DESIGN CONSIDERATIONS FOR REINFORCEMENT OF COAL MINE ROADWAYS IN THE ILLAWARRA COAL MEASURES

By

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ABSTRACT

The application of reinforcement techniques to enhance the stability of underground coal mine roadways subject to high stresses is discussed. Research conducted in the Illawarra Coal Measures has been aimed to delineate the factors which influence the behaviour of rock above roadways and the performance of the reinforcement placed. Design considerations for the reinforcement of mine roadways in the Bulli coal are based on a quantification of the rock response together with a reinforcement strategy to enhance the structural integrity of the roof strata.

INTRODUCTION

Underground coal mining is being undertaken at increasing depth and within highly stressed rock masses. Mining developments are being undertaken in areas affected by large horizontal stress components and the effects of stress redistribution about extraction panels.

Many coal measure rocks are relatively weak engineering materials which require artificial support or reinforcement to maintain stable openings during coal mining operations.

High production mining systems require rapid roadway development techniques and unobstructive support during extraction operations.

Rock reinforcement strategies using rock bolts and cable tendons (bolts) have been employed successfully to maintain opening stability. The use of reinforcement techniques allows effective opening stabilisation with minimum obstruction and delay to both development and extraction operations.

The major feature of rock bolt and cable bolt reinforcement is to reinforce the falling rock about the excavation to act as a more competent structural support and thereby reduce the requirement for artificial structural support (props, steel sets, piers) during mining operations.

This paper presents an overview of the research conducted into the application rock reinforcement strategies to mining operations within the Bulli seam of the Illawarra Coal Measures, N.S.W., Australia.

LOCATION AND GEOLOGY

The Illawarra coal measures are located in the southern portion of the Sydney Basin, a broad basin structure containing extensive coal reserves (Fig.1) of Permian Age. The coal measure strata are gently dipping between 0 - 50°. Dominant structural features within the coal measures are broad folds, minor monoclinal flexures and normal faults with displacements up to 100 m. Igneous dykes, sills and volcanic plugs intersect the coal measures. The...
stratigraphy and structure of the coal measures has been discussed in greater detail by Bynn (1972) and Wilson (1975).

The typical strength properties of strata above the Bulli seam are presented in Table 1.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Mean UCS (MPa)</th>
<th>Range</th>
<th>Mean R</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstone</td>
<td>67.1</td>
<td>70-133</td>
<td>18.0</td>
<td>10-25.8</td>
</tr>
<tr>
<td>Sandstone</td>
<td>51</td>
<td>60-128</td>
<td>15.0</td>
<td>10-25.8</td>
</tr>
<tr>
<td>Sandstone</td>
<td>43</td>
<td>53-137</td>
<td>15.0</td>
<td>10-25.8</td>
</tr>
<tr>
<td>Saltstone</td>
<td>74</td>
<td>60-128</td>
<td>15</td>
<td>10-25.8</td>
</tr>
<tr>
<td>Limestone</td>
<td>53</td>
<td>60-128</td>
<td>14</td>
<td>10-25.8</td>
</tr>
</tbody>
</table>

These rock types are typically interbedded forming a composite roof section. An example of composite nature of the roof strata is given in Figure 2 where a profile of unconfined compressive strength has been plotted. Roof sections are typified by rapid and gross vertical variation in material properties.

VIRGIN STRESSFIELD MEASUREMENTS

Stress measurements conducted in the coal measures, and the Sydney Basin in general (Enever et al., 1980; Enever & McKay, 1980; Walton, 1983; Gale, 1983; Gale et al., 1984 (a), and 1984 (b) delineate the existence of high and anisotropic lateral stress components.

In situ stress measurements have been made at 13 sites in the Southern Sydney Basin using the CSIRO H1 stress cell and the overcore technique (Worotnik and Walton, 1976). Localities at which stress measurements have been made are shown on Figure 1 and represent a sample coverage from the Burragorang Valley to the coast. Stress measurements were made at distances of 6.5 - 12.5 m from development roadways in collieries and represent the virgin stress environment into which roadways are driven.

Results from the in situ stress measurements conducted the maximum principal stress, \( \sigma_1 \), is effectively horizontal and that the virgin stressfields are often oriented with respect to local and regional structural features. Stress measurements above the Bulli seam at depths between 400 and 550 m revealed that \( \sigma_1 \), typically had magnitudes between 18-27 MPa. The vertical stress components varied between 10-17.5 MPa and were often significantly greater than vertical stresses attributable to overburden alone.

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DESIGN CONSIDERATIONS FOR REINFORCEMENT OF MINE ROADWAYS

The application of rock reinforcement strategies to coal mining operations relies on a sound knowledge of the factors influencing behaviour of the rock to be reinforced and the performance of reinforcement at various excavation stages. This requires a characterisation of rock behaviour and action of reinforcement.

CHARACTERISATION OF ROCK MASS BEHAVIOUR

The gross deformation occurring in roadways during driveage is characterised to allow quantification and predictability of the particular rock deformation characteristics. This procedure is typically undertaken from back analysis surveys and detailed measurement of rock mass displacement.

Gross Characterisation:

Characterisation of the rock mass behaviour has been made on the basis of delineation of the major factors influencing the rock behaviour. In the Bulli coal under the laminite roof strata gross roof behaviour of development roadways is largely influenced by the orientation of the virgin stress field, relative to the direction of roadway advance (Gale et al., 1984 a; b). Rawlings and Gale 1982; Gale and Blackwood (in press). These studies showed that roof behaviour could be predicted and quantified on the basis of the angle between $\theta$; (maximum principal stress) and the direction of advance, $\theta_{ag}$. A number of the relationships obtained are shown in Figure 3, which presents the percentage of roadway driveage affected by substantial shear fracturing of the roof rock at the face during development mining in two collieries. Further characterisation can be undertaken to predict the location of shear fracturing occurring in the roof of those roadways delineated as subject to this rock behaviour. Research conducted (Gale et al., 1984 a), Gale and Blackwood (in press) showed that the rock shear fracturing could be predicted to occur on a particular roofside in driveage oriented with $40 < \theta_{ag} < 70$. Driveage with $\theta_{ag}$ between 70° and 90° was affected by shear fracturing across the central area of the roadway.

The examples presented show that the immediate response of the roof strata was controlled by the stress redistributions about the roadways driven and that the occurrence of gross roof rock behaviour modes can be quantified and predicted.

Characterisations such as this, which are based on rock failure, rely on prior or concurrent information of the stress field and rock distribution in the roof.

Other factors which may influence the characterisation of a rock response include faults, joint zones, seam rolls, seam splits, dykes, the thickness of coal tops, fluid pressure, topographic irregularities and the distribution of rock types having particular properties.
Detailed Characterisation:

Detailed characterisation entails extensometry to determine the height and nature of rock failure occurring at various excavation stages. Figure 4. shows a roof displacement profile of a development roadway subject to rock fracture occurring at the face. The data indicates the height to which rock failure occurs during face advance. Analysis of this data allows definition of nature of the roof deformation. Figure 5. shows a strain profile, generated from the displacement data. This indicates the zones where rock failure is developed and their upward propagation during initial roadway advance.

The results from Figure 5. show that roof displacement is caused by two distinct zones of rock failure occurring during face advance. These zones of rock failure are commonly associated with the occurrence of particular rock types in the roof section. The location and magnitude of these zones indicates the length of bolts required, which in this example would need to be approximately 2.7 m long to extend across the dominant rock failure horizons (A, B: Fig. 5).

Characterisation of the rock response associated with stress redistributions during longwall extraction can be undertaken in a similar manner. Figure 6. shows the nature and height of rock displacements.
occurring in a longwall gateroad during extraction operations. The rock displacements are indicated as occurring at a number of strain zones which increase in height and magnitude as extraction proceeds. The existence of these zones would require reinforcement to extend up to approximately 8-10 m above the roof.

Reinforcement of the zones is achieved by the use of fully grouted, birdcaged cable tendons (bolts).

**ACTION OF REINFORCEMENT TO MAINTAIN ROCK MASS INTEGRITY**

The reinforcement developed by fully grouted bolts or tendons as applied to coal mining occurs via point restraint of axial and shear displacement occurring in the rock mass. These modes are depicted in Figure 7.

The benefit of reinforcement is to strengthen the rock mass to sustain greater stresses and increase the integrity of the roof strata.

The laboratory studies of Angers slate (Tincelin and Sinou, 1980) found that the strength of the failed rock was markedly increased by rock bolt type reinforcement.

The relationship delineated was found to indicate that $T = (20 - 30)\,pi$ where $T$ = increase in rock strength above non-reinforced samples.

$pi$ = average confining stress.

Similar results are obtained from studies of confined rock samples. Nassani et al., (1984) found an increase in the strength of failed rock in the order of $(10 - 15)*$ the confinement applied in the practical range. The effect is shown in Figure 8.

![Diagram](image)

The primary aim of reinforcement design is to enhance confinement and restraint of axial and shear displacements occurring in the rock as it is exposed at the face in order to:

1) maintain the structural strength of the roof strata to maximise the self-supportive capability to bridge or arch across an opening, and
2) to restrict the height and lateral extent of failure in the roof.
In order to apply these principles the capability of bolts and cable tendons to develop a perceptible reinforcing mode must be determined. Design criteria rely on a quantification of the rock deformation mode and maximising the effect of each reinforcing action within a predetermined system.

LABORATORY AND FIELD ACTION OF ROCK BOLTS

The laboratory performance of typical roof bolts is shown in Figure 9, for axial displacement and shear displacement, together with the axial performance of cable strand. The results show that forces acting to restrain against axial displacement are rapidly generated in bolts until the yield load of the metal is exceeded. After yield of the steel the forces exerted by bolts to restrict displacement and increase confinement are developed at the expense of greater roof displacement and roof weakening. The response for shear displacements is similar and significantly affected by the yield capacity of the steel. The strength properties of the grout and surrounding rock also affect shear performance as they provide restraint against lateral bolt displacement.

The action of roof bolts monitored in development roadways show that reinforcement is rapidly developed across distinct zones of rock failure. This is shown in Figure 10, where the axial forces developed along a "fully encapsulated" roof bolt are presented. The effectiveness of roof bolts and cable bolts is increased where the peak forces developed along their length can be isolated (Positions A, B, C, Figure 10). The use of full encapsulation is required to achieve this. Otherwise the forces will be distributed over a longer length of bolt and allow greater displacement to occur per unit restraint achieved.

Figure 11 shows the locations where reinforcement is developed to restrain shear displacements along a roof bolt installed above a roadway. This reinforcement mode is monitored with a bending moment developed in the bolt. The results show that significant reinforcement is generated at a number of locations along the bolt. Encapsulation of the bolt surrounding these zones is required to allow the bolt to develop immediate reinforcement against shear displacements.
BEHAVIOUR OF ROOF BOLTS AS A SYSTEM

The response of a bolt pattern to roof deformation as a system is an important criterion in the overall design rationale for reinforcement.

The systems response incorporates the interaction of axial reinforcement, shear reinforcing action and yield between bolts in the pattern.

During installation only minor forces are developed in a zone 2.0 m above the centre-left region of the roof. As the face is advanced (excavation sequence A) high axial forces are developed about specific zones of rock failure occurring between 1.0 m and 2.0 m on the centre left hand roadside. Yield is initiated in these bolts at this stage.

Axial Reinforcement:

The distribution of axial forces developed in a set of bolts placed at the face across the roadway as roadway advance occurs is given in Figure 12. The point forces developed along each bolt have been contoured for various advance positions.
forces developed in the bolts exceed yield in the central roof areas and the distribution of forces along each bolt and between adjacent central bolts becomes relatively uniform. Once this occurs the central bolts are reinforcing the rock between 1.0m and 2.5m as a single entity which reduces the stiffness and effectiveness of the reinforcement offered when compared to excavation sequence B where individual zones of rock failure were being reinforced in this roof section.

An important effect of yield occurring in a significant proportion of bolts is that the capacity for additional reinforcement is reduced. The effect is shown in Figure 13, where the average load of 13 bolts is plotted relative to rock displacement in thebolted section. The reduction in additional reinforcement capacity is indicated by the marked change in the slope of the load-displacement plot.

The reduction in reinforcement-rock stiffness allows additional roof displacement to occur until the reinforcement and roof strata come into equilibrium. This reduction in stiffness in the lower roof section is typically associated with an increase in the height of rock failure above the roof. This then places additional requirements on the bolts, particularly the ribsode roof bolts, to maintain the lower roof integrity.

Shear Reinforcement:

A typical system response of the bolts reinforcing against lateral shear displacement is given in Figure 14, for various excavation advance sequences. The location of shear displacements and the extent of reinforcing action developed by the bolts is contoured above the roof as point bending moments developed along each bolt.

Low bending moments occur during installation but initiate in specific horizons during excavation A. During excavation sequence B and C shear reinforcement rapidly develops above the ribsode roof sections in specific zones.
The marked development of the ribside lateral shear reinforcement is associated with extensive yield and stiffness reduction of the central bolts. The shear restraint of strata above the ribside is an important consideration to maintain roof integrity.

The reinforcing action of a system is clearly a combination of axial and shear restraint developed in a bolt pattern. Both modes of action must be considered for design.

Factors influencing the behaviour of individual bolts such as forces developed, load transfer onto borehole wall, anchorage performance and installation procedure can be reliably monitored by the use of field instrumentation and data analysis techniques discussed elsewhere (Gale and Fabjanczyk, 1986).

**CABLE TENDON AND ROCK BOLT SYSTEM DESIGN RATIONALE**

The action of cable tendon reinforcement is similar to that of rock bolts discussed above. The longer length of tendon able to be placed in the roof allows reinforcement of rock failure occurring at greater distances from the roof than standard bolts. The high load capacity of currently available cable tendons coupled with their ease of placement makes long tendon reinforcement of longwall gate roads areas an effective alternative to standing supports. Cable tendons are fully grouted with surface anchors and untensioned.

In longwall applications, cable tendons, roof bolts, rib bolts and W straps are used as a system. Cable tendons are designed to reinforce the upper rock sections in particular, whereas W straps, roof bolts and rib bolts are designed to enhance the integrity of the lower roof section.

**Detailed research into improving the reinforcement capacity of rock bolts and cable tendons is being undertaken under an AMIRA research project. The research has shown that the effectiveness of cable and rock bolt reinforcement can be readily improved by the use of higher strength tendons (bolts), stiffer and stronger grouts and enhanced grout-rock bond capacity.**

**CONCLUSION**

Bolt patterns are designed to restrict the extent and height of roof fracturing, axial bolt yield and shear displacement occurring in the roof section. The location and length of bolts placed can be designed on the basis of the characteristics of rock failure and the reinforcing action developed by the roof bolts. Maintenance of the integrity or structural strength of the roof as close to the face as possible is necessary to restrict the upward propagation of the roof deformation.

The strategy or considerations employed in the research of reinforcement design in the Bulli coal workings incorporates:

i) Characterisation of the rock response on both a mine wide and site specific scale.

ii) Definition of the performance and effect of reinforcement during mining operations.

iii) Design for a predetermined reinforcing mode on the basis of a known rock response to enhance the self supporting capability of the roof strata.

Design studies based on this type of approach are being undertaken under AMIRA Project support and reinforcement systems based on field characterisations have been trialled successfully in both development and extraction operations.
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REFERENCES


