The Integration of Advanced Rock Bolting Technology with Chinese Roadway Development Systems

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Abstract: Currently, gateroads supported solely by rock bolting currently account for less than 20\% of the 2250km annual gateroad driveage in China. According to the Ministry of Coal Industry’s 9\textsuperscript{th} Five Year Plan, the stated target for rock bolted roadways should reach 50\% by the year 2000. Hence, the next few years will witness a significant increasing percentage of gateroads being developed using rock bolting in China.

The increasing adoption of rock bolting practice in longwall gateroads in Chinese coal mines has seen a learning phase characterised by uncontrolled application, low driveage rates and frequent roof falls. The recent introduction and continuing development of advanced rock bolting technology in China, now offers the opportunity to more fully exploit the benefits of rock bolting in terms of improving safety, roadway development rates and longwall productivity. This paper discusses the current status of rock bolting and roadway development systems in China. The considerations and potential industry benefits of integrating advanced rock bolting technology with Chinese roadway development systems are examined.

Keywords: rock bolting technology, longwall gateroads, roadway development systems

Introduction

History of Rock Bolting in Chinese Coal Mines

The application of rock bolting in Chinese coal mines can be traced back to the early 1960’s. Benefits gained from the application of rock bolting methods are so great that nowadays it is almost the exclusive support method for roadways developed out of seam (ie rock driveages). However, up until the mid-1980’s rock bolting was used only in main development roadways and, almost with no exception, in conjunction with shotcreting techniques. At that time, rock bolting was considered inappropriate and ineffective for longwall gateroads developed in-seam, which were often badly influenced by longwall abutment stresses. Standing steel supports were perceived as a more reliable method. Besides, collieries were able to obtain a low cost government subsidised steel supply for the manufacture of steel supports.
This low cost steel supply situation began to change with Chinese market economic reforms in the late 1980’s when collieries were forced to consider ways to reduce costs and to raise efficiency. It was under such an environment that the application of rock bolting in longwall gateroads began increase, often more by necessity than choice. The application of rock bolting in gateroads has since gained a wider industry acceptance as the outstanding advantages over traditional support methods began to be realised. Benefits such as low material cost; reduced physical labour; less injury in material handling and higher longwall productivity due to longwall face end conditions saw due enthusiasm given to the application of rock bolting to longwalls gateroads (Xui et al, 1997).

Current Situation

In the early 1990’s, more than 200km of longwall gateroads solely support by rock bolting methods were driven annually in Chinese coal mines. However, this figure still only accounted for around 10-12% of the industry’s 2250km of annual longwall gateroad driveage. According to the Ministry of Coal Industry’s 9th Five Year Plan (1996-2000), the stated target for rock bolted roadways should reach 50% by the year 2000. Hence, the next few years will witness a significant increasing percentage of gateroads being developed using rock bolting in China.

While the future for gateroad rock bolting looks quite encouraging, efforts are needed to overcome the introductory stage of this technology. The increasing adoption of rock bolting practices in China has seen a learning phase characterised by uncontrolled application, low driveage rates and frequent roof falls. The industry average development rate is 10m/day for fully mechanised development units (i.e. roadheader) and 6m/day for conventional heading (i.e. drilling/blasting). Almost 100 major roof falls in rock bolted gateroads have occurred, with some of these resulting in fatality or injury (Xui et al, 1997).

Advanced Rock Bolting Technology

“Advanced rock bolting technology” is an integrated package of:

1) rock bolting design methodology and roadway monitoring systems;
2) high performance rock bolting consumables and accessories; and
3) efficient rock bolting machinery with rapid and effective placement capabilities.

The recent introduction and continuing development of advanced rock bolting technology in China now offers the opportunity to more fully exploit the benefits of rock bolting. It has been demonstrated that the integration of advanced rock bolting technology with Chinese roadway development systems has the potential for significantly for improving safety, roadway driveage rates and productivity.

Since the application of rock bolting requires a much greater degree of technical sophistication than conventional standing support systems, the correct technical design approach will become a key issue in determining the extent to which potential industry benefits are realised. In addition, the advance rock bolting technology developed in Australia will need to be modified to some extent to more fully suit the mining conditions and practices in Chinese coal mines.
Overview of Chinese Roadway Development and Support Practice in China

Longwall Gateroad Development

Single entry driveage is the normal practice for the development of retreating longwalls in China. Typically, tailgates are driven alongside the goaf of the neighbouring longwall panel with only a small barrier pillar (3-5m wide) being left to separate the roadway from the goaf.

Currently, about 80% of longwall gateroads are developed by conventional drilling and blasting methods, with a typical average driveage rate of only around 6m/day. These conventionally driven roadways suffer from poor profiling and loosening of surrounding strata, making conditions less favourable for rock bolting.

Mechanised roadway development using roadheaders and bridge conveyors generally provides much better driveage rates than conventional development with an average driveage rate of around 10m/day. However, the current Chinese roadheader systems are not well suited for cyclic rock bolting operations in longwall gateroads.

The use of continuous miners, whilst not yet widespread in the Chinese industry, has been tried in a very limited number of Chinese coal mines with good performances being achieved. A national in-seam driveage record of 2705m/month was set at Dalita Mine (Shenfu Coal Co., Shaanxi Province) using a Joy 12CM18 continuous miner and a Long-Airdox 488 battery coal hauler. This performance was achieved under favourable mining conditions which permitted low density bolting to be used.

Current Roadway Support Systems

Currently, about 80% of Chinese longwall gateroads are supported by trapezoid steel sets. Although this type of standing support is very simple to install, it has several problems such as higher material cost, higher physical labour requirements, more material handling accidents and results in inconvenience and restrictions at longwall face ends. Conventional support systems tend to limit roadway widths due to reduced support capacity of longer cross members. As a result of the above disadvantages the use of steel sets are unsuitable for gateroads of modern high production, high efficiency longwall faces.

Rock bolting has been successfully used in longwall gateroads with competent roof strata. However, problems have occurred when trying to adopt rock bolting in longwall gateroads under relatively difficult mining conditions. Some of the problems that have been found with the current rock bolting systems are described below.

Low Capacity Consumables
Mild steel bolts point anchored with either resin or cement capsules have been the dominant bolt type in longwall gateroads. These low strength and low stiffness system provide a significantly lower support performance than those used in Australia, UK and USA. Under difficult mining conditions, the high bolt densities required, result in poor driveage rates. Although full column resin encapsulation was
first tried in 1992, it was not until 1996 that the application of this technique began to
rapidly increase.

Poor Equipment Performance
There are several domestic manufacturers of rock bolting equipment, but as a result of
the dispersed domestic manufacturing design efforts to date, none have been able to
provide appropriate roof bolting machines to match imported machines.

Drill Bit Quality
The inability to obtain suitable drill bit diameter tolerances in domestic drill bits
results in poor rock bolt performance due to oversize borehole diameters.

Inadequate Design Methods
With the continuing application of rock bolting to more and more difficult mining
conditions, traditional empirical bolting design methods have shown their
shortcomings. Roof falls have occurred due to incorrect designs and inappropriate
application for rock bolting.

Inappropriate Bolting Practice
For a 3 shift/day mechanised heading development operation, a typical practice is to
advance the heading face for two 8 hour shifts using temporary standing supports, and
then replace these temporary supports with roof bolting on the third 8 hour shift. With
this practice, the support provided by these temporary standing supports is often
ineffective and significant strata deformation and roadway deterioration occurs before
bolt installation, thereby reducing the effectiveness of the rock bolting.

A similar problem occurs in drilling and blasting faces, where rib bolting is usually
done 5-10m behind the face to prevent the mesh being damaged by blasting. This
allows additional rib spalling to occur prior to placement of rib support.

Lack Of Adequate Monitoring Techniques
Although several types of geotechnical monitoring instruments have been developed
domestically in the past few years, there is still an urgent need of sophisticated
monitoring instruments for application of rock bolting to longwall gate roads.

Development of Rock Bolting Technology

Previous Research Programs
During the 5th Five Year Plan period (1991-95), several research programs for
gate road rock bolting were funded by the Ministry of Coal Industry. These programs
covered most aspects of rock bolting technology including gate road stability
classification, rock bolt behaviour mechanisms, bolting design parameters and
methods, rock bolting consumables and equipment, measurement and monitoring
techniques and secondary reinforcement techniques. The results and experience
gained from these programs have provided a basis for the on-going development and
application of rock bolting technology in China.
Introduction of Advanced Rock Bolting Technology into China

In 1996-97 a project to determine the applicability of advance rock bolting technology to Chinese coal mines was undertaken by an Australian consultant company (SCT) and the Ministry of Coal Industry at Xingtai Coal Bureau’s Dongpang Mine in Hebei Province. This involved a detailed investigation program to monitor and assess the site conditions and a detailed feasibility design study using computational modelling to examine roadway behaviour and support performance under the anticipated mining conditions.

Successful introduction of a total package of rock bolting technology occurred, with a 300m section of trial driveage being completed in September 1996. This trial utilised a system of advanced rock bolting technology (design, consumables and bolting machinery) together with existing Chinese roadheader development equipment. During the field trial stage, locally produced high strength full column resin encapsulated high capacity rock bolts were installed with pneumatic roof bolters imported from Australia. Aspects of the project are described below.

Upgrading of Rock Bolting Consumables
Prior to the commencement of the project’s field trial, suitable rock bolting consumables were not available in China. During the feasibility study, tests on the standard Chinese rock bolt consumables indicated that they are low capacity systems and are unsuitable for moderate to high deformation roadway conditions. Development of suitable rock bolting consumables, which could be used for the rock bolting trial, was undertaken in China according to the specifications proposed by SCT. The suitability of the rock bolting materials developed was assessed as part of the feasibility study by testing the consumables in the laboratory and underground in Australia and by measuring the performance of the rock bolt/resin system in the underground investigation area in China.

Results of the rock bolting consumables assessment program are summarised in Tables 1 and 2. Stress/strain curves of the high strength Chinese bolt and a typical Australian bolt are compared in Figure 1.

At present, the price of the high capacity Chinese bolt has been reduced by 50% since it was first developed for the project. This cost reduction has made the high capacity rock bolting systems more suitable for wider application throughout the Chinese coal industry.
Table 1: Specifications of Rock Bolts

<table>
<thead>
<tr>
<th>Type</th>
<th>Proposed Specifications</th>
<th>Chinese Consumables</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
<td>Preferred</td>
</tr>
<tr>
<td>Nominal Bar Diameter</td>
<td>21.5mm</td>
<td>22-24mm</td>
</tr>
<tr>
<td>Ultimate Tensile Strength</td>
<td>500-600MPa</td>
<td>800-900MPa</td>
</tr>
<tr>
<td>Bolt Ultimate Capacity</td>
<td>230kN</td>
<td>300-320kN</td>
</tr>
<tr>
<td>Yield Strength</td>
<td>350MPa</td>
<td>600MPa</td>
</tr>
<tr>
<td>Bolt Yield Capacity</td>
<td>180kN</td>
<td>220kN</td>
</tr>
<tr>
<td>Elongation (over 5d length)</td>
<td>15%</td>
<td>17%</td>
</tr>
<tr>
<td>Elongation at Peak Load</td>
<td>7%</td>
<td>9%</td>
</tr>
</tbody>
</table>

Table 2: Comparison of Short Encapsulation Pull-out Tests for Various Rock Bolt/Resin Systems (300mm encapsulation length)

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Bolt Type (diam.)</th>
<th>Resin Type</th>
<th>Drill Bit Diam.</th>
<th>Depth into Roof</th>
<th>Pull-out Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Australian Bolt (22mm)</td>
<td>Australian</td>
<td>27mm</td>
<td>1.8m</td>
<td>≥200kN</td>
</tr>
<tr>
<td>2</td>
<td>Chinese Bolt (22mm)</td>
<td>Chinese</td>
<td>29mm</td>
<td>1.8m</td>
<td>110-140kN</td>
</tr>
<tr>
<td>3</td>
<td>Australian Bolt (22mm)</td>
<td>Australian</td>
<td>27mm</td>
<td>1.8m</td>
<td>130-200kN</td>
</tr>
<tr>
<td>4</td>
<td>Chinese Bolt (22mm)</td>
<td>Chinese</td>
<td>28mm</td>
<td>1.8m</td>
<td>150-180kN</td>
</tr>
</tbody>
</table>

![Stress/strain curve of high strength Chinese and Australian bolts.](image)

Fig. 1 – Stress/strain curve of high strength Chinese and Australian bolts.
Design Methodology

Where rock bolting is intended to be utilised as the primary support in longwall gate roads, a well-proven and sound design methodology is required to ensure the safe and efficient introduction of rock bolting under a wide range of geotechnical environments. During this project, SCT demonstrated a methodology, which is not an empirical approach, but instead a site-specific method based on in situ measurements and the following procedures:

- geotechnical assessment
- initial design
- design verification
- routine monitoring

Rock Property Testing

Rock samples obtained from the field trial area were tested both in Australia and in China to determine the mechanical properties of both the roof strata and the floor strata. Borcholes were also drilled at 30° to the bedding planes to provide rock samples for testing the bedding plane properties of the roof and floor strata.

Stress Measurement

A program of stress measurement was undertaken in Dongpang Mine to determine both the virgin stress field and the mining induced stress field in the trial site area. An overcoring stress measurement technique was used with instrumentation and a geotechnical drilling rig imported from Australia. The results indicated that the maximum horizontal stress is 1.4–1.5 times the vertical stress.

The stress measurement data and the rock property data were utilised in the roadway reinforcement design.

Monitoring Procedure

The introduction of high capacity rock bolting at the Dongpang trial site was done in a controlled and supervised manner, with monitoring of rock bolt performance and roadway behaviour being used to justify and confirm the expected performance of the roadway support design. This systematic monitoring approach also provided the management, supervisors and workforce with improved knowledge and confidence in the rock bolting system.

The following monitoring program was undertaken in the trial section to ensure the safe and efficient introduction of high capacity rock bolting in these sections:

- installation of sonic probe extensometers in the roof and ribs to assess the roadway behaviour with the rock bolted reinforcement system;
- installation of strain gauged bolts in the roof and ribs to assess the performance of the rock bolting reinforcement system; and
- systematic installation of ‘tell-tales’ (roof strata monitors) during roadway development to provide a continuous visual indication of the roof conditions and alert officials to changing roof conditions and the requirement to take remedial action.

The location of the investigation sites and the layout of the instrumentation are shown in Figures 2 and Figure 3.
Results of the Project

Performance of Rock Bolting System

The feasibility study and field trial investigation program confirmed the performance and suitability of advanced rock bolting systems for Dongpang Mine, provided they are used within specified design guidelines.

The performance of the rock bolting support systems was also verified during longwall extraction, when significantly improved roadway conditions and associated productivity improvements were achieved.

The performance capabilities of the new rock bolting system have been shown to provide a significant improvement in roof stability over the mine’s current roadway support systems. Roadway deformation was reduced by 50% as compared with other sections of the same roadway supported by the standard rock bolting system.

Monitoring results indicated that the actual bolt loads were as high as 250kN in the roof and 150kN in the rib, which are far in excess of the capacity of the standard bolting system. This lower capacity is one of the main reasons for the frequent roof falls in roadways supported by the standard rock bolting system.

Fig. 2 – Location of rock bolting investigation sites at Dongpang Coal Mine.
‘Tell tale’ roof strata monitors were placed at regular intervals (approximately 50m) along the trial roadway. The results are summarised in Figure 4 and indicated that the high capacity roof bolt system was able to provide significantly improved stability of the immediate roof. However, due to the roadway being located alongside the goaf of the previously extracted longwall, even the high capacity system was not able to restrict roof movement occurring above the height of the bolts. This situation is discussed later.

Roadway Development Performance

In order to make full use of the advantages offered by the rock bolting technology, modifications were made to the existing roadway development practice, thereby effectively integrating the advanced rock bolting technology with the existing Chinese roadway development system. As a result, record drivages for the mine of 15m in a shift and 38m in a day were achieved during the trial. An overall improvement in development rates of 30% was achieved.

The main factors that contributed to achieving improved development rates were considered to be:

- Undertaking an integrated cycle of coal cutting and roadway support on all production shifts, rather than the standard practice of separate cutting and bolting shifts. This eliminated the requirement for erection of temporary support.
- The roof and sides of the roadway were supported effectively and rapidly by high capacity bolts with a reduced bolting density. This reduced bolt density significantly reduced bolting cycle times.
- A support installation sequence that restricts the maximum amount of unsupported roadway and does not allow a significant deterioration of roadway conditions prior to the placement of rock bolts improved the easy rock bolt installation.
- Mining crews who are trained and competent in the use of the bolting equipment and have a good understanding of the requirements of the support system.
- Small diameter drill holes (27mm) allow rapid drilling rates.
- The use of rapid mixing and setting rock bolt resin.
- The use of a shear pin configuration on the bolt nut allowed resin mixing and nut tightening to be accomplished in one pass, resulting in a significant improvement in installation efficiency.

Expected Benefits

Appropriate integration of advanced rock bolting technology with Chinese roadway development systems is expected to have a number of benefits as discussed below.

Safety

This proven, high performance, roadway reinforcement system and its systematic application have the ability to significantly reduce the incidence of roof fall accidents.
Improved Utilisation and Productivity of Mining Machinery

The ability to effectively stabilise and control roadway openings and junctions, whilst providing access for the large mining machinery free of standing supports, improves the utilisation of this equipment. The potential to provide stable roadways free of standing support reduces delays associated with restricted longwall gate-end conditions and the removal of standing supports, thereby improving longwall retreat rates.

Increased Roadway Driveage Rates

The advanced rock bolting system can offer the potential to increase current productivity and roadway advance rates due to the reduced support installation time and improved utilisation of roadheading machinery.

Increased Roadway Width

Increased roadway widths will facilitate the use of mobile mining machines as well as providing less congested working environments. The ability to effectively stabilise and control roadway openings and junctions, whilst providing wide roadways with access free of standing supports, is essential for operation of the large mobile mining machinery involved in modern mechanised development systems. Hence, the use of advanced rock bolting systems is considered the key factor in allowing the effective and productive operation of continuous miner systems in Chinese coal mines.

This is an important consideration for the planning for new mines, as the opportunity will exist for new mines to efficiently utilise advanced rock bolting and permit the application of advanced mining machinery and systems.

Appropriate Application of Rock Bolting

The Donggang Mine rock bolting project was intended to show that introducing advanced rockbolting technology is not just a matter of replacing low capacity bolts with high capacity bolts. It is critically important for the successful, on-going application of the technology that its introduction is managed correctly such that the technology is applied in a controlled manner and utilised under appropriate conditions. Appropriate detailed design studies are essential to ensure correct application of rock bolting technology occurs under the varying geological and mining conditions encountered throughout the Chinese coal mining industry.

The greatest concern with the introduction of the rock bolting technology is that its use will be uncontrolled and unsupervised. If this situation occurs, the result will be the use of inappropriate designs and consumables and the possibility of applying the technology under inappropriate geological and mining conditions and mining layouts. Under these conditions there exists a high risk for failures to occur. Such failures are not a fault of the technology but rather its incorrect application.
Monitoring the performance of the reinforcement and the behaviour of the roadway should be used to confirm the roadway support system. This systematic and site-specific monitoring approach will provide the management and workforce with improved knowledge and confidence in the rock bolting system. The information obtained in this investigation is used as the basis for developing guidelines for the continuing application of advanced rock bolting support systems throughout the mine.

The successful and wider application of advanced rock bolting systems throughout the Chinese coal mining industry will require the establishment of training programs to support the new rock bolting technology. These training programs should be designed and structured so a sufficient number of trained personnel who can manage the ongoing application of the design guidelines are available at the mining bureau and industry level. These personnel should be capable of undertaking on-going training of management and technical staff who are required to take active roles in the implementation of rock bolting technology, to ensure that the roadway support recommendations and design requirements are met.

Future Industry Developments

*General Stability Problem of Gateroads Driven alongside Goaf Areas*

The tailgate roadway was driven alongside the goaf of the previously extracted longwall panel with only a 3-4m wide barrier pillar being left. Computer modelling and in situ monitoring indicated that rock bolting can effectively reinforce the strata within a certain area around the tailgate. However, goaf fractures extend over the tailgate roadway and rock bolting can not prevent the potential for the formation of large caving blocks and roadway collapse.

For roadways located adjacent to goaf areas, as shown in Figure 5, the general stability of the roadway will depend on the fracture geometry of the adjacent goaf and the strength of the small pillar and is not significantly influenced by the roadway support system. An appropriate chain pillar size is critical to control caving stability in the area around the roadway. This pillar size would need to be designed depending on the site conditions, however, the pillar will need to be larger than the current practice of using a 3-5m wide pillar. The concept of a larger pillar to control caving stability is shown in Figure 5.

*Potential Problems with Steel Bolts*

High density rib bolting is needed in the majority of Chinese coal mines due to the large mining depths (300-1000m). The use of steel bolts in the longwall block-side has potential safety and operational problems (ignition risk striking bolts with shearer, jammed AFC, blockages and damage to coal handling systems). The use of cuttable rib bolt systems would solve or reduce these problems, however, no effective cuttable systems are commercially available on the domestic market. Some development and field trials of domestic prototype systems are underway.
Fig. 3 – Layout of instrumentation at the investigation sites, 2707 Tailgate, Dongpang Coal Mine
Fig. 4 – Summary of ‘Tell Tale’ roof monitoring results.
Fig. 5 – General stability problem of roadways developed in close vicinity to goaf areas.
Application of Rock Bolting to Sub-Level Caving Longwall Gateroads

Reserves of coal in seams thicker than 4.8m accounts for 48% of the total coal reserves of all Chinese state-owned coal mines. The application of the sub-level caving longwall method has been rapidly increasing in recent years. Currently in China there are 32 sub-level caving longwall faces mining coal from 4.8m to 10m thick. Gateroads of sub-level caving longwalls are normally developed at the bottom of the seam and are typically characterised by thick top coal, which is generally weaker and less intact than the immediate roof strata. Despite potential difficulties associated with the use of rock bolting in a thick coal roof, the following benefits of rock bolting in these roadways exist:

- High production from sub-level caving longwall faces requires wider gateroads for ventilation and equipment transportation. The use of steel set standing supports to achieve these wider roadways results in higher density support requirements and higher physical labour requirements.
- Standing support systems permit the top coal to loosen and sit on top of the supporting members. The fractured nature of the top coal increases the risk of spontaneous combustion and several incidents of fires attributable to this cause have occurred in recent years.
- Gateroads supported by steel sets cause inconvenient and restrictive gate-end conditions for the operation of sub-level caving longwall faces.

Previous experience has shown the specific difficulties of using rock bolting in sub-level caving gateroads. The application of advanced rock bolting technology to these gateroads will require further extensive technical design studies. Initial field trials have recently been completed with satisfactory results. However, much more development work is needed to allow rock bolting to be successfully adopted in the increasing number gateroads of sub-level caving longwalls.

Conclusions

The recent introduction and continuing development of advanced rock bolting technology in China, now offers the opportunity to more fully exploit the benefits of rock bolting in gateroads of retreating longwalls. However, it is critically important for the successful, on-going application of this technology that its introduction is managed correctly such that the technology is applied in a controlled manner and utilised under appropriate conditions.

During the Dongpeng Mine project, it was demonstrated that the appropriate utilisation of advanced rock bolting technology with Chinese roadway development systems has the potential for significantly improving driveage rates, productivity and safety. The key factors that contributed to an improved roadway development system have been identified. Such factors should be considered for incorporation into future roadway development systems.
The appropriate integration of advanced rock bolting technology with Chinese roadway development systems is an area that is recommended for further investigation work. Also, several other rock bolting issues have been identified as requiring further development work. Addressing these required developments in the application of rock bolting technology has the potential to provide significant productivity benefits for the Chinese mining industry as a whole.

References
