2005

Practical Considerations in Longwall Support Behaviour and Ground Response

T. P. Medhurst
AMC Consultants, Brisbane

Publication Details

This conference paper was originally published as medhurst, TP, Practical Considerations in Longwall Support Behaviour and Ground Response, in Aziz, N (ed), Coal 2005: Coal Operators' Conference, University of Wollongong & the Australasian Institute of Mining and Metallurgy, 2005, 49-58.

Practical Considerations in Longwall Support Behaviour and Ground Response

T P Medhurst[1]

ABSTRACT

This paper examines the interplay between longwall support design/geometry features, operational controls and geological features on ground response. Experience from several investigations is used to demonstrate the influence of factors such as longwall support capacity and geometry, setting pressure, coal seam strength and stiffness, tip-to-face distance and hydraulic supply and control system parameters on longwall ground response. These factors are then used to outline the requirements on key controls such as retreat rate and cutting height and their influence on allowable roof convergence.

The ground response curve concept as a means to provide graphical representation of longwall support and strata interaction processes is presented. The approach was developed to address the requirement for a practical longwall support evaluation and selection tool that can take account of support load influences such as changes in roof geology or cover depth. An example of the comparison between single pass longwall and top coal caving in a thick seam environment is given to demonstrate the influence of the various factors discussed.

GROUND CONTROL AND RISK

Poor ground response and the associated business impact of longwall downtime is a major issue for the Australian underground coal industry. Geological features such as thick overlying sandstone channels, very weak immediate roof conditions, high stresses and highly cleated and friable coal seams are common. A more detailed understanding of longwall support and strata interaction processes is needed. Such an understanding requires a multi-disciplinary approach taking account of the mechanical, structural and geotechnical influences on longwall support performance.

On close examination of both mining and civil tunnelling industries, geotechnical risks can be virtually eliminated when a suitable monitoring and operational support program is implemented. The key feature being that the level and detail of the monitoring and support program must match the project risk profile. For example, significant fall-of-ground incidents are rare in the tunnelling industry. This can also be said of gateroad development operations, where optimisation of mining and ground support practices has been considerable in the last ten years. Longwall production activities however, show that the frequency of 'unforeseen' events still remain unacceptably high.

A rough examination of a typical longwall operation reveals that whilst the majority of revenue is generated from the longwall, most of the geotechnical monitoring and effort is directed towards roadway stability. Clearly, the effort put on development ground support and trigger action response plans has yielded significant improvements. The principles of monitoring and operational support programs are therefore proven in the coal industry.

GROUND RESPONSE CURVES

Strata management plans with trigger levels based on measured convergence would be familiar to most in the coal industry. Such an approach has been around for years and was originally developed for the civil tunnelling industry. In geotechnical engineering it is known as the observational method, in which the timing and method of ground support is determined via support pressure and convergence monitoring during construction. The underlying tool of the observational approach is the ground response curve (GRC). The general concept is outlined by Brown *et al* (1983) and shown in Figure 1.

The GRC shows the relationship between roof convergence and the support pressure applied. Upon excavation, initial roof relaxation occurs which would require the support resistance to match the primary stress level to prevent any convergence (Point A). As the roof begins to deform, the required support resistance to prevent further convergence reduces, as arching and the self-supporting capacity of the ground is utilised (Point B). The roof then reaches a point where failure begins to develop (Point C). Required support resistance then begins to increase as self-supporting capacity is lost, and support of failed ground is required (Point D).

The ground support line (PB) shows a typical point at which ground support might be installed following initial roof convergence (δ). The slope of the line (PB) reflects the support stiffness. The aim is to operate as close to Point C as possible provided that the corresponding roof convergence is tolerable, thus allowing the available strength of the rock mass to be utilised whilst minimising the loads taken by the ground support elements. It is also possible for the support to be too stiff, or installed too early, so the load bearing capacity of the ground is not fully mobilised and the load in the supports are too high. Similarly, ground support which is too soft, or installed too late, will be ineffective in controlling roof convergence.

The roof convergence monitoring and support design philosophy outlined in Figure 1 has been applied to gateroad development and roof support design for several years on an informal basis. Typically, primary support is designed/installed and then monitoring is used to guide decisions for secondary support. This is the basis of convergence monitoring, establishment of trigger levels and remedial support plans that form part of the strata management plan. A typical relationship between roof convergence trigger levels and the GRC is shown in Figure 2.

For each set of conditions (changing geology, cover depth or stress levels) there is a unique GRC. Optimal ground support practices rely upon monitoring of ground behaviour and development of appropriate action plans. Such processes are well developed for assessing and managing roadway stability and comprise a core role of the site geotechnical engineer. Given its success in development operations and gateroad stability, there is significant scope to reduce geotechnical risk through application of these principles to longwall ground behaviour. The GRC provides a convenient means to show ground behaviour, its relationship to shield performance, and roof stability within the broader context of longwall operations.

STRATA-SUPPORT INTERACTION

Two basic models exist for analysing support loading, namely force-controlled or convergence-controlled roof behaviour (Barczak, 1990). Historically, support load was estimated assuming an overlying detached roof block to be maintained in equilibrium by the support resistance (Wilson, 1993). The premise of the detached roof block approach is force-controlled

1. MAusIMM, Principal Geotechnical Consultant, AMC Consultants Pty Ltd, Level 8, 135 Wickham Terrace, Brisbane Qld 4000. Email: tmedhurst@amcconsultants.com.au

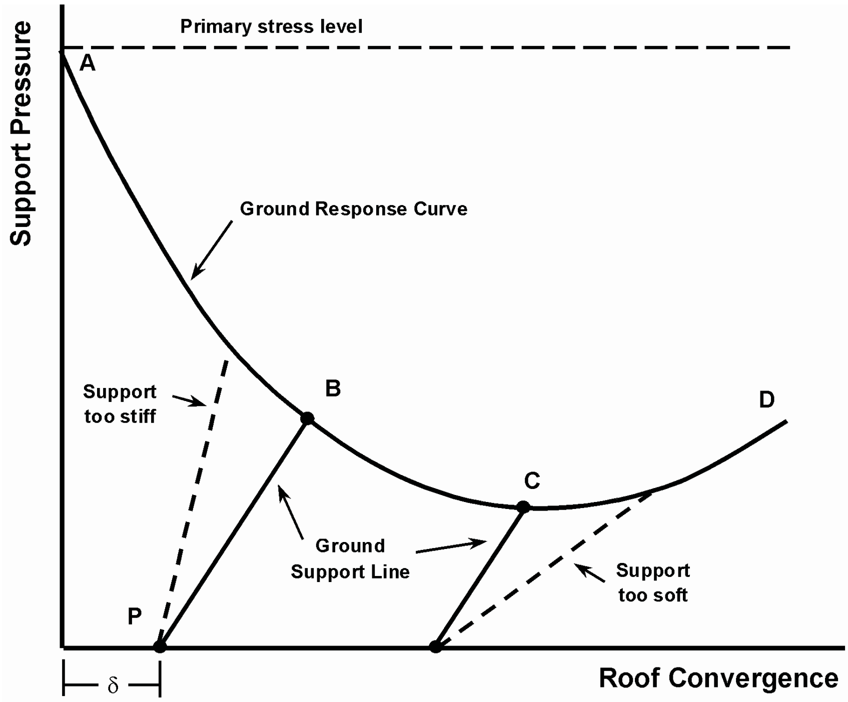

FIG 1 - Rock-support interaction diagram.

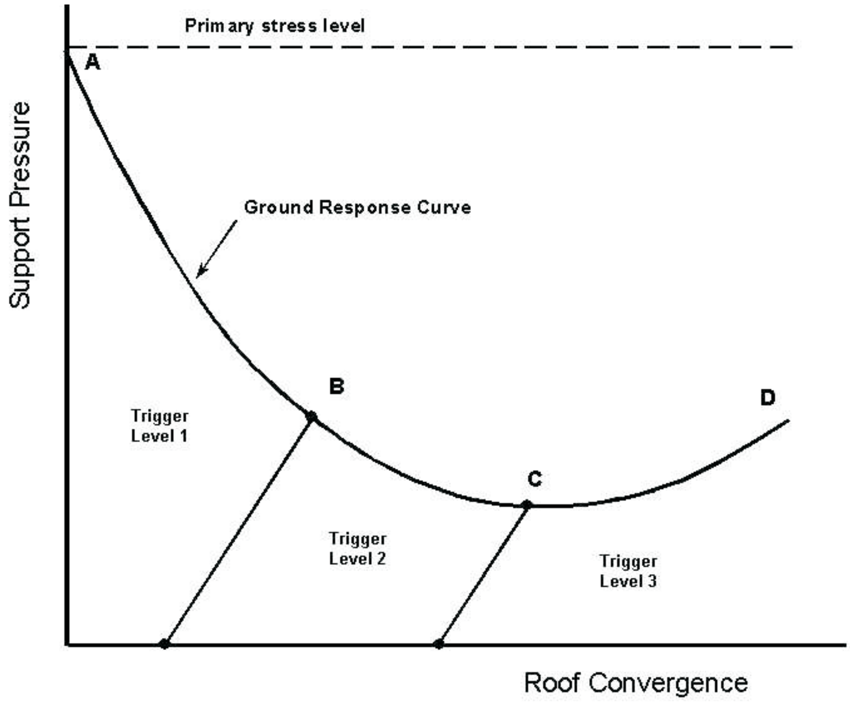

FIG 2 - Rock-support interaction diagram showing trigger levels.

roof behaviour. It does not consider load development resulting from main roof convergence nor does it consider the influence of the stiffness of the total ground supporting system on face convergence.

Evidence from several longwall mines operating at greater depths and/or under massive roof conditions suggests that convergence-controlled roof behaviour is generally more applicable to support response. This approach relies on determining the load distribution between the coal seam, roof strata, longwall supports and goaf, which is a function of the relative stiffness of each supporting element. The 'overall stiffness' of the four main support elements governs the amount and rate of roof convergence.

To assess convergence driven roof behaviour requires the use of the GRC. A typical example might be to investigate the effects of poor hydraulics on support performance and roof convergence, as demonstrated in Figure 3. A typical range of roof conditions is shown by the upper and lower GRCs. Clearly, roof degradation over time will result in higher loads and increased convergence. The support setting line shows the point at which the roof

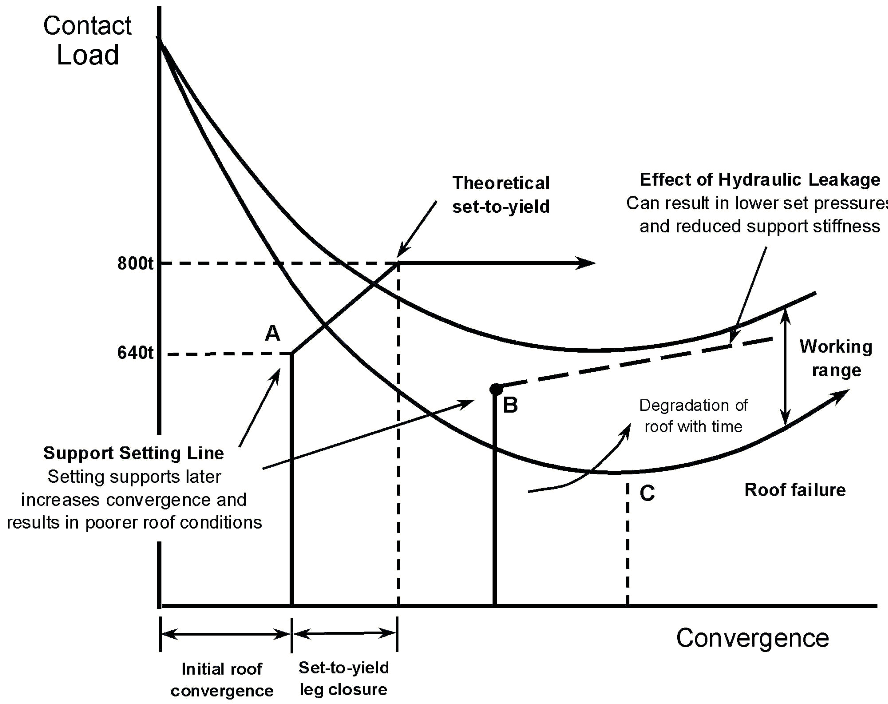

FIG 3 - Strata-support interaction diagram for longwall support.

supports are set. An 800 t longwall support with 80 per cent set-to-yield ratio is shown. Usually an amount of initial roof convergence occurs, then as the supports are set, additional roof convergence then taken up as leg closure (due to compression of the hydraulic fluid). Depending on the self-supporting capability of the strata, roof convergence would cease at the point where the support setting line meets the ground response curve. If the support does not have sufficient capacity or is set too late, roof convergence would continue as the support goes into yield.

Hydraulic leakage effectively increases the convergence permitted between set and yield. This shows how poor hydraulic maintenance can severely limit support effectiveness and contributes to poor face conditions. The net effect of hydraulic leakage is the reduction in support stiffness and setting loads. In contrast, fully operational supports (theoretical set-to-yield profile) set under similar conditions would be expected to provide stable roof conditions.

LONGWALL SUPPORT CAPACITY

In order to perform an assessment the four main support elements about the longwall face, namely the coal seam, roof strata, longwall supports and goaf, need to be considered. There are several data sources available to estimate support parameters, particularly from an operating longwall face. In general several input sources can be used:

- monitored leg pressure values from the operating longwall face;
- leg convergence/stiffness test results usually supplied by the longwall manufacturer;
- underground observations of coal seam and face conditions and associated measurements of coal seam strength and stiffness characteristics;
- goaf geometry from subsidence data and other sources such as surface-to-seam extensometers or microseismic monitoring; and
- routine geotechnical data such as roof strength from laboratory data and/or borehole geophysics.

Using leg pressure values, leg stiffness values and underground observations a rudimentary strata-support interaction diagram can usually be derived. Provided that the longwall face is not loaded to the point that the yield valves are continually activated, the leg pressure distribution along the face can provide a range of loads that can be matched against face conditions. A measure of face conditions can be deduced from an estimate of coal seam compression, leg stiffness data and underground observations, which in turn can be matched against coal seam strength data.

This approach provides the capability to graphically represent typical longwall support response from real operating data. To augment the initial assessment, the GRC also provides a series of data points that can be used to calibrate numerical modelling analyses. Modelling may then provide the means to assess the impact of variance on the existing operating conditions. One example is the recent work carried out at Ulan Mine (Medhurst and Reed, 2005).

A series of analyses were undertaken to examine strata-support characteristics for a number of modern two-leg support systems. Due to the effect of different support types, it was more convenient to present the results in terms of load density rather than load. The resulting GRCs are shown in Figure 4. Under normal operating conditions, the analyses indicate that two-legged supports imparting a load of 100 t/m^2 or greater would be adequate for the future Ulan operation.

Fluctuations in hydraulic line pressure are common on longwall systems, for example if several supports are activated simultaneously or hydraulic leaks develop. Variations in setting pressure across the face can therefore often lead to uneven roof loading and roof stability problems. Figure 4 shows that the 110 t/m^2 supports could be set at 80 per cent or possibly even 70 per cent of yield load in order to accommodate support load variance whilst limiting excessive roof convergence. The recommended support configuration for Ulan included 2 m wide, two-legged supports with a support density in the range 100 - 110 t/m^2. The upper limit at yield load was suggested to provide passive resistance in the event of heavy weighting, for example at panel startup or when mining through structures.

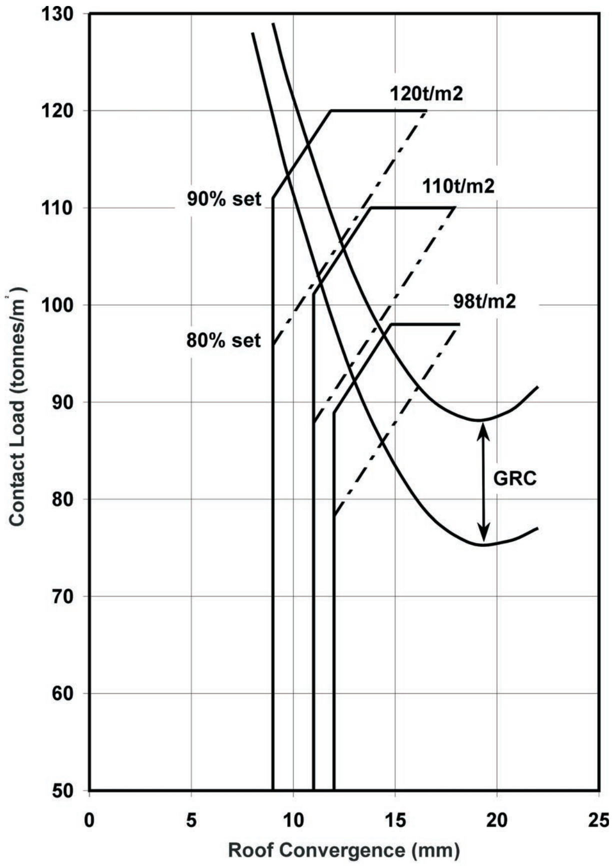

FIG 4 - Strata-support response for various support capacities.

COAL SEAM AND SUPPORT STIFFNESS

One of the most important, but often overlooked, support elements on the longwall face is the coal seam itself. The coal seam supports the forward abutment load and in doing so, can provide a measure of active load transfer mechanisms. Detailed experimental studies of the mechanical behaviour of coal have shown that deformation associated with the onset of fracturing in unconfined coal typically occurs at just over 0.5 per cent axial strain (Medhurst and Brown, 1998).

The development of face spall generally corresponds to the peak strength of the coal seam. The presence of face spall therefore conveniently provides a measure of both deformation and imposed load at the coal face. A measure of the imposed load can be back-analysed from an estimate of coal seam strength. Previous studies have shown that measures of coal seam rank in combination with brightness profile mapping can be used to estimate seam strength properties (Medhurst, 1999).

A simple difference in stiffness and strength for various coal seams can be used to demonstrate the possible impact on longwall support response. For example, a typical thermal coal seam such as Ulan with a strong, dull coal might have a stiffness up to 4 GPa and mass unconfined strength of 6 MPa. In contrast a weak, cleated coking coal seam such as the Bowen Basin might have stiffness as low as 2 GPa and mass unconfined strength of 4.5 MPa. A typical 3 m cutting height over a longwall face puts the onset of face spall at about 3 m × 0.5 per cent strain = 15 mm vertical compression. In general terms, it can be easily realised that Bowen Basin type conditions would only be able to withstand about three quarters of the imposed abutment load of that of the stronger thermal coal before poor face conditions and increased longwall support loads develop. Similarly if the same abutment load was imposed in both cases, poor face conditions are likely to develop more quickly in the weak and softer seam.

Analysis of longwall support leg pressure data often reflects the distribution of load carried on the face but can also reveal specific changes in strata response such as the effect of depth changes or jointing in the immediate roof. Once a measure of support load is obtained, the manufacturer's leg stiffness test results can be used to estimate typical support convergence. This allows a comparison between compression of the longwall supports during mining, coal seam compression and face spall. Following studies at several mines, it appears that most modern longwall supports tend to compress between 5 mm and 7 mm per 100 tonne of applied load.

It is noteworthy that many longwalls operate in seams of 2 m to 3 m thick with the difference between setting load and yielding load of the supports commonly 150 to 200 tonne. In these conditions tolerable levels of vertical compression are in the order of 10 mm to 15 mm for both the coal seam and the longwall supports. The successful application of longwall support technology in recent years therefore might be partly due to close matching with coal seam stiffness characteristics to ensure good roof control. A uniform vertical compression profile helps to minimise the effects of mining induced shear stresses in the immediate roof.

OPERATING FACTORS AFFECTING STABILITY

Canopy tip-to-face distance

Roof stability is a function of lateral confinement, which is generated by the support resistance and the coal seam. In general, stability of the roof strata is highly dependent on the span-to-thickness ratio of the roof beam. Two basic principles apply:

- rock strength must be high enough to resist failure if the beam is thin; or
- the beam must be thick enough to be able to generate lateral confinement.

Roof stability is dependent on the spanning capabilities of the individual beds within the roof unit. For typical Australian roof strata in which rock strengths (UCS) are greater than 20 MPa, it has been found that long-term stable roof generally prevails when the span-to-thickness ratio ≤4. In other words, for bedding spacing of about 0.2 m, a canopy tip-to-face distance up to about 0.8 m would remain stable.

In some cases when bed spacing is thin and/or bedding surfaces are weak, the immediate roof skin can often delaminate. In one example, as mining activity progressed below 200 m depth, the immediate roof coal had started to fall at irregular intervals across the face. The penny band separating the coal ply from the overlying mudstone provided a convenient delamination plane. A simple unsupported span delamination model (Shen and Duncan Fama, 1999) was applied.

Figure 5 shows the relationship between factor of safety (or stability) and depth for a 0.3 m thick coal roof beam. The plot shows the influence of horizontal confinement on roof stability. This can be affected by the amount face spall, which in turn, can result in the forward abutment moving further into the solid coal with loss of confinement and/or clamping stress on the roof beam. It may also be affected by the lower-advance-set cycle of the roof supports, for example, the influence of contact advance.

Hydraulic supply and control settings

The importance of reliable positive set pressure across the entire faceline has been emphasised many times in discussion on maintaining face stability. All too often the effects of faulty

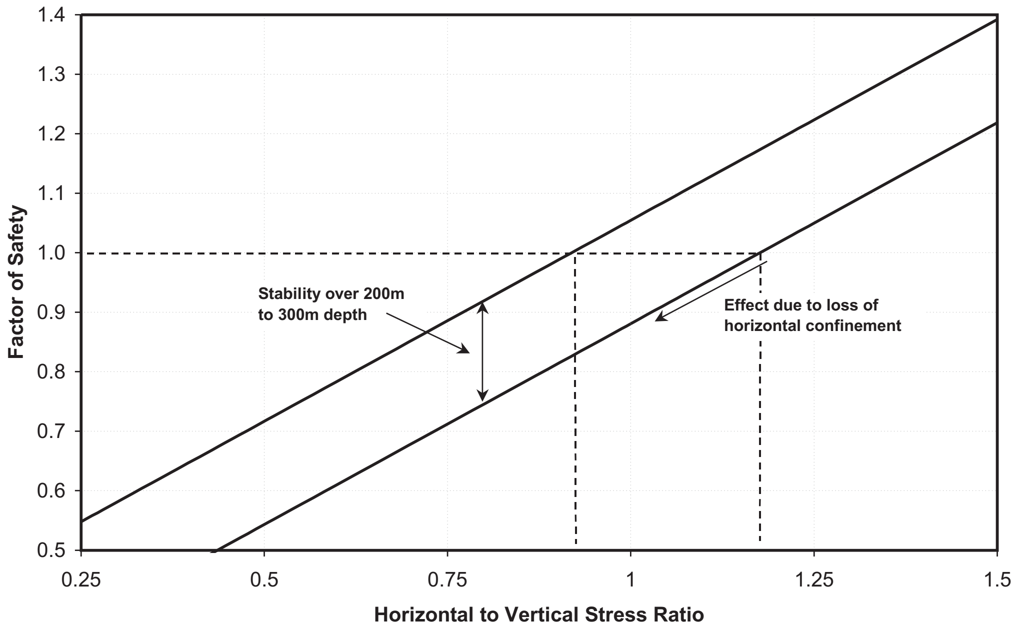

FIG 5 - Roof stability as a function of lateral confinement.

blipper valves and/or inadequate pump pressure have been known to result in adverse face conditions. In general, specification of set pressures needs to take account of factors such as:

- coal seam yield/face spall,
- extra load during support advance,
- need to minimise roof convergence, and
- extended downtime.

It is noteworthy that the impact of face spall (based on 1 m of broken coal in advance of the supports) would typically be expected to result in a minimum of 40 tonnes additional load on each support. Similarly in poor conditions, if methods such as double chocking are employed, additional 50 t weighting cycles may be imposed in the roof and adjacent supports during support advance.

In weaker conditions, more frequent and/or out-of-sequence support moves often result in higher demand on the hydraulic supply system. It is therefore important to ensure that the hydraulic supply and control settings are matched to the load demand on the face. Modern hydraulic supply control systems commonly use pressure threshold values that control when adjacent supports are to operate, triggering of positive set and reactivation threshold, and sufficient pressure to push the AFC. The basic support control parameters can be often changed from default values without recognition of their impact on support performance. The main factors that need to be considered are:

- Is sufficient supply pressure reaching the centre of the face?
- In situations of high hydraulic supply demand, supply pressure to the legs may be low. Is the threshold value sufficient to ensure positive set is activated?
- Is the differential between nominal set pressure and positive set reactivation set at the right value? In some instances, this setting can result in repeated loading or 'pumping' of the supports on a continuous cycle, particularly for older legs that normally have a measurable leakage rate.
- Is the pumping rate sufficient to ensure correct setting times and support advance speed? Is initial roof convergence beyond acceptable levels before adequate set pressure is achieved?

Cutting height

The introduction of longwall mining into thick seam environments has raised new and challenging issues in ground control. As previously mentioned face stability and the associated matching of coal seam and longwall support stiffness is critical to successful longwall mining. In general, the higher the cutting height, the greater potential for face spall and then larger canopy tip-to-face distances. Anecdotally, it is well known that reduction of cutting height can have a favourable impact on longwall face stability. In poor ground conditions, it may be therefore advantageous to have a suitable working range of the supports to temporarily lower the cutting height. Ground response curves for different depths of cover and cutting heights under typical Bowen Basin conditions is shown in Figure 6.

In terms of normal 'static' performance, Figure 6 illustrates how the support resistance at 4.5 m height is barely adequate at depths of 250 m but is improved by lowering the cutting height to 3.8 m. Also note that approximately 30 mm of roof convergence could be expected prior to setting the supports in the lower-advance-set cycle when operating at the greater depth. This presents a situation in which the margin for error in support operation is significantly reduced. Small amounts of additional roof convergence are likely to result in roof guttering, which can easily be exacerbated by factors such as poor set pressures or inadequate hydraulic supply issues.

A large working height range for longwall supports can offer both advantages and disadvantages. Apart from the requirements of shearer clearance during cutting and transport considerations, the supports need to be able to provide active thrust to the roof in all situations. There are two main considerations:

- the canopy tip generally moves in a vertical locus plane over the working range; and
- support geometry and leg size have been designed to ensure sufficient stiffness and stability at high working heights.

The tip-to-leg distance of modern two-leg supports is commonly about 3.7 m. At cutting heights greater than 3.7 m, the supports are therefore required to operate under conditions in which the main support zone is higher than it is wide. In essence at cutting heights greater than about 3.7 m, the supports go past the 'square' and

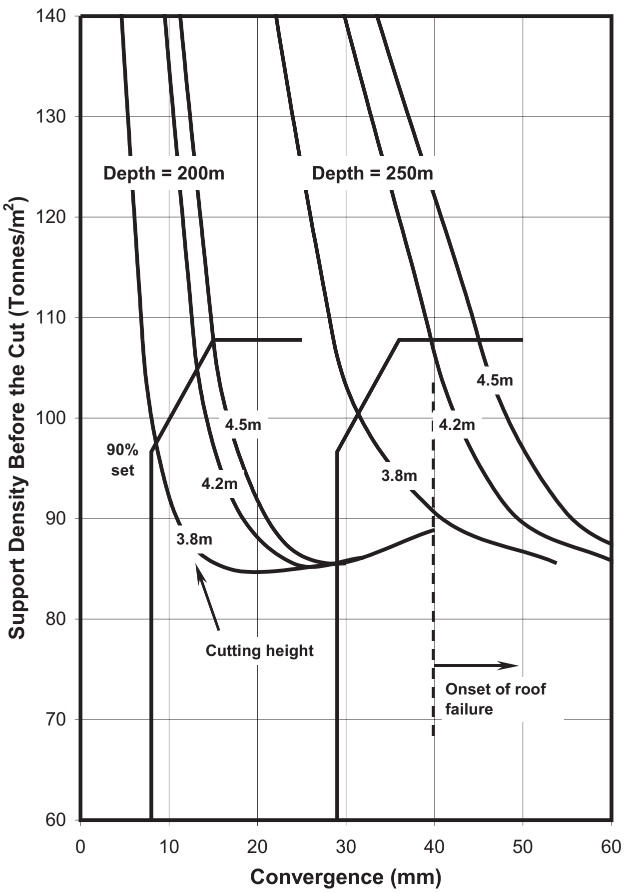

FIG 6 - Effect of cutting height on ground response.

revert from a beam type loading scenario to a column type condition. Anecdotally, this appears to produce effects such as:

- greater potential for caving over the support canopies;
- reduced magnitude of canopy tip loads;
- torsional effects due to cross-dip with leakage in leg seals and poor alignment of canopies; and
- increased potential for support rotation into the floor.

Retreat rate, stand-up time and convergence

In general, the time-dependent effects on caving and support loading are not well understood. However, the background rate of roof convergence is important in controlling roof stability and can sometimes be related to the impact of a slow retreat rate. In general, most Australian longwalls would operate under typical convergence limits as follows:

- face spall initiated after 15 to 20 mm vertical compression in coal seam;
- cavity development when roof convergence exceeds 30 to 50 mm; and
- overlying strata broken when roof convergence exceeds 100 mm.

In heavy weighting environments, longwalls are routinely subjected to loads that result in a convergence rates in the order of 10 mm/h. Similarly, convergence rates during a weighting cycle can typically exceed 20 mm/h. This suggests that roof cavities will develop over a period of a shift or less under slow retreat on the basis of exceeding a critical convergence level of 100 mm.

Anecdotal evidence indicates that maintaining a critical minimum retreat rate can often mitigate the effects of poor face stability. A typical first quartile Australian longwall operation cutting at 3 m height has an average annualised retreat rate of 11 m/day over a typical longwall panel. This equates to a typical daily retreat rate of 20 m/day and a maximum of 30 m/day.

The extent of the damage to the coal seam in front of the face would typically be in proportion to the seam thickness, say 2 - 3 m for a typical longwall. Therefore to maintain relative competent ground ahead of the face, a minimum retreat rate in the order of 5 m/day is warranted. However, as the size of the damage zone grows, the effect of shearing ahead of the face becomes more pronounced. Shear failure of roof material in thicker seam environments can result in damage 5 m to 10 m ahead of the face. Study of daily retreat rates in weak seams indicate that average retreat rates in excess of 10 m/day are required to limit the influence of time-dependent face loading issues and related longwall delays. Retreat rates less than 5 m/day for two consecutive days or more often result in development of cavities and poor canopy/roof contact.

GEOTECHNICAL FACTORS AFFECTING STABILITY

Weak immediate roof

In the discussion of canopy tip-to-face distance, it was noted that roof stability is a function of lateral confinement, generated by the support resistance and the coal seam. This is particularly important for operating under weak immediate roof. The preceding discussion outlined some issues relating to delamination of a weak immediate roof layer. Another important issue however, is shearing and cavity development in thicker roof layers, often in the presence of a rider seam or weak clay layer within the lower 2 m of the roof horizon.

The shear strength of weak rock increases significantly with confinement. In basic terms, the coal seam and the longwall support legs act as the main abutments for arching of the immediate roof strata. The canopy itself then serves to provide active pressure within the arch zone. This support mechanism however, breaks down if either abutment is lost by:

- significant amounts of face spall or initial seam compression leading to a wider arch, that is beyond the span limits of the immediate roof beam; and/or
- inadequate set pressure, which is below the active pressure requirements and allows roof convergence beyond stable limits.

This problem often manifests itself when the weak layer is between 1 m and 2 m into the roof. This is because the influence of the bearing pressure of the support canopy is diminished 1m or more into the roof and stability becomes dependent upon the self-confining effects of the roof strata. The main control in such situations is to preserve the end constraints of the roof beam so that lateral constraint can develop. In other words, damage or face spall in the coal seam needs to be minimised. An example of the effect in a thick seam environment, in which the effect of reduced cutting height increases confinement in the immediate roof and seam zone; is shown in Figure 7.

The confining effect on roof stability is sometimes counter-intuitive as it is common to focus solely on the roof strata properties alone and its potential to delaminate. The potential for shearing, however, is a localised stress related phenomenon and to some extent can be managed by the choice of a suitable cutting geometry and complimentary longwall configuration. In more extreme situations, ground improvement methods are commonly used to consolidate the face and immediate roof strata. There are many examples of the need to inject PUR into the coal seam for a significant distance ahead of the face to ensure a self-supporting roof beam can develop.

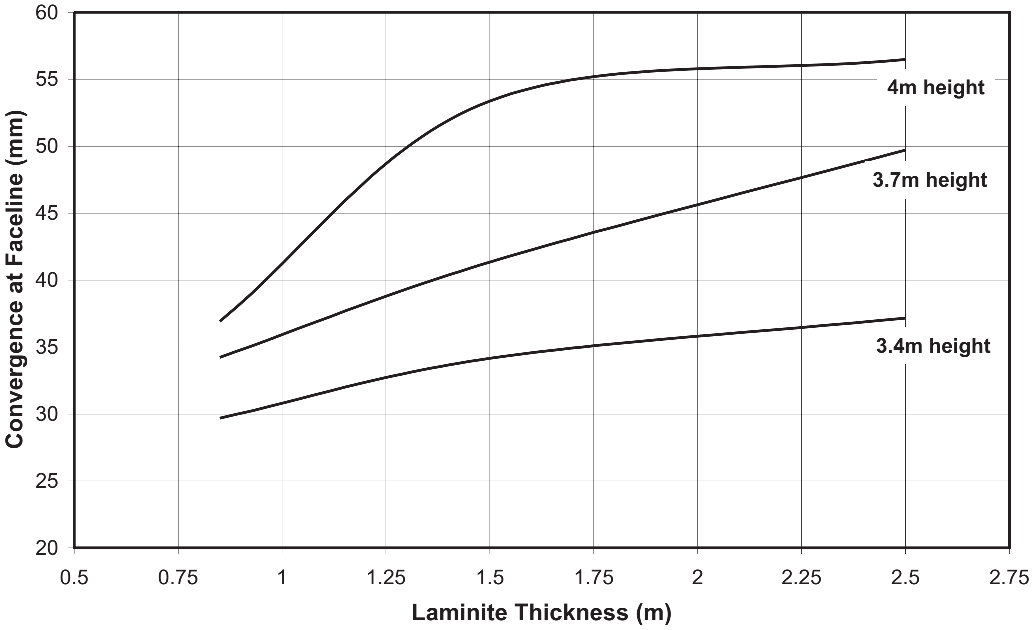

FIG 7 - Effect of laminite thickness on roof convergence.

Massive overburden strata

The presence of overlying sandstone channels presents an additional consideration in relation to periodic weighting issues. Massive strata beams commonly break at a minimum length to thickness ratio of 1:1 and can be up to 2:1, especially in cross-bedded sandstones. The strength, distribution and character of the overlying sandstone units presents several issues for longwall mining, including:

- cantilever effects that overload supports under 'massive' conditions (including panel start-up);
- detachment of large blocks that are able to overload supports; and
- development of small blocks in tip-to-face area that disrupt cutting.

Clearly, the closer the massive strata unit is to the seam, the greater influence on support loading that is developed, particularly when the strata is able to bridge and overhang behind the canopy. This is shown in Figure 8. The net effect of overhanging strata is that the centroid of the block moves from forward of the legs to behind the legs. The length of overhang then becomes critical for support loading. Its effect is demonstrated in Figure 9 and shows how support capacity can be rapidly exceeded as a result of strata overhang.

Thick seam

Most Australian coal operators have access to potential thick seam longwall mining reserves and are looking to maximise the return on investment in these mines. The preceding topics point out several issues that require extra consideration in the thick seam environment, namely the matching of coal seam and longwall support stiffness, support geometry, retreat rate and maintaining face stability for roof control. One key issue is the potential for the cave line moving over the support canopy.

Due to geometrical factors, it is more likely for the cave line to develop above the canopy in a thick seam operation. For two-leg supports this presents a unique situation. The canopy essentially acts as a fulcrum over the leg hinge-point; therefore the canopy tip load is dependent upon the opposite reactive load behind the line of the legs. The effect is demonstrated in Figure 10.

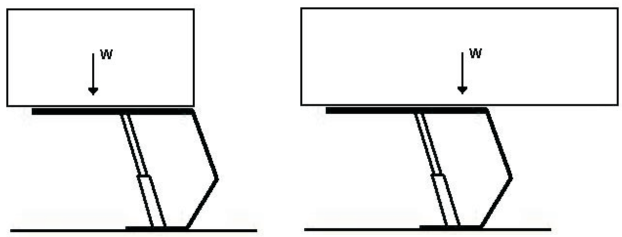

FIG 8 - Detached block-support loading mechanisms.

As the distance behind the legs reduces, support pressure in this area of the canopy increases. The pressure in the immediate roof behind the legs increases until localised crushing develops, which in turn, can result in a progressive weakening of roof over the canopy. As the cave front moves forward, canopy tip load reduces approximately in proportion to distance. The net effect is zero tip load when the cave line reaches the line of the legs and the tips begin to be pushed down.

Whilst this effect is detrimental to conventional longwall mining, the very same mechanism is exploited in the longwall top coal caving (LTCC) method. LTCC supports are of four-leg design (to eliminate the fulcrum effect) and are also of lower capacity to facilitate caving over the canopies. The performance of a typical 620 t LTCC support along with support capacities of 800 t and 1000 t for a typical 8 m thick weak Australian coal seam (3 m cutting height) at 200 m and 400 m depths is shown in Figure 11.

In the 400 m deep case, the amount of initial convergence is in the order of 80 to 90 mm. This is a key issue for face stability and would result in a large damage zone above and in front of the supports. Anecdotal evidence suggests that Chinese coal seams tend to be more 'blocky' than the weaker Australian coking coal seams. Blockier coals tend to produce high shear strengths and are stiffer; enough to maintain face stability whilst at the same time weak enough to cave. The analysis suggests that LTCC support capacity in the order 900 t or greater might be required in a typical Australian panel layout in deep (+300 m) conditions.

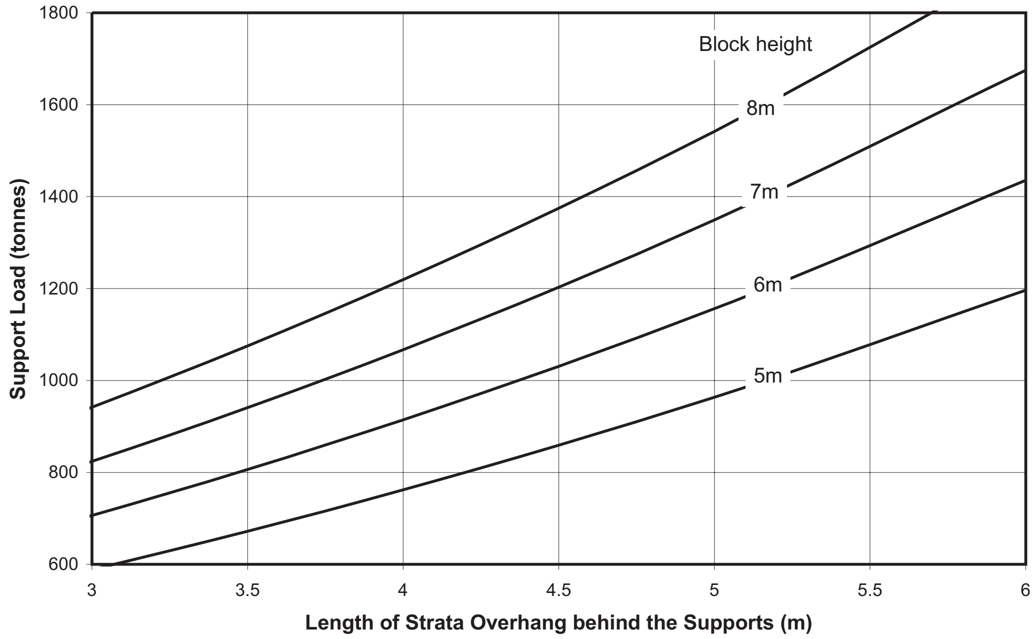

FIG 9 - Effect of block overhang on support loading.

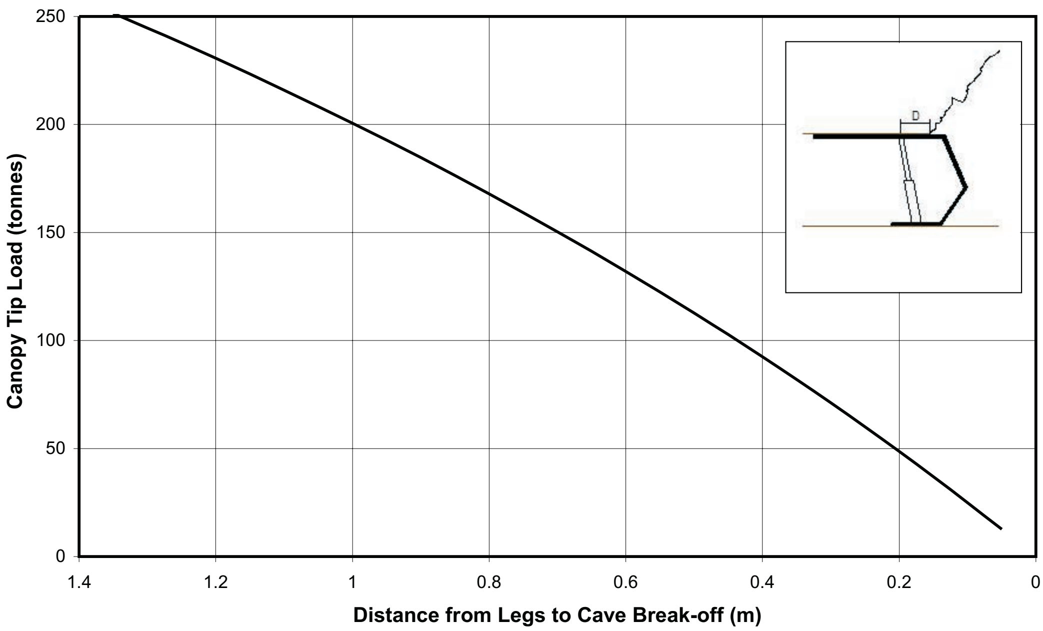

FIG 10 - Reduction in canopy tip load.

POTENTIAL TECHNOLOGY REQUIREMENTS

One of the most common problems encountered is when operating under weak immediate roof. Invariably, poor roof conditions force operators to turn the positive set system off to maintain a consistent canopy attitude. This in turn usually leads to poor set pressures across the face and exposes the longwall to increased roof convergence as a result of hydraulic leakage (Figure 3) and other factors such as poor canopy/roof contact.

One possible solution is to reconfigure the posi-set system, which is currently based on pressure control, to include a leg convergence based control parameter. In other words, once the supports are set against the roof, the posi-set system is activated to maintain the support within an allowable convergence limit. This will require appropriate sensor technology to measure convergence, presumably either by a potentiometer system, tilt sensors or leg fluid flow sensors. Factors associated with support geometry may also need to be considered.

Accurate measurement of leg convergence may have many benefits, particularly when the longwall is often operated in yield. For longwall automation purposes, it could be linked to horizon control in the lower-advance set cycle. Similarly, the use of face monitoring data is becoming more prevalent for predicting weighting cycles and support diagnostics. The leg convergence rate reflects the work done by any given support. The on-line measured work rate of a longwall support can provide a fundamental measure of its life cycle attributes as well as to reflect load transfer effects such as heavy weighting (Crisafulli and Medhurst, 1994).

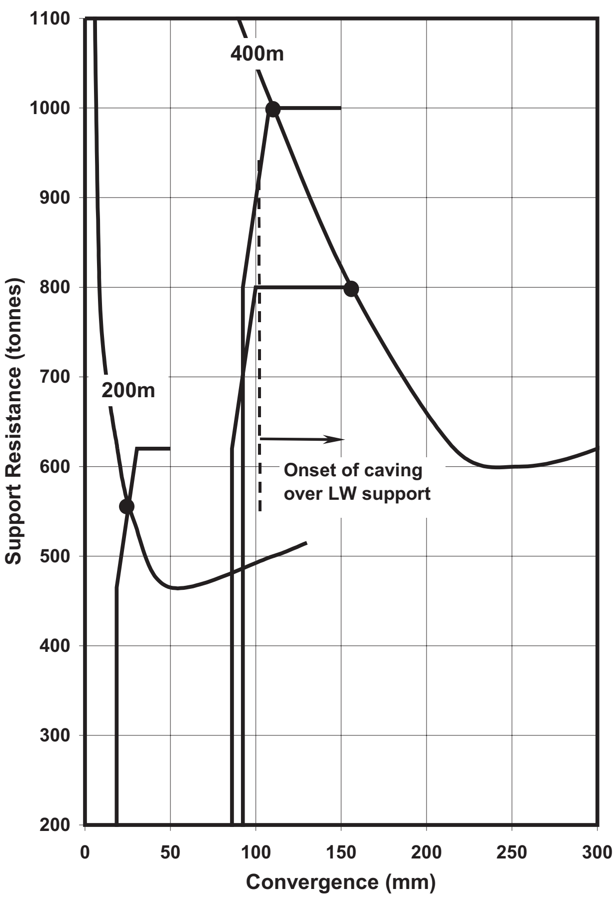

FIG 11 - Strata/LTCC support interaction in weak coal.

ACKNOWLEDGEMENT

The input and support provided by representatives of Xstrata Coal Australia, Anglo Coal Australia and BMA are kindly acknowledged.

REFERENCES

Barczak, T M, 1990. Practical consideration in longwall support selection, in *Proceedings Ninth International Conference on Ground Control in Mining*, pp 128-134, Morgantown.

Brown, E T, Bray, J W, Ladanyi, B and Hoek, E, 1983. Ground response curves for rock tunnels, *Journal of Geotechnical Engineering,* 109:15-39.

Crisafulli, S and Medhurst, T P, 1994. Robust on-line differentiation techniques with an application to underground coal mining, *Control Eng Practice,* 2(2):201-209.

Medhurst, T P, 1999. Highwall mining: practical estimates of coal-seam strength and the design of slender pillars, *Trans Instn Min Metall,* Section A: Mining industry, 108:161-171.

Medhurst, T P and Brown, E T, 1998. A study of the mechanical behaviour of coal for pillar design, *Int J Rock Mech Min Sci and Geomech Abstr,* 35:1087-1105.

Medhurst, T P and Reed, K, in press. Ground response curves for longwall support assessment, *Trans Instn Min Metall*, Section A: Mining industry.

Shen, B and Duncan Fama, M E, 1999. A coal roof failure model for highwall mining span stability assessment, in *Proceedings Eighth ANZ Conference on Geomechanics*, pp 633-639.

Wilson, A H, 1993. Soft rock properties and strata control, in *Comprehensive Rock Engineering* (ed: J A Hudson) Volume 2, Chapter 23 (Pergamon Press: Oxford).