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Tailgate Support Design - An Empirical and Analytical Approach

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TAILGATE SUPPORT DESIGN – AN EMPIRICAL AND ANALYTICAL APPROACH

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ABSTRACT: There are currently no methods that provide mine operators with reliable tailgate support design. The reliance on experience or at worst, trial and error for tailgate support design is a major contributing factor responsible for longwall downtime and has potentially catastrophic consequences.

An ongoing approach to tailgate support design seeks to better understand tailgate strata mechanics and the interaction between the strata, installed support and longwall powered support.

The approach combining empirical and analytical methods for roadway layout and detailed gateroad support design is an alternative to statistically based assessments.. It is also expected to provide greater rigour for pillar design where roadway serviceability is a key determinant.

INTRODUCTION

The consequences of a major gateroad roof fall can be catastrophic and include:

- Abandonment of longwall.
- Inability to recover longwall equipment.
- Disruption to ventilation in the goaf which has the potential to initiate spontaneous combustion.

Whilst major events are uncommon, problematic tailgate behaviour is a common occurrence, frequently leading to longwall downtime of days or even weeks. In many cases the appropriate response cannot be achieved because of difficulties accessing the tailgate to install additional support.

An incident of tailgate instability and longwall downtime leads to a loss of confidence in the support design. This typically results in a legacy of costly overdesign extending into future extraction panels.

The current understanding of tailgate strata mechanics, support behaviour and the interaction of powered supports is not sufficient to provide mine operators with confident in the tailgate support design.

TAILGATE STRATA MECHANICS

Discussion of tailgate behaviour is broken down into the following three broad categories:

- The loading environment.
- Geological controls.
- The interaction with the support elements of primary and secondary tendons, standing support and powered longwall support.

Loading Environment

In a typical two heading gateroad layout for longwall extraction, the tailgate within a multiple extraction panel will experience a wide range of loading conditions over its history, these include:

- Driveage either within a virgin stress field or one that has been modified by previous extraction.
- Driveage under the influence of an adjacent goaf as the maingate travel roadway.
- Driveage under the additional influence of the approaching longwall extraction as a tailgate proper.

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The behaviour of the roadway on during development will influence its response to subsequent changes in the loading environment. Clearly if the strata has already softened on driveage, any further stress changes will result in an increase in permanent deformation.

The tailgate support design should take into consideration the style and magnitude of deformation experienced on driveage and the integrity of the primary reinforcement system.

Stress changes associated with longwall extraction
Determination of the distribution of stress during longwall extraction is an area of continuing investigation.

Relative weight distribution between goaf and abutments
Figure 1 illustrates a general model for the distribution of weight between the goaf and the abutments.

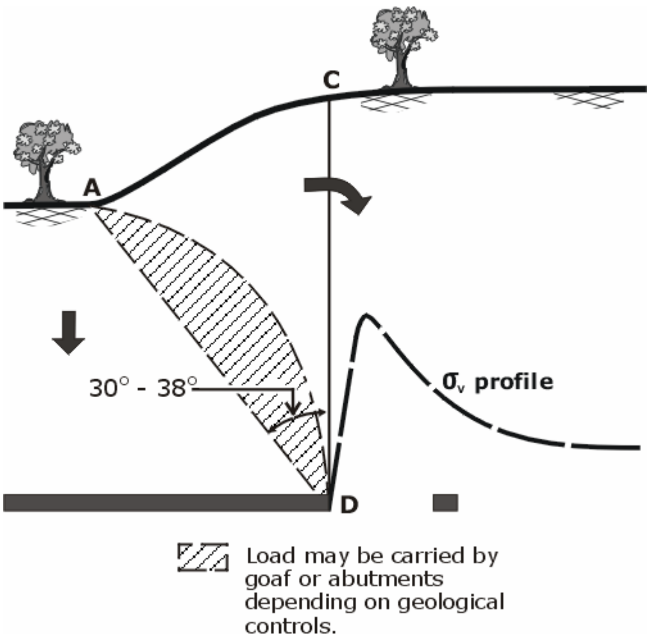

FIG. 1 - General model for the distribution of weight between the goaf and the abutment.

Consideration of the surface profile in Figure 1 illustrates a portion where subsidence has not yet occurred and a portion where the subsidence has reached a maximum. The tree marked 'C' in Figure 1 is fully supported by the abutments and the tree marked 'A' is fully supported by the goaf (in this case a supercritical scenario in subsidence engineering terms).

The proportion of weight distributed between the goaf and abutments between trees A and C is dependent, among other things, on geological controls, caving behaviour and the in-situ stress state. The relative weight distributed between the goaf and abutments in the shared region will vary between mines and should be confirmed through field measurement.

In the absence of field measurement, a conservative approach to pillar load estimation is represented by the straight line 'AD' in Figure 1, this line representing the highest conceivable load distributed to the abutments. Where field and analytical data exists, the line 'AD' has been found to overestimate the total load distribution by at least 25% and in some cases up to 40%.

The curved line connecting point A with D represents a possible division of relative loading between goaf and abutments that is still consistent with surface subsidence behaviour and would more closely agree with field data.

The shape of the vertical abutment

The theory of elasticity provides exact formulation for the distribution of stress about a circular hole within an isotropic, homogeneous and elastic medium. It is worth noting that the stress distribution for this ideal case is independent of the elastic parameters of the medium and depends only on the geometry of the hole.

Openings other than circular or departure from isotropy or homogeneity preclude the exact calculation of stress about an opening. Numerical techniques (modelling) are required to determine the approximate elastic stress distribution. The introduction of rock softening further modifies the distribution of stress to the extent that a single generic equation for the distribution of stress about a longwall would not be expected to properly reflect the real distribution at every mine.

Figure 1 illustrates the current conceptual model for the distribution of vertical stress about a longwall panel in which rock softening has occurred. The key aspects of the distribution include:

- A ramping up of the vertical stress from near zero at the ribline to a peak value on the boundary of the softening zone.
- A decay of the vertical stress abutment away from the peak value.

Absolute stress measurement and stress change monitoring about longwall extraction are in general agreement with the generic distribution shown in Figure 1 and indicate that:

- The distance of the decay part of the curve extends approximately 0.5 times depth.
- The peak stress is often between 2.5 and 3.5 times virgin.

It is beyond the scope of this paper to discuss the relevance of the stress distribution in terms of pillar design, however in terms of roadway behaviour, the shape of the stress distribution curve is considered to be very important to understand tailgate strata behaviour and will be discussed further.

Horizontal stress changes

The importance of horizontal stress changes about longwall extraction is well recognised and forms a fundamental consideration for longwall layout.

Horizontal stress changes about a longwall are the net result from various competing influences, namely:

- The relief of tectonic horizontal stress towards the extraction.
- Response to vertical stress changes (Poisson effect).
- Gas desorption and fluid pressure changes.

The horizontal stress changes about longwall extraction are superimposed on the stress changes that have occurred on driveage. In this respect the level of roadway softening on driveage and the behaviour of the primary reinforcement system all contribute to the final stress state about the tailgate.

Shear stress on bedding

Figure 2 illustrates an example based on FLAC3D modelling of the distribution of vertical stress in the vicinity of the tailgate/faceline corner.

The high gradients of stress that exist in the vicinity of the tailgate/faceline corner impose high shear stresses on bedding within individual layers and on interfaces between layers.

The slip along bedding and interfaces between layers as a consequence of the high stress gradients is considered to have a major impact on gateroad strata behaviour.

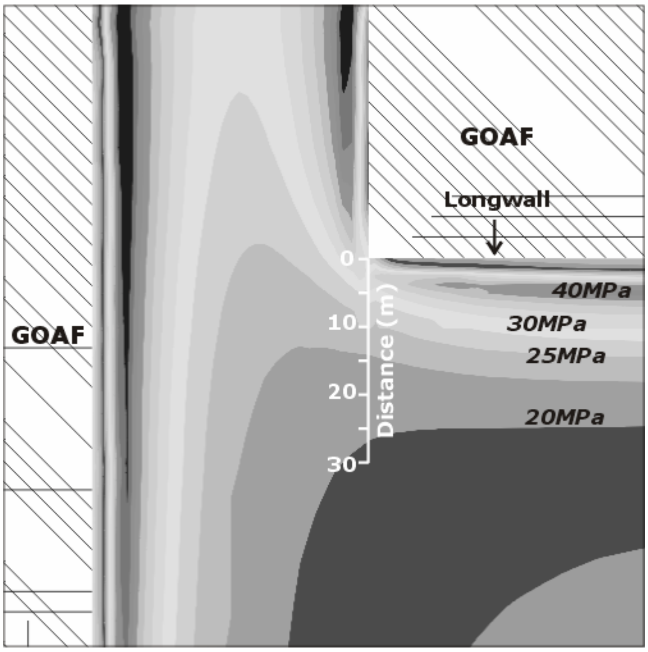

FIG. 2 - Distribution of vertical stress about a longwall tailgate, depth 500m, panel width 140m.

Load distribution

The tailgate in a typical longwall layout is located within a region of high stress gradients, where, large variations in stress occur across and along the gateroad towards the advancing longwall extraction.

In terms of the vertical component, the stress gradient is so large and so influenced by geological controls, that the notion of average stress across a chain pillar becomes ill-defined and of limited value for assessment of gateroad behaviour or support requirement.

In terms of the horizontal component, the stress gradient is the net result of relief towards the approaching opening and change (increase or decrease) as a result of the vertical abutment (Poisson effect). Strata softening processes further redefine the horizontal stress regime.

The high stress gradients impose high shear stresses along bedding within layers and along interfaces between layers.

The extent of stress redistribution about a longwall occurs at the scale of the longwall, not the scale of the roadway.

In order to better control difficult tailgate environments, better definition and understanding of the loading environment from driveage to extraction of the second pass longwalls is required. Improvements in computation that now allow realistic simulation of the longwall softening processes in three dimensions together with targeted field measurements of the stress distribution about longwall extraction are expected to provide advances in these areas.

Geological Controls

The preceding discussion highlighted that post driveage, a tailgate is likely to be influenced by the following general stress changes:

- An elevation in vertical stress during extraction of the adjacent wall, when it acts as an maingate travel ling road, and during the time it is a tailgate proper.
- A competing influence of horizontal stress changes from vertical changes (Poisson effect from increased vertical stress) and horizontal stress relief towards the approaching extraction.
- A potentially high component of shear stress along (horizontal) bedding.

The strata sequence is typically composed of geological units of varying strength and deformability properties, together with discontinuities such as bedding and joints, themselves of varying shear strength and shear stiffness properties.

In order to discuss the relevance of the high stress gradient in relation to strata behaviour, it is necessary to outline some basic mechanics principles. Figure 3 illustrates the relative horizontal movement of layered strata under the influence of a uniform vertical load. The key points of Figure 3 include:

- Softer layers (lower Shear Modulus) move further than stiffer layers, all other things being equal.
- Shear stress is generated at the boundaries of the different layers as a consequence of the different amount of horizontal movement.

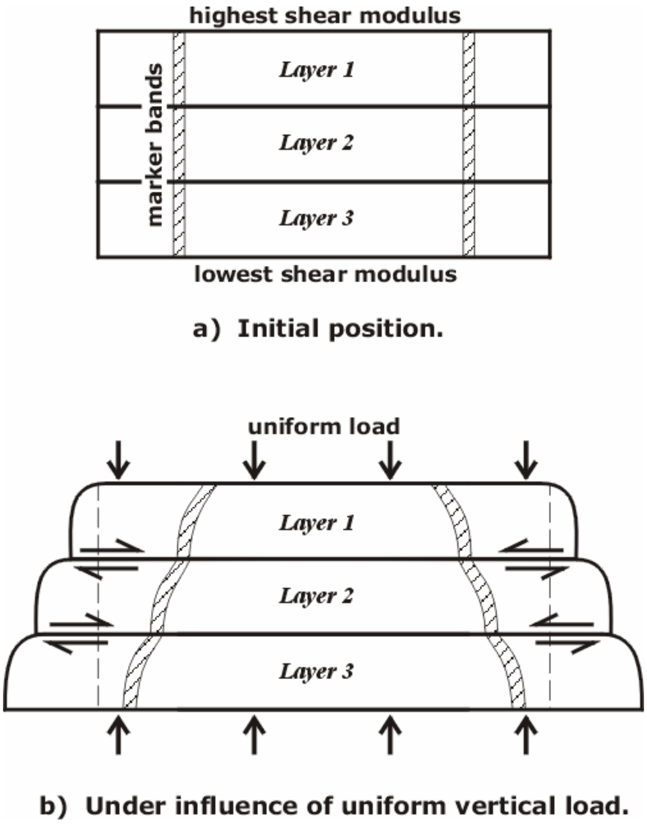

FIG. 3 - Relative horizontal movement of layers of varying shear stiffness under uniform load

In a sequence containing coal, mudstone and sandstone for example coal would move further than mudstone which in turn would move further than sandstone.

If the relative movement between the layers imposes sufficient shear stress along the interfaces or along bedding within an individual unit, then irrecoverable slip along the interfaces may occur. Depending on the relative stiffness of the layers and strength of the interfaces, a variety of deformation modes are possible.

Consider the coal/mudstone/sandstone sequence under the influence of a high vertical load. The coal is predisposed to move further than the mudstone so the coal/mudstone interface acts to restrain the coal movement, generating shear stress along the interface.

If the coal/mudstone interface fails, then the coal becomes decoupled from the mudstone and moves freely into the opening. Under these circumstances, the coal rib can override the first roof bolt as shown in Figure 4(b).

Figure 4(c) illustrates an alternative scenario where the coal/mudstone interface has remained intact however the mudstone/sandstone interface has failed. Under these circumstances the mudstone may experience an elevation in horizontal stress from the movement of the coal below and may consequently soften. There is a roof shortening process with similar characteristics to that exhibited by driveage within a high horizontal stress zone which would typically produce guttering. In this environment stress relief towards the goaf may otherwise have been expected.

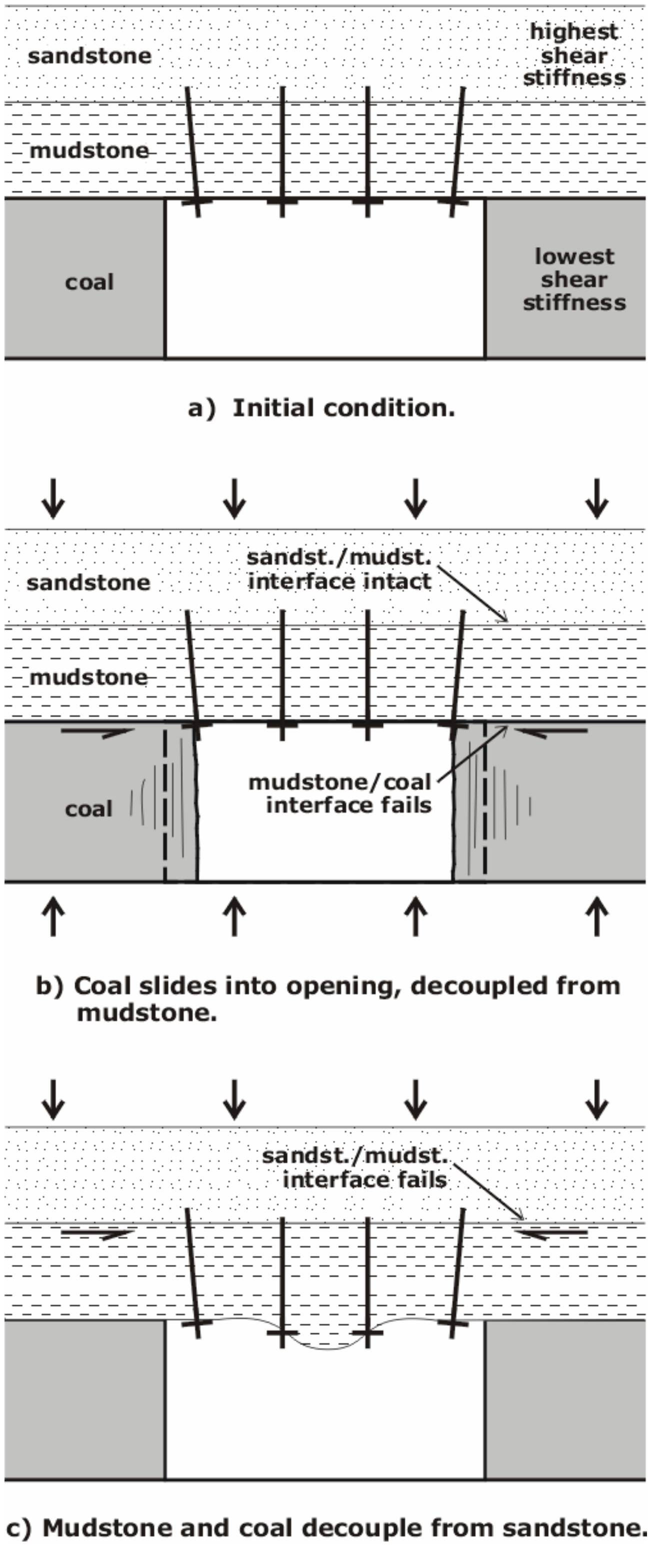

FIG. 4 - Variation in style of roadway behaviour as a consequence of slip along differing interfaces

The two examples above illustrate possible scenarios within an evenly loaded environment where movement of the various layers towards the roadway is more or less symmetrical about the roadway centreline. Consideration of the stress distribution about a tailgate indicates that the potential direction of shear displacement along interfaces is not symmetrical about the roadway centreline, leading to further possibilities for roof behaviour.

Figure 5 illustrates a general style of roof behaviour observed on a consistent basis in a variety of forms in tailgates and in traveling roads adjacent to the goaf.. The general behaviour is consistent with that shown in Figure 4 however the sense and magnitude of shear movement is asymmetrical with respect to the roadway centreline (in response to the asymmetrical stress distribution). The mechanism has been observed to continue to the point where the immediate roof has been pulverised against the block side. On the basis of observed behaviour, installed long tendons in this environment have offered little resistance to the shear behaviour.

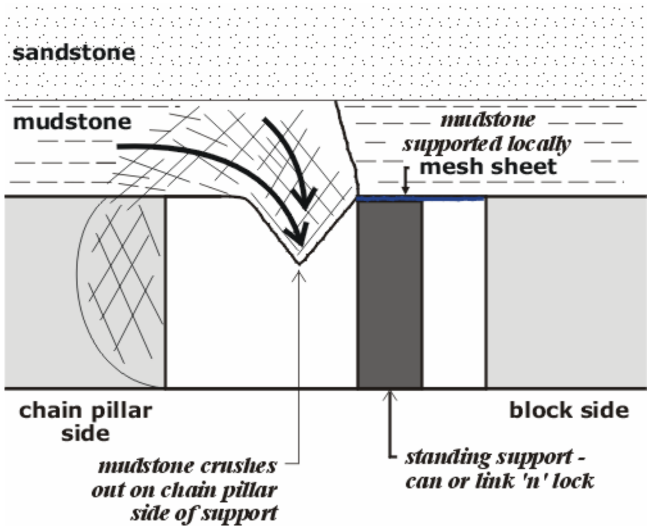

FIG. 5 - General style of observed excessive roof movement towards goaf – displacement controlled

Strata behaviour

Shear displacement along interfaces and within individual geological units is recognised as an important mechanism controlling roadway behaviour generally.

During drivage, it is self evident that the strata softening and stress redistribution processes are related to the scale of roadway. In general the displacements are intimately linked to the stress changes and the system would be considered load controlled, rather than displacement controlled.

Similarly, during longwall extraction, shear displacement experienced by the surrounding strata comes into equilibrium with the longwall stress changes and stress gradient present.

If one now considers the tailgate within the context of stress changes and movement about an approaching longwall, the roadway would experience an environment where the displacements are imposed upon it. In a sense the roadway is a passenger (or is slaved) to the movements associated with the approaching longwall. In this respect, the roadway deformation may become displacement controlled, rather than load controlled.

In a layered medium the magnitude of lateral movements is dependent, among other things, on the location and extent of shear along the interfaces. In a scenario such as that shown in Figure 5, an immediate roof unit has become decoupled from the overlying unit and is effectively being driven towards the longwall block side, slaved to the movement of the surrounding strata.

Observations of roof shortening in roadways (Figure 5 for example) during the approach of extraction (as a tailgate proper) is consistent with the conceptual model that roadway deformation is partly in response to a displacement controlled environment.

To better control the tailgate environment, clearly the location and mechanical properties of interfaces must be determined in order to assess the potential behaviour under partially displacement controlled conditions. A combination of field measurement to characterise the deformation environment and 3D numerical analysis to better understand the potential behaviour, particularly of slip planes, is required.

Support Elements

Significant advances in the product range for standing supports have been made. The common types and their comparative laboratory load/displacement characteristics are shown in Figure 6.

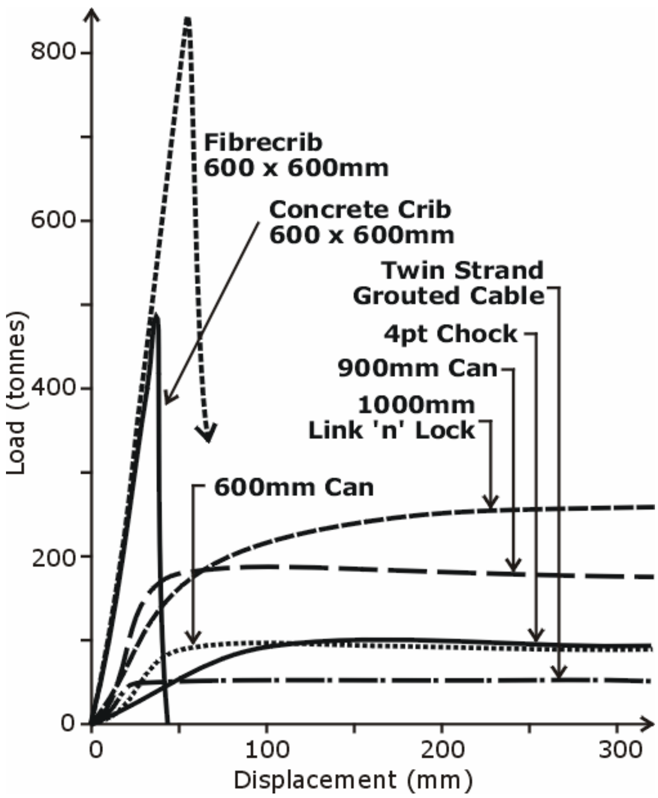

FIG. 6 - Comparative load/displacement of various standing supports

Clearly there is a wide selection from which the mine operator may choose. The range includes the very stiff, strong types that rapidly load but have poor post failure characteristics to very soft types that are slower to load but maintain peak load over a large convergence range.

If the inclusion of long tendons is added to the list of secondary support choices together with the use of combined systems, then it is unlikely that even the total experience base of all mine operators would be sufficient to account for even a small proportion of the total possible designs over the range of geological and loading environments that may be encountered.

A rigorous design approach that can evaluate the choices available without resorting to trial and error is proposed.

TAILGATE SUPPORT DESIGN

Current Approaches

Statistical evaluation of anecdotal data in relation to tailgate serviceability has led to a characterisation of those circumstances under which gateroad serviceability has been unacceptable. The ARMPS (Mark and Chase, 1977) method has been developed for US mines and a modified version, ALTS (Colwell, 1999) has been developed for Australian mines.

Whilst these methods use the current database of experience to assess potential tailgate serviceability, the methods provide little guidance in regard to the actual support design if poor serviceability is identified.

It is not considered appropriate to use a statistically based approach for support design since no insight into the underlying mechanics of the strata behaviour, the driving forces or factors controlling the strata behaviour is provided. The use of subjective experience alone whether characterised within a broader population of experiences or whether restricted to an individual mine, does not allow assessment of future conditions outside that experience base.

NIOSH have conducted full scale testing of a range of standing support products. Barczak (2000) has developed a computer program (STOP) for use in US mines, designed to assist mine operators in the optimisation of standing support.

Barczak (2000) emphasises that the STOP program should not be used to determine the initial design but is intended to be used to evaluate alternative support strategies once an initial support requirement is established. The program includes optimisation on the basis of cost and handling issues.

Tit is suggested that a support design type be adopted to bridge the gap between those methods that seek to identify potentially adverse tailgate behaviour (ALPS, ALTS and others) and programs such as STOP that seek to optimise the practicalities of the support strategy once support requirements are defined.

Proposed Approach

The objective of any support system is to control the deformation environment by way of intervention by artificial means. In this case, the relative horizontal movement of interfaces either between specific geological units or within individual units is a deformation mechanism that requires consideration in the support design.

The conceptual model for tailgate behaviour includes the notion that shear displacements (along layer interfaces or along bedding within individual units) that occur as a consequence of longwall extraction are imposed upon the micro environment of the tailgate. A component of displacement control is introduced into the deformation environment.
The introduction of a component of displacement control has significant consequences for tailgate support design.

In a completely displacement controlled environment, a certain magnitude of the shear displacement along interfaces and roof to floor convergence would occur irrespective of the installed support or reinforcement. The movement would be by definition, irresistible. The support elements would load up in response to the deformation but would not affect the magnitude or sense of displacement that occurred. Under these circumstances, the function of the standing supports or tendons would be to maintain integrity of the fractured rock mass on a local scale throughout the deformation process.

If the deformation environment is only partially displacement controlled, then possible control measures may include:

- Direct reinforcement by installation of solid bars across interfaces (wire tendons would not be expected to provide sufficient shear restraint).
- Generation of confinement across interfaces through the action of loaded standing supports, this may include preloading supports (perhaps using longwall hydraulics).

At this stage further investigations are required to better define whether the tailgate environment is partly or significantly displacement controlled and to therefore better define the strata mechanics and the role of the standing supports and installed bolts and/or tendons.

Current investigations are directed towards:

- Improved understanding of the deformation environment (load versus displacement control).
- Better definition of the stress distribution in the vicinity of the tailgate.
- Measurement of field loading characteristics of standing supports. This includes evaluation of the zone of influence of standing supports and assessment of the most appropriate standing support pattern.
- Measurement of loads developed in primary roof bolts and secondary tendons.
- Improved 3D modelling techniques (adaptive meshing).
- Modification of the stress environment in the vicinity of the tailgate through modified mine design.

It is envisaged that tailgate support design would include:

- Determination of loading environment including consideration of longwall extraction and pillar geometry.
- Characterisation of geological elements, particularly the properties of interfaces between layers and bedding within layers.
- Assessment of potential shear displacement in addition to potential roof to floor convergence.
- Assessment of roof softening and primary bolt loading on drivage.
- Measurement of field loading characteristics of standing supports or long tendons.
- Assessment of powered support loading and longwall extraction method.

It is anticipated that reliable support design will only be achieved through a better understanding of the strata mechanics and measurement of support interaction, rather than statistically based approaches.

Given the complexity of the loading and deformation environment and the array of possible interactions, it is suggested that 3D numerical modelling with verification through field measurement is an appropriate approach that will lead to reliable support design.

CONCLUSIONS

There are currently no methods that provide mine operators with reliable tailgate support design. The reliance on experience or at worst, trial and error for tailgate support design is a major contributing factor responsible for longwall downtime in many mines and has potentially catastrophic consequences.

A conceptual model for tailgate strata behaviour is presented which recognises that:

- Stress change about longwall extraction occurs on the scale of the longwall. The gateroads, in particular tailgates, are subjected to a range of displacements that would occur irrespective of the presence of the roadway. This imposes a component of displacement control, in addition to load control, on the roadway behaviour.
- The high stress gradients about longwall extraction impose high shear stresses on bedding within individual geological units and along interfaces between units. Some of the displacement control occurs as shear displacement along these interfaces.

The laboratory load/displacement characteristics of various secondary support types has been established, however, since the deformation mechanics of the tailgate environment are ill-defined, appropriate support selection and design is not rigorous and is reliant on previous experience or trial and error.

The objectives of current investigations are to:

- better define the stress changes in the vicinity of the tailgate corner
- improve the understanding of strata behaviour in the vicinity of the tailgate corner
- determine the field load/displacement characteristics of the various support types
- define the interaction between gateroad behaviour and the longwall powered supports
- further develop 3D numerical modelling techniques to assess support options and to better understand the functions required of the support elements.

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