Roofbolting and place change practices in US coal mines

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Self propelled roof bolting machines have been used almost exclusively in the US coal mining industry for over thirty years. Roof bolting machines were phased in with 'conventional' and 'continuous' mining systems using 'place change' practices in room and pillar mining systems. 'Place change' is also the most common system in longwall gate entry development, but integral roof bolter/continuous miner machines are gaining some acceptance in the US as well.

Roof bolting machines have a number of advantages over the hand held drills commonly used for roof bolting in the UK and Australia.

Safety

The machine incorporates temporary roof support and drill operators' canopies which provide protection against rock falls during the bolting operations. Also, exposure during the placement and removal of manually set temporary supports is eliminated.

Operators are afforded protection from rib fall hazards with the walk-through chassis design and inside boom drilling controls.

Reduced labour and fatigue

The machine does the lifting, and materials can be stored close at hand. The drilling dust is vacuum collected, so the operators stay dry. In mining heights beyond normal reach of the roof, the elevating work platforms lift the operators to within a comfortable reach of the roof surface for resin and bolt installation (see Fig 1).

Improved roadway conditions

Dry roof drilling results in improved roadway conditions.

Improved strata control effectiveness

This is becoming apparent at the mines in the UK and Australia where roof bolting machines have been introduced. The improvements in strata control effectiveness are the result of the higher bolt installation thrust and available torque provided by roof bolting machines than is possible with hand held drills.

In some applications in the UK, it may be possible to extend continuous miner cut depths before place changing due to improved strata control. Improved strata control may permit a reduction in the number of bolts required per metre of advance. These possibilities have yet to be demonstrated and proven in the UK. However, improved strata control achieved with the roof bolting machines in two Australian mines formerly using hand held drills has permitted substantial gains in productivity.

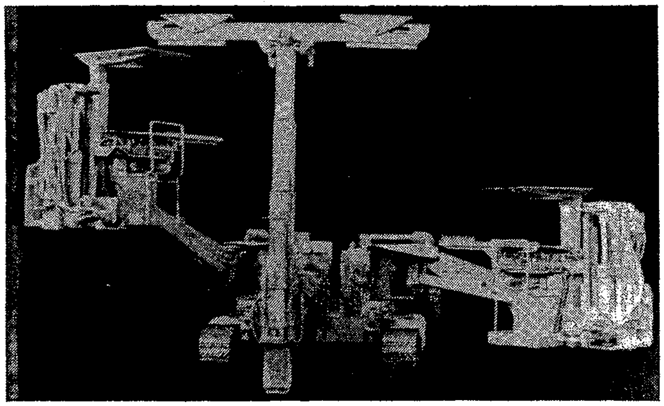

Fig 1 J H Fletcher and model HDDR roofbolting machine with integral temporary roof support, operators' canopies, and elevating booms.

Following is a summary of the evolution of the US roof bolting and place change practices in the room and pillar system.

EVOLUTION OF ROOF BOLTING MACHINES IN THE UNITED STATES

Background

Early in the 1950s, roof bolting machines in the United States were other purpose self propelled vehicles adapted with a drill or drills attached. As the demand and competition grew, special purpose designs were introduced in single and dual drill machines suited to various seam mining heights.

Other than coal seam clearance parameters, the design emphasis early on was toward improving productivity through rapid drill boom repositioning functions which permitted installation of as many bolts as possible without moving the machine chassis. Operator protection was provided by manually set strata supports, usually posts with wedges, placed in a prescribed grid pattern under the exposed roof prior to roof bolting.

Vacuum dust collection

Drilling the strata bore holes for installation of bolts has from early stages been dry. Augers were first used to remove cuttings, and for obvious health reasons efforts toward dust collection followed immediately. Dust was collected into a cup held mechanically under the hole at the roof line. The cup had a hole in the centre at the bottom which allowed the auger to pass through. The first efforts at vacuum dust collection had the vacuum hose attached to the collection cup.

J H Fletcher and Co developed 'through the hollow drill rod' vacuum dust collection during the latter 1950s. For a time, the company manufactured the hollow drill rods since there were no other sources. By 1960, all United States roof bolting machine manufacturers had adopted 'through the drill rod' vacuum dust collection, and several specialised manufacturers offered the drilling tools.

Currently, vacuum drilling is still the norm throughout the United States. Water is used for flushing the bore holes for approximately five per cent of roof bolting operations in conditions where mud or soft clay streaks are found in the strata or where hard, abrasive sandstone strata exists.

Innovations which enhance safety for roof bolting machine operators

Injury from falling rock had been the leading cause of accidents in United States coal mines for decades. Falling rock injuries were particularly common to roof bolter operators.

Canopies

In 1973, United States Federal regulations required that overhead canopy protection be provided for roof bolter operators. The regulations were phased in at first in high mining conditions and the canopy regulations now applies to all mining heights above 1.07 m. The canopies have proven to be of benefit in reducing accidents from falling rock in the area of the drilling controls.

Drilling controls canopy regulations did not address the major source of fatal or crippling injury accidents common to roof bolter operators or other face workers involved with manually set temporary roof support.

Temporary roof support

The major source of accidents to roof bolter operators occurred while working inbye permanent bolted strata preparing, setting, repositioning, and removing manually set temporary supports. Through co-operation between mine management and labour, the equipment manufacturers began to develop remotely controlled mechanised temporary roof support structures integral to the roof bolting machine. In 1971, J H Fletcher and Co and the Manson Machine Co (currently Simmons-Rand) had in service unique versions of 'automated temporary roof support' systems. These are referred to as 'ATRS' or 'TRS' systems.

There were a number of factors which took years to resolve through the 1970s which slowed the acceptance of the TRS systems. Without manually set supports, means had to be developed and proven concerning, (i) remote measurement of methane liberation at the face, and (ii) extending ventilation curtains or tubing. Also, concerns of the depth of continuous miner advance with unsupported strata, along with the acceptable time interval between mining and bolting had to be established.

By 1978, a modest twenty-one per cent of all the roof bolting machines in use had TRS systems (800 machines). The effect in accident rate reduction soon became clear. So in 1981, the State of West Virginia imposed regulations mandating the use of TRS systems on all roof bolting machines. The states of Virginia and Kentucky soon followed, and by 1987 there were over 2 200 roof bolting machines in use so equipped[1].

Currently, there are United States Federal requirements for the use of TRS systems as well as canopies on all roof bolting machines operating in seam heights over 1.07 m. Under 1.07 m, only the TRS is required for mining heights as low as 0.76 m.

Rib Protection

In many United States mines, the coal ribs are as much concern for roof bolter operator safety as the roof. In 1977, J H Fletcher and Co built dual boom roof bolting machines which position the operators on the inside of the booms away from the ribs. From this inside location, the operators can install all bolts required in the row.

In 1983, a customer having severe rib roll problems requested development by the company of a dual boom roof bolter which would provide a passage through the centre of the chassis from rear to front. The purpose of the passage through the chassis was to avoid risks associated with travel between the outside of the machine and the ribs.

This 'walk-through chassis' design appeared at the time to be unique for one customer, but the concept rapidly gained acceptance throughout the United States. Currently, 150 machines with the walk-through chassis are operating in the United States, Canada, Australia and the United Kingdom.

Elevating booms

Since 1977, roof bolting machine models have been manufactured by J H Fletcher and Co specially designed for mining heights over 2.5 m which provide the operators an elevating platform. The elevating platform enables the operator to reach the surface of the mine roof in mining heights beyond normal reach working from the mine floor. The platform eases the task of resin cartridge and bolt installation.

In most designs the drill mechanism can be elevated so that rib bolts or angled bolts may be located to suit varying mining heights. Angled holes which project through the roof strata and extend over the solid coal ribs are required for installation of 'truss' supports.

The capability of the booms to elevate the drills and operator platforms benefits safety particularly in high seam conditions such as would be the case in construction of overcasts. Drill rod lengths are confined to those that are best suited to hole depth and drill feed limits. Extremely long drill rod lengths required with the drill positioned at the mine floor can be hazardous due to the column length.

Remote control of drilling dust collectors

Drilling dust collector boxes have traditionally been of designs which require the roof bolter operators to periodically empty the contents manually. This can expose the operators to breathing the dust particles during the cleaning process of the box and filters.

The use of hydraulic cylinder activated, remotely controlled 'drop bottom' collector boxes is growing. Incorporated in most of the designs is a system which reverses the air flow through the filter in the enclosure which cleans the filter.

A quartz content present in the drilled strata dust can require further steps. Through manufacturer-customer co-operation, systems are in use on roof bolting machines which collect the discharged dust from the collector box in bags for disposal away from the face area.

ROOM AND PILLAR SYSTEMS

Coal mining in the United States has for over one hundred years been primarily of the room and pillar system. Parallel sets of rooms and pillars are developed branching off main and sub-main entries extending progressively throughout the property boundaries.

Pillars are recovered to the extent permitted for worker safety and in many areas surface subsidence considerations. Therefore, in some mines pillars are not recovered at all. Instead, mining widths and pillar dimensions are designed to permit safe mining practices through effective strata control. Pillar dimensions are designed for the optimum recovery of the coal deposit while still providing sufficient long term column support for the overlying strata.

In other mines pillars can be recovered nearly completely (up to ninety per cent) with the strata controlled through the mining cycles. The key to pillar recovery operations is the predictable roof fall sequence following the pillar removal. In the last few years the use of self-propelled high load capacity roof support machines have been introduced which have aided pillar recovery operations with enhanced safety and productivity. The supports resemble longwall shields with crawlers attached, and their use replaces most of the wooden timbers and cribs otherwise required.

In retreat mining where pillar recovery operations are enhanced with the mobile roof supports (or breaker line supports) production can average 2 500 t per eight-hour shift.

The room and pillar mining system still accounts for approximately two-thirds of the total United States underground mining production. There are approximately 1 700 underground coal mines in the United States.

Typical number of entries, intersection centre distances, and mining widths for US coal producers using the three mining methods follows:

'Conventional' mining room and pillar: seven to nine entries, 18.3 m intersection centre distance, 6.1 m mining width

'Continuous' mining room and pillar: five entries (or multiples of five driven alternately), 22.9 m intersection centre distance, 5.5 m to 6.1 m mining width

'Continuous' mining longwall gate entry development: three entries, 27.4 m intersection centre distance, 4.9 m mining width.

All US longwall operations are retreat mining.

THE PLACE CHANGE SYSTEM

The place change system is traditionally used in United States coal mining room and pillar operations. The continuous mining machine advances a specified distance and then 'place changes' to another entry or extending cut through (cross-cut). As the continuous miner is withdrawn from the advanced face, the self-propelled roof bolting machine is brought in to install roof bolts in the unsupported strata. The continuous miner is moved to another previously bolted entry to resume production.

The average depth of cut of the continuous mining machine has been approximately 6.10 m since the early versions of the machines. This figure is the distance from the cutter bit tips to the operator's controls. Since the development of radio remotely controlled systems for continuous mining machines, cut depths of up to 12.19 m are permitted where roof strata conditions allow. This distance corresponds to the miner bit tips to the front of the shuttle car operator's compartment.

The place change system using 'continuous miner' and 'roof bolter' (machines) was a natural progression from the 'conventional mining' era in the United States. With conventional mining, several machines (up to four) were involved in the face operations. First in the sequence, an undercutting machine, resembling a self propelled chain saw with a 3.35 m long bar, undercuts the coal parallel with and just above the mine floor to provide a 'free face' for blasting. Second, a self-propelled horizontal face drill bores a prescribed series of holes for explosives. Third, after blasting, a loading machine is brought in for loading the coal into shuttle cars.

The fourth, or final, phase of the cycle was roof support. The traditional means was cross bars and timber legs until around 1950 when roof bolting began to gain acceptance. In the final era of wooden or rail cross bar supports, self-propelled timbering machines were used extensively to raise and support the cross bar while legs were installed.

In this 'conventional mining era', the skills in rotating four face machines plus two or three shuttle cars with cable handling and ventilation techniques in the place change cycle became well advanced. Production of over twenty cuts averaging 3.05 m depth was the norm in an eight-hour shift. Currently, approximately ten per cent of United States underground coal production is by conventional mining methods.

Forty years ago, problems encountered with rubber tyre machinery striking and dislodging timber legs supporting cross bars contributed to the rapid acceptance of the roof bolting concept. Also, due to the labour intensive nature of the conventional mining system, 'continuous miners' were introduced at least in part to reduce the manpower requirements. In the decade of the 1950s, trends in the United States towards roof bolting and the use of continuous miners greatly expanded. Several manufacturers of timbering machines, as was the case of J H Fletcher and Co, introduced self-propelled roof bolting machines. This was a case of necessity since the market for timbering machines disappeared rapidly.

ORIGINS OF ROOF BOLTING IN THE UNITED STATES

For the first twenty years of roof bolting in the United States (the decades of the 1950s and 60s) the roof bolt design used almost exclusively was 14 mm diameter steel rod material with a forged 28 mm square head and 16 mm 'rolled' thread at the upper end. The anchorage was provided by various available types of expansion shell anchors. A 35 mm diameter bore hole is required for this expansion shell type of roof bolt.

The expansion shell type of roof bolt is still used in thirty-four per cent of United States coal mines. The expansion shell bolt has been used so extensively that it is referred to as a 'conventional bolt'. The conventional bolt is available in several steel alloy and diameter versions which affect the strength (and cost).

The two major principles for the effectiveness of roof bolting are suspension and the formation of a self supporting beam by compressing strata laminations.

The expansion shell roof bolt must have competent strata anchorage to withstand the high compressive force at the anchor to be effective with the principles discussed. Some strata formations initially exhibit sound anchorage, but over time the rock supporting the expansion anchor deteriorates causing failures.

One very important influence of the expansion anchor roof bolt is the comprehensive force applied on the roof surface by the properly tensioned roof bolt exerted through the bearing plate. The pattern of uniformly tensioned bolts assist in retarding roof sag, and when most effective, the roof surface is maintained in compression where the rock exhibits greatest strength. If sag occurs, the roof surface is in tension where the rock is relatively weak.

From the origins of roof bolting to the present, the typical bolt spacing in the United States coal mining has been 1.22 m between bolts in the row across and 1.22 m between rows.

Conventional bolts and resin 're-bar' bolts longer than the mining height are bent once (and sometimes twice in low seam conditions) to permit installation.

The use of polyester resin for coal mine roof bolting in the United States began in 1970, and by 1975 the use of resin was fully accepted and the applications were expanded. Two key elements in the expanded use of resin anchored bolts have been the vast improvements in curing time and the development of 25 mm diameter hole resin and bolt systems.

At this time, forty-eight per cent of the bolts installed in the United States coal mines are the fully grouted resin type. Of these, three-fourths are used in 25 mm diameter bore holes. The bolts most commonly used are 19 mm or 22 mm nominal diameter concrete reinforcing bar (re-bar) material which has a yield strength of 276 MPa. The forged bolt head is 28 mm square, and there are no threads.

A critical influence in selecting a coal mine site has always been the geologic overlying strata. The 'good coal' with 'good roof' locations have been sought out and exploited in previous years. The roof strata was of necessity self supporting or nearly self supporting to permit mining using only posts or cross bars and legs for primary support.

Roof bolting using expansion shell bolts has permitted mining under more difficult strata, but competent anchorage for the expansion shell is critical. The competent anchorage rock must be within a practical distance from the roof surface for bolt length and bolt loading considerations. The success of fully grouted resin bolting systems has further expanded the 'mineability' of United States coal seams.

It should be noted that cost of production is critical in operating a United States coal mine as it is in a mine anywhere else in the world. Mining companies in the United States using room and pillar methods alone cannot compete with mines using longwall operations unless the strata can be controlled routinely using conventional or fully grouted resin bolts 1.22 m to 1.83 m in length.

Also critical to maximising productivity is that the roof bolting operations must stay ahead of (or at least equal to) the mining rate of the continuous miner.

We recently spoke to a management official of an Ohio coal producer who provided the following productivity information. The coal mining height average is 1.52 m and mining width is 5.49 m. The mine operates two ten-hour shifts per day, with workers on a four day work week. The production standard is 983 t per shift, and a production bonus is paid on production over the standard with the average calculated on a monthly basis. This mine averaged 1 251 t per shift for a recent month — a section foreman, a crew of nine workers and three shuttle cars were used. As many as 700 fully grouted 1.22 mm bolts have been installed in a ten-hour shift with the dual boom roof bolting machine and two-man crew.

The production bonus is not paid in the event of a lost time accident or if violations of mine safety regulations are discovered. The mine has an excellent safety record(2).

CURRENT TRENDS IN US STRATA CONTROL

US coal producers are mining reserves with increasingly adverse ground conditions. This is particularly the case in mines developing longwall gate entries. Producers are faced with thinly laminated weak strata, sometimes combined with horizontal in-situ stresses or stresses induced by adjacent longwall panels.

These difficult strata control conditions have required specialised rock mechanics studies and innovative roof support devices. Solutions found for one mine will not necessarily work at an adjoining mine.

Often a very stiff laminated strata beam is sought provided by high bearing plate clamping loads.

Mechanically anchored resin assisted bolts

Bolting systems using expansion shell anchors supplemented with resin in the zone of top anchorage are currently used extensively in the US in weak strata conditions. The concept is to compress the strata laminations through the entire bolt length. The bolts are torqued to seventy per cent of the yield strength for the grade of steel. Anti-friction washers are occasionally used to assist in maintaining consistent installed torque to tension relationships in all bolts installed. Bolt lengths, coupled sections, of up to 3.66 m may often be required. Installation torque of up to 542 Nm are required from the roof bolting machine. In 1991, twelve per cent of the roof bolts sold in the US were of this type.

Truss systems

In other cases, success in strata control requires installation of trusses. The truss systems are offered by several US manufacturers, and their products vary in design. In essence, 45° angle holes are drilled, starting 0.61 m to 0.91 m off each rib and extending over the solid support of the pillar. The resin anchored bolts installed in the angled holes are connected by