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GROUND CONTROL IN COAL MINES IN GREAT BRITAIN

James Arthur

ABSTRACT: In deep coal mining support of the underground roadway is fundamental and without knowledge of the mechanics of ground control a mine is unlikely to be operating safely and efficiently. It is therefore important for the support system to be designed satisfactorily for the size of the excavation required and to do so an understanding of the behaviour of the surrounding strata is required. Over the last 15 years there has been a major change in the mining industry and the support systems adopted. Roofbolting has been adopted as the primary support system, the industry has been privatised, legislation has been updated, a comprehensive research programme has been carried out and guidance documents produced.

INTRODUCTION

For many years the main roadway support system in Great Britain was steel frame or arch type supports. However, since the introduction of rockbolting systems in the early 1990s these have become the main support system for roadways and accidents in roadway drivages have been reduced. This reduction was attributed initially to the introduction of a code of practice, which introduced systematic monitoring and then later to the introduction of a simple and easy to erect mesh cage system at the face of roadway drivages. The system has proven to be so successful that it has been introduced into roadways supported by square set steel type supports. A working group is currently reviewing support in large roadways supported by steel arch supports to design a mesh cage system for this type of roadway.

In 1993 a major accident at a coal mine resulted in the deaths of three people. The subsequent hearing recommended that 'A national research programme in rock bolting technology, the associated geology, improved instrumentation for monitoring, effects of pillar edges, gate side packs, pillar sizes etc. should be agreed between the industry and the universities with a rock mechanics capability' (Crossland, 1994). The Health and Safety Executive (HSE) sponsored a comprehensive research programme to address this recommendation. This research has led to improvements in monitoring techniques, rockbolt materials, consumables, and a better understanding of the strata conditions and support mechanisms.

MINING CONDITIONS

Mining takes place at depths of up to 1100 m, the typical depth being 800 m to 900 m. Many of the mines are over 100 years old. Many seams have been worked and therefore interaction between seams can be a major problem. The geology of the rock above the coal seams is variable, ranging from weak mudstones up to 5 m in thickness grading up to siltstone and sandstone with a compressive strength, which can exceed 60 MPa. The stress field is a major factor in dictating mining conditions. The magnitude and direction of the major horizontal stress component can have a major influence on roadway failure, (Altounyan and Hurt, 1998)

HISTORY OF ROCK BOLTING

Investigations into the use of rockbolting as a support system were being carried out by Her Majesty’s (HM) Inspectors of Mines as early as 1954. They researched the use of roof bolts in mines in the USA and they emphasised the need for care and experiment where bolts are to be used and concluded ‘that roof bolts should not be used as the only means of support in roadways likely to be affected by future workings, where natural weaknesses in the strata are present and where bed separation occurs’, (Hodkin and Lawrence, 1954)

Rockbolting was introduced in 1964 using mechanical point anchored bolts but following a number of roof falls the use of these bolts ceased. Further trials using resin anchored bolts took place in the 1970s and early 1980s. They were found to be unsuitable for the conditions due to their low strength and a lack of understanding of the forces involved. In the mid 1980s a review of current bolting techniques throughout the world took place. The systems that were in use in the United States and Australia were trialled. The Australian bolting system, utilising high strength rockbolts fully bonded with polyester resin were found to be the most effective for British mining conditions.

1 HM Mines Inspector of Mines, UK
Due to the previous failures with rockbolts and because the majority of the mines are deep and use single entry roadways (up to 3000 m in length) for longwalls it was felt that the system must be introduced in a controlled manner via an extensive programme of research and development. The development of a code of practice was also seen as essential to enable the rockbolted system to be introduced safely. It was also essential to build and maintain the confidence of the miners, supervisors and Trade Unions and to provide comprehensive training to ensure that the installation standards were high. Rockbolting was safely and successfully introduced into coal mines as a primary support system in the 1990s. Today approximately 95 per cent of all new roadways are supported by rockbolt systems.

**PRIVATE\NSATION OF THE COAL INDUSTRY**

In 1994 the government announced that the nationalised coal industry (British Coal Corporation) was to be privatised and at the end of 1994 the coal mines were transferred to the private sector.

Before taking the decision the government consulted with the Health and Safety Commission and sought advice on how the industry could be effectively regulated. The government stated its commitment to safety, recognising that the maintenance of safety standards was of prime importance. The Health and Safety Commission provided a report to ministers in October 1993 and in this report recognised that ‘the legislation be flexible enough not to restrict the introduction of new technologies or new methods of work, but still ensure that health and safety was not prejudiced’ (HM Government 1993)

The Commission recommended the formation of the Deep Mine Coal Advisory Committee (IAC) and that key guidance be progressively adapted and updated. The Chief Inspector of Mines chairs this committee, which has subsequently been renamed The Mines Industry Advisory Committee (MIC). Representation includes employers, employees, mines rescue, healthcare providers, equipment suppliers and contractors.

The updating and replacement of British Coal guidance with official guidance is managed through working groups made up largely of MIC nominees. One of these working groups is the ‘Support Guidance Working Group’.

**LEGISLATIVE RENEWAL**

The Mines and Quarries Act 1954 contained the requirement to control strata and secure working places. The Coal and Other Mines (Support) Regulations 1966 that applied to coal and stratified mines specified minimum and maximum distances for a range of support systems. These regulations were detailed and complex and with the introduction of newer technologies many exemptions were required. This was particularly the case when rockbolting was introduced.

A fundamental review of legislation was carried out in 1970 and the review was critical of prescriptive law, which was difficult to change. The review was the foundation for the Health and Safety at Work etc Act 1974 (HSWA) (HM gov, 1974). This act came into force on 1 January 1975 and provided for the introduction of new regulations that set broad objectives to be achieved, to progressively replace older detailed and prescriptive legislation. These regulations are supported by codes of practice and guidance documents.

Under the HSWA 1974 the Coal and Other Mines (Support) Regulations 1966 were updated and the Control of Ground Movement Regulations (CGMR) 1999 introduced, Figure 1. The regulations differ from the 1966 support regulations in that they apply to all mines, not just coal and stratified mines.

The CGMR 1999 places a general duty on the manager to ensure the safety of the mine, assess ground conditions, design the ground control measures, draw up ground control rules, notify new ground control proposals in coal mines to the Mines Inspectorate of HSE, ensure that the rules are implemented and assess the effectiveness of the ground control measures.

There is a duty on the mine manager to ensure that before any excavation is undertaken an assessment of ground conditions must be undertaken. The assessment should take into account the geology, rock properties, stresses, extent of ground to be controlled, possible failure mechanisms, and effects on other working places, environment and historical data.
There is a duty on the manager to ensure that a design document has been prepared, which, takes into account the assessment of ground conditions and describes the ground control measures which are to be undertaken to keep places in the mine secure. The design should include the limits of extraction, excavation dimensions, pillar sizes, support density, support materials, methods of work, abnormality procedures other known risks such as faults.

There is a duty on the manager to ensure that the design document is turned into practical instruction, direction and guidance. From this information support rules are constructed that show the ground control measures described in the design document and instructions on how to implement them safely. Contained within the rules are details of support materials and equipment, methods of work, support density, sequence of excavation etc.

There is a duty on the manager to ensure that an appropriate monitoring system/scheme is introduced that ensures that the adequacy of ground control measures is being assessed at all times. The scheme must be appropriate for the circumstances and should allow time for action to be taken to recover and stabilise the situation. The results must be recorded and the system regularly reviewed. The systems adopted for roof bolt support systems are by tell tale, Figure 2 and extensometers, Figure 3.

There is a duty on the manager to notify the HSE, in writing no less than 28 days prior to making the change, if he wants to make a significant change to any ground control measure.
IAC GUIDANCE/STANDARDS DOCUMENTS

The Support Guidance working Group developed the first code of practice “Guidance on the use of rockbolts to support roadways in coal mine”, Figure 4 (Deep Coal Mines Advisory Committee, 1996a). It provides guidance on the safe use of rockbolts to support roadways in coal mines. Other guidance documents have been developed for cable bolts (Deep Coal Mines Industry Advisory Committee, 1996b), flexible bolts, (Deep Coal Mines Industry Advisory Committee, 2000), lifting bolts and passive supports in coal mines (Deep Coal Mines Industry Advisory Committee, 2002).

The rockbolt systems used utilise consumables that comply with a prescribed performance standard. The consumable items specified in the code of practice must meet criteria specified in the British Standard, BSI 7861 Pt 1 and 2, (British standards 1996a and 1996b). This standard applies to both rockbolt and cable bolt/long tendon systems. Due to improvements in technology and consumables BSI 7861 Part 1 has been updated, and was currently going through the consultation process. BSI 7861 Part 2 was in the process of being updated.

Guidance on the use of rockbolts to support roadways in coal mines

The guidance document ((Deep Coal Mines Industry Advisory Committee, 1996a) govers the following matters:

1. definitions,
2. classification of the geotechnical assessment and site investigation,
3. support system design,
4. design verification monitoring,
5. routine monitoring and recording scheme,
6. training, and
7. list of consumables.

Contained within the annexes are tests for bond strength; short encapsulation pull tests; descriptions of tell tales and extensometers; training required for workmen, officials, roof bolting staff and managers.

The guidance document is not suitable for places in coal mines such as goaf scours; gate roads serving advancing faces; cross measure drifts and headings formed by shotfiring off the solid.

A supplementary guidance document on the use of flexible bolts in reinforcement systems for coal mines has also been constructed (Deep Coal Mines Industry Advisory committee, 2000). This document is to be read in conjunction with the above rockbolt guidance document.
Geotechnical Assessment and Site Investigation

To carry out the assessment the manager, if not suitably qualified or competent should appoint a design engineer, who should be a chartered engineer or equivalent, who has had three years experience in work related to mine strata control.

The assessment should define the area covered and take into account all factors which are likely to affect the performance of the support system throughout the life of the roadway.

The site investigation should include reference to the following:

1. geology
2. stress,
3. pillar design and effects, etc,
4. environmental effects,
5. bond strength and
6. stand up time.

Support System Design

Where the assessment indicates that the stratum is suitable for the use of rockbolts a support design needs to be prepared. The design engineer will prepare the design on the basis of the results of the site investigation. As a minimum the design should take account of the following:

1. profile of the heading,
2. length of the rockbolt - minimum 1.8 m,
3. density of rockbolts - minimum 1 bolt/m²,
4. placing of rockbolts,
5. type of rockbolt,
6. holes drilled for rockbolts (finished hole diameter not to exceed bolt diameter by more than 7 mm) and
7. the system of support for the roadway sides.

Design Verification Monitoring

The initial design of the support system needs to be verified by comprehensive monitoring, which includes detailed measurement of roof dilation and rockbolt loads. A station is normally set up with at least four x seven meter length strain gauge bolts or sonic extensometers installed across the roadway that can measure a dilation of at least 1 mm over 15 points on the bolt. This installation is set up at the entrance to the intended development. If the drivage is intended to be of a long length then ideally another station should be set up inbye, normally prior to turning onto the face line. However, the guidance document does not require more than one station to be installed.

Routine Monitoring and Recording Scheme

The manager requires a scheme for the routine monitoring of roadways and should appoint a suitable qualified person to implement, audit and co-ordinate the scheme. This person would be called the rockbolting co-ordinator and be qualified to Higher National certificate standard in a mining related subject.

The scheme should describe the routine monitoring devices, the minimum is dual height tell tales every 20 m and extensometers every 200 m. The manager’s scheme must set action levels and for rockbolted roads in coal mines the maximum roof dilation allowed is 25 mm before remedial action must be taken. In some mines the action levels are set lower than 25 mm due to localised conditions, lack of horizontal stress.

A plan of all roadways supported by rockbolts should be prepared and a schedule of measurement zones and frequency should also be prepared.

All workers involved with rockbolting need to be suitably trained. The appendix to the document should describe the minimum training required for workmen, officials, rockbolt co-ordinators and managers.

Guidance on the use of cable bolts to support coal mines.

In coal mines cable bolts are used as a secondary support system to improve conditions when roof bolts systems are beginning to fail. A guidance document has been constructed for the use of cable bolts (Deep Coal Mines
Industry Advisory Committee, 1996 b). The guidance applies to situations where cable bolts are installed as additional support when excessive strata movement is experienced in places principally supported by rockbolts. The document is constructed along the same lines as the guidance document for rockbolts, i.e. assessment, design, monitoring and training. Tell tales are used as monitoring but they must be installed to at least the height of the cable bolt length +1m.

Where cementitious grouts are used it is important that the liquids to solid ratio of the mixed grout is accurately measured to ensure the correct consistency for both pumping and strength.

Skilled workmen are used to install cable bolts.

**BSI 7861 Strata reinforcement support system components used in coal mines – Part 1 Specification for rockbolting**

This part of BS 7861 specifies dimensional, material and performance requirements for rockbolting support system components use in coal mines (British Standards, 1996a). Included are steel rockbolts, glass reinforced plastics (GRP) rockbolts, resins, nuts, conical seats and domed washer plates.

The standard defines for example, minimum bond strength for a rockbolt/resin/rock system and system stiffness, nut breakout facility, equivalent diameter of the bar and gel setting times.

The standard describes the composition of the rockbolt. This should be made from steel with a homogeneous structure having a chemical composition with maximum of carbon 0.3 per cent, manganese 1.6 percent, sulphur 0.05 percent and phosphorous 0.05 percent.

The rockbolt has a minimum yield strength of 640 N/mm² with a minimum elongation after fracture of 18 per cent.

One of the most important changes to the standard was a fracture toughness requirement. Research, described later, has shown that an average charpy value of 27 joules is required to give the bar the desired fracture toughness properties.

**RESEARCH AND DEVELOPMENT**

A Health and safety Executive sponsored programme has covered research into the following:

1. Rockbolt metallurgy,
2. Mining systems,
3. Roadway stability,
4. Risk assessment techniques, and
5. Instrumentation.

The main falls of ground and related major injuries in rockbolted roadways have been due to, broken or corroded rockbolts, collapse of the ribside, failure to monitor correctly/ respond to monitoring or failure to install remedial support.

**Rockbolt Metallurgy**

In the early 1990s a number of falls occurred in roadways supported primarily by rockbolts. It was found that a number of the rockbolts had broken. These broken bolts were examined at the Health and Safety Laboratory (HSL). It was found that most of the failures were associated with bends in the bolts but all of the broken bolts had corroded to some degree. The fractures had initiated at the root of a corrosion pit and the fracture surfaces indicated brittle failure. Some fracture surfaces were heavily corroded indicating that failure had occurred some considerable time before roof collapse. Indications were that the original rockbolt materials were sensitive to the presence of defects. With corrosion pit defects the material changed from plastic failure with good elongation to sudden brittle failure without any elongation.

Corrosion studies were carried out and the results indicated that a small amount of corrosion could have a significant effect on a bolt. The tests showed that the corrosion depth must be at least 6.25 times the radius at the base of the pit to cause brittle failure with little or no plastic deformation. The depth of corrosion pit that was needed to cause brittle failure in the original type bolts was found to be 1 mm.
It became clear that the rockbolts possessed a low toughness. A modified steel was produced that increased the fracture toughness of the bolt threefold whilst still complying with the chemical and tensile strength requirements of BS 7861 Part 1. Following improvements to the fracture toughness of the steel, the critical defect size of the corrosion pit has been increased to 3 mm. It was thought that this is unlikely to occur in normal conditions. It was also found that the presence of hydrogen sulphide increases the tendency for brittle corrosion cracking occurring.

Fracture toughness tests are expensive to carry out therefore research has been carried out to determine a correlation between Charpy impact values and fracture toughness. A minimum Charpy impact energy requirement of 27 joules was recommended. This minimum value has been incorporated into the updated part 1 of the BSI 7861 document. The Charpy value is a surrogate, cheap and simple, indicator of fracture toughness, which is a much more scientific but also more difficult and expensive to carry out.

Risk assessment techniques

Experience with rockbolting under high stress conditions has shown that, even with good design procedures incorporating numerical modelling and detailed monitoring, it remains difficult to predict, during drivage, the behaviour of gate roadways under the influence of increased stress generated by the retreating longwall face. The use of risk assessment techniques was used to categorise areas with an increased risk of instability and to comply with modern health and safety legislation, which requires that an assessment of risk be, carried out in mine roadways. The initial work was carried out at Thoresby Colliery (Cartwright and Bowler, 1999) leading to a practical assessment technique being developed. The main principles are: identify the falls of ground hazards, identify the mechanisms that lead to the hazard, incorporate them into a survey sheet, examine the roadway in detail, and complete the survey sheet. Input the data into a spreadsheet, and a risk assessment is produced for the roadway identifying areas that require attention. This approach is routinely applied in coal mines.

Laboratory short encapsulation pull test

System performance has been measured by the ‘double embedment test’, that is defined in BS 7861 Part 1 1996. The test involves axial loading of a tendon that has been grouted into two undersized steel tubes; the inner walls of the tubes are threaded to give a good bond. When the steel tubes are pulled apart in a tensile testing machine, the load transfer capability of the resin/bolt (or cable/grout) interface is tested. The bond length used in the test is designed to ensure that bond failure occurs below the yield load of the steel. The problem with the double embedment test is that in practice bond failure can occur at the resin/rock boundary. Research has enabled a Laboratory Short Encapsulation Pull Test (LSEPT) to be developed. This test enables measurement of the system performance at the resin/rockbolt interface to be measured in the laboratory. It consists of confining a sandstone cylinder using a biaxial cell to simulate the stresses imposed underground. A hole is drilled in the sandstone cylinder and a rockbolt inserted through resin into the hole. The system is then pull tested and the bond strength measured. The LSEPT has been incorporated into the updated BSI 7861 Part 1 document.

Lifting and suspending from rockbolts

Equipment is lifted and suspended routinely from the roof in roadways supported by rockbolts. Research was carried out into the effects of lifting and suspending from these anchor rockbolts. Results showed that the most likely failure mode for anchor bolts used for lifting is bond failure due to poor installation, or loss of resin on installation. Anchor bolt failure due to bolt deformation associated with subsequent roof movement is also possible, particularly where the immediate roof shear results in significant bolt bending. The guidance on the use of lifting and suspension of equipment in rockbolted roadways was updated after this research.

Ground control at small coal mines

Small shallow mines have different support problems to those experienced in the larger and deeper mines. A guidance document was developed for small coal mines that would enable the small mine owner to benefit from the techniques developed for large mines.

Instrumentation of flexible bolts

Flexible bolts, typically 4 m length, are constructed of a number of cable strands, which are installed in polyester resin. They are installed in the same diameter hole as rockbolts (27-28 mm). This resulted in longer tendon reinforcement being installed at the face and consequently less reliance on cable bolting as a remedial tool. Flexible bolts are routinely used in combination with rockbolts to support the face of drivages as part of the primary support system. With the introduction of flexible bolts at the face new instrumentation techniques had to be developed to extend the basic monitoring principles previously applied only to rockbolts.
Triple height tell tales were introduced to allow monitoring of the area above the rockbolt to distinguish movement occurring within the rockbolted height and movement in the section supported by the flexible bolt. This is a simple device which extends the dual height tell tale concept to three heights, Figure 5. The A indicator shows movement below the top of the rockbolt, the B indicator shows movement between the top of the rockbolt and the top of the flexible bolt and the C indicator showed movement above the flexible bolted height. The triple height tell tale is used nearly as frequently as the dual height tell tale in coal mines.

![Fig. 5 - Triple Height Tell Tale](image)

**Mesh cage support system**

Where on board bolter miner systems cannot be used a mesh cage system of temporary support is used. The mesh cage system of support, Figure 6, has been adopted in most coal mines where rockbolts are used as the primary support system. It has proven to be so successful that it has been adopted in roadways that are passively supported with steel delta type supports.

![Fig. 6 - Mesh Cage](image)

The mesh cage system enables workmen to work under supported ground at all times when at the face of the heading. A mesh panel is pushed to the roof using two stinger air leg machines and another mesh panel is hung vertically from the roof at the face. The side mesh is unfolded from the roof mesh and draped down the rib side and fixed to the previous panel. The roof and rib bolts are then installed. When the bolting cycle is completed the remaining unbolted mesh panel is tied back horizontally to the roof ready for the next cutting cycle.
A working party is currently looking at ways that this system can be adapted for use in large roadways supported by steel arches.

**FALLS OF GROUND ACCIDENT'S**

The introduction of rockbolts as a primary support and the introduction of the mesh cage support system have enabled accidents caused by falls of ground to be reduced. The last fatal accident that occurred in UK coal mines caused by a fall of ground was in a heading supported by passive arch supports in December 2001. If you restrict this to roads supported primarily by rockbolts then the last fatal accident was in September 1997 at Riccall mine, due to a ribside collapsing. If you further restrict that to fatalities caused by a fall of roof in rockbolted roads then there has not been a fatal accident since 1993.

In 1995/6 there were no fatal accidents and a total of 29 major injuries caused by falls of ground. Eleven were in roadways supported by rockbolts and 18 in roadways supported passively. The mesh cage was introduced as a temporary support system in roadways supported by rockbolts in 1996/7 and the major injuries reduced to three.

Table 1 (health and Safety Executive, 2005) shows the accident rates/100,000 work shifts for fatal (F) and major injuries (MI) caused by falls of ground from the reporting year 1999/2000 to 2004/2005.

<table>
<thead>
<tr>
<th>Type of support</th>
<th>99/00</th>
<th>00/01</th>
<th>01/02</th>
<th>02/03</th>
<th>03/04</th>
<th>04/05</th>
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<tr>
<td>Rockbolt</td>
<td>0</td>
<td>0.036</td>
<td>0</td>
<td>0.085</td>
<td>0</td>
<td>0.09</td>
</tr>
<tr>
<td>Passive</td>
<td>0</td>
<td>0.36</td>
<td>0</td>
<td>0.34</td>
<td>0.05</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Approximately 95 percent of the roadways in UK coal mines are supported by rockbolts yet less than 20 percent of the accidents occur in these roadways.

**CONCLUSIONS**

The updating of the legislation, introduction of guidance documents and improved temporary support systems along with the results from a comprehensive research programme have been fundamental in improving underground safety and efficiency. This has brought the industry much nearer to being able to choose the appropriate support system for any particular application.

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