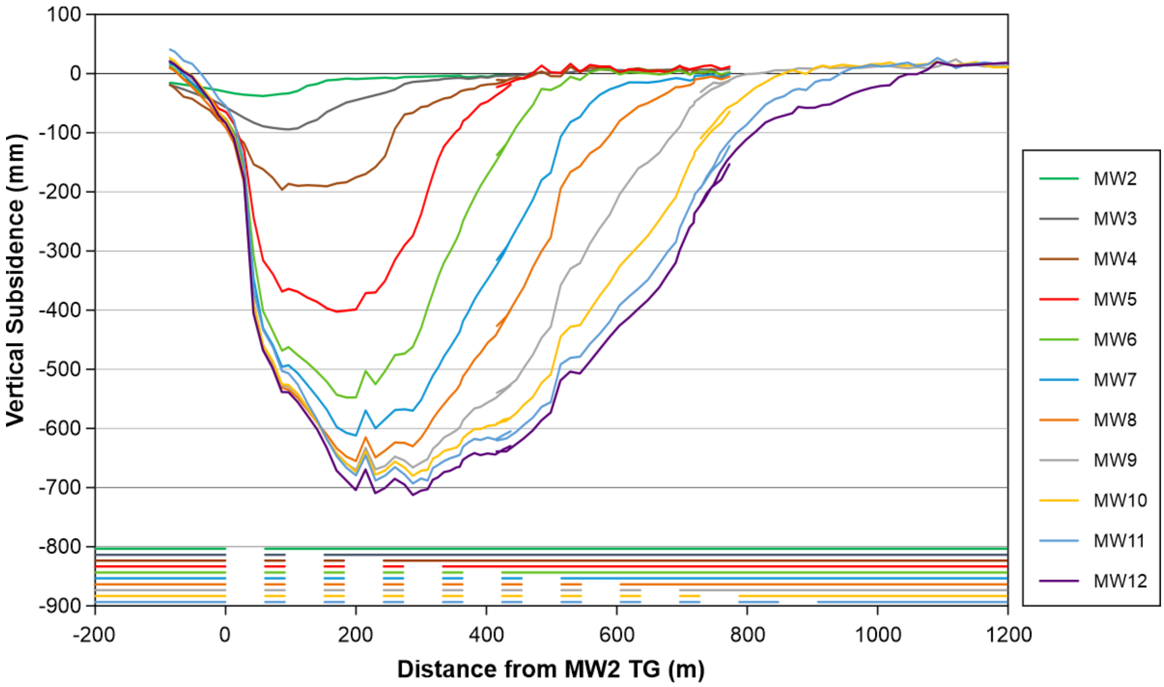

Figure 5 Vertical subsidence on A and B survey lines across MW2 to MW11.

5. Subsidence Mechanism

5.1 Numerical Model Outcomes

A 270m depth of cover model was produced and 61m void width miniwall panels were sequentially extracted, leaving 30m solid pillars. The results of these models, showing the mode of failure for extraction of MW2-7, are presented in Figure 6. The primary modes of failure observed are bedding shear failure (purple), shear failure of intact rock (red) and tensile failure (blue). The surface subsidence from each model stage is noted on each figure.

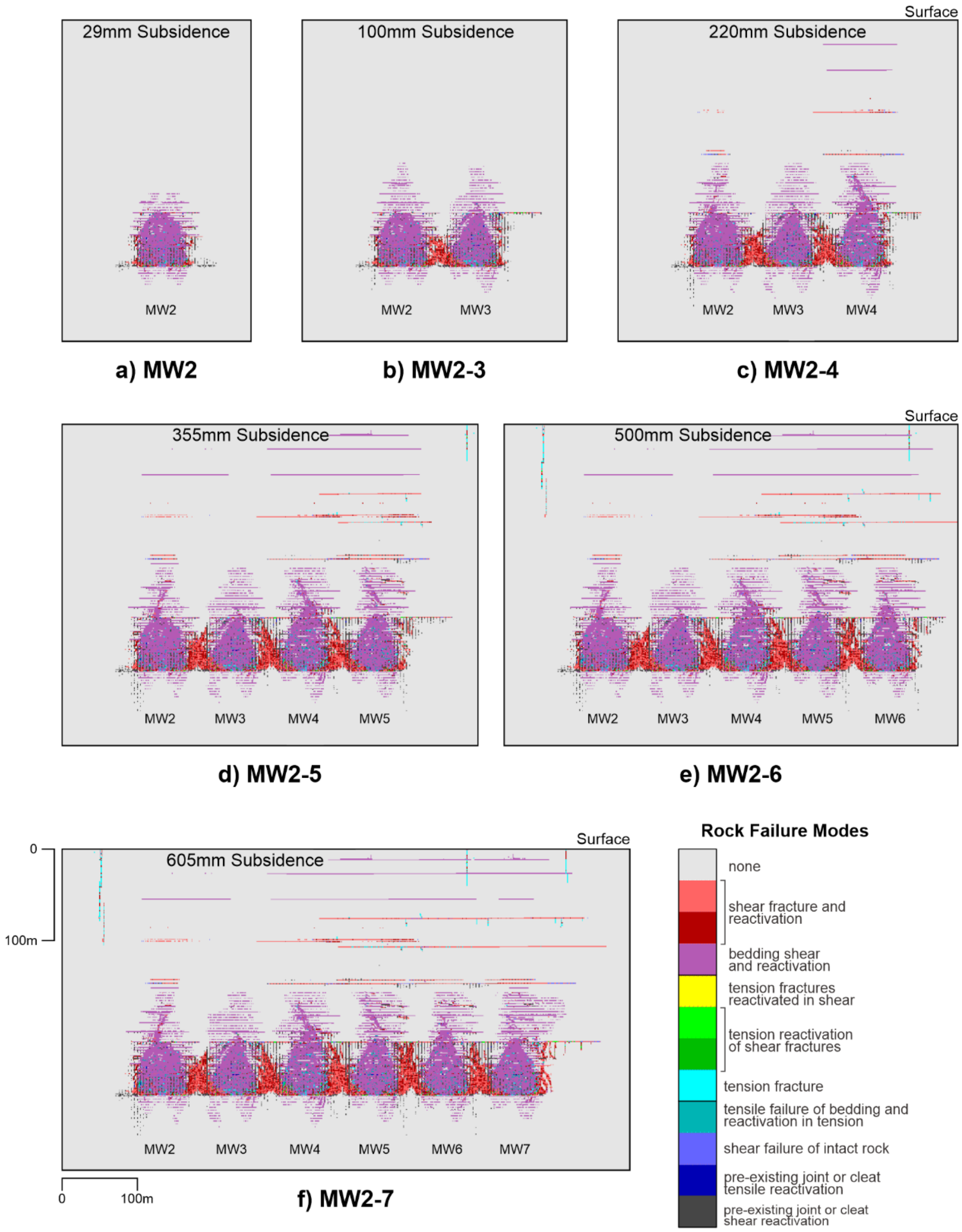

Figure 6 Modelled mode of failure for six miniwall panels (MW2-MW7).

Key features of the model outputs include:

- A low level of sag subsidence in the order of 30mm was observed from the extraction of the first panel.
- Extraction of a single miniwall panel creates a caved zone approximately 60-70m high (purple bedding shear failure).
- The strata above the pillars and between the caved zones shows significant shear failure from the abutment load and reduction in confinement (between each longwall goaf). Once the rock fails, the stiffness of the strata reduces, and the strata further compresses under the vertical load.
- The surface subsidence increases with each additional miniwall extracted due to increased abutment load compressing the fractured strata above the pillars.

The modelled vertical displacement profile through the centre of the pillar between MW3 and MW4, after MW4 extraction, is presented in Figure 7.

The modelled vertical displacement profile shows the majority of subsidence occurs between 10m and 35m above the seam. This highlights that the majority of the surface subsidence is due to the compression occurring in the softened strata above the pillar.

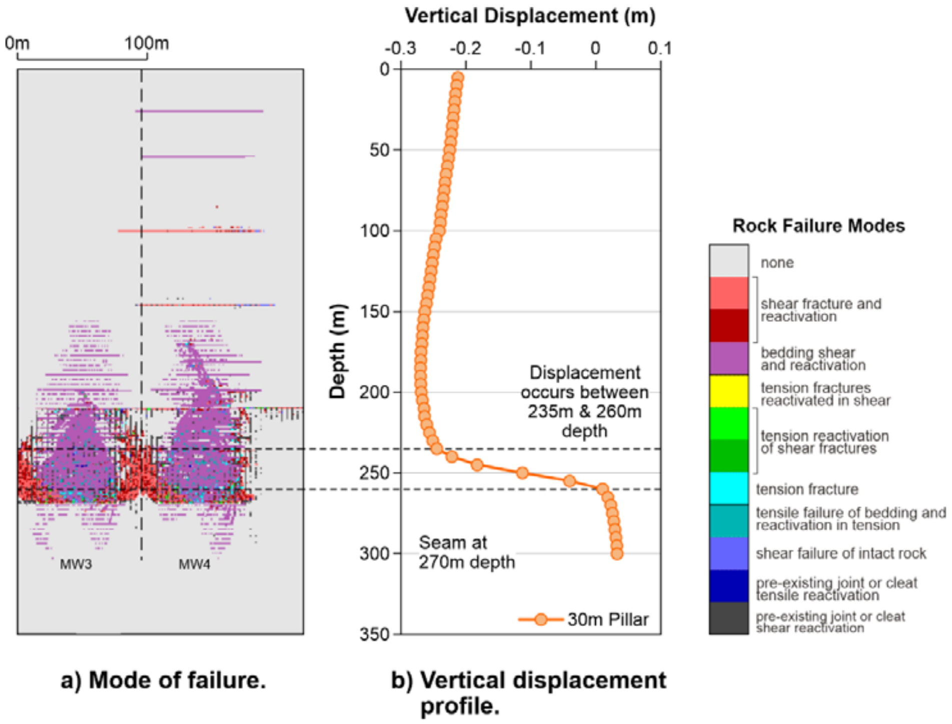

Figure 7 Vertical displacement trough the fractured strata above the MW3-4 pillar.

5.2 Summary of Subsidence Mechanism at Airly Mine

The numerical modelling highlighted the subsidence mechanism at Airly Mine. The subsidence mechanism was found to be primarily due to fracturing of the strata above the pillars, creating a reduction in stiffness of the strata that compresses further under progressive and increased abutment loading. The fracturing of the strata above the pillars primarily consists of compressive shear failure of intact rock from the vertical stress.

Key factors that contribute to this rock failure mechanism occurring above the pillar include:

- The relatively weakly bedded strata for the 110m of Illawarra Coal Measures above the Lithgow Seam reducing the ability of the rock to generate confinement and strength.
- Abutment load from the progressive miniwall extraction concentrating in the pillars.
- A reduction in confinement of the strata between the miniwall goafs, reducing the strength of the strata. (Confinement can be generated by horizontal stress or by Poisson’s effect).
- The small chain pillar width, increasing the average abutment load and reducing the confinement.

Parametric modelling of varied rock properties highlighted that the massive Burra-Moko Sandstone unit that forms the caprock of the Mt Airly mesa has a partial bridging effect. The partial bridging of this unit results in a reduction of surface subsidence.

These outcomes highlight that the magnitude of surface subsidence is sensitive to the lithology throughout the entire overburden strata.

5.3 Model Validation

A comparison of modelled and survey subsidence for 6 panels (MW2-7) is presented in Figure 8. The curves show the surveyed and modelled subsidence profiles, while the horizontal lines show the location of the extracted miniwall panels in relation to each profile.

The model results show similar subsidence profile curves and similar maximum subsidence to the surveyed subsidence. The western edge is steeper in the surveyed data due to focussed strain at the MW2 tailgate, rather than the smooth elastic model curve shape.

6. Control of Subsidence

The modelling assessment not only provided an understanding of the mechanism causing the higher magnitudes of surface subsidence, it also provided a predictive tool to control subsidence for future mining.

Mine design to control the surface subsidence is a combination of:

- Pillar width
- Number of adjacent panels
- Extraction height

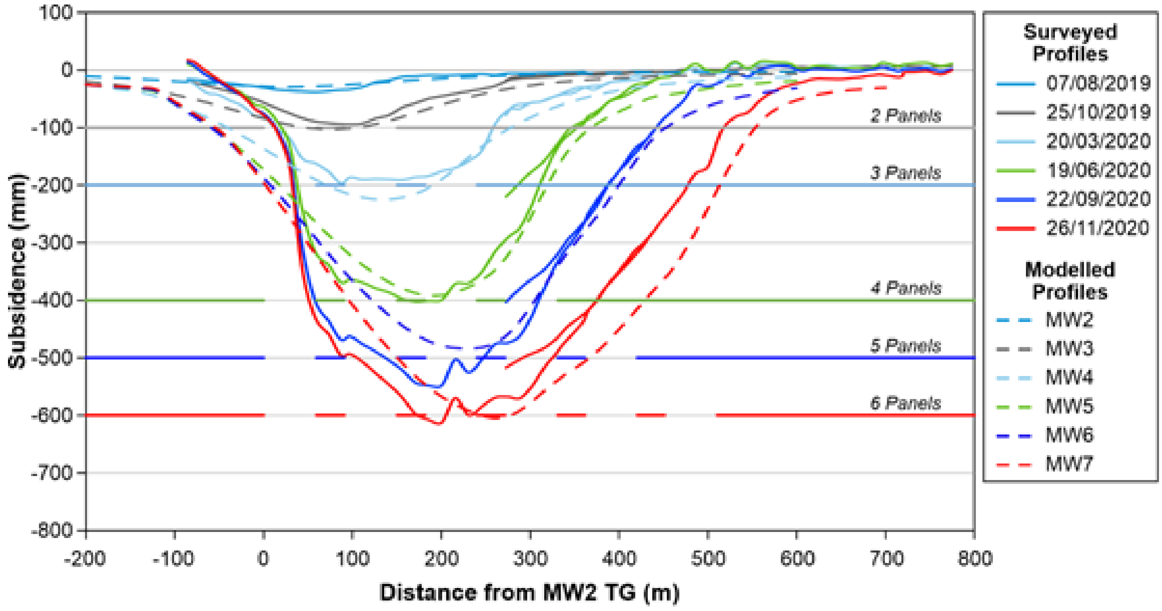

Figure 8 Surveyed and modelled vertical subsidence comparison.

6.1 Pillar Width

Increasing the pillar width acts to reduce the average abutment load. A reduction in average abutment load to magnitudes above the strength of the strata will stop the fracturing of the strata above the pillars from occurring.

Increasing the pillar width also increases the confinement of the strata above the pillars. Increasing the confinement of the strata has the effect of increasing the strength of the strata.

Therefore, increasing the pillar width, increases the strata strength and reduces the average abutment load.

6.2 Number of Adjacent Panels

In a mining environment with a subcritical panel geometry, extraction of adjacent panels increases the overall abutment load across a number of pillars.

Therefore, the overall load across all extracted panels needs to be considered in the pillar design. Modelling provides a useful tool in estimating the load distribution across multiple panels.

6.3 Extraction Height

The height of extraction affects the bulking of the caving within the goaf. An increase in extraction height increases the void space and reduces the stiffness in the goaf. The result is less horizontal stress transfer through the caved zone and also through the strata between the caved zones (above the pillar).

Reduced stress transfer through the strata above the pillar reduces the confinement of the strata. This reduction in confinement results in a reduction in strength of the strata, which can lead to additional rock failure.

7. Future Mine Design

For the mining geometry, lithology and depths at Airly Mine, modelling showed that a pillar width of 70m was sufficient to control the fracturing of the strata above the pillars for 4-5 adjacent panels. The modelling results for a 70m wide pillar, 61m panel width and 280m depth of cover are presented in Figure 9. The significant reduction of rock failure in the strata above the pillars is highlighted in this model.

For this 70m wide pillar model scenario, surface subsidence was modelled to be 120-130mm for 4-5 adjacent panels. In comparison, the surveyed subsidence at Airly Mine for 30m wide pillars was significantly greater at 400-550mm.

The model shows that by controlling the fracturing of the strata above the pillars, surface subsidence can be significantly reduced.

This concept can also be applied to longwall operations, where fracturing of the strata above the pillars is observed in modelling (Heritage, 2017).

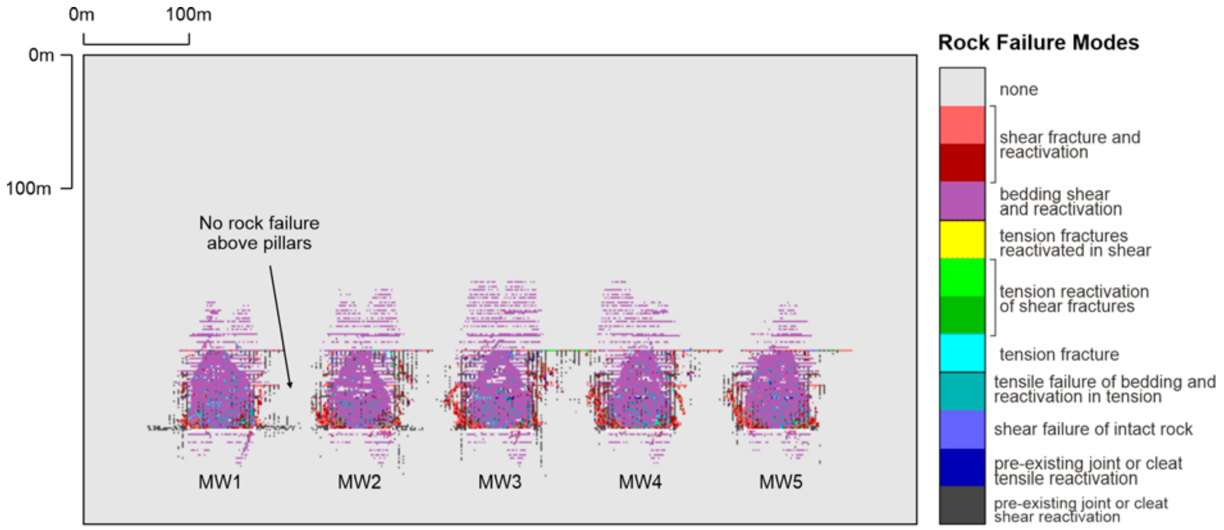

Figure 9 Modelled mode of failure for increased pillar width to 70m.

8. Conclusions

The mechanism contributing to the majority of the subsidence at Airly Mine was found to be fracturing of the strata above the pillars creating a reduction in stiffness of this strata. This less stiff strata compresses further under abutment load.

Changes in mine design that increases the pillar widths is considered an appropriate approach to control the mechanism producing increased subsidence and therefore control surface subsidence.

The magnitude of surface subsidence was found to be sensitive to the overburden lithology, such as relatively weak or massive strata. This sensitivity highlights the importance of site-specific geotechnical assessments in predicting subsidence.

Numerical rock failure modelling was found to be a valuable tool to investigate the subsidence mechanism at Airly Mine and to provide a design tool to control subsidence magnitudes for future mining.

9. Acknowledgement

Thank you Centennial Coal Pty Ltd for allowing publication of the Airly Mine subsidence case study. We can all benefit from the knowledge gained through the sharing of experiences within the industry.

10. References

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