Geotechnical Aspects of Place Change Mining at Ensham

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GEOTECHNICAL ASPECTS OF PLACE CHANGE MINING AT ENSHAM

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ABSTRACT: The Ensham bord and pillar mine in the central part of the Bowen Basin is developing panels in the 5-6 m thick Aries/Castor Seam, using the place change mining method. The development mining height is typically 3.5 m, with the remaining floor coal and bell outs extracted on retreat. The depth of cover ranges from 45 m up to 150 m. In geologically unstructured areas, low-density roof support patterns are installed due to the competent roof conditions provided by the high ash, roof coal.

Ensham is currently producing at an average rate of 0.96 Mtpa from each of the three development units. To achieve these levels of productivity, optimisation of the geotechnical design aspects of the mine including the ground support, pillar dimensions, panel orientation, selection of mining horizon, mining at shallow depths of cover and drivage through fault zones has been necessary. This is supplemented with regular inspections and ongoing assessment of the geological and geotechnical conditions, as development progresses into new mining areas.

INTRODUCTION

The Ensham Resources Pty Ltd (ERPL) open cut and underground operation mines seams from the Rangal Coal Measures, in the central part of the Bowen Basin (Figure 1). The open cut operation started in 1993 but with increasing depth the productivity of the operation has decreased and the decision to access the large underground resource was made.

Excavation of the travel and belt road drifts from the open cut, backfilled to the Aries 1 (A1) Seam level, commenced in March 2011 to access the underground reserves (Figure 2). These drifts are inclined at 1 in 8 and reached the coalesced Aries 2/Castor (A2C) Seam in September 2011, approximately 200 m from the portal entries.

Figure 1: Location Plan

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The underground workings at Ensham are characterised by typically good roof and rib conditions at relatively shallow depths, with no gas makes detected from the Aries/Castor Seam. As shown in Figure 2, the panels are laid out between a number of geological faults, with the pillars dimensioned to satisfy the mine’s consent conditions below the Nogoa River and flood plain. At this stage, mining has been carried out in several panels below the Anabranch channel but has not been continued under the Nogoa River (Figure 2).
ENGINEERING GEOLOGY

Seam Characteristics

The underground workings are located in the central part of the Ensham mining lease where the Aries/Castor Seam (A2C and A3C) is typically 5-6 m thick, at 45-150 m depth of cover (Figure 3 and Figure 4). The maximum depth in the western part of the planned workings is 200 m (Figure 3).

To the north and south of the underground workings, a number of roof and floor splits are present in the Ensham area (Figure 4). The most significant split that has affected mining operations to date is the A211 roof seam split (Figure 5). Where this roof split is typically closer than 3 m above the main seam, tensile cracking of the coal roof has been experienced, at depths of 80-100 m.
Roof and Floor Lithology

The immediate stone roof above the Aries/Castor Seam typically consists of interbedded siltstone and sandstone, with occasional thicker sandstone units <1 m thick (Figure 6). The immediate 100-200 mm of roof is weaker, averaging 10-20 MPa and may delaminate when mining to stone roof. The average strength of the immediate 2 m of stone roof is 20-40 MPa, increasing to 30-40 MPa for the 2-6 m horizon.

Figure 6: Immediate Roof Lithology
The immediate stone floor consists of mudstone, grading to siltstone then sandstone, with an average strength of 10-15 MPa. Very weak floor layers (<2 MPa), which could potentially lead to pillar punching and significant failure of the floor have not been identified in the current mining area. Minor heave (<100 mm) of the basal coal plies left after floor coaling has been observed in localised parts of the secondary workings. These observations are consistent with the Floor Strength Index (FSI)\(^1\) values greater than 4 in the majority of the area. Experience at other Bowen Basin mines indicates significant floor heave is more likely to occur when the FSI is <3.

**Faults**

3D Seismic has been carried out over the majority of the Ensham underground area to supplement the existing close spaced exploration borehole data and identify geological features ahead of mining (Figure 7). The seismic has been found to locate the faults and even rolls to an accuracy of 10-20 m. This has allowed the layout of the panels to be optimised between the geological features (Figure 2). From a safety perspective for operational personnel, the accuracy of the seismic also allows standoff zones to be put in place as development advances towards predicted faults.

![Figure 7: 3D Seismic Coverage and Exploration Borehole Data](image)

The major faults (throws up to 12 m) encountered in the underground workings so far have been normal in character and relatively clean (Figure 8). The fault zones are also associated with greasy backs,

\[\text{Strength Index} = \frac{\text{Strength}}{(\text{Depth} \times 0.025)}\]
slickensides and smaller faults, which may have reverse characteristics. Delamination of the coal roof may also occur in close proximity to the faults.

![Image: Clean Normal Faults](image)

**Figure 8: Clean Normal Faults**

**Horizontal Stress Direction**

The occurrence of roof guttering in the immediate 100-200 mm of weaker stone roof has only been encountered in geologically structured areas and is consistent with the NE orientation of the major horizontal stress determined by acoustic scanner and overcoring (Figure 9). The guttering has not been observed to progress higher up into the roof.

![Image: Examples of Guttering of Weak Immediate Roof Stone](image)

**Figure 9: Examples of Guttering of Weak Immediate Roof Stone**

Where tensile cracking of the roof coal has been encountered, it is inferred that there has been compressive failure of the weak stone interburden between the A211 seam split and the main seam. This cracking is restricted to areas where the Roof Strength Index of the stone is less than about 6 (Gordon and Tembo, 2005).

**MINING METHODOLOGY**

The development of bord and pillar panels at Ensham uses the place change methodology in two stages:

- The primary development height is typically at 3.5 m, leaving high ash coal in the roof to prevent dilution and provide a competent roof beam.
- Floor coal (typically 1-1.5 m thick) and bell outs are mined on retreat.
Development

Development roadways are nominally 6.5 m wide and 3.5 m high, excavated with double pass, 3.6 m narrow head Joy 12CM27 continuous miners. The coal is loaded into Joy 10SC32D shuttle cars and the plunges are bolted with Joy multibolters. The roadway height is decreased to 3.2-3.3 m in thinner seam areas to improve wheeling conditions. Poor floor conditions can develop where the coal floor thickness reduces to typically <1 m, due to the continual shuttle car wheeling, particularly in the presence of water.

The maximum plunge distance is 14 m corresponding with the position of the shuttle car driver under supported roof. In poorer ground conditions, the plunge distance is reduced, as well as the number of places that can be left unsupported. In the majority of the workings developed at depths up to 150 m, the typical ground conditions experienced are shown in Figure 10.

Localised poorer ground conditions have been encountered in some parts of the workings including:

- A zone of blocky and cleated roof coal in the NW Mains and at the outbye ends of 101, 102 and 103 Panels (Figure 2).
- Tensile cracking of the coal roof in the A211 seam roof split area, at depths of 80-100 m.
- Slabbing of the immediate 100-200 mm of weaker stone roof.
- Shallow delamination of the roof (both coal and stone) in unsupported plunges driven towards geological structures.

![Figure 10: Typical Development Conditions](image)

A key aspect of productive place change mining is the management of water. The excavation of floor sumps in the flanking headings is routinely used to catch water and keep it away from the face area.

Bottom coaling and mining of Bell Outs

On retreat, a 5.5 m wide head continuous miner is used to mine the floor coal and extract the bell outs on the outside of the panel. This wide head miner leaves a nominal 0.5 m canche on each side of the roadway, which has a number of benefits including (Figure 11):

- Reduce rib bolt requirements.
- Improve pillar stability.
- Reduce the amount of tramp and rubbish that is loaded out.
The bell out sequences typically contain 1500-2000 tonnes of coal in non-structured conditions, where 14 m plunges are stable (Figure 12). In structured areas, the plunge distance is decreased and stooks are left to reduce the unsupported span.

By developing stubs of consistent length on both sides of the panel and maintaining a standard sequence of extraction for the bell outs, a pillar is formed with dimensions similar to the panel pillars (Figure 12). At the inbye end of the bell out entry stub, an infill row of breaker line roof bolts is also installed. In poorer ground conditions, such as in close proximity to geological features and/or within the seam split zone, these infill bolts are supplemented with additional roof support.

Initially, the SW Mains Panel was developed with nine headings but operational personnel have since found that the drivage of seven headings with stubs driven on the flanks of the panels to allow the mining of bell outs on retreat is more productive (Figure 2). For a seven heading panel layout with bottoms extraction and bell out mining on retreat, 60% of the coal is produced without the requirement for bolting.
Production Rates

Ensham is currently producing at an average rate of 0.96 Mtpa per unit and produced 2.62 Mt in 2015. Peak rates have reached 1.15 Mtpa per unit. The best production in a month of 305,000 tonnes was achieved in December 2015 and 200,000 t/month has been consistently produced since May 2015 (Figure 13). Average rates in development are around 230 t/operating hour and 210 t/operating hour when mining floor coal and extracting bell outs. These ERPL unit rates are comparable with the top producing bord and pillar operations in both the USA and South Africa.

![Figure 13: Production Rates](image)

A fourth floor brushing contract unit commenced in late October 2015 with a wide head continuous miner, to supplement the development coal produced by the Ensham narrow head, double pass continuous miners.

MINING HORIZON

The pit bottom roadways and the initial mains drivage were mined to stone roof; however, delamination of the immediate 100-200 mm of weaker roof occurred in some plunges, requiring the routine application of mesh (Figure 14).

Because of this delamination, mining to a high ash coal roof was trialled in the SW Mains and was found to provide a more competent roof beam (Figure 10). Leaving the high ash coal in the roof also improved the quality of product, as the coal is simply crushed and screened before loading onto the trains. It should be highlighted that the coal roof beam does not perform as well in geologically structured areas (Figure 14).

The miner drivers have utilised the penny band, located typically 0.8-1.2 m from the top of the seam, for horizon control. In most areas, this band is a distinct off white colour and can be easily followed by the operators (Figure 15). Towards the north, the band does becomes darker and slightly harder to follow in places.
Due to the variability in the seam thickness across the underground mining area, the amount of coal left in the roof varies from 0.5-0.6 m in the thinner seam areas, up to 0.9 m in thicker seam panels such as 103. These roof coal thicknesses are consistent with a voussoir beam analysis of high ash Aries/Castor Seam roof coal, spanning across a 6.5 m wide roadway (GGPL 2015).

In the zone of blocky and jointed coal roof encountered at the outbye ends of 101-103 Panels, the roadways were mined to the base of the 0.3 m thick A211 ply at the top of the seam (Figure 16). As detailed in the Development TARP, roof meshing is required when mining to this horizon due to the potential for the delamination of the coal plies.
Figure 16: Roof mining horizons

PILLAR DESIGN

Pillar design at Ensham uses the empirical methodology developed by the UNSW (Galvin et al, 1998). The standard pillar sizes at shallow depths of cover (<125 m) are 21 m x 28 m (centre) and 22.5 m x 28 m (centre) pillars. Where the depth increases to >125 m the minimum centre distance is increased to 24 m. Larger wings are formed in the headings to allow the cut-throughs of the 24 m pillars to be holed in one sequence.

As the size of the underground workings increases, the importance of leaving suitably sized barriers between panels cannot be emphasised enough. Furthermore, with increasing depth either compartmentalisation of extraction areas using intra-panel barriers or reduction in floor coal thickness is planned to ensure long term stability below the flood plain (Mine Advice Pty Ltd 2015). In addition, the location of geological features is considered when designing the floor coaling sequence. As part of the mine’s consent conditions, all coal pillars beneath the Nogoa River flood plain must have a FOS>1.6.

Now that a number of panels have been developed at Ensham and bottom coal extracted, a back analysis of the pillar dimensions in each panel so far (maximum heights used) is presented below in Figure 17. This figure shows that the Ensham pillars mined in the shallower part of the area, plot well away from the empirical database of Australian and South African failed pillars presented by Hill (2005).

The pillar design at Ensham has also considered the strength of the floor. Bearing capacity analysis indicates that floor strengths of <2 MPa are required before failure can occur below 21 m x 28 m (centre) pillars. Analysis of the sonic velocity values for the immediate floor across the area indicate typical average floor strengths >10 MPa.

GROUND SUPPORT

The Code Green development ground support consists of 4 x 1.5 m roof bolts every 1.5 m in a 6.5 m wide roadway, supplemented with 1 x 1.5 m rib bolt mid pillar and 2 x 1.5 m rib bolts on the corners. The AX roof bolts are anchored with 500 mm fast set resins providing an average encapsulation of 927 mm (87 measurements) when installed in 28 mm diameter holes. The roof bolt length is increased in seam split and faulted conditions.
In coal roof areas, meshing is only carried out in the services roadway (a sheet every second row of bolts) or when triggered by the TARP (Figure 18). In stone roof areas, all roadways are meshed due to the potential for delamination of the immediate 100-200 mm of weaker stone roof (Figure 14).

Figure 17: Pillar factor of safety and width: height ratio.

Figure 18: Roof mesh in the services road installed every second row of bolts

Pull testing is routinely carried out at Ensham, with all roof bolts pulled to >13 tonnes without movement (105 tests). Additional short encapsulation tests have been carried out in both coal and stone, indicating that the anchorage in the high ash roof coal is comparable to the overlying immediate roof stone (Figure 19).
When installing 1.5 m roof bolts, 1.5 m rib bolts are correspondingly used to simplify the bolting and supply process. Analysis of potential wedges indicates that these 1.5 m rib bolts can prevent sliding on cleat planes inclined at <70° in 4 m high roadways. The inclination of the cleat in the workings is typically >80°, indicating sufficient anchorage is available behind potential failure planes in the rib. 103 Panel has now been developed to 140 m, with only minor spall encountered on corners less favourably aligned to the dominant north/south cleat direction.

The typically good ground conditions in the underground workings are confirmed by the CLOCKIT readings, with the majority of movement less than the Code Blue trigger of 10 mm (Figure 20). In the A211 seam split zone, where tensile cracking was encountered, approximately 60% of the CLOCKITs show movement between 4-10 mm. This is compared to outside the seam split area, where 90% of the movement measured is <2 mm.
MINING AT SHALLOW DEPTH

Development was carried out at the inbye end of 203 Panel where the depth of cover reduced to 45 m, with 27 m of fresh rock head (Figure 3). The immediate roof strength in this area was as low as 6-8 MPa, however stable 14 m plunges were still achievable on development, followed by floor coaling and mining of bell outs.

Experience at other mines indicates potholes due to tensile failure of intersections generally reach the surface at depths <50 m. As such, an assessment of the risk of pothole subsidence was carried out, prior to development in 203 Panel, using the limiting equilibrium analysis documented in Brady and Brown (2006). Both dry and wet conditions were analysed, with failure along cohesionless joints assumed. The stress ratio was also reduced to account for the shallow depth of cover.

To maintain a Factor of Safety of >2 in wet conditions, at least 20 m of fresh rock is required for a large intersection with side dimensions of 10 m, applying a Factor of Safety of 2 (Figure 21). This analysis is consistent with the good conditions experienced at the inbye end of 203 Panel.

CONCLUSIONS

To maintain the current production rates in the place change operation at Ensham requires regular inspections and ongoing assessment of the geological and geotechnical conditions, supplemented with back analysis. This assists in fine tuning the strata control aspects of the mining process, as development progresses into new mining areas.

A key element in the continuity of the operation is the accuracy of the 3D seismic, which supplements the exploration borehole data. Not only does this allow panel geometries to be optimised, it also provides proactive warning of deteriorating ground conditions to the underground workforce. Ensham plan to continue this exploration approach in new mining areas.
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