HORIZONTAL STRESS CONTROL IN UNDERGROUND COAL MINES

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ABSTRACT

The magnitude and orientation of the in situ stressfield has been determined as a key factor in controlling the stability of openings for both coal mine development and extraction. Monitoring of roadway and pillar behaviour in conjunction with numerical analysis has identified specific stress control measures that have been successfully applied to improve productivity in underground coal mining operations.

The influence of the major horizontal stressfield on the stability of openings has been identified at a wide range of sites including mines in Australia, Britain, the USA, New Zealand and Japan. Stress mapping, stress measurement and stress monitoring techniques have been applied to define the in situ stress regime and, together with the correlation of measurements of rock deformation and rock reinforcement behaviour, has enabled appropriate stress control measures to be developed.

Stress control measures for development headings have required the selection of roadway orientation, roadway sequencing, reinforcement density and pillar size. The monitoring of behaviour at a range of trial sites has confirmed significant improvements in development stability.

Stress control measures for longwall extraction have required rational selection of longwall orientation and extraction direction. Where a mine layout design incorporating the optimum longwall layout design has not been possible, the use of sacrificial roadways has been successfully applied to protect key roadways from stress concentration effects. Comprehensive in situ monitoring of behaviour has been carried out to confirm the mechanisms involved.

1. INTRODUCTION

Field measurements and associated numerical analysis have been undertaken at a range of mine sites in Australia, the United Kingdom, USA, Japan, Mexico and New Zealand. These measurements and analyses have been used to develop an understanding of stress induced failure associated with both development and extraction operations.

The application of stress control methods involves modifying the stressfield acting on an opening. In the underground coal mining environment, this can be achieved by varying the geometry of the opening with respect to the stressfield or locally modifying the stressfield where it is sufficiently high to lead to instability of an opening.

In Australian coal mining areas, the major horizontal stressfield is generally significantly greater than overburden as shown in Figure 1. As a result, even at relatively shallow depths, the stress is sufficiently high to result in significant rock failure. This may be evident as biased gatering in roadways, (cutter roofs) and as major stress concentration problems around extraction areas with roof failure and floor heave in gateroads. If optimisation of reinforcement systems (Gale et al, 1992) is insufficient to control these problems, then stress control measures may be required.

The general approach adopted in implementing stress control procedures is to quantify the in situ behaviour by field measurements, to assess and analyse the measured behaviour and to optimise the mine design to reduce stress effects.

Ideally, the initial application of stress control methods should occur at the mine design stage to ensure that:-

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1. The orientation of longwall blocks or key roadways is at a favourable orientation to the major horizontal stress direction.

2. The sequencing of development headings is appropriate if stress relief techniques are to be utilised.

2. FIELD MEASUREMENTS

Stress mapping (Gale et al., 1984), stress measurement and stress monitoring techniques have been used to define the in situ stress regime.

Stress fracture mapping is routinely used in both Australia and the U.K. to identify the direction of the stressfield which is inducing rock failure. Even at depths in excess of 800 metres, the horizontal stress may be dominant in controlling rock failure particularly where there is a contrast in strength/stiffness ratio of individual rock units. In this case stress concentration in higher modulus relatively weaker rock units can result in preferential failure occurring in these units.

The use of stress fracture mapping is best suited to roof bolted roadways where a large area of the rock is exposed for observation. At sites in the U.K., Japan and Mexico where roadways have been developed on arched steelwork, directional stress effects may be indicated by roadway deformation, driveage rate or difficulty of driveage. In situ stress measurements at these sites have been undertaken to confirm the interpreted stress directions.

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) Hollow inclusion Stress Cell has been the principle instrument used for stress measurement. (Woroniecki and Walton, 1976). Smita Control Technology Pty. Ltd. (SCT) has successfully utilised this instrument as a monitoring device and the use of an instrument that can assess the full three dimensional stressfield has proved invaluable in developing an understanding of stress concentration effects. A typical monitoring site, as shown in Figure 2, will consist of multiple stress monitoring instruments in conjunction with...
extensometers and instrumented bolts. Data from these instruments is monitored with varying face distances and processed.

The stress monitoring instruments quantify the full three-dimensional stress changes and for convenience the results are typically presented on plans, cross sections and long sections. Some examples of the results obtained from an individual stress monitoring site are indicated in Figure 3, with vertical stress changes and changes resolved in the horizontal plane presented as plan views.

Figures 4a to 4c indicate the general variations in stress regime occurring around an extraction area developed at an angle to the major horizontal stress field.

Additional monitoring of rock displacements using multi-point sonic probe extensometers and the monitoring of reinforcement loads using strain gauged bolts enables the effect of stress control measures on opening stability to be quantified.

In addition to the field measurements of stress, displacement and reinforcement loads, a detailed data base of the pre and post-failure characteristics of the relevant rock types is required. Computational analysis of a range of field trials has been undertaken using FLAC, a finite difference code. Studies to-date have been undertaken to simulate the behaviour of roadway sequencing and investigate the optimum positioning of gate roads influenced by multi-seam extraction. The general procedure adopted is to ensure that the numerical model can simulate monitored behaviour prior to extending the analysis as a design tool.

3. APPLICATION OF RESULTS

For a range of sites studied world-wide, the magnitude and direction of the major horizontal stress was a key factor affecting stability. This monitoring has indicated a relationship between the stress concentration measured and the angle of the major horizontal stress to the opening as shown in Figure 4b.

If stress concentrations associated with lateral stresses are to be minimised, the extraction area can be laid out to optimise the stability of key roadways such as longwall ribs and gate roads. Generally, if gate roads are driven in the most favourable direction, then panel access roadways are likely to be driven at adverse angles to the lateral stress. In this case, stress control techniques suitable for development roadways can be applied.

3.1 STRESS CONTROL LAYOUT DESIGN FOR DEVELOPMENT ROADWAYS

The concept of stress relief layout and sequencing of roadways has provided very successful laminite and interbedded strata under high stress conditions. Results from an Australian coalfield demonstrate that roadways subsequently developed within 25m of a first driven driveave (which has suffered roof deformation) will be in stress relieved ground, requiring lower support densities and exhibiting significantly improved stability. The results obtained under laminite roof are presented in Figure 5. In this case, H heading is the first driven heading and has provided stress relief for the adjacent G heading driven on a 22 metre centreline distance. As a consequence, the roof deformations, height of softening, and reinforcement loads are all significantly lower in G heading.

Similar effects have been observed in U.K. coalfields where, at depths in excess of 800 metres, face installation roadways have suffered large scale deformation but stable second driven replacement roadways have been developed with a small (10-15m) pillar between first and second driven headings. Whilst at these depths the absolute magnitude of the vertical stress may exceed the major horizontal stress, the strength/stiffness contrast of the immediate roof strata can result in failure being primarily controlled by the horizontal stress magnitude.

Whilst the roadway and pillar geometry required to achieve a functional stress relief mechanism is site specific, a range of techniques are available to define the stress regime, roof and rib deformations and reinforcement loads so that an applicable design can be developed for a particular site. As the design of an optimum reinforcement system for a first driven stress relief heading should endeavour to provide adequate stress relief with minimum roof deformation, detailed monitoring of both first and second driven headings is required.

3.1.1 Production Benefits of Development Stress Control

Stress control methods using sequencing and optimum roadway spacing have provided significant improvements in roadway stability and improved panel development rates. The use of less critical roadways as first driven stress relief headings can provide major improvements in the stability of flanking roadways used for travel or conveyor roads. With effective stress relief, the flanking roadways

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VERTICAL STRESS (MPa)  
(As Measured Underground)

PRINCIPAL HORIZONTAL STRESSES  
(As Measured Underground)

Fig. 3  In situ stress monitoring.
Fig. 4 Longwall stress control options.
Fig. 5 Horizontal stress relief methods.
will benefit from faster development rates, reduced reinforcement requirements and improved intersection stability, together with reduced long term roadway maintenance.

3.2 STRESS RELIEF METHODS FOR EXTRACTION AREAS

The primary method of stress control for extraction areas should be to ensure optimum orientation of the extraction area with respect to the stressfield. If the primary control on stability is the horizontal stressfield, then extraction areas should be oriented near parallel to the major horizontal stress. If this is not possible then two methods of stress relief have been assessed and developed. The options are illustrated in Figures 4d and 4e. These are:

3.2.1 Driveage of a Stress Relief Roadway

The location of key gateroads in distressed ground provided by a stress relief system.

This requires three heading panel development and has been successfully used for a number of longwall blocks at a South Coast N.S.W. Colliery. The stress relief heading must be the first driven heading and a significant height of roadway softening and modification of the stressfield must be achieved during development of this heading. The pillar width used between the stress relief heading and the maingate heading was designed to provide a minimum width pillar stable under vertical load but having the maingate situated close to the stress relief heading in order to maximise horizontal stress relief.

At the trial site, an 8-9m pillar width was developed and monitoring indicated that this pillar remained stable until after the longwall face had passed.

Monitoring of the vertical stress indicated that an increase of approximately 10 MPa occurred in the small pillar and this pillar did not yield until the longwall face had passed. An effective method of rib support using steel bolts and diagonal straps was important in maintaining the stability of this narrow pillar.

Monitoring of the horizontal stress changes indicated that stress relief was occurring in the lower roof outbye of the longwall face, whilst stress concentration is restricted to the upper roof of the stress relief roadway. This stress profile results in the immediate roof of the maingate being in a lower stress environment. During longwall extraction, breakup of the stress relief heading was occurring 40-50 metres outbye of the longwall face enhancing the stress relief provided to the maingate.

A critical factor in achieving sufficient horizontal stress relief was the height of roof softening occurring in the stress relief heading. Where insufficient stress modification was achieved during the initial heading development, blasting of the roof and floor of the stress relief heading was carried out prior to longwall retreat.

3.2.2 Direction Reversal of Longwall Retreat

This option relocates the major horizontal stress concentration to the lower priority gateroad (taigate) where the adjacent coal will provide some stress relief to that zone. The maingate is then located in the lower stressed area resulting in improved stability. The success of this method is dependent upon the ratio of the major horizontal stresses as the secondary horizontal stress will then be concentrated on the maingate side. The method has been successfully used where the mine design has permitted coal clearance to take place in the opposite direction to that originally planned.

3.2.3 Production Benefits of Extraction Stress Control

Figure 6 indicates the comparative performance of adjacent longwalls at two Australian Mines each with and without specific stress control methods. At both mines, maingate stability has been significantly improved with the elimination of the gateroad falls which had resulted in major production delays, together with a reduced requirement for secondary reinforcement.

![Fig 6: Effect of stress control options on longwall productivity.](image-url)
4. CONCLUSIONS

The effects of stress concentrations about underground mine openings has been monitored at a wide range of sites. An understanding of stress control methods and prediction of potential stress concentration zones are now considered to be major features for mine planning and extraction planning.

5. REFERENCES


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