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DEVELOPMENT OF SUPPORT SYSTEMS FOR LONGWALL MINING IN THE BOWEN BASIN, CENTRAL QUEENSLAND

George Klenowski¹ and Phil McNamara²

ABSTRACT: The first longwall mine in Queensland was Central Colliery, located at the German Creek Mines. Production commenced in 1985 and shortly afterwards it broke the world record for longwall coal production. At that time longwall mining was generally not considered viable in Queensland due to technical problems associated with weak coal and excessive gas and water. Engineering solutions were developed and included properly designed chain pillars, in-seam methane drainage and efficient, dewatering pumping systems (Klenowski 2000; Klenowski and Winter, 2017).

Following success at Central Colliery longwall mining commenced at the Oaky No.1 Underground Mine and Southern Colliery. This was followed by Gordonstone, North Goonyella and the Moranbah North Mines. Longwall mining is now accepted as the most efficient extraction method in Queensland coal mining with rapidly increasing annual production rates to 10 million tonnes from one longwall at the Grasstree Mine.

INTRODUCTION

Longwall mining commenced in Queensland in 1985 at the Central Colliery. At that time support systems in underground coal mines mainly comprised point anchored roof bolts, W-straps and timber beams, props, pig-sties and sprags. A number of innovative solutions which were developed at Central Colliery, Southern Colliery, Oaky North, North Goonyella, Moranbah North and Grasstree Mines, have become standard practice in Australian mines. The Bowen Basin continues at the leading edge of the industry in Australia.

Fully encapsulated rock bolts with two speed, integral resins were designed to ensure adequate pre-load. Bolting patterns were varied according to the geotechnical conditions, as defined by hazards plans and sections. Mesh mats and butterfly plates were introduced for fretting roof and massive strata. Cable bolts and pre-stressed Megabolts with extended anchorages replaced timber props as secondary support. Drill bit improvements included a modified tri-flush blade bit for puggy roof conditions and the PCD bit for longer holes.

Cuttable dowels were designed to support longwall ribs. Fibreglass dowels were initially used but were subsequently replaced with plastic dowels to reduce washing plant contamination. Shotcrete is now being applied for primary rib support.

Passive support systems which included fibrecrubs and tin cans, were introduced to withstand abutment load and unstable roof conditions. Fibrecrubs installed in longwall panels are extracted by the longwall shearer.

Dual pass continuous miners were initially used for heading drivage in conjunction with hand held drills to install roof and rib supports. Roof and rib bolters were progressively mounted onto

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continuous miners leading to the current standard configuration of a full face continuous miner equipped with four roof bolters, two rib bolters and temporary hydraulic roof support.

Computer modelling has been used to design efficient powered supports. Four leg chocks were originally installed but now two leg shields are used. Support capacity has increased from 800 tonnes to well over 1100 tonnes. High pressure hydraulic circuits now operate at 420 bars and set pressure is 90% of yield pressure, which prevents face spall. The hydraulic fluid reservoir is stored on the pantechnicon. Face sprags mounted on the fronts of shields are used on some faces. Improved horizon control systems for longwall shearsers are being developed. On board inertial navigation systems provide accurate positioning and shearer tracking is recorded and replicated.

Support techniques for roof cavities and longwall recovery have improved. Polyurethene injection is used to control roof falls on longwall faces. Take-off measures now include Huesker minegrid and fully supported and backfilled, pre-driven, recovery roadways.

Ventilation shafts are constructed and lined remotely. Pre-sink excavations are either excavated conventionally or supported using the secant piling method. Shafts are completed by raise boring or blind boring using drilling mud. Lining is completed using robotic shotcrete machines or with steel casing. Nitrogen inertisation is required for raise boring.

Future advances in heading development will include increased automation of continuous miners with continuous coal discharge and robotic roof and rib bolters. Longwall operation is trending towards remote control with TV cameras and automated guidance.

HISTORICAL OVERVIEW

Prior to 1985 much underground support for headings comprised point anchored roof bolts, W- straps and timber beams, props, pig sties and sprags. Better systems were needed to improve production and safety. Heading development needs to proceed in advance of longwall retreat for optimum production.

New, technologically improved support systems were developed at Central Colliery, Southern Colliery, Oaky North, North Goonyella, Moranbah North and Grasstree Mines. These innovations have now become standard practice in Australian underground coal mining. The Bowen Basin continues as the leading edge of the industry in Australia.

Rock Bolts, Mesh Mats and Butterfly Plates

Rock bolts with resin anchorage and W- straps have been routinely used for roof support in coal mines. At the commencement of Central Colliery roof bolts were installed using hand held drills but roof bolting rigs are now mounted on continuous miners. Because wing bits became blocked in pughy mudstone bands a modified tri-flush blade bit was designed (Figure 1). The central tungsten carbide insert protects the central waterway and there are two grooved waterways on the outer sides of the bit.

Point anchored rock bolts were initially used at Central Colliery with 300 mm long, fast set resin cartridges. Because fully encapsulated bolts are far more effective, particularly under abutment load, trials were completed to obtain full encapsulation and proper tensioning. Celtite Pty Ltd developed an integral, dual speed, resin cartridge which consisted of an upper fast set section separated from the lower slow set portion by a partition seal. These cartridges are now routinely used.
Bolt spacing varies depending on the roof conditions and the effects of stress. Bolts are normally installed in rows ranging from 1.5 m to 1.0 m apart, with four to six bolts per row. Bolt lengths are generally 1.8 m to 2.4 m with longer bolts being installed where headings are wider. Where roof rider seams occur, bolt lengths and densities need to be varied according to the strength of the partings.

The immediate roof at Central Colliery is laminite. With increasing in situ stress and abutment load, fretting of the immediate roof occurred with loose rock fragments being detached. The Aquila Steel Company Limited recommended trialling mesh mats for improved safety. The trial was successful and installation of mesh mats became routine throughout the industry as primary roof support with patterned rock bolts.

At the initial longwall panels of Southern Colliery the immediate roof consists of massive sandstone. Because of the competent strata, butterfly plates were used instead of W-straips to speed up development. Butterfly plates and rock bolts are a simple support system for competent roof strata which do not readily delaminate.

**Cable Bolts and Megabolts**

Cable bolts were introduced at Central Colliery mainly to replace timber props and pig-stie supports in intersections, areas of deteriorating roof and for longwall installation roads, which are wider. The initial cable bolts at Central Colliery were actually cable dowels which were not pre-stressed. Sonic extensometers were used to determinate height of strata delamination. Cable bolts were generally 6 m or 8 m long. Cementitious grout was used. Drilling of cable bolt holes using wing bits was inefficient. Polycrystalline Diamond (PCD) bits (Figure 1) were introduced at Central Colliery, resulting in much more rapid installation.

Megabolts were developed by W. Hutchins and J. Hetherington in 1996 and were then commercially produced by Megabolt Australia Pty Ltd. The advantages of Megabolts include a high pre-load, increased bolted horizon and the ability to be installed as primary support using an initial, point anchored, resin cartridge and tensioning for immediate resistance, followed by later cementitious grouting for full encapsulation (Figure 2).

Following a major roof fall at the Oaky North Underground Mine in June 1998 Megabolts were first used as primary roof support in a longwall mine. Two rows of 8 m long Megabolts at 2 m spacing, together with mesh mats and pattern rock bolts were installed.

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**Figure 1: Roof support drill bits**

Wing bit  Modified, tri-flush blade bit  Longyear PCD bit
Figure 2: Passive support systems

Rib dowels
At the commencement of longwall mining of 301 panel, the first panel at Central Colliery, timber sprags were used to prevent maingate rib spall adjacent to the conveyor. Celtite Pty Ltd was engaged to develop a dowel which was cuttable by the longwall shearer. A fully encapsulated, 1.2 m long, fibreglass dowel with a plywood plate was successfully trialled. Because the fibreglass dowels caused wash plant contamination Du Pont (Australia) Ltd was commissioned to produce a plastic dowel which replaced the fibreglass dowel.

Passive Support
Resistant passive support is required in headings subjected to increasing abutment load, which can result in roof and rib failure. Pig-sties and heavy timber props were originally manually installed.

Fibrecrubs are steel-fibre, reinforced concrete cribbing which when installed are a positive, passive, support system (Figure 2). The main advantage of fibrecrubs is that they are cuttable and can be removed by the longwall shearer. They are transported as pallet sized bundles.

Fibrecrubs were first used at Central Colliery in downdip, stub headings, excavated in longwall panels to collect tailgate water. Fibrecrubs were installed to prevent these sumps from collapsing under front abutment load. The longwall then successfully mined through these supported excavations.

Tin cans were developed by Burell Mining International and consist of steel lining filled with cementitious composite (Figure 2). They have been extensively used for tailgate support at mines such as Crinum. The tailgate needs to remain open for ventilation under abutment load, until the longwall passes.

Longwall Equipment
Longwall equipment comprises powered supports, Armoured Face Conveyor (AFC), stage loader, shearer (Figure 3) and pantechnicon. During initial longwall mining in Queensland, powered supports were four leg chocks but now two leg shields are used. Initial chocks each had 800 tonnes capacity and generally functioned well even under periodic weighting. Regular
Checking of longwall hydraulics was necessary to ensure that an adequate set pressure of at least 80% of yield pressure was achieved.

Computer modelling was completed to analyse powered supports. The SUBSOL, three-dimensional boundary element program and the LUSAS, finite element program were used. Analyses included lemniscate linkage, legs configuration, canopy and pontoon base areas and canopy tip to face distance. Design faults were rectified prior to fabrication.

Initially at Central Colliery the chocks hydraulic fluid (Solcenic emulsion and water) reservoir was located outbye in the main headings. Because of accessibility and monitoring problems the reservoir tank was attached to the longwall pantechnicon. This reduced the total fluid volume in use, improved fluid filtration, reduced contamination and decreased fluid return line pressures.

A longwall shearer is shown in Figure 3. A 1.0 m wide web has been generally cut. Coal drums and stone drums were developed to be able to cut basaltic dyke rock with strengths to 200 MPa.

![Figure 3: Longwall face equipment](image)

**Pillar stability**

Pillars in main headings need to be designed as rigid pillars whereas chain pillars in longwall gate roads are designed as yield pillars to minimise coal sterilisation. At the German Creek Mines, the rigid pillars in coal with an average laboratory uniaxial strength of 9.6 MPa were designed with a minimum safety factor of 1.5, using Bieniawski’s tributary load method (Bieniawski, 1982).

The Minlay displacement discontinuity program (Wardle and Klenowski, 1988) was used to design yield chain pillars for increasing depths of cover. This approach allowed for a chain pillar safety factor of 1.5 after single panel extraction and 1.0 after second panel extraction. Recommended solid chain pillar widths for increasing depth of cover are included in Table 1. These chain pillar widths have now been generally adopted throughout the Bowen Basin.
Table 1: Recommended solid chain pillar widths

<table>
<thead>
<tr>
<th>Pillar width (m)</th>
<th>Depth range (m)</th>
<th>Laminite Roof</th>
<th>Sandstone Roof</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>70 – 100</td>
<td>70 – 120</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>100 – 160</td>
<td>120 – 180</td>
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<td>25</td>
<td>160 – 210</td>
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<tr>
<td>40</td>
<td>320 – 380</td>
<td>330 – 390</td>
<td></td>
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<tr>
<td>45</td>
<td>380 – 400+</td>
<td>390 – 400+</td>
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</tr>
</tbody>
</table>

CURRENT MINING PRACTICE

Heading development rates and longwall production have increased significantly in recent times. This has been achieved through technological improvements, more efficient work practices and effective methane drainage.

Heading Development

Full face continuous miners with retractable cutting heads are now being used for heading drivage (Figure 4). Cutting width varies from 4.2 m to 5.2 m. Four roof and two rib bolters are mounted on the continuous miner (Figure 4). The continuous miners typically operate a hydraulically powered temporary roof support to provide additional protection for operators. Primary roof support generally comprises mesh mats, pattern rock bolts and where necessary, Megabolts or similar longer restraints.

Figure 4: Current continuous miner

Cuttable rib dowels are routinely used in longwall ribs and steel dowels are usually installed elsewhere. Where adverse geological structures such as mid-seam shear zones and excessive coal cleats consistently affect rib stability, shotcrete is now being applied as primary support. Different types of shotcrete are being trialled.

Longwall Equipment

Powered supports are now invariably two leg shields each with a capacity well over 1000 tonnes. Face sprags are sometimes installed to support spalling faces and immediate roof (Figure 3). Efficient longwall retreat now occurs electro-hydraulically in sequence.

It is important for the powered supports to have a set pressure of at least 80% of yield pressure, but preferably 90%. A high set pressure reduces roof delamination and face spall. Set
pressures need to be constantly measured and yield valves accuracy should be routinely checked. High pressure hydraulic circuits now operate at 420 bars.

Longwall top coal caving has been developed for very thick seams where good quality roof coal is left because longwall equipment is currently unable to operate beyond a 5 m mining height. The lower section is cut by a conventional shearer. The shield has a longer rear canopy extending past the base into the goaf (Figure 5). The extended canopy has a sliding door to capture goafed roof coal. This mining method was successfully introduced into Australia at Austar Mine and is currently being trialled elsewhere.

Efficient longwall ploughs which can cut 3 to 4 million tonnes are now being used for thin coal seams with unstable roof conditions. The plough web thickness can be varied to suit the roof geotechnical condition. Manufacturers are aiming to achieve an annual production rate of 6 million tonnes.

During mining longwall faces tend to be dusty even with efficient water sprays. Pre-drained coal generates more dust. Air stream helmets have been introduced for safer breathing on longwall faces and foams are being developed to mix with dust suppression water.

At the end of each longwall panel equipment recovery is a technically difficult operation due to adjacent goafed roof. Initial take-off roof support comprised up to 10 rows of roof bolts and W-straps at 1.0 m spacing installed between the canopies tips and the longwall face during final longwall retreat.

A fully supported, pre-driven, recovery road way was trialled at Central Colliery. During entry the weak coal fender between the longwall and recovery road failed, resulting in excessive load on the chocks. Continuous yield occurred and the chocks almost became iron bound. Subsequent recovery roads are now pre-driven, supported and backfilled with filler prior to holing in.

Conventional longwall recovery is currently achieved using Huesker minegrid which is progressively installed during final longwall retreat (Figure 6). This system was initially pioneered at the Oaky North Underground Mine and now has widespread usage.
Systems for polyurethane injection were introduced to assist in the control of cavities formed from roof falls on longwall faces. Expanding cuttable void fillers were also used to reduce the risk to operators in these recovery procedures.

During mining of NLW2 panel at the Oaky North Underground Mine in 1999 the longwall became badly bogged on a soft mudstone floor. During major roof failure a vast sinkhole formed on the surface 90 m above the longwall. Topsoil and tree roots gravitated down to the longwall face. Because of the extremely difficult situation it was decided to retrieve the longwall by excavating a slot from the surface using two draglines (Figure 7). The excavation was completed with one dragline located on the ground surface and another operating at a depth of 45 m. Safe blasting procedure was achieved by using programmable, electric detonators which restricted the maximum peak particle velocity to 45 mm/sec. The longwall was successfully retrieved in 12 weeks at a cost of $13 million. At that time a new longwall was worth about $55 million.

Ventilationshafts

Downcast and upcast ventilation shafts are required in longwall mines. Shafts were originally excavated by drilling and blasting with initial mesh and rock bolt support, followed by a final lining of concrete or shotcrete.

Ventilation shafts are now mechanically excavated and lined. The two construction methods used are raise boring and blind boring. Prior to raise boring a pilot hole is drilled and a pre-sink excavation is completed down to fresh rock by both conventional excavation and concrete lining, or by drilling and installing a circular, secant pile concrete wall. During raise boring nitrogen inertisation is used at the cutter head, for safety. Following excavation weak zones
and coal seams are fibrecreted. A robotic shotcrete machine is now used (Figure 8). Fibrecrete thickness generally varies from 50 mm to 150 mm. Where structural strength is required thickness is increased to 300 mm. Robotic rock bolters are currently being investigated.

Blind bored shafts are drilled at the required diameters to include lining. Drilling mud is used to maintain stability. Steel casing is used to line down to fresh rock. Commonly the full shaft length is steel lined. It is possible to shotcrete weak zones and coal seams below the surface steel liner but there are problems associated with dewatering and ventilation.

Figure 8: Robotic shotcrete machine in a ventilation shaft

FUTURE ROBOTICS

Longwall mining is progressing towards full automation. Research emphasis is now on robotics.

Heading development

In the future continuous miners could be automated to remotely do full face drivage, discharge coal onto a continuous haulage system and install rock bolts and rib dowels. Bolts and dowels could be stored in carousels. Break offs for cut throughs would initially need to be manually controlled. With advancements in shotcrete application coal ribs could be simultaneously supported as mining proceeds.

Automated longwall production

Longwall shearers can now operate remotely using on board inertial navigation systems. As a coal seam rolls the re-training of the shearer tracking is required. For automation video cameras need to transmit back to the control room and shear tracking needs to be electronically monitored. Laser guidance will assist in maintaining horizon control. Recently the longwall at Grosvenor Mine was remotely operated for 24 hours. Longwall automation is achievable with advanced electro-hydraulic controls and periodic, manual retraining of the shearer as the coal seam dip changes.

DISCUSSIONS AND CONCLUSIONS

A number of innovative support systems and design criteria were implemented at Central Colliery, Southern Colliery, Oaky North, North Goonyella, Moranbah North and Grasstree Underground Mines and these have become standard practice in Queensland longwall mines. In rock bolting integral, dual speed, resin cartridges have been developed for proper pre-load and full encapsulation. A modified, tri-flush, spade bit was fabricated to drill through pughy mudstone without blockages. Mesh mats were introduced to replace W straps in fretting roof
conditions and butterfly plates replaced W straps in massive sandstone roof. Rock bolt spacing and lengths were determined for differing geotechnical conditions, with adequate factors of safety. Plans and sections of geotechnical hazards were developed for safety and to predict conditions in advance of mining.

Cable bolts were introduced at Central Colliery to replace timber props and pig sties. Cementitious grout was used. Following roof failure at the Oaky North Mine Megabolts were installed as primary support in weak strata.

Cuttable rib dowels were developed to replace timber sprags. Fibreglass dowels were initially used but were replaced with plastic dowels to prevent blockage problems at the wash plant.

Resistant passive support which has been implemented for headings subjected to increasing abutment load and for unstable roof conditions includes fibercribs and tin cans. Fibercribs which are cuttable, were successfully used to support sump headings in panels during longwall retreat with front abutment loading. Tin cans have successively supported tailgate roadways under abutment stress.

Powered longwall supports have been analysed by computer modelling to determine required capacity and to complete design checks. High set pressure alleviates stability problems. Two leg shields are now invariably used with support capacity of well over 1000 tonnes and all hydraulic circuits are electronically monitored.

Extensive modelling and in situ stress measurements have been completed to design stable rigid pillars and safe, yielding chain pillars which minimise coal sterilisation. Monitoring under abutment load has confirmed the accuracy of design parameters.

Current full face continuous miners now have four mounted roof and rib bolters and are equipped with hydraulic temporary roof support. Primary heading support generally comprises mesh mats, pattern rock bolts, Megabolts and rib dowels. Shotcrete is now being applied as primary rib support.

Powered supports are invariably two leg shields each with a capacity well over 1000 tonnes and recommended set pressure of 90% of yield pressure, which needs to be routinely checked. High set pressure reduces face spall.

Longwall top coal caving has been developed for very thick seams and has been successfully implemented in Australian longwall mines. Additional coal is extracted using this method.

Longwall shearers generally mine bi-directionally and stone drums have been designed to cut igneous dyke rock with strengths to 200 MPa. Drums can be changed to cut a 1.0 m web or a 0.5 m web where roof conditions are unstable and the prop free front needs to be reduced. Shearer tracking can now be recorded and remotely repeated.

Longwall retrieval is difficult due to adjacent, flushing goaf and significant abutment load. Huesker minegrid is now commonly used for controlled support during longwall take-off. An alternative is to enter a fully supported, recovery roadway which has been backfilled with filler.

Ventilation shafts are mechanically excavated by raise boring or bling boring. Secant piling is sometimes used for pre-sink excavations. During raise boring nitrogen inertisation is required and shotcrete lining is applied to coal seams and weak zones using robots. Steel lining is generally installed in blind bore shafts.

Future heading development could become fully automated. Self-controlled continuous miners could have robotic roof and rib bolting drilling rigs equipped with appropriate support installers. Video monitoring would reveal the geotechnical conditions and be used to control mining advance.
Coal Operators' Conference

Longwall shearers can now operate remotely and have recorded tracking for repeated cutting. With current technological advances continuous, remotely controlled longwall operation will be possible. Longwall shearers will use video cameras and inertial navigation systems providing accurate three dimensional positioning data.

REFERENCES


