OPTIMISATION OF REINFORCEMENT DESIGN OF COAL MINE ROADWAYS

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ABSTRACT

The design of the reinforcement systems required to stabilise mine roadways has developed through the application of field measurement techniques. These techniques have allowed the level of security of a given opening to be determined from an assessment of the loading within the reinforcement, the extent of roof deformation and experience. The design systems developed are now used extensively in a wide variety of geological environments.

Recent interpretative techniques have been developed to improve the level of confidence when designing roadway reinforcement. The techniques are particularly applicable for roadways subject to either weak materials or extreme stress levels. A second area of application is where roadway advance rates and hence the timing of reinforcement placement are critical.

The newly developed techniques include both analytical and computational models. The validated computational techniques allow a more rational approach to investigation of the effect of varying reinforcement type, timing of placement and density on the level of stability achieved.

1. INTRODUCTION

A system of reinforcement design based on initial geotechnical monitoring followed by systematic monitoring of reinforcement and rock behaviour has been well documented. (Gale and Fabjaneczky 1987, and Siépall and Gale, 1992).

This technique has been used in a wide range of geological and stress environments to quantify and assess the performance of the strata around openings and the reinforcement placed.

The measurement methodology is summarised in Figure 1 which illustrates the following aspects of the investigation:

i) Definition of the lithology of the roof strata and variation in its physical properties.
ii) Quantification of the effect of confinement, such as that provided by reinforcement, on modifying the strength properties of the rock.
iii) Definition of the position, magnitude and timing of failure within the roof strata.
iv) Quantification of the load generation within the reinforcement members.

Past experience, together with detailed roadway monitoring in different stress environments has highlighted a number of reinforcement design issues which relate to the style and magnitude of the rock deformation.

2. REINFORCEMENT FUNCTIONS

For a given roof lithology the behaviour and stability about an excavation will be controlled by the magnitude of the stresses acting relative to the strength of the strata about the excavation.

The design of reinforcement systems to maintain roadway stability must therefore be related to the deformation mechanisms occurring within the strata at the various stress levels. These issues are discussed below. The stress levels are discussed in general terms.

2.1 LOW STRESS ENVIRONMENTS

Where the stresses acting in the roof strata are not sufficiently high to cause fracture or failure of discrete units of the rock to occur, the forces
Fig. 1 Summary of roadway reinforcement investigation monitoring methods.
generated in the reinforcement restrict delamination of the bedded strata and enhance its spanning characteristics.

A relatively low density of reinforcement is required in this environment with a typically even spacing of bolts.

This style of behaviour is usually limited to low horizontal stress environments such as areas of shallow cover and moderately good quality rock.

2.2 MODERATE STRESS ENVIRONMENTS

Under moderate stress conditions, it is more probable that fracture of stiffer bands within the roof strata will occur. Under these conditions, the reinforcement is designed so as to maintain the structural integrity of the roof by controlling the dilation of the fractured layers and maintaining their residual strength. With an adequate design, the roof deformation can be maintained at low levels and a high level of stability maintained.

Bolting patterns within this environment are typically related to driveage direction, with isolated patterns of bolts used in roadways driven at angles to the principal horizontal stress. The reinforcement distribution reflects the level and distribution of rock deformation.

2.3 HIGH STRESS ENVIRONMENTS

As the relative stress level is elevated, the level of rock failure and the depth into the roof that rock failure occurs increases. The primary role of the reinforcement is to maintain sufficient strength within the fractured ground so that it can act as a self-supporting structure. The reinforced failed rock can then provide resistance against roadway distortion.

By maintaining the load bearing capacity and integrity of the bolted section of the roof strata, the reinforced rock will minimise further stress redistribution around the opening leading to a higher level of stability being maintained. This is achieved through minimising the height to which failure is occurring within the roof strata.

Typically a high density of high capacity reinforcement is required to maintain a stable roadway under these conditions. With an optimised design it is not unusual for a large percentage of the bolts to exceed their yield capacity. This is a function of the efficiency of the reinforcement in generating load in response to the deformation occurring and is required to provide the confining forces which are maintaining stability.

Figure 2 shows the effect of change in reinforcement practice on maintaining the integrity of the immediate roof strata and its associated increase in stability. Two sections of roadway in the same geology and stress environment were reinforced with different bolt types. The first site used a bolt with 13.5 tonne yield while the second used 22 tonne yield bolts with improved post yield stiffness. The bolts at the second site generated much higher loads and associated confinement to the rock. This increased confinement resulted in reduced deformation of the roof strata and an increase in the load bearing capacity of the strata from 4.5 to 8.5 MPa.

2.4 VERY HIGH STRESS ENVIRONMENTS

Where the stresses acting significantly exceed the strength of the rock mass, for some distance into the roof floor and ribs about the roadway, conventional reinforcement practice may not be sufficient to maintain the integrity of the immediate strata. In these conditions there is a possibility that the load bearing capacity of the immediate roof can not be maintained leading to further stress redistribution and failure higher into the roof strata. Under these conditions the use of secondary high capacity reinforcement systems such as cable bolts provides a method to stabilise the opening by providing confinement to the rock well above the bolted horizon.

Figure 3 shows the displacement characteristics of a typical example of a roof in which stability is reached following driveage, but which shows a rapid increase in the level of deformation and height of failure when subjected to the increase in stress associated with a longwall abutment.

3. STRESS EFFECTS

The discussion to-date has looked at the rock reinforcement system behaviour under different stress levels. In reality, within a single area of a colliery it is possible the strata behaviour can change, as the stresses acting change, due to geological or mining induced factors.

3.1 DEPTH STRESS RELATIONSHIP

The magnitude of the stresses acting on the roadway in general will increase with the depth of mining. Figure 4 shows the depth stress relationship measured within Australian coal mines.
Fig. 2 Comparison of roof behaviour and stress distribution with different reinforcement practice.
Over the typical range of mining conditions of between 200 and 550 metres, this can lead to a variation in the magnitude of the principal horizontal stresses of between 12 and 28 MPa. Regional dip of the strata and potential variation in topography can lead to changes of in excess of 30% in magnitude of stress in a typical colliery.

3.2 DIRECTIONAL DRIVEAGE

Depending on the ratio of the minor and major horizontal stress, the effective stress acting across the opening can vary with the direction of driveage. (Gale, 1986).

Effective stresses acting on the opening can differ by up to 50% depending on the angle of the roadway to the major principal horizontal stress direction and the ratio of the horizontal stresses.

3.3 MINING INDUCED STRESS CONCENTRATION

During the extraction of the coal seam using either pillar recovery or longwall methods, stress concentrations will occur around the extraction area. Figure 5 shows the measured stress distribution occurring about a longwall retreating at an angle to the major horizontal principal stress direction. This illustrates that concentrations in excess of 100% of an original stress component can occur if the longwall is retreated at large angles to the direction of the major principal horizontal stress. The concentration can increase further as the angle between the direction of retreat and the direction of the major horizontal stress increases.

4. DESIGN CONSIDERATIONS

With the possibility of the stress levels varying over the extent of the colliery and during the extraction cycle of the seam, it has been critical to define the response of the roadway to the differing stressfield magnitudes.

4.1 TRADITIONAL APPROACH

Since the development of techniques for rock and reinforcement monitoring, the aim has been to define the range of anticipated behaviour using field mapping techniques and measure the actual performance under these conditions. Where this has not been possible conservation in terms of the reinforcement design, has been used to allow for the additional stress increase predicted.
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Fig. 5 Measured stress redistribution around a retreating longwall.
4.2 DEFINITION OF CHARACTERISTIC ROOF BEHAVIOUR

Extensive monitoring over a wide range of conditions has shown that for a certain lithology in a given roadway width and vertical stress regime, a relationship exists between the magnitude of roof deformation and the height to which significant failure into the roof is generated. (Height of softening.)

Figure 6 illustrates this relationship for a range of Australian collieries.

The position along the graph where stability is reached is dependent on the magnitude of the stress and the level of reinforcement provided. As the reinforcement density is increased, stability is reached at a lower roof displacement and hence lower height of softening. Conversely, if the stress level is increased, the magnitude of displacement and associated height of softening will increase.

This relationship, once established for a colliery, allows the assessment of the level of stability achieved in the opening and the likely response of the heading to increasing stress levels. Actual colliery data is obtained from either monitoring of roadways with low reinforcement levels or areas which are subject to increasing stress due to extraction of adjacent areas.

![Graph showing relationship between height of softening and roof displacement at different Australian collieries.]

**Fig 6. Summary of measured relationship between height of softening and roof displacement at different Australian collieries.**

4.3 APPLICATION OF COMPUTATIONAL MODELLING

The results of the field based investigations coupled with:

- measurement of the actual stress distribution within the roof strata under different reinforcement strategies,

- has enabled a high level of understanding of the behaviour of rock and reinforcement under known conditions.

With this understanding of the mechanics of the behaviour, it has been possible to utilise computational methods to assess rock and reinforcement performance.

The availability of computational models which allow realistic modelling of stress state and deformation mechanics of the materials, and the ability to quantify material properties to a satisfactory level of detail, have allowed realistic modelling of the rock and its associated reinforcement behaviour.

The modelling allows an assessment of the predicted behaviour and methods of ground control for which direct experience of monitoring is not available. These situations commonly arise in:

- feasibility studies of greenfield sites,
- mining in new areas or geology in a mining lease which is significantly different than that currently experienced,
- modification of the mining method or layout which may significantly alter the stress conditions experienced,
- planning or feasibility assessment of the adoption of a new or optimised reinforcement system.

Figure 7 gives an example of the correlation of the actual roof displacement and height of softening discussed in section 4.2 with that predicted by modelling. The ability to model this characteristic is only one of the validation techniques available.

For use in design of both mine layout and reinforcement, the modelling enables a relationship between deformational criteria (total displacement and height of softening) and level of stress to be determined.

Figure 8 shows one of the typical relationships established by the modelling for a given mine. It can be noted that under low stress levels the deformation occurring is low and greater flexibility can exist in the level of reinforcement and, more specifically, timing of reinforcement placement (Zone 1). Under these conditions, significant
opportunity exists to optimise the efficiency of the reinforcement placement through the control of cut out distance and potential sequencing of support placement.

At a given level of stress (onset of failure within the roof) the level of deformation increases more rapidly (Zone 2). In this environment, the optimisation of the reinforcement placed can increase the stress levels tolerated before significant displacement levels occur.

Under very high stress levels, high deformation occurs even where high reinforcement densities are used (Zone 3). In this environment, options such as alteration of layout and stress relief (Gale, Fabjanczyk, and Matthews, 1990) options can be considered as an alternative to the use of secondary reinforcement methods.

Results have shown that the magnitude of stress increase required to move from Zone 1 to Zone 3 can vary significantly. Under certain lithological conditions the stress magnitude required may be as low as 5 MPa.

Factors such as this stress sensitivity and the variability in response of the strata to reinforcement defined by the modelling, has increased the level of understanding of previously obtained measurements. This has allowed a more rational approach to problem definition and solutions.

5. CONCLUSIONS

Advances in the understanding of rock and reinforcement behaviour gained from the extensive application of field monitoring techniques, has allowed a more rigorous appraisal of reinforcement design.

The application of computational modelling has further extended the technology to allow more rigorous extrapolation of results to differing stress environments as well as the assessment of reinforcement strategies.

Future monitoring design and requirements can be much better assessed and targeted to ensure the effectiveness of the reinforcement systems and mine layouts.

6. REFERENCES


