Developments in controlling the roof in South African coal mines—a smarter approach

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Synopsis

Techniques used to safely control the roof in UK coal mines for some 10 years have been applied to a South African coal mine. This new approach known in the UK as advanced rockbolting technology, is based on applying four fundamental principles:

- ➤ Understanding the roof failure mechanisms
- ➤ Using an effective roof support system
- ➤ Designing this support using measurement
- ➤ Monitoring the performance of the system.

The paper summarizes the approach in detail and describes how it is being applied by Anglo Coal, giving results obtained to date.

Investigations at a number of South African coal mines, including stress measurements at two Anglo Coal mines, have confirmed that the mode of roof failure (lateral shearing due to horizontal stress) is the same as in other coalfields worldwide, and aspects of current world best practice, including the use of advanced technology rockbolting, are therefore relevant in South Africa.

The stress measurements indicated a high level of stress field anisotropy and further investigation of stress conditions in South African coal mines is recommended.

The most effective bolting system to resist shear failure is one with high bond strength and stiffness. Short encapsulation pull testing of existing South African systems confirmed that they have low bond strength and stiffness. An improved rockbolt system with the required performance, and features allowing rapid installation and installation quality and performance audit, has been developed and is currently under full-scale trial.

Design by measurement and routine monitoring procedures including the use of a rotary telltale device are also under trial.

It is anticipated that South African coal mines will be able to obtain significant safety and productivity benefits from the application of this technology.

Introduction

The use of rockbolting as roof support is an essential element of high productivity mechanized coal mining. In South Africa, the USA and Australia, rockbolting has been used in coal mine room-and-pillar operations for many years, and the productivity of this mining system continues to increase with advances in equipment design and capacity. More recently, rockbolting has been applied to the support of gateroads for longwall retreat systems, allowing the productive potential of modern heavy duty longwall equipment to be realized.

In contrast the general situation in the remaining European coalfields is one of limited technical change, with longwall retreat mining widely practised, but with steel arch gateroad support, and consequently with relatively poor productivity. One reason for this difference lies in the perception that in European coal mining conditions, with large depths of working, weaker rocks and interaction from previous workings, rockbolting would be unsafe. However rockbolting has been successfully applied in exactly these conditions in UK coal mines in the last ten years with unprecedented levels of safety (Arthur *et al.*[1]). The introduction of rockbolting was the result of a comprehensive research and development programme undertaken by British Coal prior to industry privatization in 1994 and part funded by the European Coal and Steel Community. This work resulted in a fundamental advance in the science of rockbolting, which allowed its successful application in these difficult conditions.

Four key steps in applying rockbolting in these conditions were identified:

- ➤ Understanding the roof failure mechanisms
- ➤ Using a rockbolt system which provides effective support against these failure mechanisms
- ➤ Designing the support pattern using *in situ* measurement
- ➤ Monitoring the performance of the system.

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The resulting rockbolting system, together with the associated technology of design by measurement and routine monitoring of roof movement has been termed 'advanced technology (AT) rockbolting' (Bigby[2], Altounyan and Hurt[3]).

This technology is used in all UK coal mines, and has been used in successful rockbolting trials at mines in Germany, Russia, Poland, Canada, the Ukraine, Japan and China. These were all mines in which rockbolting was being introduced in relatively challenging conditions.

Anglo Coal mines, along with other South African coal mines, have a continuing requirement to improve both safety and productivity. The remarkable safety record of AT rockbolting strongly suggests that safety improvements could be made in South African mines by adapting aspects of the technology to South African mining conditions and methods. Improved roof control in problem areas could also bring productivity improvements. An in-house research and development programme was initiated by Anglo Coal in 1998 with the objectives of investigating the extent to which this technology is applicable to Anglo Coal mines, making technical changes where these are feasible and quantifying the resulting benefits.

The work, initially concentrated at Goedehoop mine, has made rapid progress and investigations are now being extended to two other mines. This paper describes the work undertaken and the results obtained to date.

Advanced rockbuilding technology

The development of advanced technology rockbolting

The development of advanced technology rockbolting has been described in a number of publications[2,3,4].

Initial research in Australia by ACIRL identified the basic mechanisms of roof failure in Australian coal mine conditions and the resulting required properties of effective bolting systems. In particular the research highlighted the role of high horizontal stress in causing roof failure in Australian coal mines. British research built on these findings, confirming similar stress conditions in UK mines and developing a UK sourced rockbolt system which improved on Australian systems and introduced a monitoring system using the telltales which has since been applied worldwide.

The main findings of the research and the essential features of the AT rockbolting system are described below.

Roof failure mechanisms

Understanding stress, particularly the horizontal stress level, combined with the ability to undertake detailed measurement of stress by overcoring has been a key step in the successful introduction of rockbolting in deep coal mines[5].

The vertical component of the stress field is equal to the weight of overburden rock and therefore depends on the depth of working. The horizontal components of the stress field are dictated by crustal tectonics. In north-west Europe, for example, including the UK, a major horizontal stress component with a NW–SE trend exists, due to the opening of the mid-Atlantic ridge. This stress exceeds the vertical stress in magnitude at depths of less than 1000 m. The ratio between the maximum and minimum horizontal stresses is usually between 1.7 and 2:1.

The significance of horizontal stress for mining stems from the concentration of this component which occurs in the roof and floor of mine openings (Figure 1a-f). If the resulting compressional forces exceed the rock strength in beds close to the opening then shear failure will occur, with lateral movement and vertical displacement of beds. Once failure is initiated, redistribution of load tends to cause progressive propagation of shear fractures higher into the roof. If these failures develop sufficiently or intersect planes of weakness such as bedding planes or slips, roof falls can occur.

Horizontal stresses are lower in the roof of mine openings developed close to the line of maximum horizontal stress, whilst those on openings at a high angle to the maximum horizontal stress are highest. The latter are therefore likely to suffer much greater deformation (Figure 2). This effect was first noted in the UK during the initial development of the Selby Mine complex in the early 1980s. The first gateroads developed NE–SW proved unsuccessful, with difficult conditions.

Following measurement of the stress field, subsequent longwalls were developed on a NW–SE line, with greatly improved conditions.

Similar effects can be seen worldwide and recently horizontal stress effects have been recognized in US coal mines[6].

Application of effective roof support systems

Rockbolting systems typically used in coal mines are point anchored with a mechanical anchor or partially or fully bonded, with a resin encapsulant annulus between the steel bolt and the rock.

Point anchored bolts have a low capacity and stiffness. The main role of such systems is in securing weak or friable immediate roof to stable upper beds and they have little or no reinforcing action or resistance to roof shear under horizontal stress. The ability of fully bonded rockbolt systems to provide reinforcement depends on the strength and stiffness of the bond between the rockbolt and the rock. This can be measured in the laboratory or underground using short encapsulation pull testing[7], Figure 3. The performance of partially encapsulated types falls somewhere between these two extremes, depending on both the bond strength and degree of encapsulation.

AT rockbolting is a fully bonded high capacity and stiff rockbolt system designed to resist rock dilation and maintain rock strength under conditions of roof shear due to horizontal stress. Stiff systems such as this work by providing confinement to the rock, greatly increasing the effective rock strength, even in a post-failure condition.

Each of the elements of the AT rockbolting system-hole size, drill bit size and type, resin properties, steel properties and bolt profile have been developed to maximize the bond strength, and yet provide a system capable of rapid installation.

The torque nut and plate assembly is designed to give resin mixing quality control during installation and to allow post-installation quality auditing to be carried out.

Design using measurement

The AT system was developed with the particular application of support of single entry roadways serving longwall panels

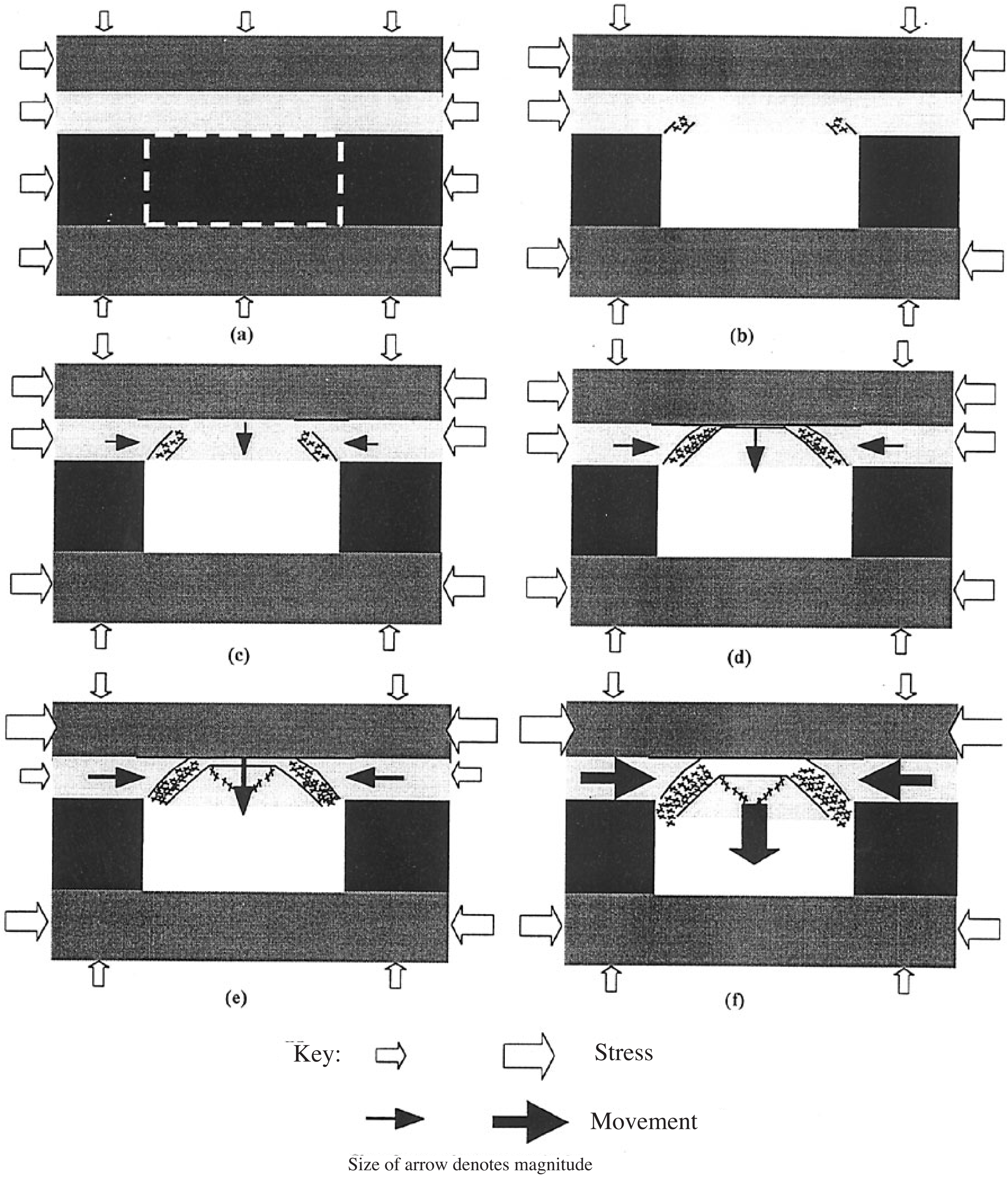

Figure 1—Diagram showing mechanism of roof failure due to shear

as typically used in the UK. In order to provide safe support in these roadways under the variable conditions found in deep mines, a system of continuous monitoring of roof movement is part of the design process. In Britain a Code of Practice[7] provides guidelines for operators of the system. There are two main elements.

- Detailed monitoring stations to provide design information.
- Routine monitoring devices to measure and display roof movement.

A typical design monitoring station is shown in Figure 4. Detailed rock movement measurements are taken using a sonic extensometer typically used in a 7.5 m vertical hole into which 20 magnetic anchors (measurement points) are placed. The relative movement of these anchors indicates where in the roof the rock is shearing. This allows informed

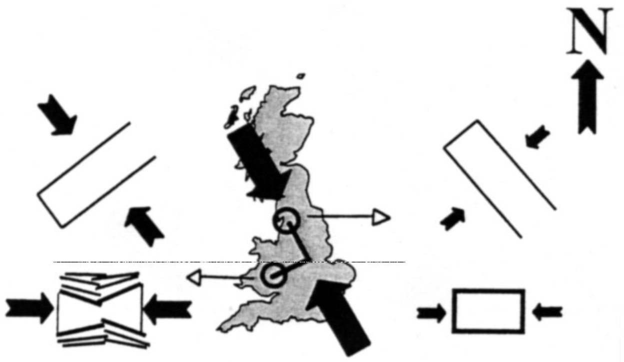

Figure 2—Directional stress effects

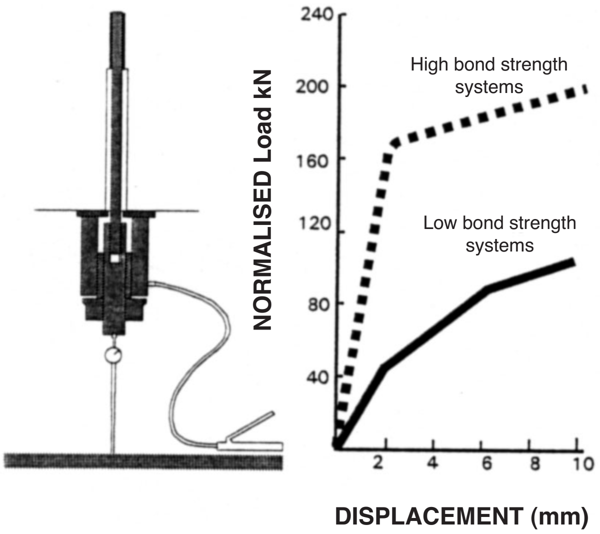

Figure 3—Pull test equipment and results

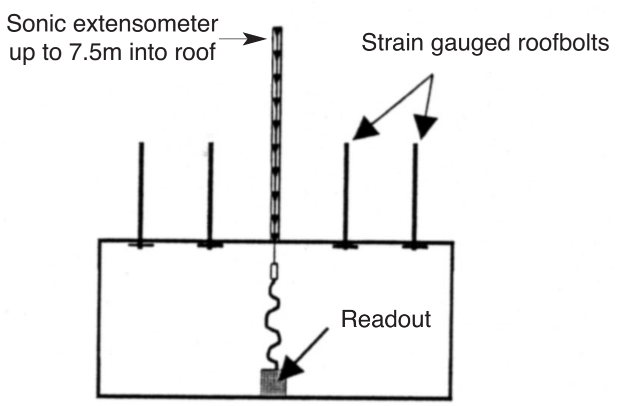

Figure 4—A typical roofbolted roadway monitoring station

decisions to be made regarding optimum rockbolt design. The other essential information is provided by the measurement of the load profile in the bolts. This information is used to confirm or improve the support design.

Following these measurements roof movement 'action levels' can be derived for a site. These are the amounts of roof displacement within and above the bolted height that can be safely allowed before additional supporting action is required to prevent a roof fall.

Design by measurement requires mine resources in the form of a trained engineer at the mine to supervise measurements, interpret results and implement changes in support design when required. It allows the level of support to be varied in response to change in conditions. Targeting of support in this way maximizes both safety and economy in the use of support.

Monitoring system performance

Routine monitoring is undertaken in rockbolted roadways by installing dual-height telltales (Figure 5) which give a visual indication of roof displacement[8]. They are positioned at regular intervals, normally at 20 m in Britain, to detect movement within and above the bolted height. They are designed so that the anchor positions are installed to a height beyond the likely extent of any expected roof movement. Each indicator has two coloured indicators graduated in millimetres, and corresponding to the predetermined action levels for roof movement within and above the rockbolted height. Telltale readings are taken by the district officials each shift and if excessive movement is detected, action is taken.

Typical action levels used in British coal mine roadways are 25 mm in the bolted height and 10 mm above the bolts. These values are by no means universal, being affected by stress conditions and geology. Once action levels have been reached, remedial support action is undertaken to secure the roof. This could be extra bolts, cable bolts or standing support dependent on where the movement occurs and the required use of the roadway.

Development and application of new rockbuilding technology in South Africa

Application to RSA mining methods and conditions

RSA coal mines are shallow and in general roof conditions are good. Support is sometimes not used, or short point anchored or partially encapsulated rockbolts are used at

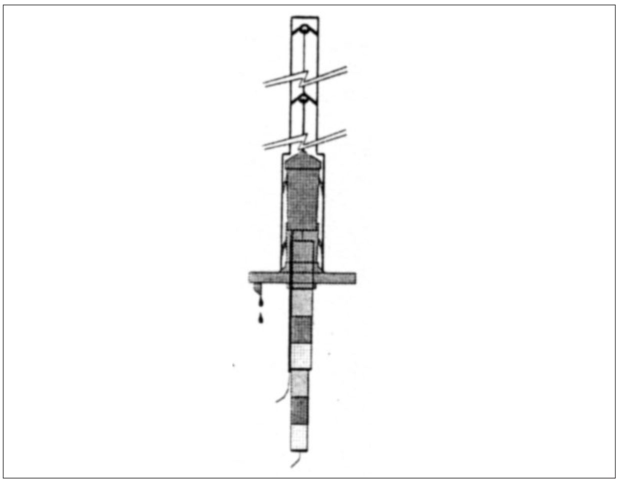

Figure 5—Dual height telltale

relatively wide spacings. However serious roof control problems do occur from time to time.

The typical roofbolt system used in South African coal mines is of relatively low capacity and stiffness and therefore has a low resistance to roof shear under horizontal stress.

The degree to which horizontal stress has a role in roof failure in South African mines is therefore of fundamental importance to the applicability of current rockbolt systems.

Rockbolt installation quality is an important issue, and South African systems do not currently incorporate features such as effective torque nuts and deformable end plates which provide quality control during installation and information on the development of post-installation end loading.

The use of measurement and monitoring systems in the South African situation will depend on what level of roof movement occurs prior to a fall and on the practicality of installing and reading monitoring instrumentation in the typical South African room-and-pillar operation with place changing and extended cuts. Finally it is important from a financial viewpoint that any new bolting systems or components are sourced in South Africa, so they can be available to the mining industry at a reasonable cost.

Anglo Coal research programme

Initial research investigations have been carried out at Goedehoop mine. Underground stress measurements were undertaken at three sites, together with visual inspection of roof failure sites to confirm failure mechanisms. An extensive programme of short encapsulation pull testing, both underground and in the laboratory, was also carried out to measure the performance of the existing bolting system.

Following from this initial work, specifications were drawn up for an improved bolt system for use at Goedehoop, and for associated procedures for measurement and monitoring of roof movement. The new bolting system has now been implemented throughout the mine, and trials of alternative telltale monitoring procedures are under way at two sites in the mine. Stress mapping and measurement work was also recently completed at Arnot mine. Similar work has also commenced at Bank mine. Results obtained during the above work and technical changes following from it are summarized below.

Stress measurements and roof failure modes

Stress field measurements were undertaken in roof rock above the seam at three underground sites at Goedehoop mine and three at Arnot mine using the overcoring technique with CSIRO cells to ISRM standard procedures.

The sites at Goedehoop were chosen to reflect a range of underground geological conditions. The regional stress field is considered to be represented by Site 2 in Figure 6. This has a maximum horizontal stress component oriented NNW–SSE.

The ratio between the maximum and minimum horizontal stress is greater than four, indicating significant directionality in the stress field. Test 1 close to a dyke shows increased magnitude for both horizontal components. Test 3 was undertaken in an area of change in both surface and underground topography, and indicating a major effect which these features can have on the stresses.

The results from Arnot (Figure 7) indicate higher average stress levels in a generally weaker roof. The directions of maximum horizontal stress differ between the mines as shown in Figure 8, indicating variation in the regional stress field which merits fuller investigation. Stress mapping techniques have also been used to identify the local direction of maximum stress at Goedehoop, Bank and Arnot mines from the pattern of visible roof shear. Figure 9 shows stress mapping results from Bank 5 seam, which confirm that the variability in direction of horizontal stress at a local scale.

Generalized computer modelling of coal mine roadways for South African coal mines using realistic material properties and measured stress levels indicates that the horizontal stress at site 3 at Goedehoop is sufficiently high on its own to cause shear failure of the roof. At site 1, close

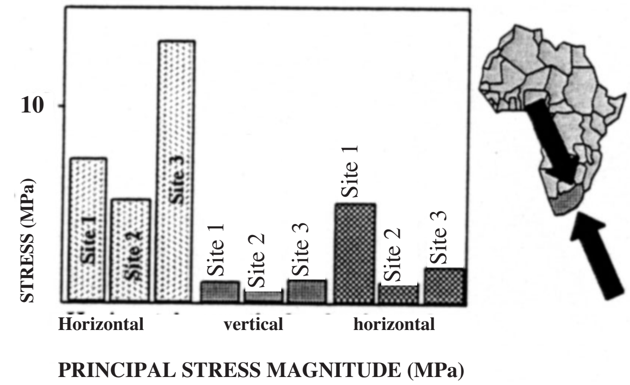

Figure 6—Stress results from Goedehoop

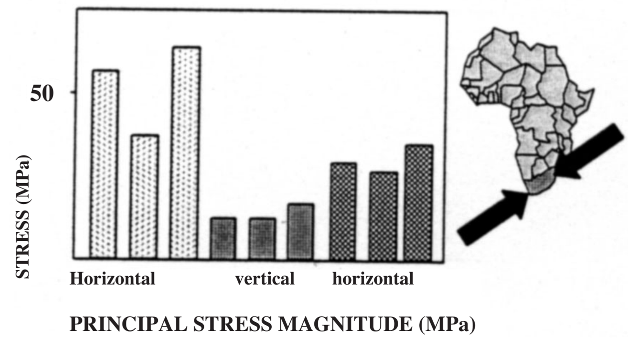

Figure 7—Stress results from Arnot

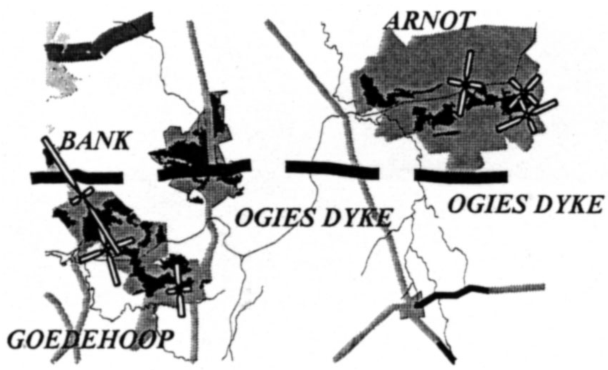

Figure 8—Regional map showing stress directions

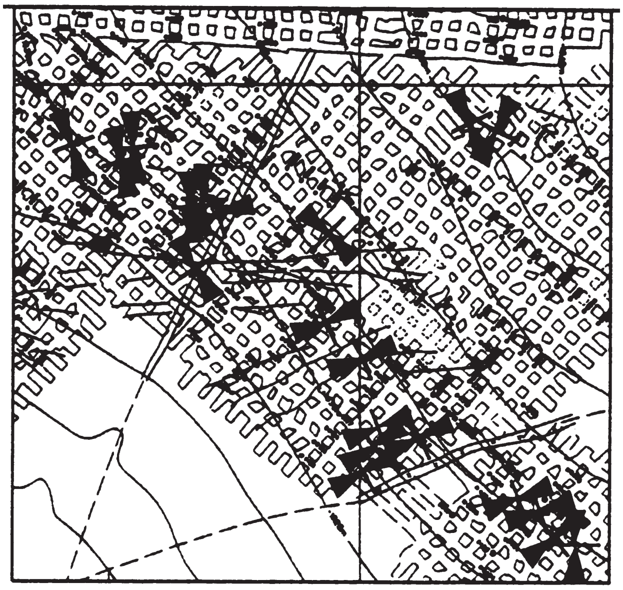

Figure 9—Stress directions of Bank Colliery

to the dyke, failure is also feasible in combination with a slip feature.

The stress levels at Arnot are also considered to be of significant magnitude, considering the low strength nature of the roof and the presence of geological features to cause roof failure.

The pattern of failure in all these cases is of lateral shearing movements and vertical displacement of the roof prior to a roof fall occurring, following the general pattern shown in Figure 1. Inspection of existing roof failure sites at Goedehoop confirmed the characteristic signs of shear failure at all the sites seen (Figure 10).

Mine planning

The results of stress mapping and measurement, together with investigation of the roof failure mechanism, confirmed the importance of stress directional effects on roof condition and failure at Goedehoop. Consequently future production districts throughout the mine have been reorientated to avoid the most unfavourable orientation for both roads and splits. In this way neither roads nor splits are subject in principle to high horizontal stress.

At the same time, hazard planning at the mine has been extended to include the potential effects of increased stress fields in the vicinity of dykes and changes in topography so that areas of concern can be identified prior to mining.

Improvements in roof support system application

Typical results from short encapsulation pull tests at Goedehoop are shown in Figure 11. Tests with existing bolting systems confirmed low stiffness. In fact it proved possible to pull out fully encapsulated 1.5 m long bolts at well below the maximum bolt capacity. This poor bond strength resulted from a combination of bolt/resin properties and poor installation quality, and confirm the need for both an improved system specification and installation standards. This contrasts with a typical stiff system capable of providing reinforcement where a 250 mm length of bond is sufficient to generate maximum bolt capacity.

A performance specification for a new bolt system has been drawn up based on performance criteria in particular the short encapsulation pull testing in rock in the laboratory and underground of the roofbolt system. A high bond strength and stiffness is specified to maximize resistance to roof movement and shear. Local suppliers have been able to meet the specification by changing the resin formulation and bar profile.

The new standard 20 mm system uses a 25 mm drill bit with a minimum of a 500 mm long capsule. The small annulus results in efficient mixing and a minimum encapsulation length of around 0.9 m. Typical test results with the new system are also shown in Figure 11.

Other features of existing bolt systems which can lead to poor installation quality include the use of a crimped nut which gives inconsistent breakout and is liable to jam, a low strength cut thread and bolt plates which are stronger than the bolt. The nuts have been replaced with shear pin, which are free running providing consistent breakout at a predetermined higher torque. The thread is rolled onto the bolt so that the threaded section of the bolt has a strength similar to that of the bar and a deforming plate is specified, which allows deformation and eventually pull through of the bolt at slightly less than its ultimate strength thereby providing a visual indication of high bolt load.

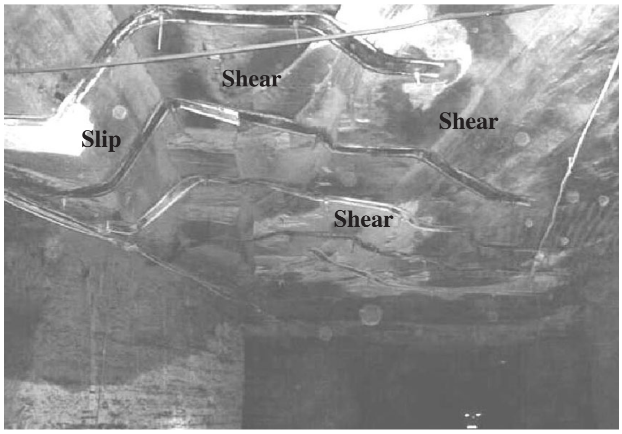

Figure 10—Roof failure at Goedehoop

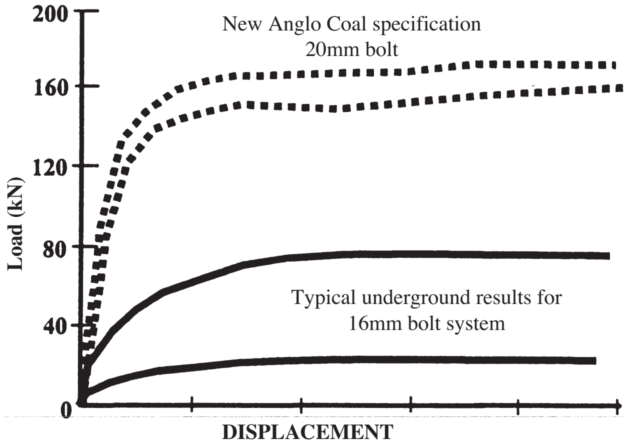

Figure 11—Pull test results

These changes make installation easier and at the same time, breakout of the torque nut provides confirmation that the resin has been properly mixed and has set. The length of exposed thread after installation can be inspected to confirm nut breakout and drilling of the correct length holes.

The new system can therefore be audited for installation quality and post installation performance.

The new system has been implemented throughout Goedehoop mine. Standard operating procedures and checklists have been drawn up for each aspect of the system and comprehensive staff training undertaken to all concerned.

Design by measurement

Sonic extensometers are currently being installed at Goedehoop. Initial installations have been placed in areas of concern as determined by a risk assessment to gather detailed information on roof movement and to confirm the level of support required. The ultimate objective is to utilize extensometry to allow the level of support in terms of number and length of bolts to be varied systematically in response to support conditions and to reduce the need for expensive remedial support such as cabling. Some 20 installations are currently in place. Figure 12 shows typical sonic extensometer results where significant shear is developing in the first metre of roof.

Monitoring

Roof movement monitoring using telltales provides a visible indication of roof movement at regular intervals. The use of telltales as support safety devices is now well proven and routine in a number of countries.

However conditions in South African coal mines differ from those typical in the UK. Although the expected roof failure mode (shearing in response to horizontal stress) is the same, international experience in equivalent shallow conditions to those in South African coal mines suggests that relatively small vertical movements may be required before a fall can occur. In addition, the typical South African mine roadway exceeds 4 m in height, resulting in difficulty in observing normal telltales at roof level.

For these reasons a new telltale type was required for typical South African coal mine conditions. The required specification is: easy to install, easy to read, accurate to better than 1 mm, failsafe, and low cost.

The rotary telltale has been developed to meet this specification. The device converts roof movement into rotation of a pointer round a dial (Figure 13) and magnifies the movement by a factor of 15. Small movements can be easily read, with the reading visible from below, even in a 5 m high roadway. The dial face is subdivided into coloured sectors corresponding to chosen action levels.

Rotary telltales are currently being installed throughout Goedehoop, with two alternative schemes being trailed. In the first telltales are being installed in areas of concern, identified from the mine plan, taking into account the position of geological features such as dykes, burnt coal and slips or changes in topography or wherever this is an observed concern on site. In the second scheme, telltales are being installed on a routine basis in every intersection and removed when no longer required. In both cases the telltales are being installed in 4 m long holes at the face of the heading by the mining crew at the completion of a bolting cycle.

The devices are read by colour every shift by the mining crew supervisor and the readings reported through line management by exception. If the dial pointer moves beyond the green (safe) into the yellow sector additional support is set. If readings enter the red (danger) access to the area is prevented.

An example of how telltales are used is given in the case history from Goedehoop Colliery.

The section was developing towards a dyke and because it was in an area of concern telltales were being installed systematically. One of the roadways met the dyke and was stopped, fenced off and a telltale installed in the previous intersection. The road was later holed through and an area of roof collapsed to a height of a few millimetres. The telltale in the previous intersection started moving and the roof fall extend in height to 1.4 metres. In response to the continued telltale movement longer bolts were installed in the affected area. Following this the telltale movement stopped and the roof remained stable.

This example shows that the mechanism of roof failure is preceded by movement and that if responded to appropriately by the mine personnel the roof can be controlled, stabilized and production can be allowed to continue safely.

Conclusions

Research investigations at a number of Anglo Coal mines

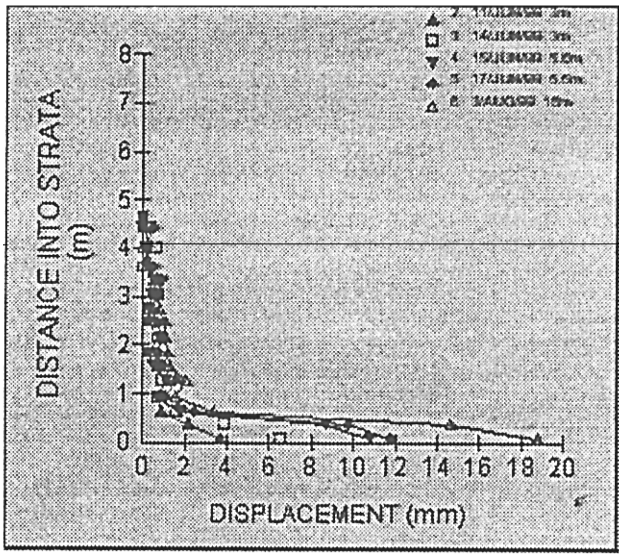

Figure 12—Sonic extensometer results from a South African coal mine roof

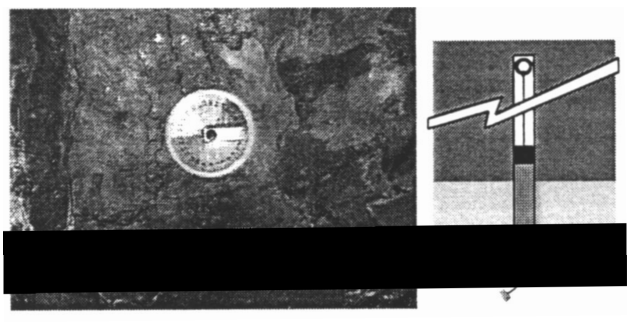

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Figure 13—Rotary Telltale

have confirmed that the mode of roof failure (lateral shearing due to horizontal stress) is the same as in other coalfields worldwide, and aspects of current world best practice, including the use of advanced technology rockbolting, are relevant in South Africa. It is anticipated that South African coal mines will be able to obtain significant safety and productivity benefits from the development of a South African version of this technology.

The most effective bolting system to resist the shear failure mode is one with high bond strength and stiffness to resist roof movement. Existing South African systems have low bond strength and stiffness.

An improved rockbolt system with the required performance, and features allowing rapid installation, and post-installation quality and performance audit, has been developed and is currently under trial with Anglo Coal.

Design by measurement and routine monitoring procedures including the use of a rotary telltale device are also under trial, with the objectives of continuous confirmation of safe conditions, efficient targeting of support and reduced requirement for secondary support such as cabling.

Following the stress field measurements obtained, further research on stress conditions in South African coalmines is recommended to identify both regional and local variations and the effect of the geological features commonly encountered.

South Africa coal mining is benefiting from research carried out previously in other countries. This example demonstrates the increasing potential for mutual benefit from research co-operation at the international level and the rapid progress which can be made by implementing existing research findings directly at the mine level.

Acknowledgements

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