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GEOTECHNICAL CONSIDERATIONS FOR LONGWALL TOP COAL CAVING AT AUSTAR COAL MINE

Adrian Moodie and James Anderson

ABSTRACT: Austar Coal Mine has had a long association with difficult strata control conditions associated with depth of mining and a highly jointed/cleated coal seam. Poor longwall face conditions, cyclic loading, heavy tailgate roadway conditions and difficulties in maintaining stable roadways on development at < 5.2 m let alone the geotechnical challenges of an 8.5 m roadway required for installation faces have been matters of conceren for management. The introduction of Longwall Top Coal Caving (LTCC) to this environment has aided in the management of some of these issues, but has also given rise to other geotechnical considerations. These additional geotechnical issues associated with LTCC not only require management during operations but also require consideration when evaluating new mining areas at Austar or potential LTCC extractable resources throughout Australia and the world.

In September 2006 LTCC commenced at Austar Coal Mine in longwall panel A1. Since that time the LTCC face has been increased from 147 m to 216 m and finally to 227 m in width, and has also been re-handed and modified in the three fully extracted panels to date. The application of LTCC in panels A1, A2, A3 and now A4 has been very successful both from a coal resource recovery point of view and also in the management of the principal hazards of spontaneous combustion and strata control. This paper focuses on the geotechnical aspects of the application of LTCC at Austar Coal Mine and also reviews some advances in general strata control management at the mine.

BACKGROUND

Location

Austar Coal Mine Pty Ltd (Austar), a subsidiary of Yancoal Australia Pty Limited (Yancoal), operates Austar Coal mine, an underground coal mine located approximately 8 km south of Cessnock in the Lower Hunter Valley, NSW (refer to Figure 1). The mine is an amalgamation of the former Ellalong, Pelton, Cessnock No.1 and Bellbird South Collieries and is located in the South Maitland Coalfields. These operations collectively extract, handle, process and transport the coal from the Austar Mining Complex.



Figure 1 - Austar coal mine locality

History

Underground mining commenced in 1916 at the Pelton Colliery and continued until 1992. Kalingo Colliery began as an underground mine in 1921 and ceased operations in 1961. In the late 1960's the Kalingo Colliery was amalgamated into the Pelton Colliery. Longwall production commenced at the Pelton Colliery in 1983 and continued until the mine, then known as Ellalong Colliery, was closed in May 1998 by

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Oakbridge. Southland Coal then acquired the assets of Ellalong and Pelton Collieries and amalgamated those with Bellbird South, which was also owned by Southland Coal.

Southland Coal developed a longwall operation mining the substantial Bellbird South coal reserves utilising the existing Ellalong facilities and infrastructure.

In December 2003, spontaneous combustion in SL4 resulted in Southland Coal ceasing mining activities. The site of the underground fire was sealed and the mine was placed on a 'care and maintenance' program for 18 months. Yancoal purchased the mine in December 2004 and changed the name to Austar Coal Mine.

Austar (the last coal mine working the Greta coal seam) introduced an enhanced form of the conventional longwall recovery system called Longwall Top Coal Caving (LTCC) to the Australian coal mining industry in 2006. The LTCC technology has since been utilised to extract the Stage 1 panels known as A1 and A2 and in 2009 commenced in the Stage 2 panel A3. Current LTCC operations are in the A4 panel with development extending into the recently Approved Stage 3 mining area beneath the Quorrobolong Valley.

Geology

Currently the depth of overburden at Austar is approximately 530 m. The Greta coal seam currently mined ranges in thickness from 4.5 m to 6.8 m. The coal produced is used for coking coal or blend coal, exhibiting extremely high fluidity values. The greatest variation to the coal quality is related to the sulphur level in the upper ply of the seam ranging from <1 to 2.5%. The ash in the current mining area is <10%.

The immediate roof strata of the Greta seam are largely laminite 15-20 m in thickness. Across many of the panels the laminites that are immediate to the seam have been eroded by large paleochannels. The paleochannels consist of fine to coarse grained sandstone. Above the immediate strata and paleochanels a massive sandstone bed exists varying in thickness from <1 m to >5 m, this massive sandstone bed is referred to as the Cessnock Sandstone. The Cessnock Sandstone marks the boundary between the massive overlying marine bioturbated Branxton Formation and the Greta coal measures. The Branxton Formation is typically within 20 m of the seam extending to the sub surface. The Branxton Formation is a fine to medium-grained sandstone with some coarse lenses and very few discontinuities such as bedding or jointing. Due to the lack of discontinuities and the >450 m massive nature of the Branxton Formation further geotechnical challenges are expected in addition to the already challenging mining environment at depths extending beyond 500 m.



Figure 2 - Typical stratigraphic column

LONGWALL TOP COAL CAVING DESCRIPTION

Longwall Top Coal Caving (LTCC) is an enhanced form of the conventional longwall recovery system, whereby a rear Armoured Face Conveyor (AFC) (refer to Figure 3) is utilised to extract coal from behind the powered supports that would otherwise be left unrecovered in thick seam environments. The major benefit of LTCC is the ability to safely optimise resource recovery in thick seam deposits. This is achieved by operating a retractable flipper at the back of each shield that allows for recovery of the otherwise wasted +3.5 m of top coal that usually enters the goaf.

It is very similar to a conventional longwall system in that the shearer mines coal conventionally at 2.9 m on the floor of the seam. The top coal is then caved through the rear of each shield onto a second AFC. The system has seen a significant increase in resource recovery from Austar with coal recovery in excess of 85% of the entire seam compared to 40-45% when the mine was previously operated using a conventional longwall system.

Further advantages to increased resource recovery include:

- Lower face extraction height: providing a more stable longwall face with less strata failure delays than is typically experienced with extraction heights greater than 4 m in this type of geological environment;
- Operating cost reductions: the LTCC method enables potentially double (or greater) returns of longwall recoverable tonnes, per metre of gateroad development. This reduces the development cost/tonne significantly, and reducing the potential for development rate shortfalls leading to longwall production disruption (Hebblewhite and Cai, 2004);



Figure 3 - Longwall top coal caving system

GEOTECHNICAL CONSIDERATIONS FOR LONGWALL TOP COAL CAVING

Development and installation roadways

The development process at Austar is no different to that of a traditional longwall mining operation. The normal development roadway dimensions are < 5.2 m wide x 3.2 m high, these dimensions are at the lower end of the scale for most coal mines in Australia. The smaller roadway dimensions are used to help with the stability of the strata. The operation experiences significant pressure bumps on development typically in association with the stiffer rock units located above and below the seam. However, the overall development conditions at Austar although challenging are generally good with coal cavities not typically extending into the overlying stone. A nominal 6 x 2.1 m roof bolt pattern supplemented by 4 m tendons is used with 3 x 1.2 m mechanical anchor rib bolts in each rib with full mesh coverage.

The use of mechanical anchor ribs bolts at Austar is not ideal but is the only method of support that can be installed successfully into the very soft rib conditions prior to the holes closing up upon retracting the drill steel. Several other methods of rib bolting have been trialled but none have proven to be economic and successful. Consequently the use of steel mechanical anchor bolts and steel mesh even on the block side rib is adopted to control buckling for improved rib behaviour (Colwell, 2004). The positive effect that

maintaining as good as possible rib conditions has on roadway roof (and in particular tailgate roof) conditions is very evident.

The drivage of installation roads is typical of most operations with the normal width of the roadway being < 8.5 m and < 12 m at the gate ends. Continued refinement of the installation support patterns are proving to be very successful in opening up the installation roads to full width, with stand time >4 months. This stand time is helping the operation maintain a significant development float and provides great opportunity for an early commencement of the installation of the longwall into the new panels.

As time progresses the greatest challenge at Austar is to develop a successful means of chemical anchor rib support moving away from the currently used mechanical anchor bolts in order to improve the rib conditions as the mine advances beyond a depth of 600 m.

Caving recovery

To the end of 2010, LTCC has been utilised in four (4) panels at Austar Coal Mine with various face widths and mining horizons as described in Table 1 and Figure 4. Extraction height is maintained within the operating range of 2.9 m to 3.2 m which is the optimum operating range for the powered supports and has proven to give optimum caving recovery given the powered support geometry.

Longwall Name	Panel Width (solid) (m)	Panel Length (m)	Seam Thickness (m)	Seam Depth (m)
A1	147.0	1412	5.50 to 6.30	390 to 460
A2	216.4	1179	5.75 to 6.10	390 to 450
A3	216.4	1319	4.75 to 6.70	490 to 530
A4	226.7	420*	4.75 to 6.60	500 to 530

Table 1- Austar LTCC panel particulars

*Retreat distance to 15th November 2010





Figure 4 - Typical LTCC face section utilised at Austar

Total seam recovery (excluding chain pillars) has been in the order of 85% to 95% with caving recovery of the top coal section between 75% and 85% and dilution between 8% and 10%. Under cavability classifications this corresponds to a "good to excellent cavability" rating (Jai, 2001). Recent modifications to the LTTC equipment for the A4 panel has enabled the coal recovery to further increase by enabling top coal recovery further towards the gate ends and also removing the tailgate ramp up to the tailgate roadway.

Jia (2001) reported that there are several major factors affecting top coal cavability including coal strength, cover depth, joints/cleats in the coal body, bands, roof strata competence and cutting and caving ratio (Cai, et al., 2004). Experience to date at Austar Coal Mine indicates that coal strength and stress are major contributors to caving recovery with other factors including joint orientation, stone banding, immediate roof strength as well as operating factors (i.e. web thickness) being secondary factors to the caving recovery.

Operational parameters other than web thickness and support set densities also influence overall recovery. At the commencement of a panel no caving recovery occurs to allow adequate ventilation across the face to the point at which sufficient immediate roof material has caved directly behind the supports to direct airflows across the longwall face. Also, during cyclic weighting events, the speed of retreat is increased and as such caving operations are temporarily suspended, this is in part due to the low capacity coal clearance system at Austar but also in that the caving recovery process can slow retreat rate in itself, particularly in thicker seam sections. The last operational control that can affect caving recovery and has become apparent at Austar is associated with the immediate stone roof. When

operating where the immediate stone roof becomes more massive (i.e. a coarse grained sandstone with limited bedding or jointing) and is within 3 m of the cut roof horizon, large blocks have resulted in damage to the rear caving doors and hydraulic rams (Figure 5). Where the coal seam is thick enough to provide a "buffer" coal can be left to protect the rear doors, however it should be noted that advance of the supports themselves without use of the rear doors will still result in ± 1 m of top coal recovery on average. Where this risk exists to extended areas of retreat and sufficient coal is not available the rear AFC may be chosen to be removed for the retreat through the risk zone.



Figure 5 - Immediate roof impacting caving doors and caving door hydraulic cylinder damage

Cyclic weighting management

More prevalent cyclic weighting events have occurred in A3 and A4 longwall panels. Weighting events on relatively wide intervals have been observed prior this and have been associated with the Branxton sandstone unit. However in A3 and A4 a more immediate sandstone channel (within 20 m of the seam roof) appears to be further contributing to the loading cycles on the longwall face. Figure 6 displays the Time Weighted Average Pressure (TWAP) of the powered supports as taken from the Longwall Visual Analysis (LVA) program. Distinctive cyclic weighting events can be seen with the following three key observations

- As the immediate channel converges towards the top of the seam the weighting intervals are shorter at 10-15 m and generally more intense;
- As the immediate sandstone channel diverges away from the top of the seam the weighting intervals spread to between 25-35 m and are generally less intense
- On cycles between 120-150 m the previously observed Branxton associated weighting events occur, which when combined with the weighting from the immediate sandstone channel cause the most severe loading.

In one instance in A3 where this occurred and again to a similar degree in A4, the combination of these weighting cycles resulted in the face becoming "iron bound" as shown in Figure 7 and eventually the formation of large cavities made recovery more difficult (note the area of blue low support pressure indicating cavities on the TWAP plot).

Austar has implemented a Trigger Action Response Plan (TARP) for weighting management that utilises both observations on the longwall face and also data displayed by LVA in the control room. The use of LVA has enabled earlier detection of an oncoming weighting event (several hours) and also a better indication of the potential severity of the event via triggers based around the support average pressure in combination with loading rate (bar/minute) and yield counts in a cycle (Figure 8). Depending on the severity (Trigger Level) the following responses are then enacted:

- Cease caving and speed up shearer rate;
- Commence taking of convergence readings;
- Stop development operations (to prevent filling of the surge bin);
- Man critical conveyor belts and belt transfers.



Figure 6 - Time weighted average pressure (TWAP) for longwall A3 and A4



Figure 7 - LWA3 iron bound event



Figure 8 - Loading rate and yield count as displayed by LVA

Application of the TARP's and prediction of weighting zones are largely still reactive measures to the weighting events with the adopted control of increased retreat rate to "move out" from beneath the weighting not always possible. As a more direct control the LTCC system is able to reduce caving

(effective extraction height) to assist in reducing the severity of the weighting event. This was trialled in sections of A3 with anecdotal success. However measuring how much this contributed to the improved weighting management in A3 is not clear as there were also several other changes occurring at the time. Conceptually reduced caving recovery means there is less effective extracted height and less mobilisation of the overlying strata that contributes to the weightings. However, as the units we are looking to control are still reasonably close to the coal seam and the additional coal left as a "pillar" to support these has little strength, the use of a "no cave" zone cannot prevent the weighting cycles but may control them. Back analysis of the A3 area where this was adopted has given us more understanding of how this may assist.

Loading rate is considered to give the best indication of weighting intensity being more independent of other factors such as retreat rate. Figure 9 displays this for an area of the same geological characteristics where full caving and then reduced caving was adopted to assist in weighting management. The following was noted:

- In the normal caving recovery area the loading rates were more intense and occurred over a shorter time interval (i.e. event more focussed);
- Where reduced caving recovery was applied the loading rates were less intense and spread over a longer period of retreat.



Figure 9 - Conceptual effect of reduced caving recovery on weighting unit rotation

This data suggests the geometry and proximity to the coal seam of the weighting units means they could not be fully controlled by additional broken coal in the goaf sufficient to stop their rotation and cantilevering forces (induced vertical and horizontal stresses) acting on the longwall face. However the loading rate data suggests that whilst the total load in the system is not reduced, the additional coal in the goaf can slow this rotation and developing cantilever forces. Thus allowing more time for the event to occur over and enabling greater time for the shields to move from beneath the detached units before reaching critical loads.

This has lead to further trials and assessment of a "no cave recovery" zone between #40 and #70 supports in longwall A4 with early results indicating improved weighting management once again. A program of further powered support pressure monitoring and data analysis with the potential of extensometery and microseismic monitoring is envisaged.

Tailgate control and pillar design

The relationship between pillar size and tailgate roadway conditions is theoretically understood across the industry (Colwell, 1998; Colwell, *et al.*, 2003; Colwell and Frith, 2009). Monitoring of operations at Austar is furthering our understanding of this and how other than just pillar dimension and stress, factors such as immediate roof geology and extraction height can affect the loading environment around the tailgate roadway during both first pass retreat and under tailgate loading.

Longwall A2 and now Longwall A4 are the first two panels to have tailgates with full double abutment loading occur on the chain pillars and about the tailgate roadway. Table 2 summarises the panel geometries and derived Tailgate Serviceability Ratios (SR) from Strata Engineering's Tailgate Design Model (TDM) (Thomas, 2009).

Tailgate	Pillar Width (solid) (m)	Depth (m)	Panel Widths (LW1/LW2) (m)	SR (%)
A2	40	400 - 450	147 / 216	0.71-0.78
A4	45	500- 535	216 / 227	0.68-0.71

Table 2- Austar LTCC tailgate parameters

Serviceability Ratio is a ratio of the actual Stability Factor (SF) and the recommended Stability Factor (SFR) and that in effect, a SR of >1 means that the chain pillar has been over-designed and a SR of <1, that the chain pillar has been under-designed (Thomas, 2009).

After approximately 500 m of retreat in A2, conditions significantly deteriorated in the tailgate roadway such that the two 8 m Megabolts installed every 1 m of roadway (prior first pass abutment) required supplementing with up to 216 tonnes per metre of standing support to control conditions to acceptable levels. For A4 the 8 m Megabolt density increases to 2.5 bolts per metre of roadway and the application of 4 m grouted tendons into both rib lines has been applied. Despite this amount of support areas of chain pillar side guttering and centreline roadway roof bagging were observed on first pass retreat in TGA4 as shown in Figure 10.



Figure 10 - TGA4 first pass abutment centreline bagging and chain pillar side guttering

The deterioration in TGA4 after first pass retreat appeared to be associated with lateral relief and movement towards the recently retreated A3 goaf. This was evidenced by two observations:

- In areas of guttering, the outer roof bolt angled over the chain pillar rib line displayed a distinctive bend in the lower 800 mm of bolt towards the A3 goaf direction (Figure 10), suggesting differential shear movement in the roof towards the A3 goaf typically along a stone band (contact with lower bedding plane cohesion);
- Areas where the guttering was occurring along the chain pillar coincided with areas that had increased span between the outer roof bolt and rib line due to rib deformation during development. Where the centreline roof bagging occurred the rib conditions were much improved.

These observations both support lateral movement in the immediate roof towards the A3 goaf with the only difference being that where the chain pillar side roof bolts and Megabolts are able to better provide confinement to the shear movement in combination with the rib line (i.e. rib has not spalled out on development) the movement is impeded at the line of Megabolts and as such centreline bagging occurs. Where they cannot the lateral movement extends to the rib line where the required confinement is produced by the pillar load and consequently rib line guttering occurs. This concept is similar to that proposed by Tarrant (2004) whereby stress rotation created by the adjacent goaf and differential movement along bedding creates a "bulldozer" affect about the roadway (refer to Figure 11). This effect may then be exacerbated by the increased extraction height (\pm 6 m) of the LTCC system.



Figure 11 - Roadway rotation (skew) and movement towards adjacent goaf (Tarrant, 2004)

Given the depth and relatively small pillar size, even under single abutment loading, it could be expected that this roof deterioration, despite the amount of secondary support, is created by the high loads on the chain pillar. However in TGA5 where a 60 m solid chain pillar exists, the first pass abutment loads from A4 are creating similar occurrences. Further, recent chain pillar monitoring in TGA4 has confirmed other pillar load monitoring at the colliery (as discussed by Colwell, 1998 and Wold and Pala, 1986) in that the maingate loading abutment angle is lower at Austar than at most other collieries at around 11.5° (Trueman, 2010) and that the significant deterioration created on first pass is not due to high pillar loads alone given the applied high support densities. This measurement of the pillar load (Figure 12) reveals an unusual profile whereby the stress is highest on the travel road side (TGA4) of the pillar and not the goaf side (Trueman, 2010) potentially being associated with the shear movement and the increased extraction height of the LTCC system. Further assessment via monitoring in the larger TGA5 pillar is planned to examine this theory.

In relation to barrier and chain pillar stress monitoring exercises undertaken at Ellalong Colliery, Wold and Pala (1986) stated, 'Observational evidence of heavy abutment loads being distributed about the longwall block more broadly than might have been expected on theoretical grounds tended to be supported by the field measurements'.



Figure 12 - TGA4 pillar loading profile (Trueman, 2010)

Now under tailgate loading conditions, TGA4 is able to be managed such that the block side area between the rib and Link n Lock is showing no signs of major deterioration. Supplementing the initial 2.5 Megabolts per metre of roadway has been 1200 mm nine point Link n Locks installed at a similar initial density to TGA2 at 216 tonnes per metre. This has since been reduced to 112 tonnes per metre following further back analysis of TGA2 using ALTS2009 (Cowell and Frith, 2009) and convergence monitoring data obtained in TGA4. This has resulted in no observable change to roadway conditions.

Longwall recovery

LTCC Recovery at Austar differs from traditional longwall operations because it is necessary to recover of the rear drives, chain and pan line from behind the shields in addition to the normal recovery of drives, chain and pans in front of the shields. To enable the recovery of the equipment from the rear of the shields the gate ends need to be heavily supported to allow for the gate end supports to be removed and provide access to the rear drives and pan line. After the rear drives have been removed the rear chain and pan line can be slid along the backside goaf end of the shields and recovered at the designated gate end prior to any additional shields been removed. The longwall recovery is conducted with a traditional pull sequence, each shield removed in order opposed to a leap frog sequence. The traditional pull sequence provides the advantage of protecting the rear caving door as the tail of the shield swings, in addition the use of a traditional pull sequence also provides opportunities to reduce the bolt density above the canopies reducing the bolt-up time.

CONCLUSIONS

The application of Longwall Top Coal Caving to Australian conditions has been successful but has also highlighted several additional operational and geotechnical factors that need to be managed. Key matters learned from the operation of LTCC equipment at Austar Coal Mine that must be considered both in new areas at the colliery and when assessing other potential thick seam applications include:

- Immediate roof geology and its effect on caving recovery and dilution;
- Immediate roof geology and the potential damage to rear caving equipment;
- Cyclic weighting management and extraction height;
- Pillar loading and tailgate support design; and
- Longwall recovery bolt up design and equipment extraction sequences.

Further investigation programs are planned for Austar Coal Mine to better understand these influences as the mine progress towards the next 20 years of operations in the Stage 3 mining area.

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